Temporal Decorrelation Studies Relevant for a Vegetation InSAR Mission

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Abstract

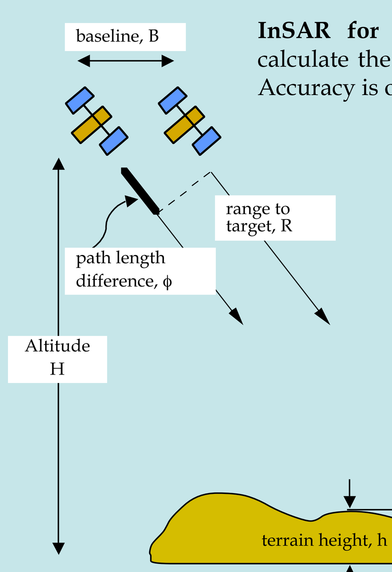
For mapping vegetation 3-dimensional structure, there are currently two principal methods. One method is to use full waveform lidar to map the canopy reflective properties as a function of range within the illuminated spot of the lidar. The second method is to use radar interferometry to collect the spatial frequencies which are used to estimate the 3-D structure of vegetation canopies over the radar swath.

A realistic scenario for implementing a spaceborne 3-D structure mapping mission will include some combination of these two technologies, thus making best use of the high resolving power of the lidar measurements while benefiting from the all weather and wide swath coverage of the SAR observations.

Because of dimensional and orbital constraints, the InSAR portion of such a mission would likely use a repeat-pass observing strategy to measure the interferometric response of vegetation one spatial frequency at a time. In this observing scenario, the change of the target's geometry over time would be the principal error source in determining the vegetation 3-D structure.

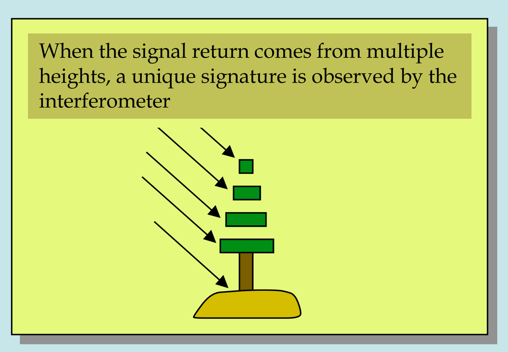
In this poster we discuss early results from existing airborne and satellite data for quantifying temporal decorrelation at L-band and P-band and present observing strategies which can be implemented in a spaceborne mission. By continuing this study of temporal decorrelation and quantifying its affect on 3-D structure estimation, we will provide critical information for designing a mission to make these measurements from a spaceborne platform.

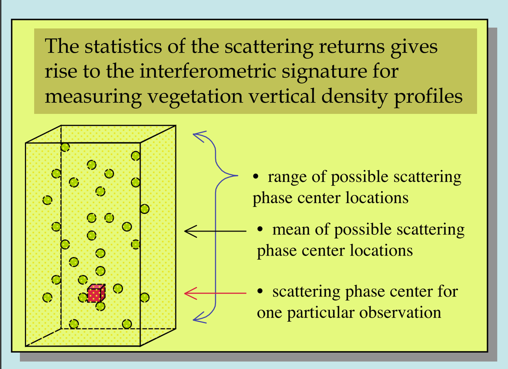
InSAR Sensitivity to Vegetation Profiles: Some Basics



InSAR for topography: path length difference is used to calculate the look angle and determine the height of the terrain. Accuracy is on the order of meters, with a 25m resolution

$$h = H - \rho\cos\left(\sin^{-1}\left(\frac{\lambda\phi}{4\pi B}\right)\right)$$

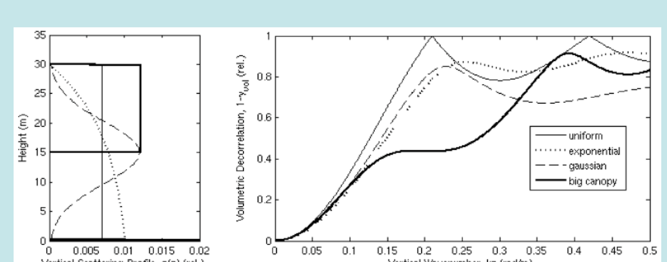




The sensitivity of the interferometric phase to changes in height, is given by the vertical wavenumber ($d\phi/dz$) as

$$k_z = \frac{akB\cos(\theta-\alpha)}{R\sin\theta}$$

Changing instrument parameters such as the baseline, range and look angle will affect the sensitivity of the measurement to the vertical density profile of the vegetation



The figure to the left shows a variety of interferometric correlation magnitudes as a function of kz for varying canopy profiles. Note that for small values of kz, the volumetric decorrelation for all profiles is the same.

