SAR, InSAR and Lidar Studies for Measuring Vegetation Structure Over the Harvard Forest

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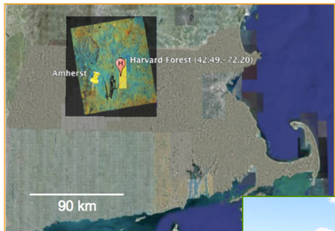
Abstract

Located near the Quabbin reservoir in Western Massachusetts, the Harvard Forest is a temperate zone mixed phase forest consisting of a variety of transition hardwood regrowth resulting from widespread disturbances that took place over 100 years ago. One of the nine NASA funded Bigfoot sites for connecting remote sensing measurements to ground process observations of carbon flux and net primary production, the Harvard Forest has been a resource for a wide variety of ecological studies on spatial scales extending from the microscopic to macroscopic. Typical characteristics of the region that are relevant to this study are an upper limit to carbon content range between 100 and 120 Mg/ha, an average height of 24m, a mean basal area of 40 m2/ha, and on the order of 1000 trees/ha.
In July of 2003, the Laser Vegetation Imaging Sensor (LVIS) overflew the Harvard region, collecting full waveform lidar data for determining the true ground elevation and the vertical extent of the canopy over a 30 kha area (9 km x 30 km). Through a coordinated effort with the Japanese Space Agency (JAXA) and the Kyoto and Carbon Cycle Initiative , since the launch of the ALOS satellite in 2006, the Harvard Forest has been the focus of many fully polarimetric, and single/dual-pol L-band observations separated by a 46 day repeat cycle. This rich and consistent data set, unprecedented even under the ALOS observing strategy, provides an opportunity to explore relationships between a wide variety of spatial and temporal interferometric baselines, an extensive time series of single-, dual- and quad-pol backscatter observations, and the LVIS lidar data, to better understand methods of combining these fundamental data sources for studying the ecosystems, carbon balance and vegetation three-dimensional structure.

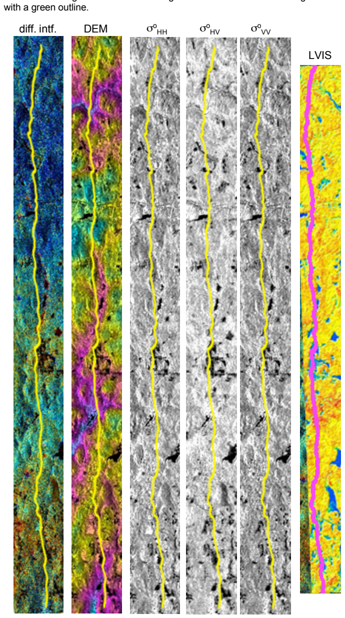


Geographic location of the SAR and lidar imagery used for this study. Shown at left is optical imagery obtained from Google Earth, and locations of the Harvard Forest study area and the town of Amherst, Massachusetts.

A mix of coniferous and deciduous trees (~20m tall) bordering the Quabbin reservoir; the large water body at the center of the study area which supplies Boston and eastern Massachusetts with much of its drinking water.

	20060702	20060827	20061012	20061127	20070112	20070414	20070530	20071015	20071130	
	PLR	4270	3800	4510	2440	5150	4580	6170	6220	20060702
		PLR	470	240	1830	890	310	1900	1950	20060827
			PLR	710	1360	1350	780	2370	2420	20061012
				PLR	2070	650	70	1660	1710	20061127
20070105	FBS				PLR	2720	2140	3730	3780	20070112
20070708	2690	FBD				PLR	570	1020	1070	20070414
20070823	2670	80	FBD				PLR	1590	1640	20070530
20071008	3030	345	270	FBS				PLR	50	20071015
20080108	3600	910	830	570	FBS				PLR	20071130
	20070105	20070708	20070823	20071008	20080108					

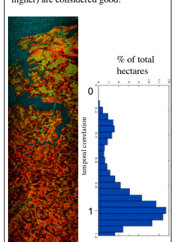
In all, some 46 interferograms were generated, most in the fully polarimetric (21.5° PLR) mode of PALSAR. Others were for the fine beam dual and single polarization mode (34° FBS and FBD) modes. Shown in the table above are the baseline separations (in meters) between the interferometric pairs. The critical baseline for these observations is 4.5 km, with optimum baselines for topograhic and vegetation measures being on the order of 500-1000 m. Colors above indicate the quality of the generated interferograms (red, orange, yellow, green), with green being the best. Dates of observation are given as indices to the grid. The two dates shown at right for the FBS and PLR modes are highlighted with a green outline.

