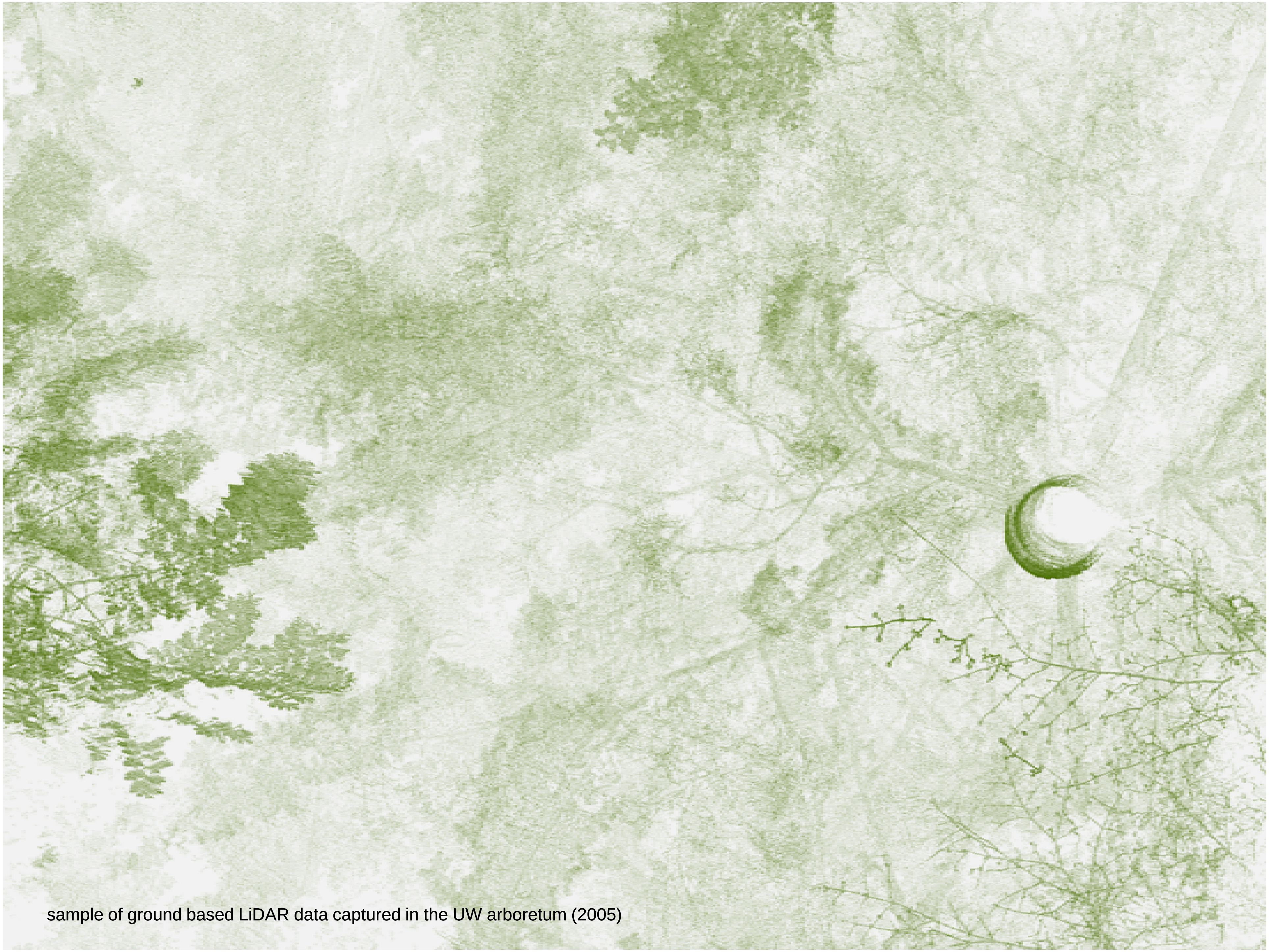
L. Monika Moskal, PhD
Assistant Professor of Remote Sensing and Biospatial Analysis
College of Forest Resources
Precision Forestry Cooperative

Seeing the forest through the leaves:

Quantifying forest structure & ecosystem services with LiDAR

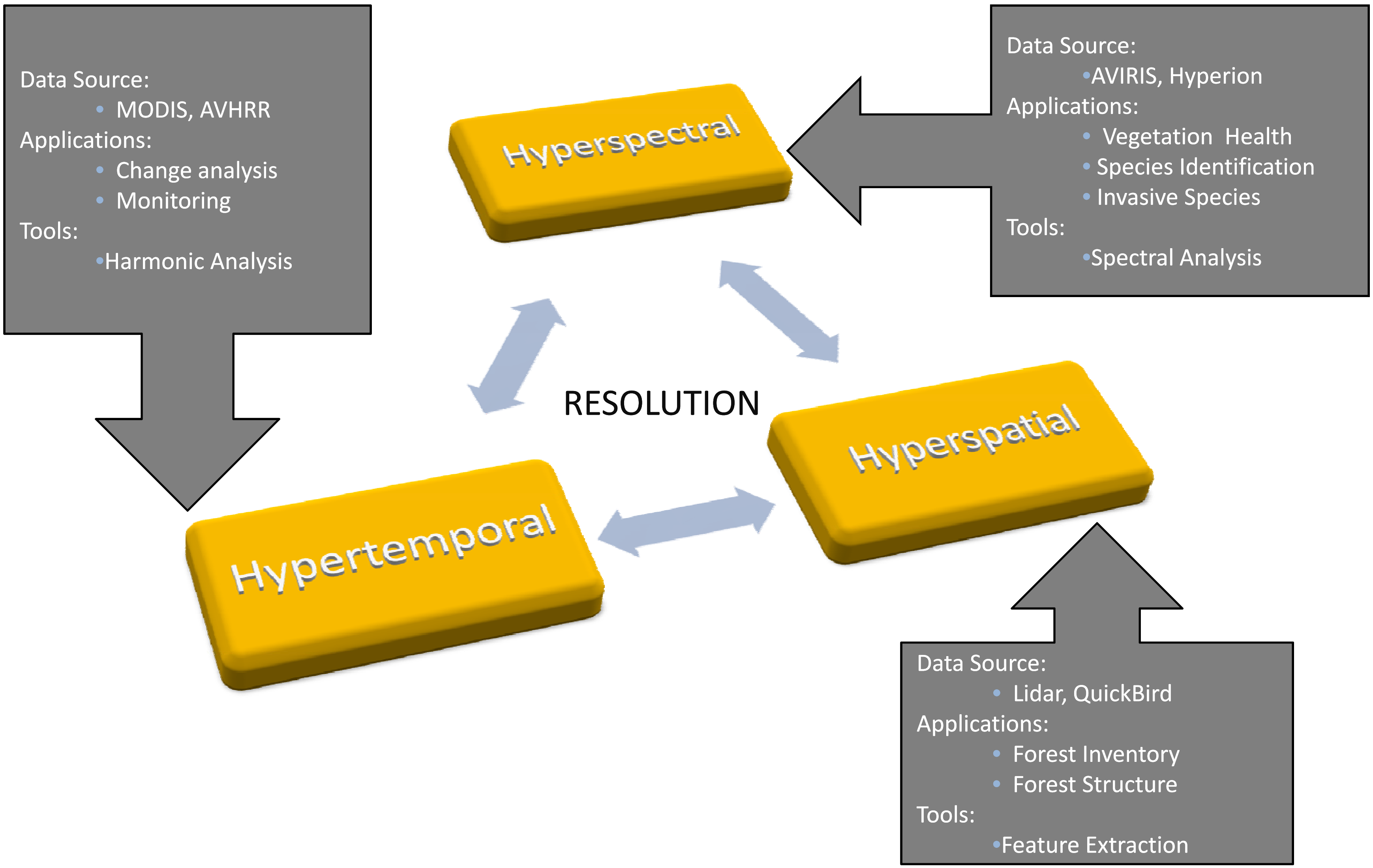
The Water Center - Annual Review of Research
14 February 2008
University of Washington



sample of ground based LiDAR data captured in the UW arboretum (2005)

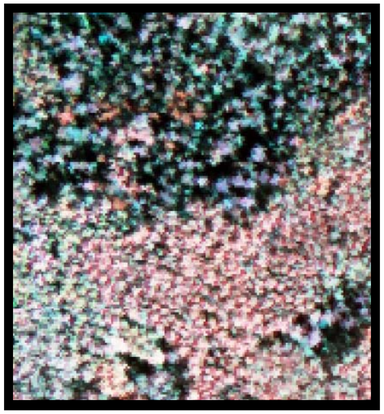

WENGER

H-resolution trends in remote sensing technology



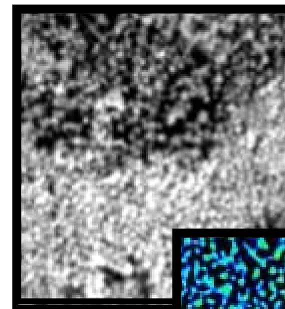
Forest structure characterization with h-resolution remote sensing

