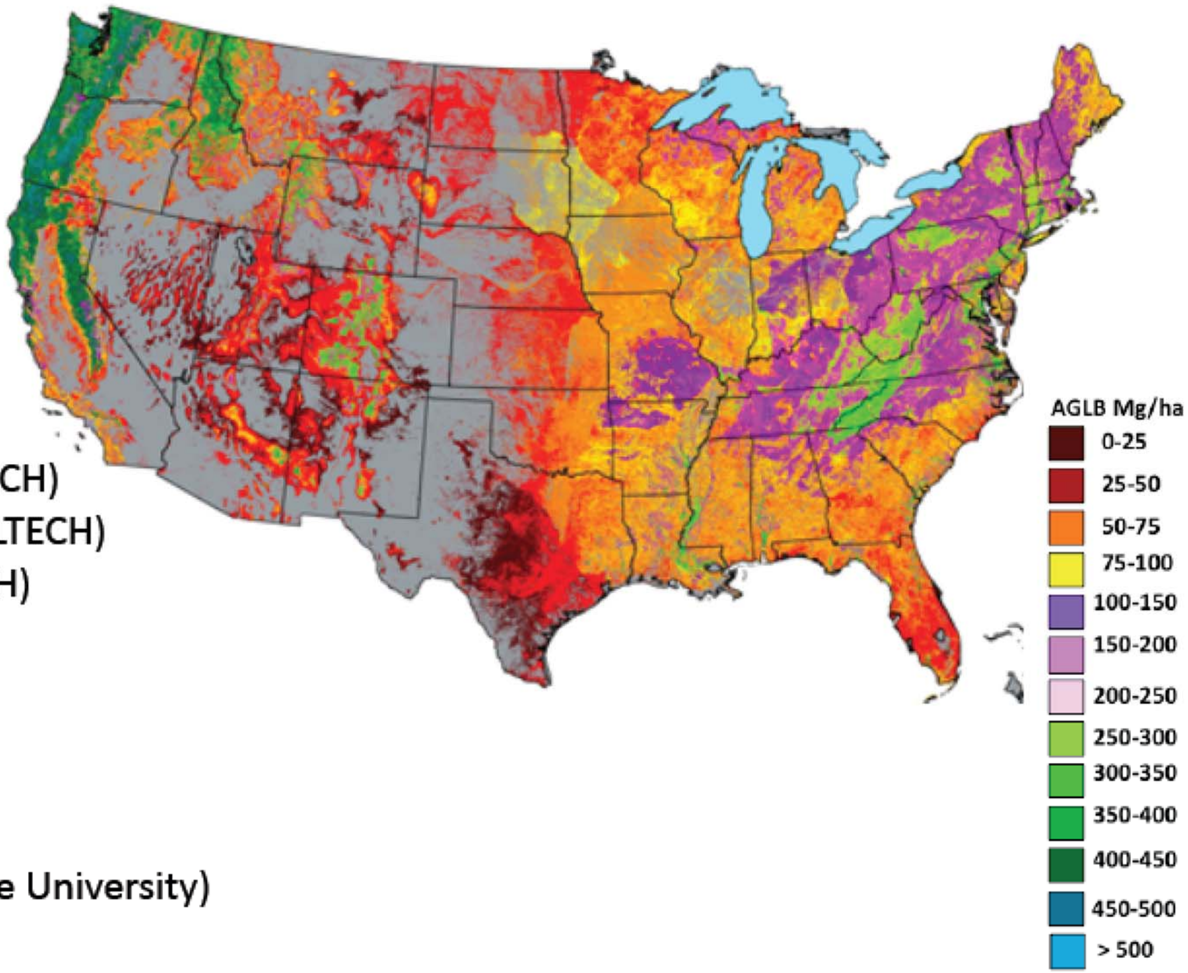
Biomass Pilot Project

A Specially Refined and Temporally Constrained Approach to Estimate Regional and Continental Scale Vegetation Carbon Stock



Contributors

S. Saatchi (JPL/CALTECH)
A. Fore (JPL/CALTECH)
Y. Yu (JPL/CALTECH)
M. Nuemann (JPL/CALTECH)
Bruce Chapman (JPL/CALTECH)
A. Freeman (JPL/CALTECH)
R. Nemani (NASA/ARC)
S. Ganguly (NASA/ARC)
P. Votava (NASA/ARC)
W. Wang (NASA/ARC)
G. Zhang (NASA/ARC)
M. Lefsky (Colorado State University)
S. Healey (USDA, FS)

CMS Team Members

NASA/JPL/CALTECH

Alexander Fore

Yifan Yu

Bruce Chapman

Maxim Neumann

Brian Hawkins

Ziad Haddad

Sassan Saatchi

NASA/ARC

Sangram Ganguly

Petr Votava

Weile Wang

Gong Zhang

Rama Nemani

NASA/GSFC

Jeff Masek

Compton Tucker

Forrest Hall

Ross Nelson

Bruce Cook

Colorado State University

Michael Lefsky

University of Maryland

Ralph Dubayah

George Hurtt

Niara Pinto

USDA Forest Service

Richard Birdsey

Sean Healey

Kristofer Johnson

Carbon Monitoring System
Biomass Pilot Project

Objectives:

❖ **Develop prototype data products of national biomass (and carbon storage/ change) that can be assessed with respect to how they meet the nation's need for monitoring (also reporting and verification) of carbon inventories.**

❖ **Demonstrate our readiness to produce a consistent global biomass/carbon stock distribution using the existing *in situ* and satellite observations to meet the monitoring (MRV) requirements.**

Outline:

❖ National Data Processing Activities

❖ Development of Methodology

❖ Regional Results and Products

❖ Validation and Uncertainty Analysis

Terrestrial Biomass Pilot Project

Goal:

Provide geospatially explicit, consistent estimates of aboveground terrestrial vegetation biomass and carbon storage for the U.S. by combining advanced satellite products with ground observations and evaluate how well these estimates meet the nation's need for monitoring carbon storage and changes in carbon storage.

Objectives:

- **Develop prototype data products of national and global biomass (and carbon storage/change) that can be assessed with respect to how they meet the nation's need for monitoring (also reporting and verification) of carbon inventories.**
- **Demonstrate our readiness to produce a consistent global biomass/ carbon stock distribution using the existing *in situ* and satellite observations to meet the monitoring (MRV) requirements.**

Terrestrial Biomass Pilot Project

<u>Objectives for Near-Term (first ~18 mos.)</u>:

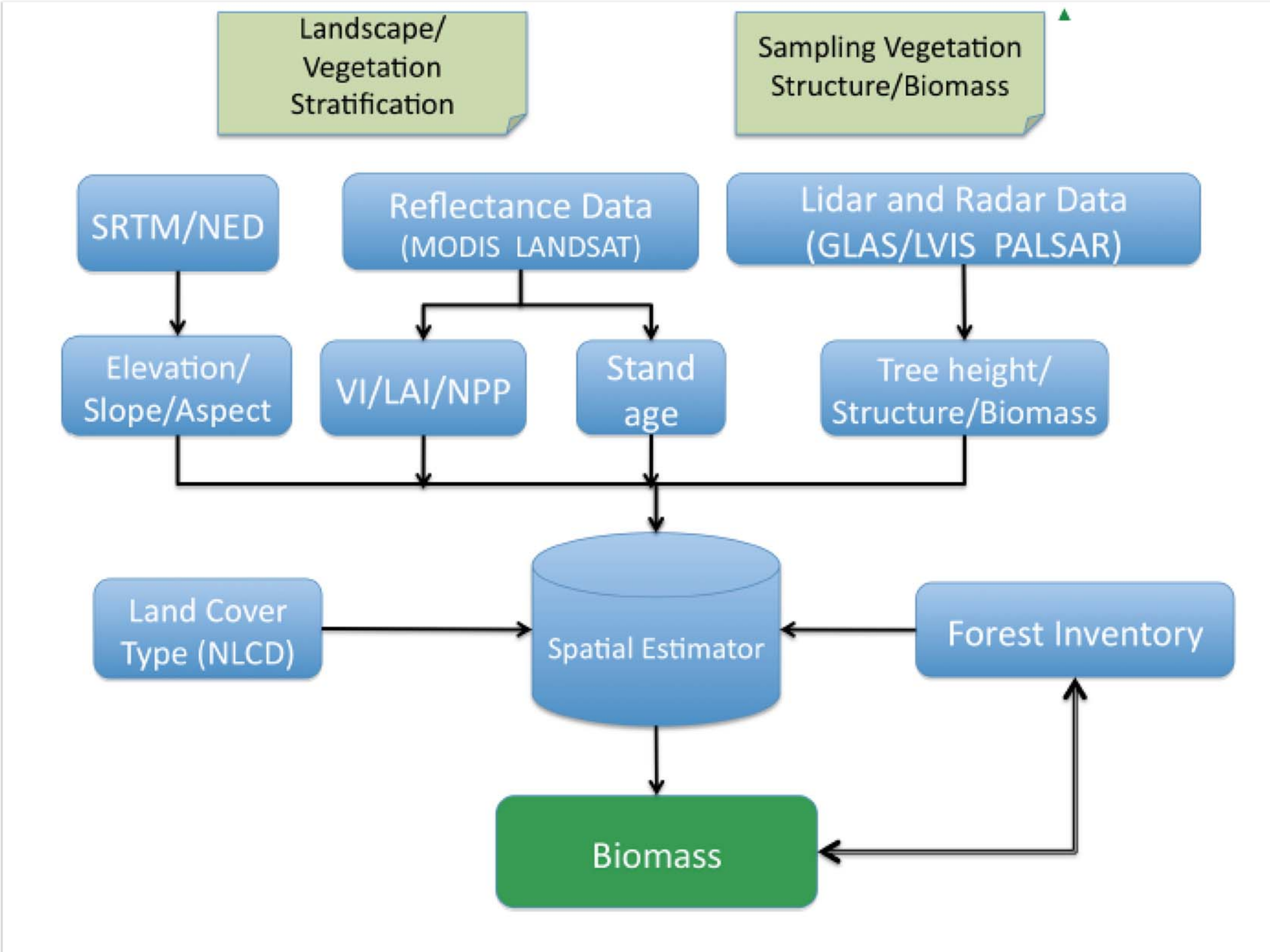
- Estimate aboveground biomass by combining data from several different satellites with ground data.
- Assess the accuracy of derived estimates by using Forest Inventory and Analysis (FIA) and other high-quality forest carbon/biomass inventory data.
- Produce a continental U.S. map of above-ground biomass, fully mapping errors and uncertainties
- Evaluate the likely improvements that could be achieved using data from future missions.
- Demonstrate how well biomass can be quantified with high-quality remotely sensed data taken at fine spatial resolution for selected sites representative of U.S. forest types and conditions.
- Develop the steps for a global forest biomass product.

→ A best possible product with what we have available now . . .