Collecting interferometric observations as a function of the baseline or vertical wavenumber will reveal the vertical profile of the vegetation. For single baselines, and the assumption of a uniform canopy, the volumetric correlation is given by a sin(x)/x, or sinc function which generally gives a slight overestimate of the decorrelation that would be observed for a tree of height, h_v. Hence, this model can be used to put a bound on the amount of decorrelation that would be occur under a particular observing scenario.

$$\gamma_{vol} \le \text{sinc}(k_z h_v/2)$$

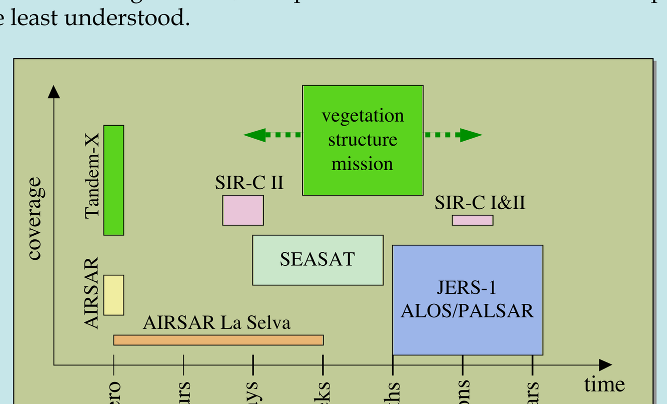
The interferometer does not directly observe the correlation due to the vegetation signature. Rather, the observation is a combination of various decorrelation signatures, including that due to thermal noise, γ_{SNR}, geometric effects, γ_{geom}, and temporal decorrelation, γ_{temp}

$$\gamma_{obs} = \gamma_{vol}\gamma_{SNR}\gamma_{geom}\gamma_{temp}$$

To find the desired volumetric correlation, and in turn determine the desired vegetation vertical profile, these effects must be removed from the observation.

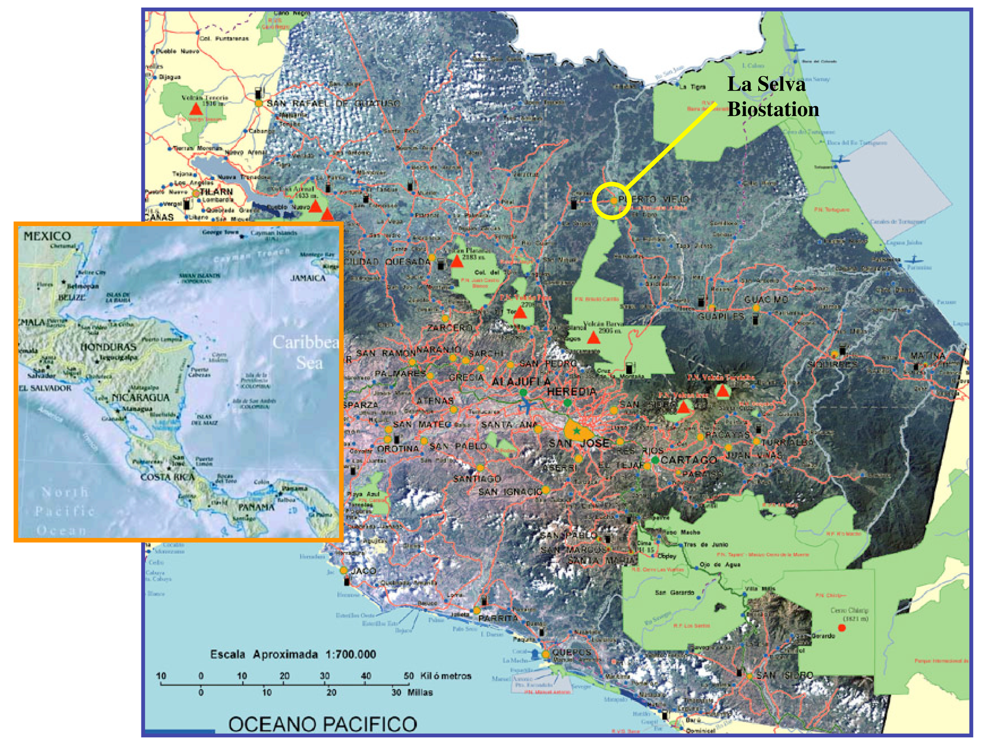
$$\gamma_{vol} = \frac{\gamma_{obs}}{\gamma_{SNR}\gamma_{geom}\gamma_{temp}} = f(h_v) \qquad h_v = f^{-1}(\gamma_{vol})$$

Of the four contributing sources, temporal decorrelation is the least predictable,and therefore the least understood.