H- resolution Multispectral Imagery

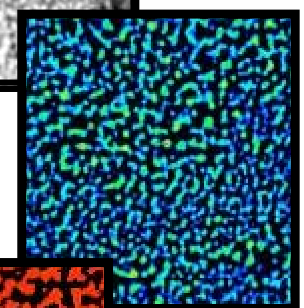


Crown Closure

Average filter

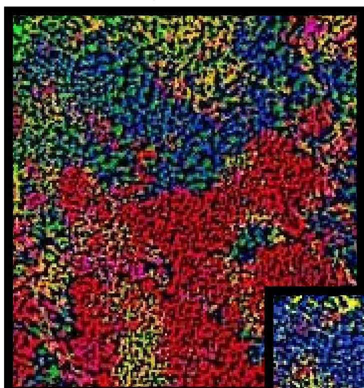


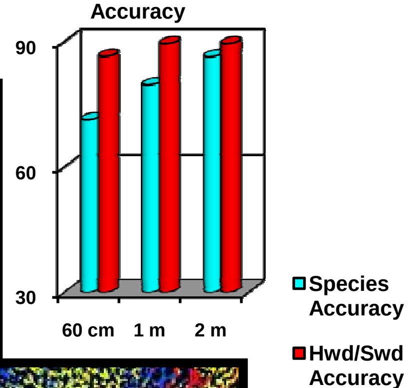
Laplacian Filter

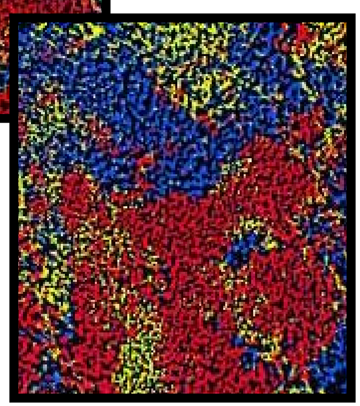


Species

Species

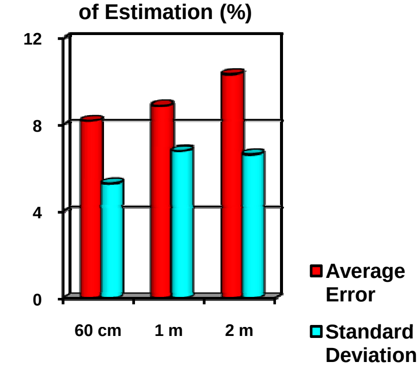






Hardwood/Softwood Classification

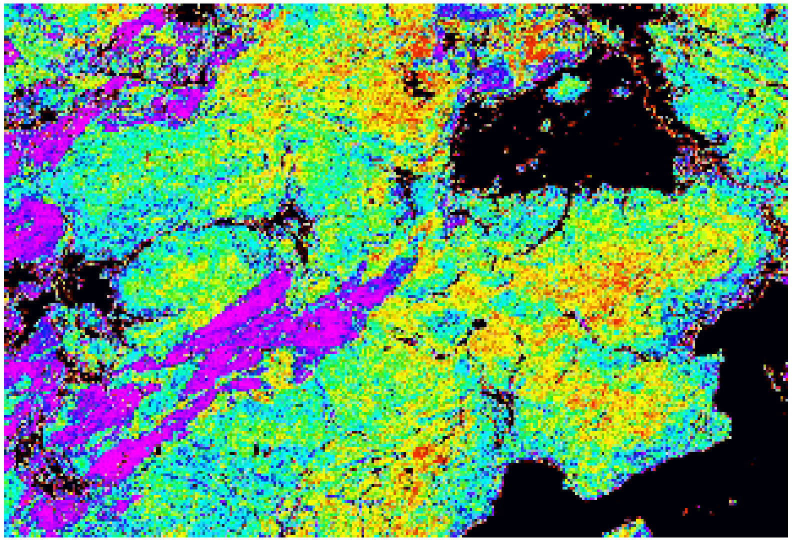
Extracted Tree Crowns



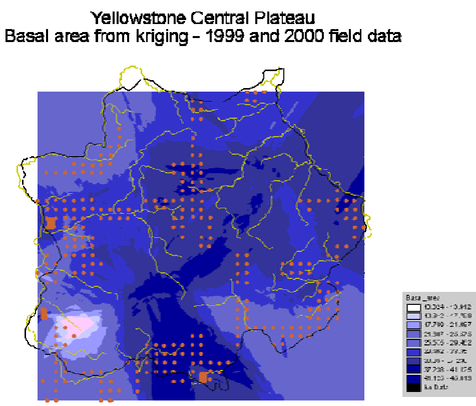
Natural Resources Canada / Ressources naturelles Canada
Canadian Forest Service / Service canadien des forêts

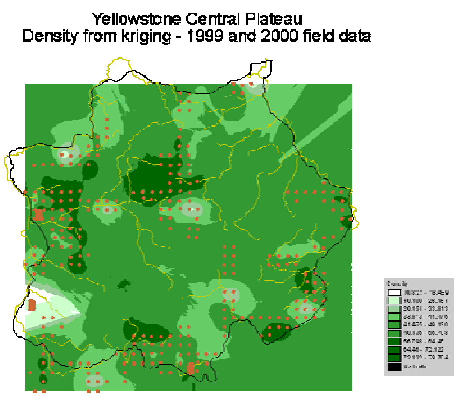
Gerylo, Hall, Franklin & **Moskal**, 1999

Remote Sensing-based Geostatistical Modeling for Coniferous Forest Inventory & Characterization



Yellowstone National Park satellite-derived (regression) forest age map





- **Focus**

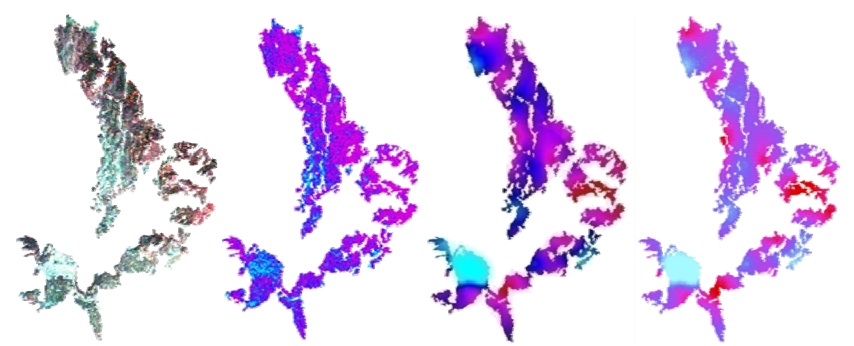
  Use of satellite imagery & geostatistical predictive models to map coniferous forest characteristics

- **Applications**

  Forest inventory, insect infestation & wildfire prediction, damage assessment, change detection

- **Pros & Cons**

  Inexpensive landscape level spatially explicit models @ coarse resolution



Landsat data | Regression estimate of basal area | Kriging estimate of basal area | Cokriging estimate of basal area

Jakubauskas & **Moskal,** 2004 NASA Report

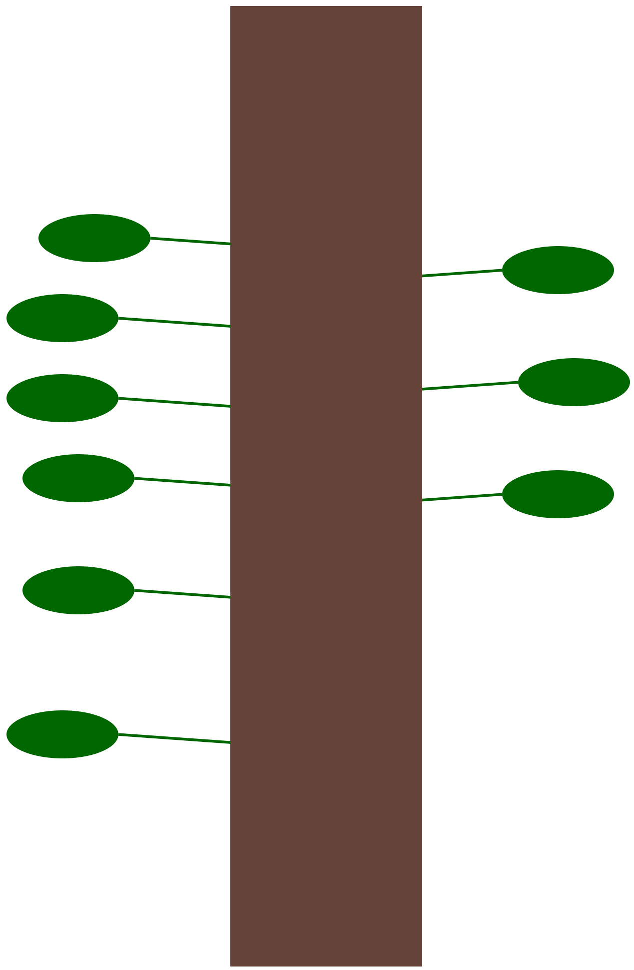
Ecosystem Services

- Provision services
  - Energy (biomass fuels) *(Lefsky, Cohen)*
  - Pharmaceuticals
  - Edibles
- Regulating services
  - Rainfall interception *(Sellers, Shuttleworth)*
  - Carbon sequestration *(De Fries, Chan, Turner)*
  - Nutrient cycling *(Waring, Running, Aber)*
- Supporting services
  - Purification
  - Pest/disease control *(Roberts, Beck, Foody)*
- Cultural services
  - Recreation
  - Scientific discovery
- Preserving services
  - Biodiversity *(Stoms, Debinski, Lefsky, Cohen)*
  - Habitat *(Jensen, Skole, Noss, Tucker)*
  - Accounting for uncertainty

A variety of ecological applications require data from broad to fine spatial extents that cannot be collected using only field-based methods. Remote sensing data and techniques address these needs.

