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Comparison of airborne and satellite high spatial resolution data for the identification of individual trees with local maxima filtering

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Abstract. High spatial resolution airborne remotely sensed data have been considered a test bed for the utility of future satellite sensors. Techniques developed on airborne data are now being applied to high spatial resolution imagery collected from remote sensing satellites. In this Letter we compare the results of local maxima (LM) filtering for the identification of individual trees on a 1 m spatial resolution airborne Multi-detector Electro-optical Imaging Sensor II (MEIS II) image and a 1 m IKONOS image. With a relatively large spatial extent, comparative ease of acquisition, and radiometric consistency across the imagery, IKONOS 1 m spatial resolution data have potential utility for forestry applications. However, the results of the LM filtering indicate that although the IKONOS data accurately identify 85% of individual trees in the study area, the commission error is large (51%) and this error may be problematic for certain applications. This is compared to an overall accuracy of 67% for the MEIS II with a commission error of 22%. Further work in developing LM techniques for IKONOS data is required. These methods may be useful to forest stewards, who increasingly seek spatially explicit information on individual trees to serve as the foundation for more accurate modelling of forest structure and dynamics.

1. Introduction

Spatially explicit information for individual trees is increasingly sought by forest managers and modellers as a means to improve the spatial resolution and accuracy of forest models and management scenarios (Mailly *et al*. 2003, Roberts *et al*. 2003, Roux *et al*. 2003). The characterization of individual trees traditionally involves expensive manual interpretation of aerial photographs or field investigation. Several

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automated and semi-automated methods to identify and map individual trees using remotely sensed data have been proposed in the literature (Gougeon 1995, Dralle 1997, Larsen and Rudemo 1998, Lowell 1998, Pitkanen 2001, Sumbera 2001, Culvenor 2002) and an overview is provided in Culvenor (2003). The utility of these methods for discerning forest structural attributes has been demonstrated (Cohen 1990, Wulder *et al.* 2000, Pouliot 2002, Leckie *et al.* 2003, Levesque and King 2003).

Most individual tree identification studies have focused on the use of digitized aerial photographs or airborne data. However, disadvantages of these data include inherent geometric artefacts that are a function of the camera or sensor optics, coupled with the relatively small area of the ground they typically cover. High spatial resolution satellite sensor imagery, as described by Aplin *et al.* (1997), has the potential to negate some of the common problems associated with airborne data and to facilitate the identification of detailed structural attributes of forest cover over large areas. IKONOS is one of the new generation high spatial resolution satellite sensors that was launched in 1999 and has been providing data commercially since 2000. The sensor records one panchromatic channel with 1 m spatial resolution and four channels of multispectral data with 4 m spatial resolution. This data source offers repeat coverage over larger areas with consistent quality, and information content suitable for both visual and digital analyses.

Local maxima (LM) filtering is a technique that has been adapted to the detection of individual trees, the assumption being that when processing high spatial resolution data with a LM filter, large digital numbers correspond to the apex of conifer crowns. A local maximum is identified where the magnitude of the digital number of a pixel is greater than all the surrounding neighbours, within a window of specified size (Dralle and Rudemo 1997). The ability to identify individual trees with this technique is dependent upon careful selection of the filter window size. Fixed window sizes can result in large errors of commission (Wulder *et al.* 2002). Typically, commission error is related to the occurrence of spurious local maxima unrelated to the reflective characteristics of the crown canopy, whereas omission error in LM is largely a function of imagery spatial resolution.

Wulder *et al.* (2000) found LM implemented on airborne Multi-detector Electro-optical Imaging Sensor II (MEIS II) imagery with variable sized window techniques reduced both errors of commission and omission for larger trees (greater than 1.5 m crown radius). Variable window sizes were determined automatically by defining break points along the gradient of reflectance around each pixel. The main advantage of the break point technique is the reduction of commission error, which is critical for some applications, such as the calculation of stand basal area.

This Letter explores some preliminary results of applying the LM filtering techniques developed using airborne MEIS II imagery in Wulder *et al.* (2000) to space-borne IKONOS imagery. The results of applying the LM filtering technique to the MEIS II and IKONOS data are compared and analysed, and directions for further research are identified.

