LASER ALTIMETRY AND SAR INTERFEROMETRY FOR VEGETATION CANOPY CHARACTERIZATION

Trade Study Report

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1 Trade Study Rationale

The characterization of vegetation canopy from space is of great importance for land use, ecological, and climatological applications. The use of laser altimetry for performing this measurement has matured sufficiently over so that the Vegetation Canopy Lidar (VCL) mission has been approved to perform global measurements for the EOS mission.

While extremely useful, laser altimetry coverage is limited by a variety of factors, including:

- **Laser spot size:** For non-scanning laser altimeters, the laser instrument swath can only provide a subsampling of canopy characteristics.
- **Laser scanning ability:** Major technological hurdles still exist in a scanning altimeter whose swath can provide global coverage, including pointing and power requirements.
- **Cloud cover:** Many regions of ecological interest can be cloud covered a substantial part of the time.

Synthetic aperture interferometric radar (IFSAR) can potentially provide measurements of vegetation canopy height/thickness. It is possible that an IFSAR system, such as SRTM, can be used in conjunction with a laser canopy system, such as VCL, to extend coverage beyond the laser instrument restrictions. The purpose of the present study is to examine the capabilities of such a merging of instruments over a variety of canopy types.

If feasible, a joint laser/IFSAR mission would be of importance for a variety of reasons:

- **Programatic Importance:** A joint laser/IFSAR measurement system can reduce future laser mission costs using available IFSAR data to extend laser data base.
- **Scientific Importance:** Global characterization of vegetation provides key inputs to climate and global ecology studies.
- **Commercial Importance:** High resolution global monitoring of vegetation canopies could provide a useful tool for commercial forestry applications.

2 Trade Study Outline

The proposed mission would consist of augmentig VCL data with interferometric data collected by a suitable IFSAR, if possible optimized to retrieve vegetation parameters. Candidate existing or proposed IFSAR systems for technique demonstration include the SRTM interferometer, and possibly LightSAR. If successful, an IFSAR system optimized for vegetation canopy characterization might be considered for future missions.

A candidate algorithm for estimating vegetation thickness based on the use of the correlation coeficient between the two radar channels has been developed at JPL, but its accuracy and applicability to all forest canopies has not been fully determined. The IFSAR algorithm measures the standard deviation of scatterers in height, while the laser altimeter provides a direct determination of tree height. The main unkown in establishing the feasibility of using IFSAR data to extend laser measurements is the uncertainty associated with the empirical mapping between the two quantities as the canopy type varies. In addition, the optimal IFSAR parameters (polarization, incidence angles) should also be determined. In order to study this issue, three different canopy types were selected for study:'

- Pacific Nortwest mature coniferous forest (Goddard laser profilometer, JPL C-band TOPSAR): Mt. Adams.
- East Coast loblolly pine plantations (Goddard SLICER, JPL C-band TOPSAR): Duke Forest.
- East Coast deciduous forest (Goddard SLICER, SIR-C repeat pass interferometry): Mahantango.

After protracted unsuccessful efforts to accurately corregister the Goddard SLICER laser data and SIR-C repeat pass interferometry data, Mahantango was dropped. Errors were due to uncertainties in SIR-C orbit determination.

3 Study Results

3.1 Mt. Adams Results

The northern portion of the data, south of Walupt Lake and east of the Cispus River, consists of a riparian zone at 700m elevation rising to the west to an elevation of $\sim$ 1200m. The vegetation around the Cispus River is a mixture of deciduous and coniferous stands, interspersed with semi-open marshy regions. The hill rising east of the Cispus river contains old growth sites (dark red in the TM image) interspersed with harvested regions which exhibit various stages of regrowth. In the lower part of the mountain, the old growth consists of mixed species stands consisting of Douglas fir, western cedar, western hemlock, and silver pine. Trees in this part of the old growth were very tall, on the order of 40m. As the elevation increases, the diversity of species decreases and the stands are dominated by western and mountain hemlock. Tree heights for the higher elevations are in the 20m-25m meter range. Typical tree separation in the old growth areas in the lower elevations is on the order of 5m-10m, with many small open areas whose typical extent is on the order of 10m-15m. The ground layer in the lower elevations consists of a dense mixture of ferns and smaller $\sim$ 3m tall bushes. At higher elevations, the tree growth is more regular, although tree spacing remains approximately constant.