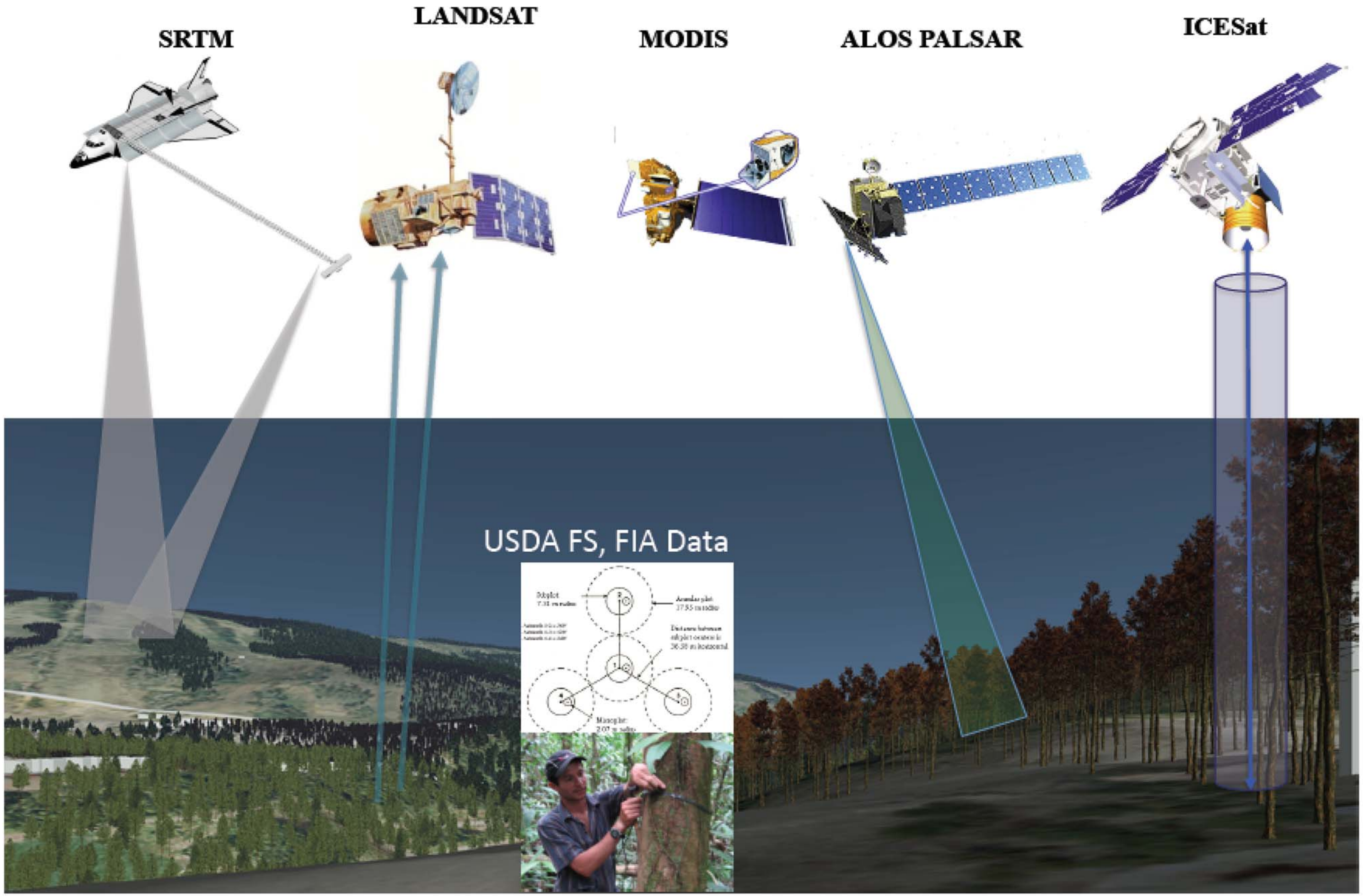
Mapping Biomass

- Forest biomass varies over the landscape as a result of several factors: Production (photosynthesis) Consumption (respiration), mortality, recruitment, harvest, and herbivory.
- Forest biomass changes as a result of factors such as: succession, silviculture, harvesting, clearing, natural disturbance (pest, fire, wind, etc.), and climate pollutants.
- Forest biomass is a useful measure to assess variations of structural and functional attributes over a wide range of environments that can be used in models.
- Environmental variables (soil, climate, and topography) do not predict forest biomass accurately.
- Systematic statistically designed sampling can provide regional and national scale carbon stock and changes, but it cannot be applied everywhere (e.g. tropics) and as frequently as needed.

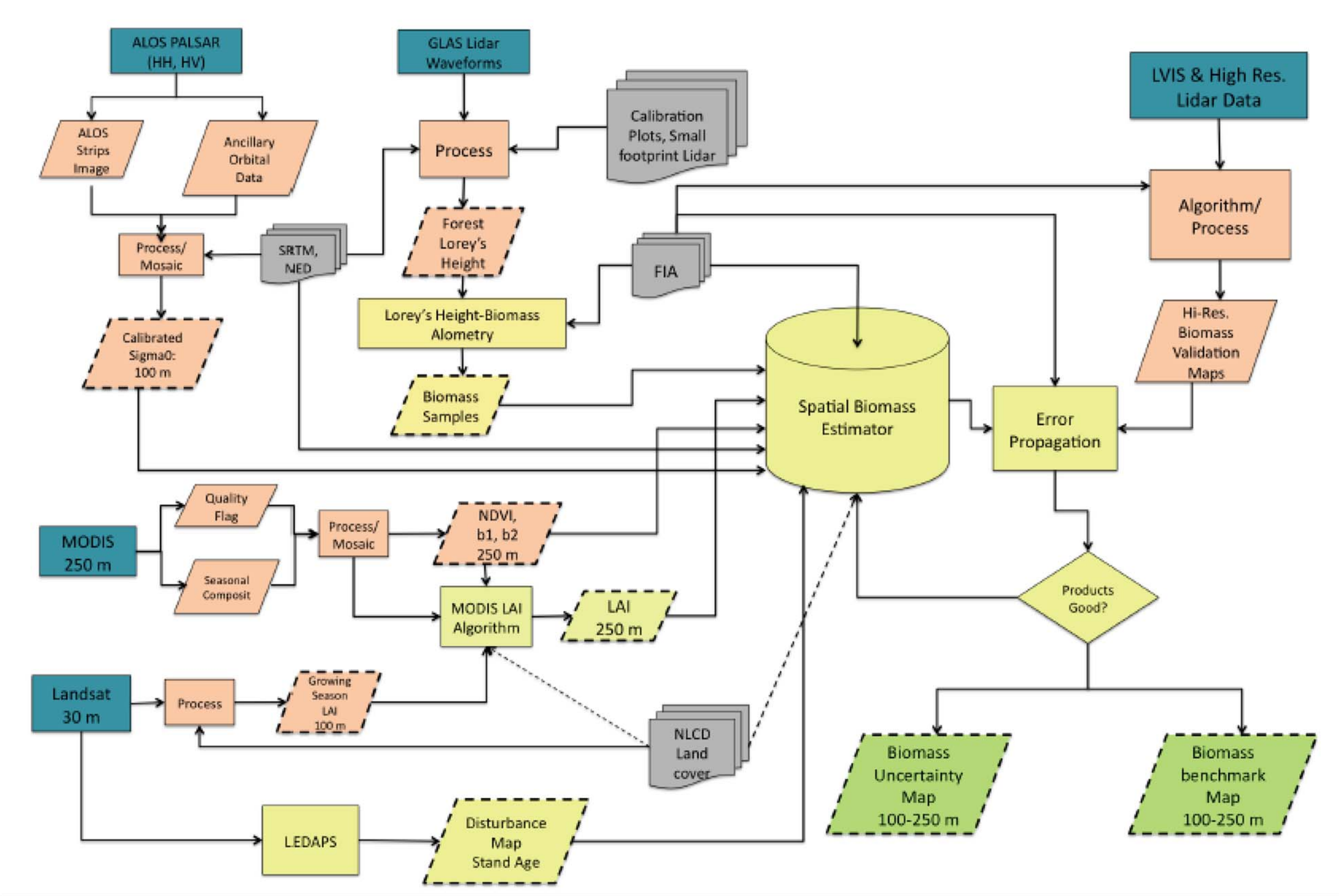
Terrestrial Biomass Pilot Project: Methodology



Satellite and In Situ Observations

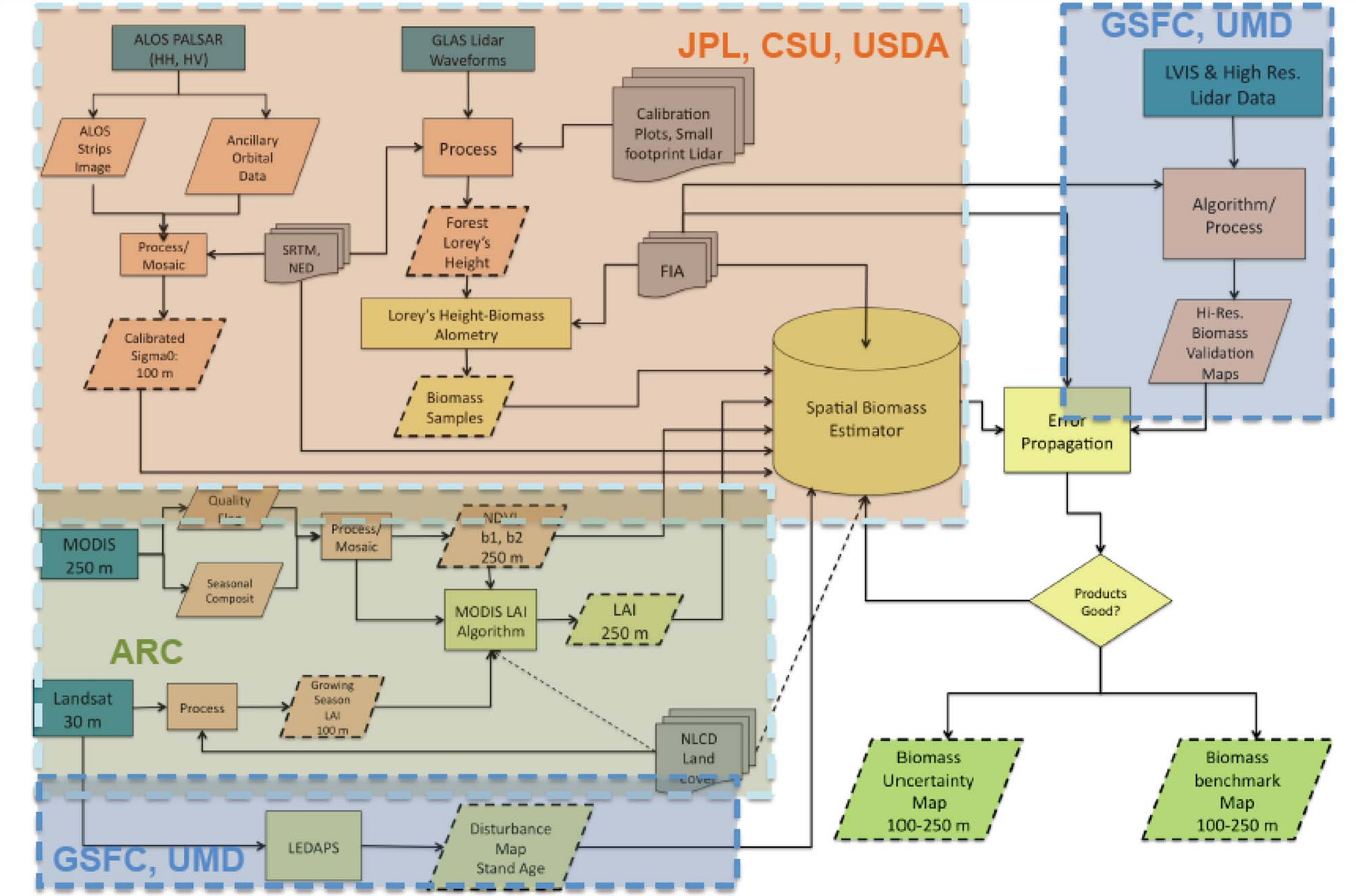


Work Plan



ALOS PALSAR (HH, HV)
GLAS Lidar Waveforms
Calibration Plots, Small footprint Lidar
LVIS & High Res. Lidar Data
ALOS Strips Image
Ancillary Orbital Data
Process
Algorithm/ Process
Process/ Mosaic
SRTM, NED
Forest Lorey's Height
FIA
Lorey's Height-Biomass Alometry
Hi-Res. Biomass Validation Maps
Calibrated Sigma0: 100 m
Biomass Samples
Spatial Biomass Estimator
Error Propagation
MODIS 250 m
Quality Flag
Seasonal Composit
Process/ Mosaic
NDVI, b1, b2 250 m
Products Good?
MODIS LAI Algorithm
LAI 250 m
Landsat 30 m
Process
Growing Season LAI 100 m
NLCD Land cover
Biomass Uncertainty Map 100-250 m
Biomass benchmark Map 100-250 m
LEDAPS
Disturbance Map Stand Age

