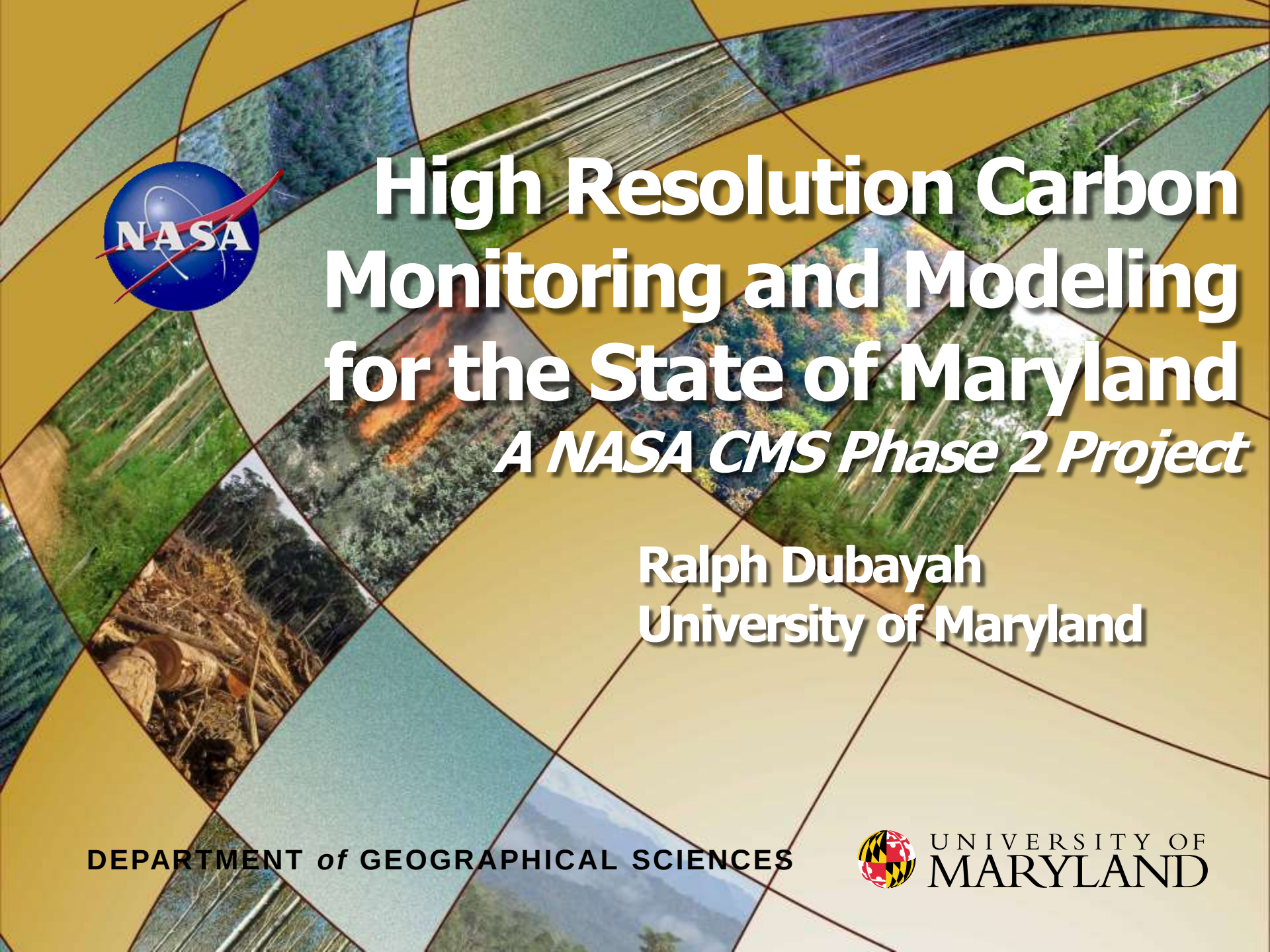


High Resolution Carbon Monitoring and Modeling for the State of Maryland

A NASA CMS Phase 2 Project

Ralph Dubayah
University of Maryland

DEPARTMENT *of* GEOGRAPHICAL SCIENCES

UNIVERSITY OF MARYLAND

Introduction

- Urgent need to develop carbon monitoring capabilities
  - Climate treaty verification (REDD+)
  - Changes in land use and climate
  - Rational policy based on prognostic modeling
- Aboveground biomass dynamics key element
  - Large variation in data, methods and models
  - Frameworks for uncertainty analysis poorly developed
  - Difficult to assess US national stocks in transparent and stable fashion

Objectives and Outline

Overview of local, county-scale mapping for NASA's Carbon Monitoring System

- Introduction to Maryland Biomass Pilot Project
- Methodological Approaches
- Summary Phase 1 Results
- Maryland Phase 2 Mapping
- Phase 2 Expected Products and Outreach
- Issues and Considerations

NASA'S Carbon Monitoring System

- NASA Congressional mandate to initiate work towards a CMS (2010 & 2011)
- Two Phase 1 pilot studies
  - Biomass Pilot Product
    - Continental and local-scale projects
  - Integrated Emission/Uptake ("Flux") Product
- Objectives
  1. *Develop* prototype national biomass data products for MRV (Measurement, Reporting, Verification)
  2. *Demonstrate* NASA readiness for MRV using existing in situ and satellite observations

Biomass Pilot Product

- Focus on quantifying terrestrial vegetation carbon stocks for US and globally
  - Continental scale (top-down) approach
  - Local scale (bottom-up) approach (fine resolution)

- Local scale objectives
  - Develop remote sensing protocols
  - Validation for continental scale work
  - Demonstrate efficacy for prognostic ecosystem modeling

