K&C Phase 3 – Brief project essentials

Combined Use of SAR, InSAR and Lidar for Measuring Forest Biomass and Structure in the Northeastern United States

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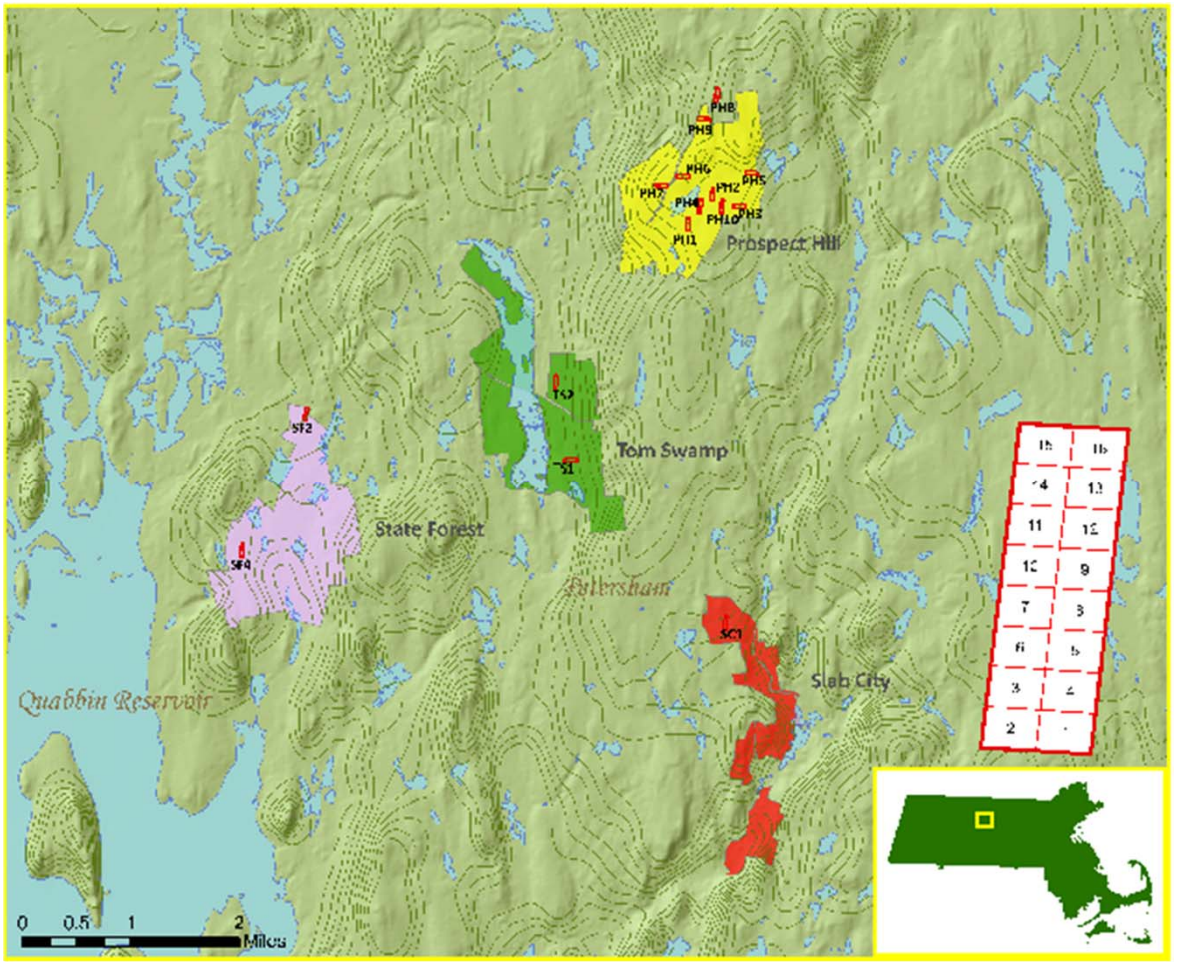
Science Team meeting #17 – Phase 3 Kick-off
JAXA TKSC/RESTEC HQ, Tokyo, March 27-29, 2012

Project area(s)

Use ALOS/PALSAR data for estimating forest physical characteristics of height, density and biomass. An assessment of the errors associated with these estimates is a critical part of this work. The principal remote sensing data type will be interferometric, but we are also looking at backscatter relationships as well.

The primary location for this work is the Harvard Forest, but we also have been investigating the Howland forest in Maine and the Injune Landscape Collaborative Project in Queensland, Australia.

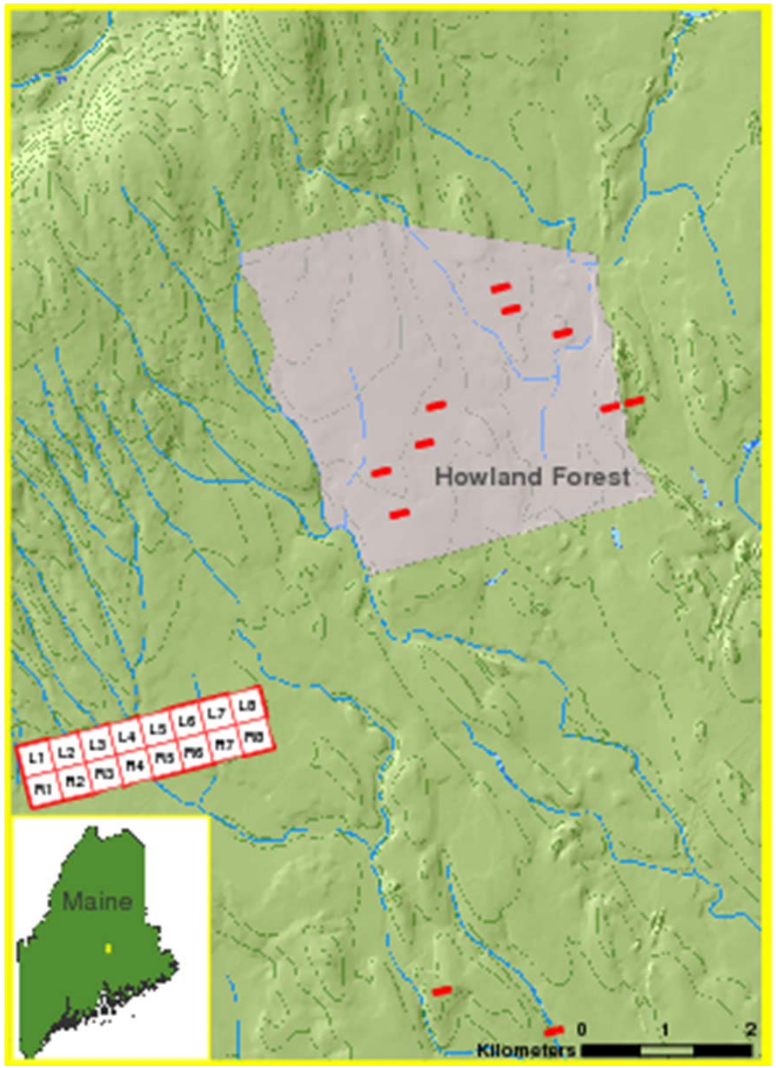
Study Sites

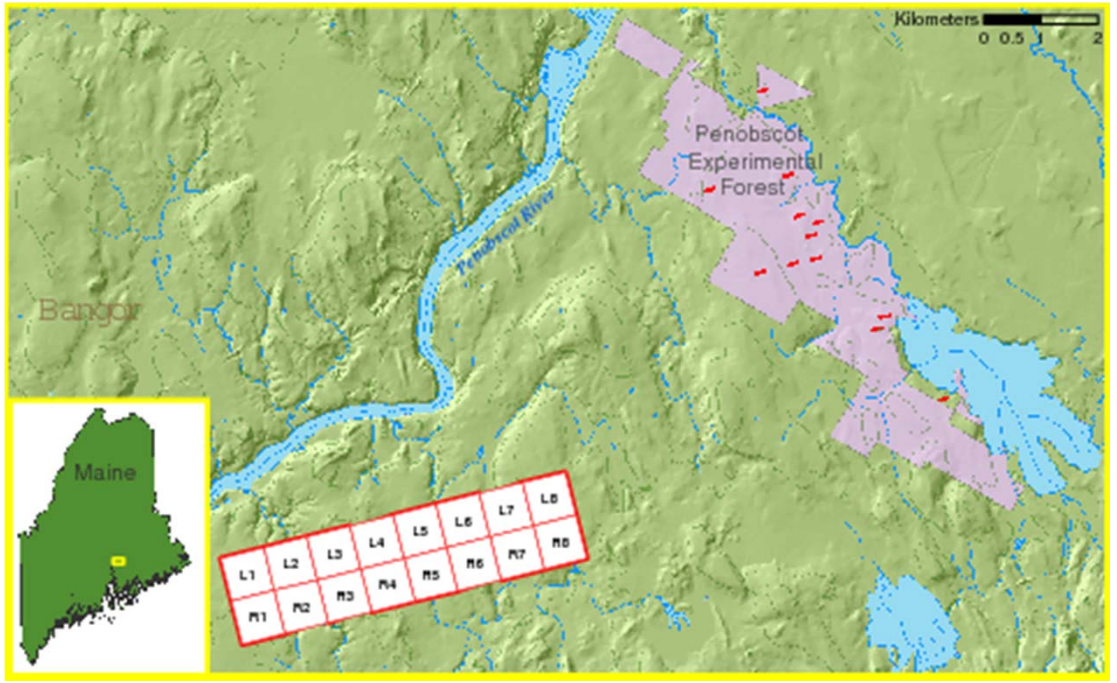


Harvard forest

Study Sites

Howland Forest





Howland Forest
(Penobscott)

Project objectives

The objectives of the project is to create algorithms that can be applied regionally and/or on a continental scale for estimating biomass and carbon storage. Hence, this work addresses the K&C thematic driver of **C**arbon cycle science.

Because carbon is estimated from forest structure, and forest structure can be used for characterizing forest ecology, this work also addresses the K&C thematic driver of Environmental **C**onservation.

Project schedule

Milestone 1 (March 2012). Provide lidar derived topography and vegetation height map for the Harvard Forest region to JAXA.

Milestone 2 (March 2013). Reporting of algorithm development and forest modeling effort ongoing in the Northeastern US.

Milestone 3 (March 2014). Final report for algorithm development and error assessment over the Northeastern US.

Support to JAXA's global forest mapping effort

- This project will aid in JAXA's global forest mapping effort through the development of algorithms that perform forest mapping using ALOS/PALSAR data. Since JAXA's global forest mapping effort will depend primarily on PALSAR data, this work will have a direct relevance to JAXA's work.
- Ground validation for the Harvard Forest will be shared. This includes ground validation data and derived products from remote sensing data from LVIS and UAVSAR.
- Derived products for other forest sites in the Northeastern US can be shared as well.

Deliverables

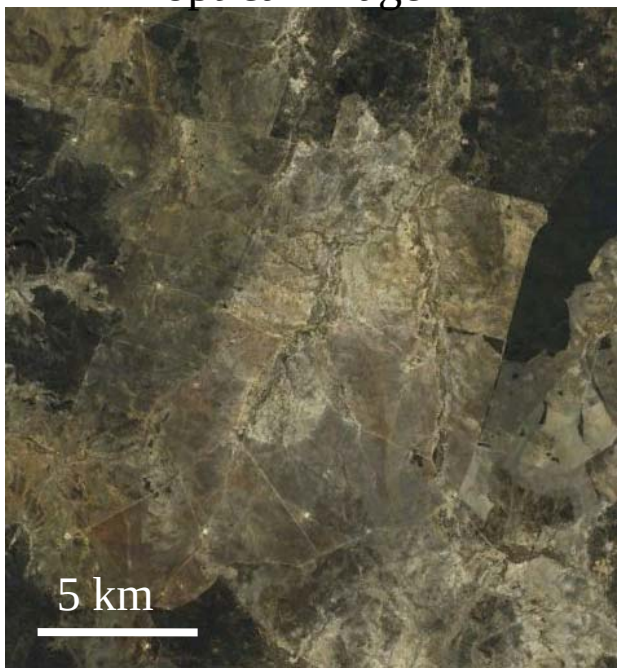
Planned output of the project.

- Lidar derived vegetation height map for the Harvard Forest
- Lidar derived biomass map for the Harvard Forest. Error estimates will be included.
- Algorithm output for combining lidar, SAR and InSAR data for Harvard Forest region
- Assessment of the ability of the algorithm to be extended to regions in the Northeastern US and other sites (on a per-site availability basis)

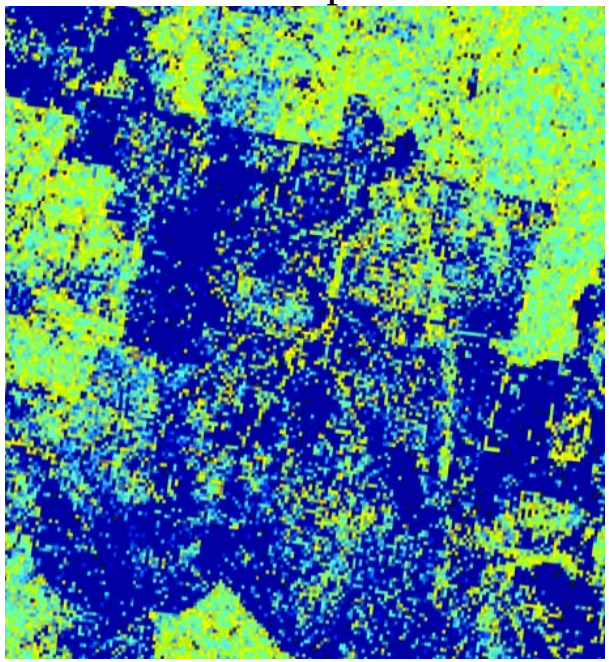
Something for REDD+

- SAR Interferometric correlation, corrected for thermal noise, can be used for sensitive detection of landcover change
- We have been using PALSAR interferometry at the Injune region (ILCP) to estimate “tree height” and detect degradation.
- A paper will be presented at IGARSS 2012

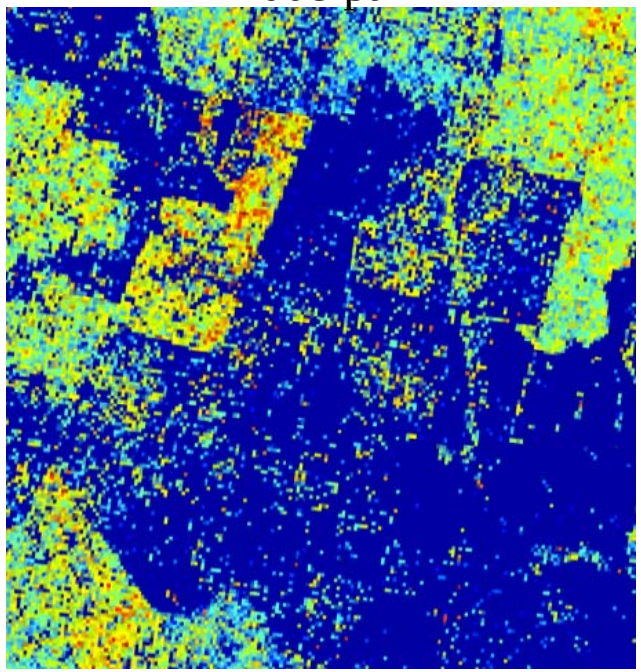
optical image



2007 pair



2008 pair



Research Update

Combined Use of SAR, InSAR and Lidar for Measuring Forest Biomass and Structure in the Northeastern United States

Motivation

- To Answer the DESDynI question

  "How to combine SAR and lidar data for estimating above ground biomass"