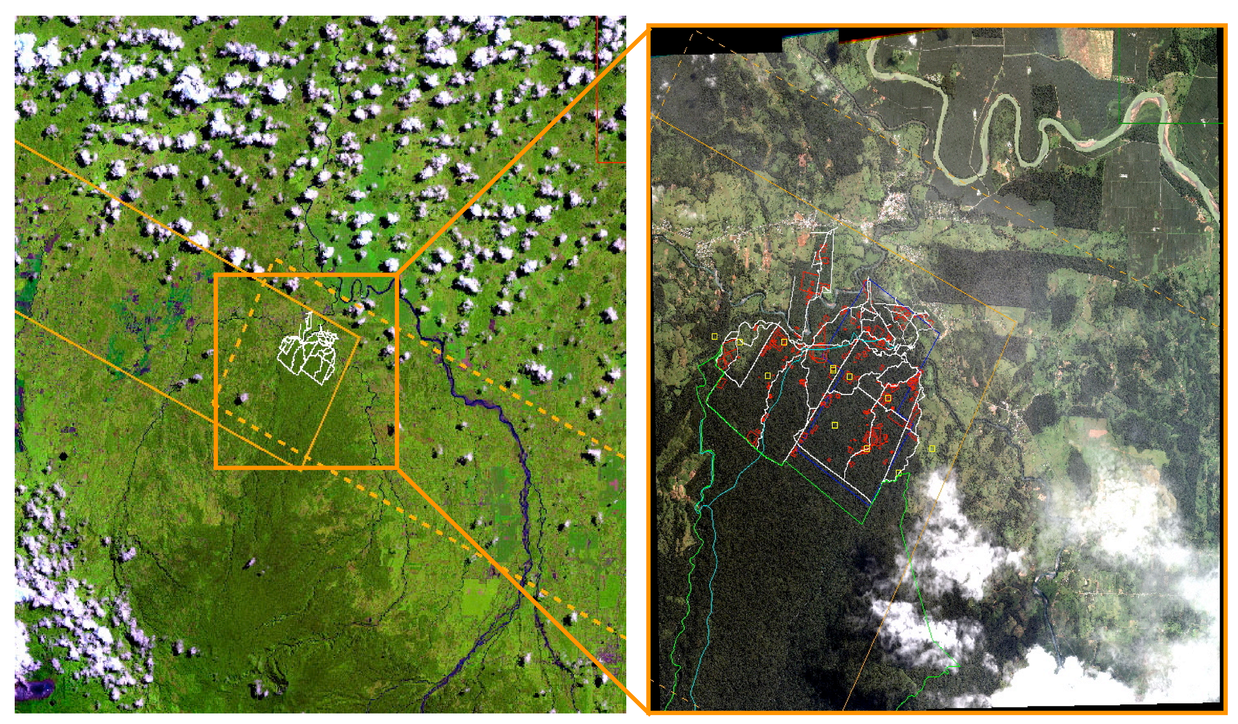
A vegetation structure mission that included repeat pass interferometry would have to choose between single-pass and repeat-pass interferometry. A lower cost repeat-pass mission would need to make the tradeoff between coverage and the time elapsed between observations (and hence temporal decorrelation). As such, we are studying a collection of observed data with a variety of temporal baselines to better understand the time dependence of temporal decorrelation.

Airborne Studies of La Selva Biostation, Costa Rica



La Selva biostation is located north of the Costa Rican capitol of San Jose. Ground cover extends from primary forest to farmland. This site was chosen for InSAR vegetation profiling studies because of the existence of coincident lidar data as well as extensive studies of the forest cover.

AIRSAR flightlines were chosen to image La Selva from two directions. Optical imagery shows a variety of primary forest as well as surrounding farmland.



• A total of 36 flight lines were flown at La Selva, Costa Rica on March 3, 6 and 20 of 2004.
• Multiple lines at same altitude flown on same day to support minimal temporal decorrelation repeat pass studies with various baselines.
• Lines flown support temporal baselines of ~ hour, 3, 14 and 17 days.
• Over 250 possible combinations of temporal and spatial baselines are possible at each of the three observing frequencies (C-, L- and P-band), as well as polarimetric data which can be used for polarimetric interferometry (PolInSAR) studies as well.
• Shown below are the variety of 8 km L-band observations superimposed on a plot of interferometric correlation as a function of vertical wavenumber, kz, assuming a 10 m tree height. Larger trees would compress the horizontal axis of the plot.