Nested Scales of Observations

National Mapping

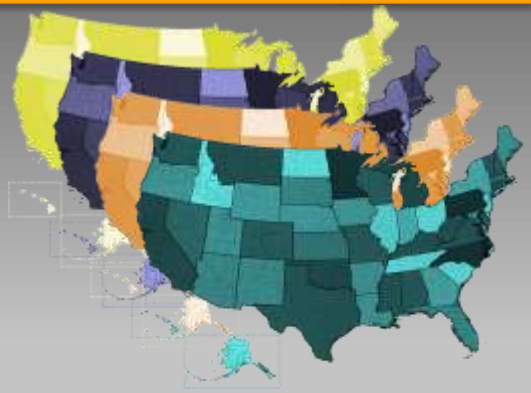
Local Mapping

Validation

National/State Reporting

Comprehensive Carbon Monitoring System

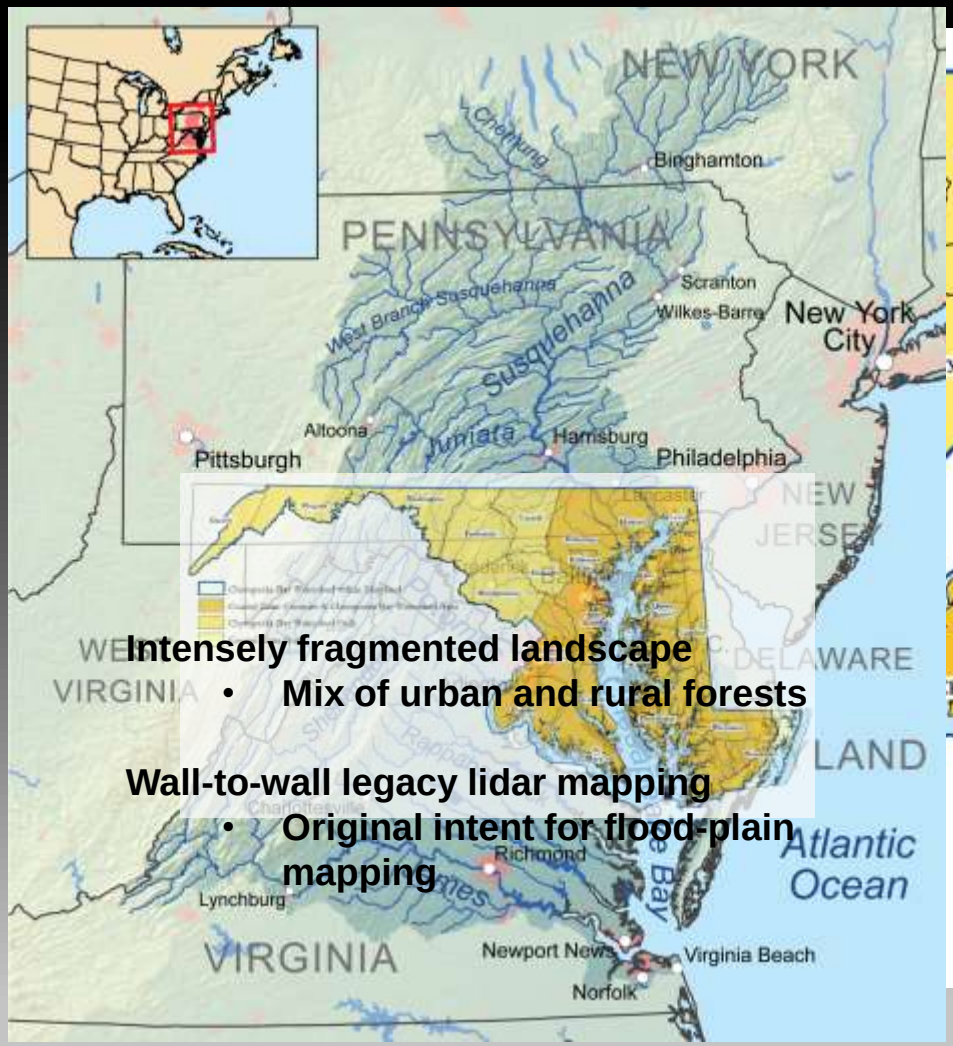
Project Valuation Policy/Management



OBSERVATIONAL DRIVERS
Inventory, Space-based

OBSERVATIONAL DRIVERS
Inventory, Aircraft & Space-based

Geographic Setting



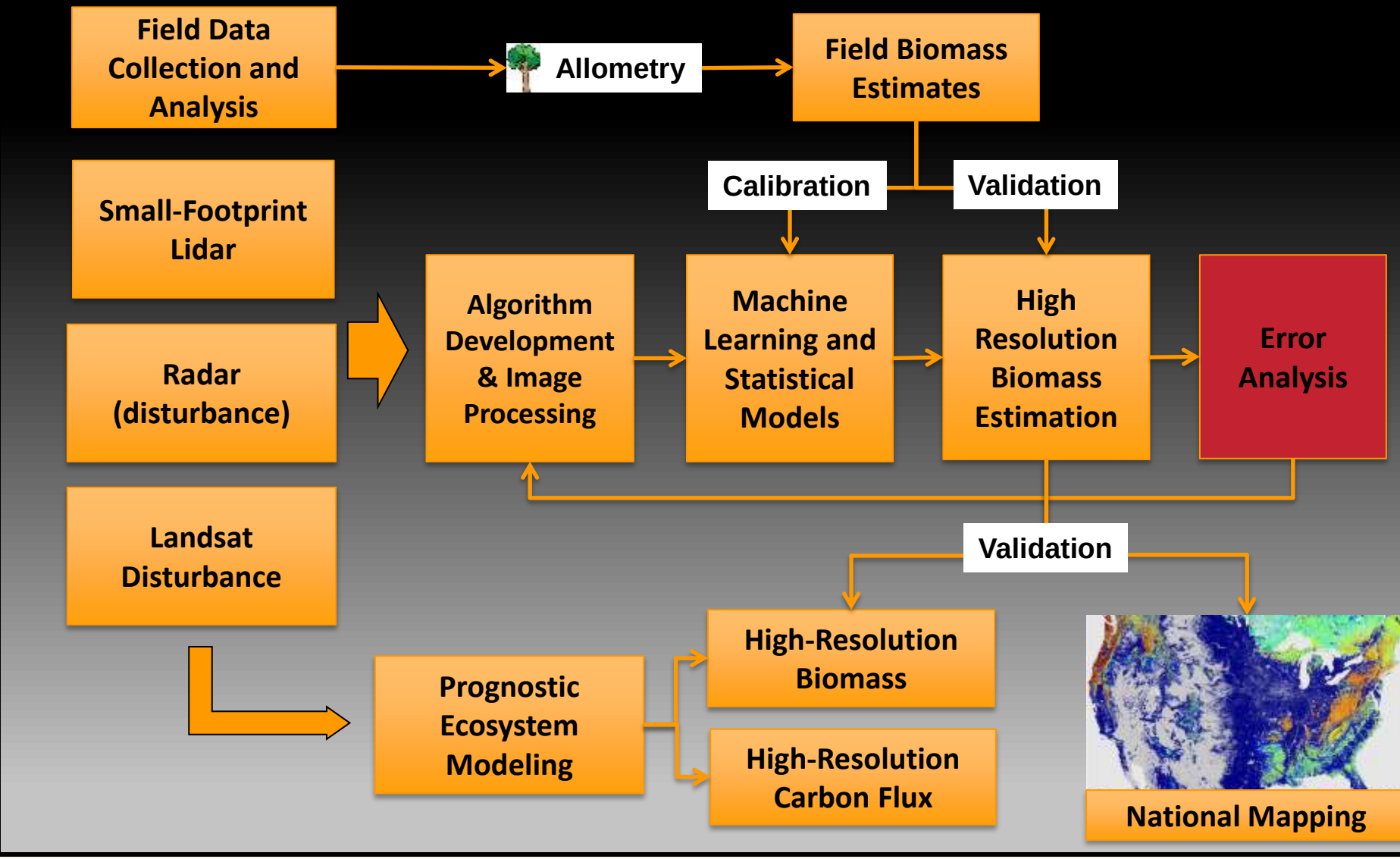
Intensely fragmented landscape

- Mix of urban and rural forests

Wall-to-wall legacy lidar mapping

- Original intent for flood-plain mapping

Methodological Approach



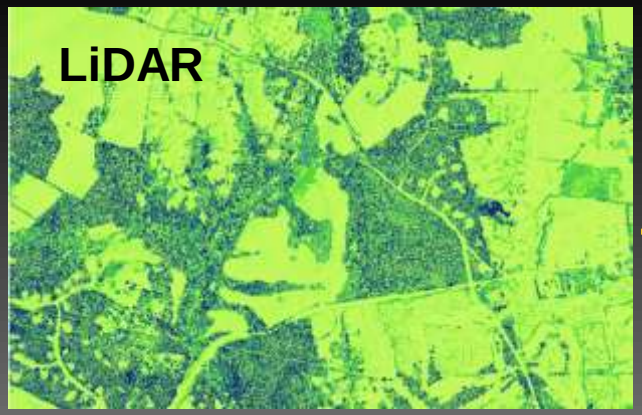
Sampling and Field Data

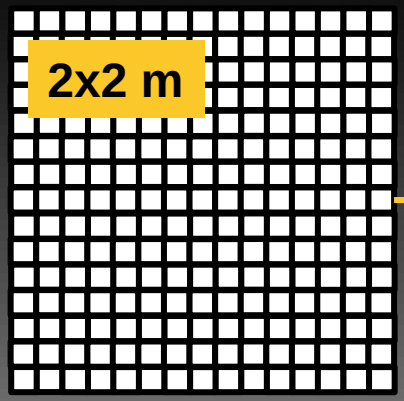
- Stratified sampling approach
  - Model-based
    - NLCD 30 m landcover classes (5 strata)
    - Lidar height (3 classes)
  - 300 plots
    - Prism-based, variable radius plots
    - Spring/summer 2011
- USFS: 20 new FIA-type plots & 20 variable radius plots
- Objective to simulate county approaches with constrained resources

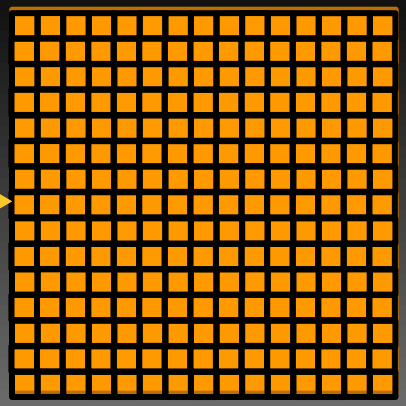
Model-based Stratification

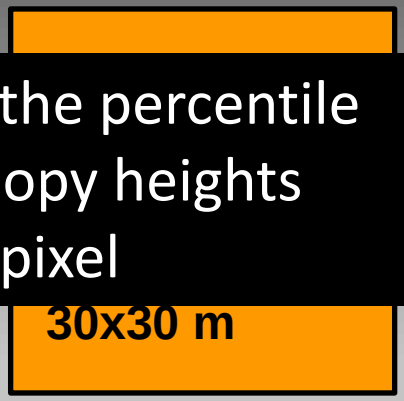
Lidar Data

- **County-level, wall-to-wall, *leaf off***
  - Data *stale* and *sparse*

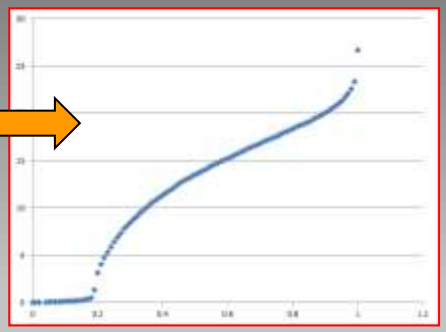








Lidar metrics give the percentile distribution of canopy heights within each NLCD pixel