Work Plan



JPL, CSU, USDA
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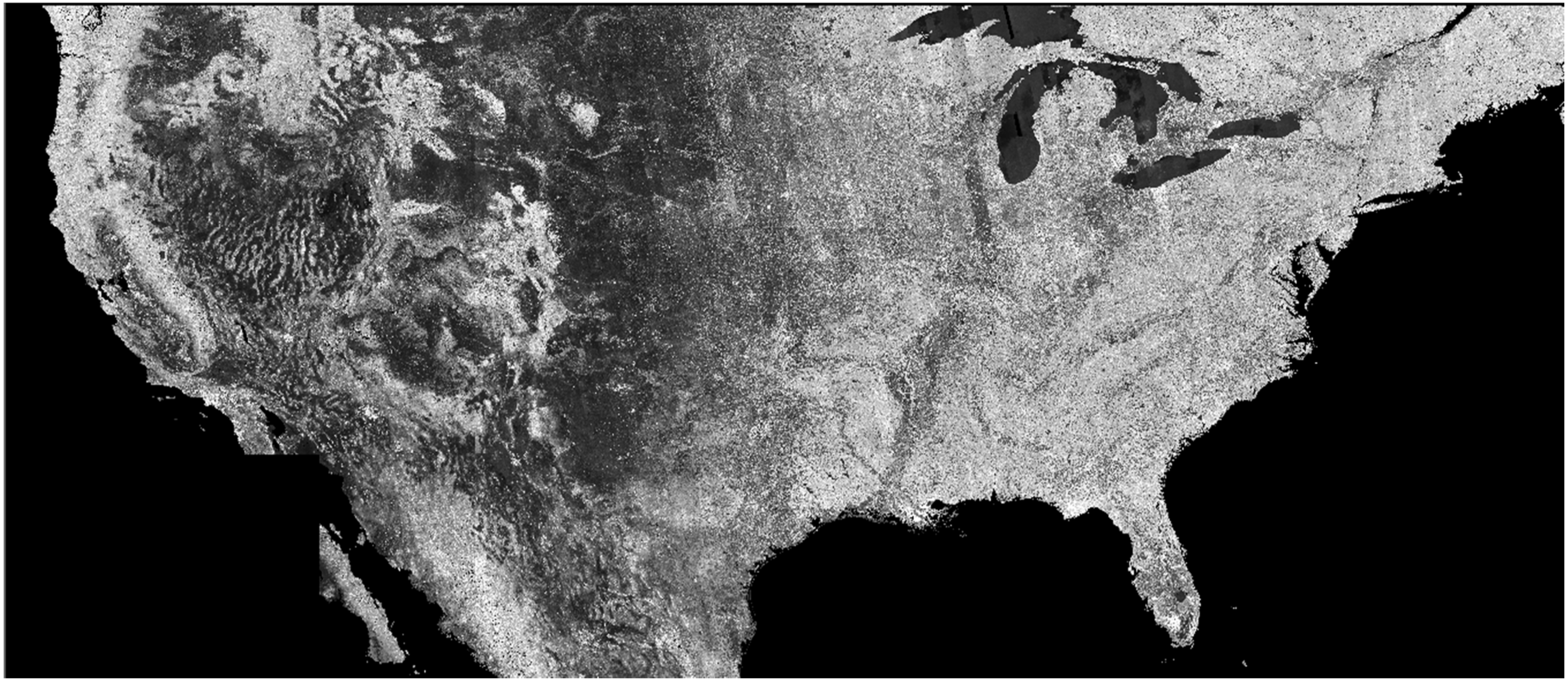
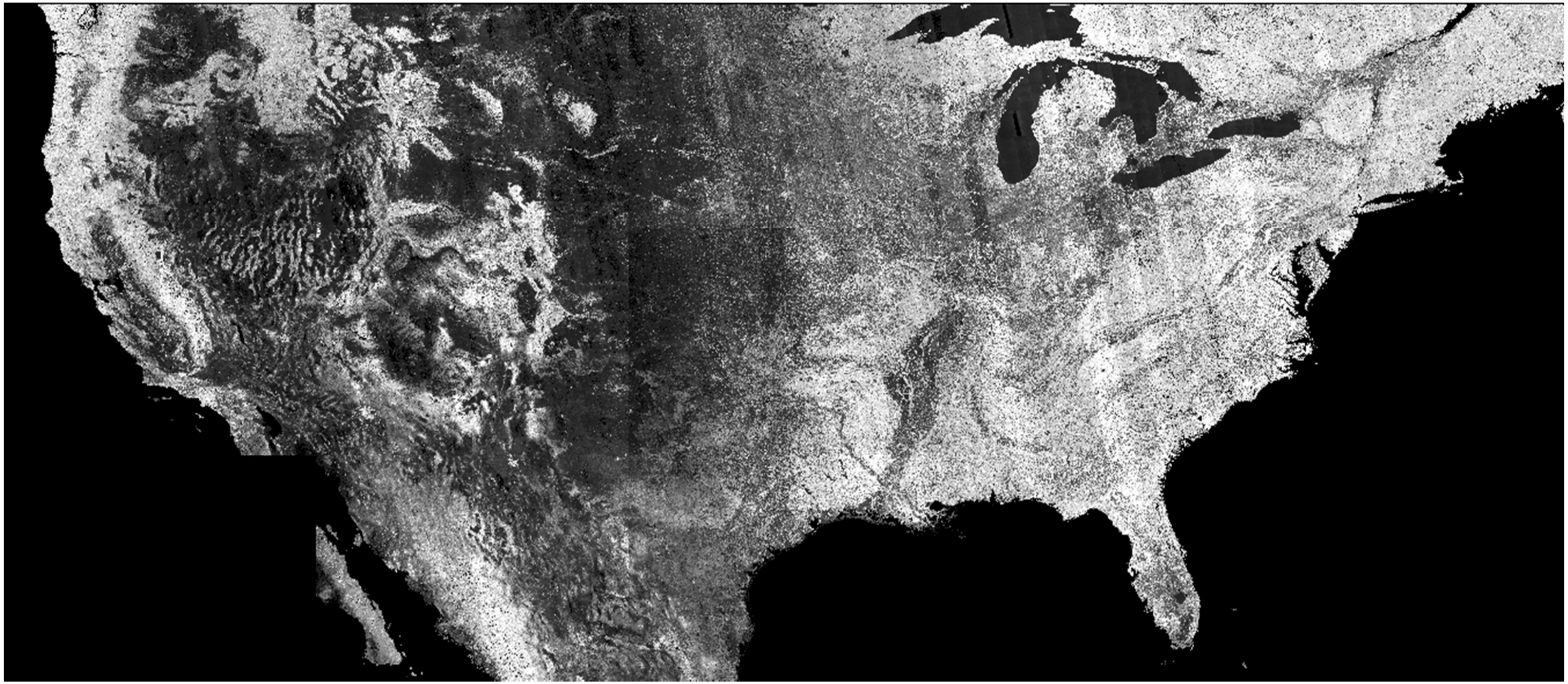
Continental US
PALSAR HH image mosaic



HV image mosaic

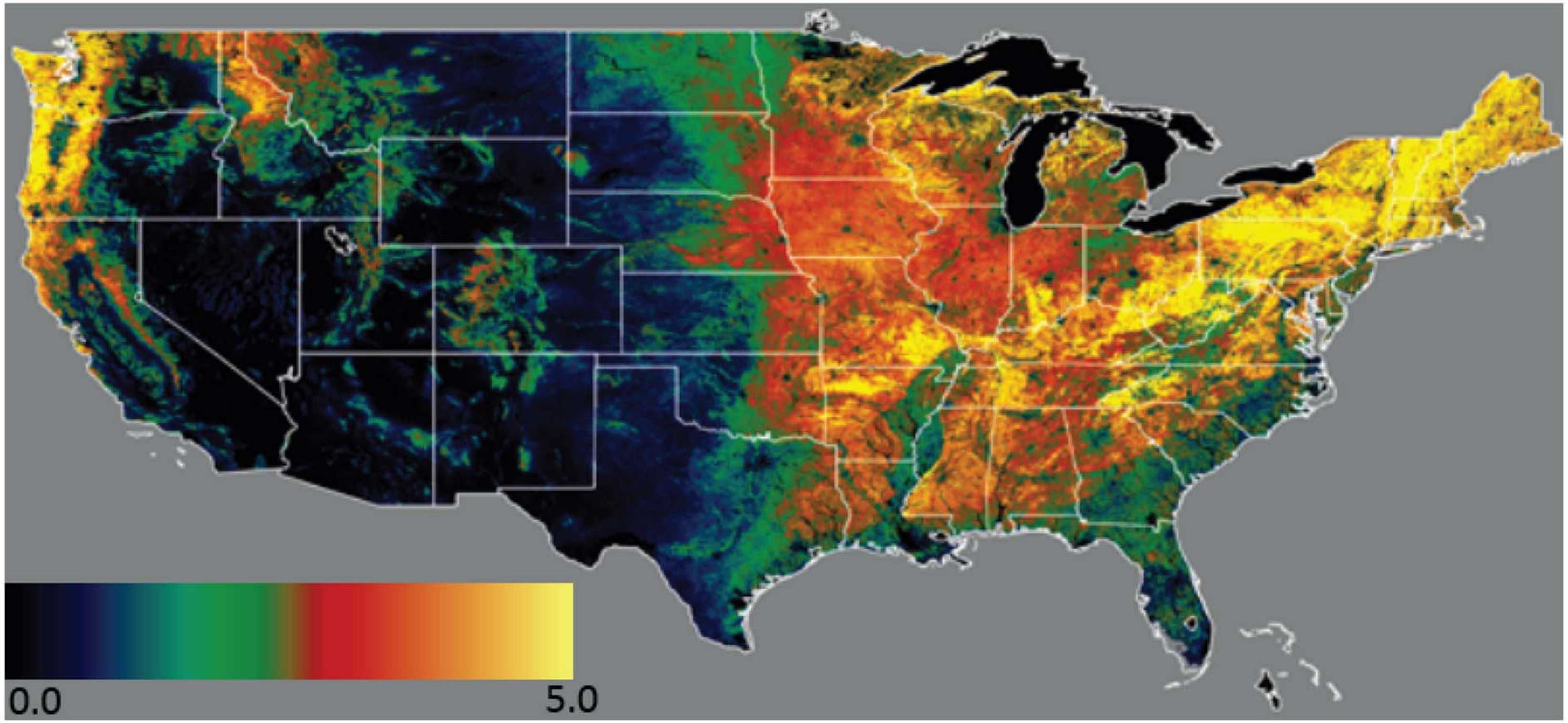


Mosaic Stats

- 396 JAXA path images (segmented by UTM tile)
- 830 ASF frame images (much smaller in size)
- 23% of HH image strips manually adjusted by an average of -0.36 dB
- 34% of HV image strips manually adjusted by an average of -0.62 dB

