Distribution of Forest Woody Biomass/Carbon of North America from Fusion of Optical and Microwave Data

PI: S. Saatchi (JPL/CALTEC
Co-Is: R. Myneni (Boston Univ.)
L. Heath (USDA, Forest Service)
M. Apps (Canada, Forest Service
Y. Knyazikhin (Boston Univ.)
Y. Yu (JPL/UCLA)
A. Baccini (Boston Univ.)

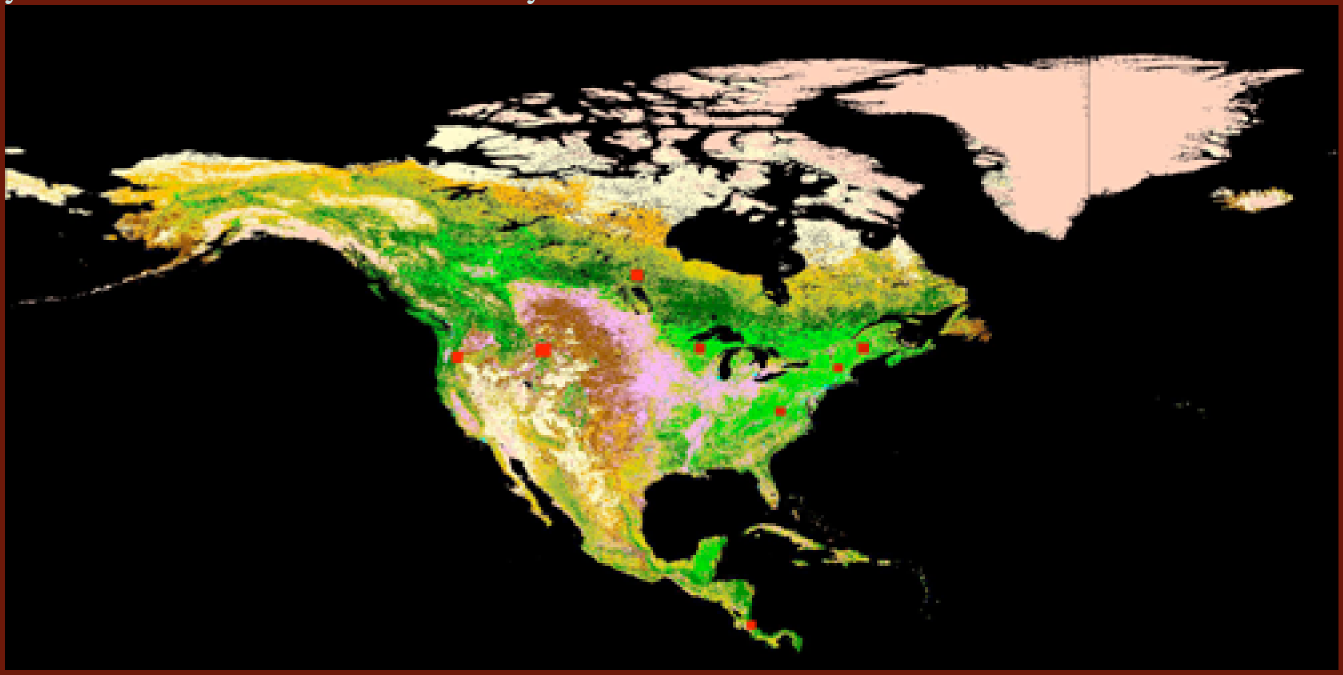
Biomass Estimates of North American Forests from Fusion of Optical and Radar Data

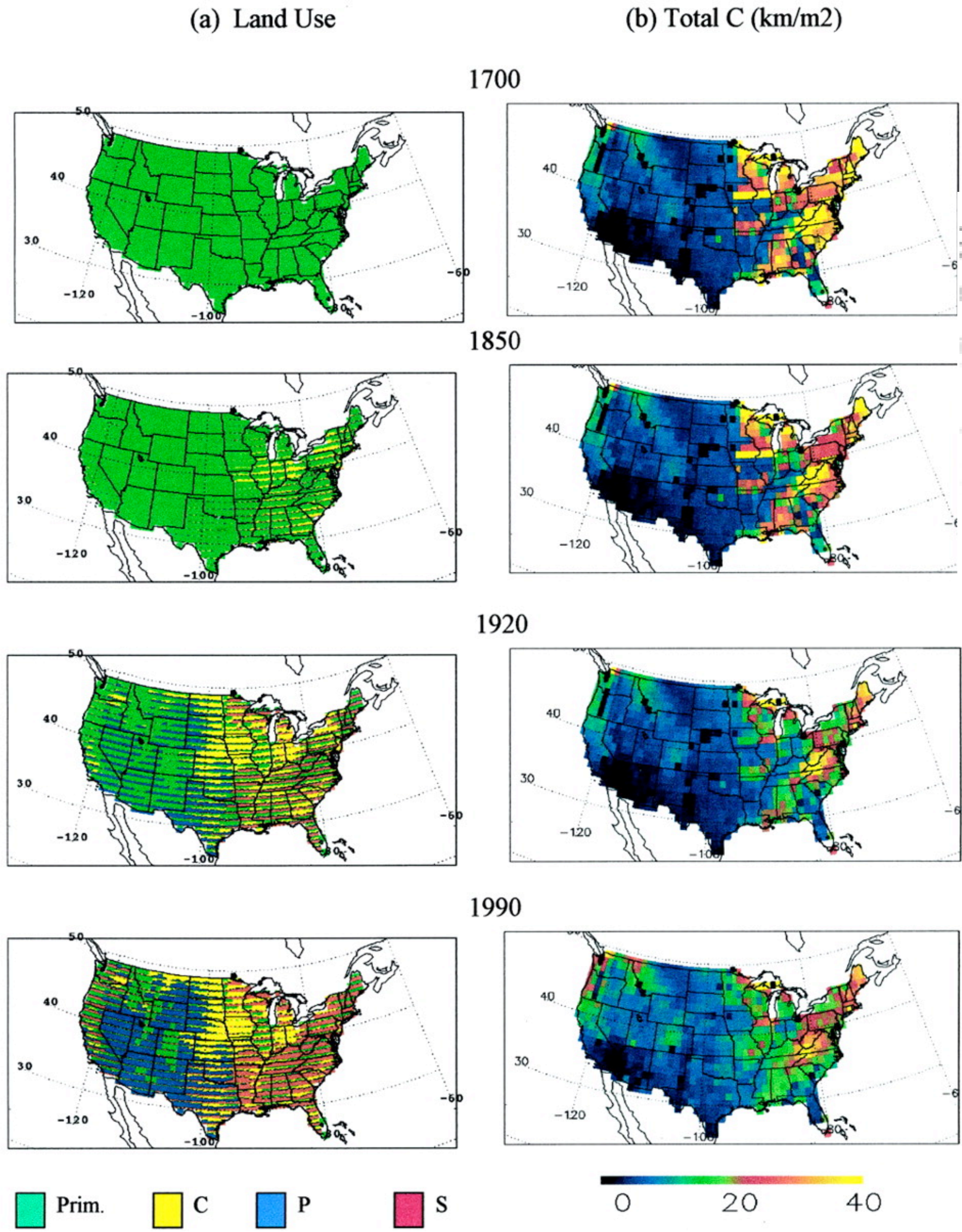
Overall Research Objective:
To integrate forest inventory data with remote sensing measurements to estimate the carbon stock in forests of North America.

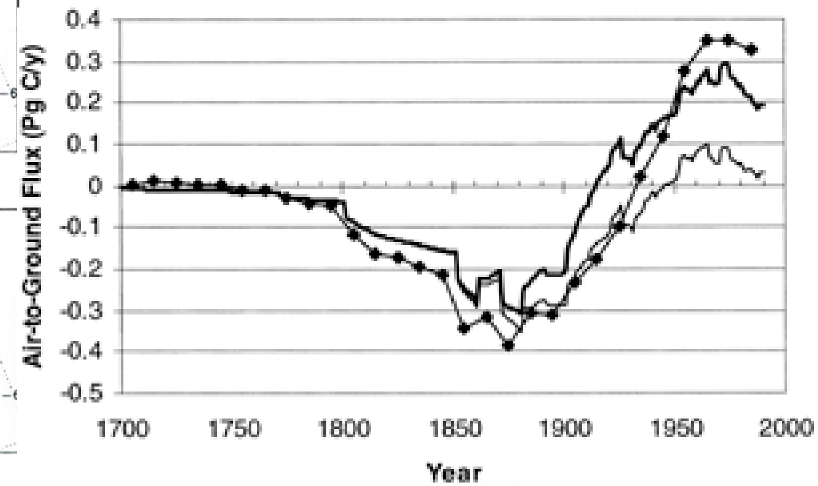
1. The use of statistical regression and physically based models in conjunction with forest inventory data to estimate woody biomass carbon at 1 km resolution synergistically from optical (MODIS) and radar (JERS-1, Radarsat, and SRTM) data.

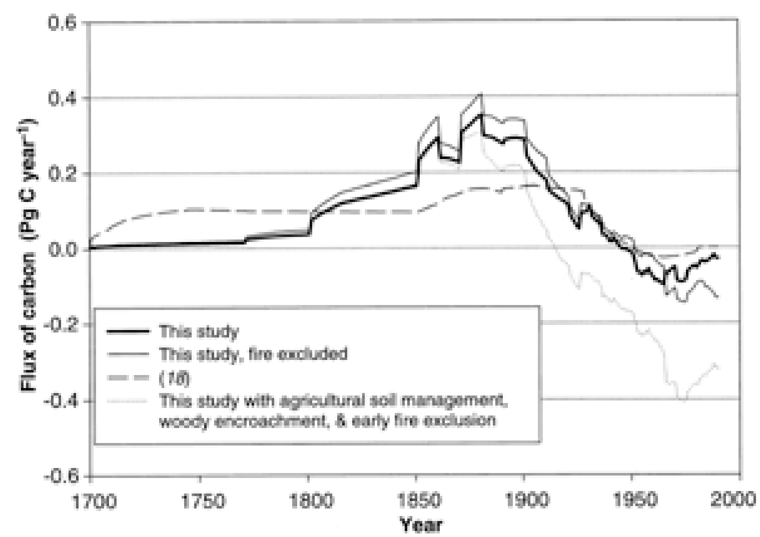
2. Validation of the forest biomass and carbon distributions using available site-specific data from various sources (US & Canadian Forest Service, LTER, BOREAS, etc.)

3. Establishing the uncertainty in biomass carbon distribution of North America by performing a comparative analysis of regression, physically based models and forest inventory data.



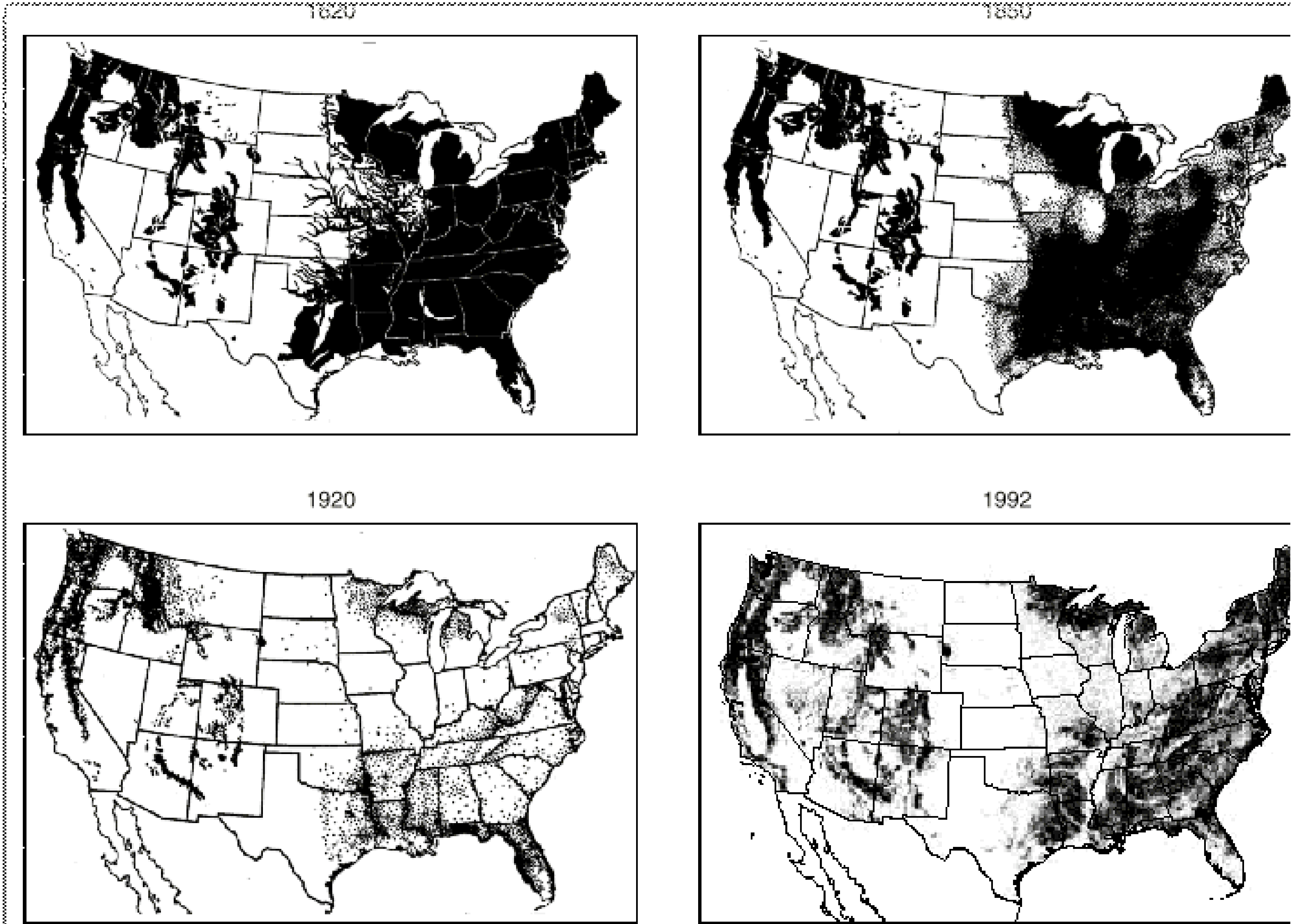






Houghton, et al. 2001)

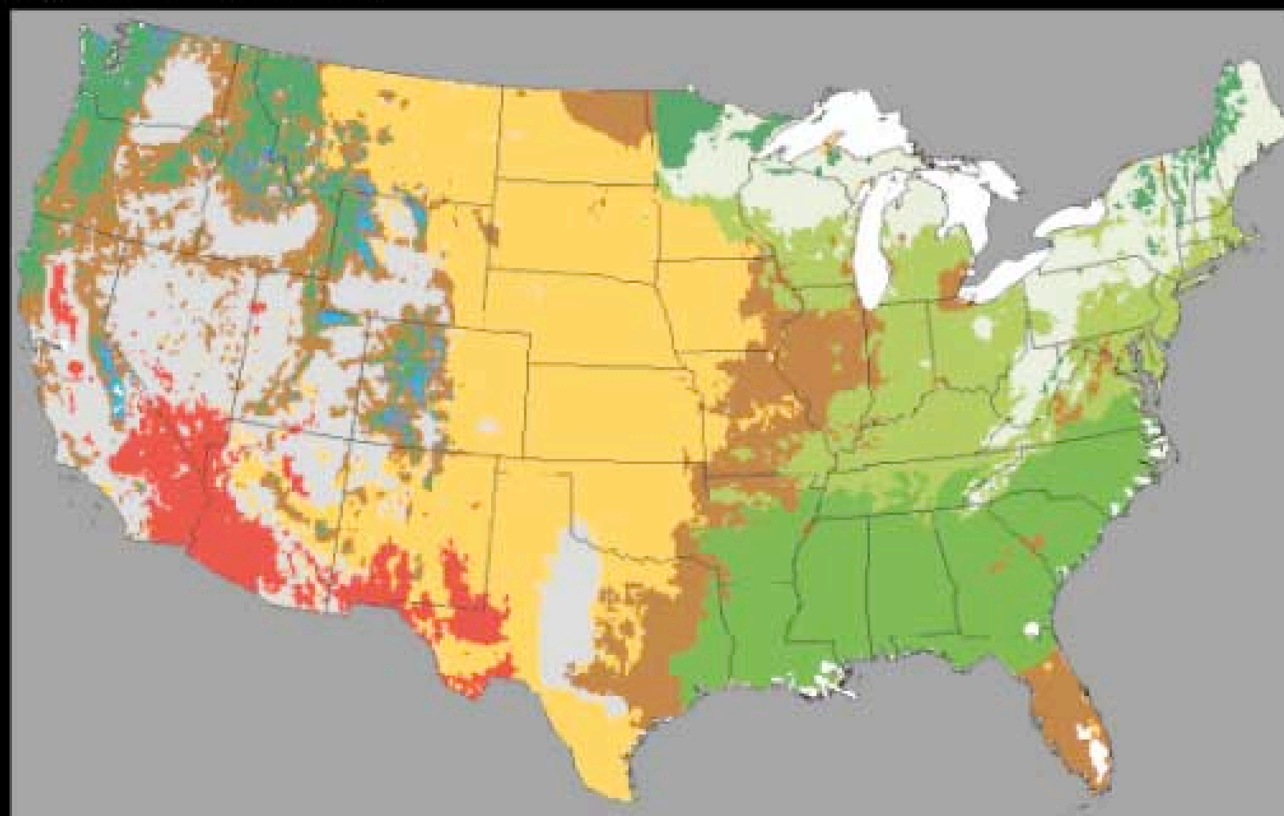
G. C. Hurtt et al., *Proc. Natl. Acad. Sci.* (2002)


