ASSESSING THE INFLUENCE OF FLIGHT PARAMETERS AND INTERFEROMETRIC PROCESSING ON THE ACCURACY OF X-BAND IFSAR-DERIVED FOREST CANOPY HEIGHT MODELS

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ABSTRACT

High resolution, active remote sensing technologies, such as interferometric synthetic aperture radar (IFSAR) and airborne laser scanning (lidar), have the capability to provide forest managers with direct measurements of 3-D forest canopy surface structure. While lidar systems can provide highly accurate measurements of canopy and terrain surfaces, high resolution (X-band) IFSAR systems provide slightly less accurate measurements of canopy surface elevation over very large areas with a much higher data collection rate, leading to a lower cost per unit area. In addition, canopy height can be measured by taking the difference between the IFSAR-derived canopy surface elevation and a lidar-derived terrain surface elevation. Therefore, in areas where high-accuracy terrain models are available, IFSAR may be used to economically monitor changes in forest structure and height over large areas on a relatively frequent basis. However, IFSAR flight parameters and processing techniques are not currently optimized for the forest canopy mapping application. In order to determine optimal flight parameters for IFSAR forest canopy measurement, we evaluated the accuracy of high resolution, X-band canopy surface models obtained over a mountainous forested area in central Washington state (USA) from two different flying heights (6,000 and 4,500 meters), from different look directions, and with different interferometric processing. High-accuracy lidar-derived canopy height models were used as a basis of comparison.

Keywords: Forest, canopy, height, cover, radar, interferometry, IFSAR, INSAR, lidar

1 INTRODUCTION

Accurate, reliable, and spatially-explicit (i.e. mapped) information relating to three-dimensional (3-D) forest canopy structure is required to support a wide variety of resource management applications, including timber inventory, habitat monitoring, and fire management. It has been well established that the two most important metrics in describing 3-D forest canopy structure are canopy cover (horizontal extent of canopy), and canopy height (vertical extent of the canopy). Foresters have long used measurements of canopy cover and canopy height to obtain estimates of stand volume from aerial photo volume tables (Paine and Kiser 2003). Estimates of canopy height and canopy cover are also needed as inputs to fire behaviour models such as FARSITE (Finney 1998). In addition, when combined with stand age information, spatially-explicit maps of maximum canopy height can provide information relating to the growth potential for a given forest area (site index).

Active remote sensing provides an efficient means of obtaining spatially-explicit information related to canopy height and cover over large areas. Lidar remote sensing provides highly-accurate, high-resolution measurements of canopy surface morphology and the underlying terrain (Andersen et al. 2001; Reutebuch et al. 2003). X-band interferometric synthetic aperture radar (IFSAR) can also provide high resolution measurements of the forest canopy surface (not the underlying terrain), but with a lower accuracy than lidar (Andersen et al. 2003). However, X-band IFSAR is typically acquired from a much higher altitude and at a higher speed than lidar, leading to significantly lower costs per unit area ($10-50/km^2 for IFSAR vs. $250/km^2 for lidar). Therefore, if accurate terrain data have been previously acquired for a given area (e.g. from lidar) then IFSAR may provide an economical means of monitoring forest structure change at more frequent intervals than would be possible with lidar. However, the accuracy of IFSAR canopy measurements is dependent upon a number of different factors, including flying height, sensing geometry, and interferometric processing. The dominant source of error in X-band IFSAR elevation measurement is “phase noise,” therefore height error is largely a function of the signal-to-noise ratio (SNR) (Mercer 2004). The SNR for IFSAR measurements can be increased by acquiring the data from a lower flying height (increasing signal power) or filtering the interferogram (decreasing noise power) (Mercer 2004; Rodriguez and Martin 1992). Because radar data are acquired at very shallow look angles, the accuracy of IFSAR measurements in forested areas is also significantly affected by sensing geometry and terrain relief (shadowing). In order to assess the influence of these various parameters on the quality of the canopy measurements (height, cover) obtained from IFSAR, we compared canopy height measurements obtained from high density lidar to those obtained from IFSAR data collected at two different flying heights, from three different look directions, and with four different levels of interferogram filtering.

2 DATA AND METHODS

2.1 Study Area

The study area for this project was a 5 square kilometre area within Wenatchee National Forest, located in the Mission Creek drainage, just west of the city of Wenatchee in Washington State (USA). This is a mixed-conifer forest, composed primarily of mature Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), and various shrub species. Since the focus of this study was on the accuracy of IFSAR canopy measurements, and not terrain measurements, a GIS polygon layer of vegetation cover type was used to isolate and restrict the analysis to the forested regions within the study area. An orthophotograph of the study area is shown in Figure 1.