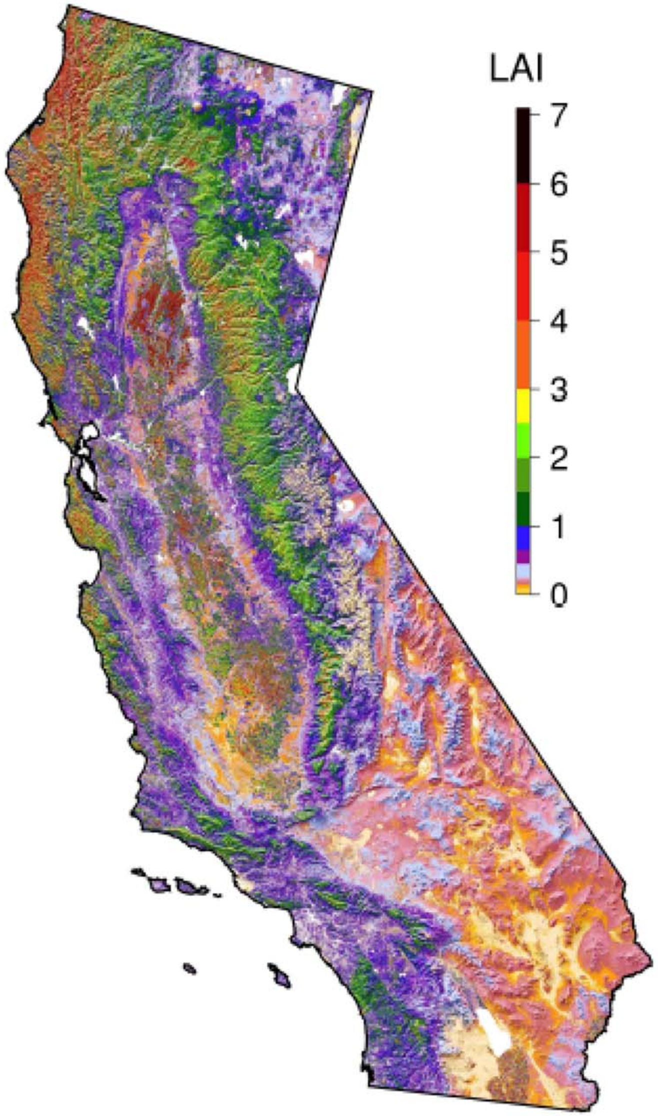
250-m LAI derived from MODIS

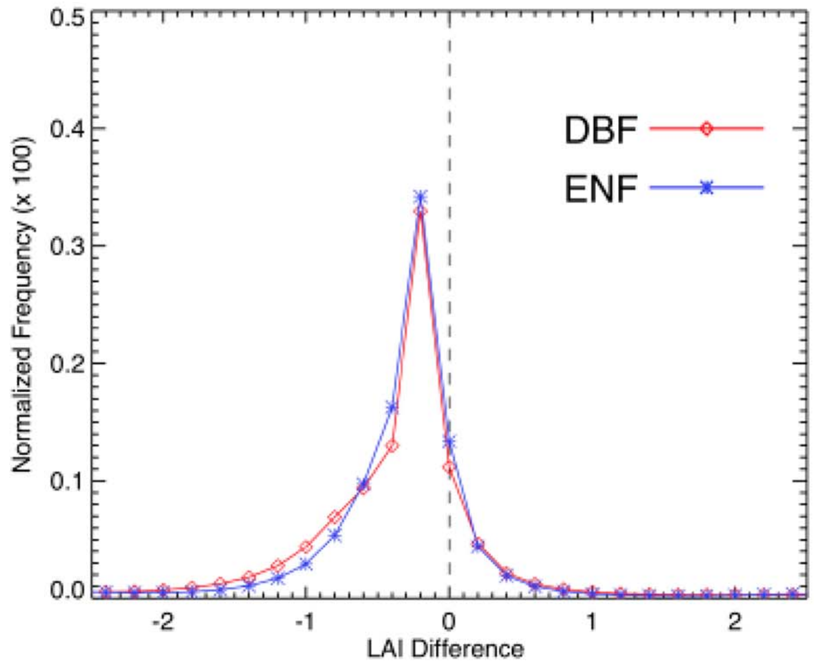
- MODIS monthly LAI Mosaic is provided at 250 m resolution
- Three years (2004-2006) of MODIS data were processed to improve image quality
- LAI estimation was implemented using the NLCD land cover map.



MODIS Summer Mean LAI (2004-2006)

30-m LAI derived from Landsat and NLCD

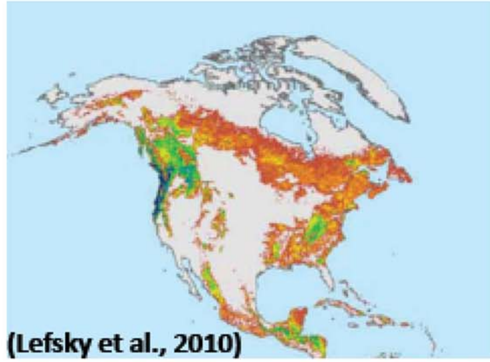




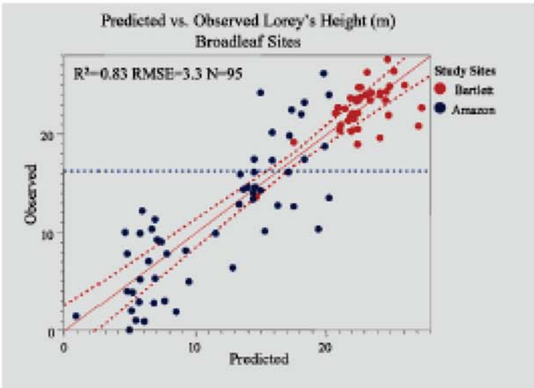
LAI difference between a 3-band inversion and 2-band inversion for pixels classified as DBF and ENF for California. The NLCD 2001 map is used to classify the forest pixels.

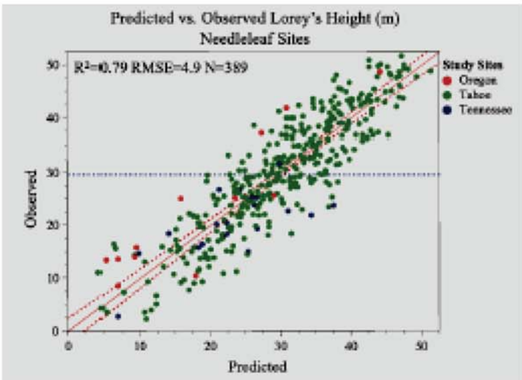
ICESAT GLAS Forest Height Metric

$$H_{lorey} = \frac{\sum_{i=1}^{N} BA_i h_i}{\sum_{i=1}^{N} BA_i}$$: basal area weighted height (crown weighted height)

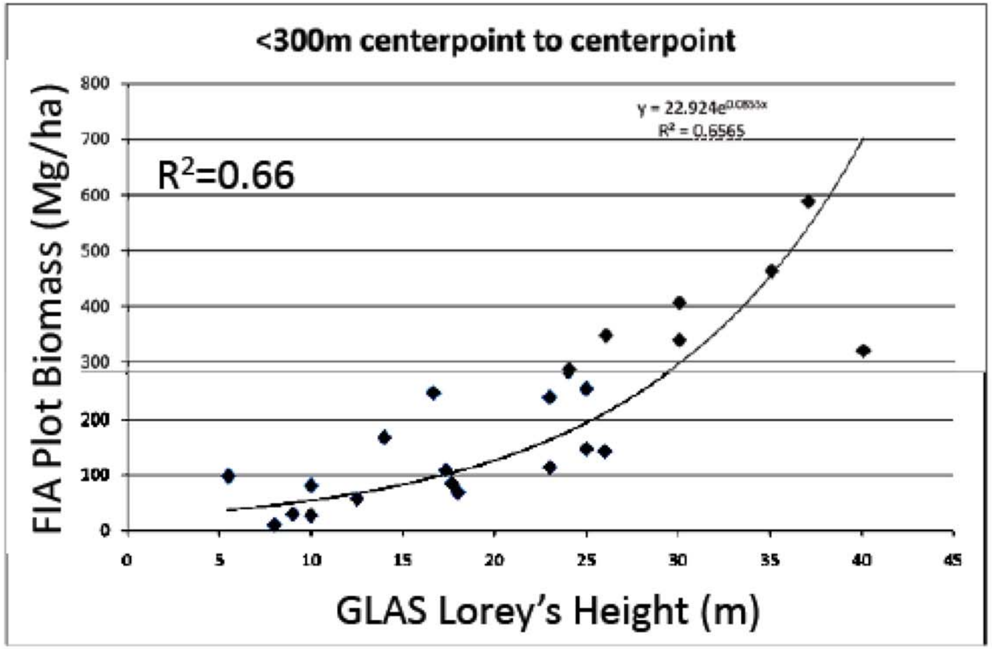


(Lefsky et al., 2010)





GLAS Validation (Sean Healey, USDA)