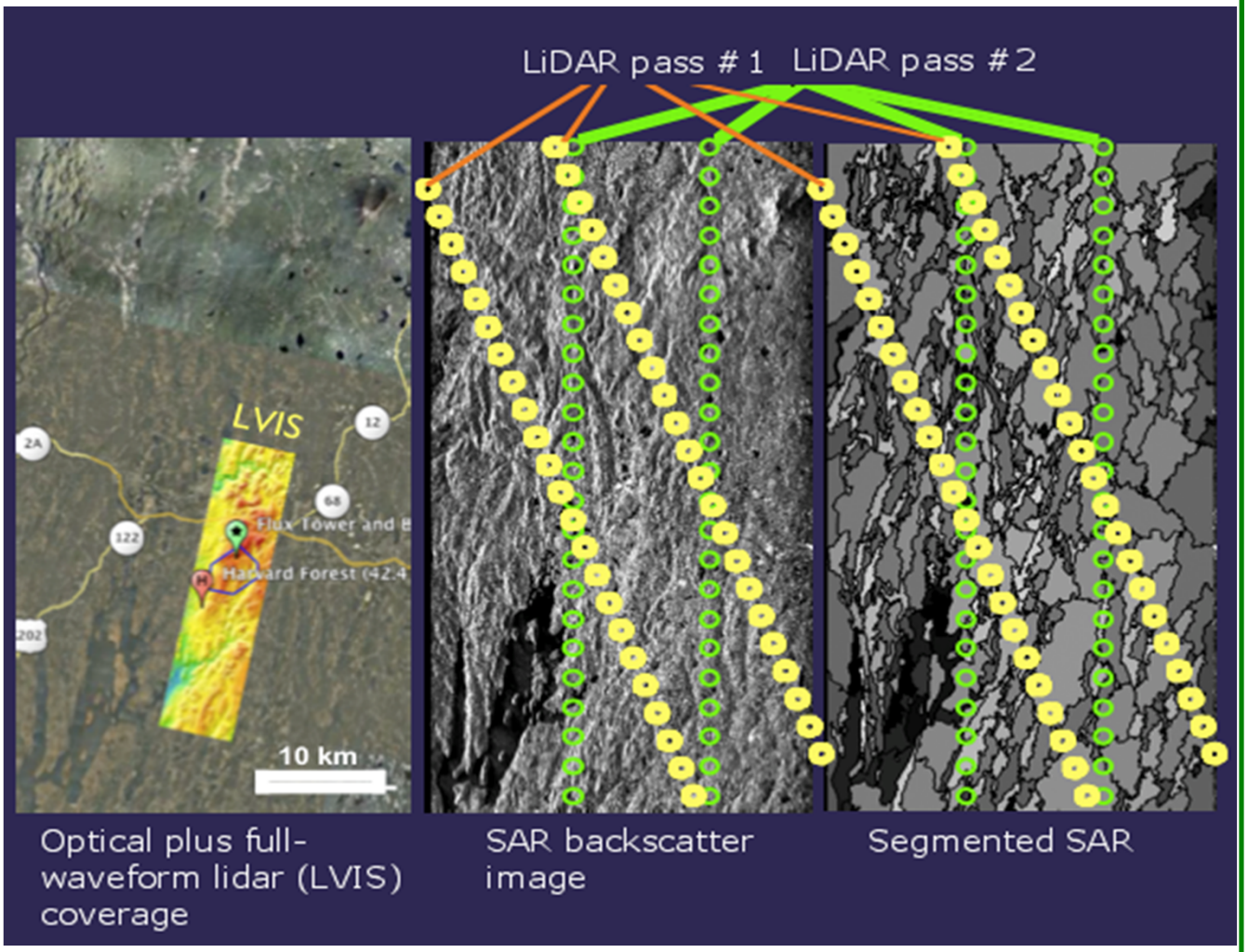
  - investigate lidar relationships to biomass
  - investigate radar relationships to biomass
  - use of lidar for sampling and radar for mapping
  - by quantifying error, system design can be related to science requirements

A Measurement and Estimation Concept

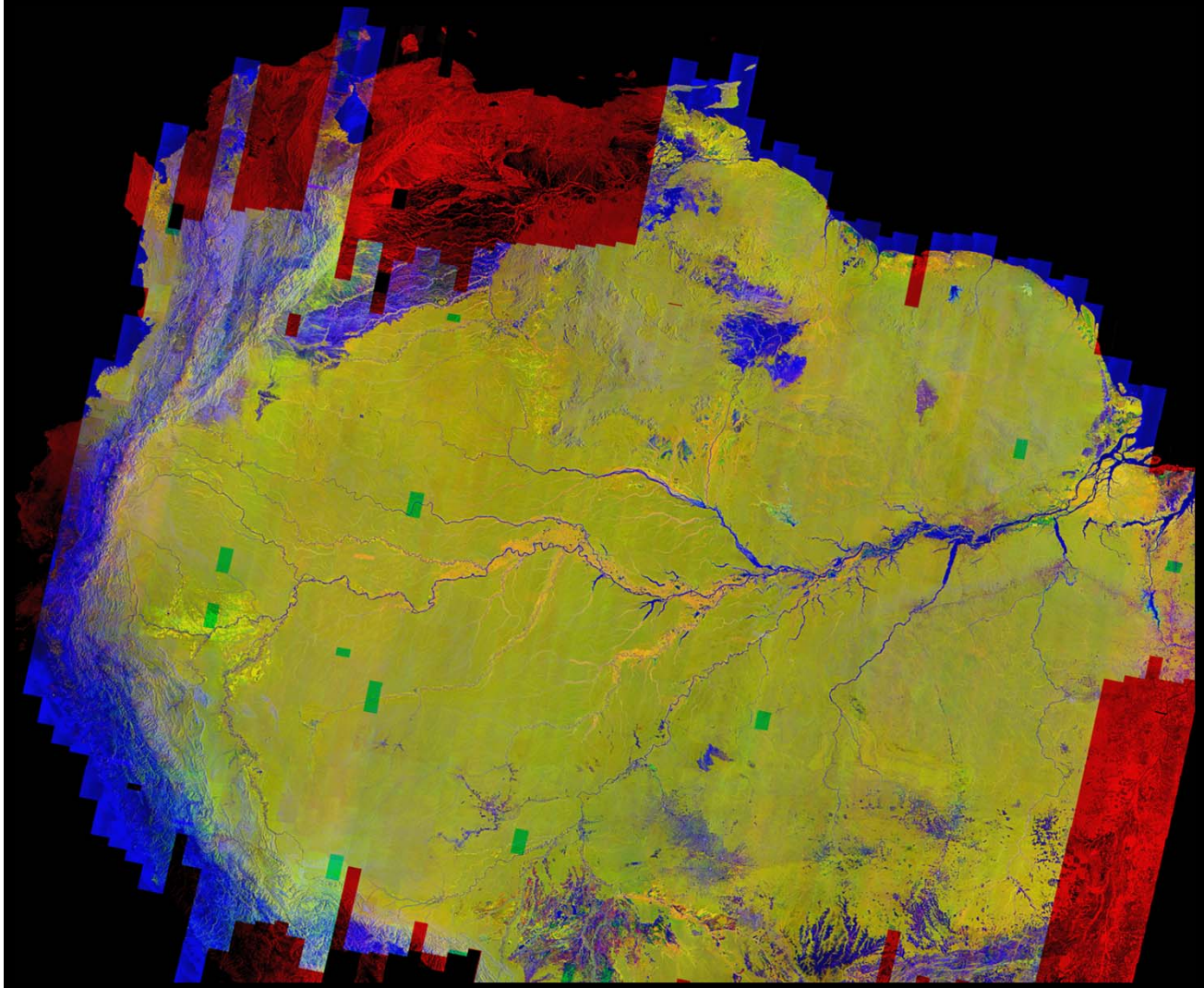
- Relies on the fundamental sensitivity of SAR backscatter power, texture and polarimetry to varying ground cover.

- Aggregate regions of a like response via an image segmentation

- Utilize coicident LiDAR observations on a scene by scene basis to assign values of interest to the segmented RaDAR image.



Vegetation and Terrestrial Carbon Storage



Siqueira et al., IEEE TGRSS, 2000

Building Blocks

Measurement planning, data collection

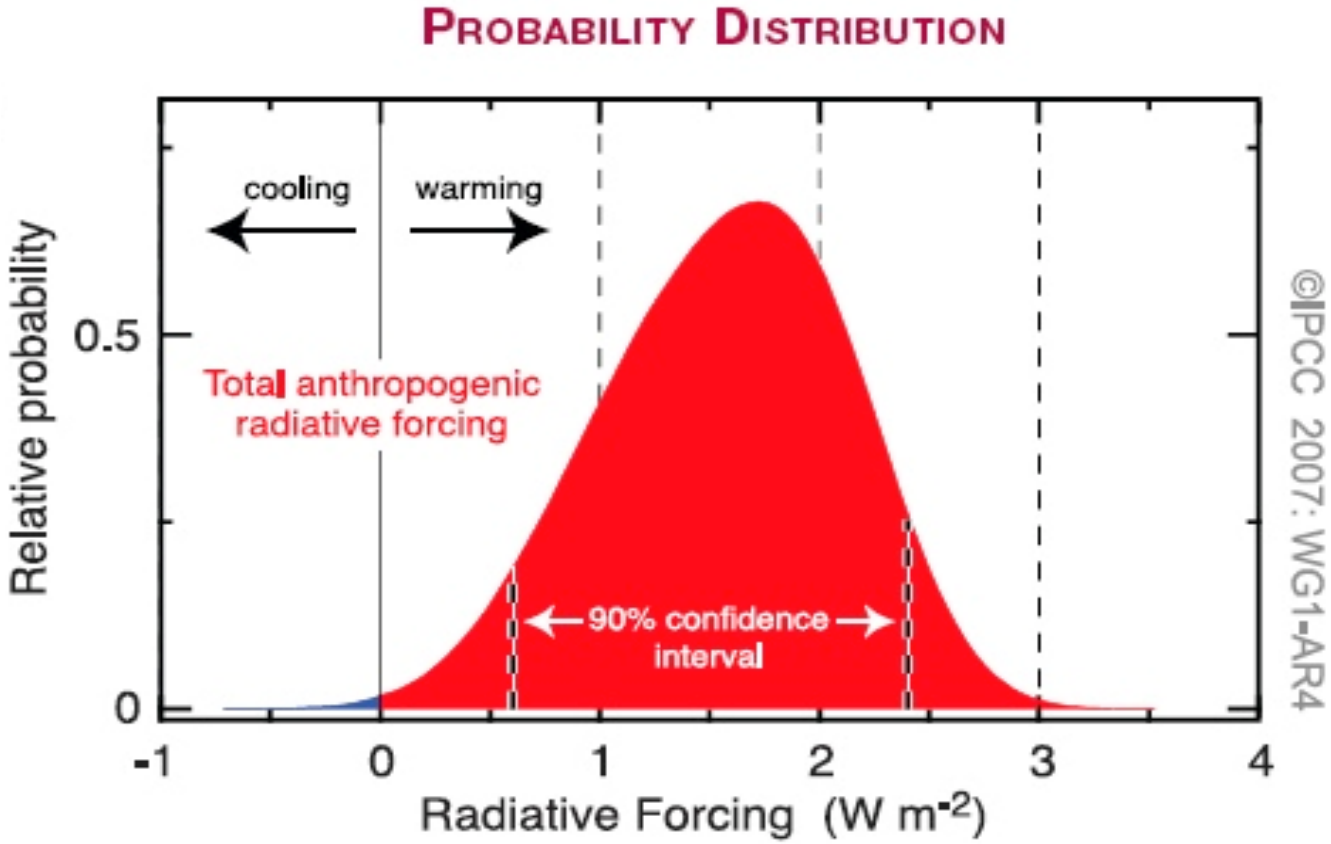
↓

Processing, mosaicking, data fusion

↓

Quantitative estimation of target characteristics

The Need for Measurement Accuracy



Human induced effects on global warming

Penzias &
Wilson 1965

HORN ANTENNA

HAS BEEN DESIGNATED A

NATIONAL HISTORIC LANDMARK

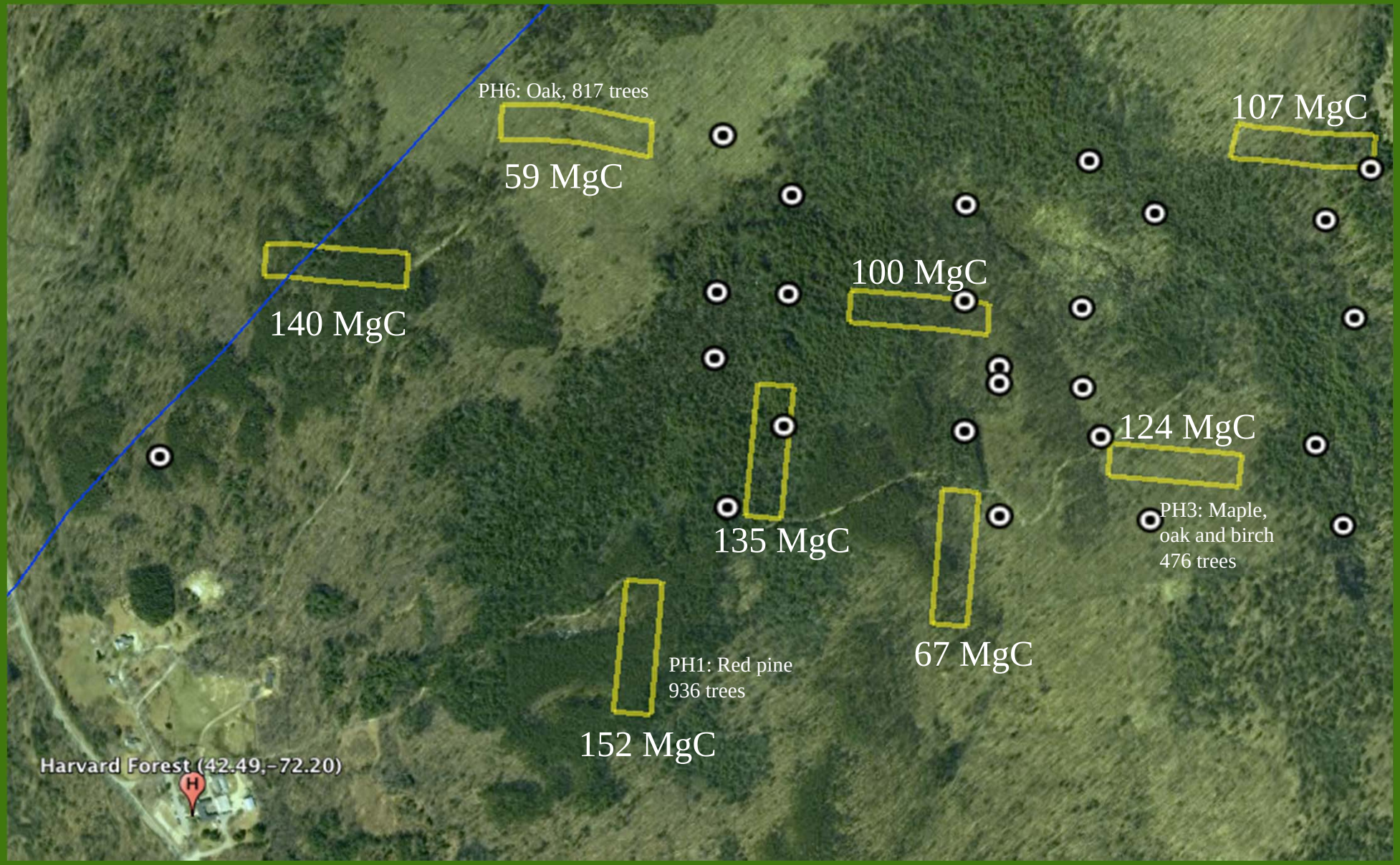
THIS SITE POSSESSES NATIONAL SIGNIFICANCE IN COMMEMORATING THE HISTORY OF THE UNITED STATES OF AMERICA. SCIENTISTS ARNO PENZIAS AND BOB WILSON WITH THE ANTENNA FOUND THE EVIDENCE CONFIRMING THE "BIG BANG" THEORY OF THE CREATION OF THE UNIVERSE, FOREVER CHANGING THE SCIENCE OF COSMOLOGY.

