RADAR AND LIDAR SYNERGY STUDIES BY MODEL SIMULATION

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ABSTRACT:

The use of lidar and radar instruments to measure forest structure attributes such as height and biomass are being considered for future Earth Observation satellite missions. Large footprint lidar makes a direct measurement of the heights of scatterers in the illuminated footprint and can yield information about the vertical profile of the canopy. Synthetic Aperture Radar (SAR) is known to sense the canopy volume, especially at longer wavelengths and is useful for estimating biomass. Interferometric SAR (InSAR) has been shown to yield some forest canopy height information. There is much interest in exploiting these technologies separately and together to get important information for carbon cycle and ecosystem science. Our three-dimensional (3D) incoherent radar backscattering model was modified to simulate coherent returns. The modified model was tested using the forest stem map and PALSAR InSAR data in Howland, Maine. Lidar and radar sense different parts of the forest canopy (lidar to the green leaves, and radar to the wet structures of a canopy). Because of the ecological and biophysical nature of the forest canopies, the amount and spatial position of various components of a forest canopy are closely correlated. The lidar and radar responses to the same canopy should be correlated in some degrees. This correlation and its limits were analyzed in this study. Results will address the possible synergies between lidar and radar data in terms of forest structural information.

1. INTRODUCTION

<u>Radar</u>, because of its penetration capability and sensitivity to water content in vegetation, is sensitive to the forest spatial structure and standing biomass. Radar data (both polarimetric and interferometric) have been used for forest biomass estimation (Ranson and Sun, 1996, 1997; Kasischke et al., 1995; Dobson et al., 1992, 1995; Kurvonen et al., 1999) and canopy height estimation (Hagberg et al, 1995; Treuhaft et al., 1996; Askne et al, 1997; Kobayashi et al, 2000). The potential to map forests with different spatial structures and to provide information on forest biomass from polarimetric radar data is limited when forest biomass is high and the structure is complex (Imhoff, 1995; Ranson et al., 1997).

<u>Large-footprint lidar system</u> (Blair et al., 1994; 1999), have been developed to provide high-resolution, geolocated measurements of vegetation vertical structure and ground elevations beneath dense canopies. Over the past few years, several airborne and space-borne large-footprint lidar systems have been used to make measurements of vegetation. The lidar waveform signature from large-footprint lidar instrument, such as the scanning lidar imager of canopies by echo recovery (SLICER) (Harding et al., 1995, 1998) and the Laser Vegetation Imaging Sensor (LVIS) (Blair et al., 1999) has been successfully used to estimate the tree height and forest above-ground biomass (Lefsky et al., 1999; Drake et al., 2003, Sun et al., 2008). The relationship between forest carbon storage and the vertical structure from Lidar waveform is relatively unexplored. Further studies on the data properties, (e.g. the effects of multiple scattering and ground slope on lidar signatures) are needed to verify and improve the retrieval algorithms. One major limitation of current spaceborne lidar systems is the lack of imaging capabilities and the fact that they provide sparse sampling information on vertical forest structure only.

The signature from these sensors bears commonality due to the biophysical and ecological nature of vegetation communities. The vertical distribution of the reflective surfaces revealed by lidar data implies the overall structure supporting the leaf distribution. The relative importance of microwave backscattering from various tree components (e.g. leaves, branches, trunks) depends on the vertical, as well as horizontal distributions of these components. Reflectance from vegetation canopy is controlled by canopy structure as well as the biochemical composition of the canopy foliage. The commonality and complementarily of multi-sensor data need to be studied to identify the critical structural variables driving the signature. Radiative transfer models (RTM) based on the same 3D canopy structure provide tool for this study.

The 3D radar backscatter model developed previously at UMD/GSFC (Sun and Ranson, 1995) was an incoherence model, in which backscattering components were incoherently summed together to get the total backscattering power from a pixel or target. This model was modified into a coherent model by using scattering matrix instead of Muller matrix in calculating various scattering components. The modified model is similar to those developed by Thirion et al., (2004) but with more flexibility to incorporate forest spatial structures.

The use of lidar and radar instruments to measure forest structure attributes such as height and biomass are being considered for future Earth Observation satellite missions. Large footprint lidar makes a direct measurement of the heights of scatterers in the illuminated footprint and can yield information about the vertical profile of the canopy. Synthetic Aperture Radar (SAR) is known to sense the canopy volume, especially at longer wavelengths and is useful for estimating biomass. Interferometric SAR (InSAR) has been shown to yield some forest canopy height information. There is much interest in exploiting these technologies separately and together to get important information for carbon cycle and ecosystem science. More detailed information of the electromagnetic radiation interactions within forest canopies is needed and backscattering models can be of much utility here. The modified model was tested using the forest stem map and PALSAR InSAR data in Howland, Maine. Preliminary results from modelling and real SAR and lidar data are presented in the paper.