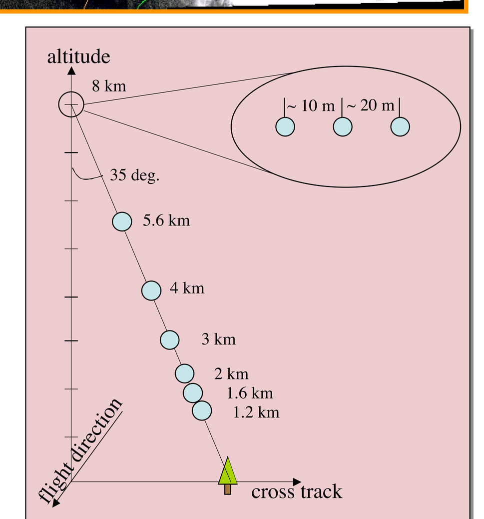
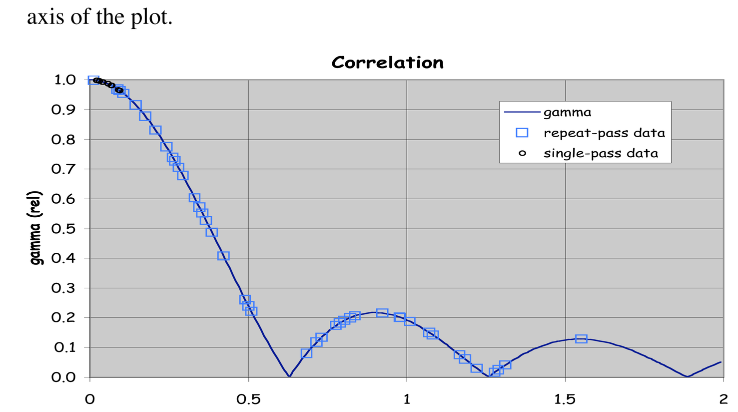
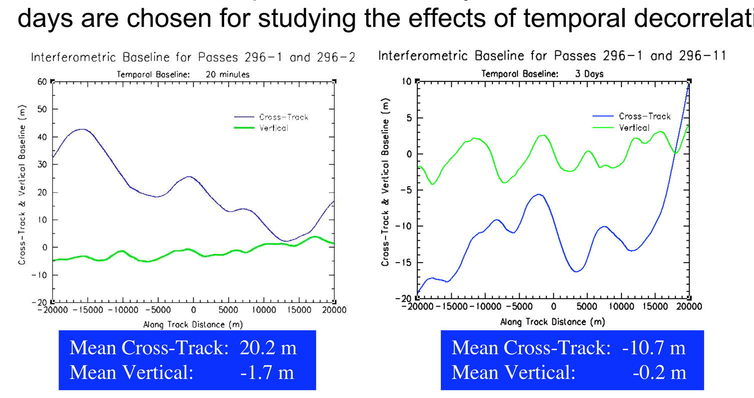


Illustration of the AIRSAR observing geometry for multiple altitudes and repeat pass observations at 8km.



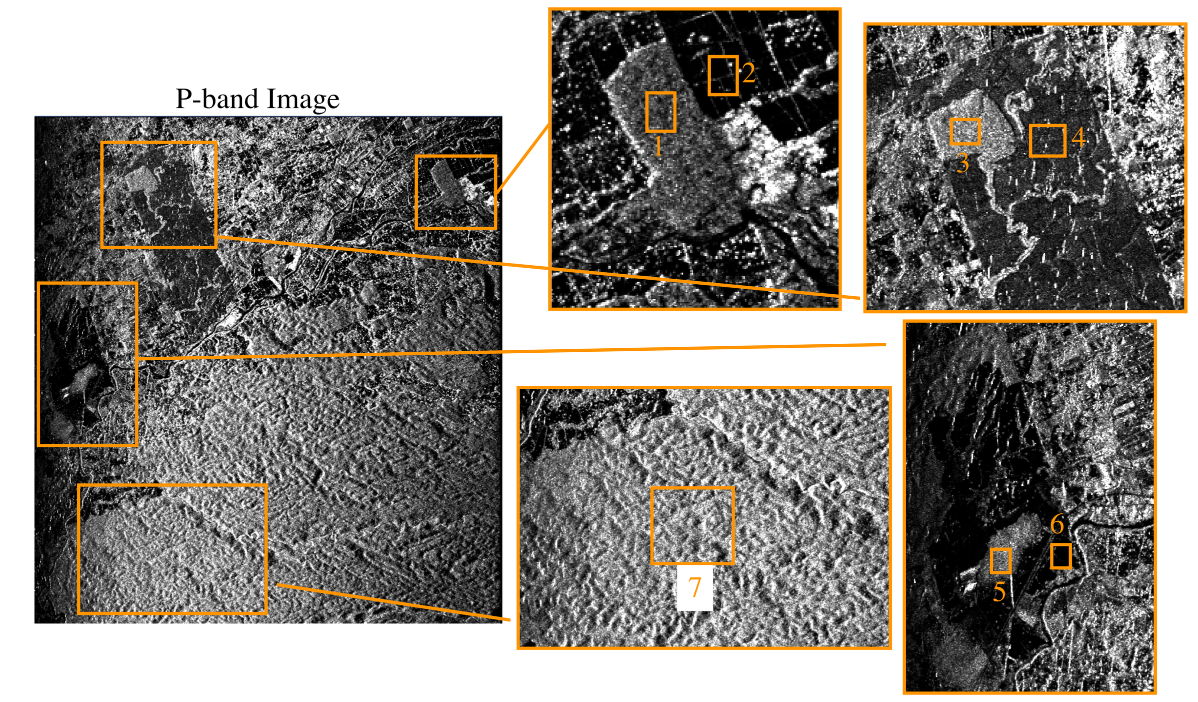
Two interferometric pairs with relatively small baselines and temporal baselines of 20 minutes and 3 days are chosen for studying the effects of temporal decorrelation in a tropical forest such as La Selva