1920
1992

Ecosystem Models

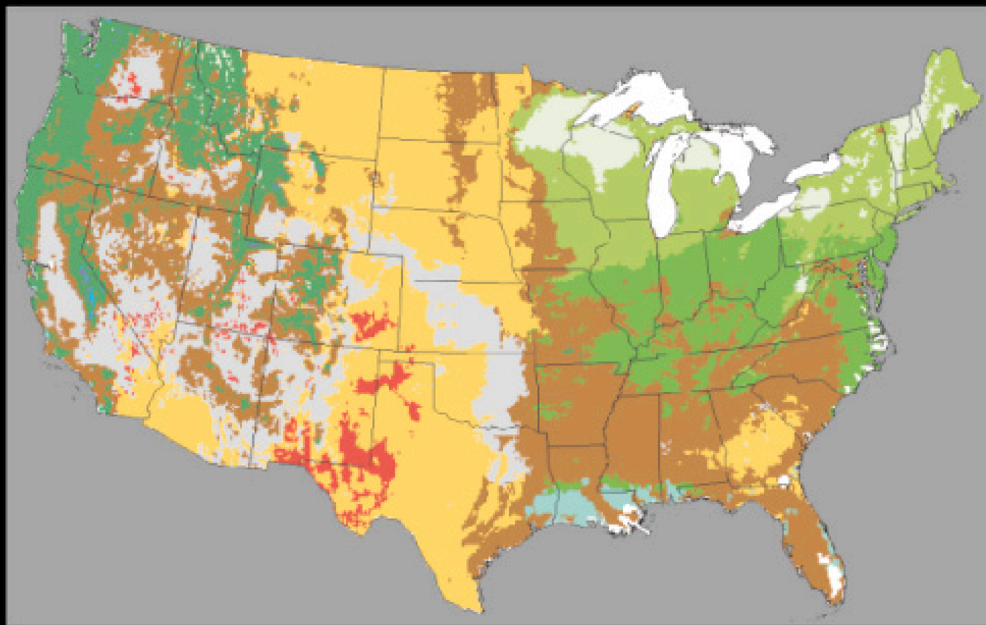
Maps of current and projected potential vegetation distribution for the conterminous US. Potential vegetation means the vegetation that would be there in the absence of human activity. Changes in vegetation distribution by the end of the 21st century are in response to two climate scenarios, the Canadian and the Hadley. Output is from MAPSS (Mapped Atmosphere-Plant-Soil System).

Current Ecosystems

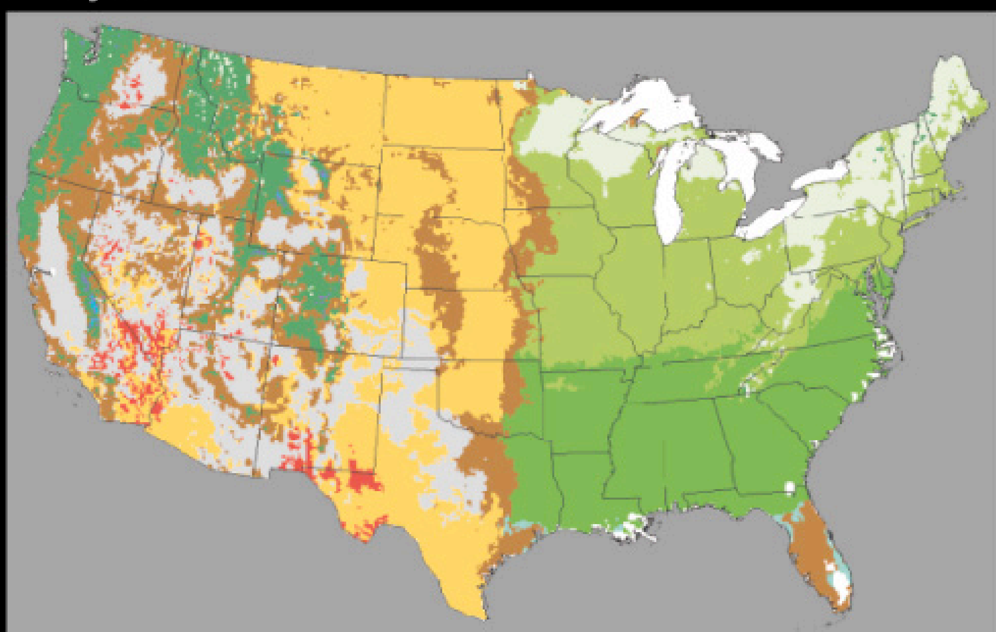


- Tundra
- Taiga / Tundra
- Conifer Forest
- Northeast Mixed Forest
- Temperate Deciduous Forest
- Southeast Mixed Forest
- Tropical Broadleaf Forest
- Savanna / Woodland
- Shrub / Woodland
- Grassland
- Arid Lands

Canadian Model



Hadley Model



A substantial portion of the Southeast's mixed forest is replaced by a combination of savanna and grassland in response to fire caused by warming and drying of the region as projected by the Canadian model. The Hadley climate projection leads to a simulated northward expansion of the mixed forest.

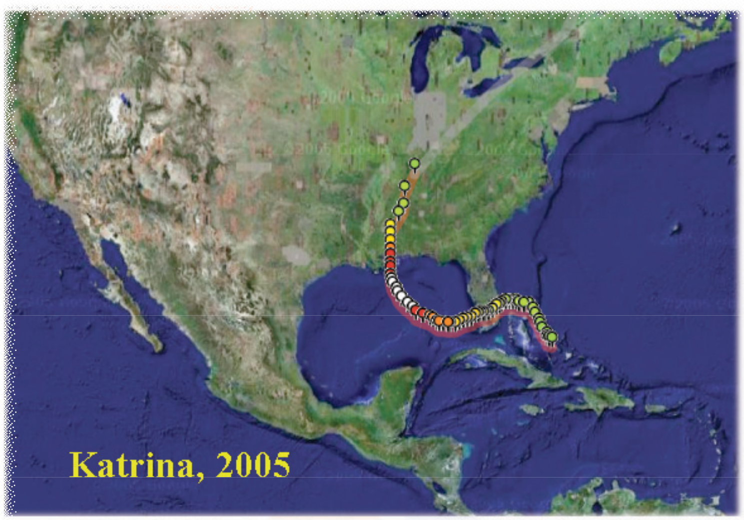
These particular model runs show the response of vegetation to atmospheric concentrations of CO_2 that have stabilized at about 700 parts per million, approximately twice the present level.

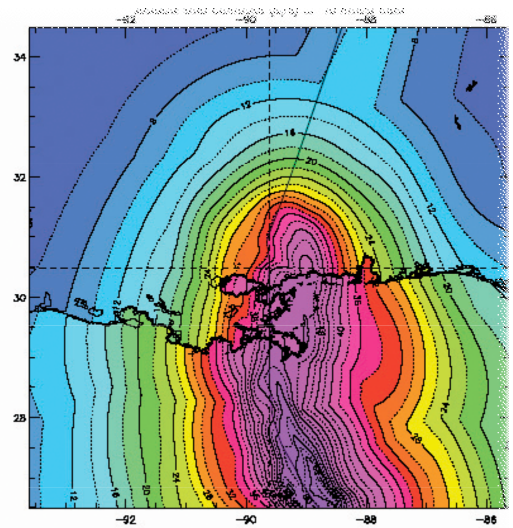
In the Southwest, large areas of arid lands are replaced with grassland or shrub/woodland in response to increases in precipitation projected by both models.

- Tundra
- Taiga / Tundra
- Conifer Forest
- Northeast Mixed Forest
- Temperate Deciduous Forest
- Southeast Mixed Forest
- Tropical Broadleaf Forest
- Savanna / Woodland
- Shrub / Woodland
- Grassland
- Arid Lands

Impact of Disturbance on US Carbon Sequestration Pool

Early estimates from forest inventories indicate potential timber losses from Hurricane Katrina alone amount to roughly 4.2 billion cubic feet of timber (15-19 billion board feet), spread over 5 million acres of light to heavily damaged forest land in Mississippi, Alabama, and Louisiana.





Work Completed:

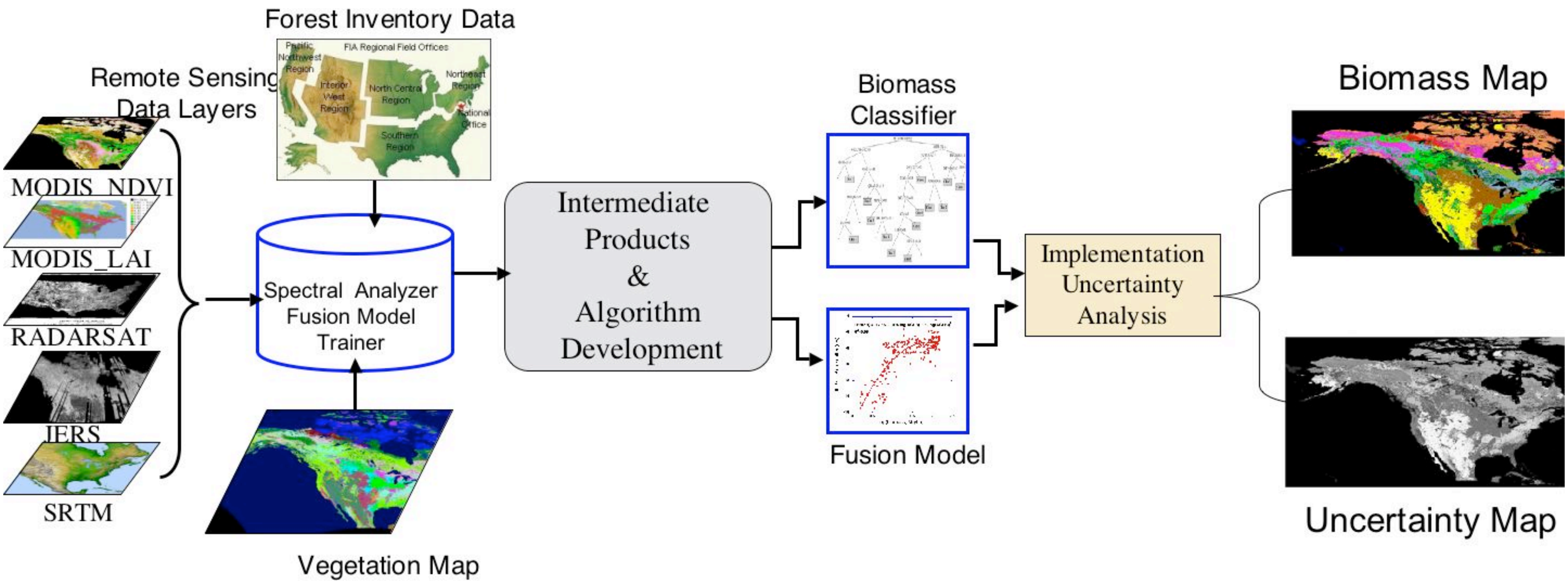
1. Data Processing

- Radar Data Processing, Radarsat (US and Canada Mosaic)
- JERS-1 Image Mosaic (Canada, Northeast and Northwest US, Alaska)
- SRTM 100 m mosaic of US
- Landsat ETM 100 mosaic of US
- NED (National Elevation Data) 100 mosaic
- MODIS 500 m 3 months growing season reflectance composite (North America)
- MODIS derived monthly averaged Leaf Area Index (LAI) (North America)

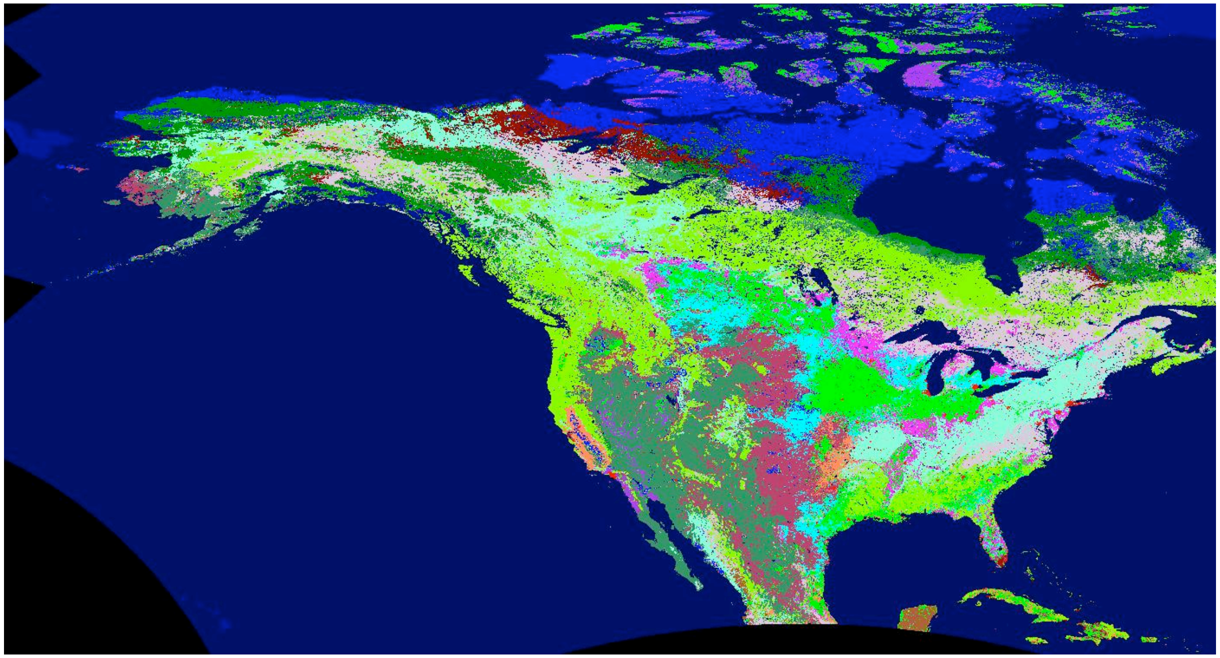
1. FIA Forest plots

- MOU has been signed by JPL and NE forest service and in process
  of being signed by Other stations
- Biomass and Carbon stock for NE forests computed by Linda Heath
- Forest types are reclassified in softwood and hardwood to be used by remote sensing data