2. STUDY SITE AND DATA

The test site for this project will be the mixed hardwood and softwood forest of Northern Experimental Forest (NEF), Howland, Maine (45°15'N, 68°45'W). This site was the location of the NASA Forest Ecosystem Dynamics (FED) Multi-sensor Aircraft Campaign in 1990 and intensive SIR-C/XSAR experiments in 1994. The natural stands in this boreal--northern hardwood transitional forest consist of hemlock-spruce-fir, aspen-birch, and hemlock-hardwood mixtures. Topographically, the region varies from flat to gently rolling, with a maximum elevation change of less than 135 m within the 10 by 10 km study area. Due to the region's glacial history, soil drainage classes within a small area may vary widely, from excessively drained to poorly drained. Consequently, an elaborate patchwork of forest communities has developed, supporting exceptional diversity in forest structure (Ranson and Sun, 1997). Every tree in a 200m by 150m area was measured for its location, dbh, and species in 1990, and was re-measured in 2003-2004, and 2006. This data set serves well for model simulation, and data analyses (Ranson et al., 1997; Kimes et al., 1997).

LVIS data were acquired in the summer of 2003 as part of a NASA Terrestrial Ecology Program aircraft campaign. PALSAR data (both polametric and dual-pol InSAR data) were obtained in 2006 and 2007. Figure 1 shows the height of lidar waveform energy centroid derived from LVIS waveforms. The dark areas were old clear-cutting areas and bare ground with low vegetations. Bright areas are those with mature forests.

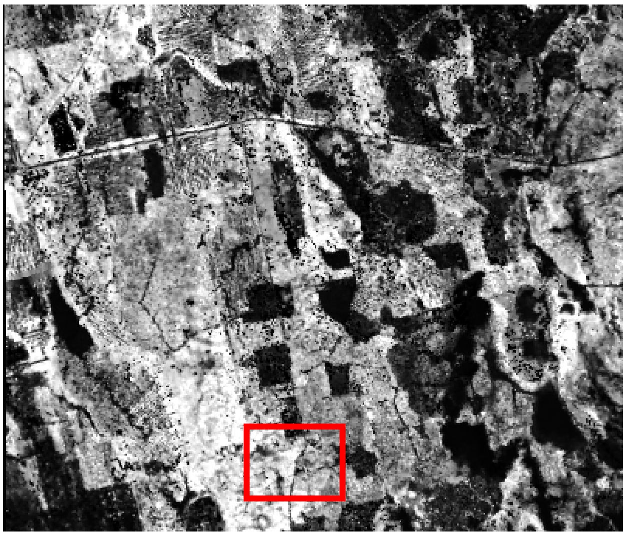

Figure 1. The height of lidar waveform energy centroid derived from LVIS waveforms.

USGS National Elevation datasets (http://ned.usgs.gov/) and SRTM data were downloaded for this test site. IKONOS image s also available for this site. Figure 2 shows the sub-area marked with the red box in Figure 1.

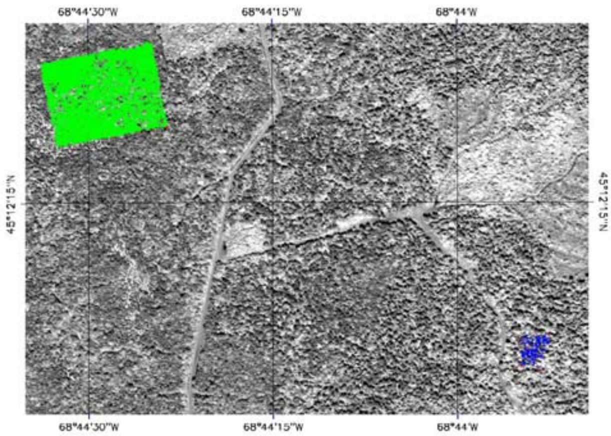

Figure 2. IKONOS image showing the sub-area marked with red box on Fig. 1 and the location of the stem map (green).

3. METHOD

3.1 Simulation of InSAR Data

The stem map data was used as input to the newly modified 3D InSAR model to simulate backscattering InSAR images at very high spatial resolution. The height of the scattering phase center was retrieved from the simulated InSAR data at original resolution. Figure 3 and 4 show the height of phase centre at C- and L-band HH polarization, respectively.