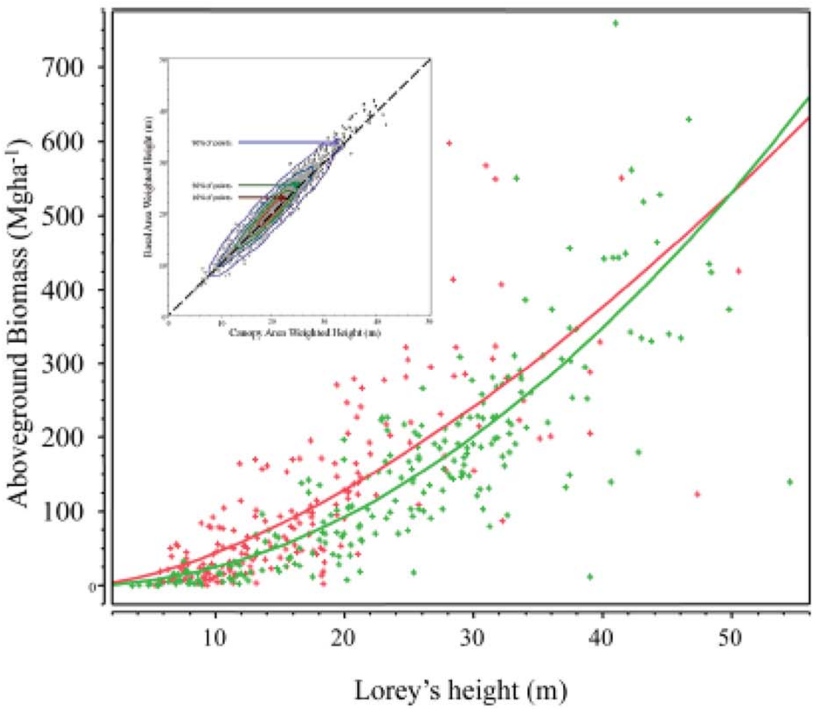


Lorey's Height Biomass Allometry

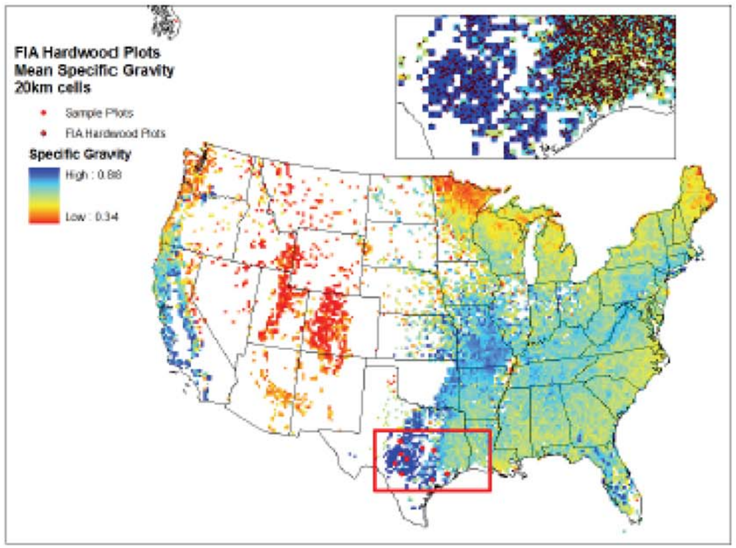
At this time, we are estimating aboveground biomass stratified by softwood and hardwood composition (for dominant individuals)

Lefsky et al. Unpublished

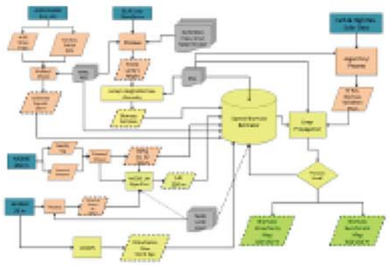
AGB (Softwood)=$0.3177*H^{1.898}$
AGB (Hardwood)=$1.179*H^{1.539}$

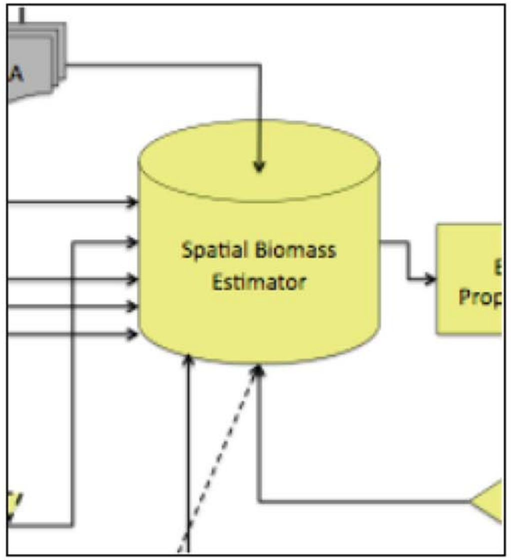


Wood Density Correction of Allometry



Spatial Biomass Estimator





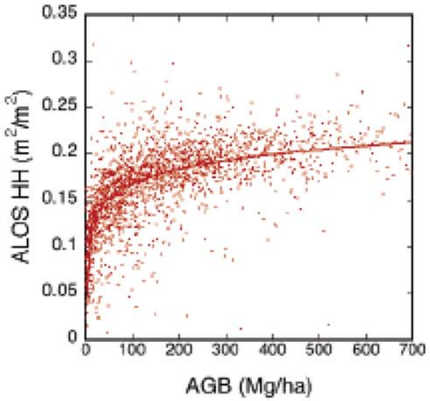
- Parametric Models:
  - Multivariate Regressions

    AGB = *f* (*VI, SAR, SRTM*)

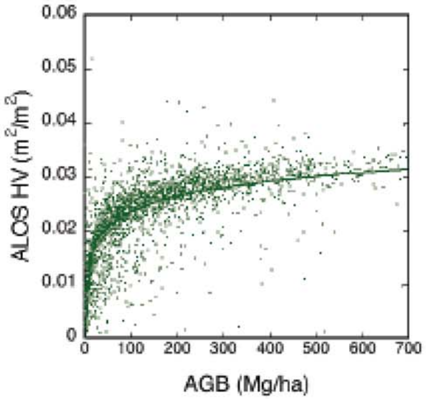
- Non Parametric Models:
  - Coloring by numbers (use of land cover maps)
  - **Image Segmentation Approach (Lefsky et al., 2010; Mitchard et al., 2011)**
  - **Decision Rule, Random Forest (Saatchi et al., 2007; Kellndorfer et al., 2010)**
  - **Maximum Entropy Approach (Saatchi et al., PNAS 2011)**

Parametric Model

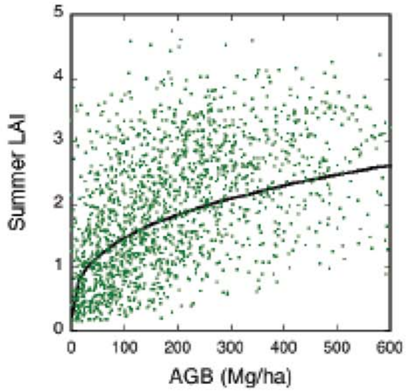
PALSAR HH



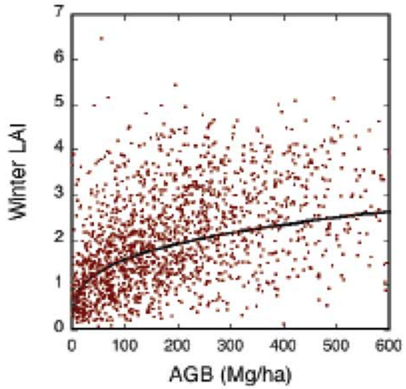
PALSAR HV

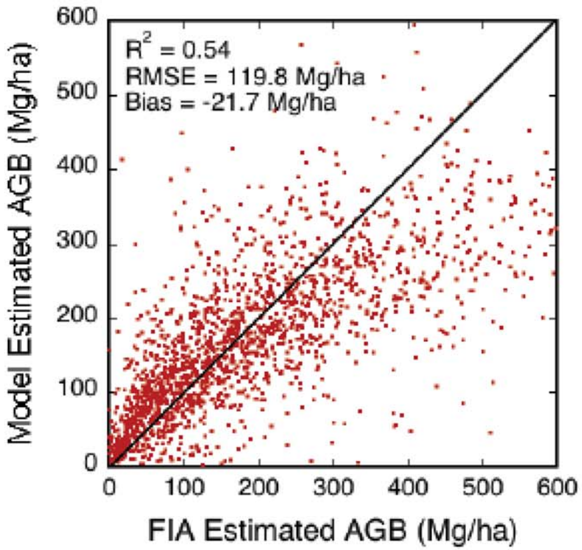


LAI Summer



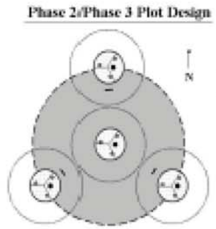
LAI Winter





$$AGB^{\lambda} = a_0 + S\sum_{i=1}^{N} a_i X_i^{\beta_i}$$

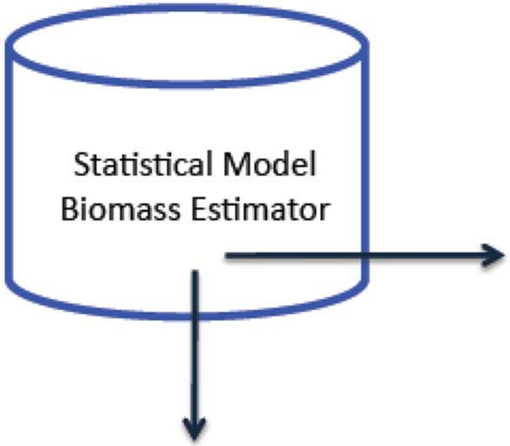
$$X = \{HH, HV, SRTM - NED, LAI_{S1}, LAI_{S2}, LAI_{S3}, LAI_{S4}, Slope\}$$



FIA Plot (< 0.1 ha)

Spatial Resolution or Remote Sensing Data (0.81 ha)

Maximum Entropy Model



1. A probabilistic framework
2. Develop incomplete empirical probability distribution based on the occurrences
3. Approximate with a probability distribution of maximum entropy
4. Use environmental variables as constraints
5. A rule classifier to produce forest biomass map

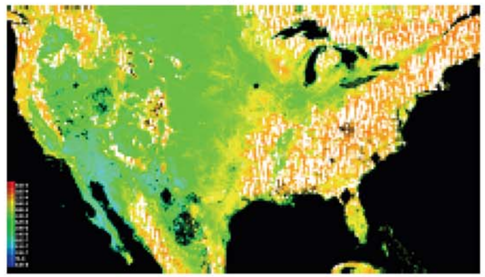
$$H(\hat{\pi}) = \sum_{x \in X} \hat{\pi}(x) \ln \hat{\pi}(x)$$

$\hat{\pi}(x)$: emperical distribution at points x (plot location)