2. Study site and data acquisition

The study site is located near Victoria on Vancouver Island, British Columbia, Canada, at 48° 23′ latitude and 123° 41′ longitude. The field data used for validation were compiled for an initial MEIS II study in 1993. A stem map was produced through a ground survey, with trees located to the nearest 10 cm, over an area with little topographic variability. In total 209 trees were mapped: 159 trees in a plantation stand (planted in 1965) that ranged in height from 8.6 m to 25 m, and were composed of a mixture of Douglas fir (*Pseudotsuga menziesii*) and western red cedar (*Thuja plicata*); and 50 trees in a mature stand (with trees aged 140 to 250 years), ranging in height from 20 m to 70 m and dominated by Douglas fir. A resurvey of the study site in 1999 found that some trees were blown down and the latter were subsequently removed from the stem map, resulting in 199 trees overall (150 plantation, 49 mature).

Details of the second generation MEIS II and IKONOS data are included in table 1. A 1 m panchromatic IKONOS image encompassing the area represented by the MEIS II data was acquired in 2000. The IKONOS image was orthorectified and spatially registered to the MEIS II data and stem map.

3. Methods

The LM filtering was initially performed using a variable window size; the window size was determined automatically by defining break points along the gradient of reflectance around each pixel. This method performed poorly on the IKONOS image, resulting in low overall accuracy (61%) and large errors of commission (48%). As an alternative, a standard LM technique using a fixed 3×3 window was used as a basis for comparison between the two data sources. The LM filtering results from a 3×3 fixed window on the MEIS II data were compared to the 1993 ground survey data. Similarly, the LM filtering results from a 3×3 fixed window on the IKONOS data were compared to the ground survey data that were updated in 1999. The ground survey points of individual tree locations were buffered by 1 m and the LM points were overlaid with these data. LM points that fell within this buffer were considered to have correctly identified an individual tree; LM points outside the buffer were considered incorrect.

4. Results and discussion

The similarity in the spatial resolution of the MEIS II and IKONOS imagery is evident in the representation of landscape features and patterns in figure 1. The differences in shadow and texture between the two images are a product of the different acquisition dates and different solar angles. Figure 2 reveals the substantial differences between the two data sources in terms of brightness, contrast, and the objects identified. The inter-pixel variance represented in figure 2 illustrates how individual objects (trees) are more clearly defined in the MEIS II data, and demonstrates the greater spectral variability present in the IKONOS data. Although the spatial resolution is the same, differences in the optical properties and the mode of acquisition of the two sensors contribute to their different information content. The MEIS II data are collected from an airborne platform

Table 1. Description of MEIS II and IKONOS imagery.

	MEIS II	IKONOS
Acquisition date	2 September 1993	3 June 2000
Time	11:30 am PST	11:05 am PST
Solar altitude	52°	60°
Solar azimuth	133°	146°
Altitude of sensor	1428 m	681 km
Spatial resolution	1 m	1 m
Spectral resolution	Simulated PAN (432.85–847.65 nm)	PAN (450–900 nm)

