# PINEMAP Project scaling loblolly pine productivity in the southeastern U.S.

Randy Wynne, Steve McNulty, and Bob Teskey

PINEMAP Webinar

January 18, 2013

Pine Integrated Network: Education, Mitigation, and Adaptation project (PINEMAP) is a Coordinated Agricultural Project funded by the USDA National Institute of Food and Agriculture, Award #2011-68002-30185

USDA United States Department of Agriculture National Institute of Food and Agriculture

# Growth and Yield Modeling in the PINEMAP Project Webinar

**January 18, 2013**

# Overall Modeling Flow Chart

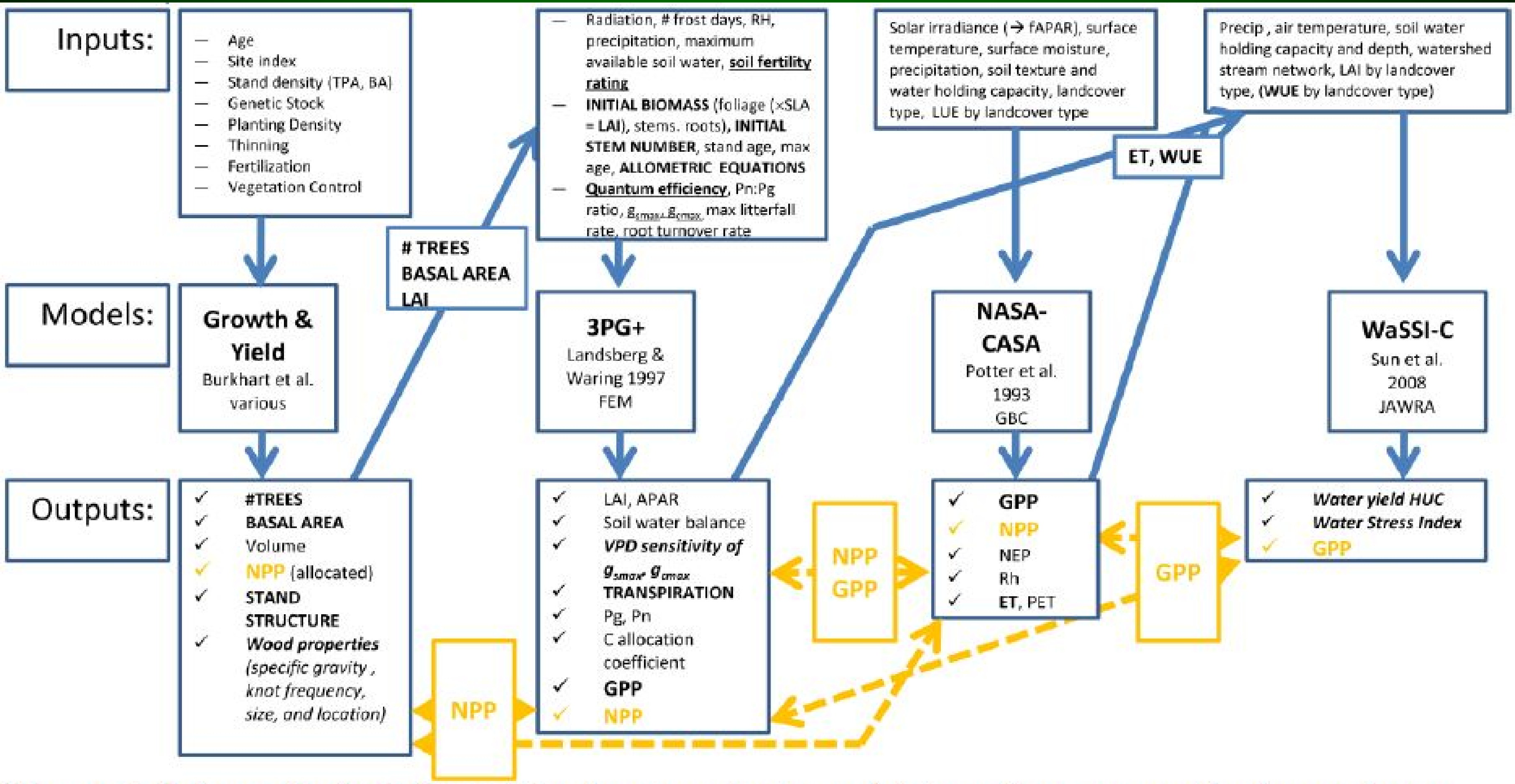



**Figure 6.** Schematic depiction of the inputs, outputs, and interactions among the four primary models. Solid blue arrows indicate data flow between models, yellow dashed arrows and variable names indicate cross comparison of common model outputs, **BOLD CAPS** input & output parameters indicate variables transferred among models, underlining indicates key sources of stand-level variability, and *italics* indicates terminal outputs unique in scale.

# Two Major Management Components

**Genetic Improvement**

- Growth
- Stem quality
- Pest resistance

**Silvicultural Inputs**

- Thinning
- Competition control