H is maximized over feature space defined by f(x)

f : satellite image or environmental variable

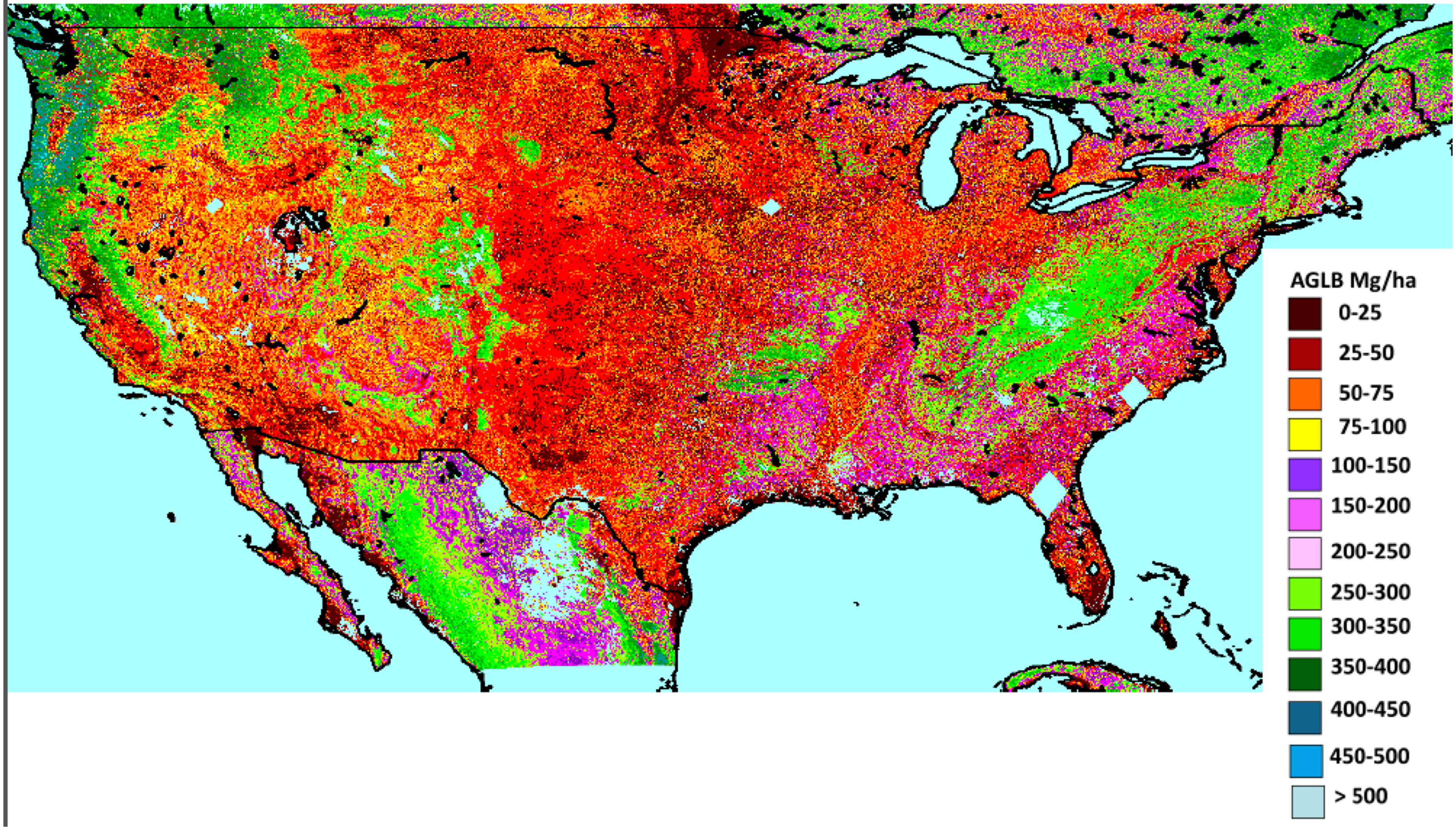
Sample Probability Space



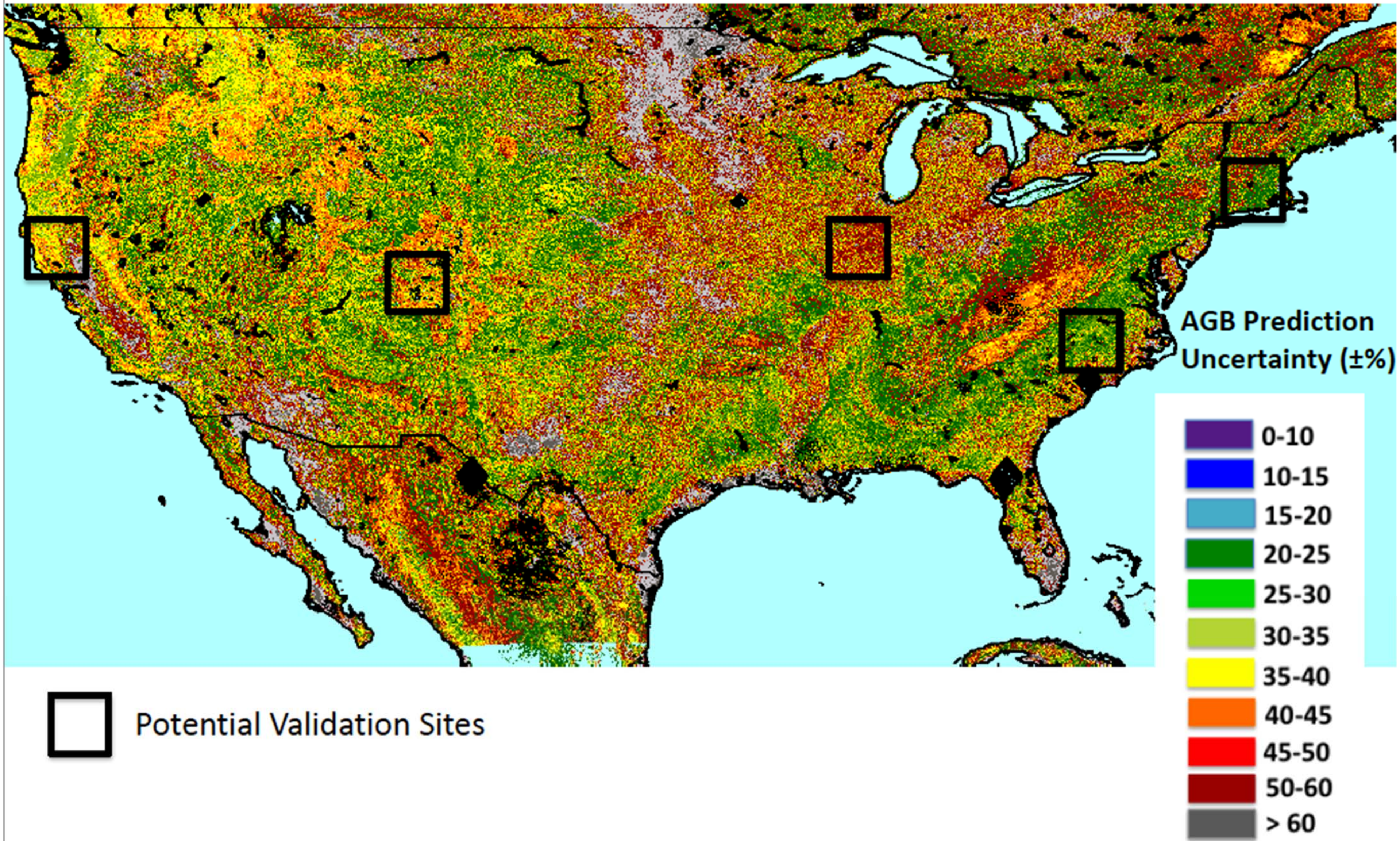
$$\hat{B} = \frac{\sum_{i}^{N} B_i P_i^n}{\sum_{i}^{N} P_i^n}, \quad for \quad n = 1,2,3,.........$$