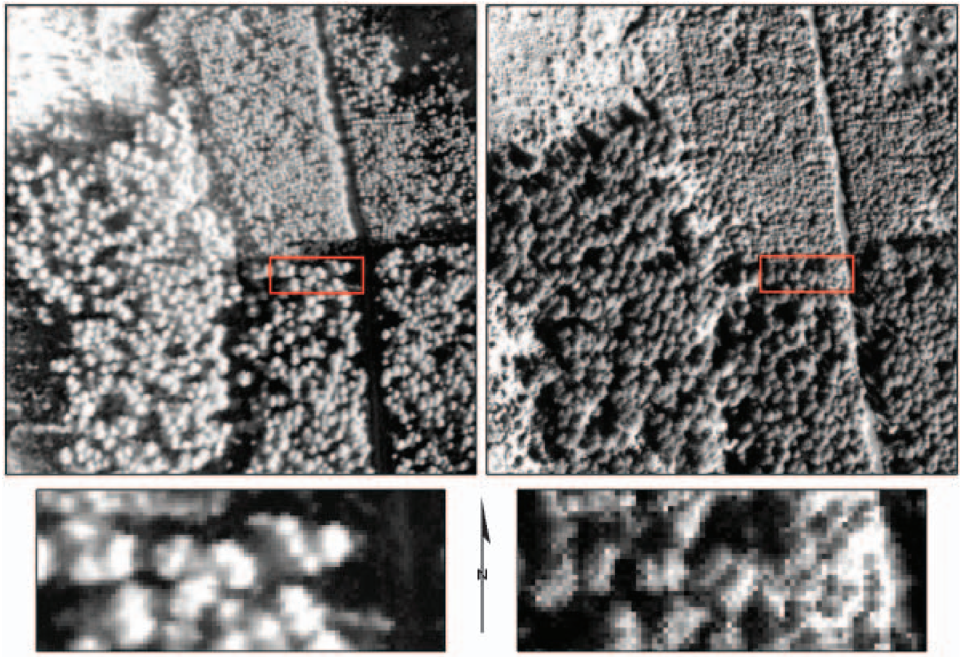

Figure 1. Georegistered MEIS II (left) and IKONOS (right) images shown at a scale of 1 : 3000 (inset images are at 1 : 700).

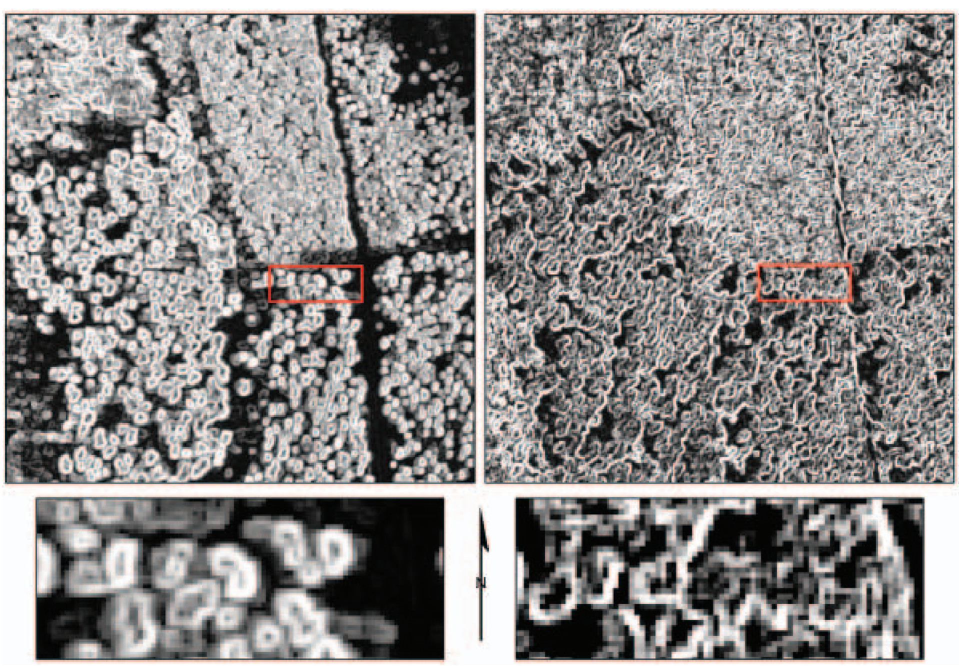

Figure 2. Inter-pixel variance (3 × 3) shown for MEIS II (left) and IKONOS (right) images shown at a scale of 1 : 3000 (inset images are at 1 : 700).

over small areas and have fewer atmospheric related influences on image quality than the IKONOS data. In addition, the MEIS II data have a smaller point spread function (PSF) and a larger signal-to-noise ratio (SNR) when compared to the IKONOS data. It is acknowledged that space-borne sensors are more strongly affected by PSF and SNR due to atmospheric effects and off nadir view geometry (Schowegerdt 1997, Huang *et al.* 2002). As a result of these differences and the greater spectral variability in the IKONOS data, the variable window size technique for LM filtering, which functioned well on MEIS II data, was not transferable to the IKONOS data.

Results obtained from the application of the LM filter on the MEIS II and IKONOS data are summarized in tables 2–4. The MEIS II data correctly identified 67% of the trees in the test area and had a larger commission error for the mature stand (78%) compared to the plantation stand (5%) (table 2). Conversely, omission errors for the smaller plantation trees (38%) were greater than the mature stand (20%). The overall results from the LM filtering of the IKONOS image indicated that individual trees were identified with greater accuracy (85%) and had a much lower omission rate for both the mature (with all of the mature trees identified) and plantation trees (19%) than was obtained with the MEIS II imagery (table 2). However, commission errors increased, more than doubling for both the mature and plantation stands (table 2). This association between fixed window LM techniques and large commission errors was found in Wulder *et al.* (2000). Large mature trees were more accurately identified with the IKONOS data (see table 3).