- Fertilizer applications

In the context of varying climatic influences.

# Overall Approach

- Build a general model structure that will accommodate tree and/or stand inputs
- Incorporate functions for genetic improvement
- Incorporate response to silvicultural treatments
- Incorporate climatic influences

# Genetic Improvement to Enhance

Growth Yield

Wood Quality

Disease/Pest Resistance

# Strategy for incorporating genetic improvement effects in growth and yield models

1) Assemble data with varying levels of genetic selection (seed source, OP, clone) and analyze in a common framework for genetic effects on
    a. Height development
    b. Diameter development
    c. Tree stem quality
    d. Disease incidence
2) Incorporate impacts in model components
    a. Height growth
    b. Diameter growth
    c. Mortality estimation
    d. Product distributions by size classes

# Incorporating response to Silvicultural Treatments

Fit general response functions with duration and rate parameters to a selected data set for

- Thinning (FMRC regionwide thinning data)
- Competition Control (COMP Project)
- Fertilizer applications (FPC, Regionwide 13)

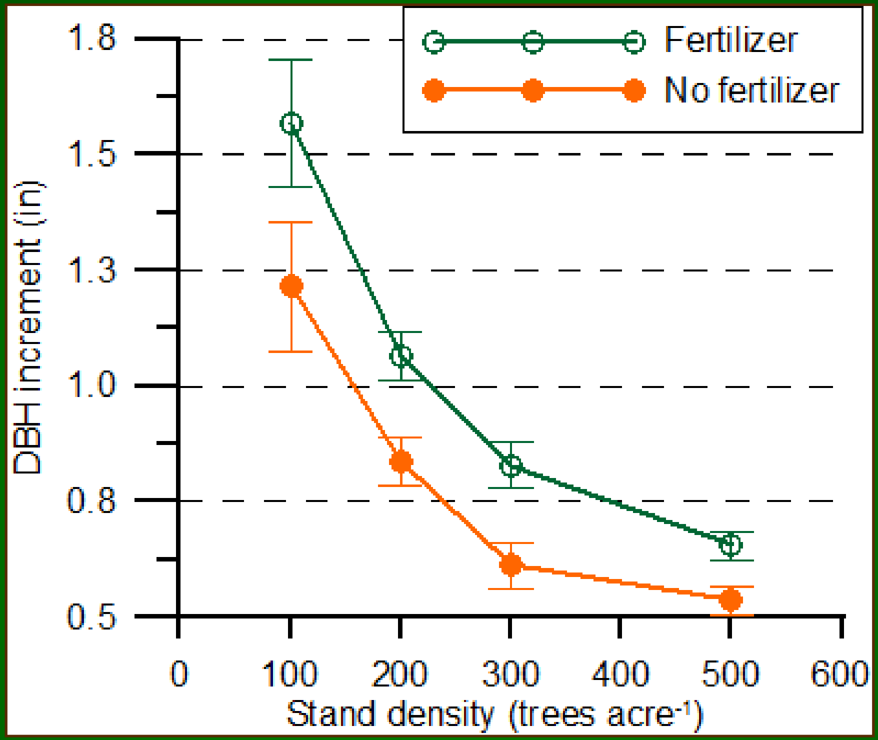
# Evaluate various general response functions