High Resolution Tree Canopy Extraction

- Object-based data fusion approach
  - Combines 4-band NAIP imagery and lidar

Landsat Disturbance Data

- Persisting nonforest
- Persisting forest
- Water

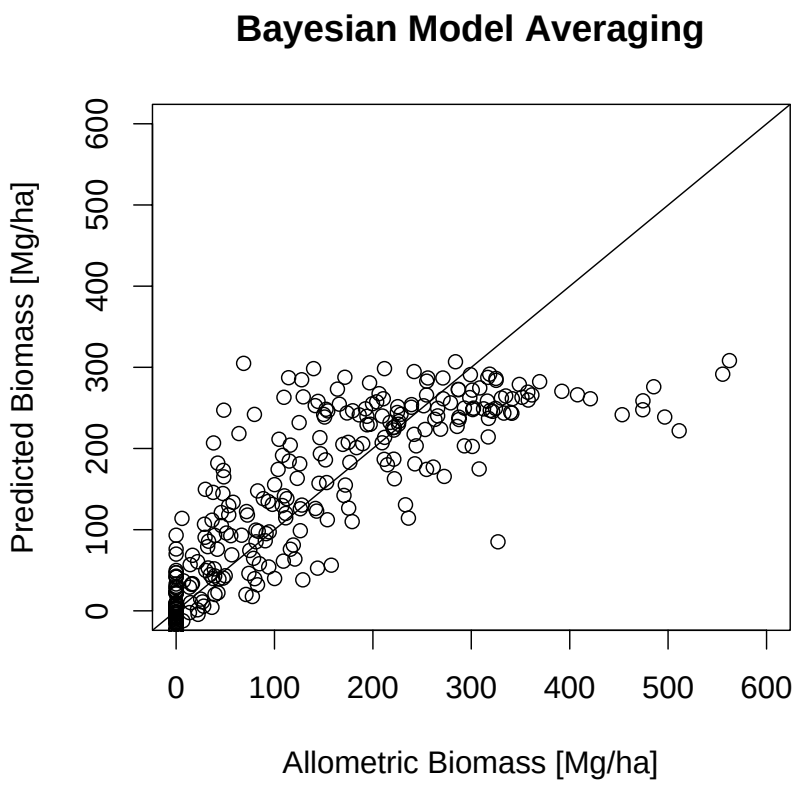
Forest Harvest Year

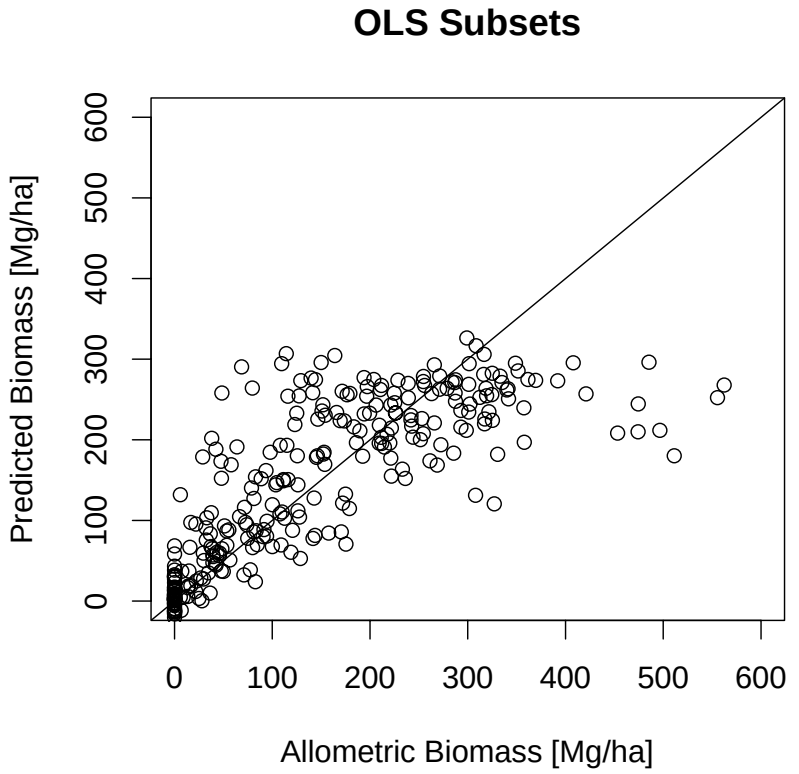
- Pre-1985
- 1985
- 1986
- 1987
- 1988
- 1989
- 1990
- 1991
- 1992
- 1993
- 1994
- 1995
- 1996
- 1997
- 1998
- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005

Statistical Methods

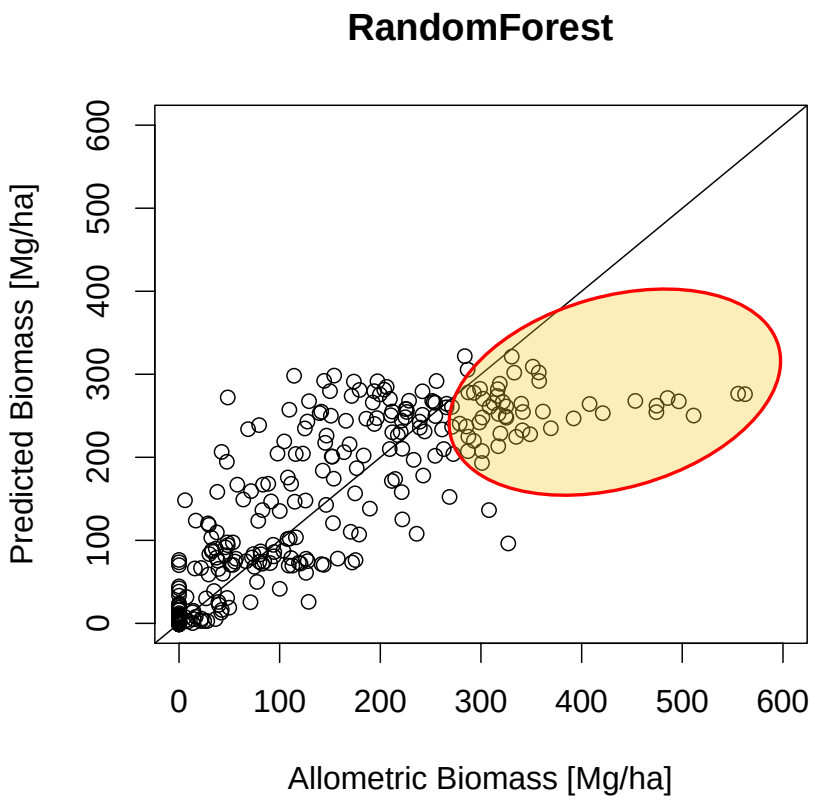
- Least-squares regression
  - All possible subsets (OLS)
  - Bayesian Model Averaging (BMA)
  - Limited to < 4 variables (out of many)
- Regression-tree
  - RandomForest
  - Quantile regression forests

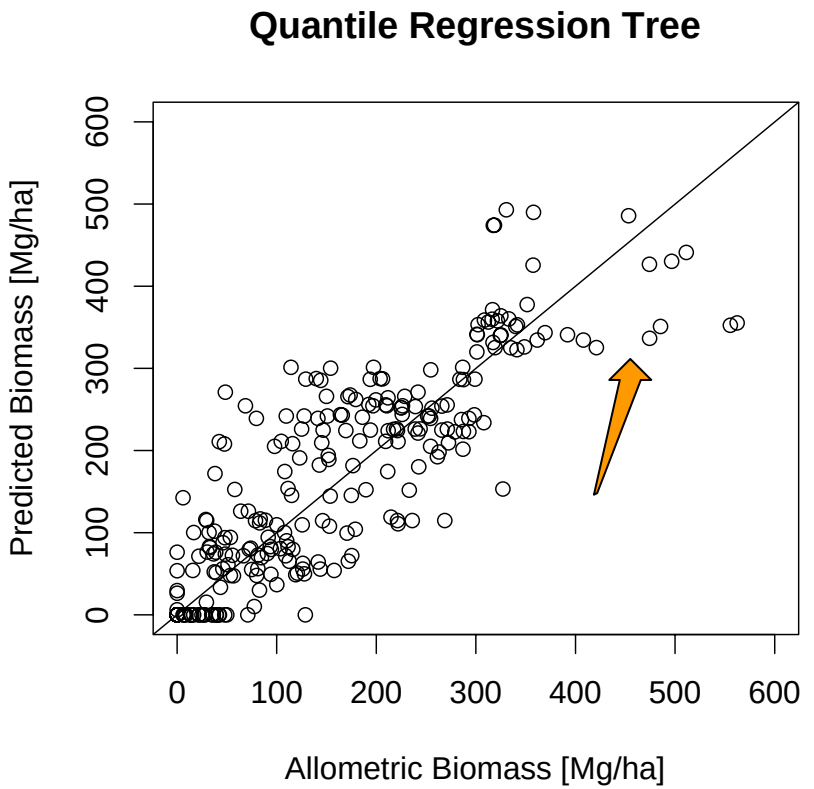
Results


Bayesian Model Averaging
Predicted Biomass [Mg/ha]
0
100
200
300
400
500
600
Allometric Biomass [Mg/ha]

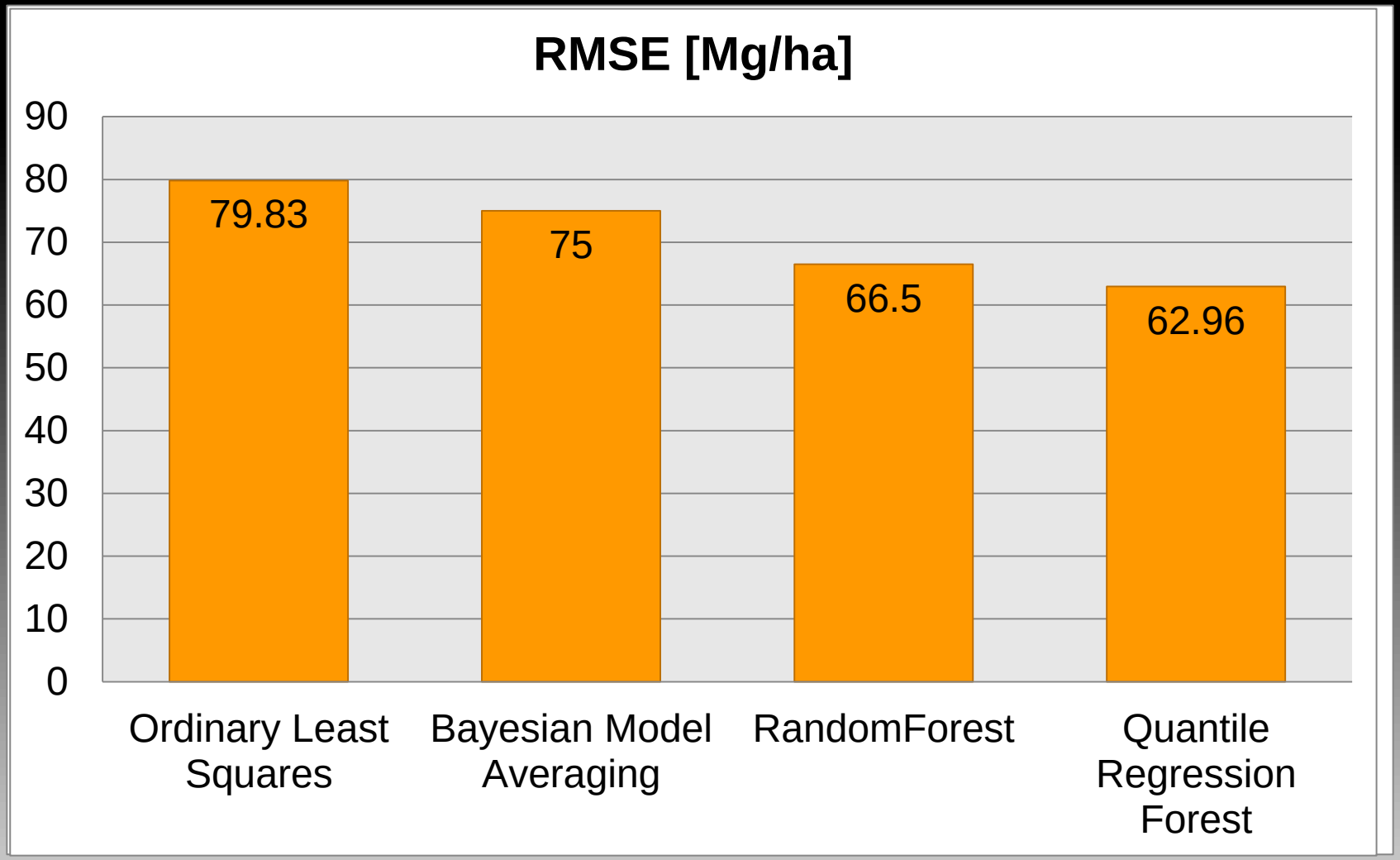

OLS Subsets
Predicted Biomass [Mg/ha]
0
100
200
300
400
500
600
Allometric Biomass [Mg/ha]