Leaf Area Index (LAI)

- is the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows
- LAI is highly correlated to NPP, rainfall interception, carbon sequestration
- RS used to estimate at the landscape level
- heterogeneous (urban) forest LAI particularly difficult



Leaf Area Index Measurement Techniques

Direct

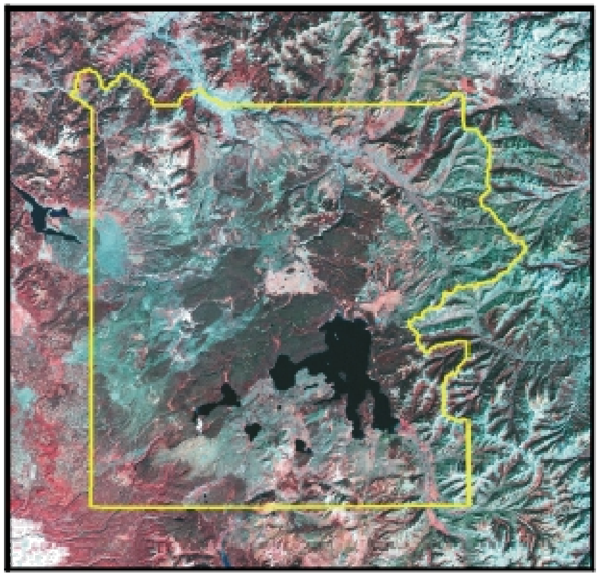
- Destructive sampling relies on taking a statistically representative sample of the leaves

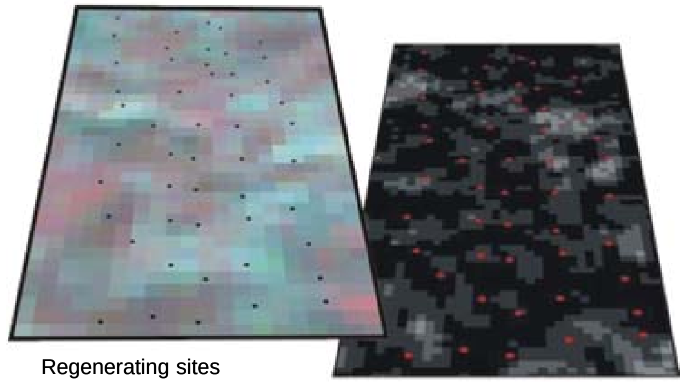
Indirect

- Non-destructive
- Contact and non-contact methods
- Some instruments measure the difference between light levels above and below canopy
- Hemispherical photography
- Remote Sensing
  - Passive
  - Active

Geostatistical modeling of LAI in post fire regenerating stands

Yellowstone National Park
Landsat TM (1999)





Regenerating sites
Landsat TM (1999)

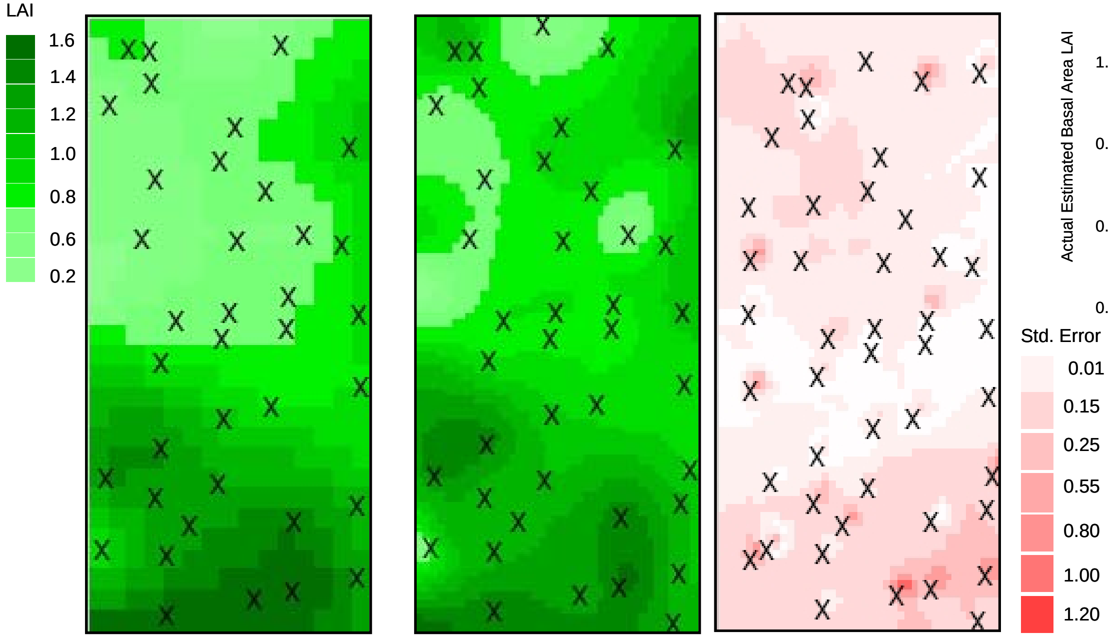
Regenerating sites
Landsat TM texture (1999)

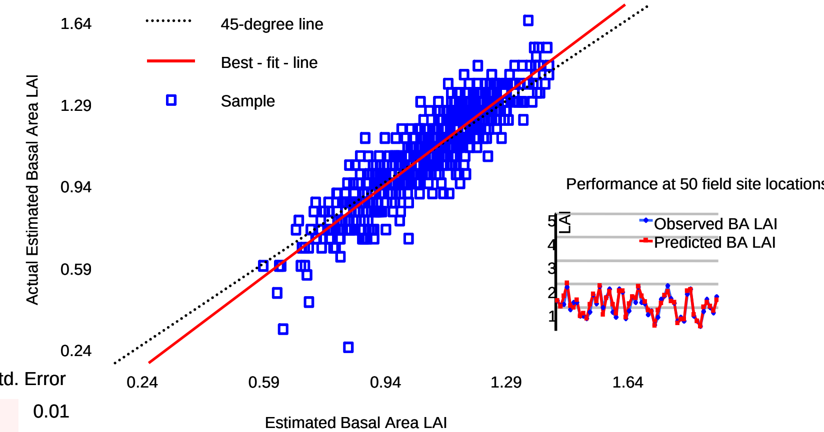
Regenerating site plot

LAI based on field data

LAI based on SAVI & field data

Error





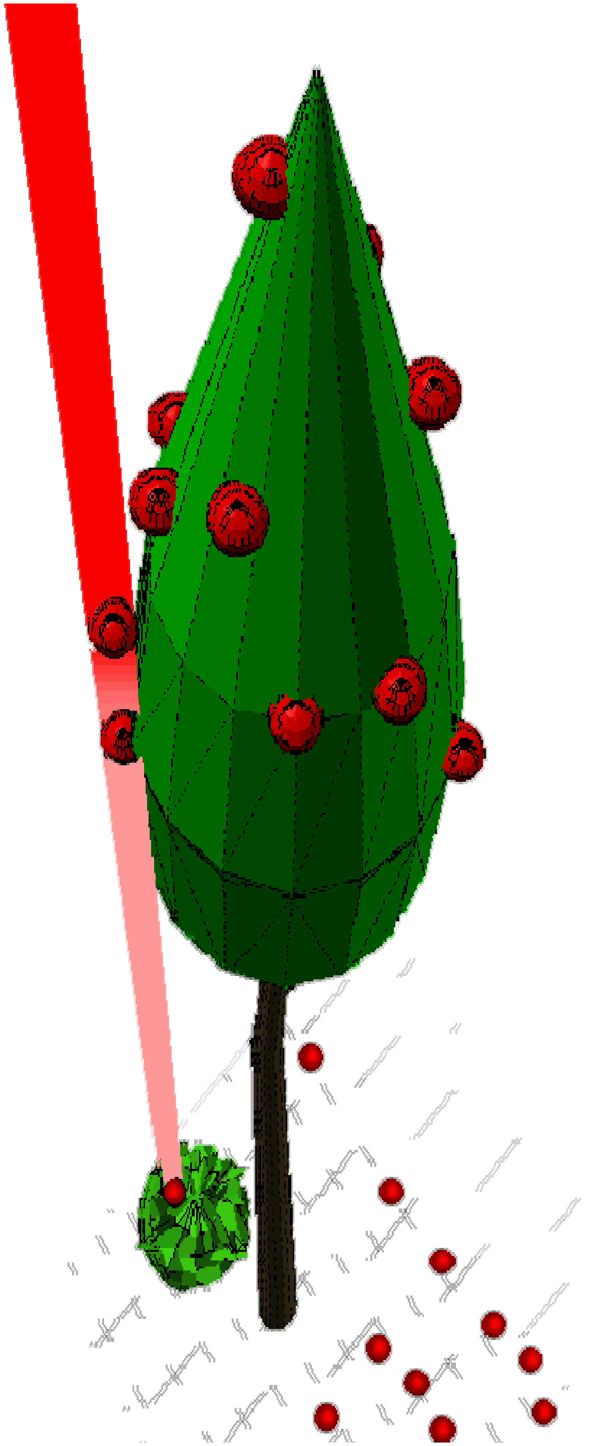
Regression Coefficient (1.0 = perfect fit) = 1.54
Proportion of Variation Explained by the Model (r^2) = 0.881
Noise in the Model (y intercept) = -0.051
Standard Error of Prediction = 0.023