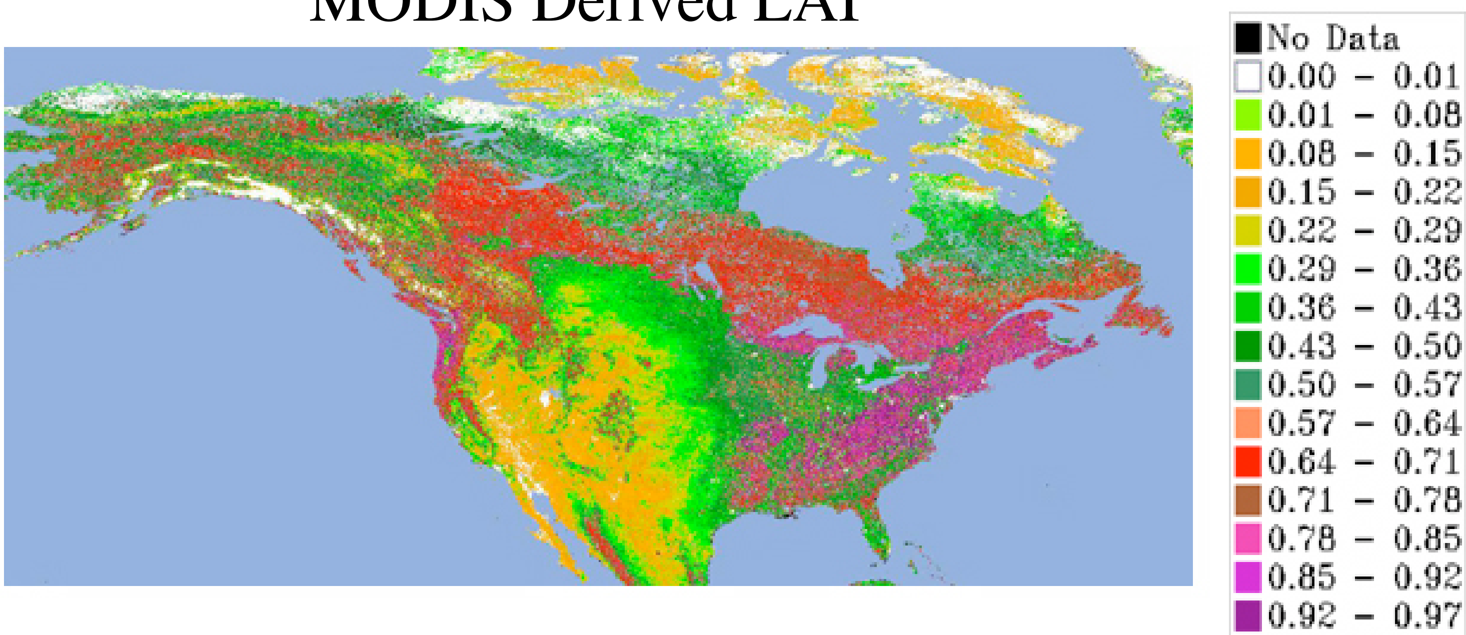
Biomass Estimation Methodology

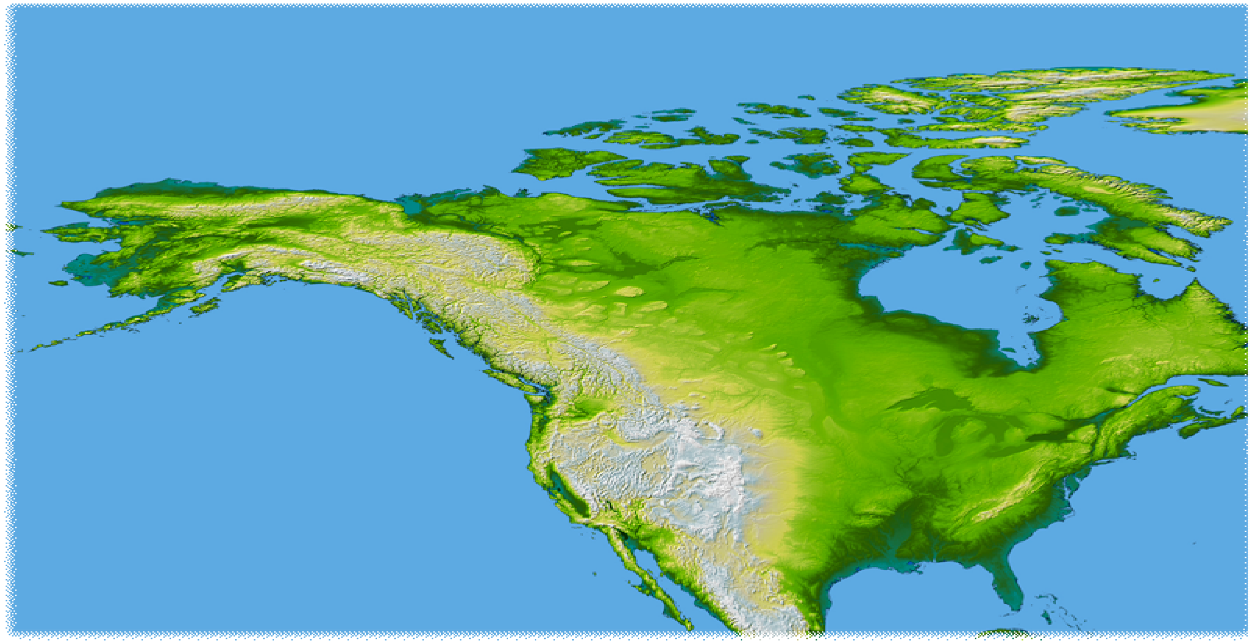


MODIS Derived Land Cover Map

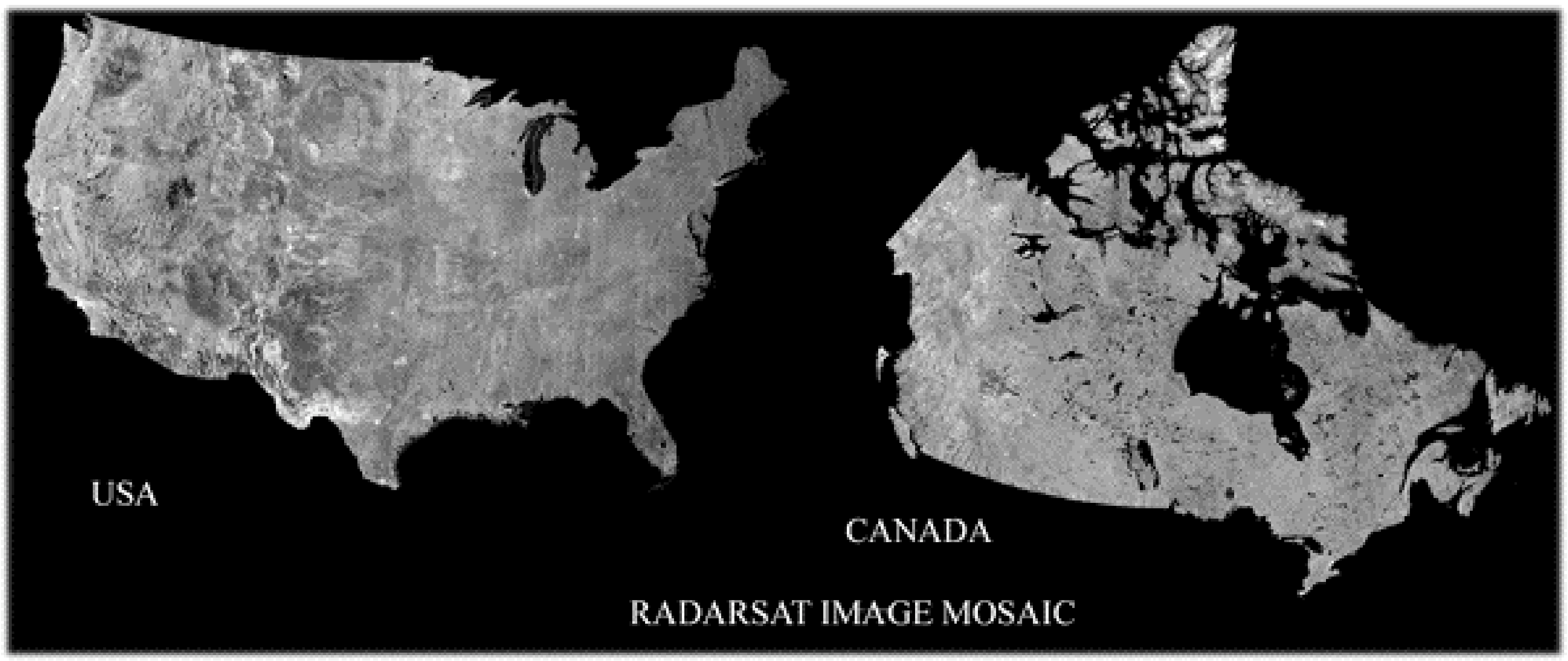


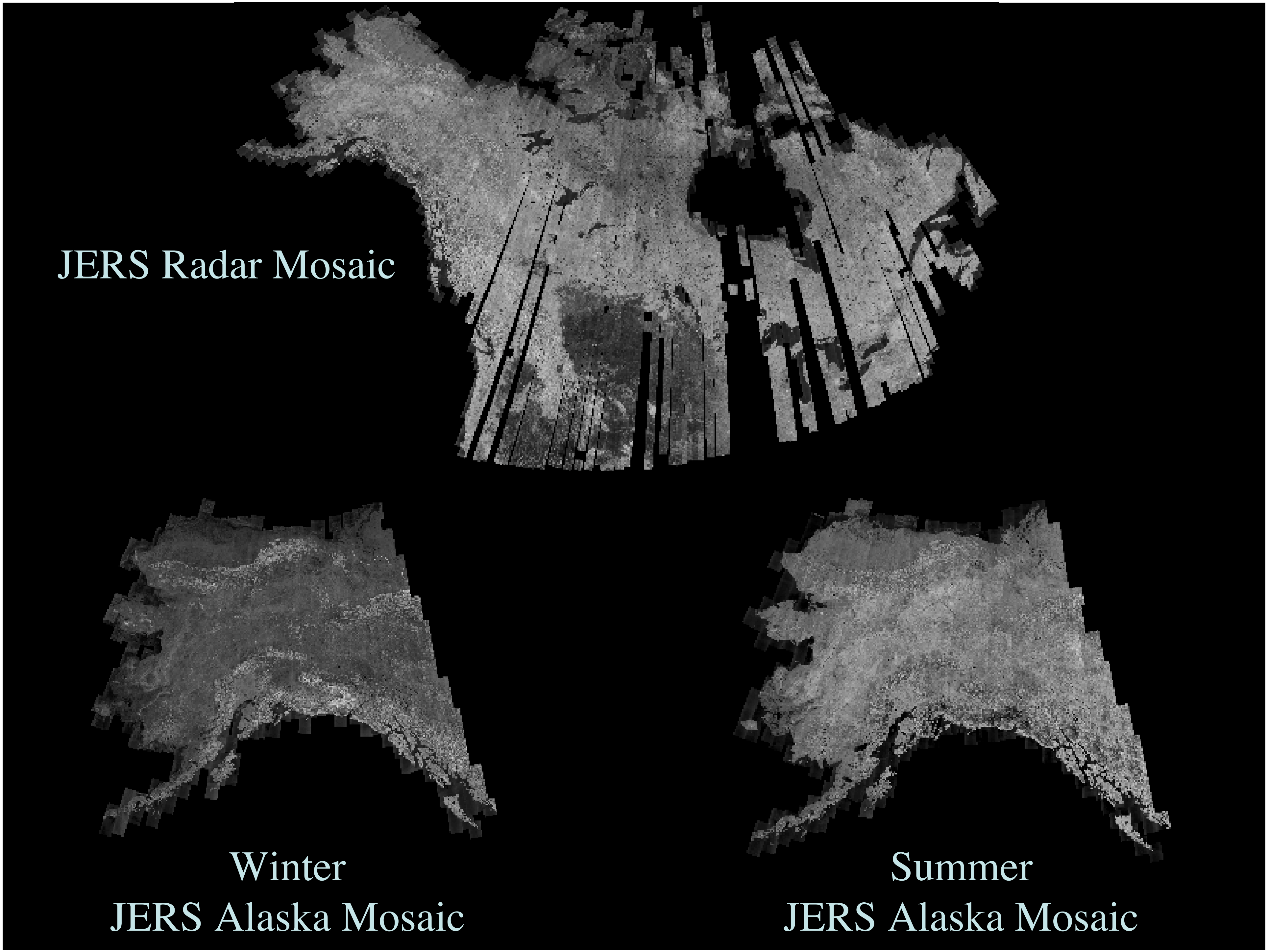
MODIS Derived LAI



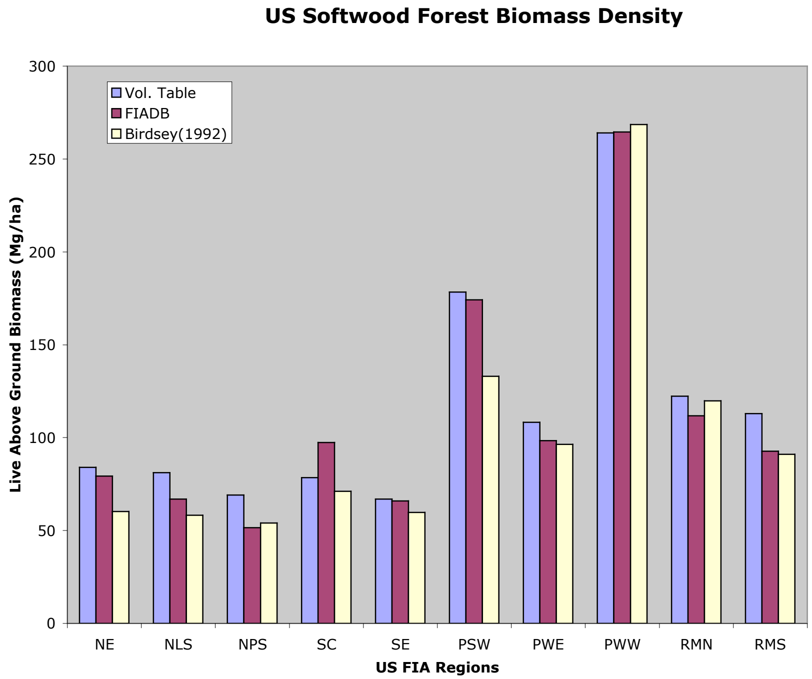


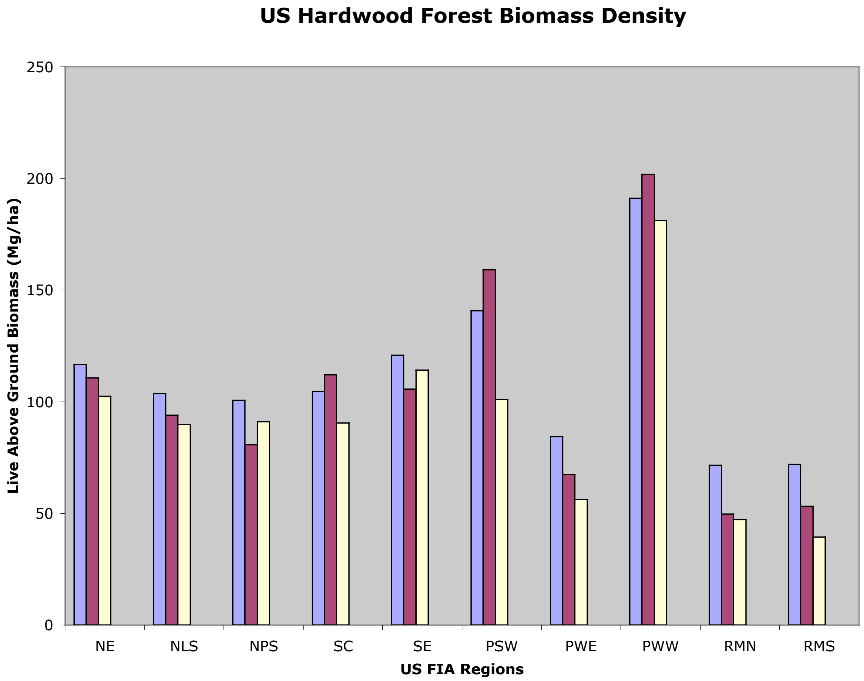
SRTM DEM

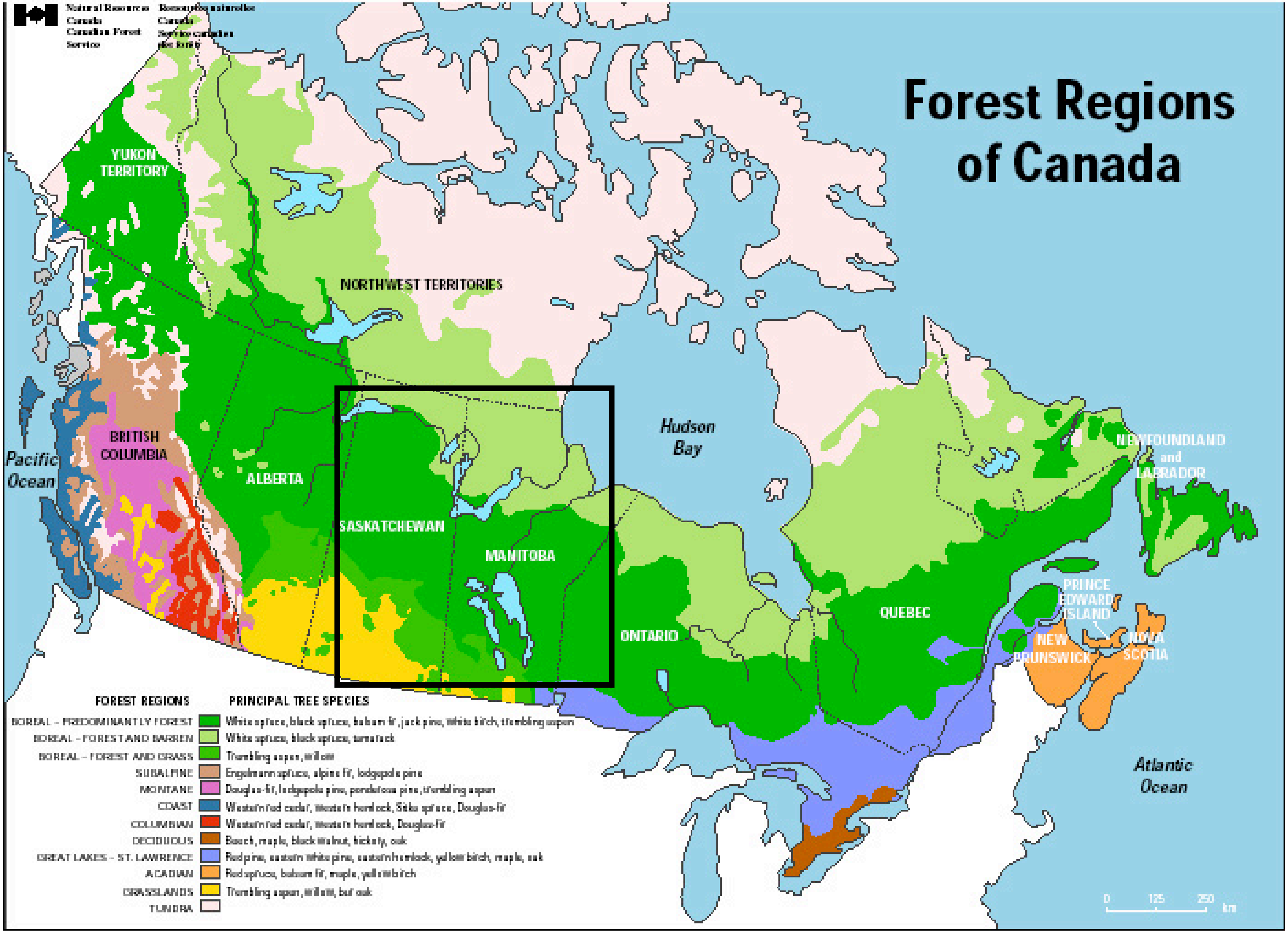



JERS Radar Mosaic
Winter
JERS Alaska Mosaic
Summer
JERS Alaska Mosaic

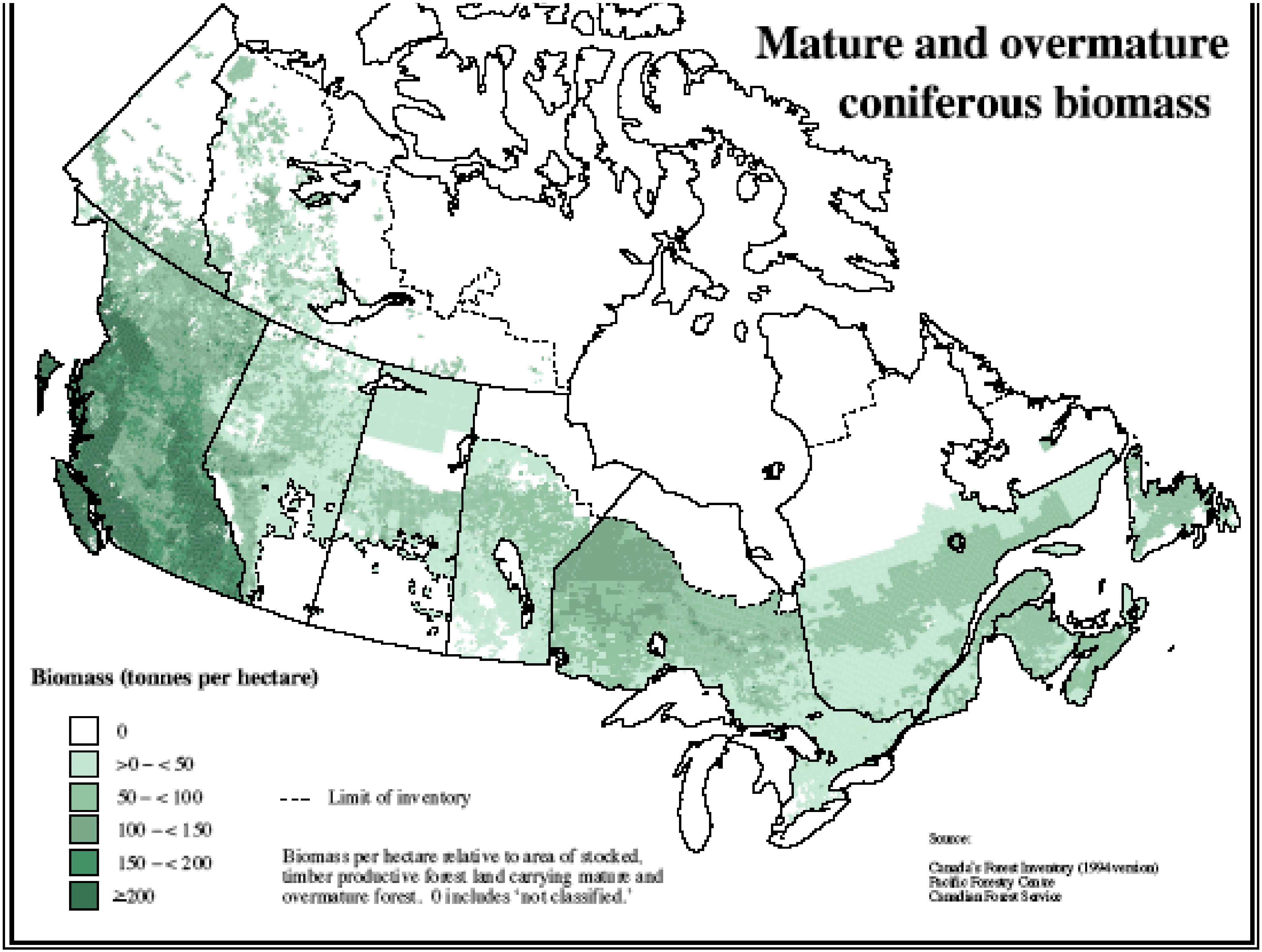
Forest Biomass Distribution in US



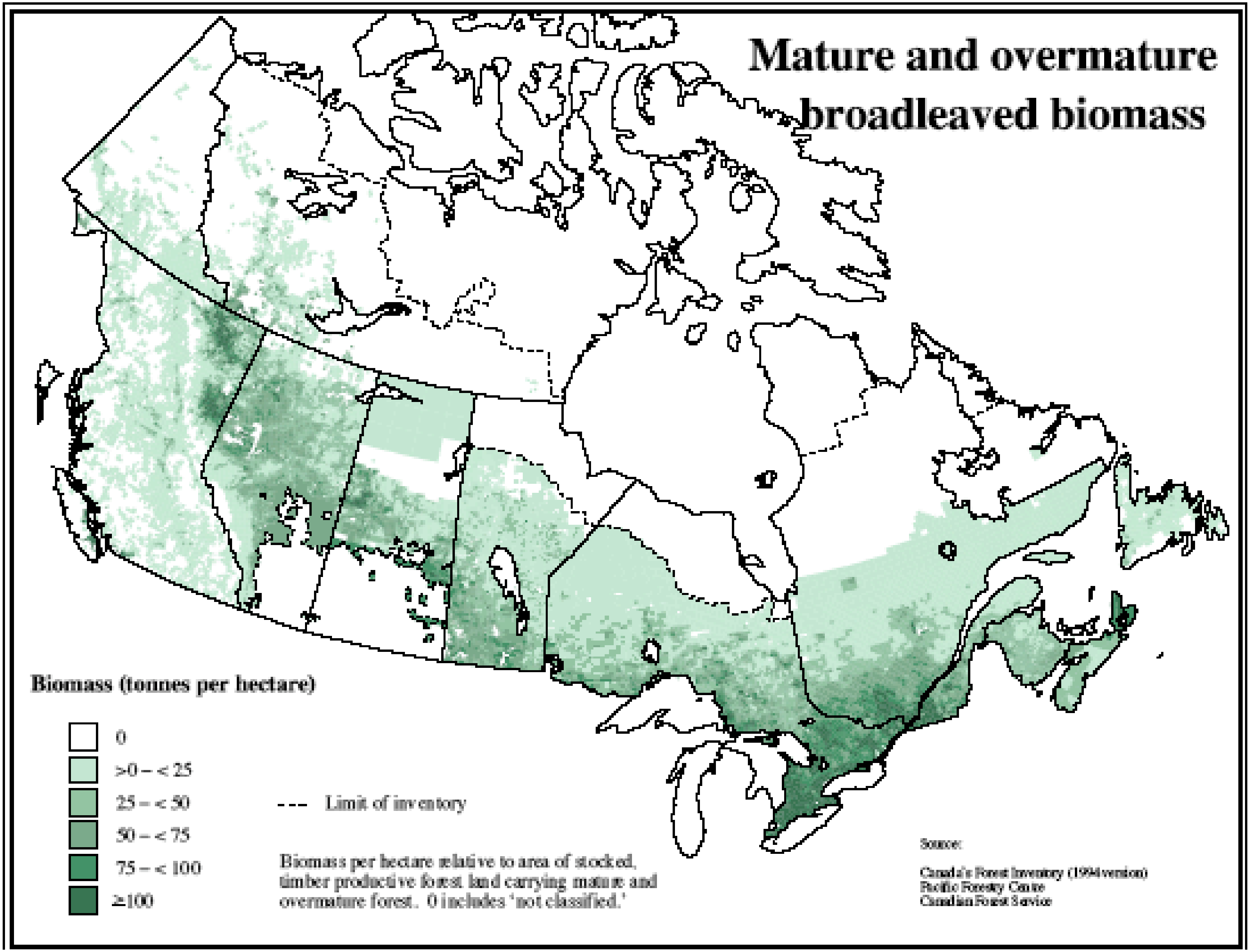




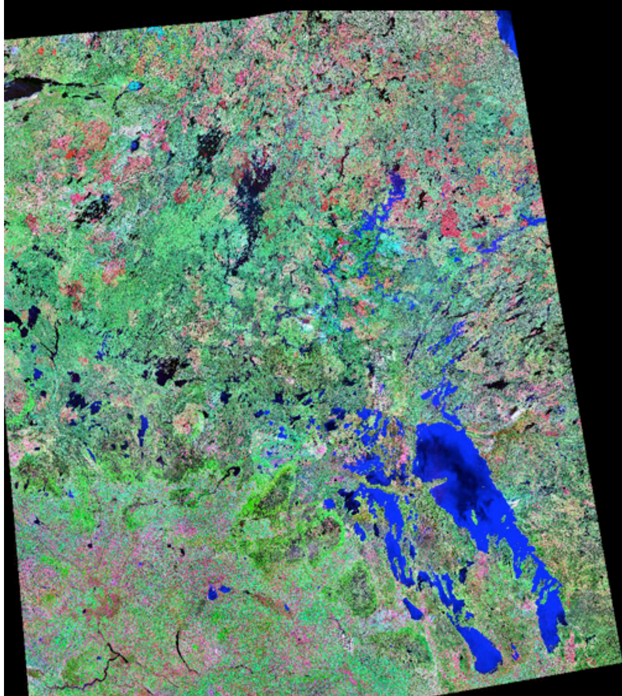
Natural Resources Canada
Canadian Forest Service
Forest Regions of Canada
YUKON TERRITORY
NORTHWEST TERRITORIES
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUEBEC
NEWFOUNDLAND and LABRADOR
PRINCE EDWARD ISLAND
NEW BRUNSWICK
NOVA SCOTIA
Pacific Ocean
Hudson Bay
Atlantic Ocean
FOREST REGIONS
PRINCIPAL TREE SPECIES
BOREAL – PREDOMINANTLY FOREST: White spruce, black spruce, balsam fir, jack pine, white birch, trembling aspen
BOREAL – FOREST AND BARREN: White spruce, black spruce, tamarack
BOREAL – FOREST AND GRASS: Trembling aspen, willow
SUBALPINE: Engelmann spruce, alpine fir, lodgepole pine
MONTANE: Douglas-fir, lodgepole pine, ponderosa pine, trembling aspen
COAST: Western red cedar, western hemlock, Sitka spruce, Douglas-fir
COLUMBIAN: Western red cedar, western hemlock, Douglas-fir