The harvested areas were cut starting at lower elevations and progressing roughly uphill and to the south. Tree heights range from 10m in the oldest clearcuts, 2m-5m in the intermediate clearcuts, to less than 1m in the newest clearcuts. Tree spacing in the clearcuts is generally smaller than in the old growth, and there are clumps were no trees have regrown. The ground is generally covered with tree stumps, felled branches and trunks, and huckleberry bushes.

South of the harvested area, there is a broad plateau probably associated with a lava flow from a small volcanic cone, called Potato Hill, which can be seen clearly in the height map. The soil in this area is poorer and the tree canopy is considerably shorter, with typical tree heights in the 10m-15m range. The diversity of species is significantly smaller than in the old growth region, and is dominated by lodgepole pine, with intermittent stands of mountain hemlock.

The IFSAR measurement can be inverted to obtain an estimate of the standard deviation of the scatterers in the canopy, weighted by their cross section (triangles). If geometric optics applies, as is likely in C-band, the laser scaterer standard deviation, obtained from the laser waveform, should be similar. Figure 1 presents a comparison of the two quantitues. In this case, the correlation coefficient is about 0.7 between the two quantities, showing that for this canopy type the IFSAR and laser are measuring similar quantities.

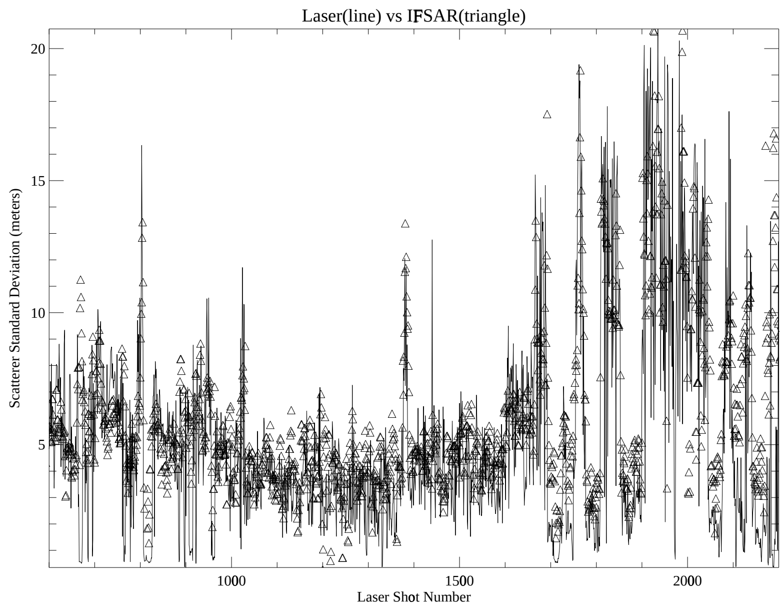

Figure 1: IFSAR (triangle) and laser (solid line) estimated scatterer standard deviation for Mt. Adams.

Figure 2 presents the estimated IFSAR tree height obtained by using an empirical relation between the laser scatterer STD and the actual tree height. The color scale scale goes from 0m (purple) to 60m (red). The data was collected by the JPL TOPSAR instrument in 1992 using vertical polarization single baseline interferometry. The data swath is approximately 8km by 40km. A comparison of the laser tree heights and the IFSAR estimated is shown in Figure 3, showing substantial agreement between the data sets. The total RMS difference is approximately 3 m.

3.2 Duke Forest Results

The Duke Forest, North Carolina, site has a vegetation canopy is dominated by loblolly pine. It is a much more homogeneous site, having been cultivated and harvested over many years. The data IFSAR was collected by the JPL TOPSAR instrument in 1994 using vertical polarization single baseline interferometry. The data swath is approximately 10km by 60km. The data quality is poorer than the Mt. Adams data, probably due to poor motion

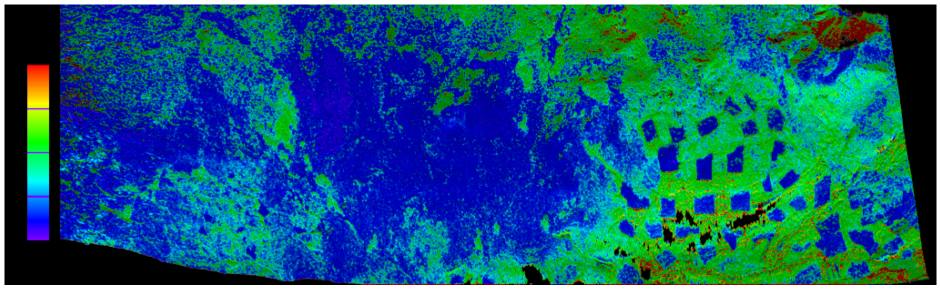

Figure 2: Tree heights estimated by the IFSAR for the Mt. Adams area.

compensation data, but perhaps also due to the presence of strong scatterers in urban areas, or increased multi-path.