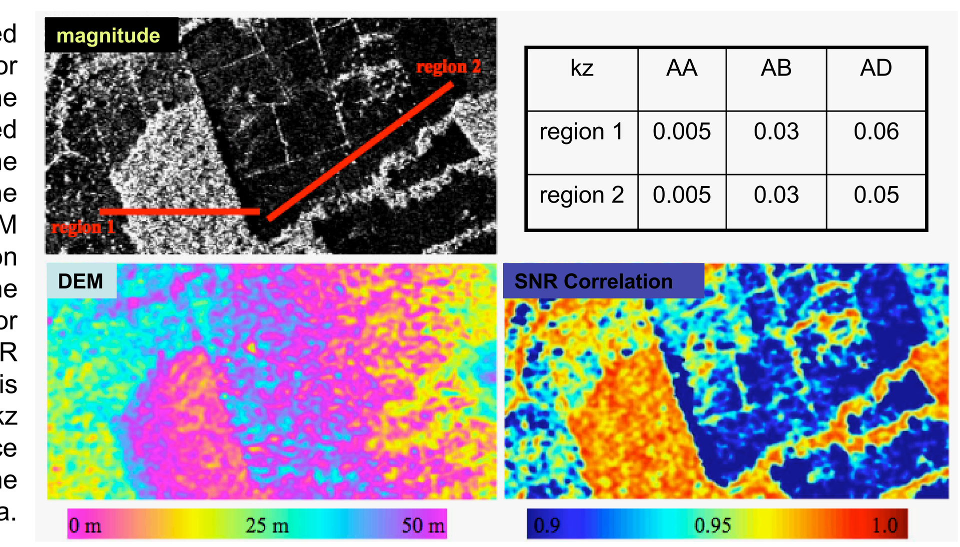
The presence of primary and secondary forest at different growth stages, as well as the variety of AIRSAR data collections will make this a valuable data set for analysis for some time to come.

La Selva (cont'd)

Repeat pass data for P- and L-band was processed over La Selva. Forested and non-forested regions were selected in close proximity to one another to gauge differences in the interferometric response.

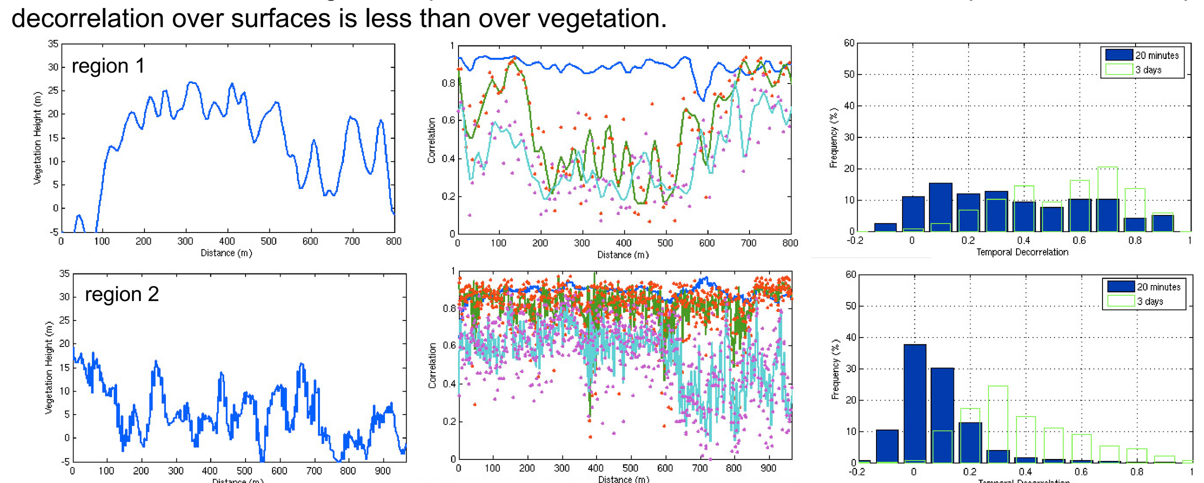


Profiles from selected areas can be used for detailed analysis of the source of observed correlation. Inputs to the model consist of the magnitude plot, a DEM (for estimating vegetation height) and zero baseline interferometry for measuring SNR decorrelation. In this study, small values of kz were desired to reduce the influence of volume scattering in the data.