1989

NATIONAL PARK SERVICE
UNITED STATES DEPARTMENT OF THE INTERIOR

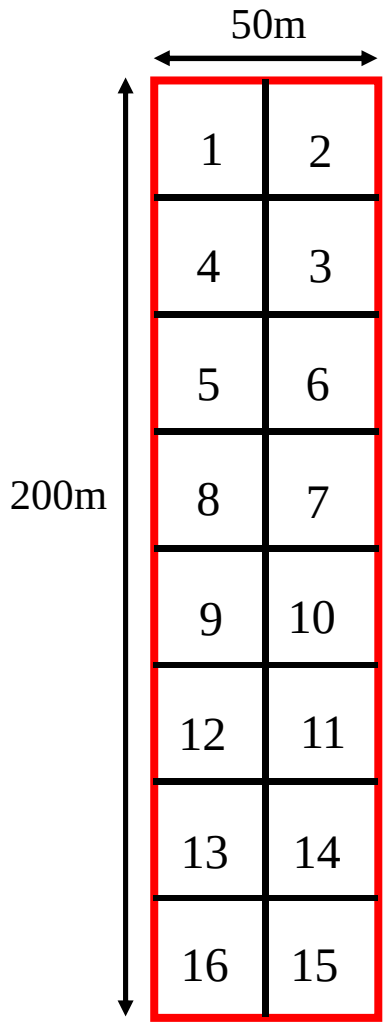
The Harvard Forest in Western Massachusetts is being used to develop scalable algroithms that can be applied world-wide. The target variety, terrain flatness and history of observation makes it an appealing remote sensing target for calibration/validation and vegetation studies.

Ground-Up Approach to Error Estimation

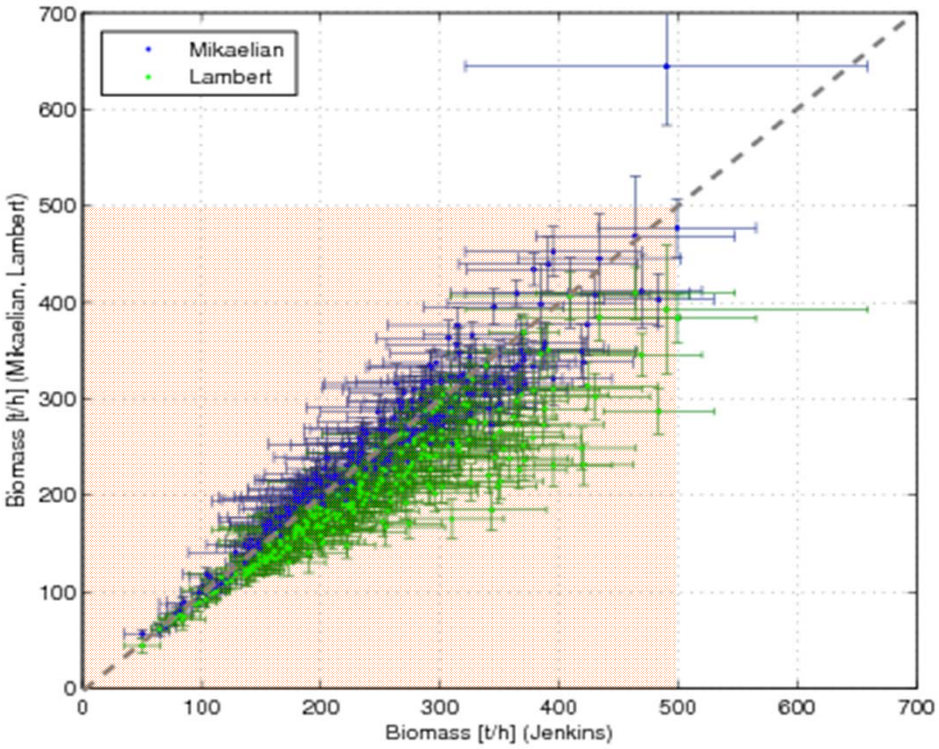


Field campaigns, summer 2009

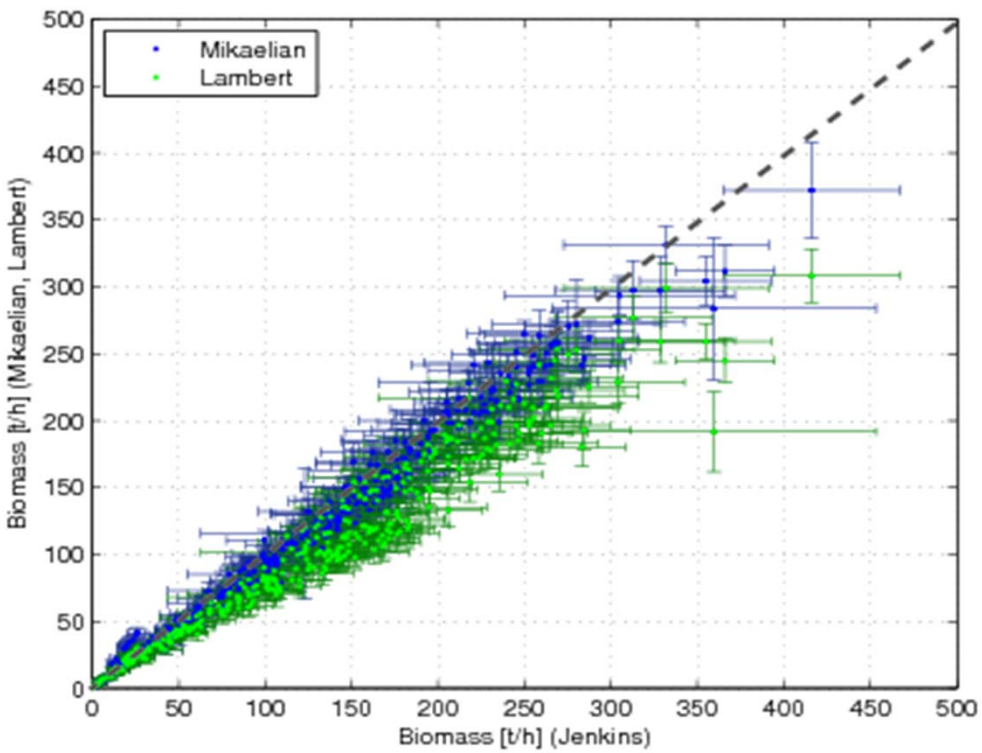
- Species, diameters, condition (live/dead) for every tree above 10cm in diameter per subplot
- Harvard Forest
  - 1200 Hectares of mixed forest
  - 15 1-**hectares** plots (240 **subplots**)
  - Dominant Species
    - Red Oak, Red Maple, White Pine, Eastern Hemlock
- Howland Forest
  - 500 Hectares of mixed forest
  - 23 1-**hectares** plots (368 **subplots**)
  - Dominant Species
    - Spruce, Fir, Hemlock, Pines and Maples
- Three sets of allometric equations were used to analyze the data and relate diameter measurements to biomass (Jenkins, Ter-M