Results

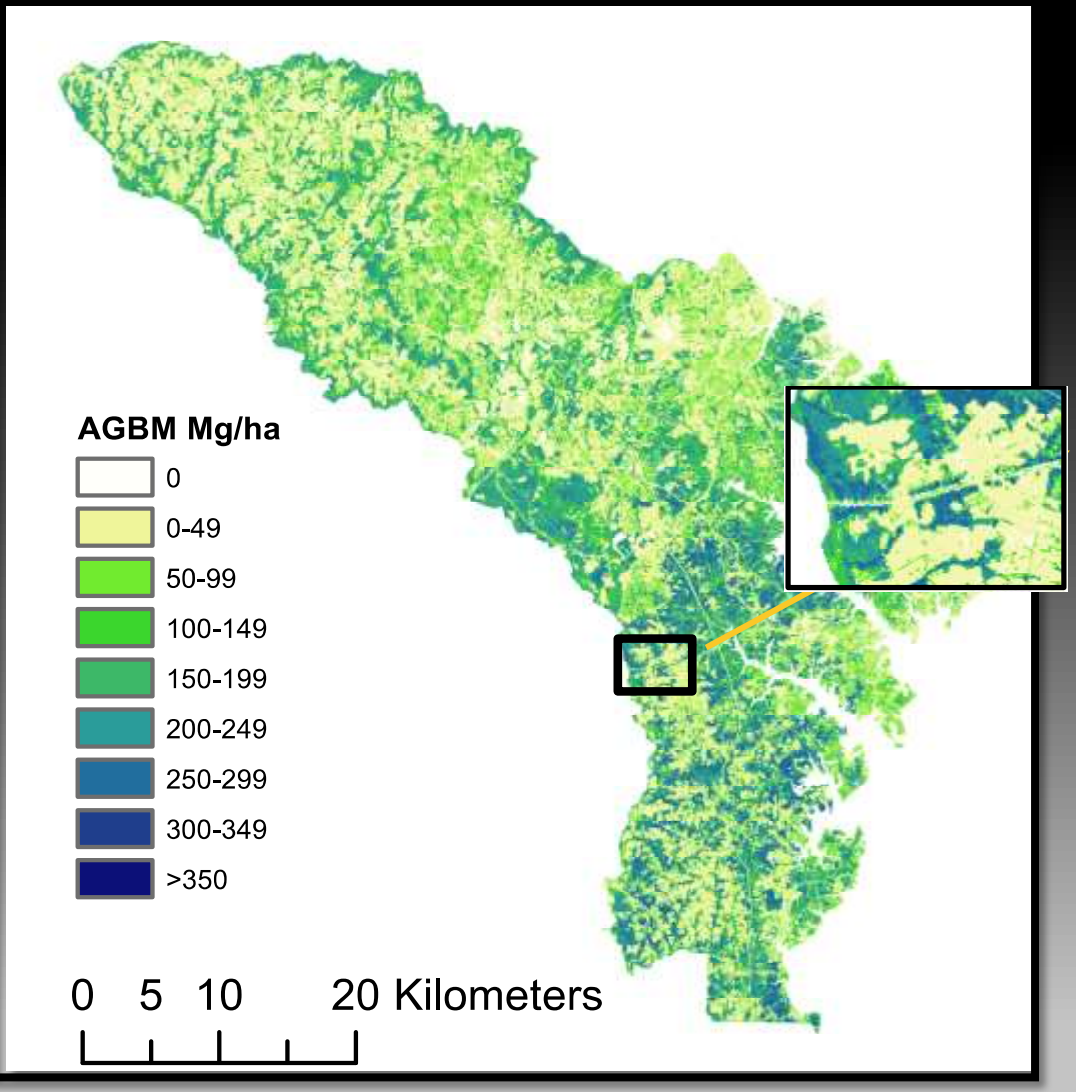

RandomForest
Predicted Biomass [Mg/ha]
0
100
200
300
400
500
600
Allometric Biomass [Mg/ha]


Quantile Regression Tree
Predicted Biomass [Mg/ha]
0
100
200
300
400
500
600
Allometric Biomass [Mg/ha]

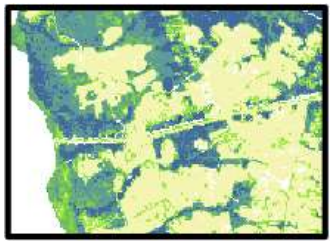
Results


RMSE [Mg/ha]
90
80
70
60
50
40
30
20
10
0
79.83
75
66.5
62.96
Ordinary Least Squares
Bayesian Model Averaging
RandomForest
Quantile Regression Forest