Figure 1: Orthophotograph of Mission Creek study area, Washington State, USA.

2.2 Lidar data

The lidar data used in this study were acquired in the summer of 2004 with an Optech ALTM 3070 system mounted on a fixed-wing aircraft. This system acquires data with a pulse rate of 70 KHz, and provided data at a nominal density of 4 points/m^2.

The lidar vendor provided all-return lidar data in UTM, zone 10, NAD 83 coordinates. Ground returns were filtered by the vendor and were gridded into a digital terrain model with 1 meter resolution. Lidar returns from the canopy surface were identified by filtering out the highest return within a 1 m x 1 m grid cell. These filtered, canopy-level returns were then gridded into a 1.25 m canopy surface model. The lidar-derived terrain model for this area is shown in Figure 2.

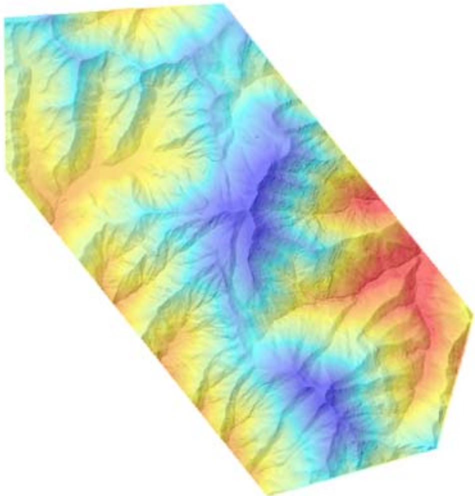
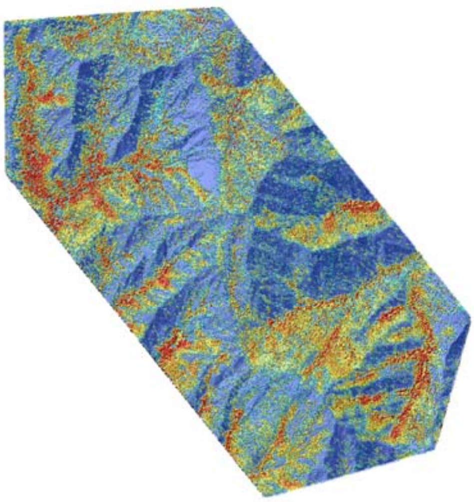


Figure 2: Lidar-derived terrain model for Mission Creek study area.

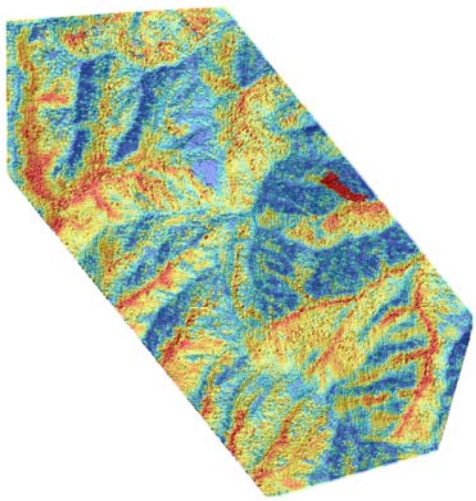
2.3 IFSAR data

IFSAR data were acquired in the summer of 2005 with the Intermap Star 3i X-band system, operating from a Lear jet aircraft platform. The wavelength for this system was 3.1 cm, and the flying speed was 720 km/h.

In order to assess the effect of flying height on the accuracy of IFSAR canopy measurements, data were collected from both 15,000 ft (appox. 4500 m) and 20,000 ft. (approx. 6000 m). Additionally, the IFSAR data were processed by the vendor using four different levels of interferogram filtering (or levels of oversampling (OSF)). The highest level of filtering (OSF factor of 8) represents the standard (default) processing parameter for the 5-meter digital surface models, and has a filtering window of slightly greater than 5 meters. An OSF factor of 1 corresponds to no filtering, so the fundamental pixel size is 1.25 meters, and OSF factors of 2 and 4 correspond to intermediate filter widths (Mercer 2005). Three flight lines, from one look direction, were acquired from 6000 meters, and 13 flight lines, from three orthogonal look directions, were acquired from 4500 meters.



a) Lidar canopy height model



b) IFSAR canopy height model

Figure 3: Lidar and IFSAR canopy models for Mission Creek study area. Color-coded by height (blue is low; red is high canopy).