Accuracy of ground truth measurements - subplots



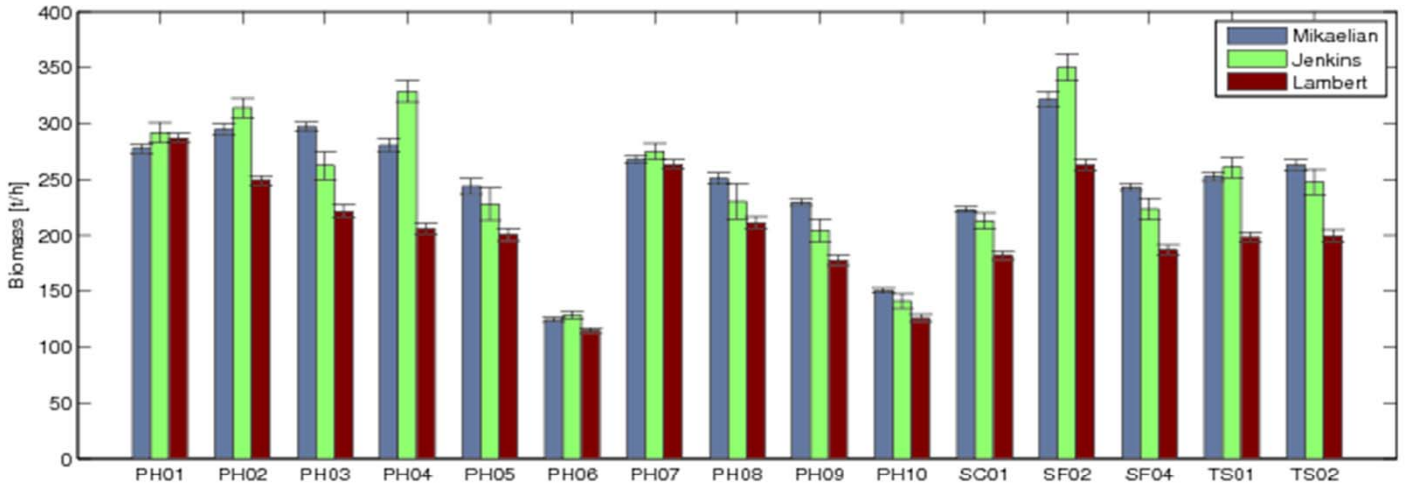
Harvard forest



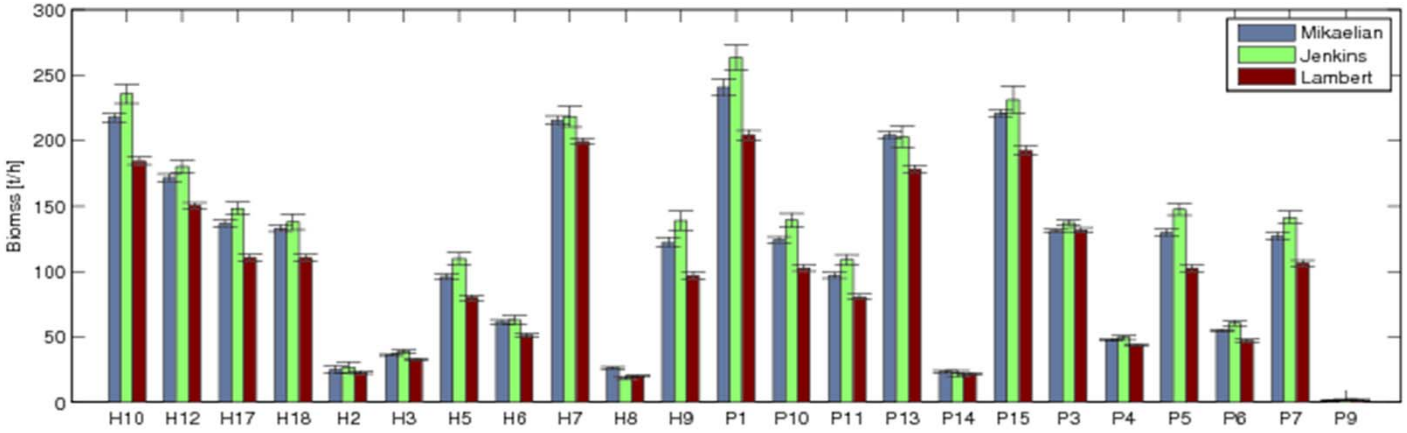
Howland Forest

Accuracy of ground truth measurements - hectares

Harvard Forest

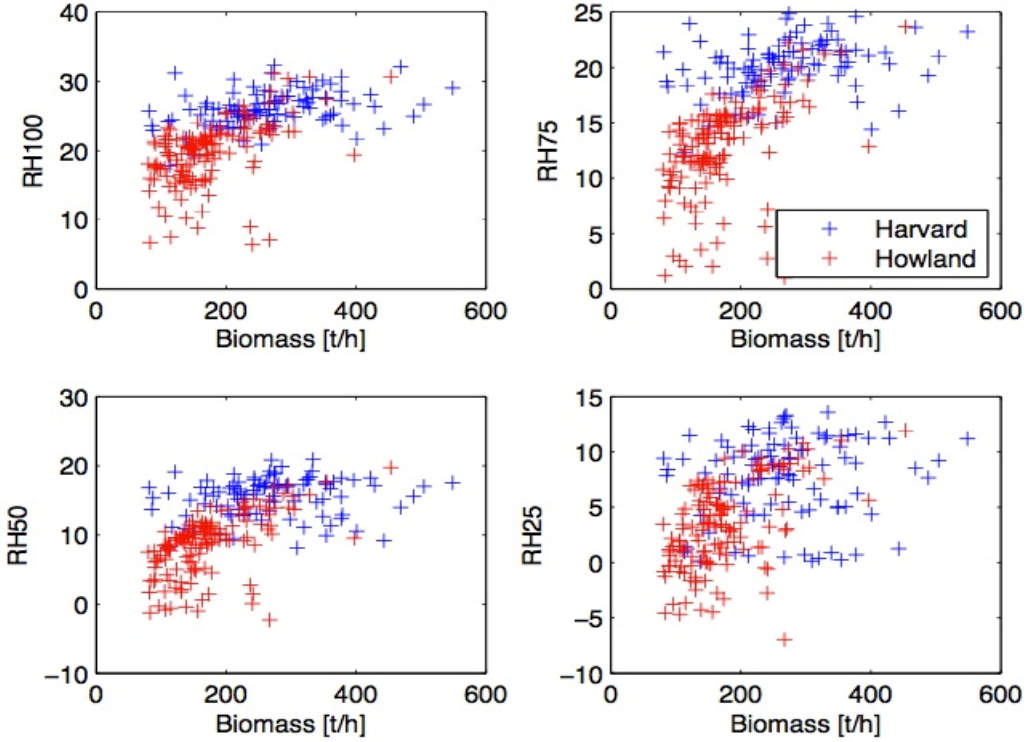


Howland Forest

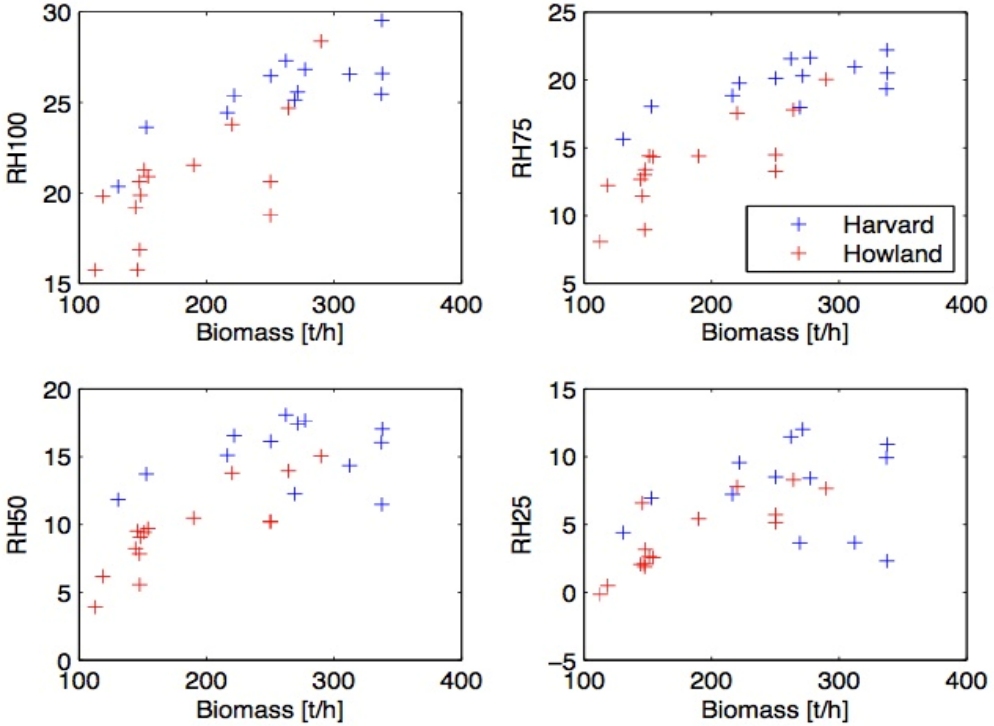


Lidar data analysis: combined data sets

subplots

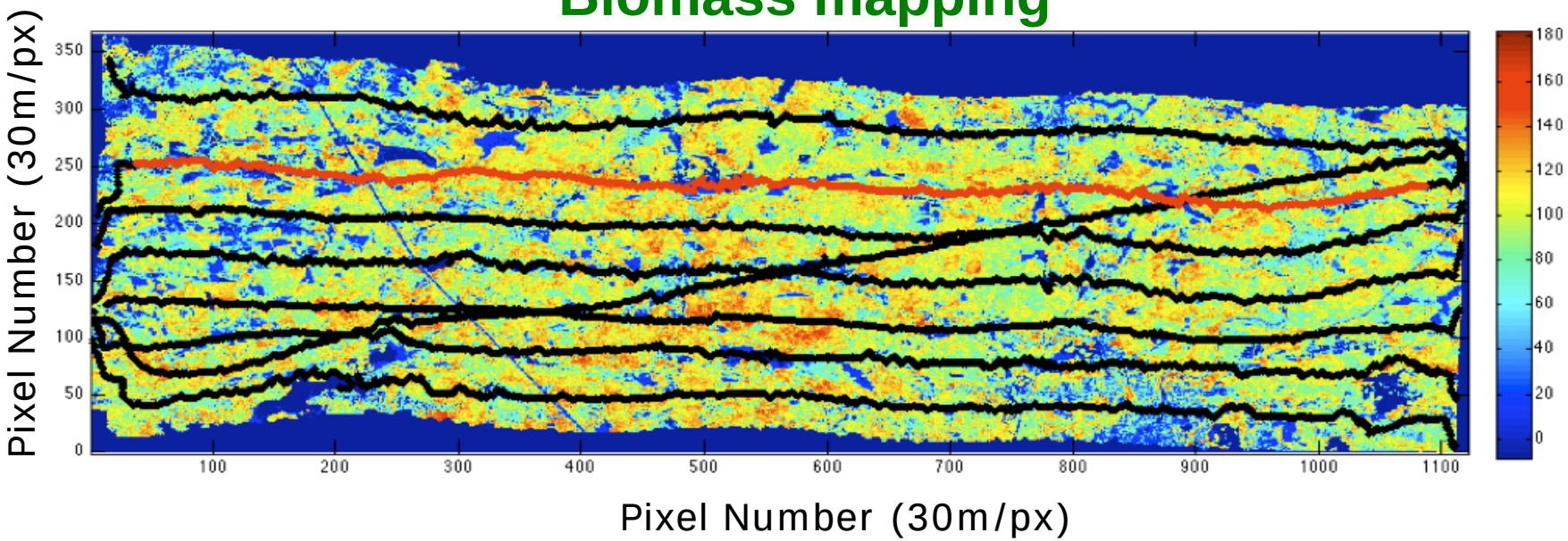


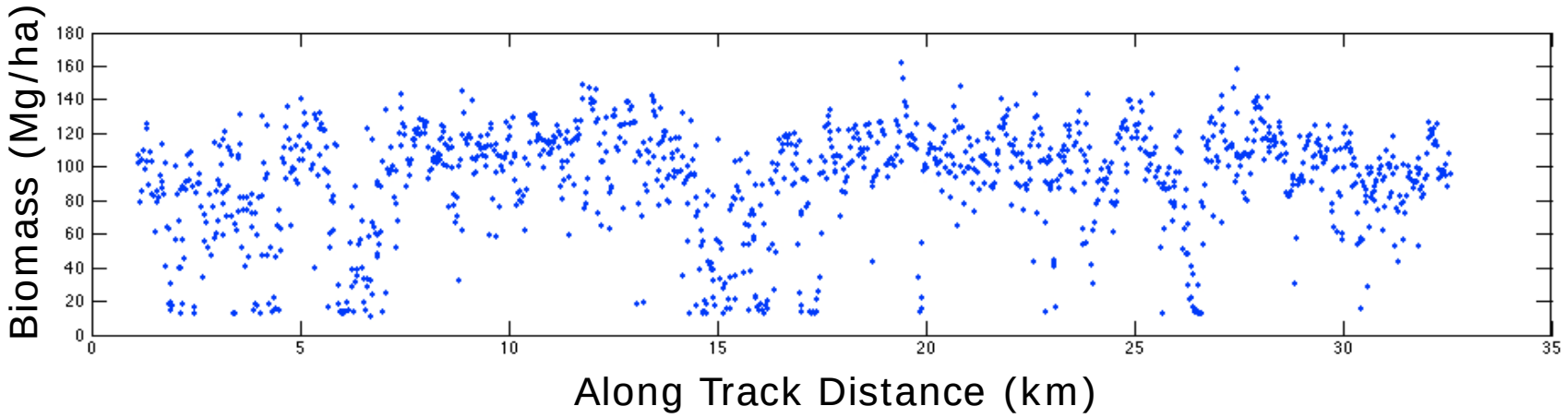
hectares



Results show that lidar is demonstrating saturation effects for high biomass

Biomass mapping

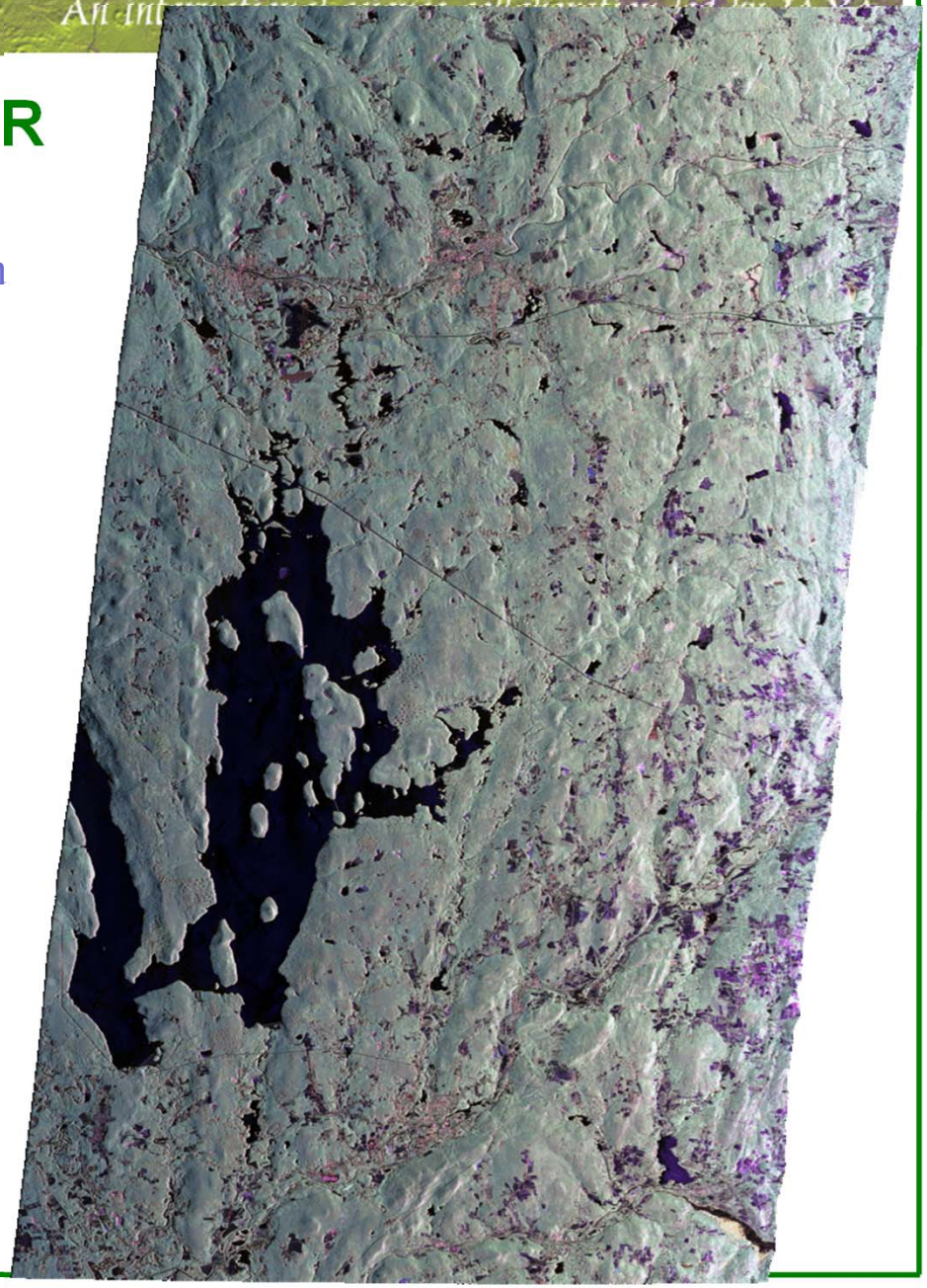




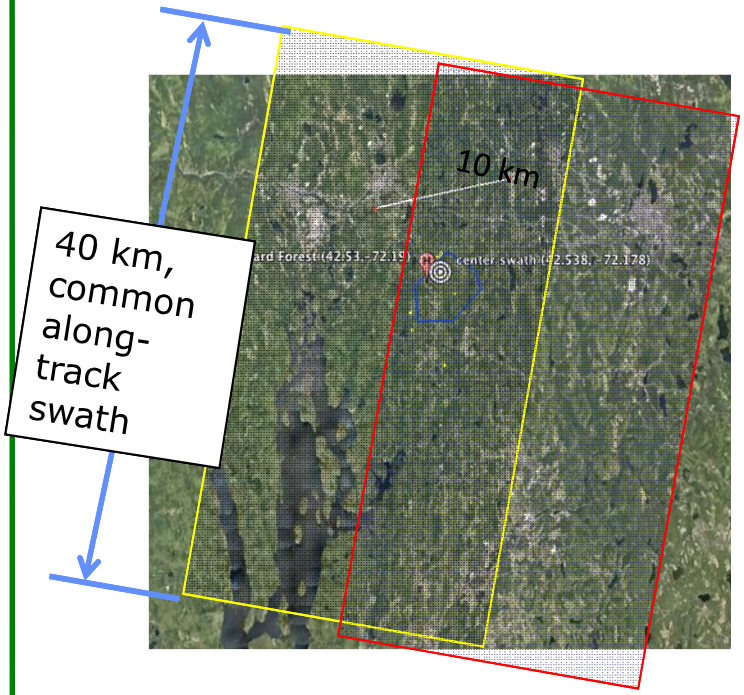
UAVSAR

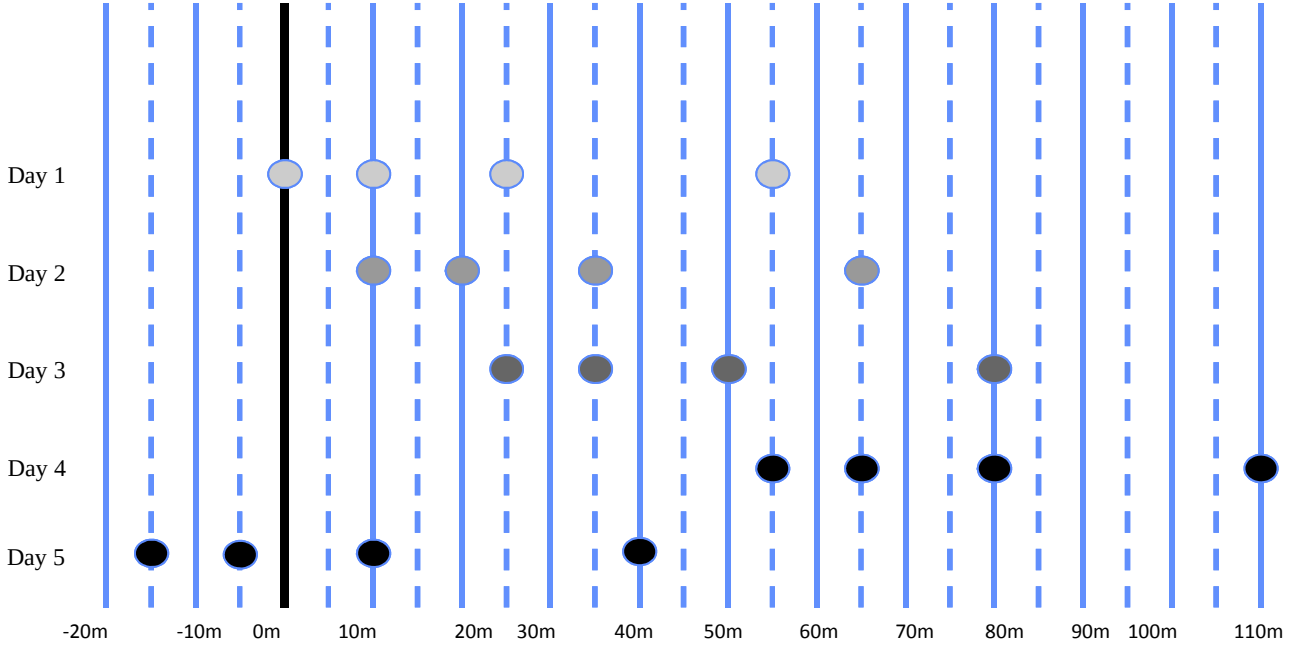
Between August 4 – 15, 2009, UAVSAR flew over the Harvard region in a repeat-pass, racetrack configuration

Parameter	Value
Frequency	1.26GHz
Bandwidth	80MHz
Polarization	HH, HV, VH, VV
Look Angles	25 - 65 degrees
Resolution	1.6 x 0.66 m



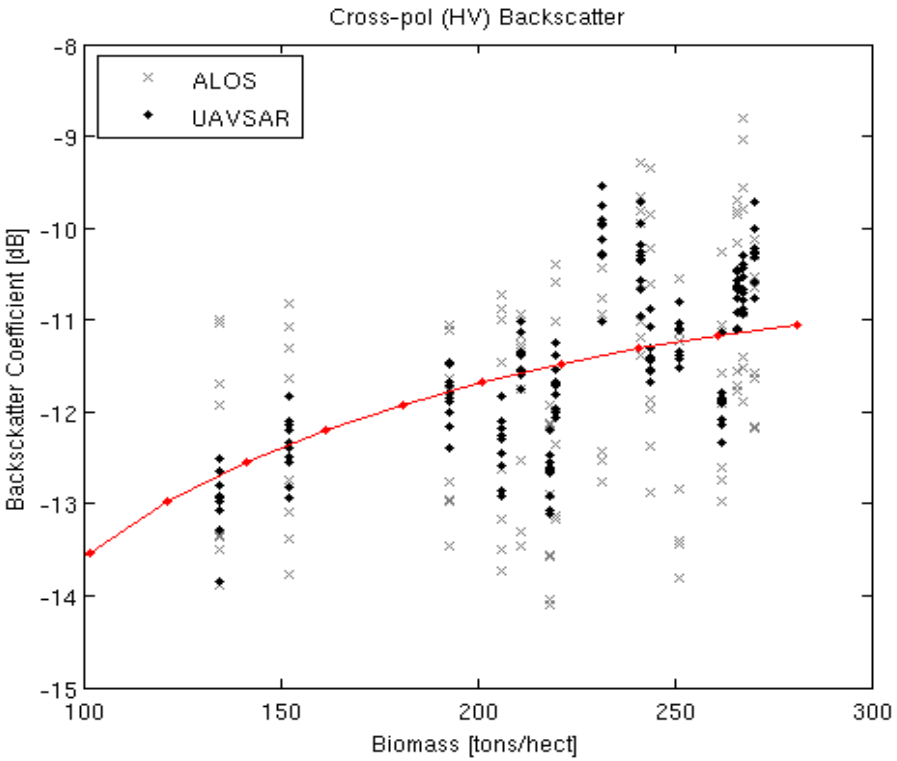
Observation Strategy

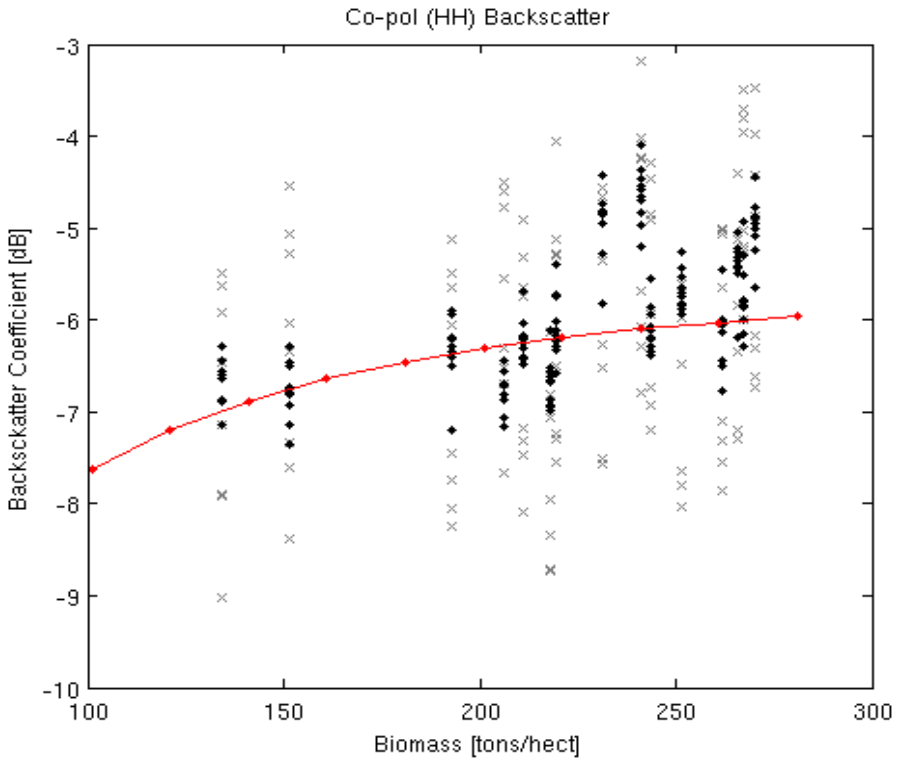




All passes occur at same altitude (12.5 km), with a 40 degree look angle to center swath