- Pienaar and Rheney (1995) For. Sci. 41:629-638
- Snowdon (2002) For. Ecol. and Manage. 163:229-244.
- Liu *et al*. (1995) For. Sci. 41:43-53.
- Franklin *et al*. (2009) Ann. For. Sci. 66:815p1-815p11.
- New formulations

Compare results using generalized response functions to performance of published results for representative data sets for thinning, competition control, and fertilizer

After initial evaluation, use the comprehensive Tier 1 PINEMAP data set to further test and calibrate response functions

# Assume Treatment Effects are Additive

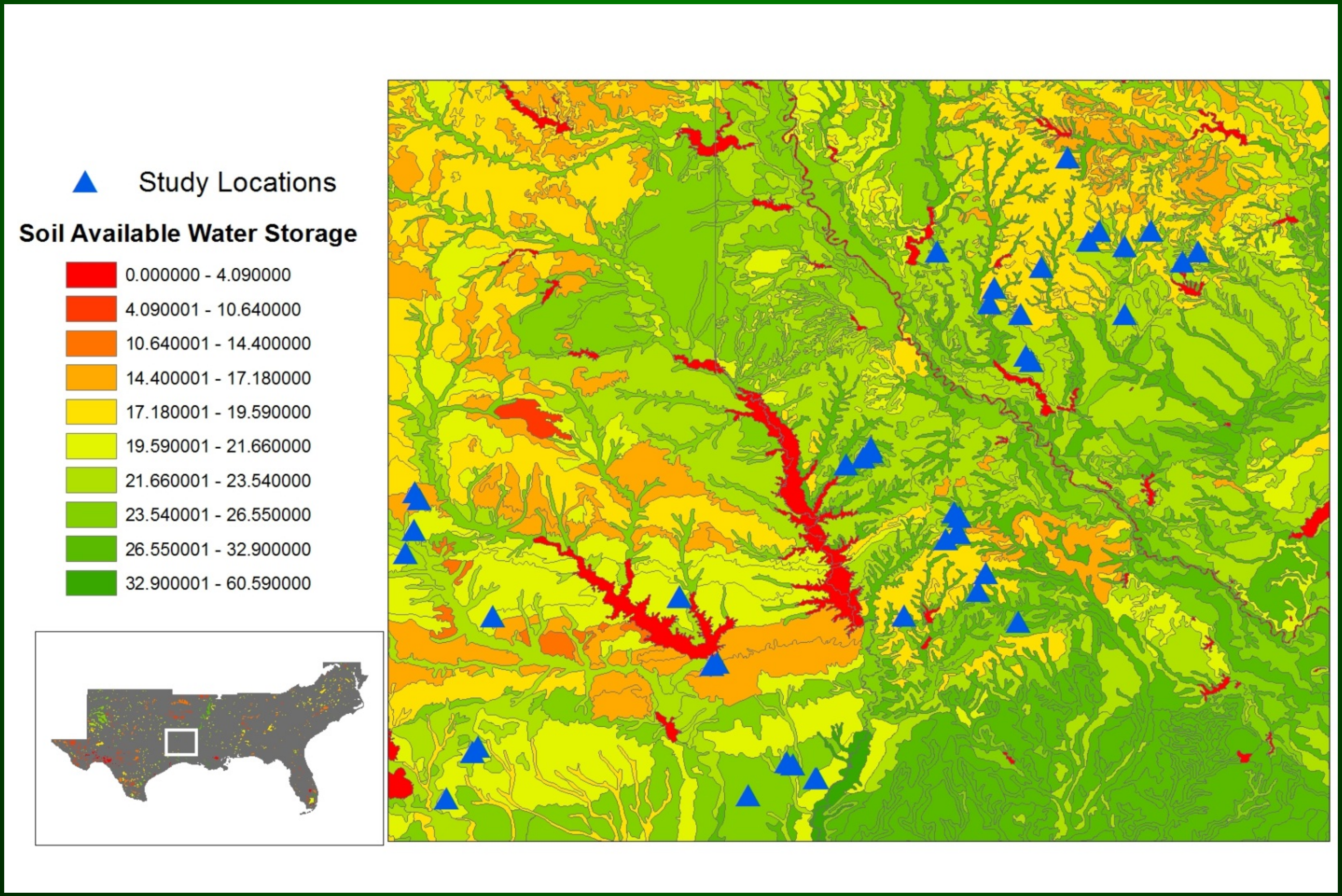



Thinning and Fertilization RW19

Combined effects of weed control and fertilization reported to be additive by Albaugh, et al. 2012. SJAF 36(1):44-53.

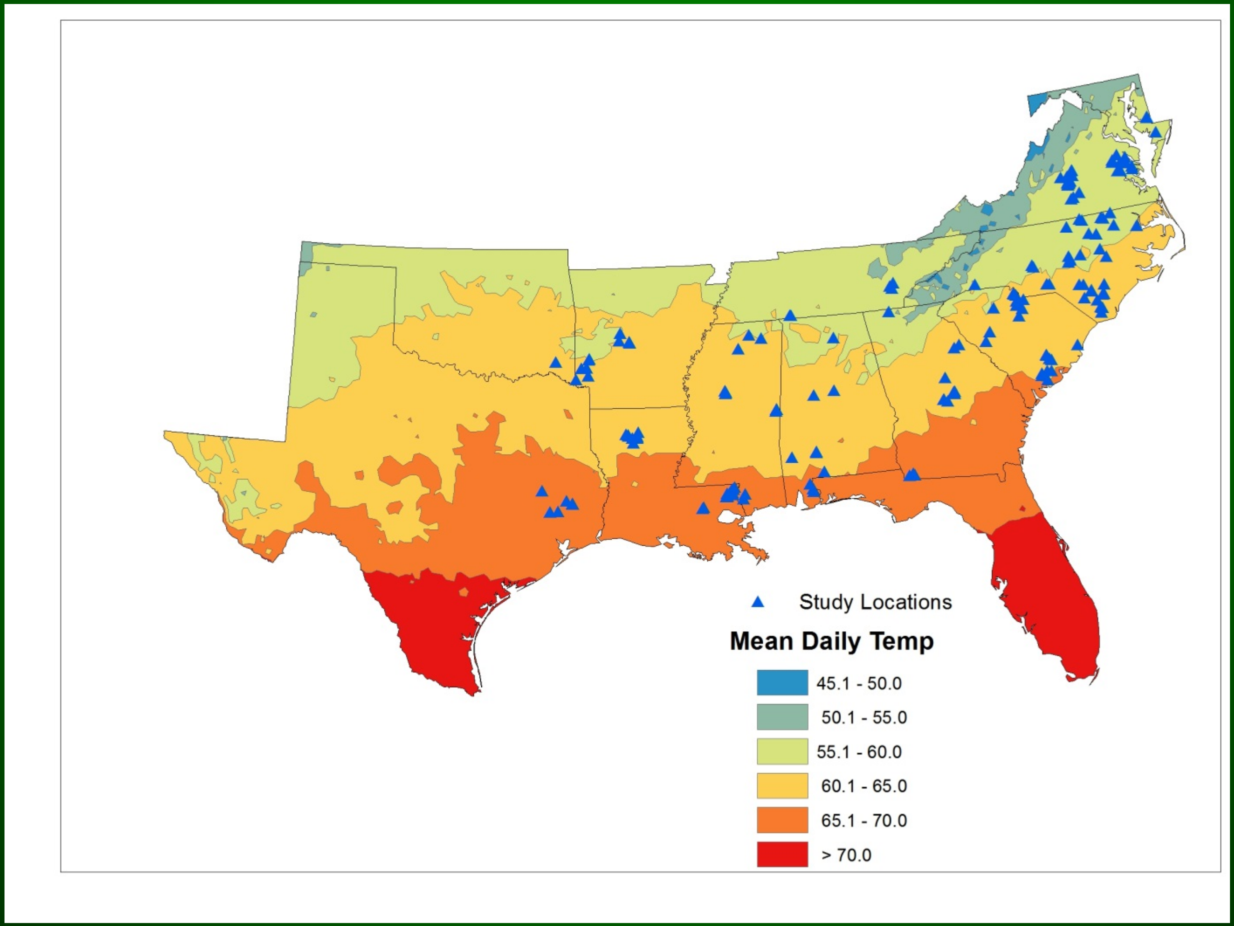
# Incorporate Climatic Effects in Growth and Yield Predictions