Figure 4 shows the same quantities as in Figure 1, but for the Duke Forest scene. There is qualitative agreement between the two quantities and they both have the same order of magnitude value. However, the correlation between the two is much poorer in this case. This disagreement may be due to differing canopy type, but may also be due to poorer data quality for this scene.

Figure 5 shows the IFSAR estimated tree heights for the Duke Forest area. The tree heights were again estimated using an the same empirical relationship used for the Mt. Adams forest. Notice the high level of noise in the far range, probably due to motion compensation errors. Figure 6 show a comparison between the heights estimated by the IFSAR and the laser. Although the magnitude of the estimated tree heights are qualitatively similar, the RMS difference between the two data sets (8.9 m) is much greater than for the Mt. Adams data set. The bulk of this disagreement may be due to the poor data quality for the Duke Forest data set, but may also indicate different performance of the algorithm for different canopy types.

4 Study Conclusions

This study has demonstrated rhe qualitative agreement between the IFSAR and laser estimated heights holds across two different types of vegetation canopies. The mean relationship between scatterer standard deviation and tree height does not seem to be strongly dependent of canopy type. The accuracy of the inversion technique, however, seems to depend significantly on canopy type, with loblolly pine having greater variability than Pacific Northwest coniferous forests. This conclusion is still tentative, however, since the data quality for the 96 data was significantly poorer than for the 94 data. (Problems with the '94 data have also been noted by other users). The data available for this study proved insufficient for the design of an optimal IFSAR system to complement laser measurements since the polarization and incidence angles available were limited, as well as the type of vegetation. Further work needs to be done with higher quality data to demonstrate the potential of IFSAR canopy measurements. This data has been collected in Spring 1999 for a variety of canopy types with existing laser altimeter data.

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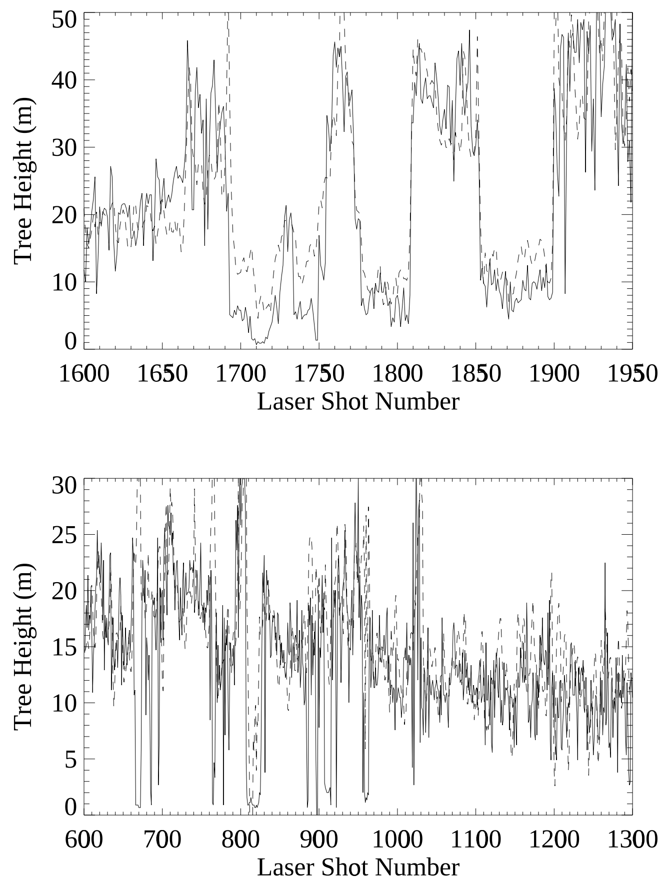

Figure 3: IFSAR (dashed line) and laser (solid line) estimated tree height for Mt. Adams.