DECIDUOUS: Beech, maple, black walnut, hickory, oak
GREAT LAKES – ST. LAWRENCE: Red pine, eastern white pine, eastern hemlock, yellow birch, maple, oak
ACADIAN: Red spruce, balsam fir, maple, yellow birch
GRASSLANDS: Trembling aspen, willow, bur oak
TUNDRA
0 125 250 km



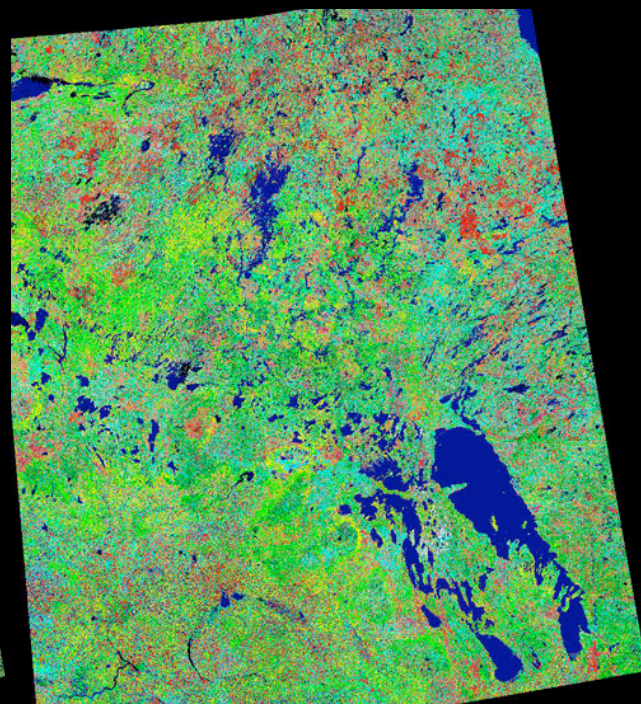
Mature and overmature coniferous biomass
Biomass (tonnes per hectare)
0
>0 – < 50
50 – < 100
100 – < 150
150 – < 200
≥200
Limit of inventory
Biomass per hectare relative to area of stocked, timber productive forest land carrying mature and overmature forest. 0 includes 'not classified.'
Source:
Canada's Forest Inventory (1994 version)
Pacific Forestry Centre
Canadian Forest Service


Mature and overmature broadleaved biomass
Biomass (tonnes per hectare)
0
>0 – < 25
25 – < 50
50 – < 75
75 – < 100
≥100
Limit of inventory
Biomass per hectare relative to area of stocked, timber productive forest land carrying mature and overmature forest. 0 includes 'not classified.'
Source:
Canada's Forest Inventory (1994 version)
Pacific Forestry Centre
Canadian Forest Service

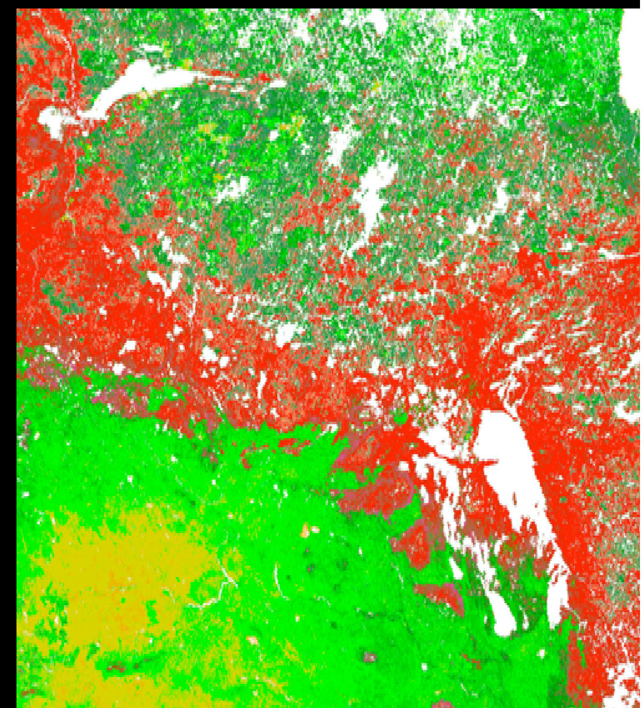
Biomass Estimation of Boreal Forests
Optical Remote Sensing Data



Landsat TM

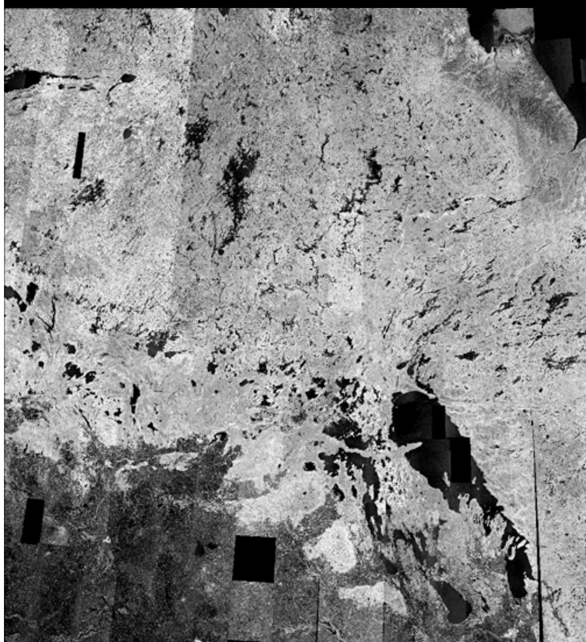


Landsat TM
Classification



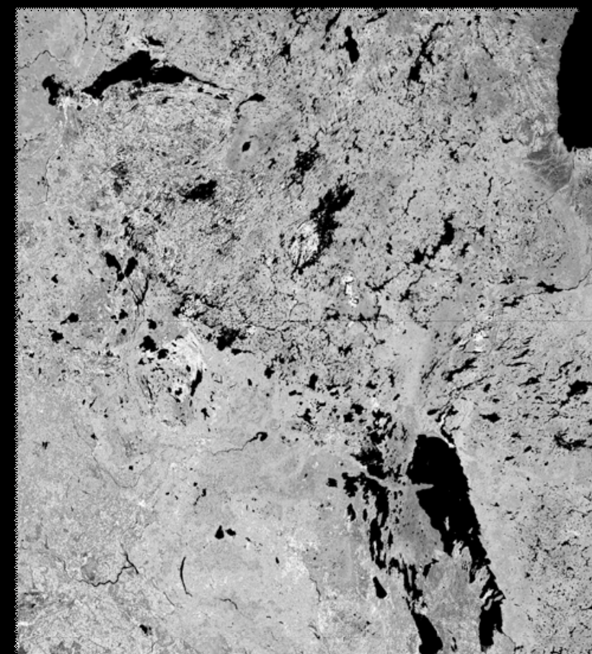
MODIS LAI

Biomass Estimation of Boreal Forests
Optical Remote Sensing Data



JERS L-band
(100 m)