kz	AA	AB	AD
region 1	0.005	0.03	0.06
region 2	0.005	0.03	0.05

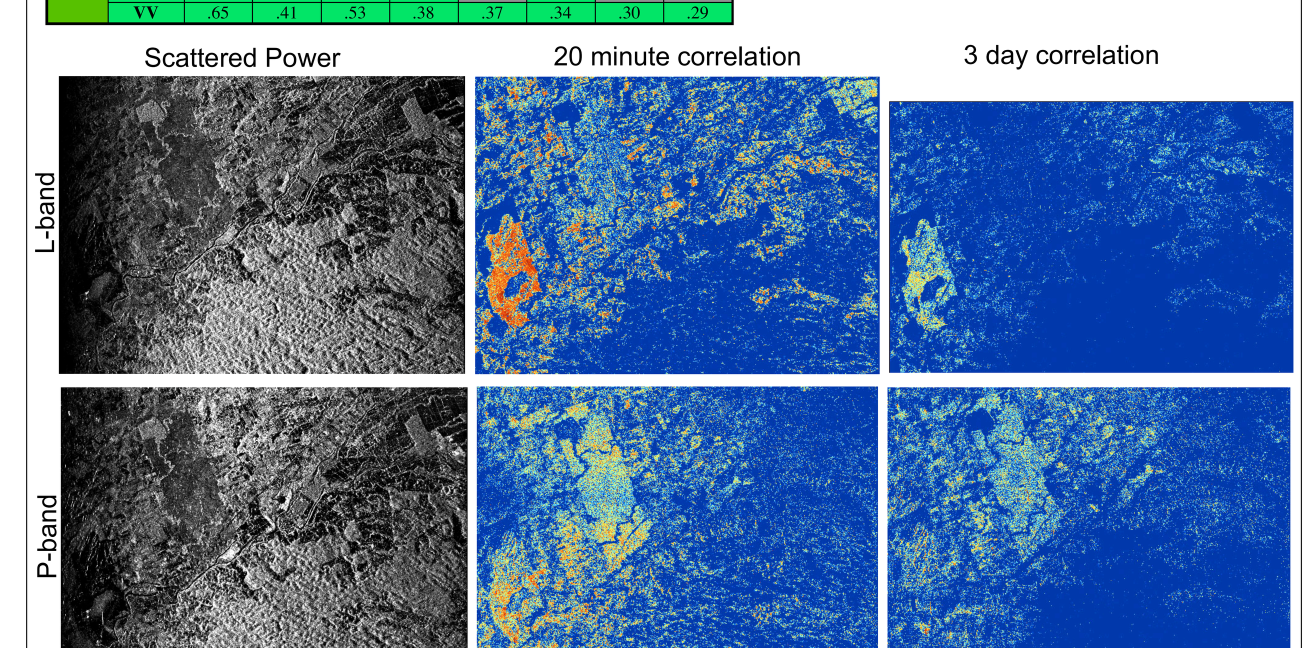
Below are shown two examples of profiles through the data. The leftmost plots show estimated vegetation height. The center plots show: expected correlation (dark blue), 20 minute correlation (green line and red dots) and 3 day correlation (light blue and violet dots). The rightmost column shows the temporal decorrelation estimated from the difference between the expected and the observed correlations. Note that longer time periods lead to increased decorrelation, as expected. Also, temporal decorrelation over surfaces is less than over vegetation.



Interferometric correlation magnitude at L- and P-band for a vairiety of regions, polarizations and temporal baselines