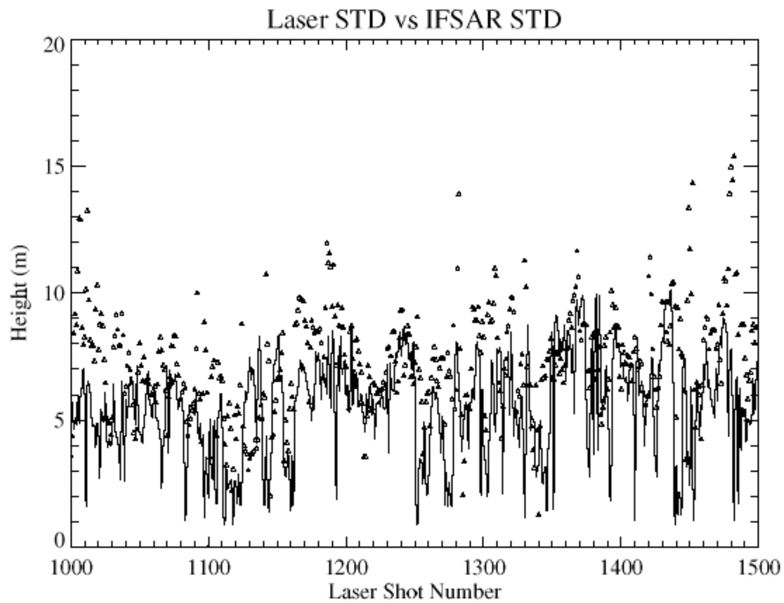

Figure 4: IFSAR (triangle) and laser (solid line) estimated scatterer standard deviation for Duke Forest.

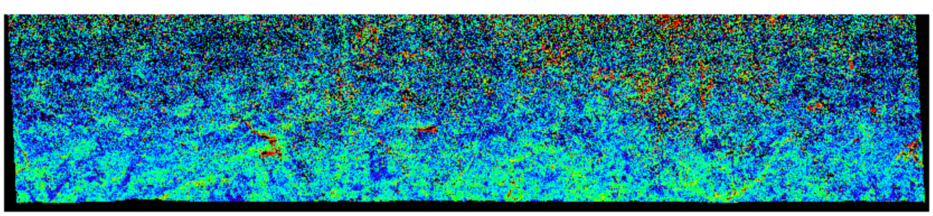

Figure 5: Tree heights estimated by the IFSAR for the Duke Forest area.

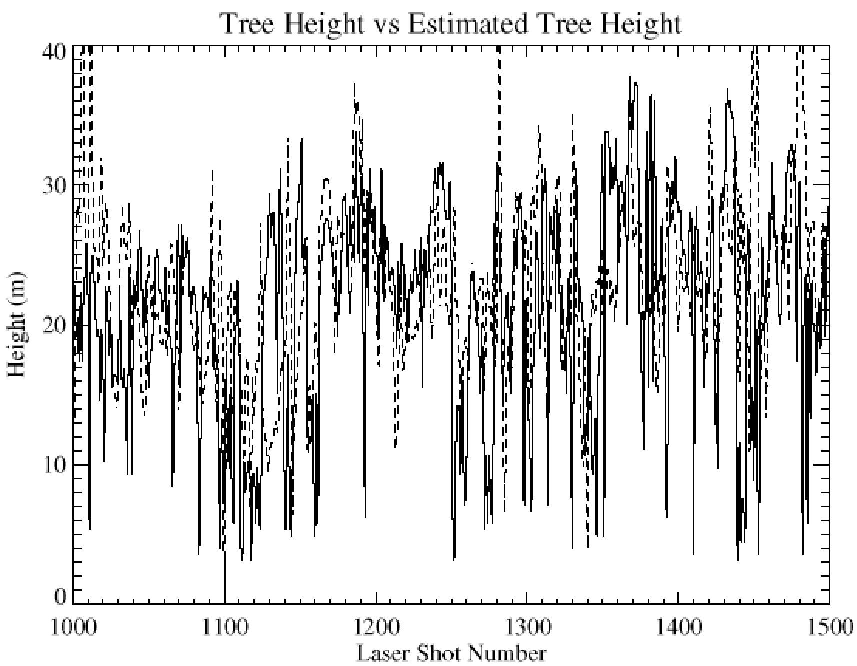

Figure 6: IFSAR (dashed line) and laser (solid line) estimated tree height for Duke Forest.