2.4 Estimation of canopy height, maximum height, and canopy cover

Lidar- and IFSAR-derived canopy height models were generated by subtracting the lidar digital terrain model from the lidar and IFSAR canopy surface models, respectively (see Figure 3). Estimates of canopy height and maximum height were generated at each 30 × 30-m grid cell over the entire study area. Use of an aggregated canopy height measurement at a 30-m resolution provides GIS-ready coverages and also minimizes the effect of any spatial offset between IFSAR and lidar measurements at the individual tree level. In this study, the 90th percentile surface height within a grid cell area (30 m × 30 m) was used as a surface-based estimate of canopy height, in order to exclude measurements of the ground, understory vegetation, and the sides of overstory trees. The maximum height was simply estimated by the height of the highest surface point within the grid cell. The 90th percentile height therefore represents a generalized (i.e. smoothed) description of canopy height, while the maximum height will capture the direct measurement of emergent canopy features. In this study, only measured elevations were included in the calculation of canopy heights – void (shadow) areas were excluded from the analysis. The difference between the IFSAR- and lidar-derived estimates of canopy height (90th percentile and maximum heights) at each 30 meter grid cell was calculated over only the forested areas of the scene, and is assumed to represent the error in the IFSAR canopy height measurement. The distribution of IFSAR error was then described via several summary statistics (mean, standard deviation, median, and quartile deviation). Quartile deviation was computed as one half of the difference between the 75th percentile height and the 25th percentile height. Canopy cover was estimated as the percentage of surface heights within the 30 meter grid cell exceeding 5 meters.

3 RESULTS

3.1 Influence of flying height

The summary statistics of the IFSAR error (IFSAR height – LIDAR height) associated with single passes at the 6000 and 4500 meter flying heights are shown in Tables 1. The study area was located close to the center of the swath for both flight lines, and only the elevations obtained via the standard interferometric processing settings (OSF of 8) were used in the comparison.

Table 1: Differences between IFSAR- and lidar-derived height estimates for 4500 m and 6000 m flying heights.

	Canopy Height				Maximum Height			
	Mean	SD	Median	QD	Mean	SD	Median	QD
6000 m AGL	-7.5	4.9	-7.2	2.9	-10.7	6.9	-10.3	2.9
4500 m AGL	-7.0	4.9	-6.7	2.8	-10.2	6.3	-9.9	3.6

3.2 Influence of filtering parameters

The summary statistics for IFSAR elevations generated using the four different levels of interferogram filtering for a single flight line are shown in Table 2. Only the elevations obtained from the lower flying height (4500 m) were used in this comparison.

Table 2: Differences between IFSAR- and lidar-derived height estimates using different levels of interferogram filtering.

	Canopy Height				Maximum Height			
	Mean	SD	Median	QD	Mean	SD	Median	QD
OSF 1	-6.5	4.4	-6.1	2.2	-1.6	9.6	-2.5	4.4
OSF 2	-6.5	4.5	-6.0	2.3	-2.7	9.5	-3.3	4.3
OSF 4	-6.5	4.6	-6.1	2.5	-4.1	8.6	-4.6	4.3
OSF 8	-7.0	4.9	-6.7	2.8	-10.2	6.3	-9.9	3.6

3.3 Influence of sensing geometry

Previous studies have indicated that using a combination of IFSAR elevations obtained from different look directions can improve canopy height models (Andersen et al. 2003). In order to reduce the underestimation of canopy height due to shadowing effects, the IFSAR elevations obtained from overlapping flight lines were merged by extracting the maximum elevation within each grid cell. The error associated with the merged surfaces obtained from overlapping flight lines with the same look directions, opposite look directions, orthogonal look directions, and all look directions are compared in Table 3.

Table 3: Differences between IFSAR- and lidar-derived height estimates. IFSAR collected at a multiple passes at 4500 m flying height (two side looks from same direction, two orthogonal looks, opposite look directions, and combination of all looks). Oversampling factor of 8.