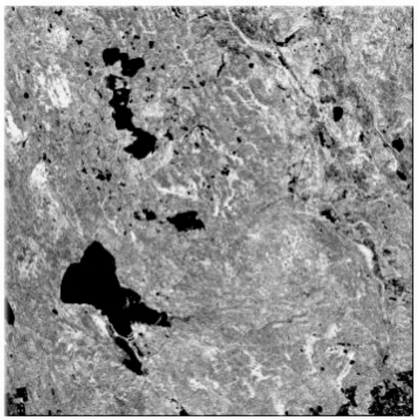
SRTM Elevation
(3 arcsec)



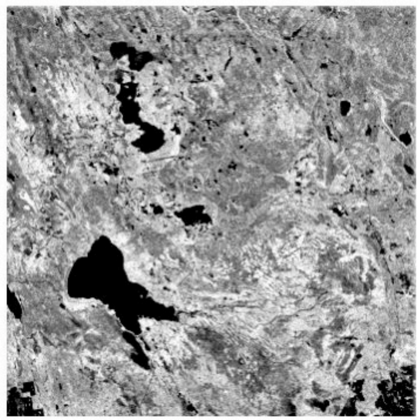
Radarsat C-band
(100 m)

Estimation of Boreal Forest Biomass

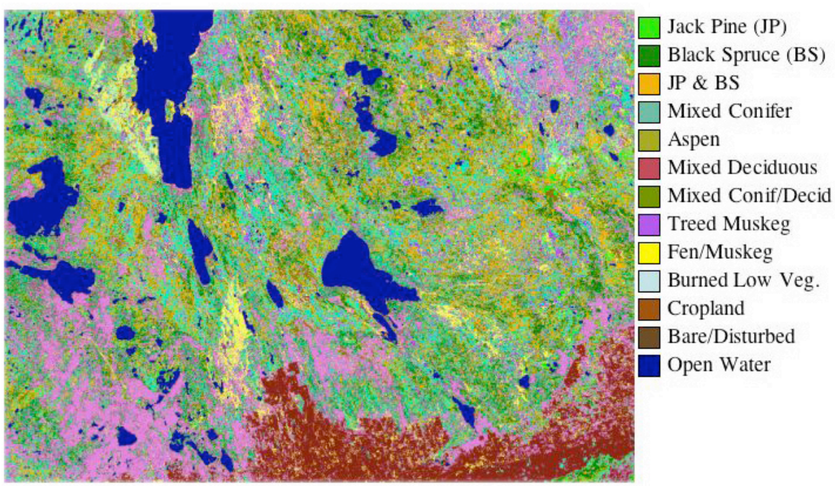
JERS-1 Images
L-band HH Polarization



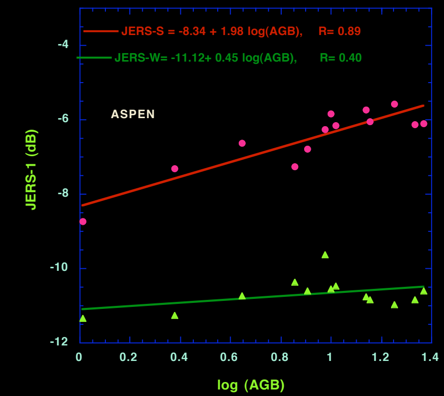
Winter

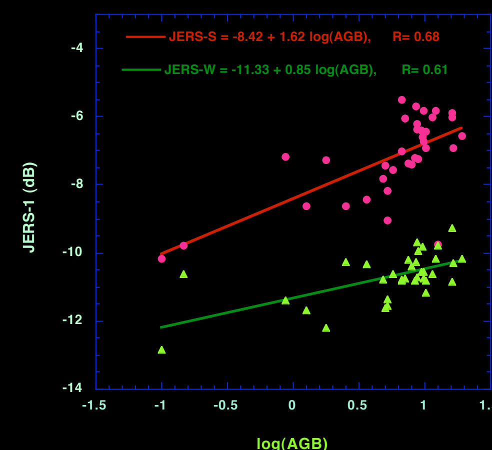


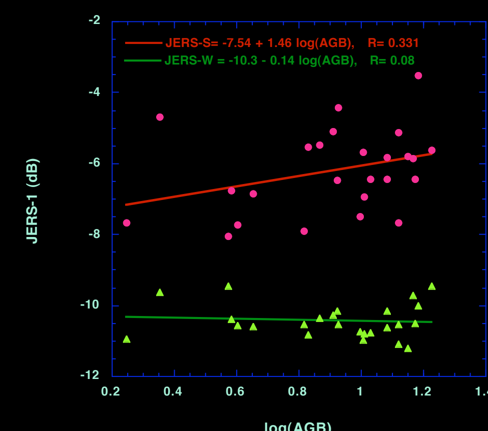
Summer

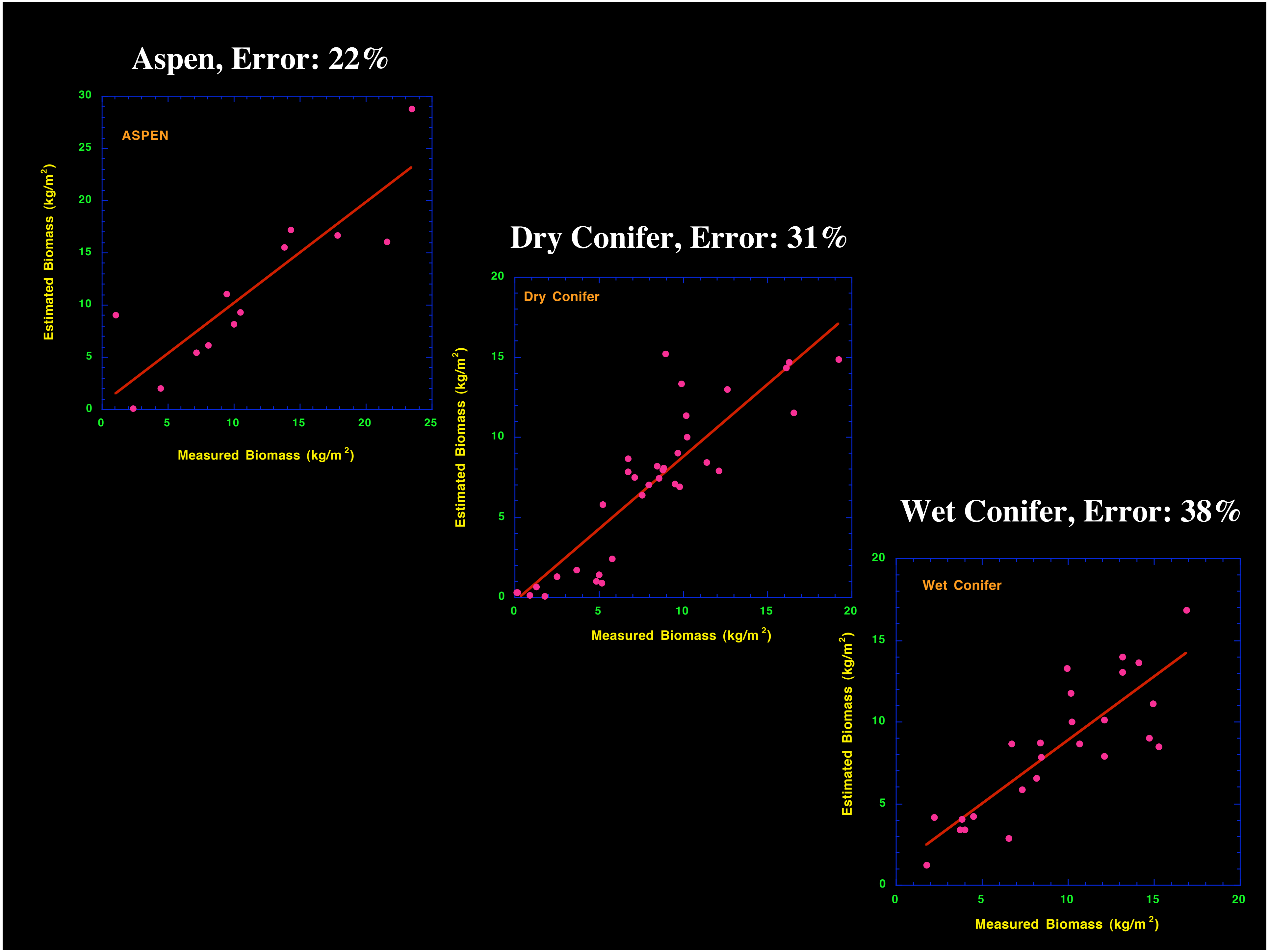


Landsat TM Derived Vegetation Map of BOREAS
Southern Study Area

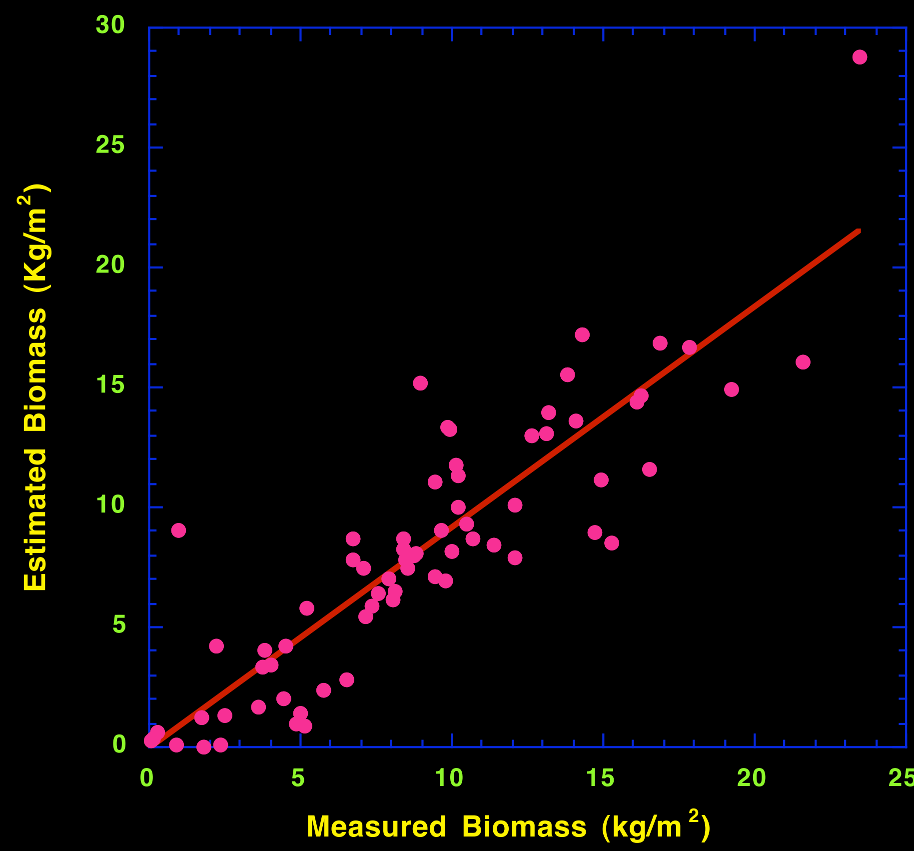






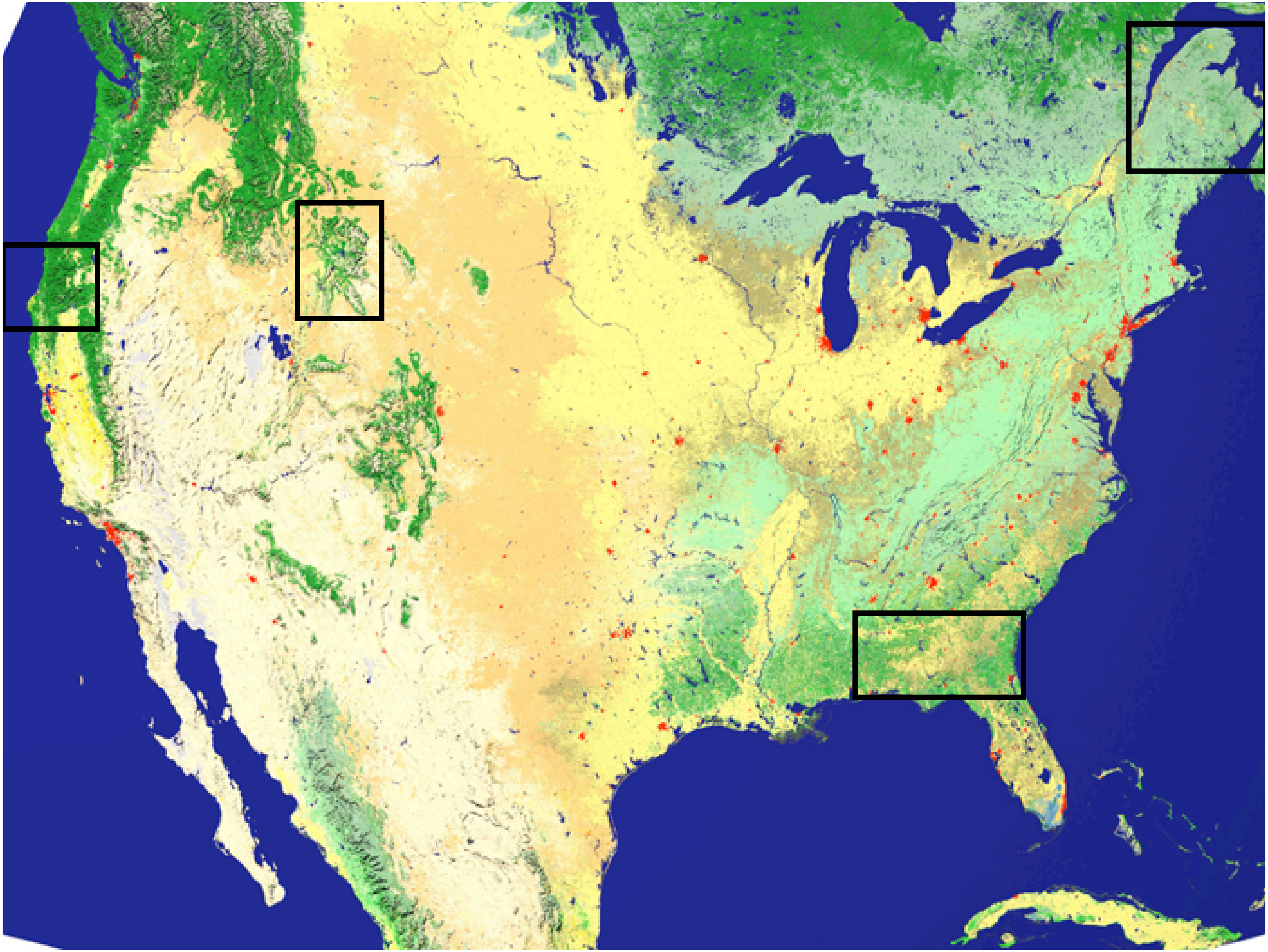

Aspen, Error: 22%
ASPEN
Estimated Biomass (kg/m2)
Measured Biomass (kg/m2)
Dry Conifer, Error: 31%
Dry Conifer
Estimated Biomass (kg/m2)
Measured Biomass (kg/m2)
Wet Conifer, Error: 38%
Wet Conifer
Estimated Biomass (kg/m2)
Measured Biomass (kg/m2)