Polarization dependence



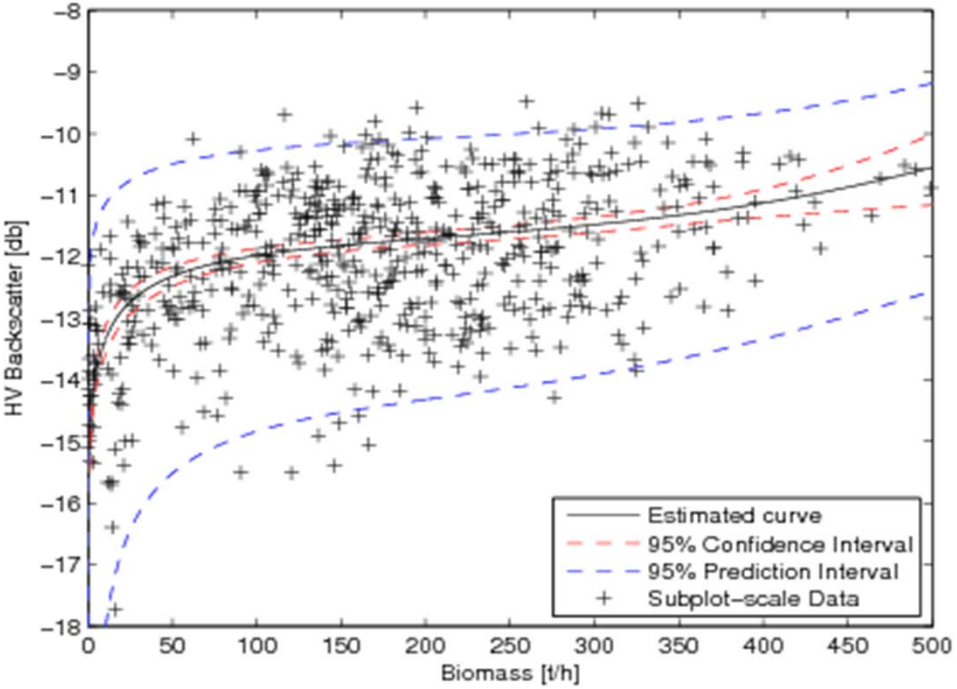


The oberved relationship is not a strong function of polarization, but a “bias” between co-pol and cross-pol is evident in the data as expected

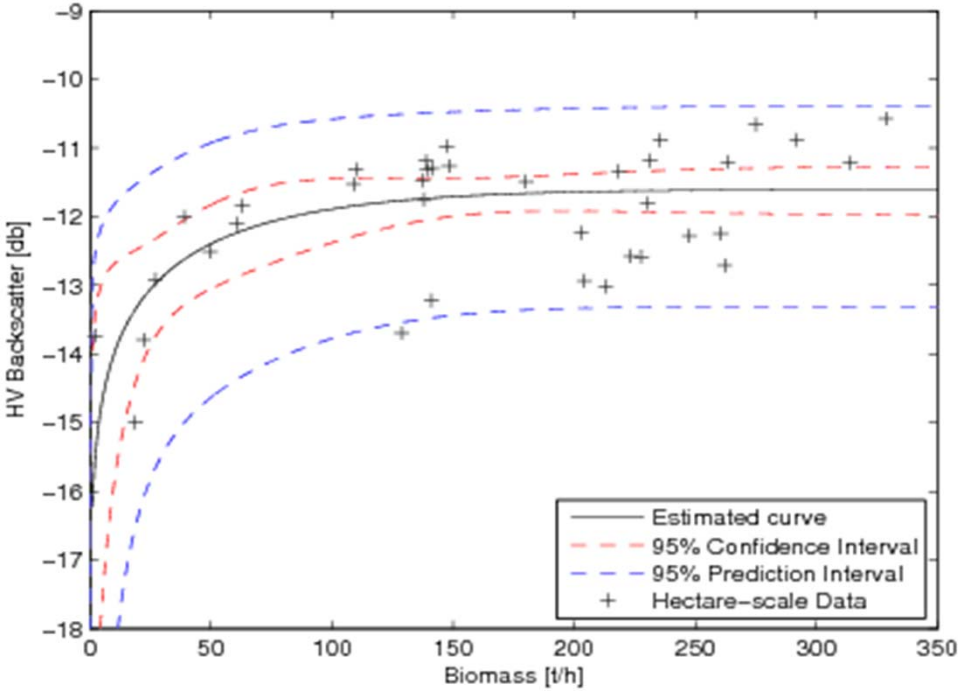
Saturation does appear to occur at lower biomass levels for co-pol compared to cross-pol

Naïve confidence intervals on backscatter estimates

subplots



hectares

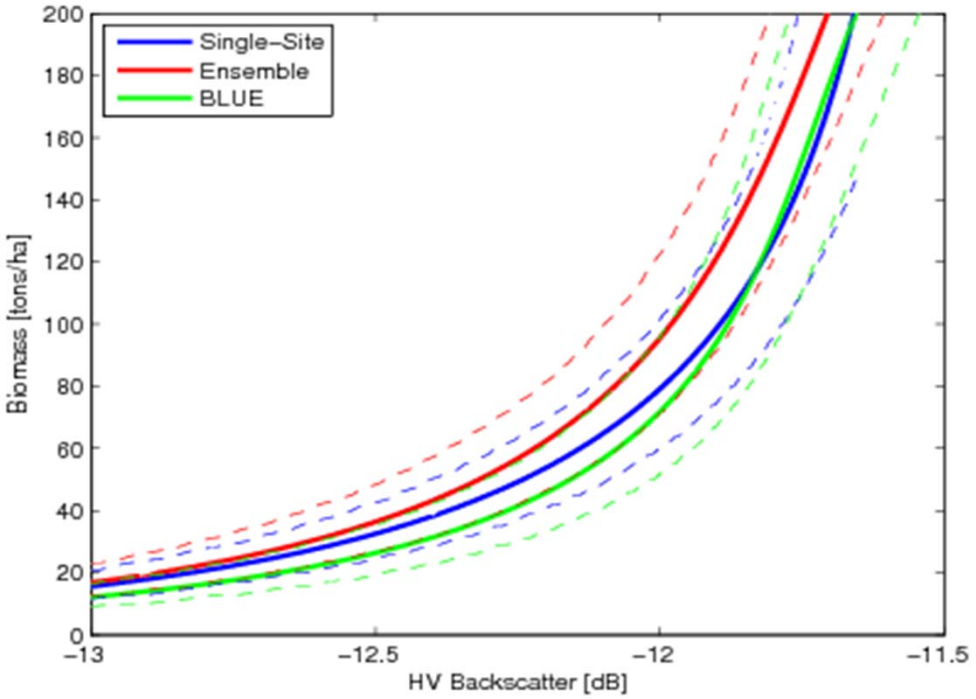


Naïve confidence interval assumes that errors for all measurements are treated equally

Hence, the confidence interval for subplots is small than hectare confidience intervals. This is the opposite of what it should be. Averaging of stationary processes should always reduce variation.

Naïve confidence intervals on biomass estimates

subplots



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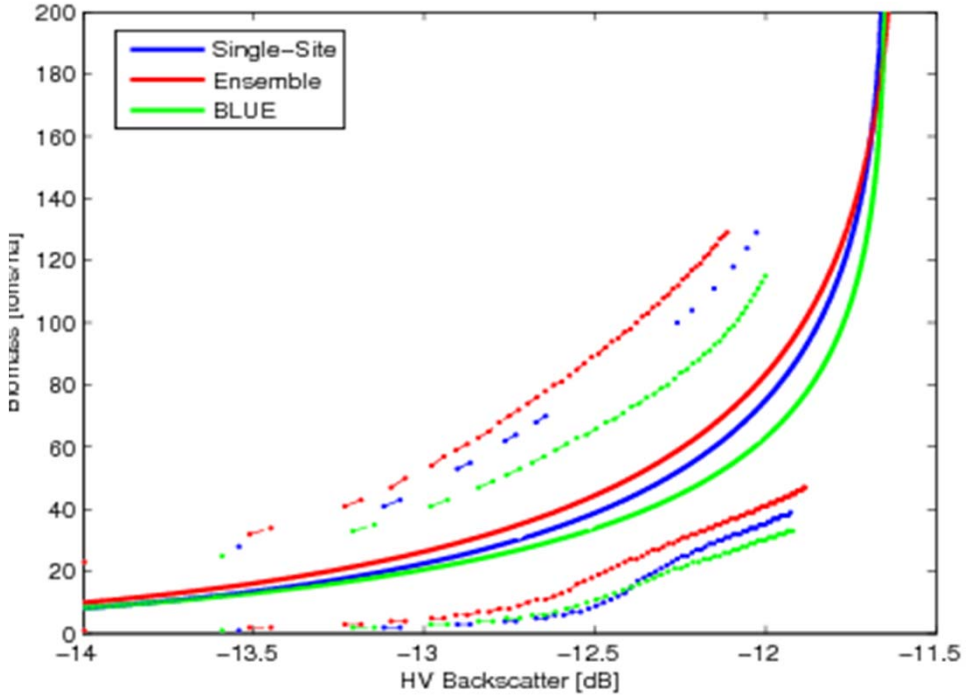
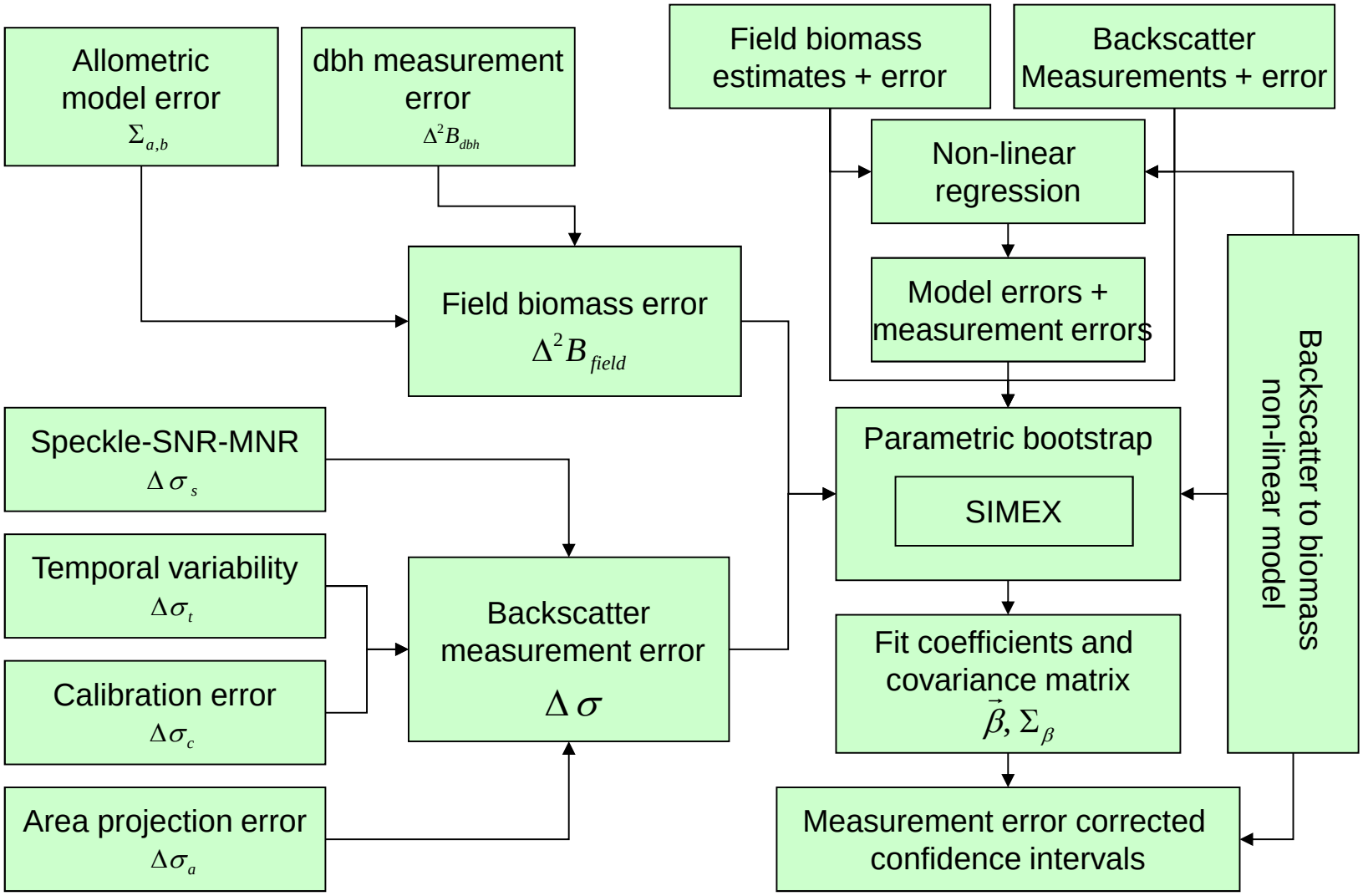


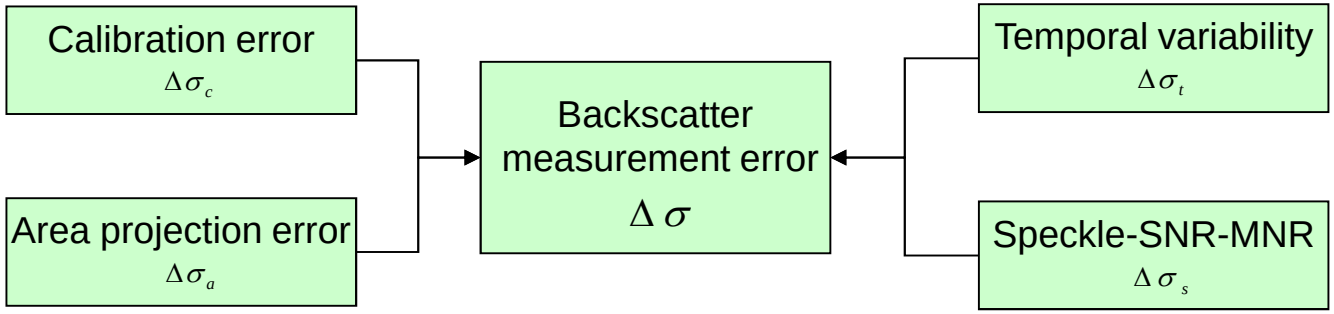
Different colors indicate different allometries.