Moskal & Jakubauskas, 2003

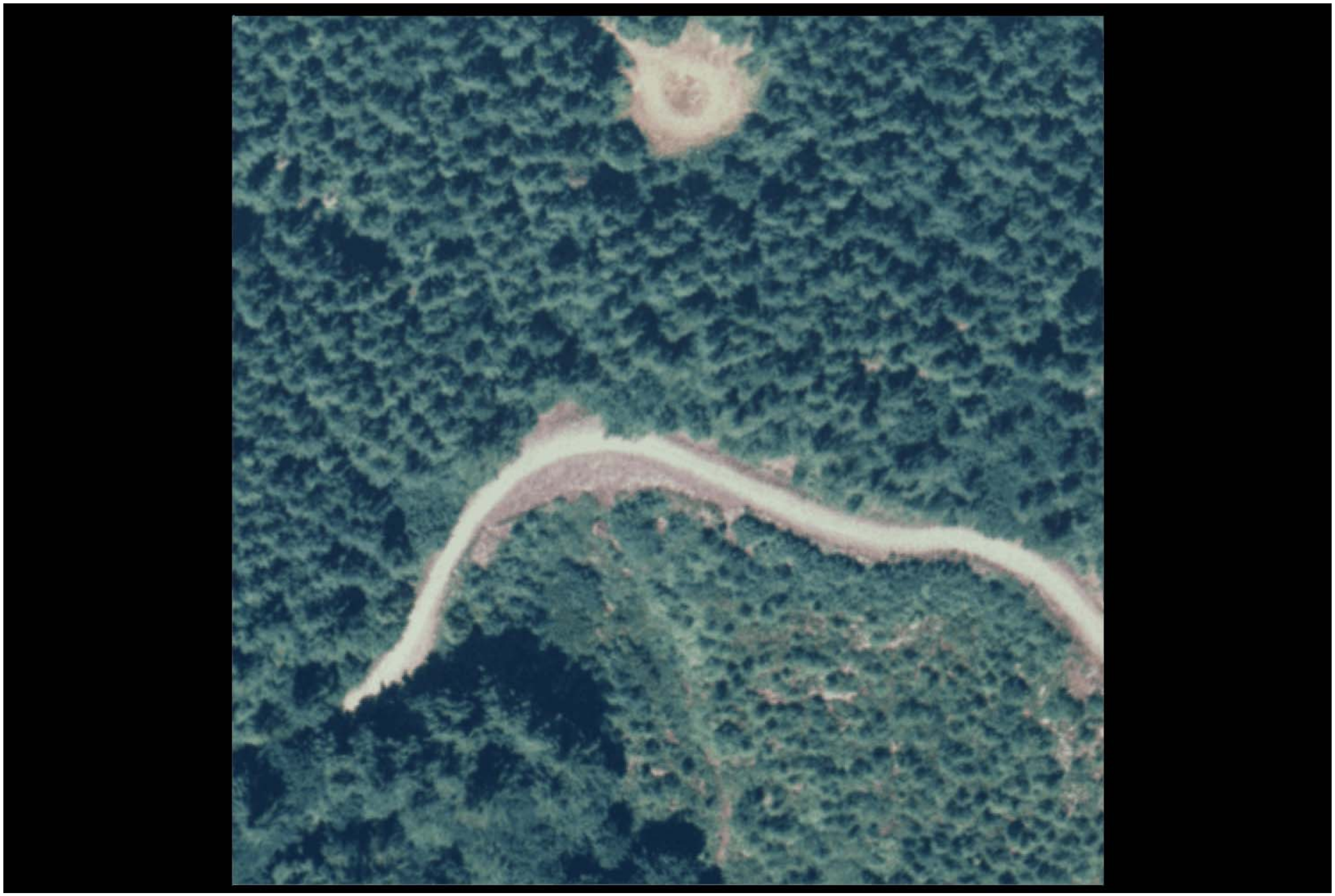
LiDAR

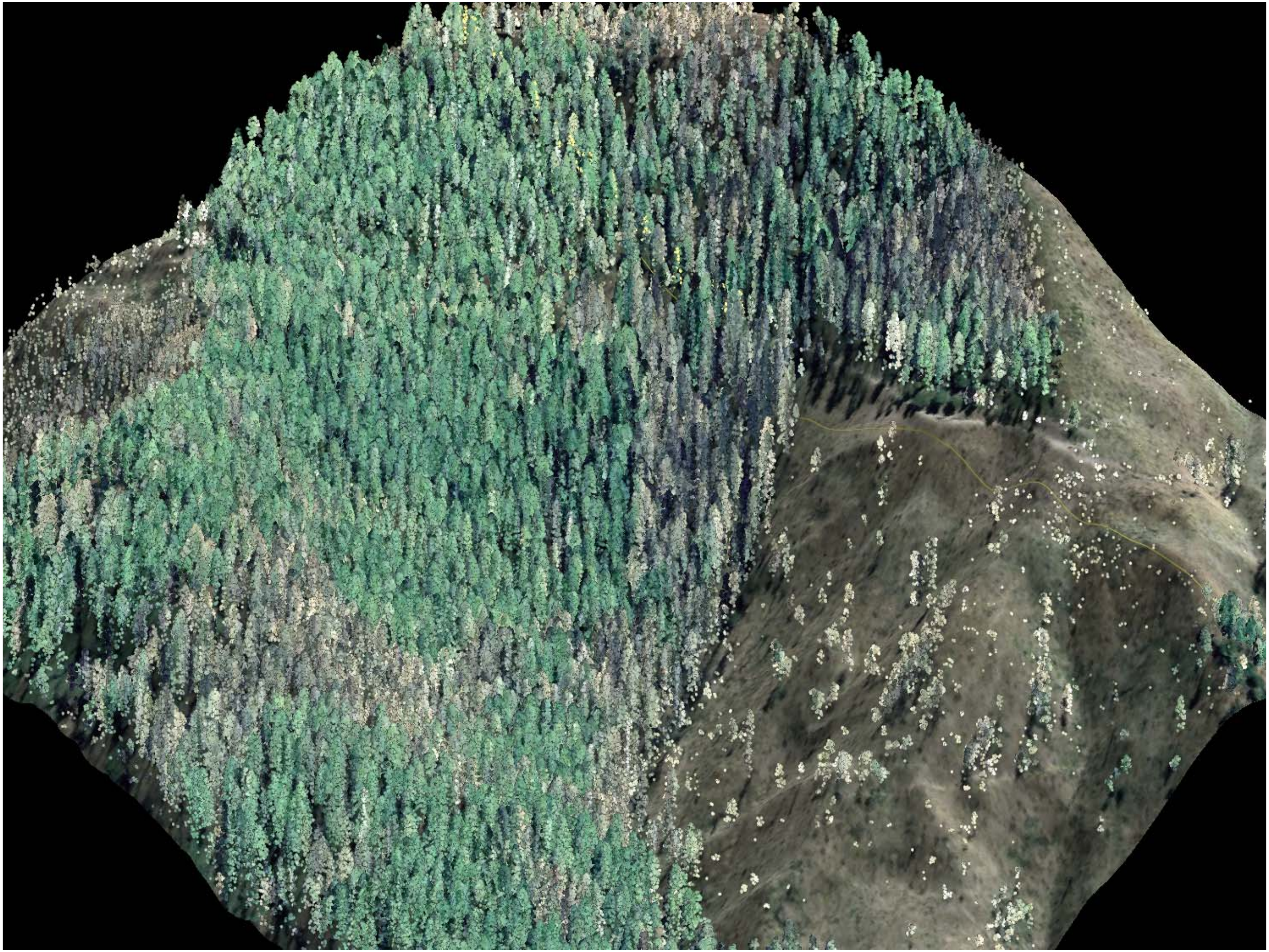
Light Detection And Ranging

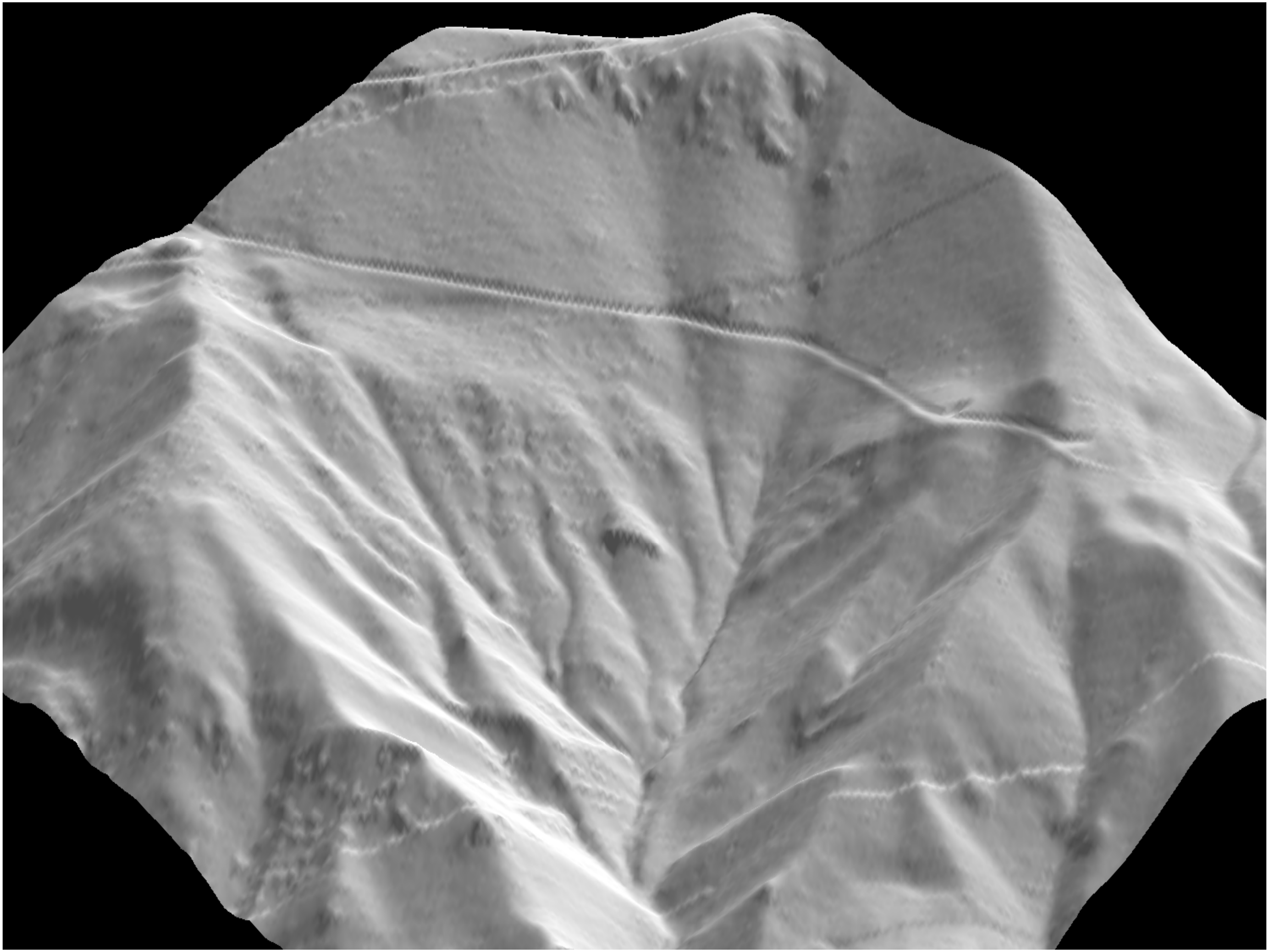
- The time for the light to travel out to the target and back to the LiDAR is used to determine the range to the target