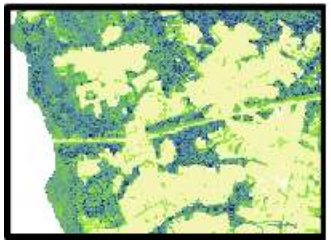
Predicted Biomass



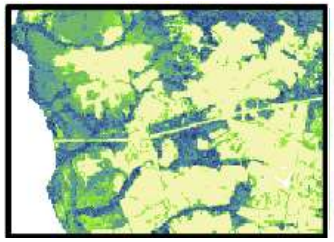
Linear Regression



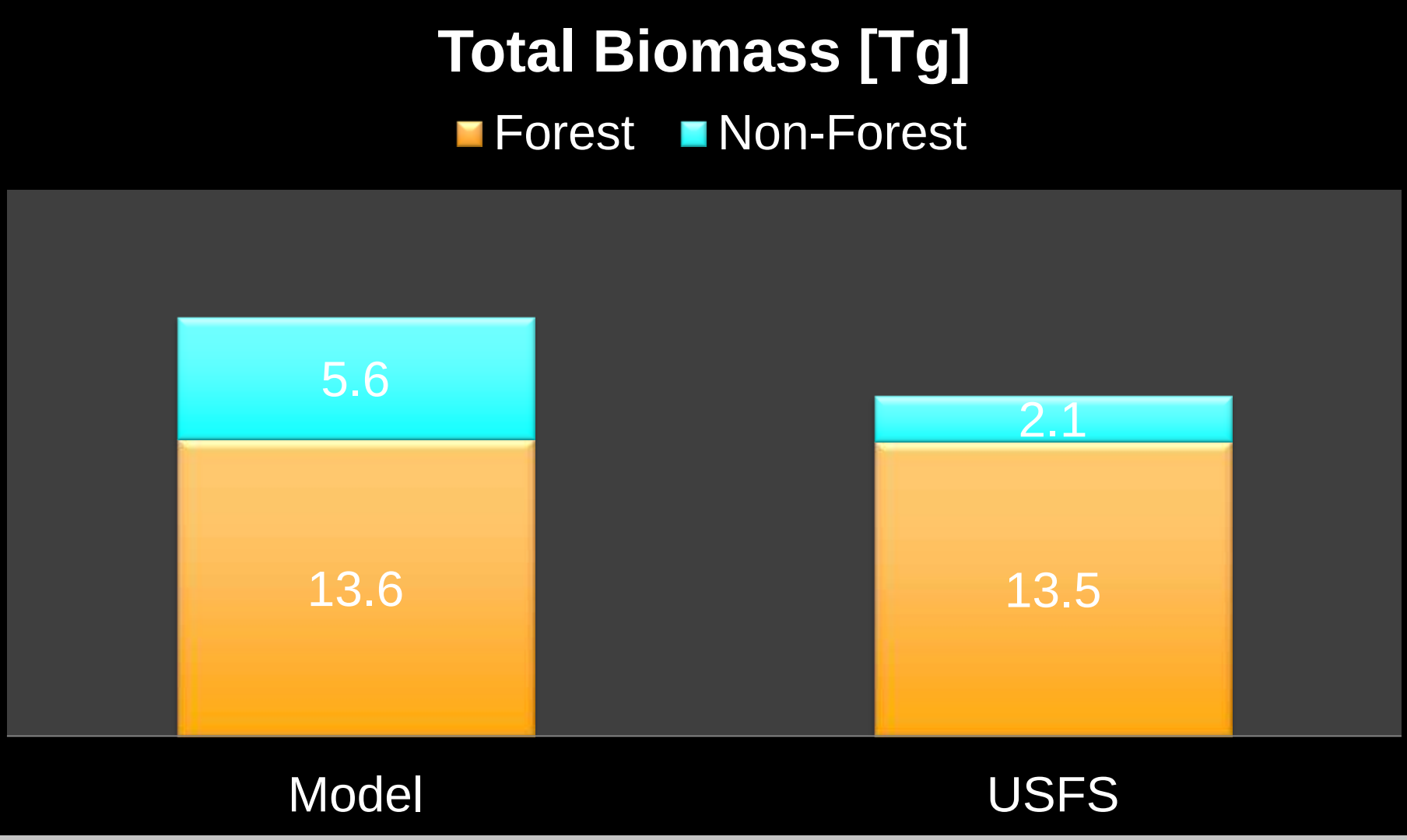
BMA Regression



RandomForest

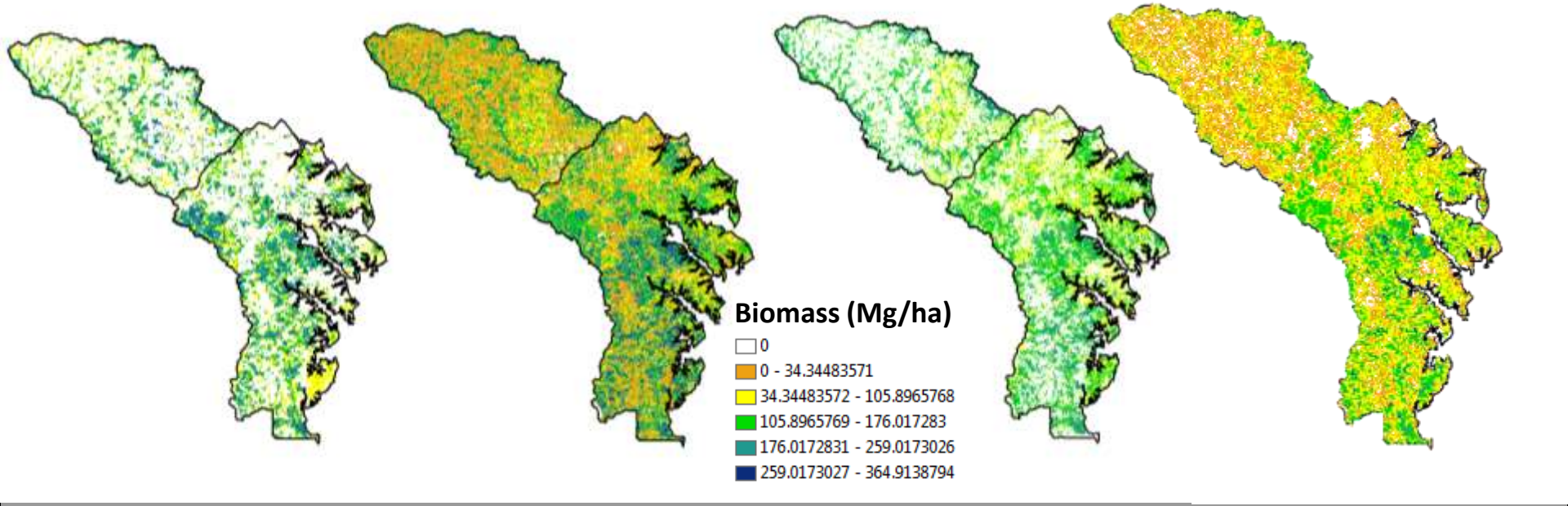


Spatial Variability & Errors

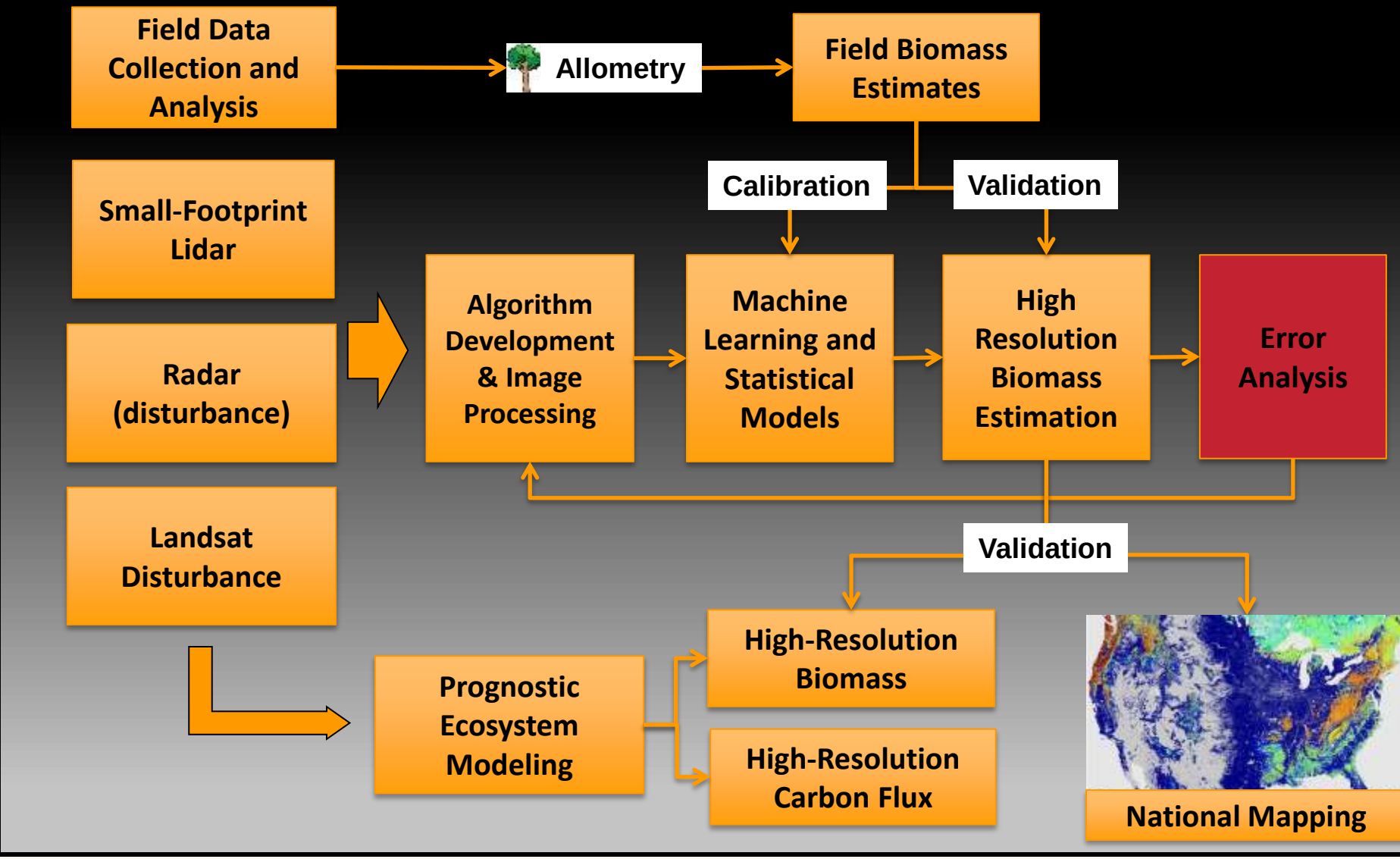


National Biomass Map Validation

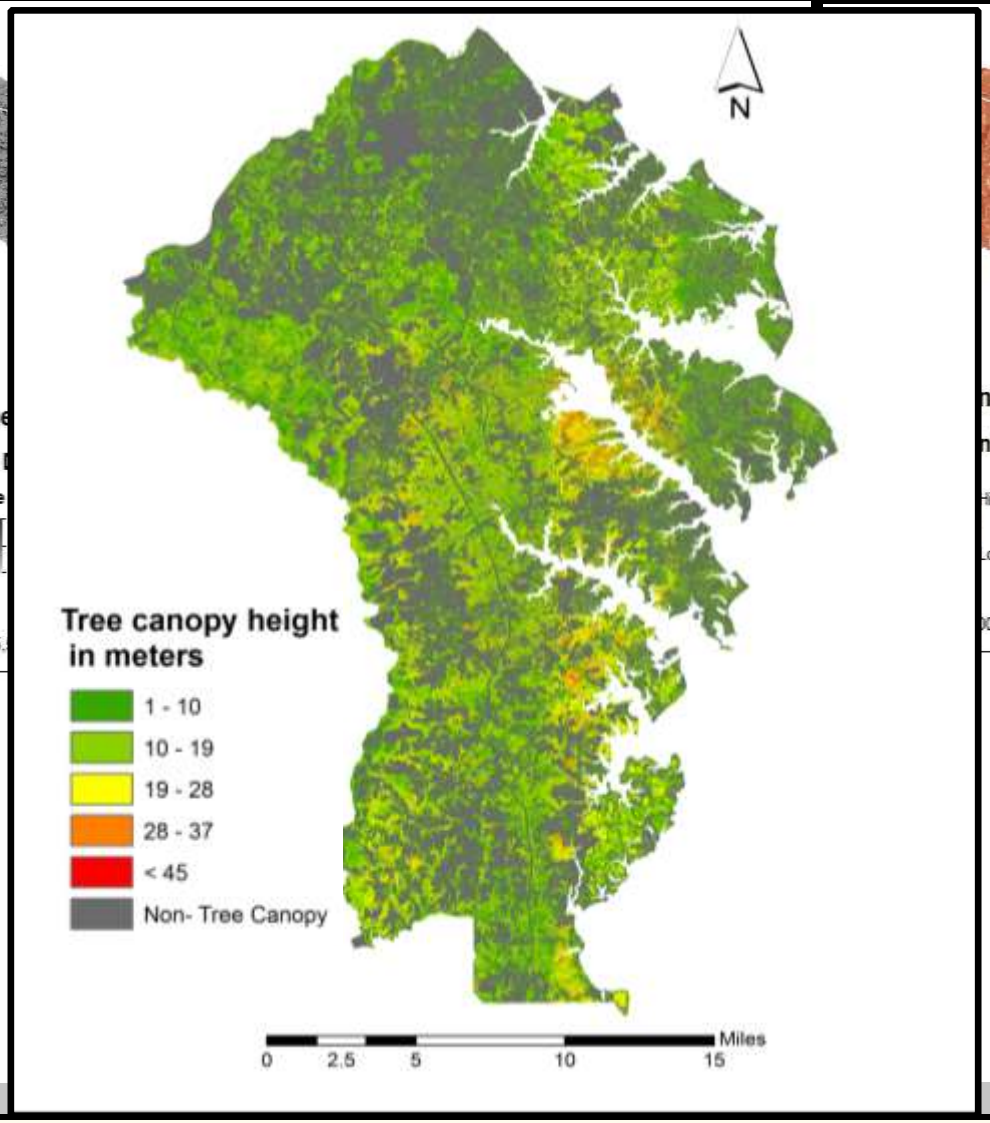
CMS National Max Ent (Saatchi et al.)	CMS Local BMA (Dubayah et al.)	NBCD (Kellendorfer,et al.)	FIA –based (Wilson et al.)
Resolution 0.022˚	Resolution 30 m	Resolution 30 m	Resolution 250 m