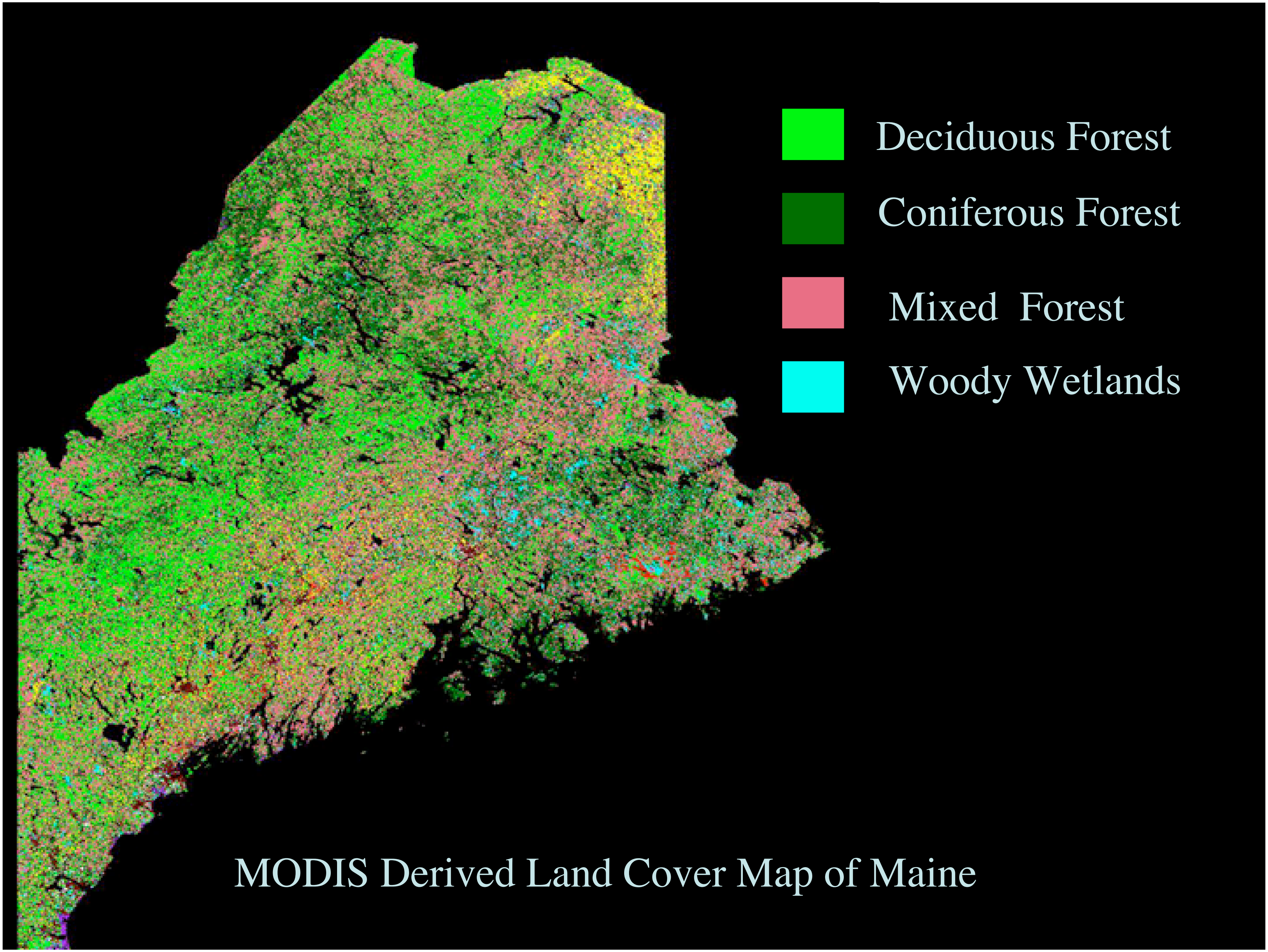
SAR Derived Biomass From:
JERS-1 Summer
JERS-1 Winter
Radarsat Summer
MODIS LAI
R^2=0.83, p<0.00001
RMSE=2.3 kg/m^2



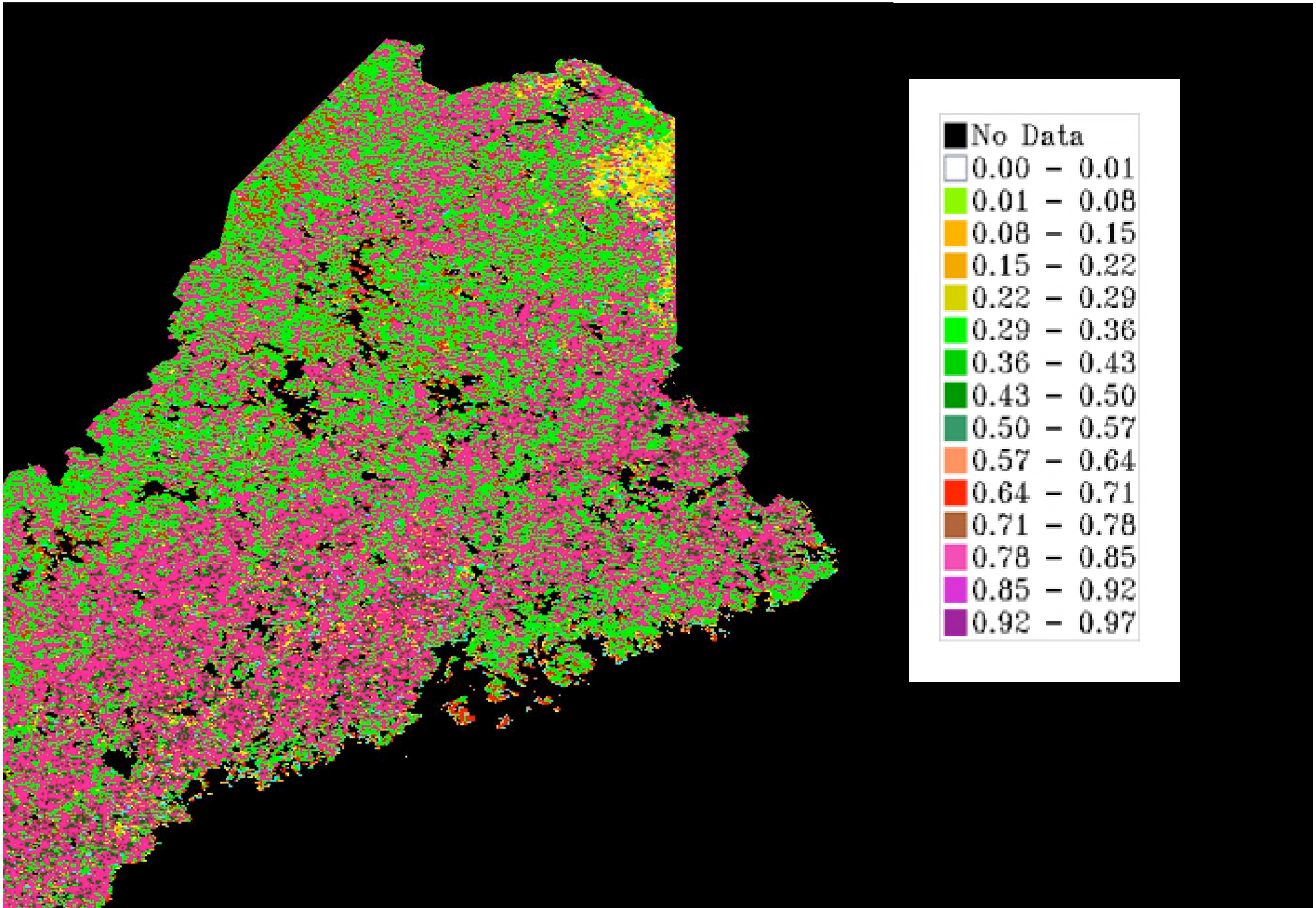
Forest Type Based Algorithm:

$$AGLB = a_0 + a_1 J_s + a_2 J_w + a_3 R_s + a_4 LAI$$





MODIS Derived Land Cover Map of Maine



Four Year Average of MODIS Derived LAI for Growing Season

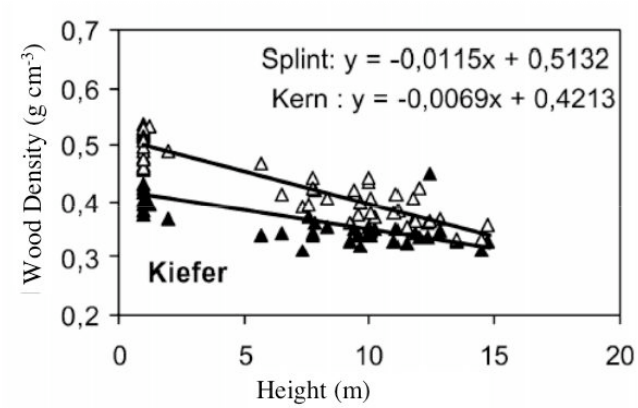
Above Ground Biomass Density(AGBD)

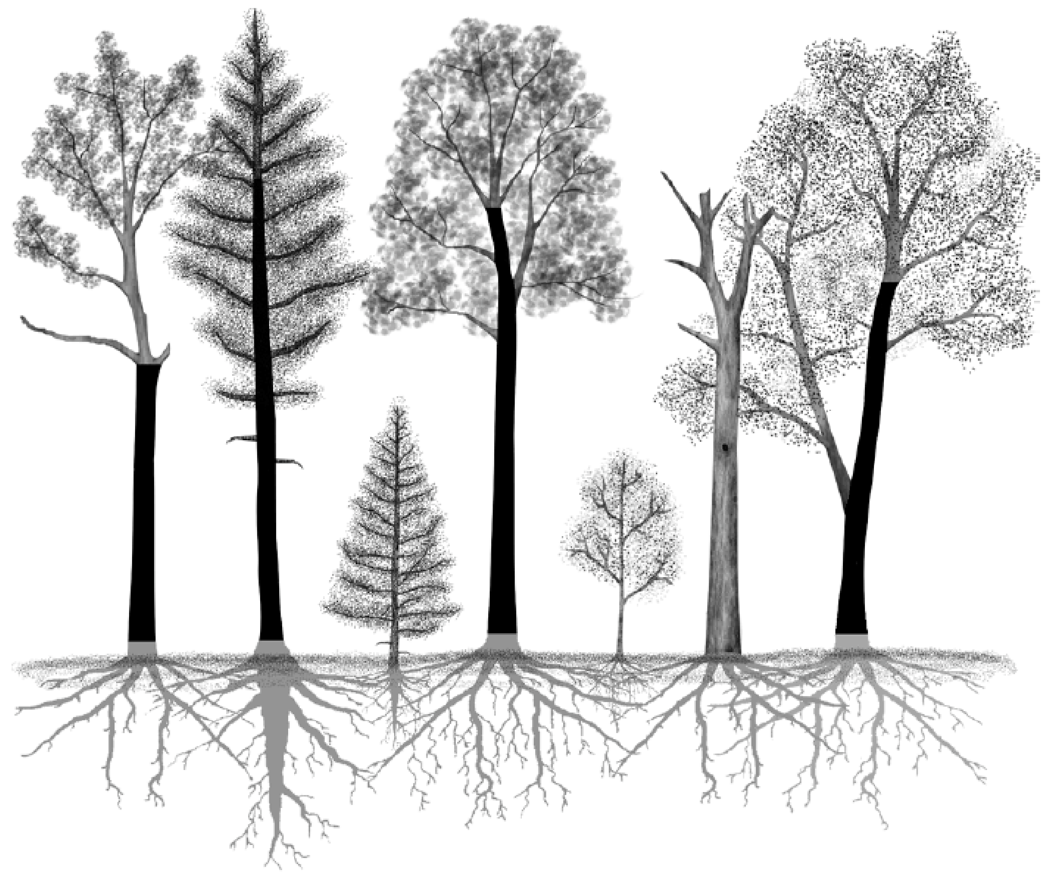
$$AGBD = \frac{1}{A}\sum_i \frac{\pi D_i^2}{4} H_i T_i W_i$$

$$Vol = \frac{1}{A}\sum_i \frac{\pi D_i^2}{4} H_i$$

$$BA = \frac{1}{A}\sum_i \frac{\pi D_i^2}{4}$$

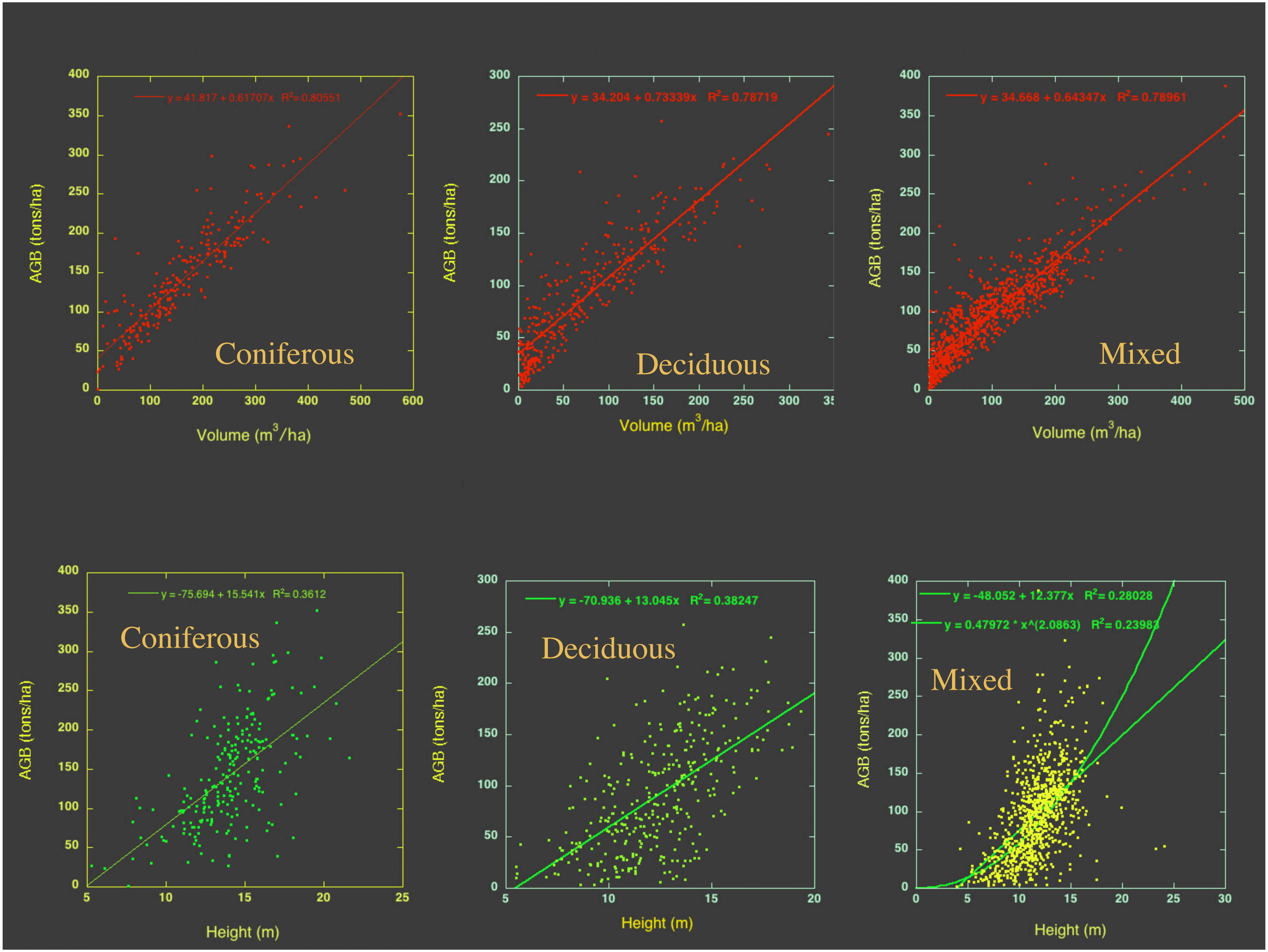
A: Area sampled
D: Diameter at Breast Height, DBH
H: Tree Height
T: Tapering Factor (species dependent)
W: Wood Density (species dependent)

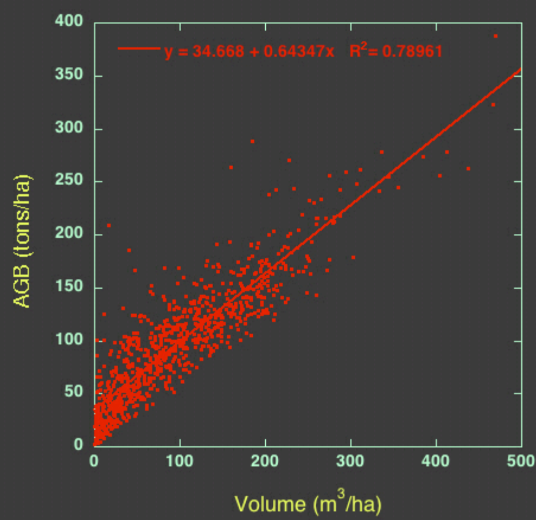


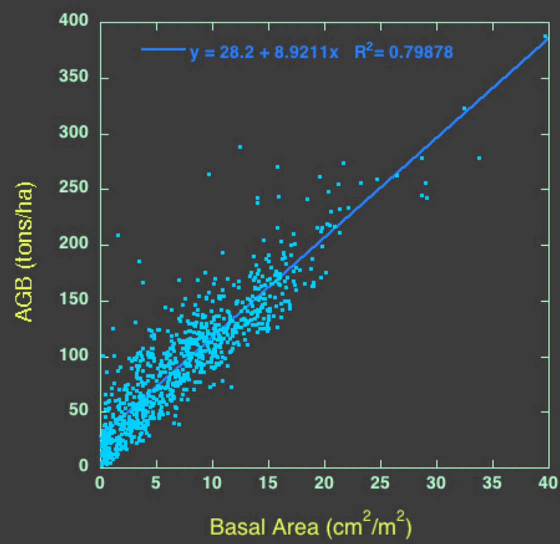


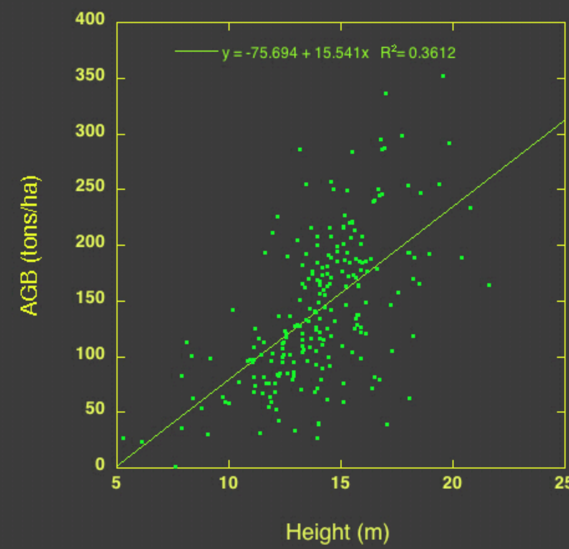
Wood density decreases as a function of tree height