- Currently high density LiDAR is only flown on aerial platforms and requires very precise real time flight inertial measurement unit (IMU) and GPS coordinates
- Three dimensional data



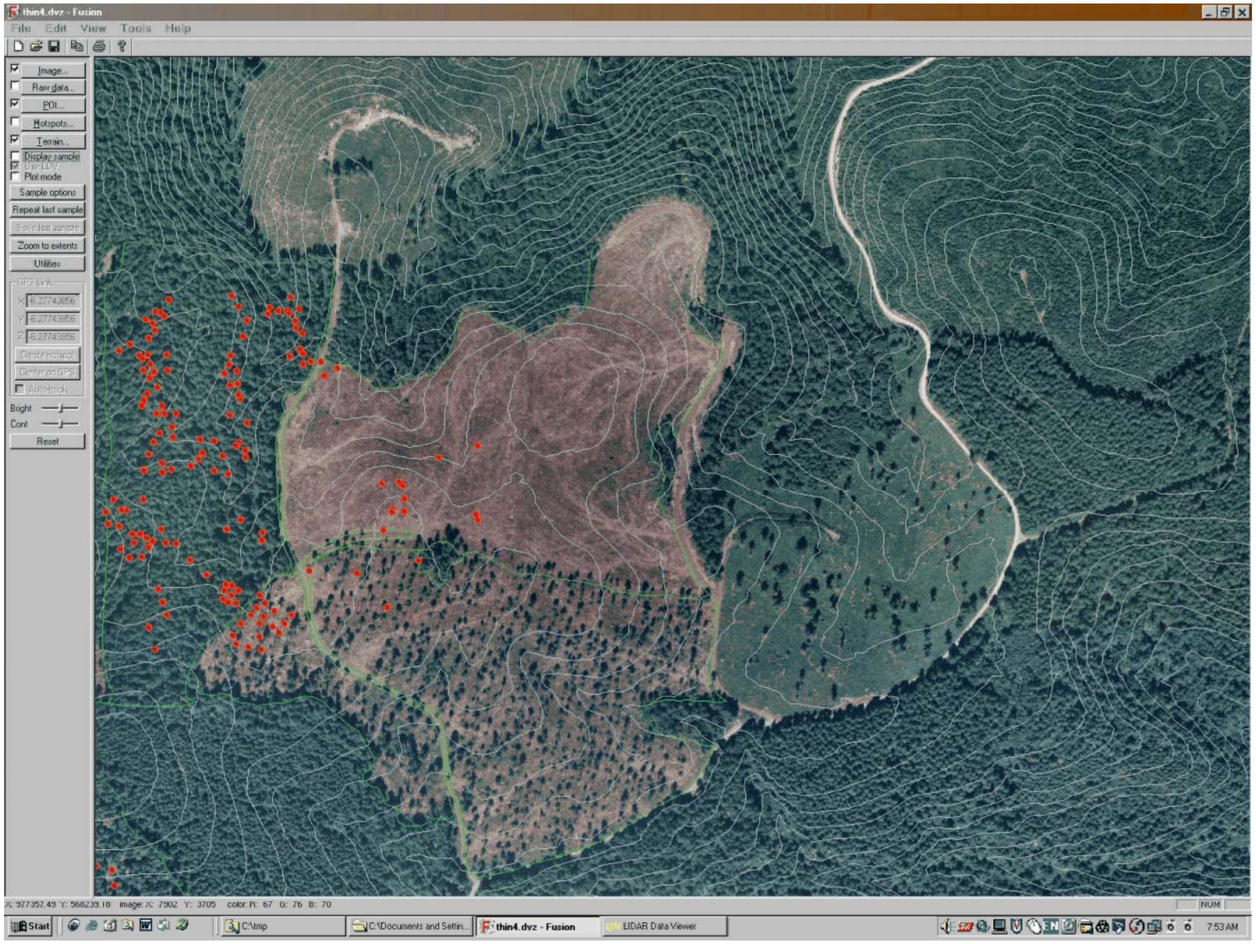
Hyperspatial Remote Sensing





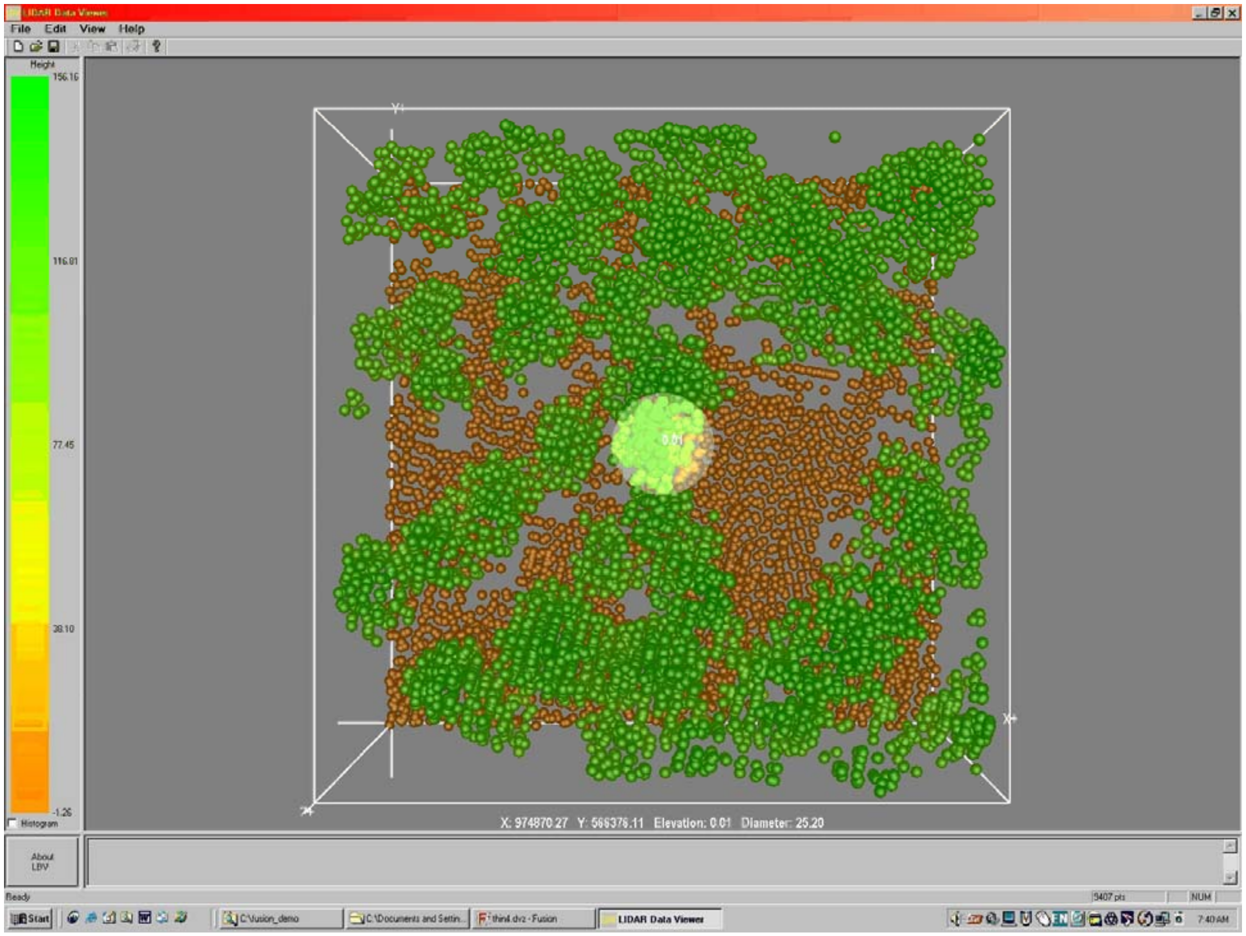


LiDAR (hyperspatial remote sensing)