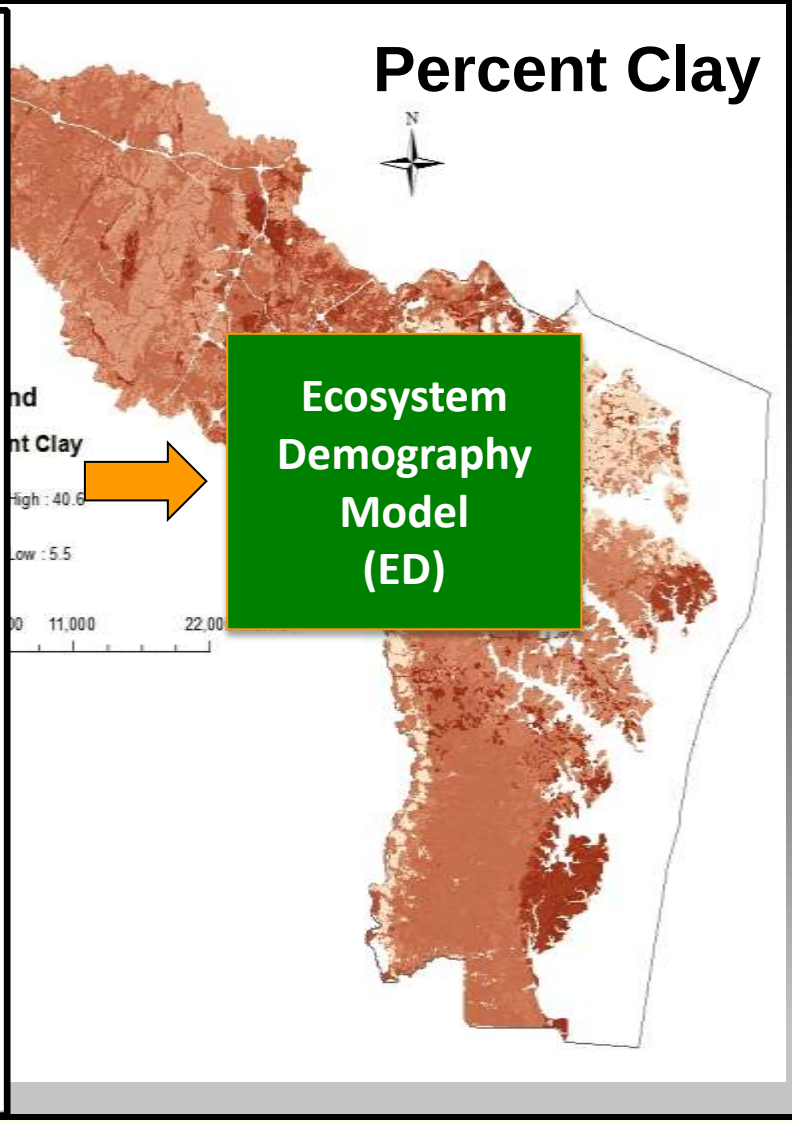


Methodological Approach

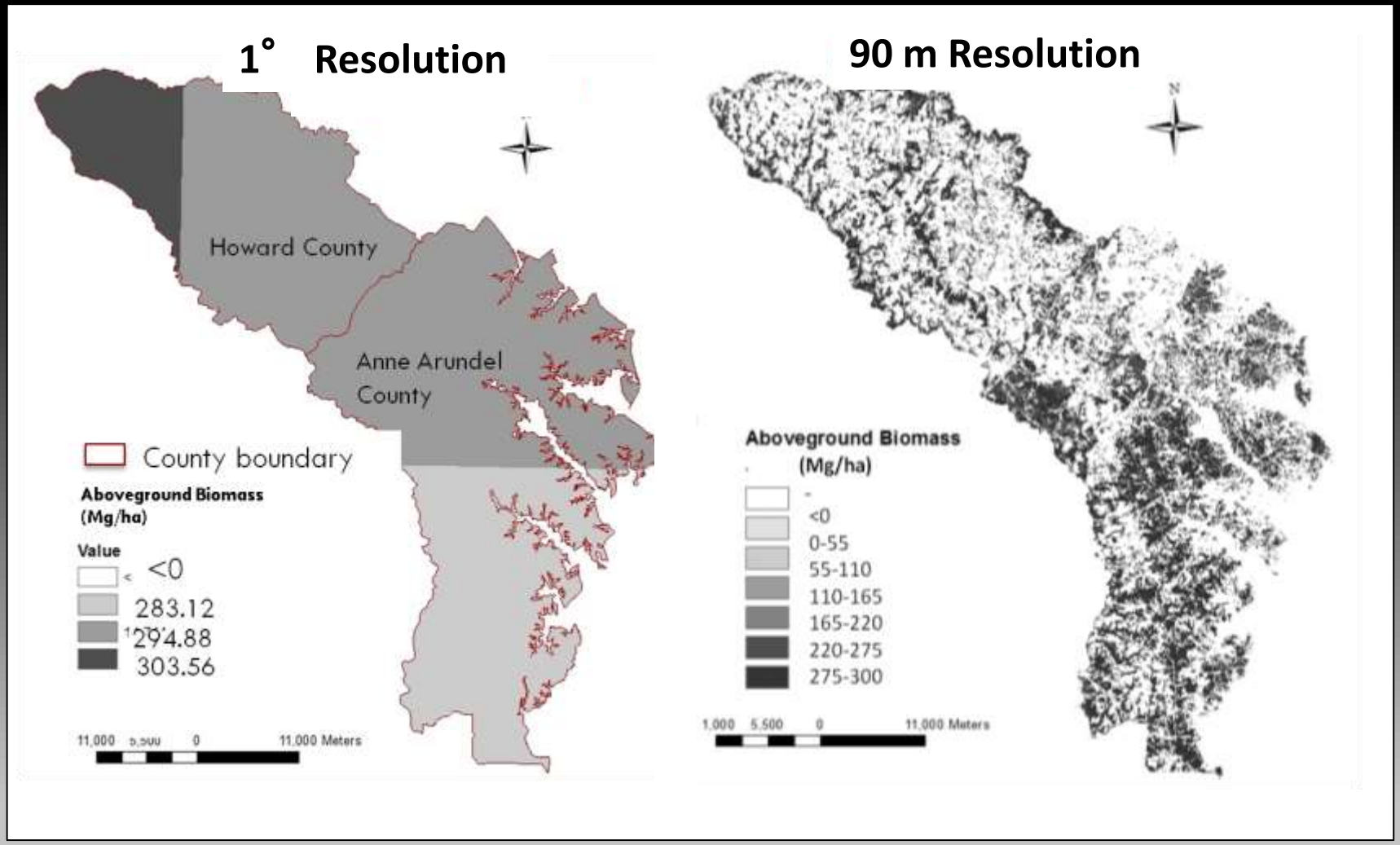


Prognostic Ecosystem Modeling





ED Model Results



CMS Phase 2 Activities

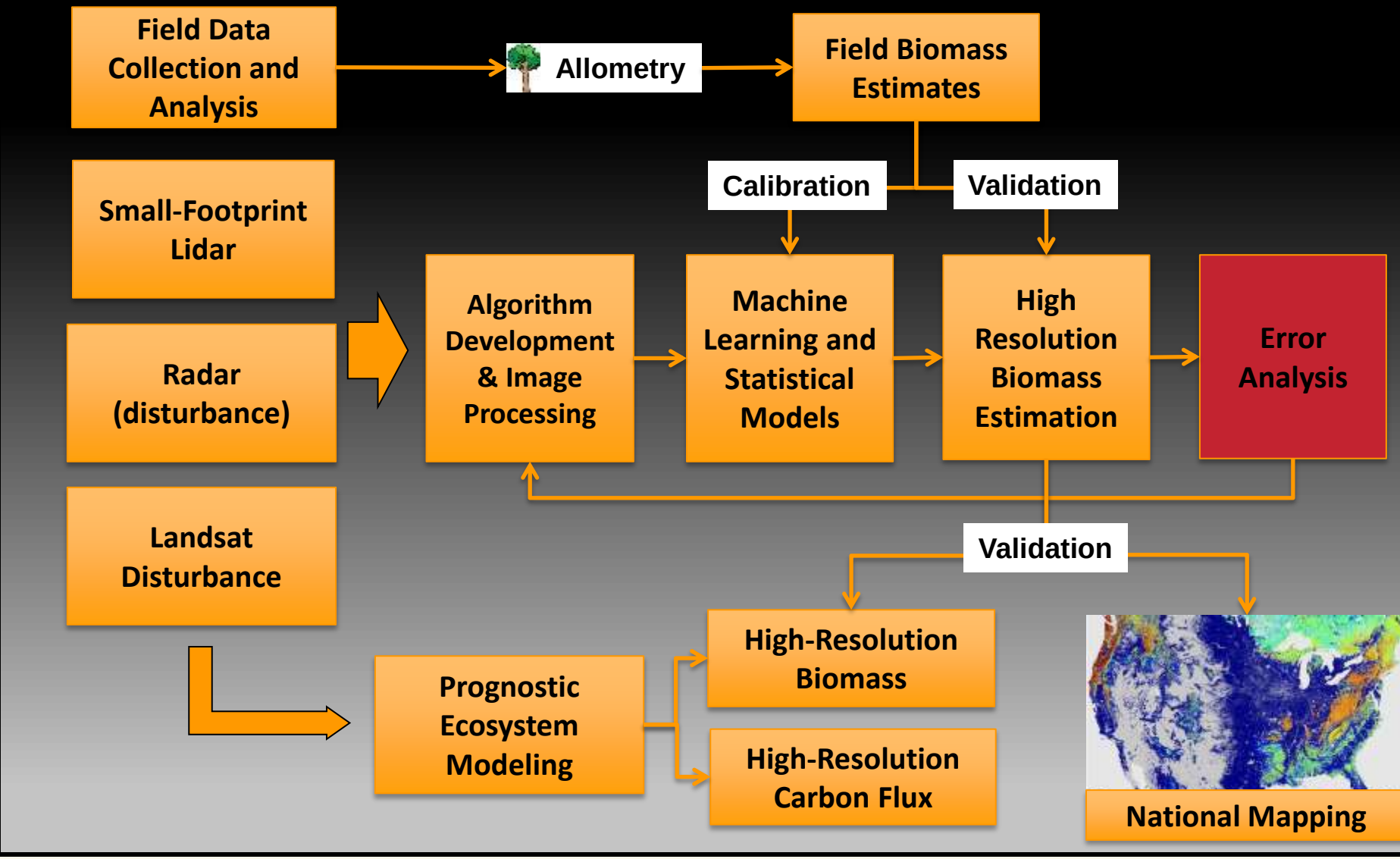
- **NASA awarded new and continued projects**
  - **18 month duration**