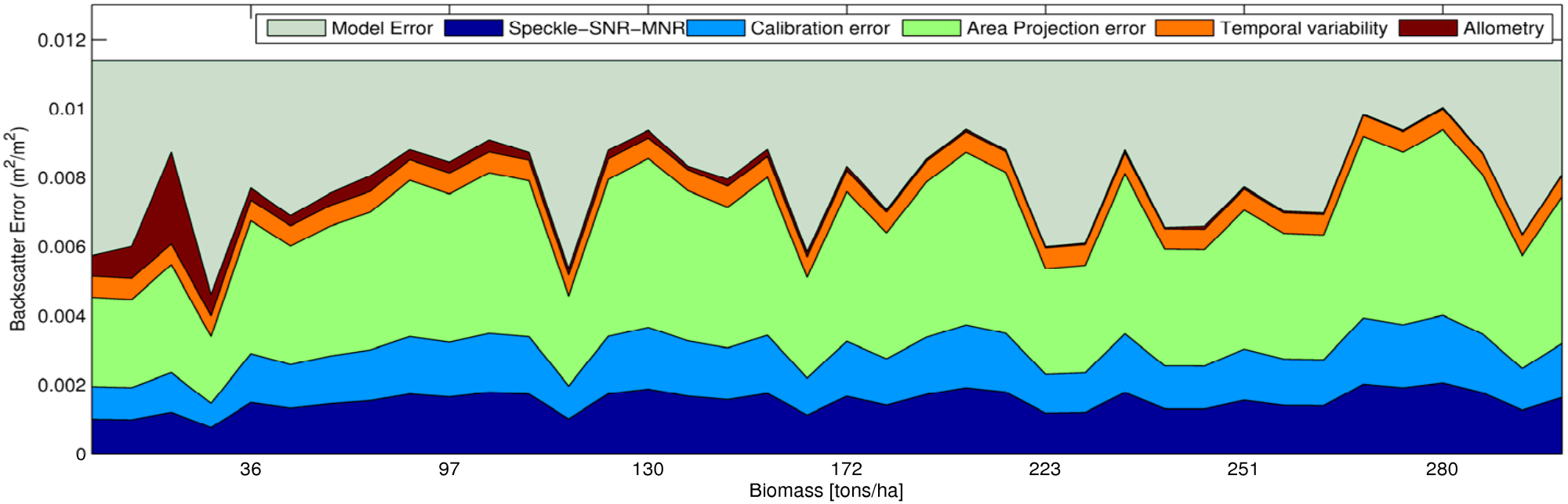
single-site: Ter-Mikailean; Ensemble: Jenkins; BLUE (Best linear unbiased estimator): Lambert

Accounting for measurement error

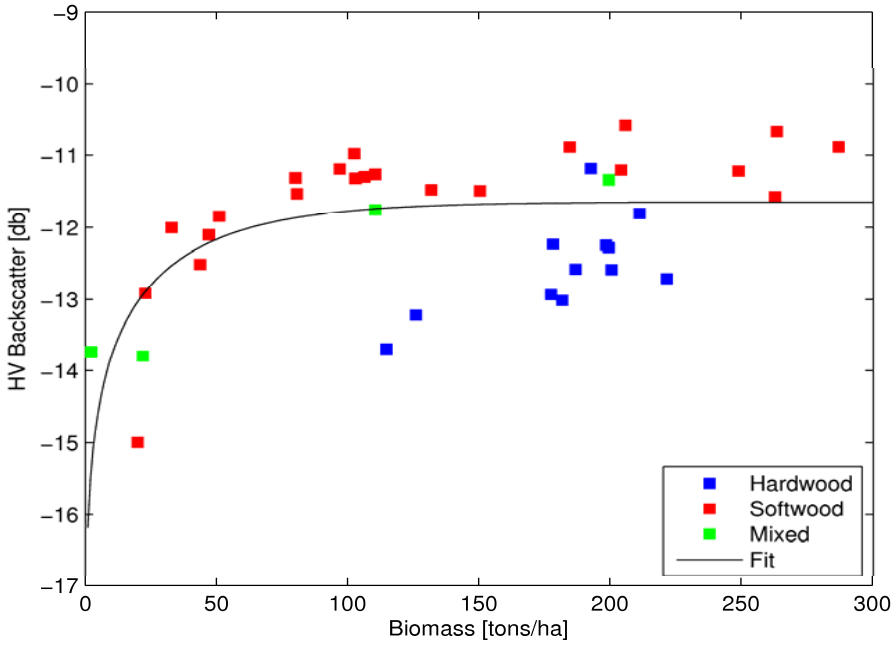


Modeling backscatter errors

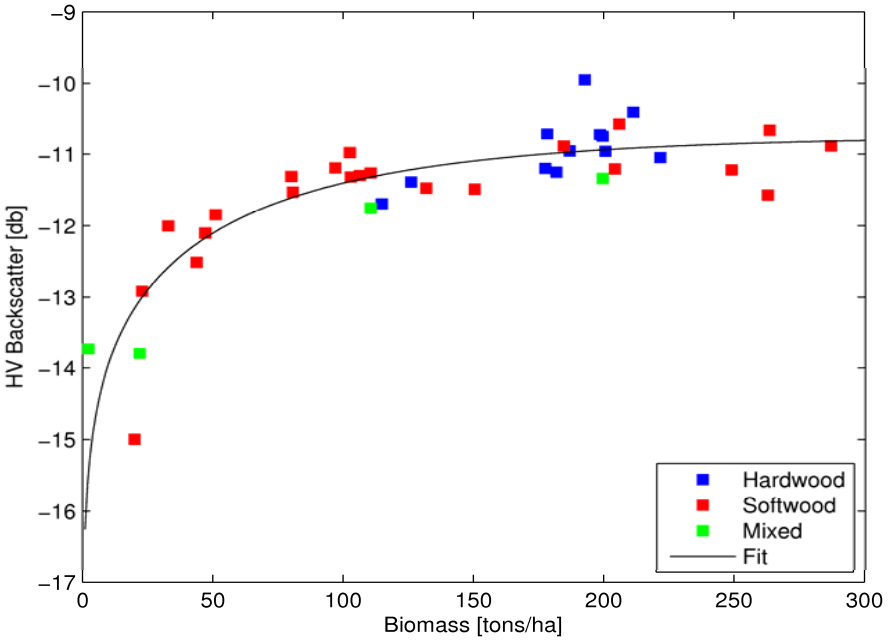




A close look at the model error

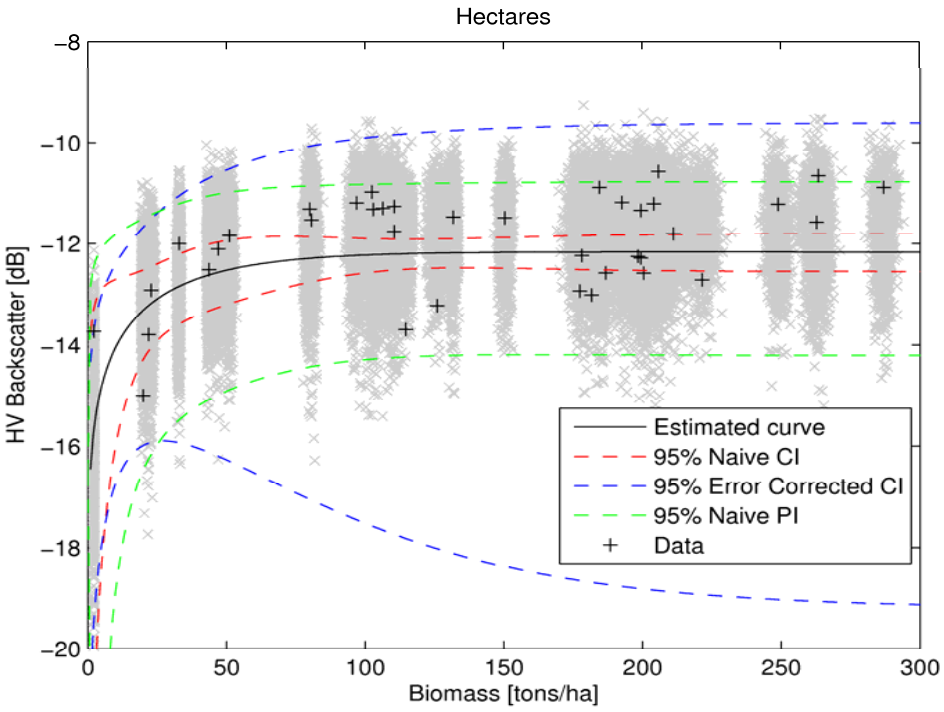


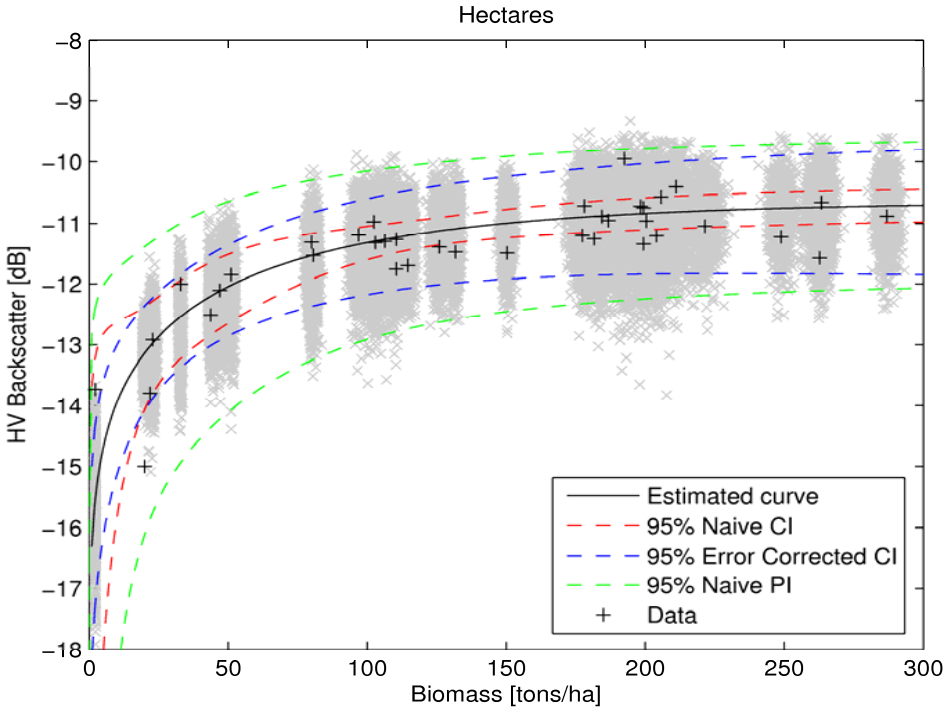
Dependence of radar backscatter on species class



Reduced model error as the mean separation between hardwood/softwood pixels is removed

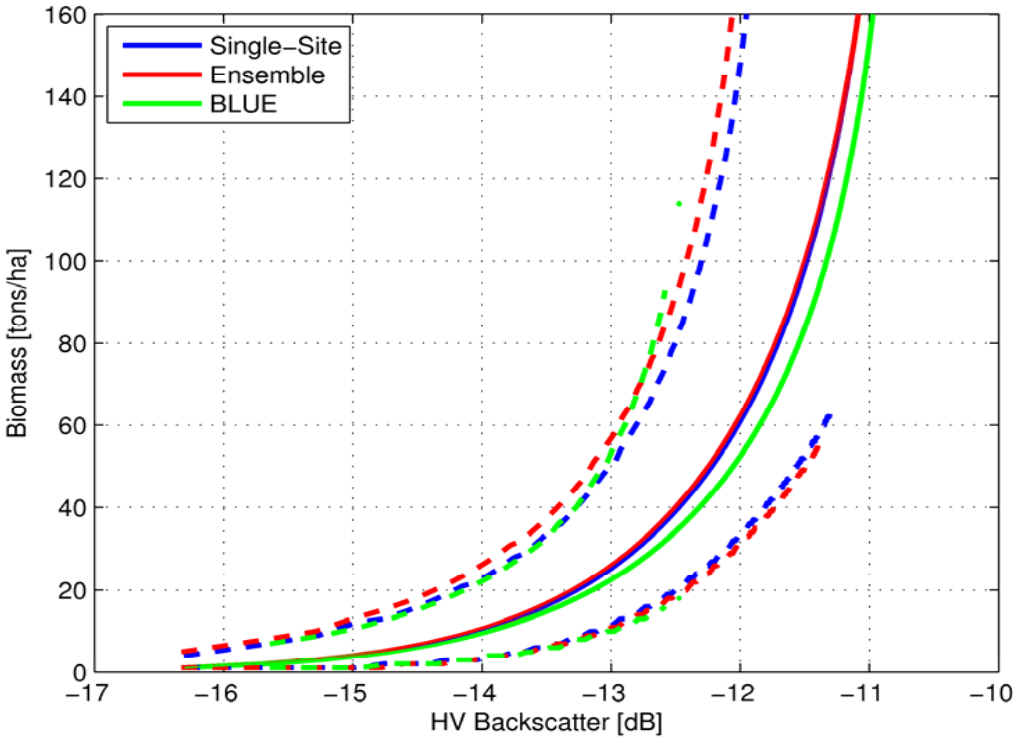
Confidence intervals with reduced model error

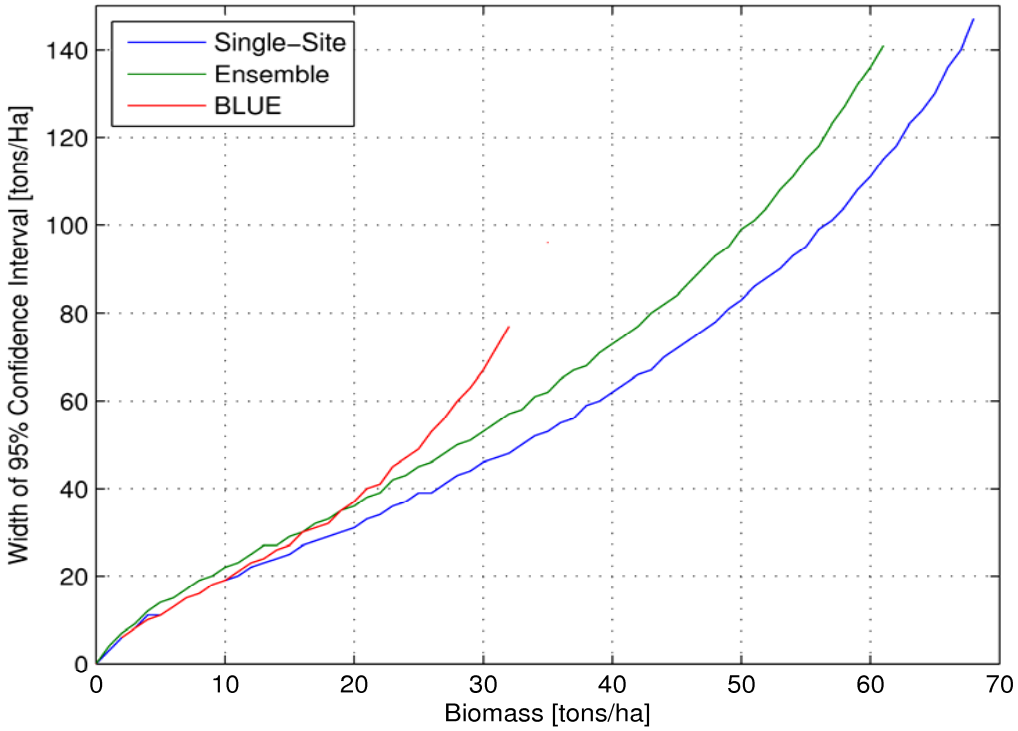




Large model error → Reduced model error (account for species)

Confidence intervals on biomass estimates





Conclusion: Radar backscatter to biomass relationships have large error bounds (> 100%). This is a problem.

Radar Relationship to Biomass Summary

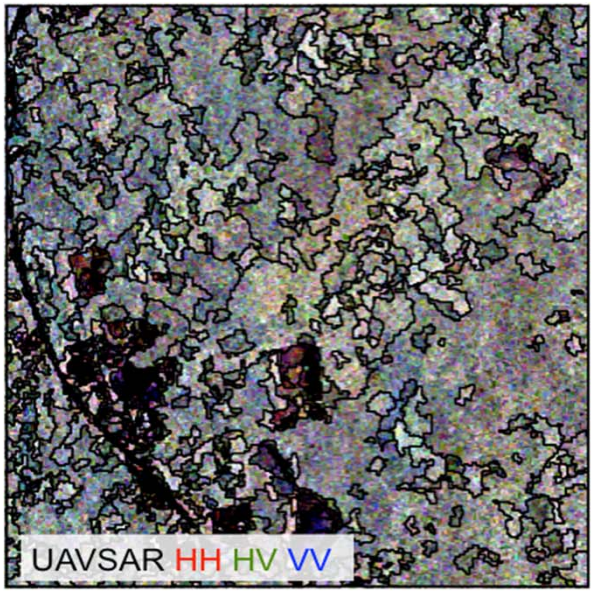
So far, we have looked at independent measures of biomass using lidar and radar.