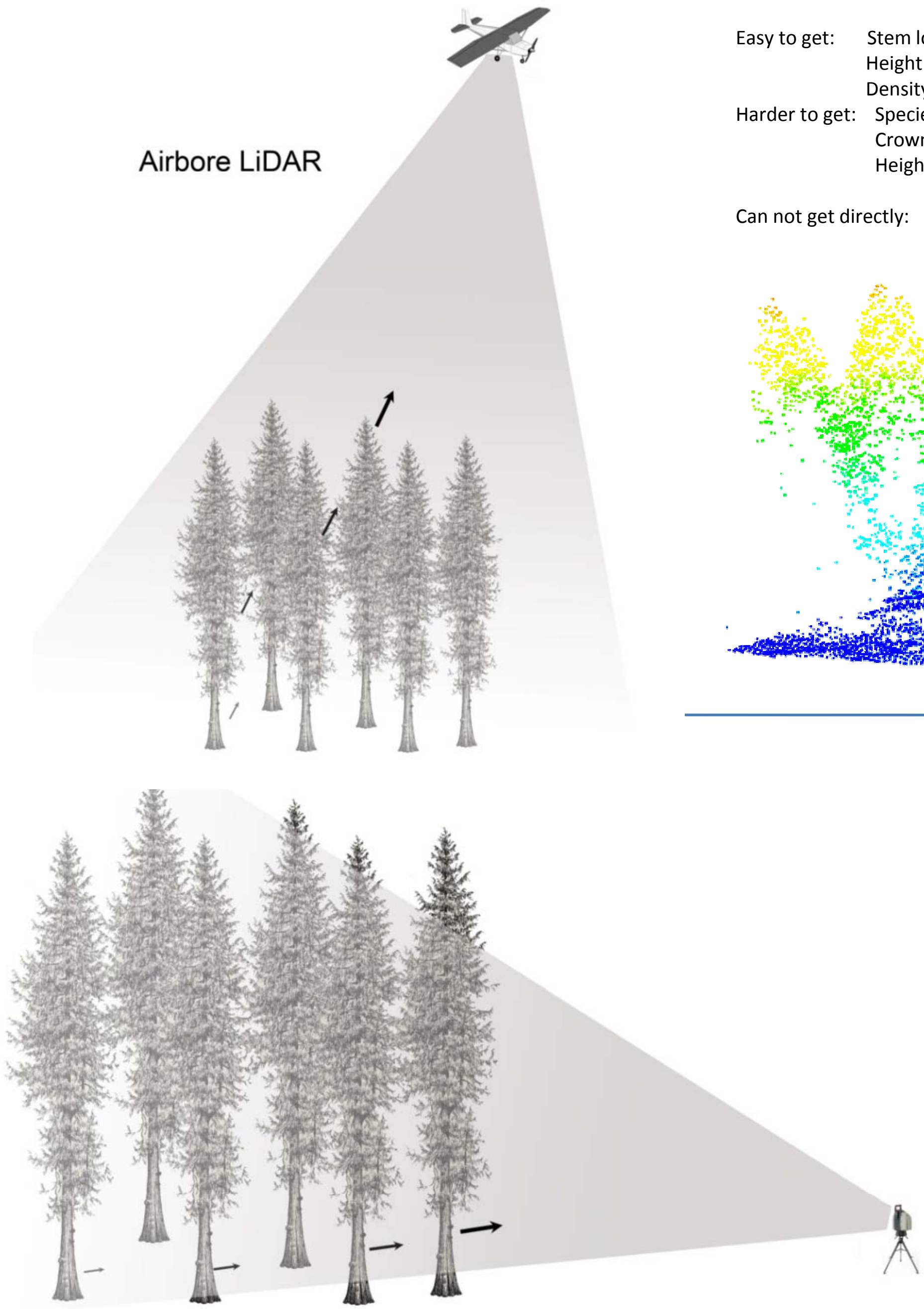


LiDAR and aerial imagery in Fusion software
(Bob McGaughey, USDA Forest Service)

LiDAR(hyperspatial remote sensing)



LiDAR based forest characterization in Fusion software
(Bob McGaughey, USDA Forest Service)



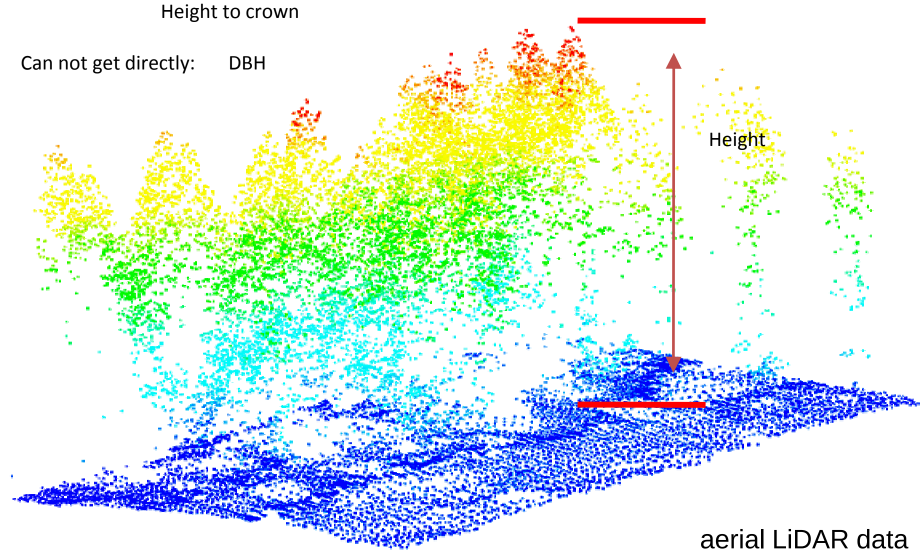
Ground-based LiDAR

Zheng & **Moskal** 2008
Kato, **Moskal** et al. 2008

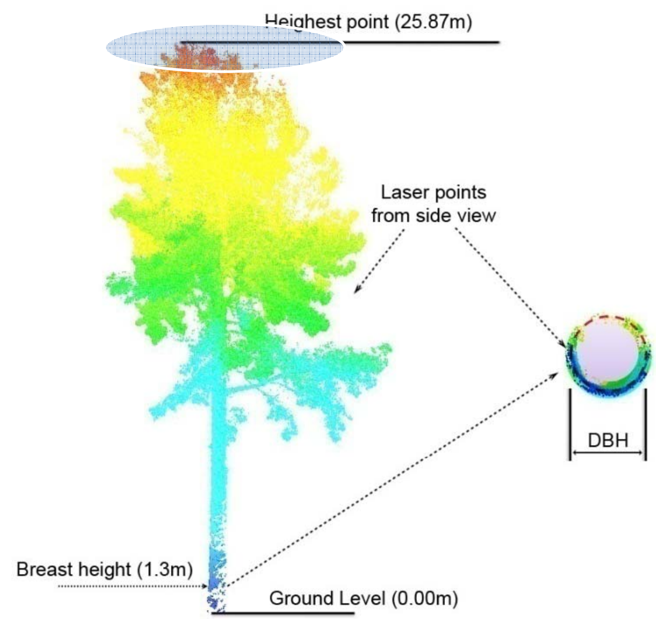
Easy to get: Stem location
Height
Density