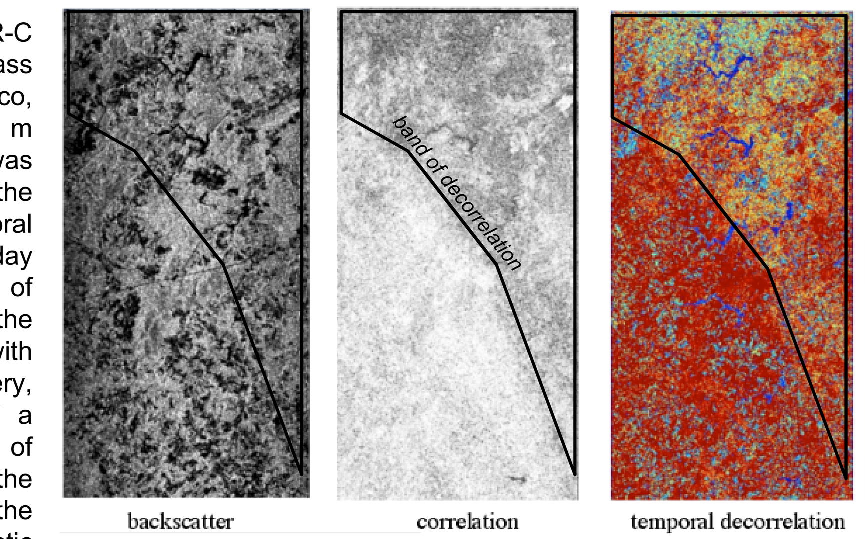
Region	Polarization	P-Band 20 minute 20 m 296-1 296-2	P-Band 20 minute 90 m 296-10 296-11	P-Band 3 day 10 m 296-1 296-11	P-Band 3 day 104 m 296-1 296-10	L-Band 20 minute 20 m 296-1 296-2	L-Band 20 minute 90 m 296-10 296-11	L-Band 3 day 10 m 296-1 296-11	L-Band 3 day 104 m 296-1 296-10
1	HH	.69	.60	.55	.53		.35		
	HV	.46	.51	.43	.44		.33		
	VV	.56	.54	.45	.47	.40	.34	.48	.29
2	HH	.62	.67	.59	.54		.79		
	HV	.35	.40	.35	.34		.70		
	VV	.50	.61	.52	.47	.76	.72	.37	.55
3	HH	.71	.40	.55	.44		.34		
	HV	.63	.37	.45	.35		.34		
	VV	.68	.38	.49	.39	.36	.34	..40	.29
4	HH	.93	.93	.86	.81		.81		
	HV	.87	.87	.80	.75		.74		
	VV	.89	.92	.85	.80	.71	.71	.67	.39
5	HH	.87	.72	.86	.69		.47		
	HV	.81	.53	.70	.53		.44		
	VV	.80	.54	.73	.54	.59	.45	.54	.36
6	HH	.82	.75	.75	.68		.65		
	HV	.56	.46	.43	.42		.60		
	VV	.83	.61	.62	.64	.79	.66	.34	.59
7	HH	.69	.43	.57	.41		.34		
	HV	.66	.42	.55	.38		.33		
	VV	.65	.41	.53	.38	.37	.34	.30	.29

Large scale comparison between 20 minute and 3-day correlations at L- and P-band shows consistent temporal decorrelation across the forested region. Shown at left is a table summary between vegetated (green) and non-vegetated sites (white). Below are images that correspond to the different frequencies and temporal baselines mentioned above. Large decorrelation during the third day is likely due to the presence of drenching rains that occurred on the 3rd day of observations.

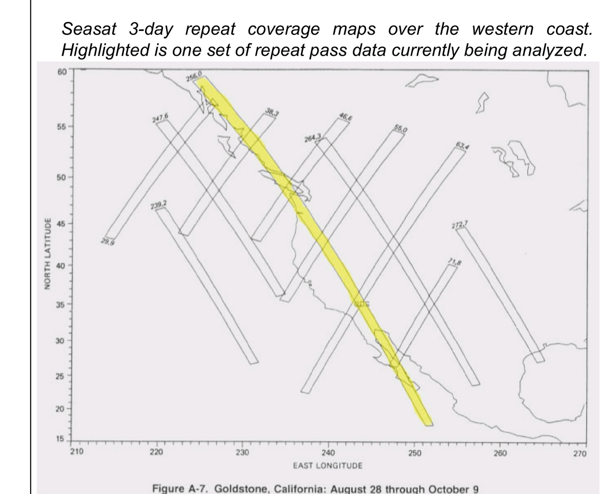


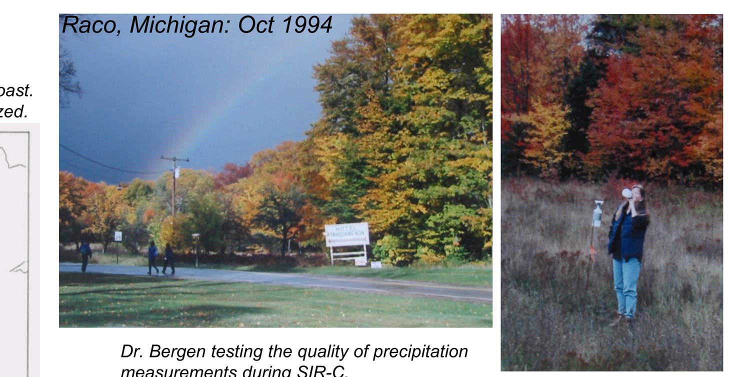
Spaceborne Studies

In October 1994, SIR-C performed repeat pass observations over Raco, Michigan. Assuming a 20 m vegetation height, it was possible to estimate the presence of temporal decorrelation for a two-day repeat. A large band of decorrelation across the image, not associated with features in the imagery, suggests the presence of a weather event during one of the overpasses. During the Michigan fall, changes in the ground cover may be drastic as well.



Seasat 3-day repeat coverage maps over the western coast. Highlighted is one set of repeat pass data currently being analyzed.