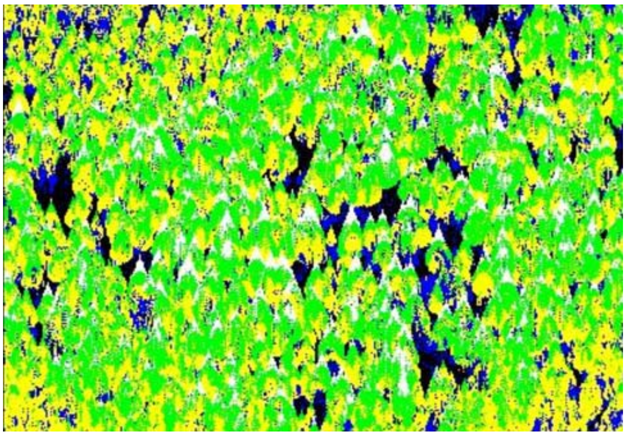

Figure 3. Backscatter phase centre height derived from simulated InSAR C-band HH images of a 150m by 200m stem map in Howland, Maine. Mean height is 9.19m with a standard deviation of 4.63m. Blue : 0-5m, Yellow: 5-10m Green:10-15m white:>15m.

The mean tree height and maximum tree height were calculated for a pixel size of 15m by 15m within the stem map (total 10 by 13 pixels). The simulated backscattering amplitude and phase center height at HH, HV and VV polarization were also aggregated into the same pixel size. The correlations between tree height parameters and InSAR signature were shown in Table 1. The correlation between tree height and backscattering signal intensity is rather bad, which may cause by few factors, but obviously show that the radar backscattering intensity signature is not a good indicator of tree height, though good for forest biomass. The promising correlations exited only between mean tree height and the InSAR phase center heights.

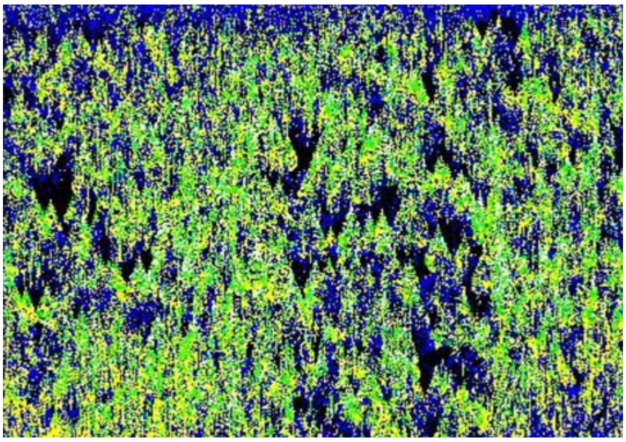

Figure 4. Backscatter phase centre height derived from simulated InSAR L-band HH images of a 150m by 200m stem map in Howland, Maine. Mean height is 5.07m with a standard deviation of 10.8m. Blue : 0-5m, Yellow: 5-10m Green:10-15m white:>15m.

There are several possible factors which affect the correlations, and the mis-coregistration between datasets is the major one. The average and maximum tree heights were calculated from an 15m by 15m surface area, representing the vertical canopy within the pixel. But the canopy volumes resolved by a radar pixel was not a vertical cube. Therefore, in practice, enough radar samples needed to reduce this artefacts, i.e. radar data tend to work on stand level rather than on pixel level.

3.2 Correlations between lidar and InSAR data

LVIS data provide the surface elevation and heights of several waveform energy quartiles for each lidar footprint. Because of its dense footprints, the data can be converted into a raster image such as the one shown in Figure 1. A pixel size of 15m was used. Because the phase centre image derived from PALSAR data is still having some problem, SRTM data was used here. One arc-second SRTM data was re-sampled into the same pixel size and co-registered with LVIS data. The phase cente height was created by SRTM-LVIS elevation. Figure 5 is the resulted phase centre height image for the study area.