"Carbon Monitoring. -- Of the funds provided within the earth science research and analysis activity, the Committee recommends $10,000,000 to continue efforts for the development of a carbon monitoring system initially funded in fiscal year 2010. The majority of the funds should be directed toward acquisition, field sampling, quantification and development of a prototype Monitoring Reporting and Verification [MRV] system which can provide transparent data products achieving levels of precision and accuracy required by current carbon trading protocols.

Maryland CMS Phase 2 Elements

- Expand from 2 to 24 counties (entire state)
- Carbon modeling using ED model
- New field data collection
  - UMD
  - USFS
- Demonstration of new lidar technology
- Demonstration of new data visualization and delivery system
- County and State agency outreach

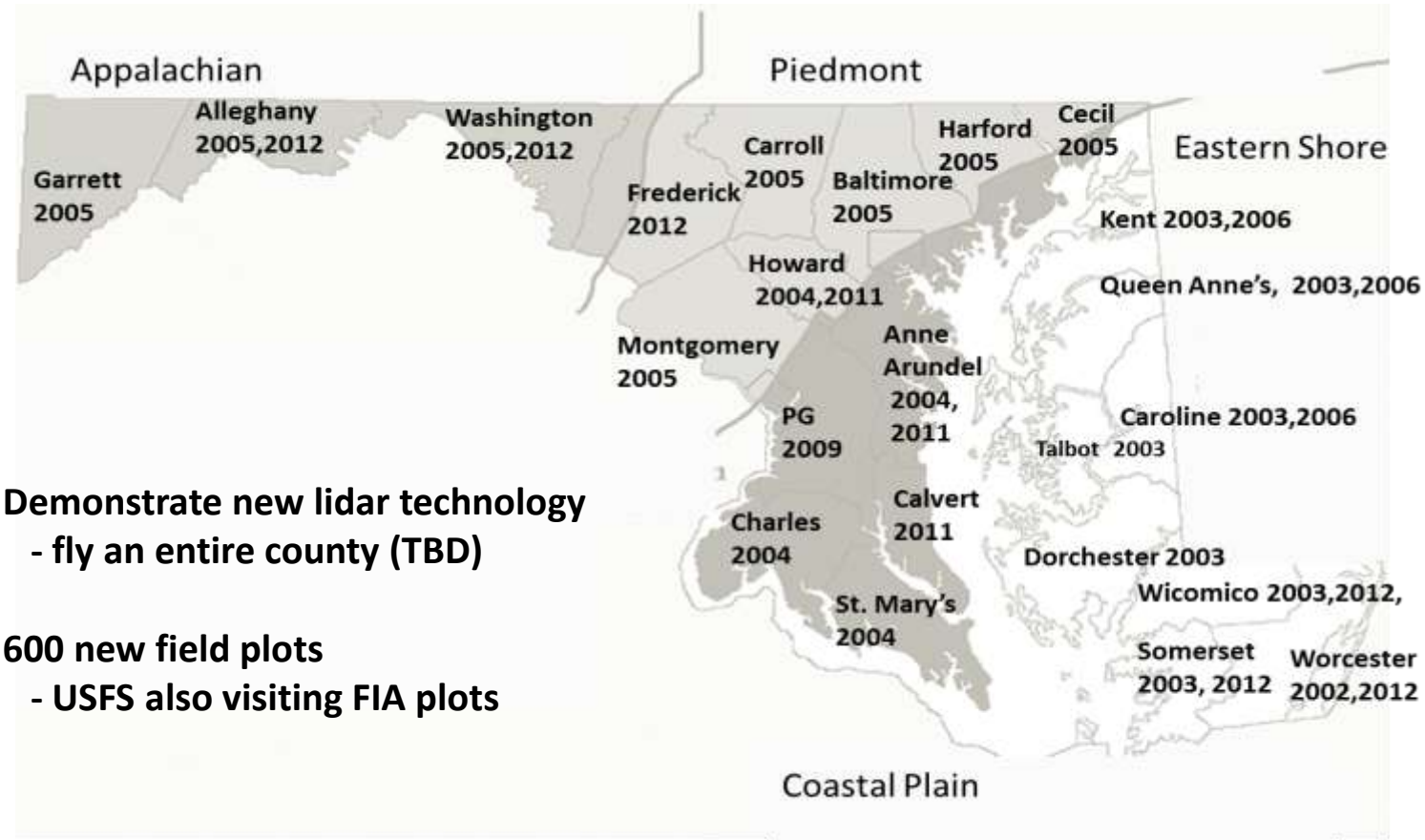
Methodological Approach



Partners

- USFS (Rich Birdsey)
  - Revisit FIA plots
  - Resolve forest/non-forest ambiguities
  - Explicit spatial error uncertainty
- University of Vermont (Jarlath O'Neill Dunne)
  - Forest/non-forest 1 m map of entire state
  - Bare earth and canopy height models
- Sigma Space
  - New lidar acquisition using single-photon lidar
- GeoDigital Inc.
  - Demonstration of Grid^Intel system

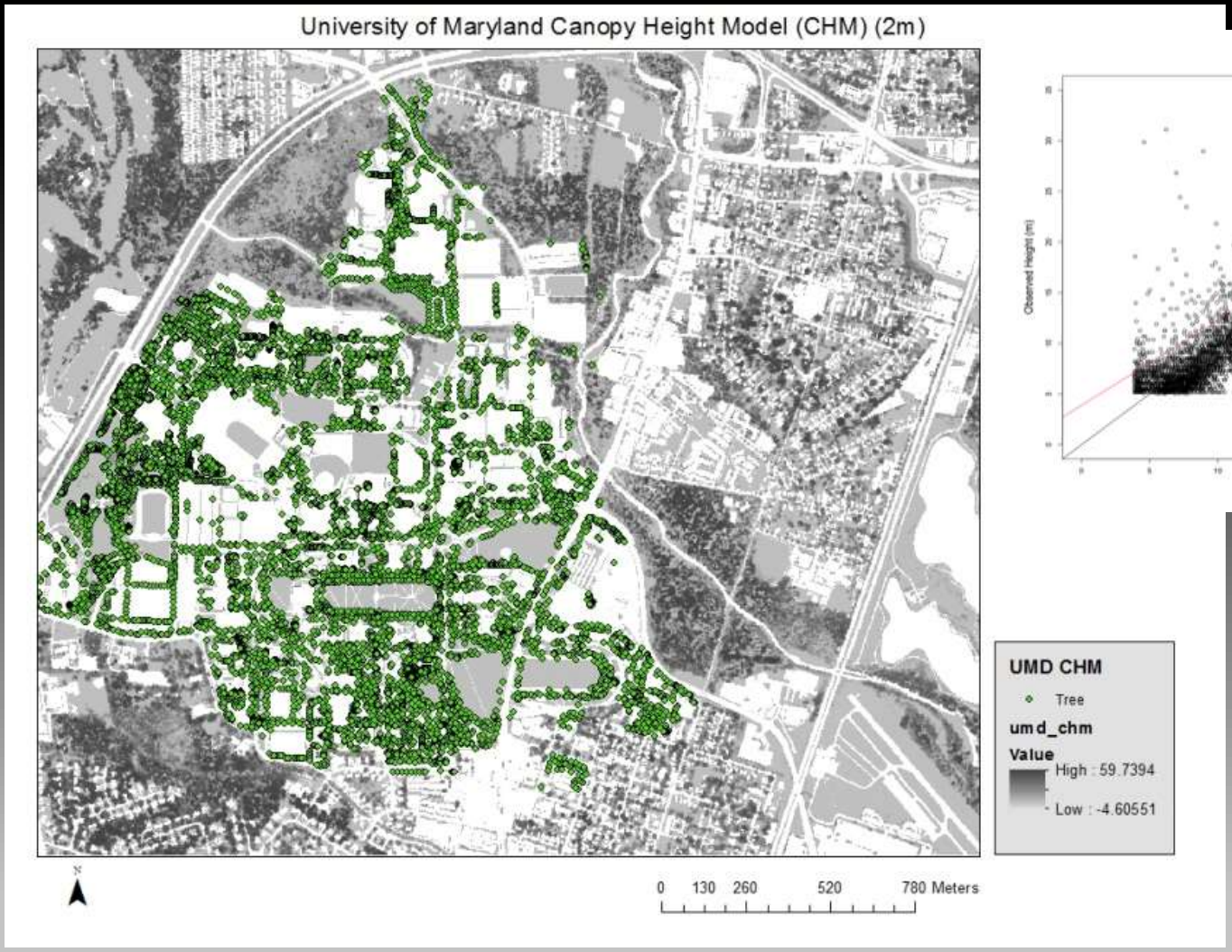
State Lidar and Field Data

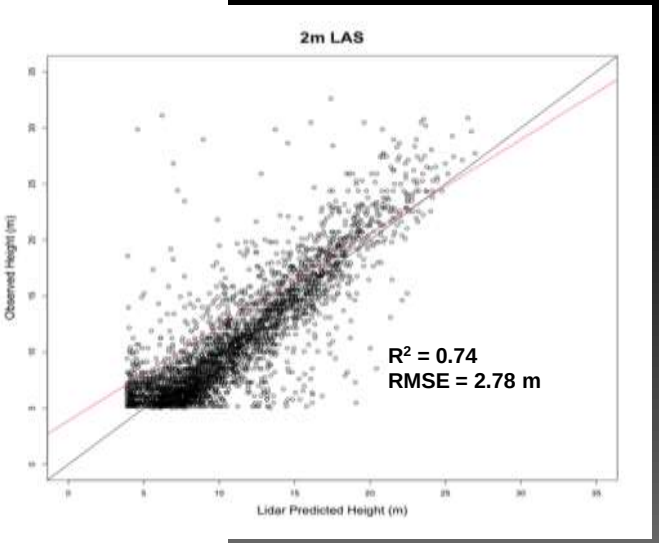


Demonstrate new lidar technology
- fly an entire county (TBD)