Table 2. Comparison of LM filtering results for MEIS II and IKONOS imagery.

	MEIS II	IKONOS
Both stands	*n* = *209*	*n* = *199*
Correct	0.67	0.85
False positive	0.22	0.51
Missed	0.33	0.15
Plantation	*n* = *159*	*n* = *150*
Correct	0.62	0.81
False positive	0.05	0.11
Missed	0.38	0.19
Mature	*n* = *50*	*n* = *49*
Correct	0.80	1.00
False positive	0.78	1.76
Missed	0.20	0.00

Table 3. Comparison of DBH estimates.

	DBH range (cm)								
	Both stands			Plantation			Mature		
	< 35	35–70	> 70	< 35	35–70	> 70	< 35	35–70	> 70
MEIS II *n*	158	14	37	157	2	0	1	12	37
MEIS II proportion correct	0.61	0.79	0.84	0.62	1.00	0.00	0.00	0.75	0.84
IKONOS *n*	149	14	36	148	2	0	1	12	36
IKONOS proportion correct	0.81	1.00	1.00	0.80	1.00	0.00	1.00	1.00	1.00

Table 4. Comparison of LM filtering based on crown radius.

	Crown radius (m)					
	0–0.9	1–1.4	1.5–1.9	2–2.9	3–3.9	>4
MEIS II *n*	6	76	71	27	25	4
MEIS II proportion correct	0.33	0.51	0.73	0.89	0.76	0.75
IKONOS *n*	5	73	67	26	24	4
IKONOS proportion correct	0.80	0.74	0.90	0.92	1.00	1.00

Table 4 shows the success of the LM filtering by crown radius. The increased accuracy of the IKONOS prediction is particularly notable for the smaller trees (crown radius of 0 to 1.4 m) and the larger trees (crown radius of 3 m to greater than 4 m).

The decrease in omission error in the IKONOS data is attributable to the image acquisition date (June) with a high Sun angle. In the MEIS II data, the presence of shadows obscures some tree crowns in the image, particularly the smaller trees as indicated in table 4. Conversely, the higher Sun angle present during the satellite sensor data acquisition may have resulted in the increase in false positives, with understorey features identified as LM. Of special interest is the substantial increase in the accuracy of identifying the smaller plantation trees with a diameter at breast height (DBH) of less than 35 cm and crown size of less than 1.5 m (tables 3 and 4) with the IKONOS data. The results may, in part, be explained by the commission error reported in table 1, since the probability of correctly identifying more trees increases as more trees are identified. The different optical properties of the IKONOS relative to the MEIS II sensor may also result in the increased identification of false positives, where more noise and variability in the image equates to more LM.

5. Conclusions

In consideration of the complex natural surfaces being characterized, the results of the LM filtering on the IKONOS data are promising for individual tree identification. The variable window method of LM filtering that increased the accuracy of tree identification from the MEIS II data did not produce comparable results for the IKONOS data and hence the LM filtering technique was implemented using a 3×3 fixed window size. The results indicate that both larger and smaller trees were identified more consistently in the IKONOS data with this technique. However, there is also a greater opportunity for false identification or commission error. In contrast, the MEIS II results were characterized by lower overall accuracy and lower commission errors. Although ongoing efforts aim to increase the accuracy of local maximum filtering, recent studies suggest that IKONOS imagery provides sufficient information on individual tree locations to allow meaningful studies of forest structure (Nelson *et al.* 2002). However, the large number of false positives identified in the IKONOS data, particularly for larger mature trees, is problematic for some applications involving estimates of basal area or volume.

Forest modelling and management are increasingly focused on spatially explicit information for individual trees. In this context, high spatial resolution satellite sensor imagery offers benefits of large area coverage, ease of collection, and considerable information content for both visual and digital analyses. Future work will explore the advantages of radiometric processing prior to LM filtering, along with the development of variable size window LM filtering techniques suitable for reducing commission error in the IKONOS data without reducing overall accuracy.

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