Two hundreds points were randomly selected within forested area on Figure 5, and LVIS indices and InSAR phase centre height were calculated using a 3 by 3 window. Figures 6 and 7 show the linear regressions between the phase centre height and LVIS quartile energy heights. Figure 6 shows the correlation between 50% energy height (H50) and the phase centre height. The relations is:

$$H50 = 0.236 + 0.962\ H_{phase} \quad R^2 = 0.67 \qquad (1)$$

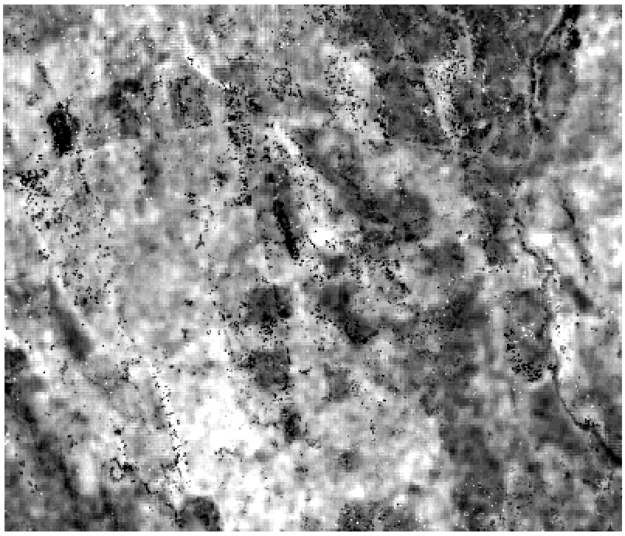

Figure 5. Phase centre height generated by SRTM – LVIS elevations.

Corre	MeanHt	MaxHt	phHH	phHV	phVV	scatHH	phHV	scatVV
MeanHt	1	0.41	0.4	0.26	0.4	-0.1	0.26	0.06
MaxHt	-	1	0.16	0.06	0.18	-0.14	0.14	0.12

Table 1. Correlations between tree height parameters (MeanHt, MaxHt – average and maximum tree height in a pixel) and radar signature (scatXX, phXX - backscattering intensity and InSAR phase center height at XX polarization)

Figure 7 shows the correlation between 100% energy height (H100 – top of the waveform) and the phase centre height. The relations is:

$$H100 = 10.27 + 1.13\ H_{phase} \quad R^2 = 0.59 \qquad (2)$$

It is obvious that the relation between H100 and InSAR phase centre height is not a good linear relationship.

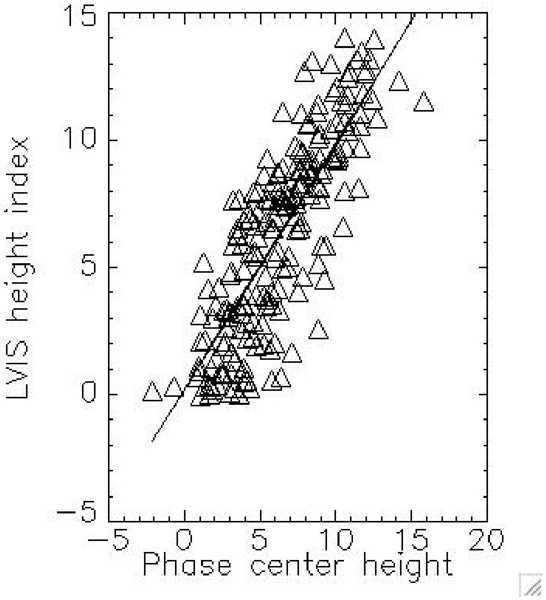

Figure 6. The correlation between 50% energy height (H50) and the phase centre height.

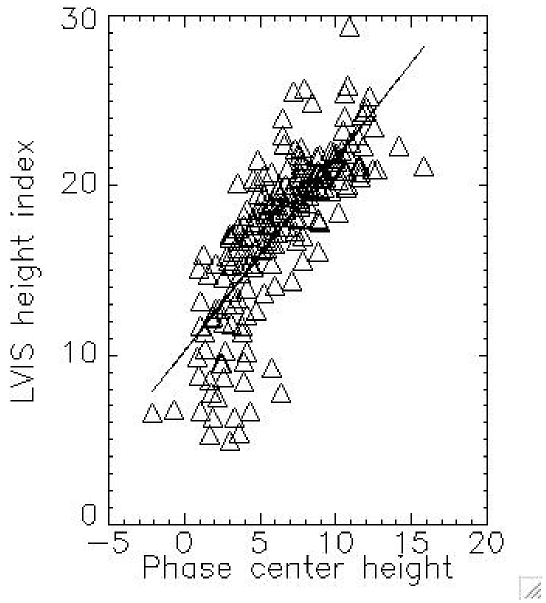

Figure 7. The correlation between 100% energy height (H100) and the phase centre height.

4. CONCLUDING REMARKS

This study shows only preliminary results on lidar SAR energy for forest parameter retrieval. Extensive simulations will be made in our future studies and the commonality and complementarily of lidar and radar data will be thoroughly explored. PALSAR data and field measurements will be used to evaluate the findings from theoretical modelling.

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