$$\sigma = \sqrt{\frac{\sum_{i}^{N} (B_i - \hat{B})^2 P_i}{\sum_{i}^{N} P_i}}$$

Preliminary Aboveground National Biomass Map

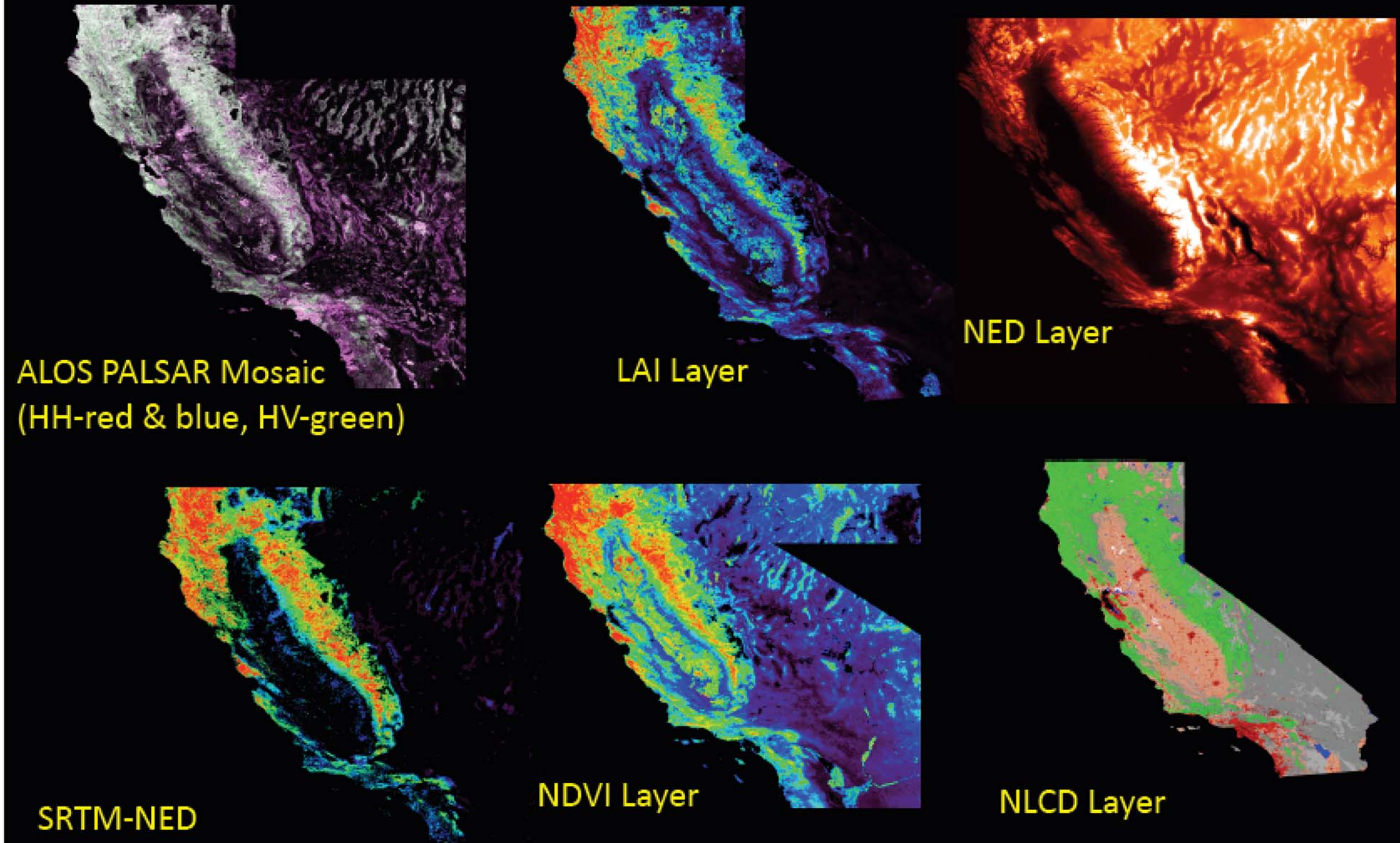


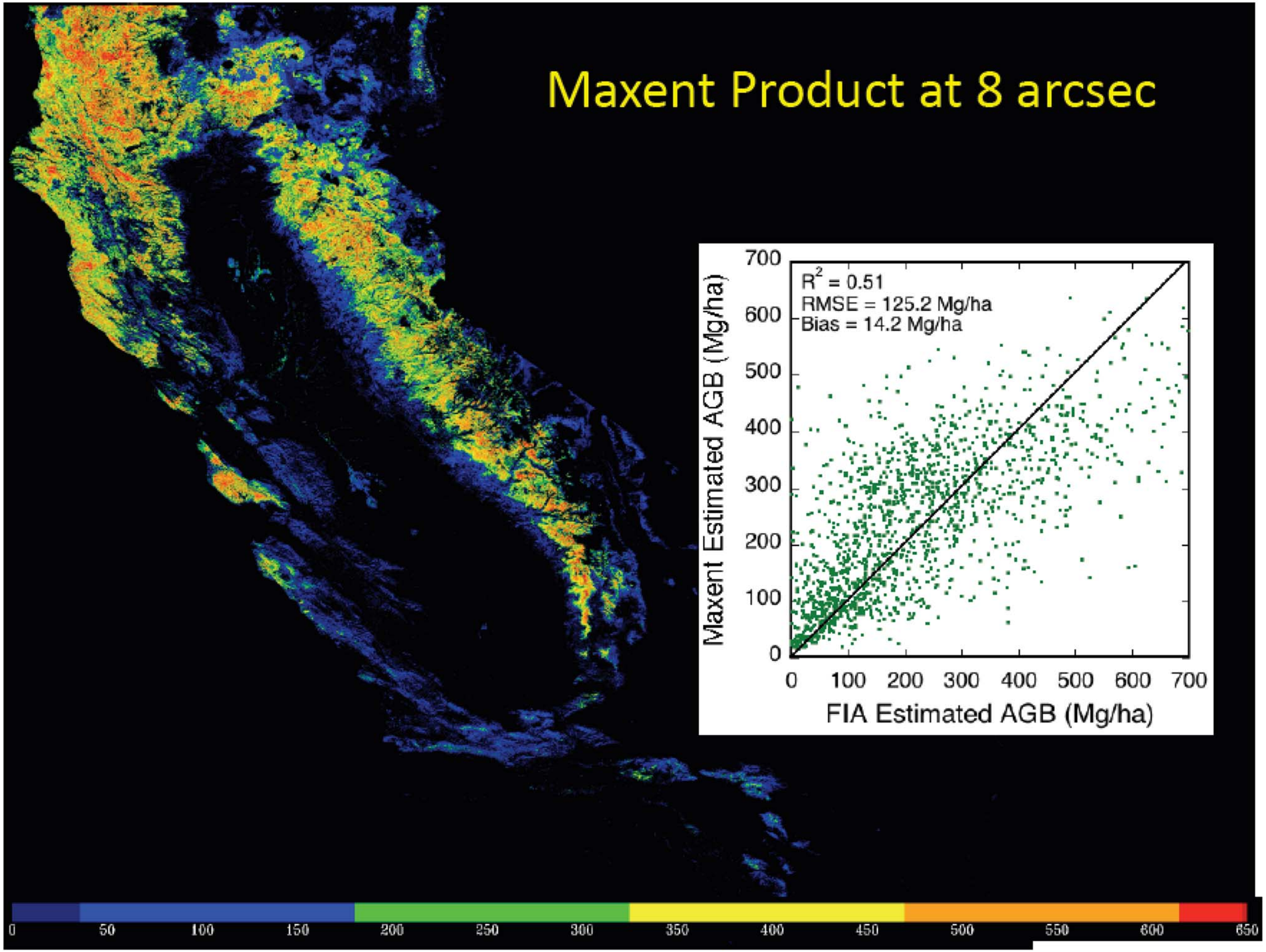
AGB Prediction Uncertainty



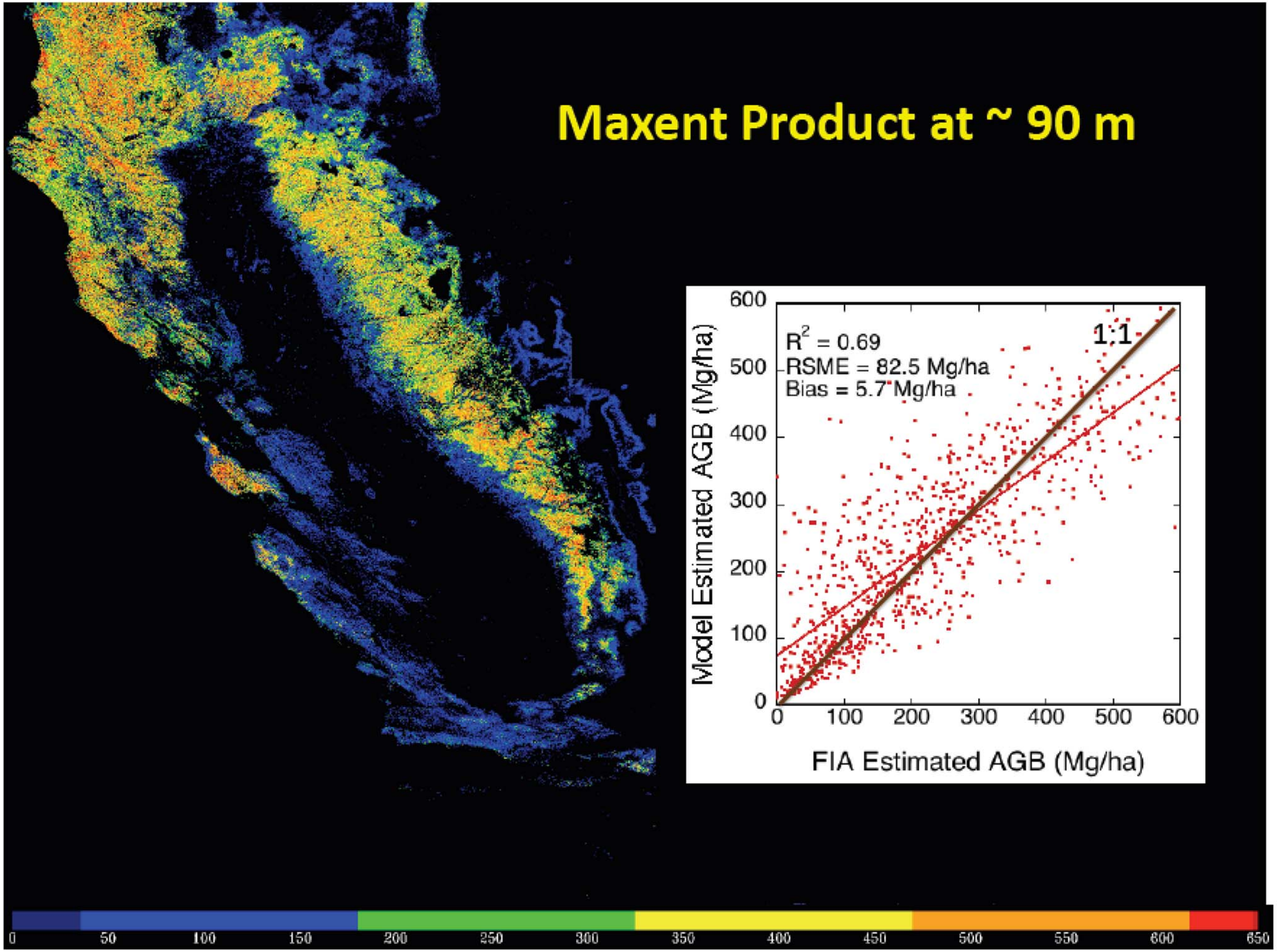
Potential Validation Sites

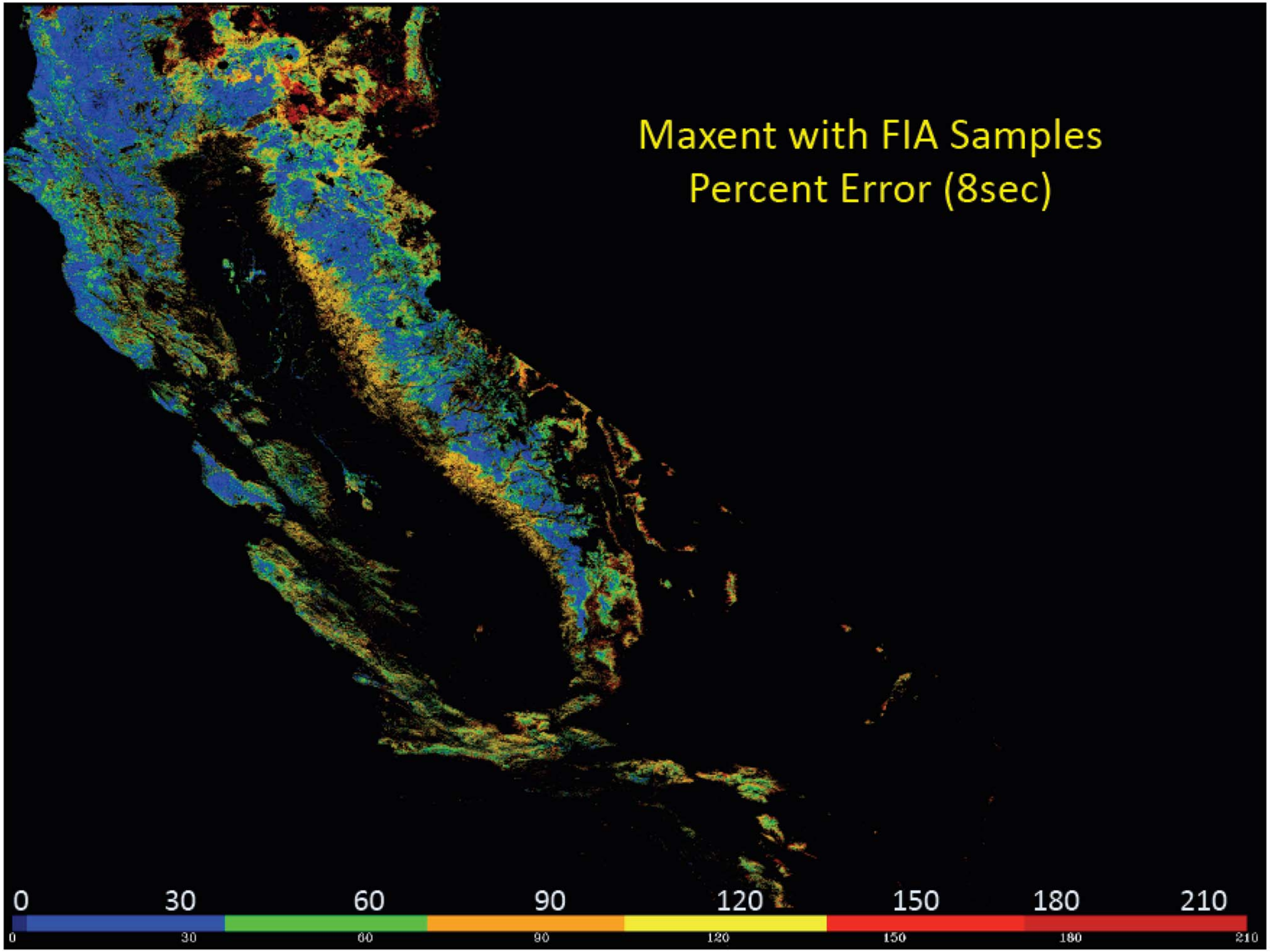
Non-parametric Model Implementation



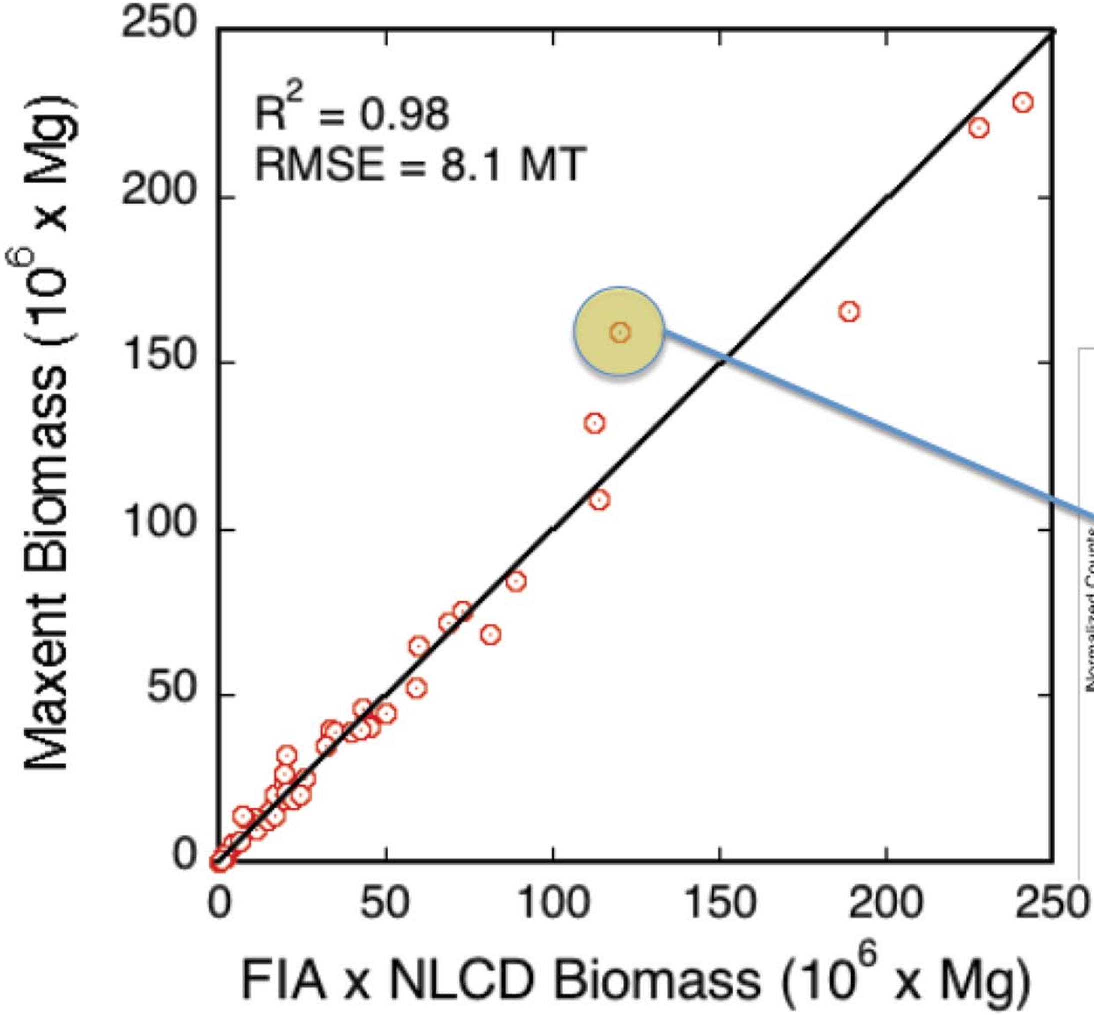


Maxent Product at 8 arcsec
R^2 = 0.51
RMSE = 125.2 Mg/ha
Bias = 14.2 Mg/ha
Maxent Estimated AGB (Mg/ha)
FIA Estimated AGB (Mg/ha)
0
100
200
300
400
500
600
700
0
50
100
150
200
250
300
350
400
450
500
550
600
650


Maxent Product at ~ 90 m
R^2 = 0.69
RSME = 82.5 Mg/ha
Bias = 5.7 Mg/ha
1:1
Model Estimated AGB (Mg/ha)
FIA Estimated AGB (Mg/ha)
0
100
200
300
400
500
600
0 50 100 150 200 250 300 350 400 450 500 550 600 650

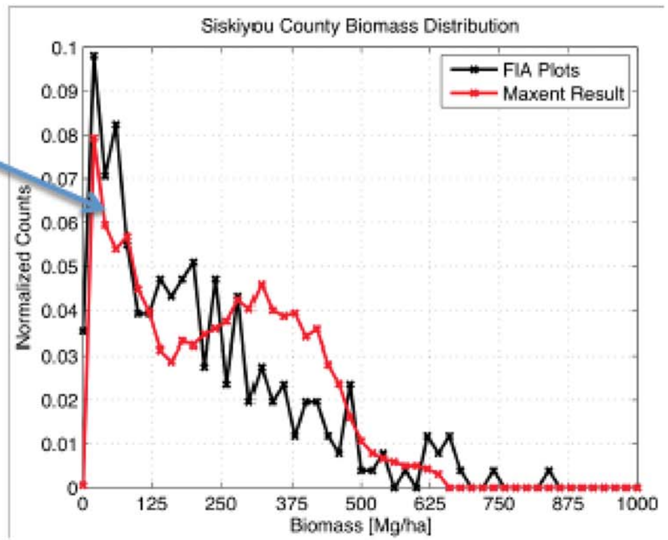

Maxent with FIA Samples
Percent Error (8sec)
0
30
60
90
120
150
180
210