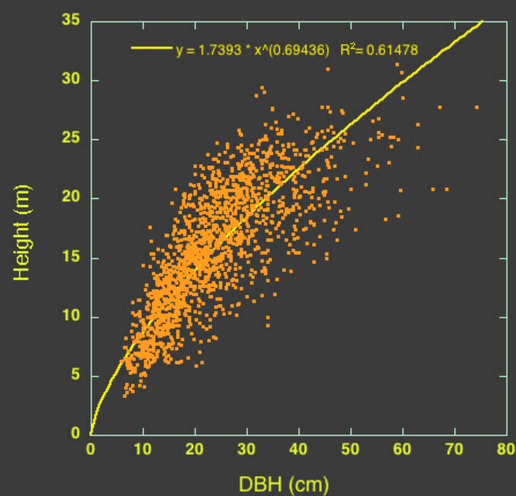
Water content(dielectric constant) increases as a function of tree height

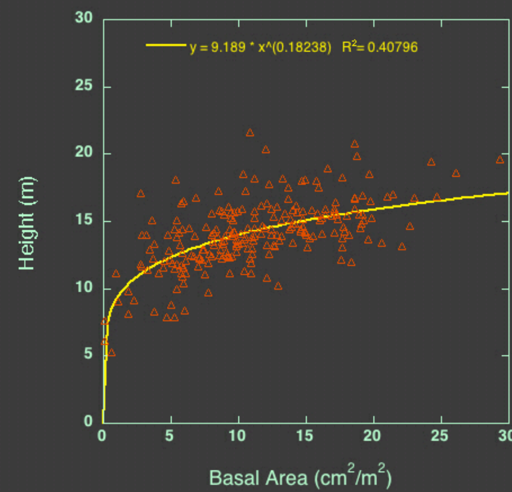

y = 41.817 + 0.61707x R2= 0.80551
Coniferous
AGB (tons/ha)
Volume (m3/ha)
y = 34.204 + 0.73339x R2= 0.78719
Deciduous
AGB (tons/ha)
Volume (m3/ha)
y = 34.668 + 0.64347x R2= 0.78961
Mixed
AGB (tons/ha)
Volume (m3/ha)
y = -75.694 + 15.541x R2= 0.3612
Coniferous
AGB (tons/ha)
Height (m)
y = -70.936 + 13.045x R2= 0.38247
Deciduous
AGB (tons/ha)
Height (m)
y = -48.052 + 12.377x R2= 0.28028
y = 0.47972 * x^(2.0863) R2= 0.23983
Mixed
AGB (tons/ha)
Height (m)









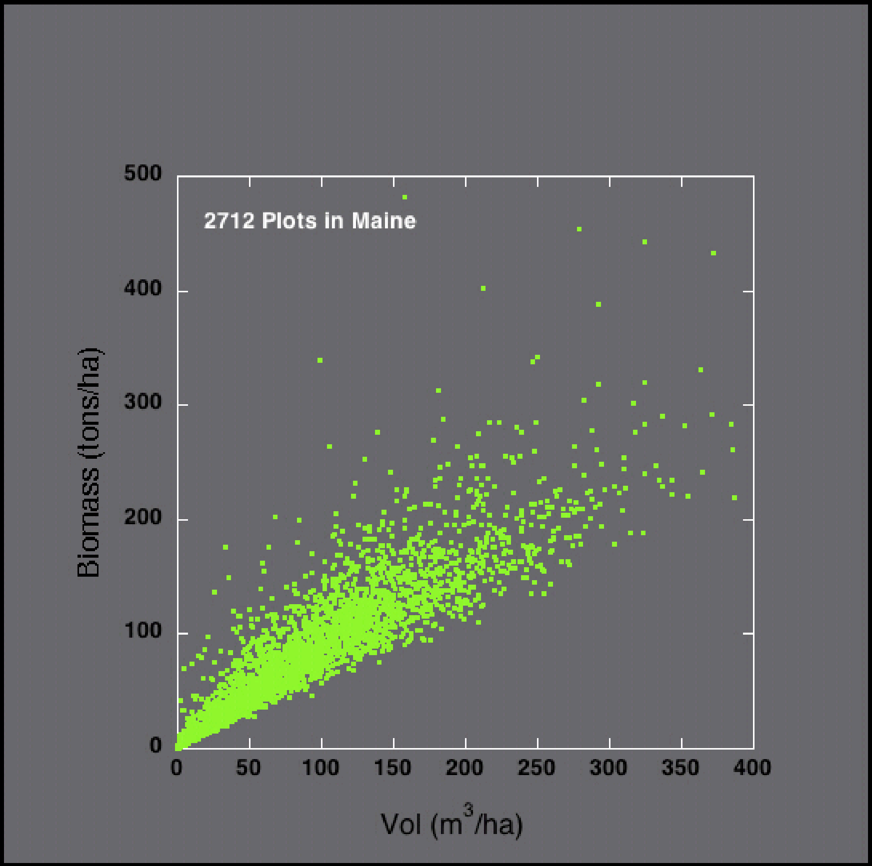


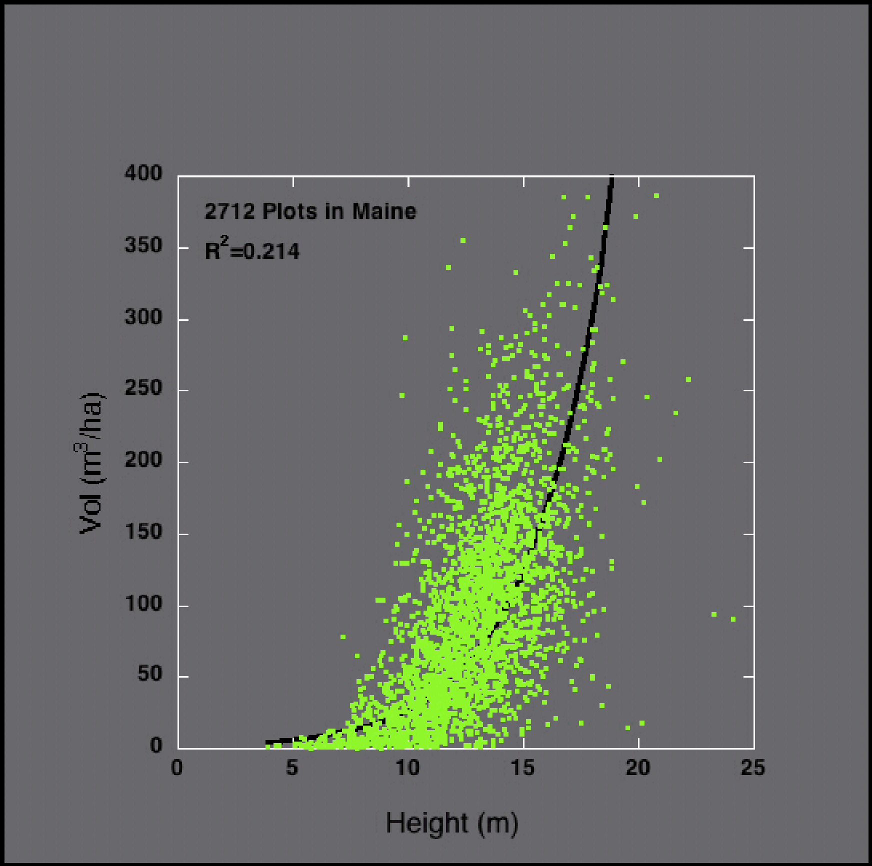
1. Volume is the best parameter to estimate biomass
2. Basal Area is the second best parameter
3. Height alone has the lowest sensitivity to biomass

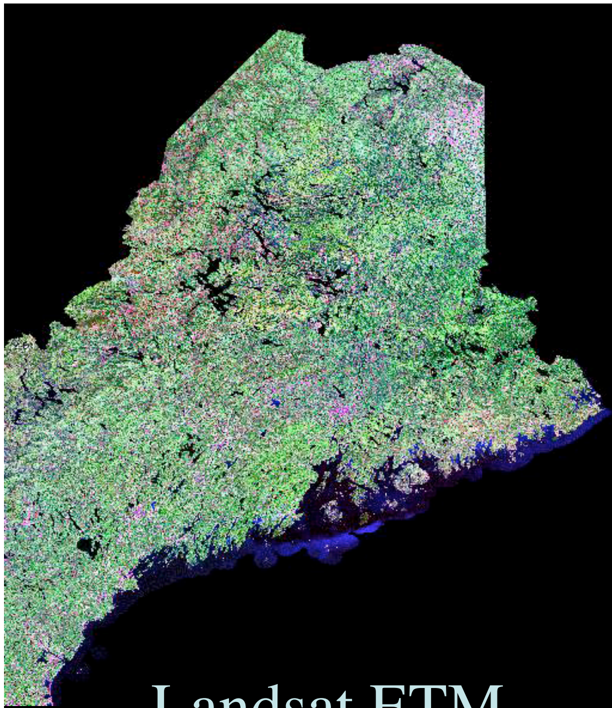
Basal Area and height are independent parameters

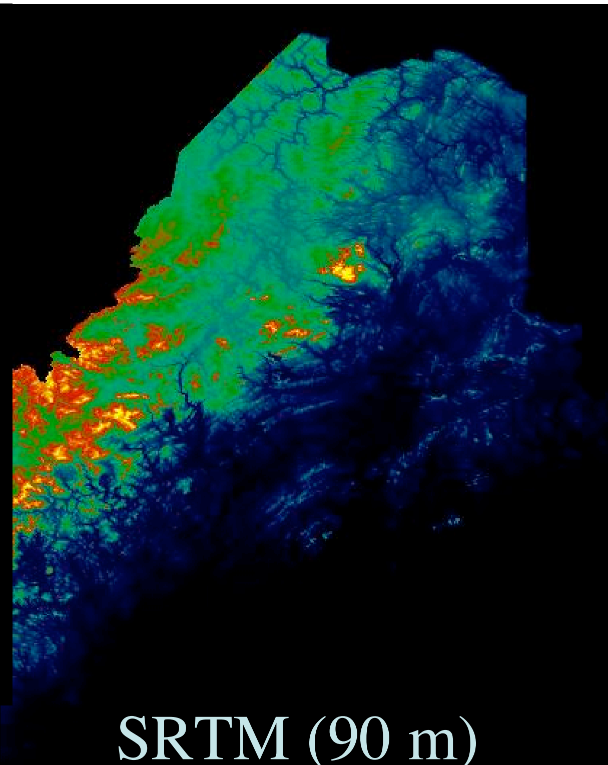
Estimation of height from dbh or basal area results in large errors

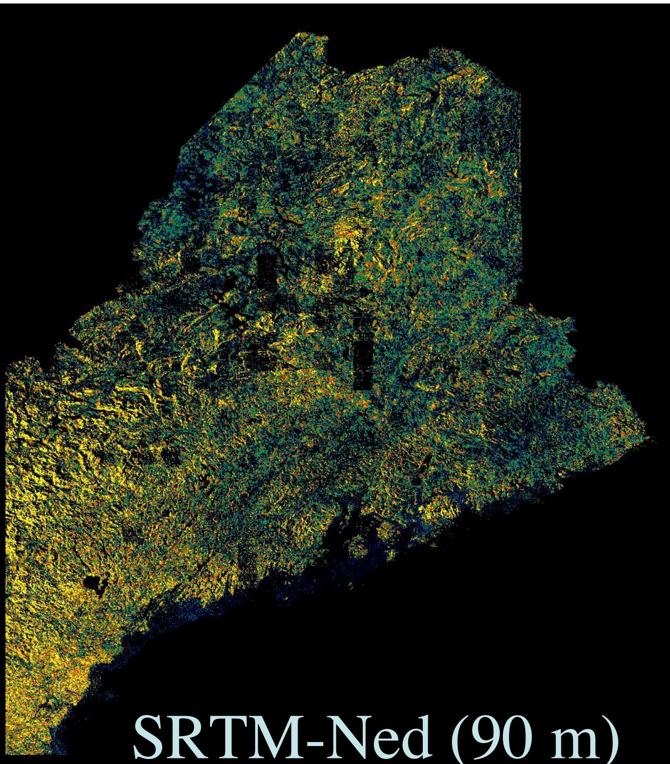
Including All Biomass Plots in Maine

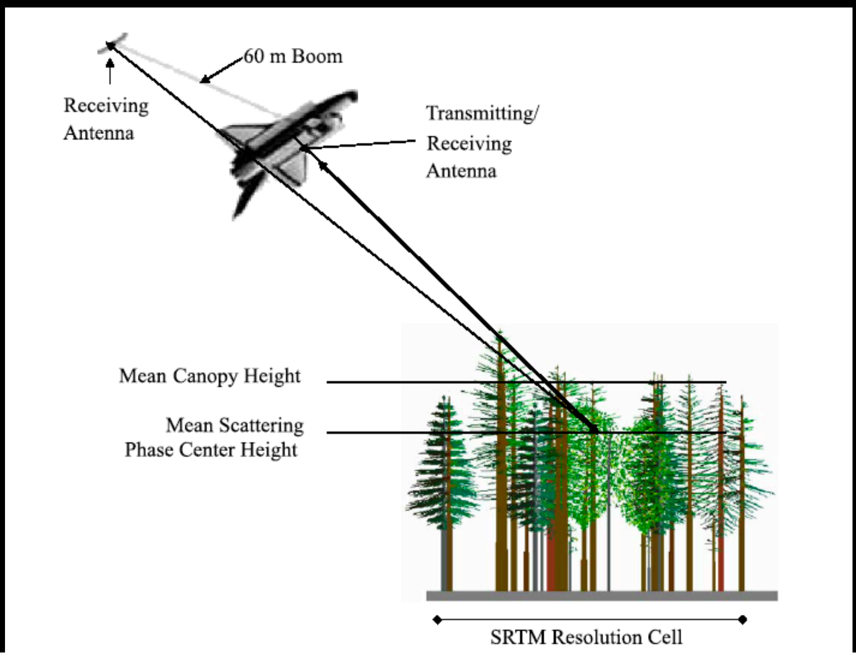


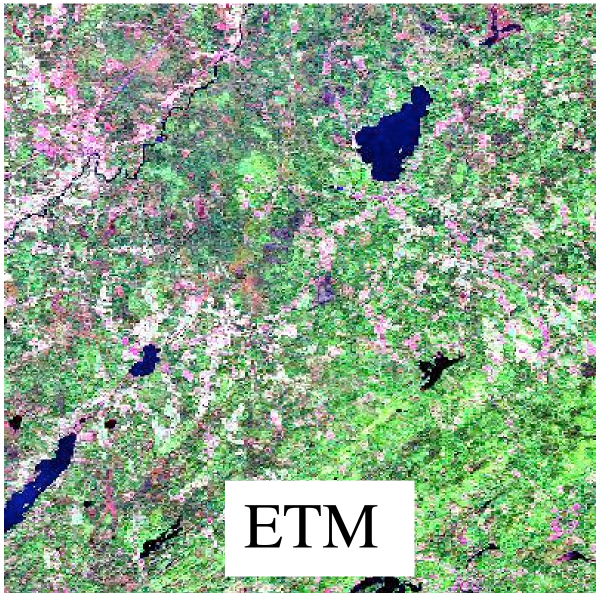


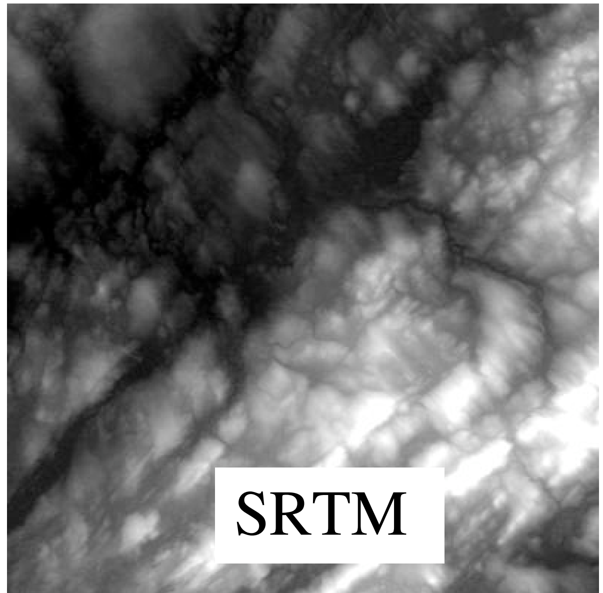

Landsat ETM
(90 m)


SRTM (90 m)