Harder to get: Species
Crown diameter
Height to crown

Can not get directly: DBH



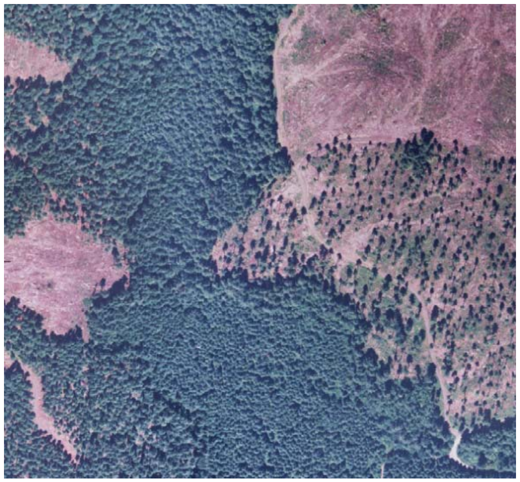
aerial LiDAR data



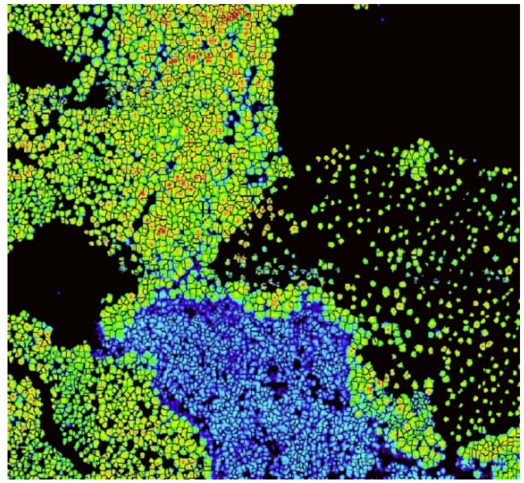
ground-based LiDAR data

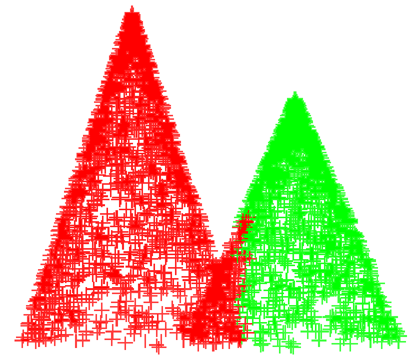
Tree crown segmentation

Orthophotograph



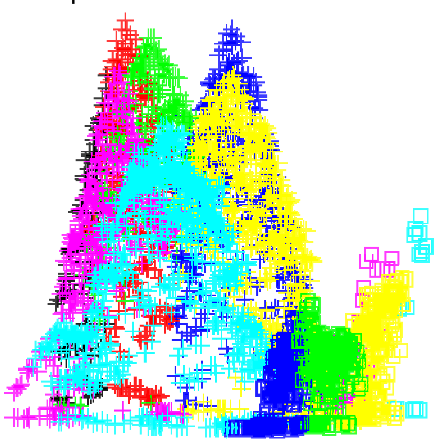
Automated tree crown segmentation
using rasterized LiDAR data

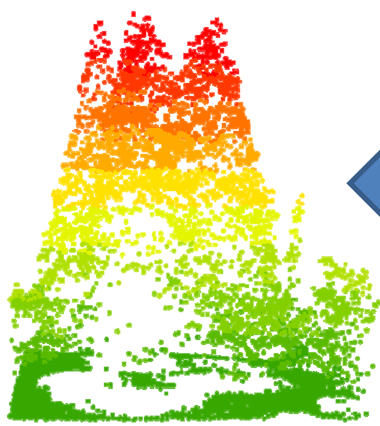




Rasterized LiDAR segmentation transposed
back onto original point cloud data

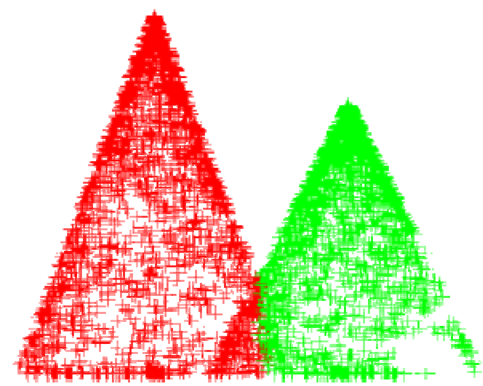
Segmentation with gaussian model
with spatial autocorrelation





LiDAR point cloud
(colored by height)

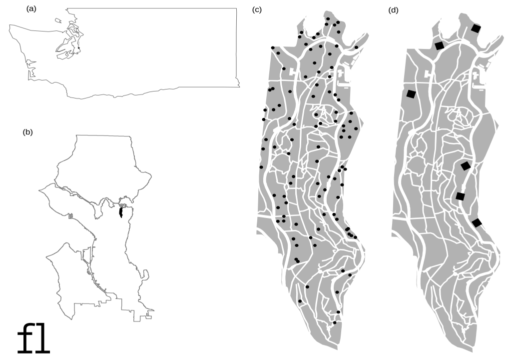
Pilot test using UW
arboretum data



Segmentation with gaussian model
with spatial autocorrelation

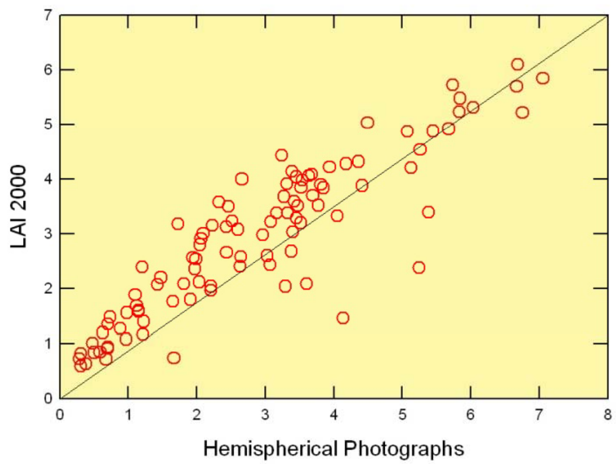
Moskal & Kato 2007

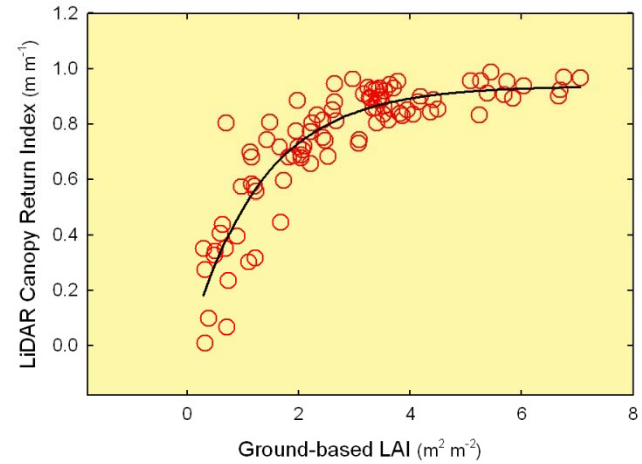
UW Arboretum LAI

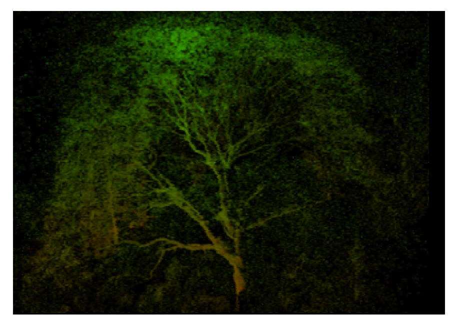


The most simple metric, the ratio of all canopy returns to the number of ground first returns (LiDAR Canopy Return Index), is well correlated to ground LiDAR, but suffers from a tendency to saturate at LAI larger than 3.

Comparison of Ground Estimates of LAI





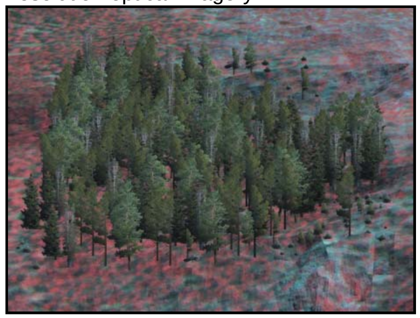


Richardson, **Moskal** & Kim (forthcoming)

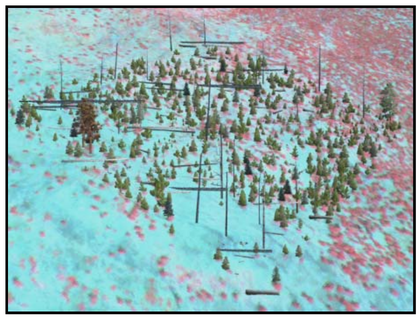
Geovisualization based on remotely sanded and geospatial data

Field photo, YNP 2001

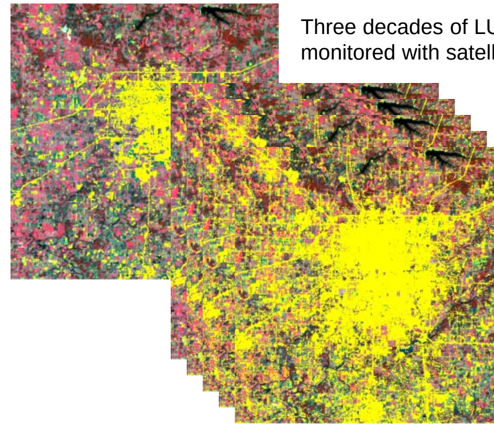
Old growth characterization from high resolution optical imagery



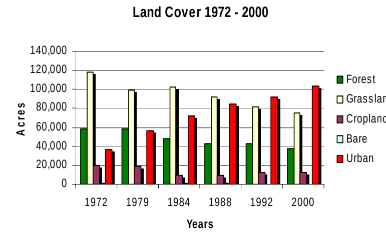
Field photo, YNP 2001

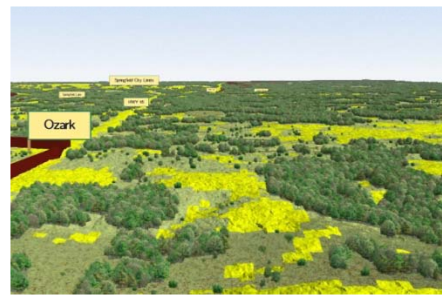


Post-fire regeneration characterization from high resolution optical imagery



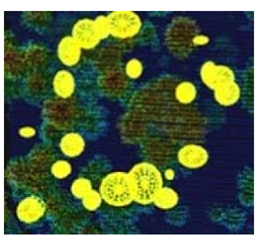
Three decades of LULC change monitored with satellite imagery