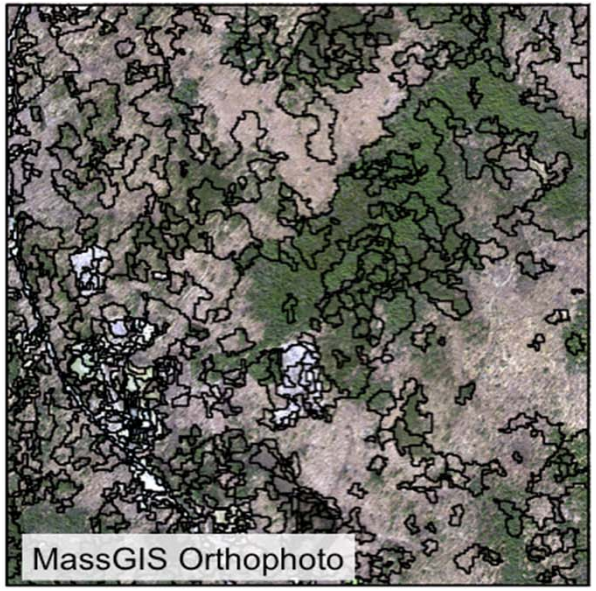
At a minimum, it is assumed that spaceborne lidar will essentially be a sampling instrument.

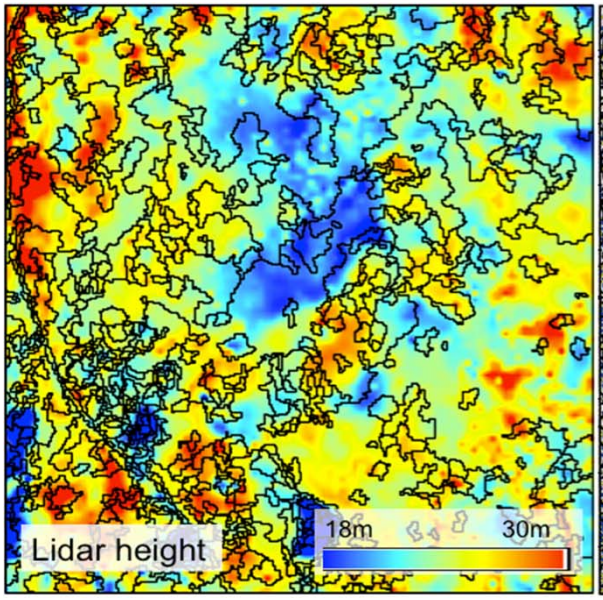
Backscatter to biomass relationships, when trained by lidar and/or ground validation shows errors of 100% or more.

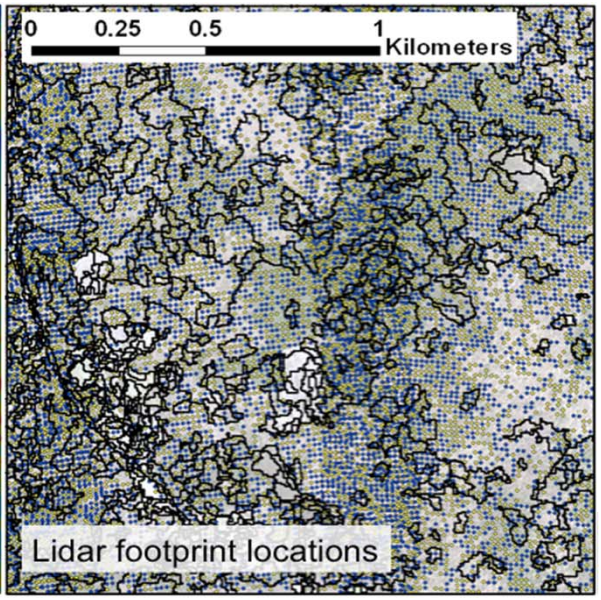
What is left? Use of the segmentation algorithm to identify regions of "self-similar" response to the radar data. Use these regions to propogate lidar metrics

Advantage of Using Radar Data for Segmentation



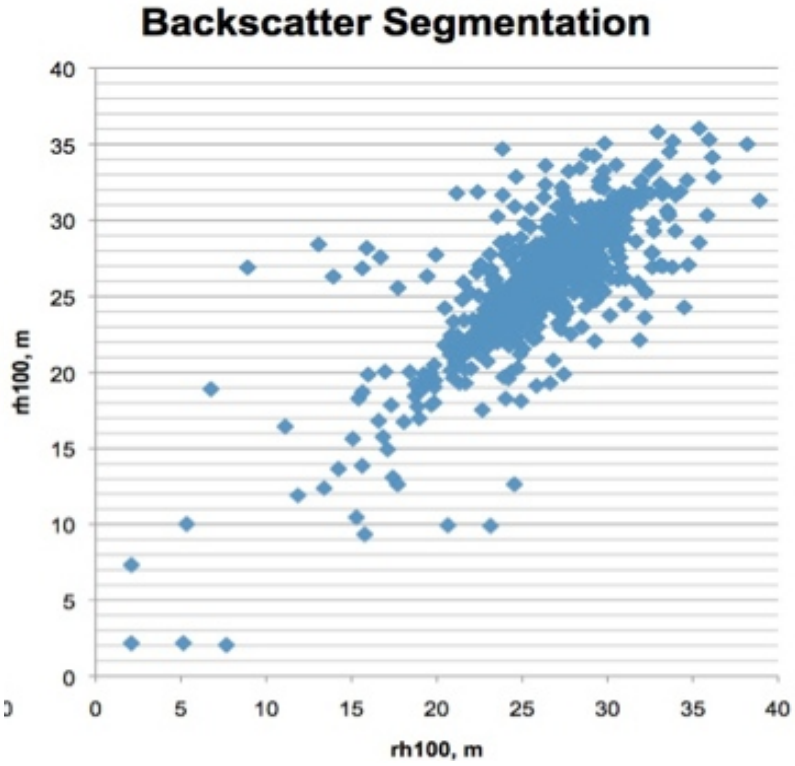






RMSE (m)

Segment Scale	Arbitrary	Backscatter
Level 1	3.32	1.76
Level 2	2.01	1.52
Level 3	1.73	1.63

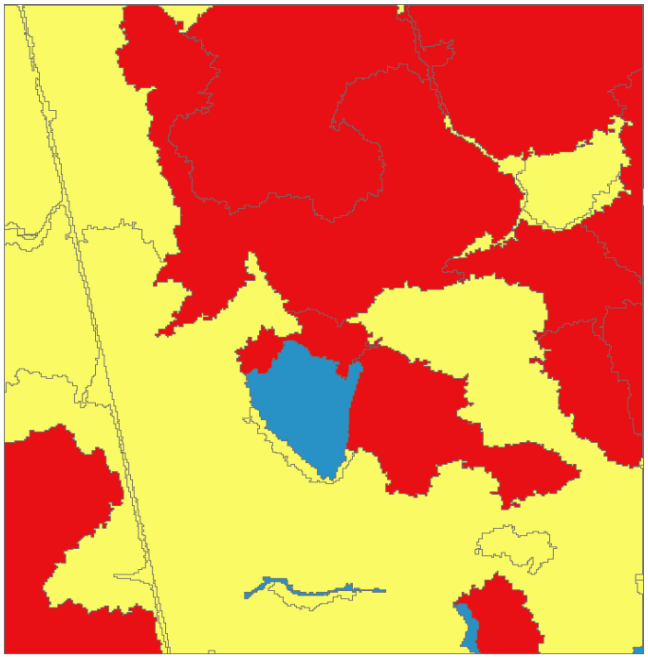


Biomass Error for 3 different segmentation classes

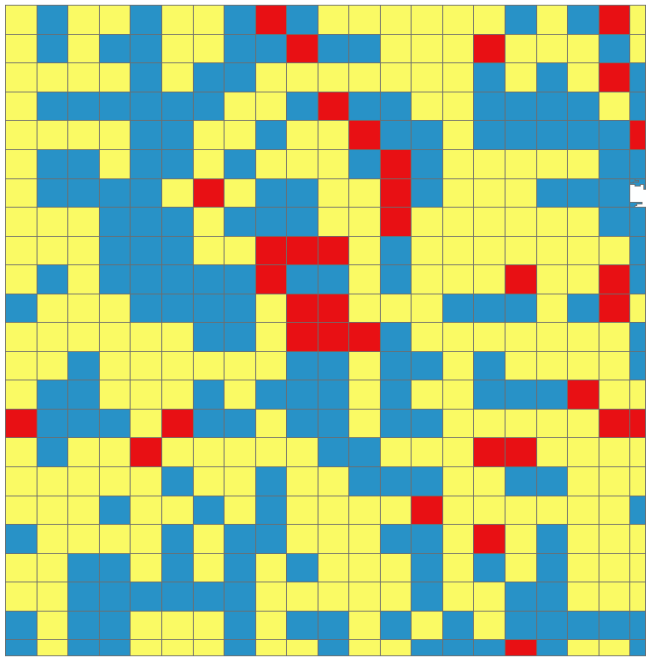
- Error represents standard deviation of biomass estimated from lidar shots within each segment.

< 20 Mg Ha^{-1}
> 20 Mg Ha^{-1}, < 50 Mg Ha^{-1}
> 50 Mg Ha^{-1}

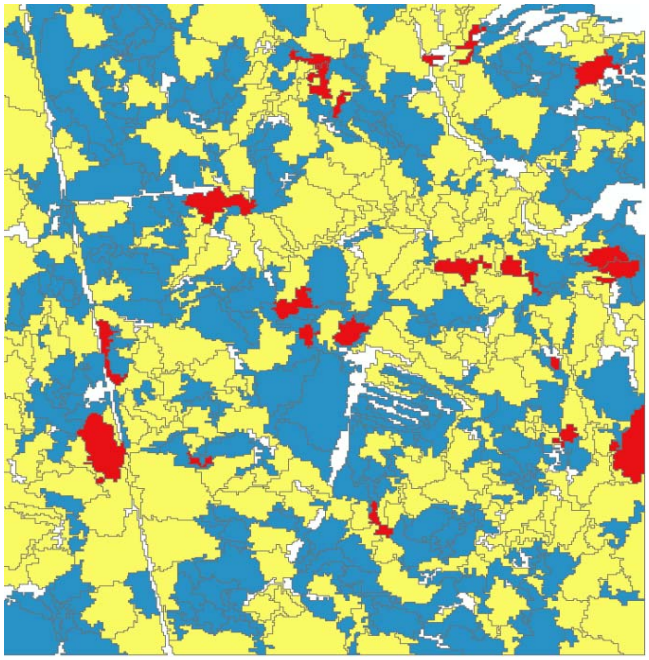
MELCD (Landcover)



Chessboard



Multiresolution



0 0.25 0.5 1
Kilometers

Error Metrics

Percentage of scene represented by each class of biomass standard deviations.

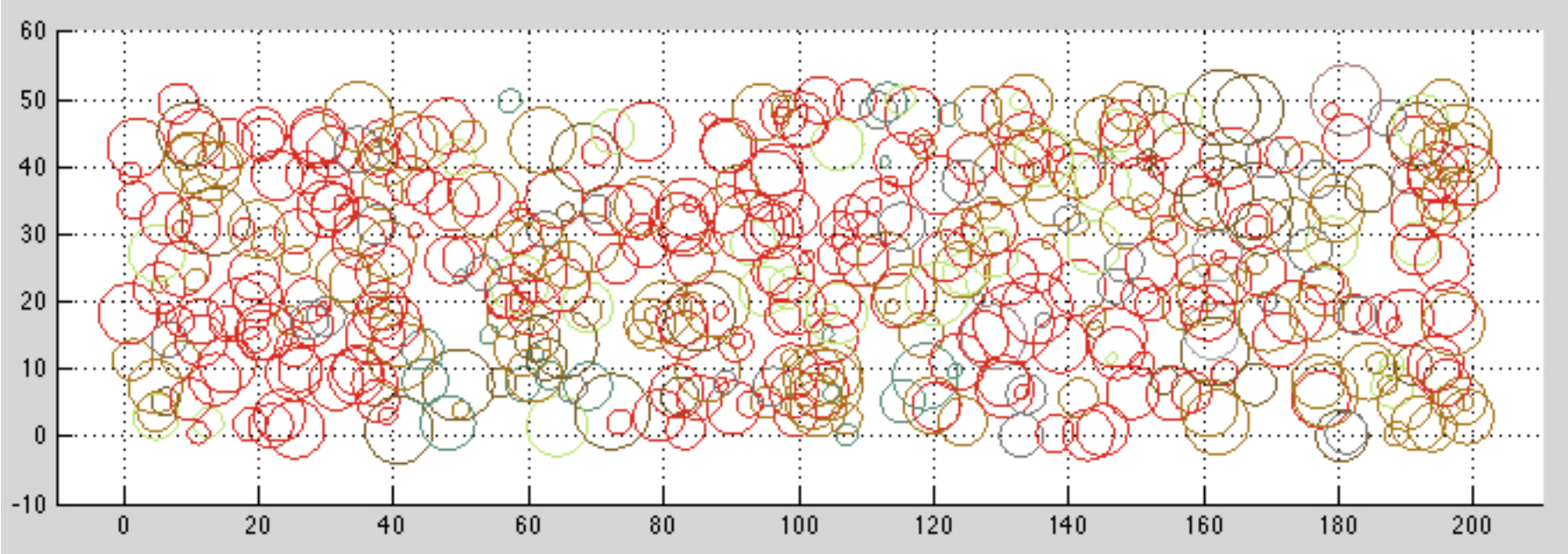
Biomass estimates are derived from lidar shots within each segment using equation developed by Sun and Ranson (2009) specifically for the Howland Forest site.

	< 20 Mg Ha^{-1}	>20 Mg Ha^{-1}, < 50 Mg Ha^{-1}	> 50 Mg Ha^{-1}
MELCD	3	50	47
Chessboard	38	55	7
Multiresolution	43	54	3

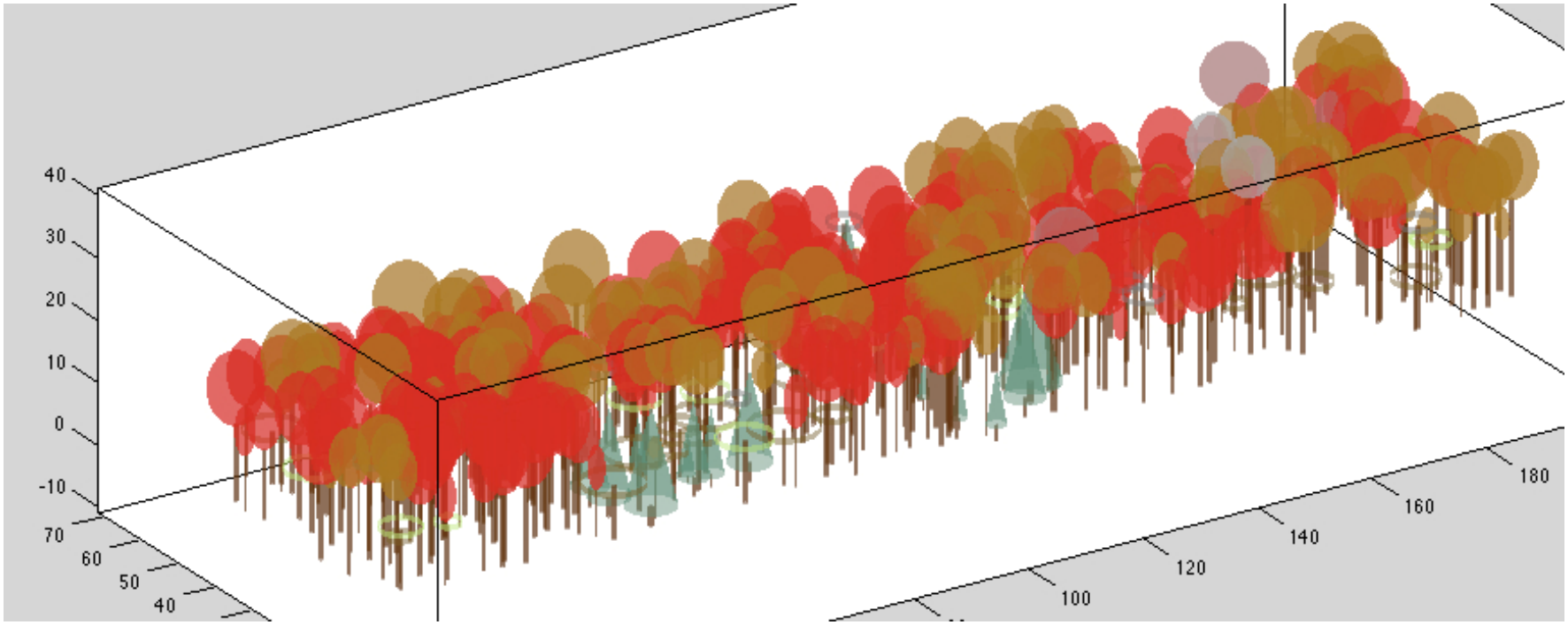
Forest Growth Dynamics Modeling

- Individual Based Model (IBM) for forest growth used to create realizations of ecologically consistent forest stands.
- Add a degree of ecological input to constrain model estimates
- Simulation of remote sensing observations (ALOS, lidar, other) from forest growth model
- Remote Sensing data used to determine which forest tragectory is most likely
- Forest structure and biomass characteristics estimated directly from forest growth model ouputs
- Assessment of estimate accuracy a direct output from the simulation results