Validation at the County Scale

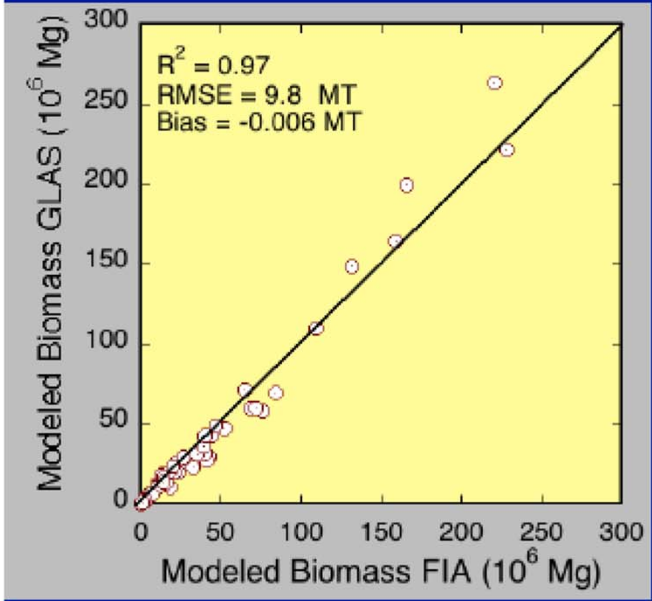


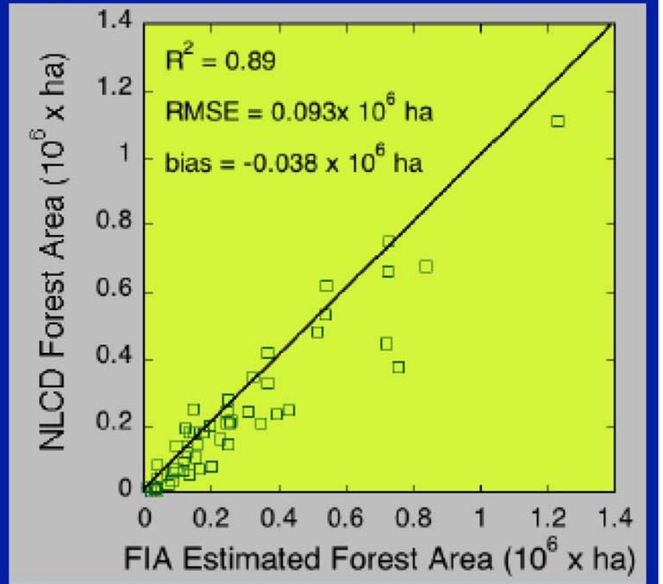
Sources of Error:

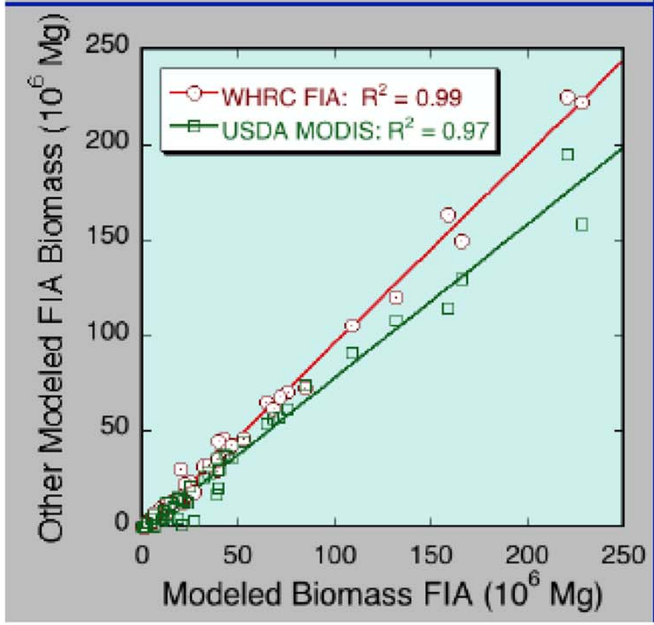
1. Forest Area Estimate
2. Maxent Prediction
3. FIA sub-sampling error

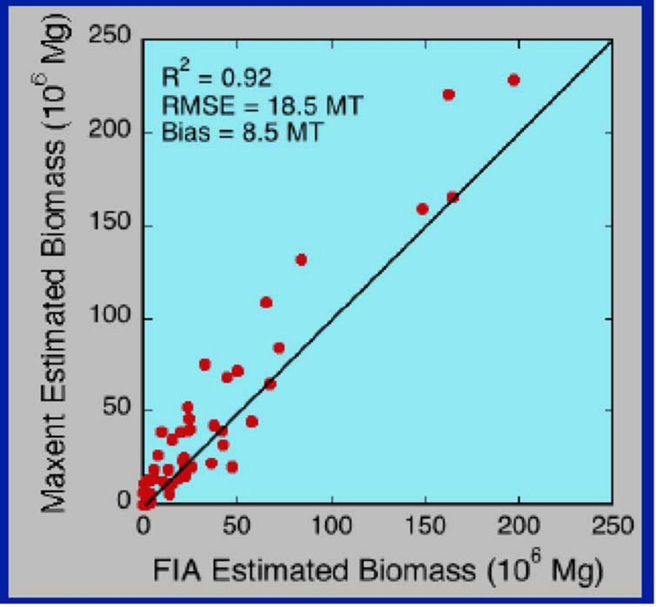


Validation at County Level









Summary

1. Combination of Lidar and satellite imagery can be used to model biomass distribution
2. Higher spatial resolution of 1-ha is the best to reduce errors associated with surface heterogeneity and smaller plot size
5. Large errors and small bias exists at pixel scale biomass estimation
6. Aggregated results on the US County scale agrees with the FIA data.
7. Uncertainty in biomass estimation is a function of methodology, location of plot data, allometry, forest area
8. The accuracy at county scale appears to be enough to estimate biomass changes at the annual scale, but needs to be verified.

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