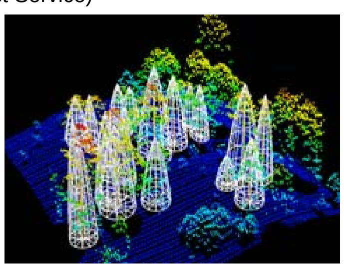




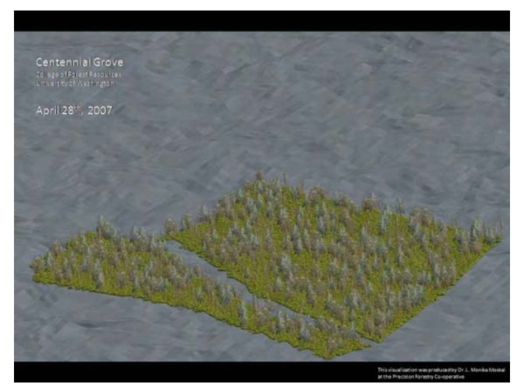
Temporal geovisualization of landuse change in the Ozarks, MO (1972-2000)

LiDAR based forest characterization in Fusion software
(Bob McGaughey, USDA Forest Service)





Temporal geovisualization of forest cover change in the James River Basin, MO (1972-2000)



Predictive modeling

Moskal, 2001 & 2007
Huggins & **Moskal**, 2006
Hunsinger & **Moskal**, 2006

Example of the new research directions at the Precision Forestry Cooperative (PFC)

Precision Forestry Cooperative

ECOSEL - A Forest Ecosystem Services Marketing Tool

Sándor F. Tóth

Introduction
Eco-services planning
Marketing options
Transactions

Introduction

ECOSEL is an analytical modeling tool that aids forest landowners and managers in selling ecosystem services from their working forestland. ECOSEL optimally allocates management actions to forest stands in order to produce various bundles of timber and non-timber benefits. The tradeoffs and opportunity costs of providing an efficient range of bundles are identified and linked to spatially explicit management plans. The figure below illustrates this linkage. Here, for simplicity, only two services are bundled: discounted net revenues from timber production (vertical axis) and old-growth forest habitat (horizontal axis). The basic idea is that the harvesting activities (grey polygons) can be reshuffled across the land-base and over time so that various amounts of mature forest habitat (green patches) could arise and evolve. Obviously, as more mature forest habitat is desired, more timber revenues must be forgone.

The profit maximizing alternative is represented by Point A accompanied by a map of the corresponding 3-period management plan that shows the harvesting activities that would need to take place in order to achieve this maximum profit. At the other end of the production frontier lies Alternative B leading to the greatest possible amount of mature forest habitat that can be achieved within the 60-year planning horizon (three 20-year long planning periods) used in this example. Several compromise alternatives exist between these two extremes, including Alternative C and E. The common feature of these alternatives is that they are efficient (Pareto-optimal) in a sense that no other alternatives exist that would lead to more profit or to more mature forest habitat without compromising the other service.

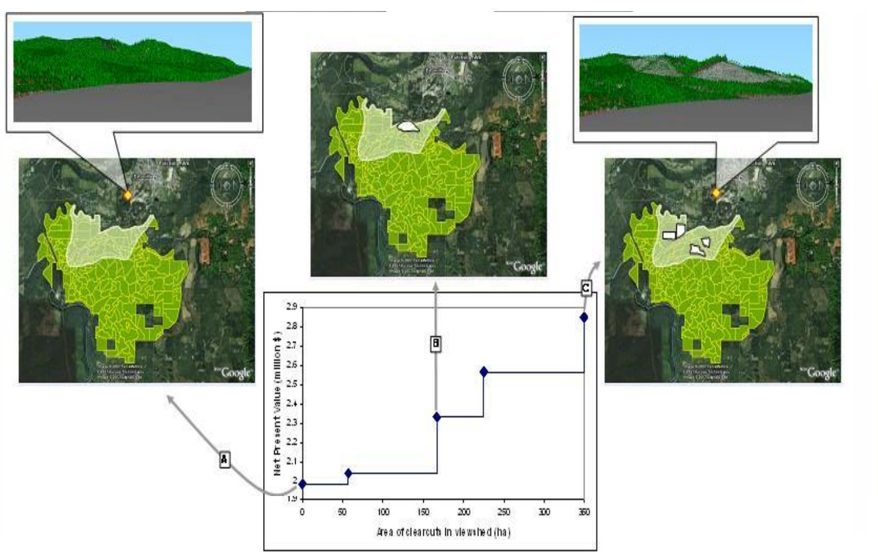


Figure 1.

This presentation has several advantageous features. First, it indicates how much it would cost the landowner to provide various amounts of mature forest services. Second, it identifies cost-efficient production opportunities such as Alternative C. Notice that this alternative achieves a significant increase in the mature forest habitat service by forgoing only very little profit. Low-cost alternatives can be important for the landowner because potential buyers are more likely to come forward and cover the opportunity costs if substantial amount of services can be purchased for a low price. ECOSEL identifies these opportunities if they exist.

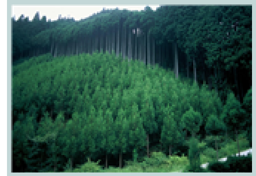
Note: If the *highest best use* of the land is not timber production then the opportunity cost structure must be adjusted accordingly.

Next: Eco-services planning

Introduction
Eco-services planning
Marketing options
Transactions

Links:

Sándor F. Tóth home
Precision Forestry Cooperative
College of Forest Resources
University of Washington



http://faculty.washington.edu/toths/ecosel_prod.shtml

Send mail to: toths@u.washington.edu
Last modified: 10/18/2007 9:00 AM

ECOSEL

A forest ecosystem service marketing tool

ECOSEL is an analytical modeling tool that aids forest landowners and managers in selling ecosystem services from their working forestland.

What ecosystem services should the landowner be thinking about producing?

Viewshed aesthetics, carbon sequestration, water quality, habitat …?

Examples of LiDAR research @ PFC

- GPS Performance (Dense Canopy)
- LiDAR Performance (Chaparral)
- Field Sampling Optimization
- Forest Inventory (FIA)
- Species Identification
- Stand Delineation
- Volume Estimation
- Fire Susceptibility
- Biomass (LAI)
- Data Fusion

Tobey Clarkin
MS Student

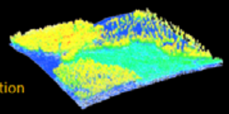
Received his BS in environmental engineering from Rensselaer Polytechnic Institute. He is now pursuing an MS in Forest Engineering & Hydrology, studying in-woods navigation.

Research Topic:
Modeling GPS Positional Error under Forest Canopy based on LIDAR-Derived Canopy Densities

Andrew Cooke
MS Student

Received his B.A. in Geography from the University of Washington. He is currently working on an MS in GIS and remote sensing.

Research Topic:
LIDAR response in chaparral and other low, dense vegetation



Jacob Strunk
MS Student

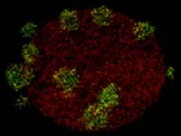
Completed his Bachelor of Science in Forest Resources degree in the Environmental Science and Resource Management program at the College of Forest Resources.

Research Topic:
Field sampling for LIDAR data validation

Yuzhen Li
PhD Candidate

She received her BS in Forestry from Shan Dong Agriculture University, in Taian China, and her MS in Forest Biometrics from the University of Washington.

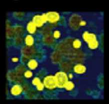
Research Topic:
Integrating LIDAR into Forest Inventory and Analysis

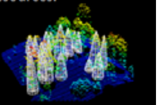


Sooyoung Kim
PhD Candidate

Attended Seoul National University from 1993-2000, earning a BS Honors in Horticultural Science and an MLA (Landscape Architecture). She has also earned a MS in Social Science from the UW College of Forest Resources.

Research Topic:
LIDAR-based tree species identification

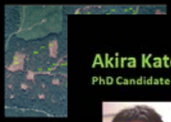




Alicia Sullivan
MS Student

Completed her undergraduate work in the College of Forest Resources at the University of Washington, she has been involved in forest inventory GIS mapping from aerial imagery.

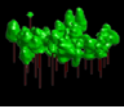
Research Topic:
Establishing the usefulness of Lidar-derived tree parameters for silvicultural modeling

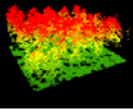


Akira Kato
PhD Candidate

Received his MS in remote sensing with a minor in forestry from the University of Tokyo in Japan. He is working on the integration of LIDAR datasets and photos using GIS software(ERDAS and ENVI) and the C programming language.

Research Topic:
Capturing tree crown formation with LIDAR data





Todd Erdody
MS Student

Completed his BS in Environmental Science and Ecology at North Carolina State University. Has worked on fire management and monitoring with the National Park Service.

Research Topic:
LIDAR derived forest structure for fire modeling

Guang Zheng
PhD Student

Completed his MS at Nanjing University in China where his research involved combining remote sensing imagery and forest age inventory for biomass mapping

Research Topic:
Fusion of satellite and LIDAI based leaf area index and biomass estimates

Jeff Richardson
MS Student

Works in the Plant Ecophysiology Laboratory at the University of Washington Botanical Gardens and is affiliated with the Remote Sensing and Geospatial Analysis Laboratory.

Research Topic:
Estimating Leaf Area Index (LAI) with LIDAR