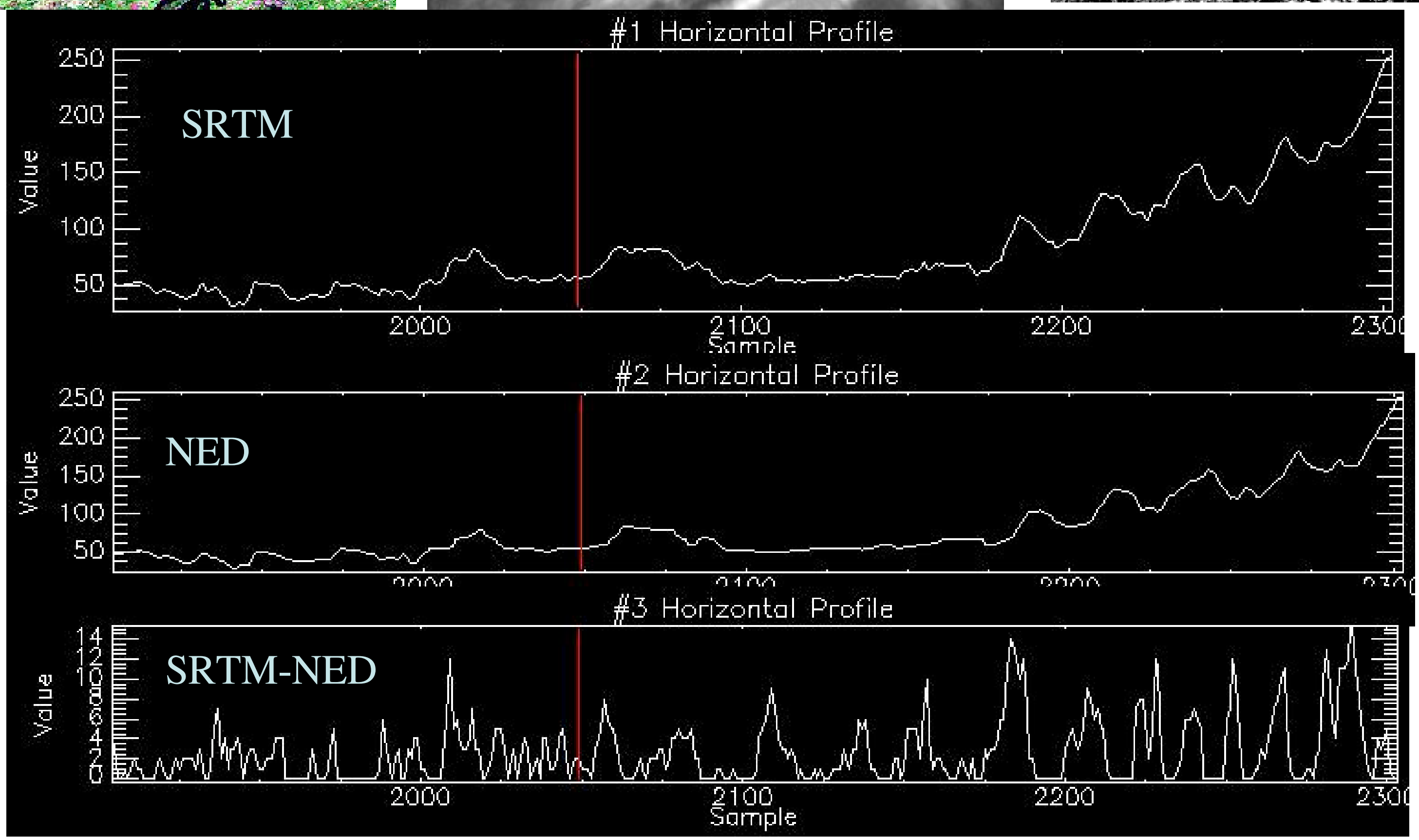

SRTM-Ned (90 m)


60 m Boom
Receiving Antenna
Transmitting/ Receiving Antenna
Mean Canopy Height
Mean Scattering Phase Center Height
SRTM Resolution Cell

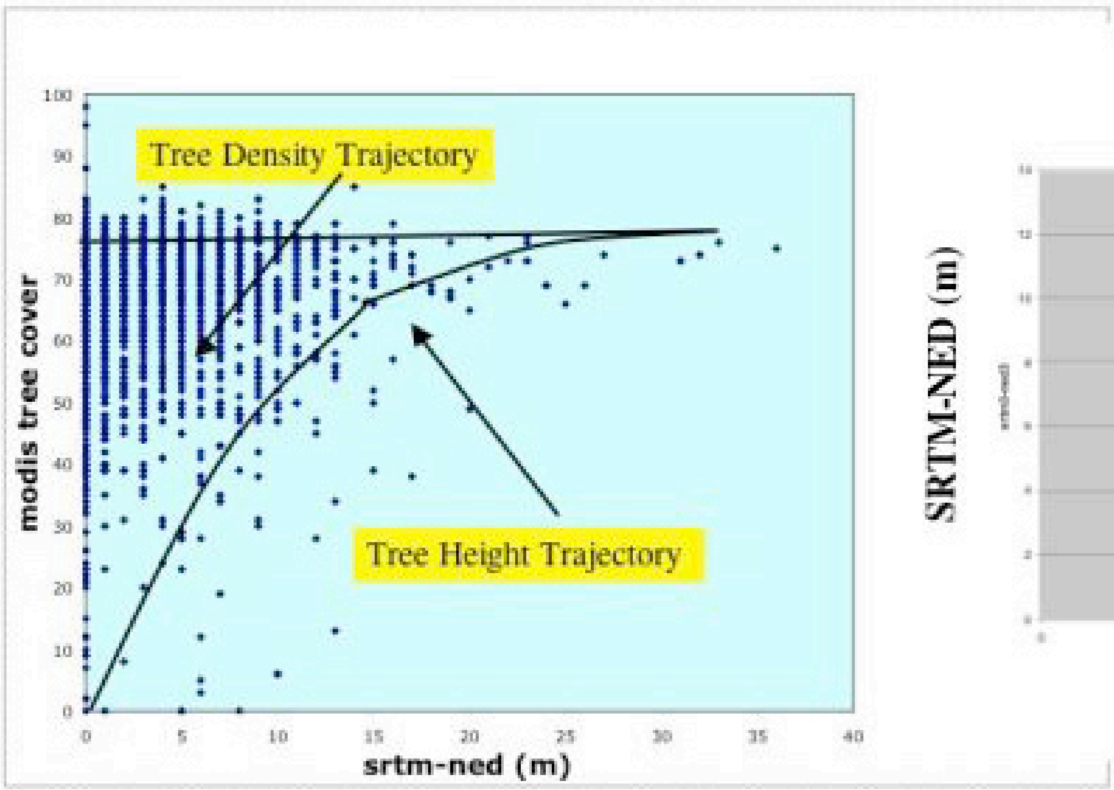

ETM

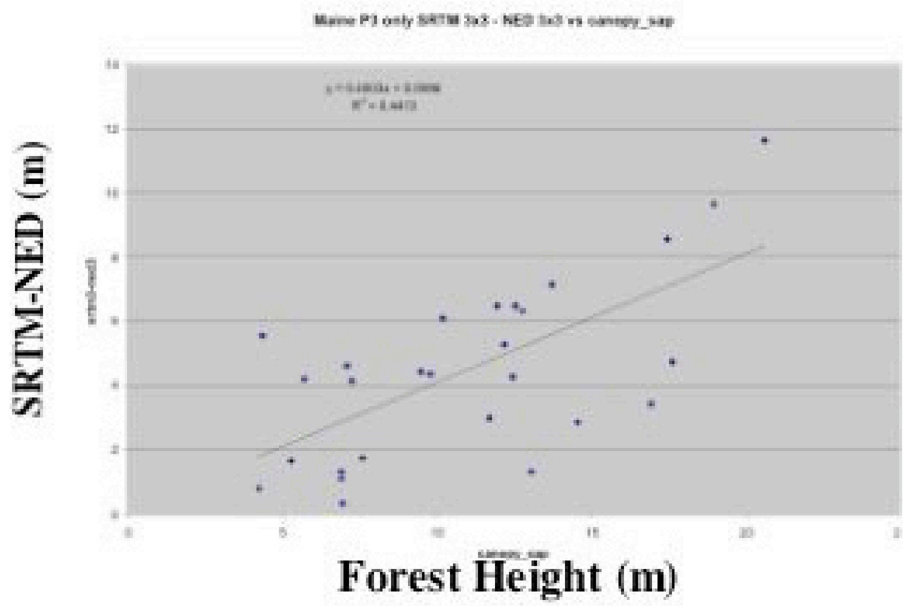

SRTM

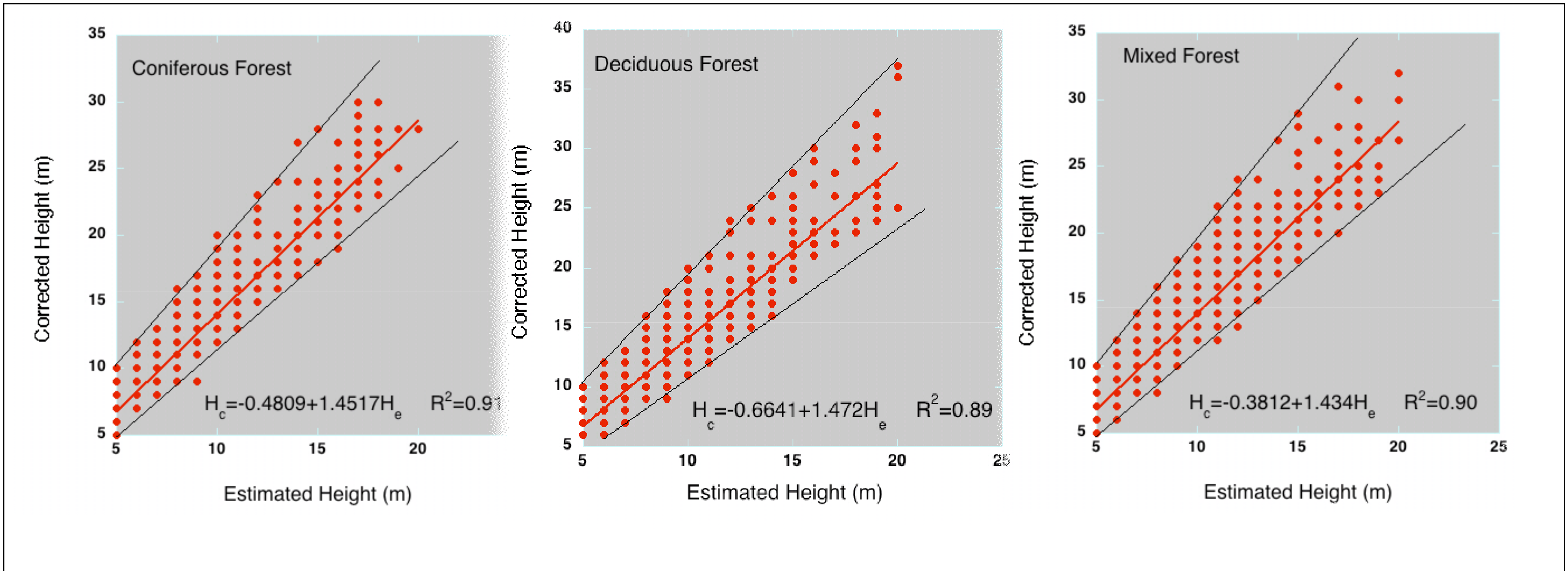

SRTM-NED


#1 Horizontal Profile
SRTM
Value
250
200
150
100
50
2000
2100
2200
2300
Sample
#2 Horizontal Profile
NED
Value
250
200
150
100
50
#3 Horizontal Profile
SRTM-NED
Value
14
12
10
8
6
4
2
0
2000
2100
2200
2300
Sample

Estimation of Tree Height from SRTM-NED



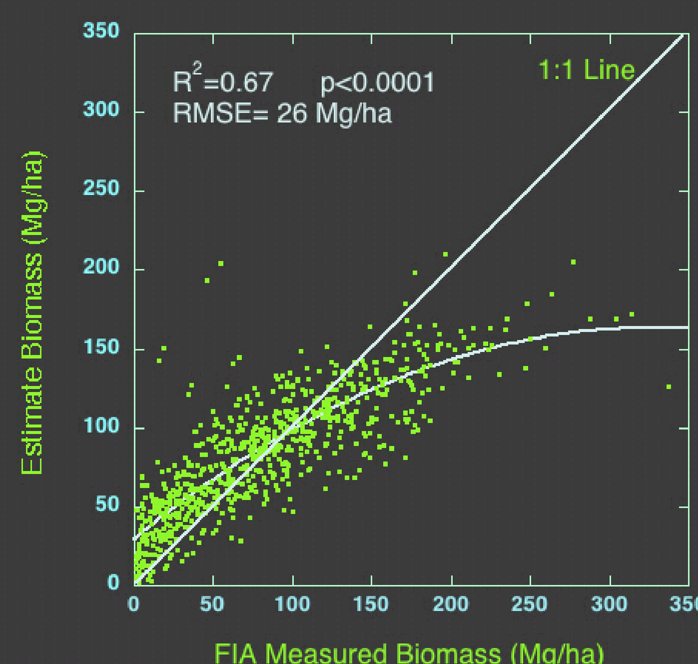


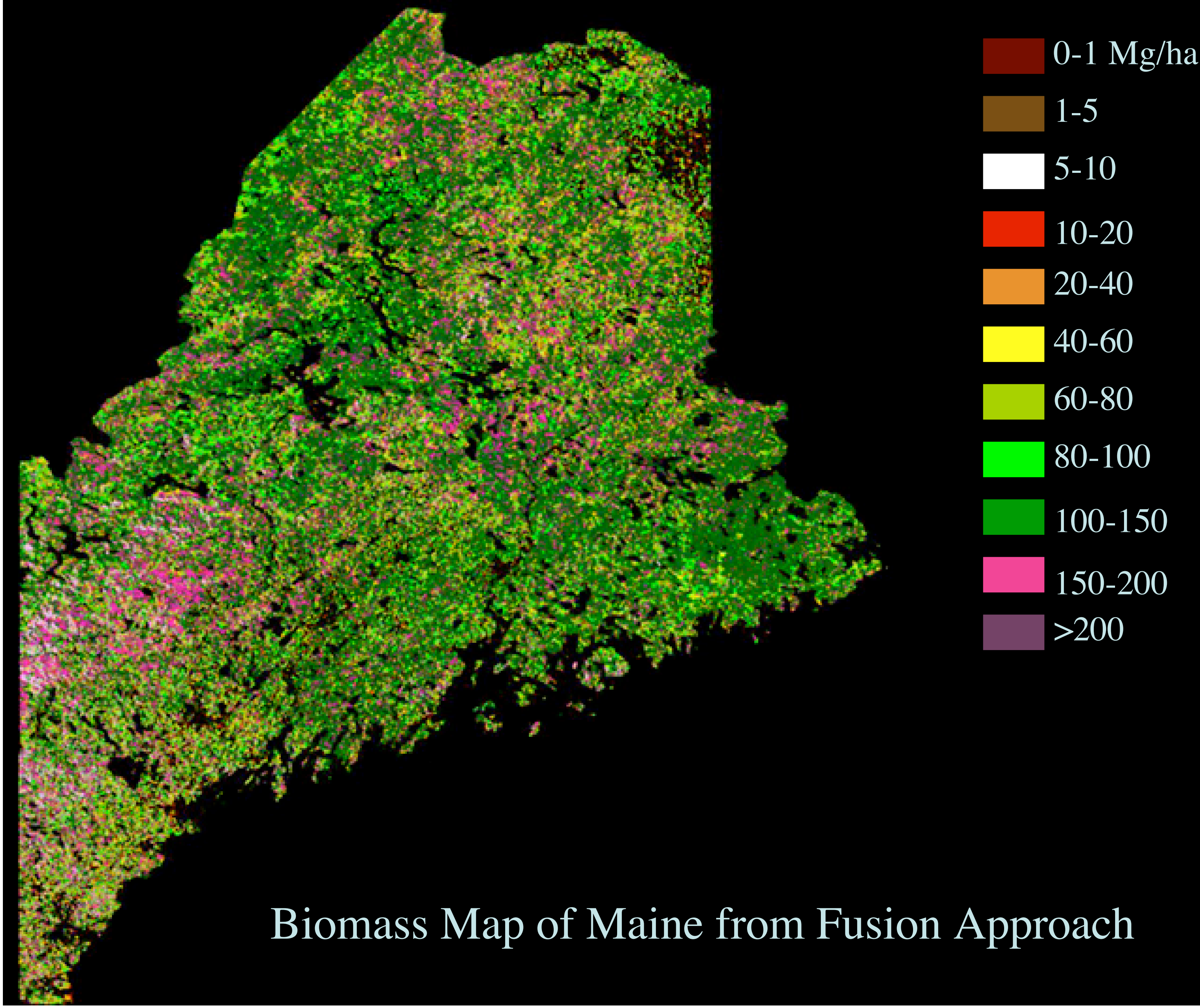


Approach:

Develop Three relations for Deciduous, Coniferous, and Mixed Forests:

$$AGLB = f(H_{srtm}, LAI, VCF)$$





Biomass Map of Maine from Fusion Approach

Preliminary Conclusions:

1. SRTM and NED data may provide a surrogate for tree height modulated with density over most of the US forests.
2. MODIS products are useful for algorithm development. However, direct spectral information will be used in final algorithms.
3. Simple MODIS derived land cover classification improves biomass algorithm.

Next Steps:

1. Development of Algorithm from MODIS, SRTM Height, JERS, and Radarsat over the US forests using Sample FIA plots.
2. Develop a spatial uncertainty for final biomass product over US using FIA data.
3. Develop Biomass Algorithm over Boreal Forest of Canada and Alaska using JERS, MODIS and land cover map.
4. Distribute data and products from website after FIA approval.