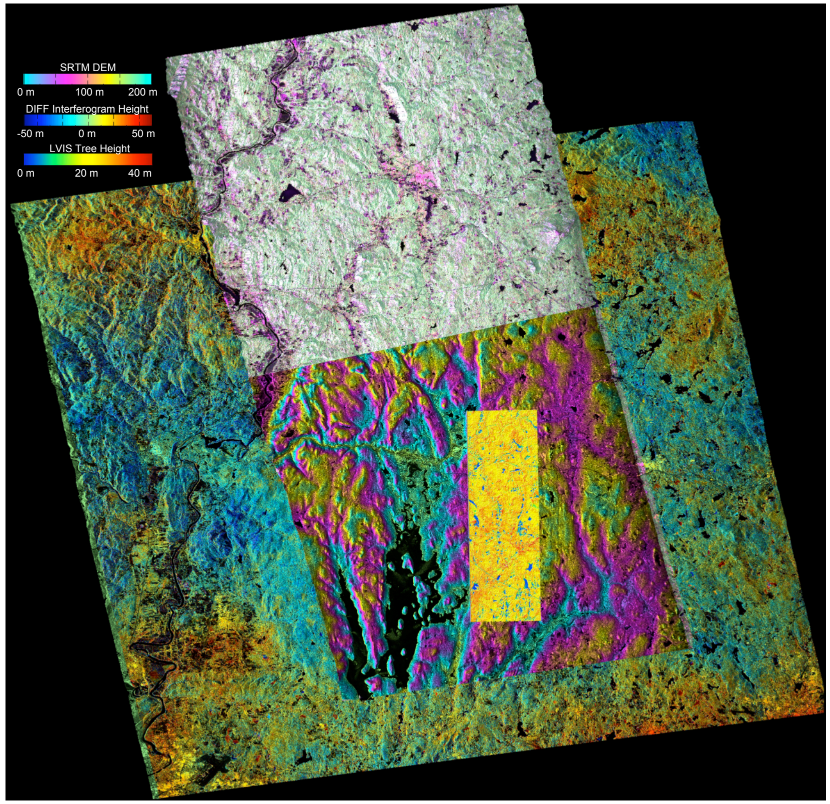


One of the nadir track from the LVIS flightline was used to sample the various data remote sensing data types for the purpose of generating relationships between the measured vegetation height and the SAR and InSAR observables in the radar data coordinates. Coregistration of the different data types are better than the multi-looked resolution elements used (30-50m) . Results from this comparison between lidar, SAR and InSAR data types is shown in the plots to the right.

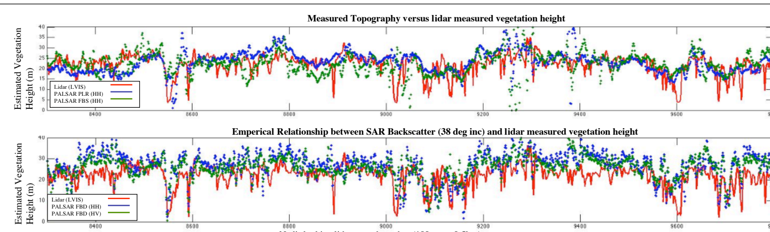
A little about temporal decorrelation

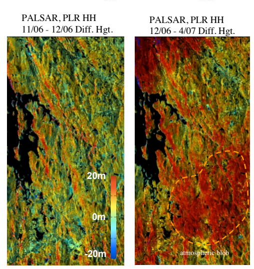
Temporal decorrelation is calculated for a two-day repeat-pass SIR-C image to show the percentage of pixels showing significant decorrelation. In the histogram, large values of correlation (1.0 or higher) are considered good.





Shown above are five types of remote sensing data collected over the Harvard Forest. These are: i.) differential interferometry (large background image), ii.) fully polarimetric backscatter power corrected for slope effects (red-hh; green-hv; blue-vv), the DEM (large center image), and lidar vegetation height data (yellow). A colorbar indicated values for the various products. SAR and InSAR data are collected by JAXA's ALOS/PALSAR, L-band SAR with a 46 day repeat, SRTM C-band interferometer, and NASA GSFC's LVIS vegetation lidar.



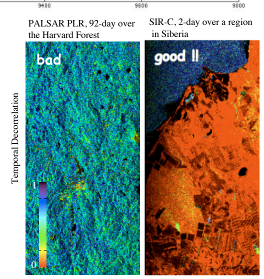


• The first line-plot above compares the lidar derived vegetation height to the interferometric height difference between the PALSAR derived topography and SRTM, for two different dates. The full differential interfergrams for these dates are shown at left, where it is clear that large-scale atmospheric disturbances modulate the difference. These disturbances have been removed to make the line-plot shown above.

• The second line-plot is the result of using a simple linear model to relate radar backscatter to the lidar measured vegetation height for both the co- and cross-pol radiometric channels at a 39 degree incidence angle.