600 new field plots
- USFS also visiting FIA plots

University of Maryland, PG County

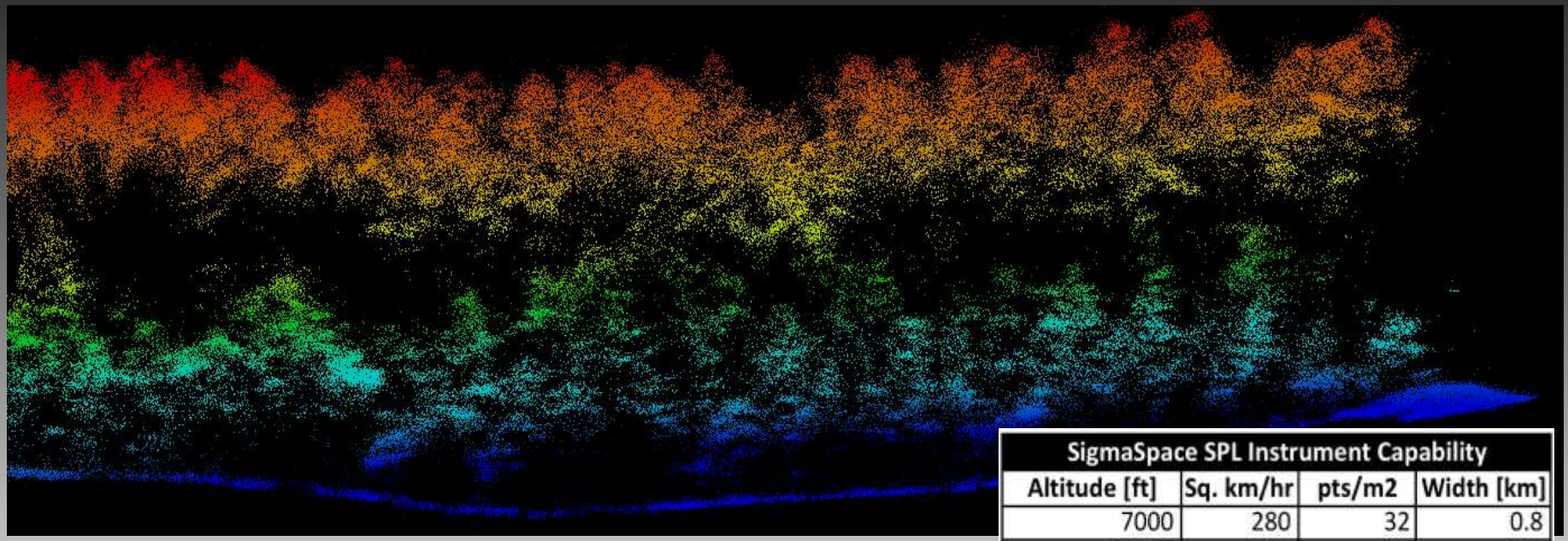




University Park, MD

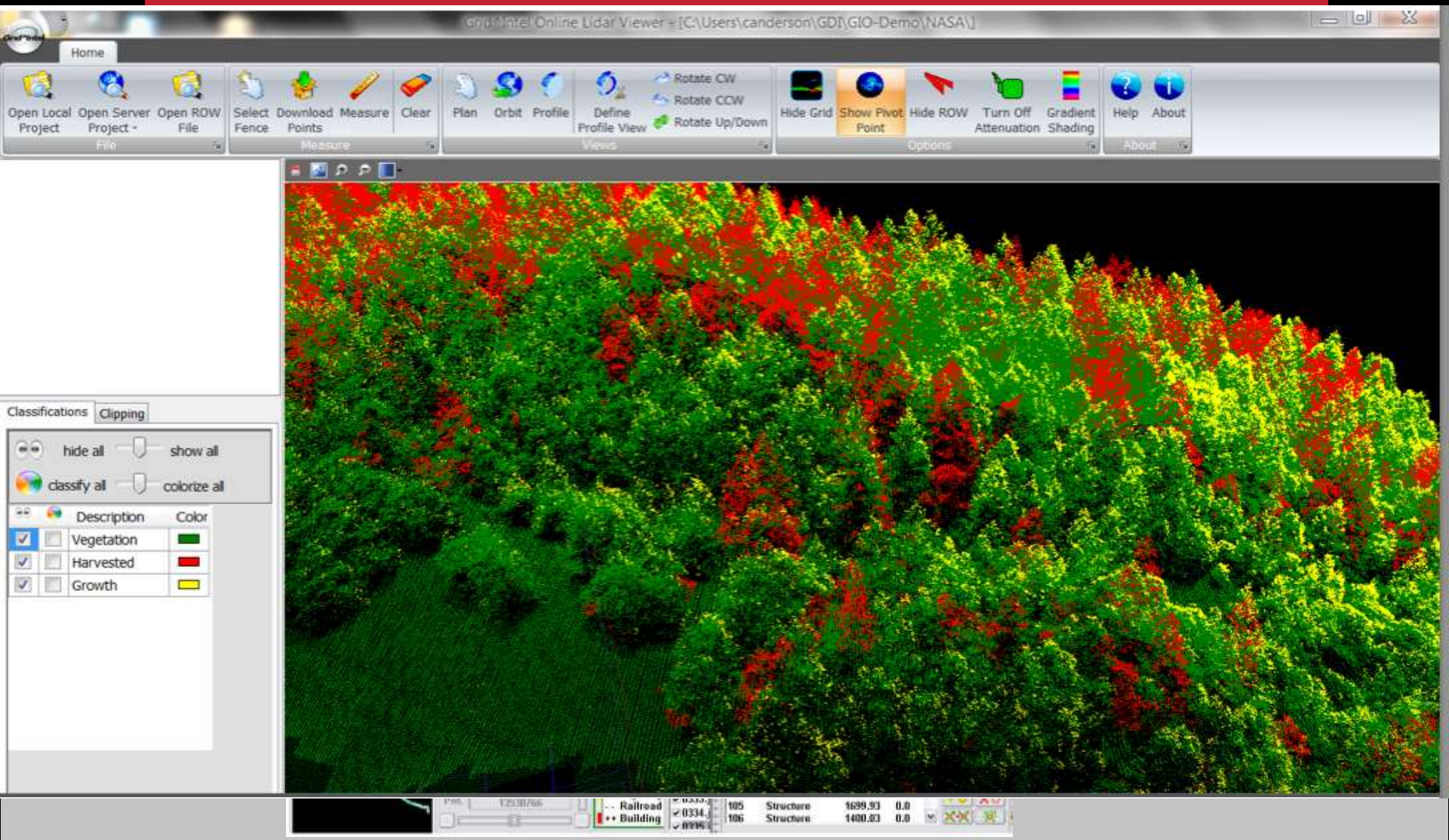
Single Photon Lidar

- Sigma Space developed mid-altitude single photon lidar
  - Visible wavelength, wide-swath
  - First large scale demonstration of single-photon lidar



SigmaSpace SPL Instrument Capability			
Altitude [ft]	Sq. km/hr	pts/m2	Width [km]
7000	280	32	0.8
10000	400	15	1.1
15000	600	7	1.6

Grid Intel Online (GIO)



Deliverables

- Tiled and mosaicked canopy height and forest/non-forest maps at 2 m and 30 m resolution
- AGBM maps at 30 m resolution with associated uncertainty maps
- ED-model based carbon and carbon-flux maps at 90 m resolution for Maryland
- ED-model maps of carbon sequestration potential for Maryland under various climate change scenarios
- SPL canopy height map for Alleghany County (?) and derived biomass
- Demonstration of a web-based data visualization and query system
- Assessment of main sources of error and proposed strategies for reducing errors in future deployment of an operational CMS.

County and State Outreach

- State of Vermont implement methodology for one county
- UMD will host one day workshop for county and state agencies
  - Describe data sets and methodologies
  - Provide framework for counties to replicate process
  - Provide free (open-source) software
- Actively seeking collaborations with interested local and state parties

Considerations and Conclusions

- Existing data sets useful for biomass mapping in the U.S. at local scales
  - Requires lidar coverage and field data
  - RMSE high (~33%) at 30 m scale
- Rapid field-survey methods may be appropriate
  - No statistical difference between FIA-style plots and variable radius plots (p=0.05)
- Choice of statistical method not critical
  - True representation of spatial variability challenging
  - Continued development of spatial models and error frameworks

Considerations and Conclusions

- Is high spatial-resolution mapping required?
  - For validation and valuation
  - Maps can be misleading
    - Errors swamp variability in adjacent pixels
    - Effective resolution *coarser* than 30 m
- County-based lidar data sets reasonable basis of local CMS efforts
  - USGS national lidar mapping
  - Continued fusion of NASA observations