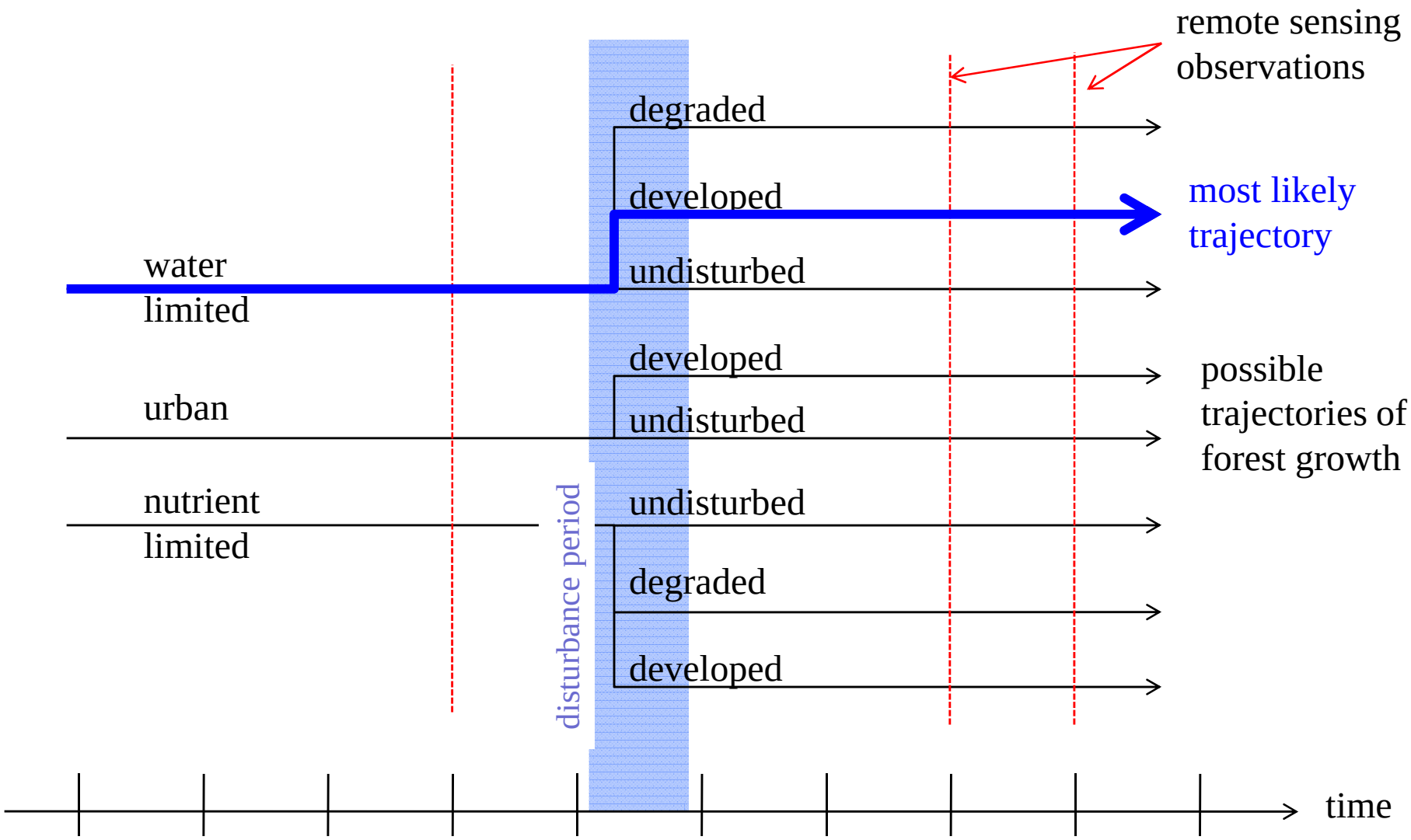
A plot of a 1 hectare region of tree crowns



A 3-dimensional model of the same forest



A time series of observations and simulations



Conclusions

- In the Northeast, lidar estimates of biomass provide accuracies on the order of 40 tons/hectare
- Radar backscatter relationships have large, unacceptable errors (100% or more)
- Use of a segmentation with radar and assigning lidar to the wider region shows evidence of hope.
- A forest dynamics model is being explored as an alternate method for integrating remote sensing observations with constraints imposed by the forest ecology.

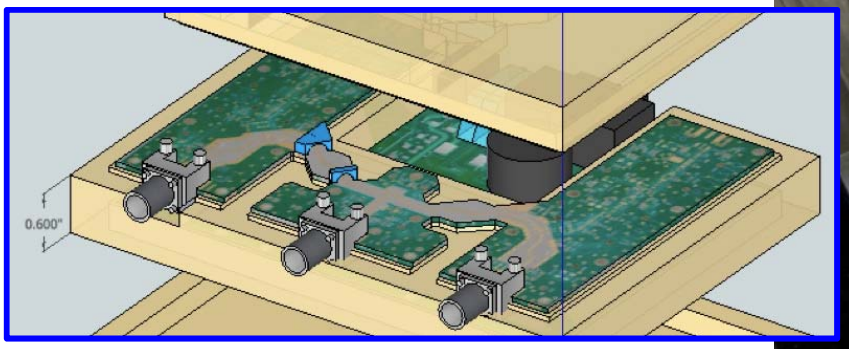
Acknowledgements

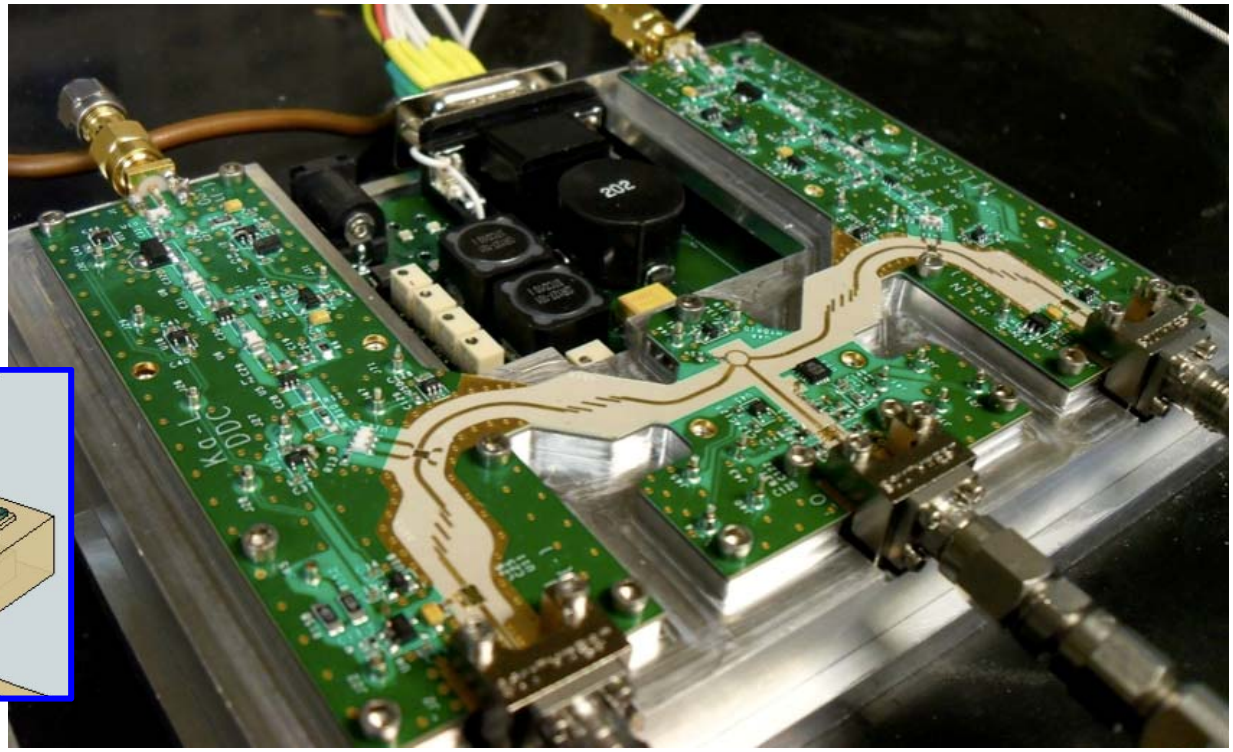
Thank you to NASA's Program in Terrestrial Ecology (grant number: NNX09AI18G)

Something new at UMass

To support the SWOT (Surface Water and Ocean Topography) mission's technology development, UMass has constructed a prototype Ka-band interferometric receiver.

For increasing the technology readiness level, we have deployed the system into different operating environments



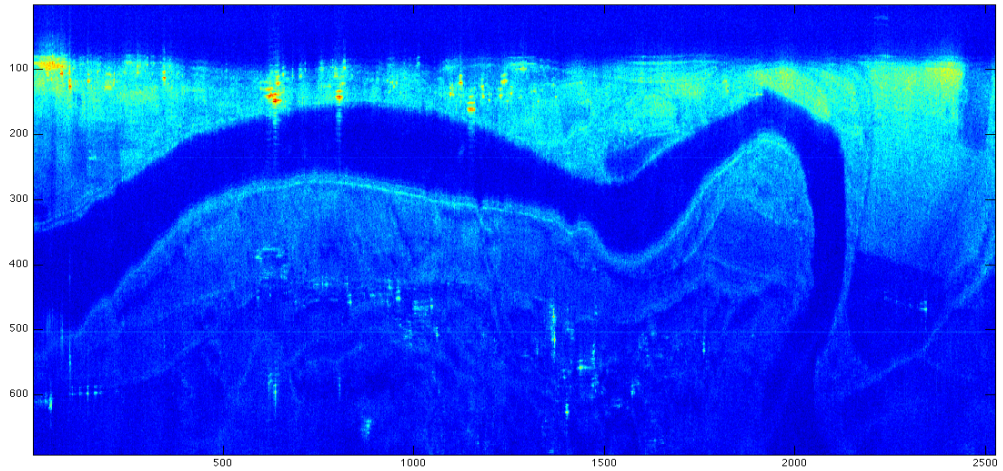


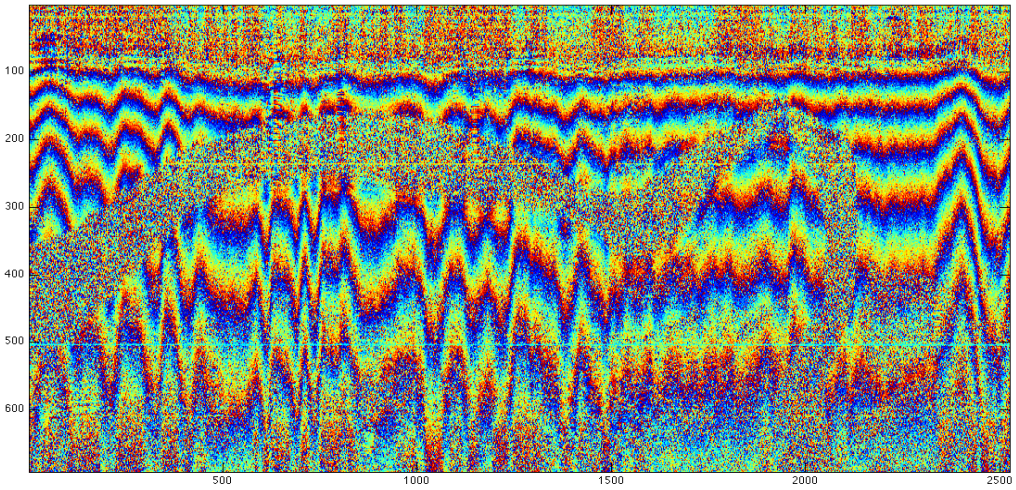
A Completed Instrument in the Field

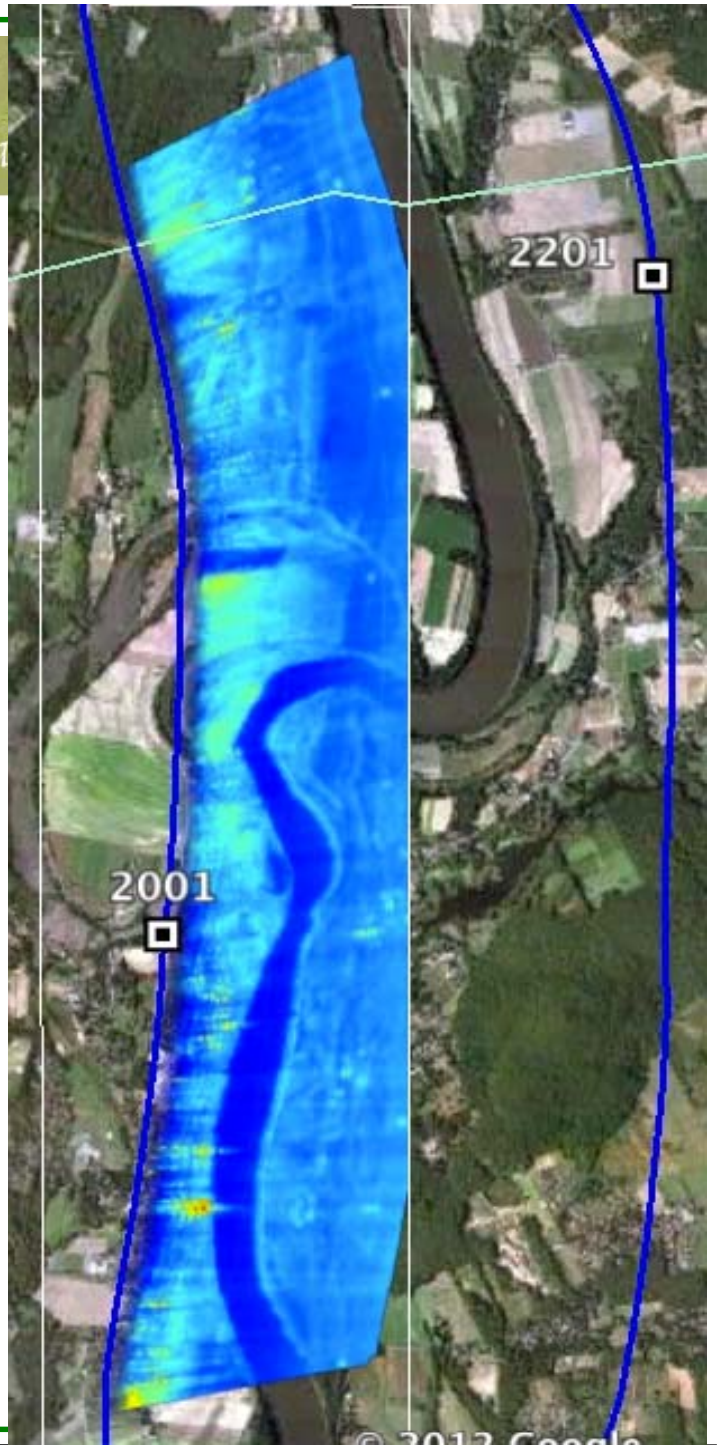
Transition to an airborne platform

Shadowing and loss of sensitivity due to low grazing angle are our biggest error sources. Hence, an effort is underway to transition the instrument onto a Cessna 206 Aerial Survey platform. This is being done with Thomas Millette, from the Geography Department at Mt. Holyoke College.

First airborne results







Large Scale Mapping Capability

- The image at right was collected in under one hour
- Swath width is greater than 1 km
- Currently only limited by transmit power
- We will be flying over the Harvard Forest soon