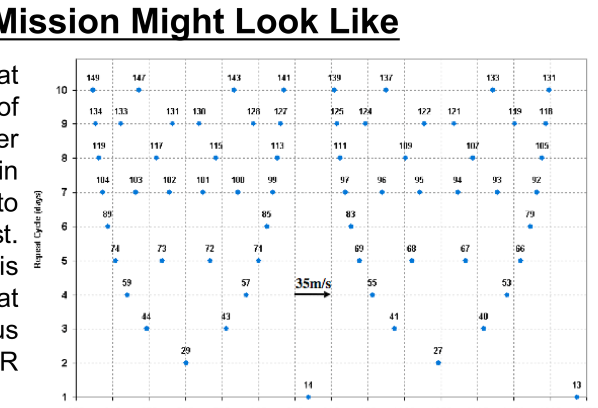


Dr. Bergen testing the quality of precipitation measurements during SIR-C.

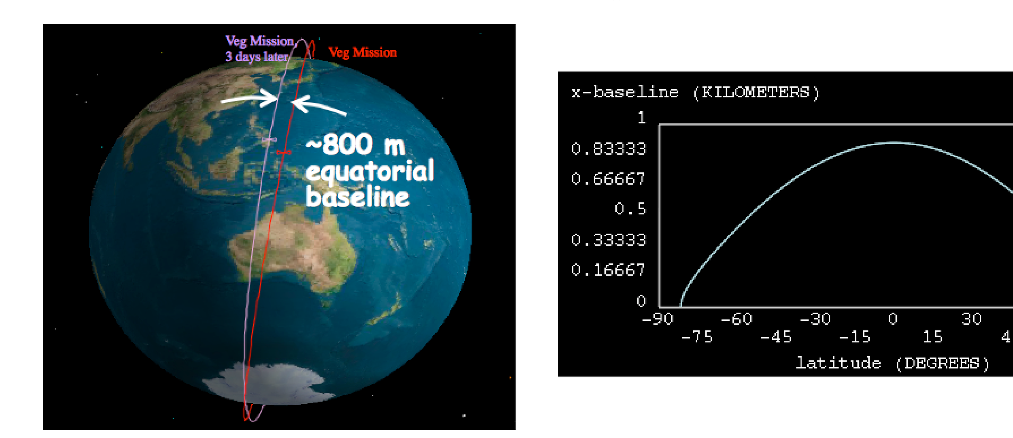
Near the end of its brief lifetime in the fall (Aug-Oct) of 1978, Seasat collected a variety of 3-day repeat-pass data. Analysis of this data, as well as more SIR-C data, will allow for a more complete, geographically diverse study to be made of temporal decorrelation.

What A Vegetation InSAR Mission Might Look Like

There are a finite number of sun synchronous repeat pass orbits. These are plotted below as a functionof altitude and days between repeat cycles. Shorter repeat cycles generally mean more difficulty in obtaining global coverage. Change in orbital altitude to change the repeat cycle is measured in units of thrust. In this case, 35 m/s of thrust, a moderate amount, is used to change altitude by 50 km. Hence, repeat coverage may be adjusted to accommodate various mission scenarios required for a realistic InSAR mission.



A near-polar satellite orbit would require a slight offset from an exact repeat orbit. This offset would be used to provide the baseline necessary for achieving interferometric sensitivity to vegetation vertical profiles. The baseline would necessarily be a function of the latitude due to the crossing of the orbits at the poles. A nominal L-band baseline separation at the equator for a 700 km orbit would be on the order of 800 meters, and would be consistent with higher biomass levels present at the equator.



It is expected that a lower frequency, P-band mission would have a larger baselilne and subsequently less temporal decorrelation if the ionosphere did not pose a problem. Studies related to a P-band mission are ongoing.

Conclusions

To date, we have just begun performing a thorough analysis of the effects of temporal decorrelation, potentially the largest source of error for a repeat pass InSAR mission for meauring vegetation vertical profiles. The resources for performing this study include data from SIR-C, Seasat, JERS-1, ALOS/PALSAR, and AIRSAR. As our methods develop, they will be expanded to include coincident Lidar and passive optical data, as well as to increase the geographic and temporal extent of the observations. Other areas of investigation will include use of interferometric phase only and PolInSAR for characterizing vegetation profiles (phase should be more robust than correlation magnitude, but requires additional measurements). The potential for single-pass (e.g. TanDEM-X, GeoSAR) and multialtitude observations will also provide valuable alternatives and ground validation by providing a superset of observations for differentiating between volumetric decorrelation and temporal decorrelation, under a variety of circumstances.

In general, the studies thus far have revealed the following:

- Both L- and P-band repeat pass observations show signs of temporal decorrelation at even the shortest of repeat pass periods (20 minutes).
- L-band shows more temporal decorrelation than P-band. In a realistic mission, this would have to be traded off with lower resolution, RFI and the presence of the ionosphere for P-band.
- Weather played a significant role in all observations of severe temporal decorrelation. It is unclear at the moment what the smallest amount of temporal decorrelation that would be observed in the absence of precipitation.
- Quantitative results to date have been over relatively small geographic areas and under short seasonal periods. More extensive studies to find examples of no temporal decorrelation for repeat pass observations would serve as a cornerstone for interpreting the observations presented in this poster.