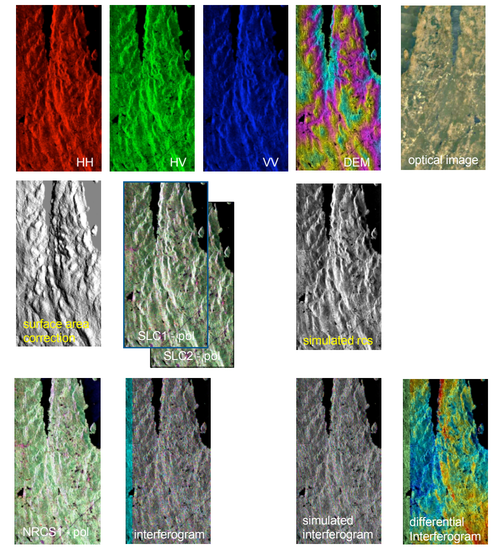
• Shown at right are two examples of estimating Temporal Decorrelation from the InSAR imagery. The image to the leftmost image is typical of PALSAR repeat-pass observations and does not encourage use of correlation magnitude for estimating vegetation height. The righmost image, from a 2-day SIR-C repeat observation in Siberia indicates excellent interferometric correlation.

• The differential interferograms shown to the left however do show good fringes, even in the presence of temporal decorrelation effects on the correlation magnitude, and therefore indicate the potential for using phase for estimating vegetation heights.



Processing

A careful set of steps are executed to process the raw SAR data into a differential interferogram which takes into account surface topography and slope effects. Once images are co-located to a geographic reference, they may be compared with other data sources for better understanding and exploring the desired vegetation signature.



Processing Steps

1. Process raw data to their highest resolution, and maintained in single-look complex (SLC) format. Scenes collected on different dates are processed to the same doppler to maintain a constant geometric reference
2. A DEM in map coordinates (from SRTM or other source) is used to simulate the backscatter SAR image intensity based on the observing geometry and the surface slopes. This simulated SAR image in map coordinates is then transformed into the radar coordinates.
3. Processed SLC's are coregistered to the simulated SAR image in radar coordinates. Resampling is performed using a sinc interpolator and maintains the complex numbers of the SLC images.
4. The DEM in the radar coordinates is used to calculate the area normalization factor to remove the effect of slop from the radar cross section (backscatter) image. This factor is used to correct the RCS and compute the normalized radar cross-section which is used for comparing backscatter power to biomass and/or vegetation height measurements.
5. The resampled and co-registered SLC's are used to form an interferogram. This interferogram contains topographic information, as well as differential path length between the two dates of observation. The phase signature is proportional to the separation of the satellite tracks from repeat passes. This separation is on the order of 50 - 5000 meters. The larger the separation, the more sensitive the measurement is to topography, vegetation and differential phase.
6. A simulated phase image is created from the projected topography obtained from the DEM in radar coordinates. This simulated phase is subtracted from the phase of the interferogram. The remaining phase may be due to I.) the difference in penetration between the SRTM DEM and the L-band interferometer, ii.) errors in the DEM topography, or iii.) atmoaspheric/ionospheric induced path length differences between the two dates of observation. At present, it seems most likely that the induced path length differences are the most likely culprit.
7. The remaining, coregistered and topographically corrected SLC's can be used to calculate things like temporal decorrelation and polarization sensitive interferometry (PolInSAR). They may also be reprojected into the map domain to compare and combine with lidar and other relevant data sources.

Conclusions

Thus far, we have processed over 46 interferograms and SAR images have been processed over the Harvard Forest region. These data have been coregistered to the SRTM DEM and have been used for comparison between the various radar derived observations (polarimetric radar cross section power, interferometric correlatoin and phase, etc.). This processing has included the removal of topographic effects, both for the backscatter magnitude and the interferometric phase. In all, the 46-day repeat cycle of JAXA's ALOS/PALSAR makes direct use of interferometric coherence for estimating vegetation vertical structure difficult. Yet, the data clearly is able to support the interpretation of phase into topographic height, even under well vegetated regions. The conversion of this topographic height into vegetation height, either through direct interpretation of differential height, or polarimetric interferometry techniques remains the subject of ongoing study.

In general, the studies of these data sets over the Harvard Forest region thus far have revealed:

o Temporal decorrelation due to the 46-day repeat remains an issue for use of correlation magnitude for estimating height.

o Interferometric phase and PolInSAR techniques, are strong candidate for solving these problems. A more controlled study of shorter repeat periods using an airborne instrument would be welcome as well.

o Future work to focus on continued studies over the Harvard Forest region as well as performing similar studies to other, well observed sites, globally.