	Canopy Height				Maximum Height			
	Mean	SD	Median	QD	Mean	SD	Median	QD
Side looks	-3.2	4.9	-3.2	2.9	-5.4	7.5	-5.8	3.6
Opposite looks	-2.2	3.5	-2.5	2.0	-4.4	5.5	-5.0	2.6
Orthogonal looks	-1.6	4.1	-1.6	2.1	-3.4	7.1	-4.2	2.8
All looks	-0.6	3.9	-0.8	2.0	-2.1	7.1	-3.2	2.9

3.4 Estimation of canopy cover

A scatterplot showing the correspondence between lidar- and IFSAR-derived estimates of fractional canopy cover for the merged surface generated from all four look directions (flying height of 4500 m; standard filtering level of 8) is shown in Figure 4.

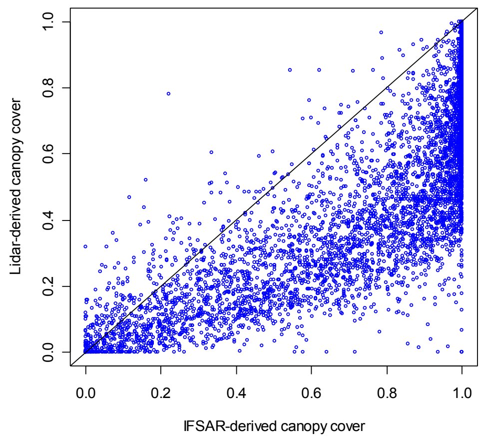


Figure 4: Scatterplot showing relationship between Lidar- and IFSAR-derived fractional canopy cover estimates at 30 m grid cells. Line indicates 1:1 relationship.

4 DISCUSSION

The results shown in Table 1 indicate that the difference in flying heights studied here has little effect on the accuracy of canopy height measurements. For both of the single flight lines used in this comparison of flying heights, the median error for 90th percentile canopy height measurements was approximately -7 meters, with a QD of approximately 3 meters. The maximum height measurements were also not significantly different at the two different flying heights. This indicates that there would be a minimal gain by acquiring IFSAR at 4500 meters vs. 6000 meters for forestry purposes.

Varying the filtering parameters does not appear to have a significant effect on the accuracy of 90th percentile canopy height measurements. The median error is approximately -6 meters, with a QD of approximately 2.5 meters at all filtering levels. The level of filtering does have a significant effect on the measurement of maximum height, with higher levels of filtering leading to greater underestimation of maximum canopy height. The magnitude of the median error ranges from -2.5 meters (QD of 4.4 m) for the filtering level of 1 (no filtering) to -9.9 meters (QD of 3.6 m) for the highest filtering level.

As expected, using a combination of several overlapping looks can significantly improve the accuracy of canopy measurements. Due to the shallow look angles characteristic of IFSAR sensing, measurements of forest canopy surface acquired from a single flight line will have many void (shadow) areas which are occluded by the topography and localized canopy relief. Acquiring data from several different directions can help to fill in void areas and improve overall characterization of forest canopy surface structure. The results of this study indicate that using a combination of two different looks will generally provide a significant increase in accuracy over a single look, as the errors of the merged surfaces for all combinations of looks (median errors of -1 to -3 meters, from Table 3) are lower than that for that for a single look (median error of -7 meters, from Table 1). Not surprisingly, the highest quality surface is the result of merging the data from all four looks, with a median error of -0.8 meters and a QD of 2.0 meters. The results indicate that acquiring IFSAR data from multiple look directions is critically important in forestry applications, especially in mountainous areas.

Estimating canopy cover using only IFSAR elevation data is a difficult proposition. In general, the sensing geometry of IFSAR does not allow for accurate measurement of high frequency details in the morphology of the canopy surface, including canopy gaps and smaller individual tree crowns. In the IFSAR canopy height model, individual tree crowns tend to be smoothed, and canopy gaps are "filled in." Therefore, in forested areas with relatively low canopy density or many small canopy gaps, a canopy cover estimate derived from the IFSAR canopy height model will tend to overestimate the lidar-based canopy cover estimate, as Figure 4 indicates.

5 CONCLUSION

This study confirms that X-band IFSAR can be an economical source of data in the measurement and monitoring of canopy height over large areas. The results presented here do not indicate a significant improvement in the accuracy of canopy height measurements by acquiring the data at a lower flying height, and suggest that the typical mission parameters used for high accuracy (Type II) IFSAR topographic survey may be also be adequate for forest monitoring applications (Mercer 2004). The results also indicate that the accuracy of general canopy height measurements is not greatly influenced by the level of interferogram filtering, but can be highly influenced by sensing geometry. These findings support the conclusion that acquiring data from multiple look directions may be the most important consideration in the planning of IFSAR flights for forest monitoring applications.

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