## Soils Data



# Incorporate Climatic Effects in Growth and Yield Predictions

## Climate Variables

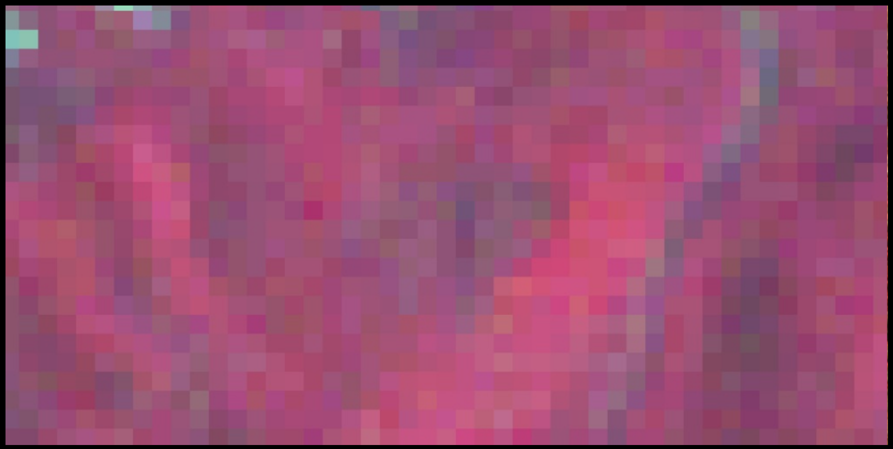


- Cross-check Growth and Yield Predictions with Process Model 3PG

- Implement Growth and Yield Module with Options for Simulating Future Conditions

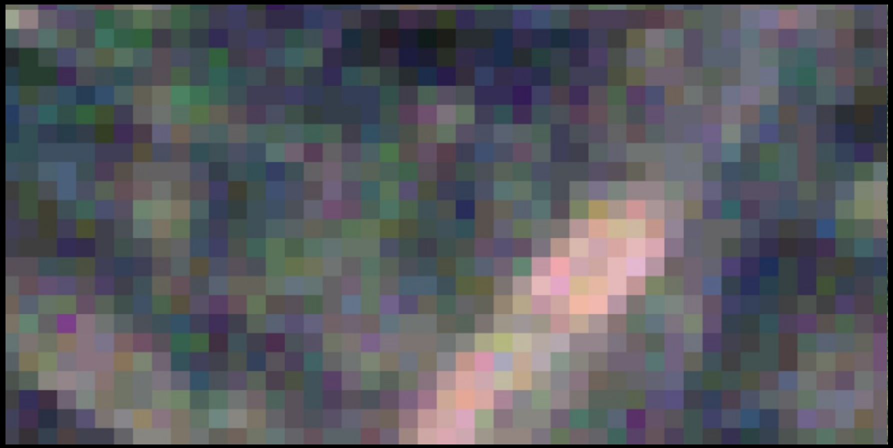
PINEMAP

# Regional Baseline Estimates of Forest Biomass at Management Scale Using Landsat



To detect when this...

When all you see is this!



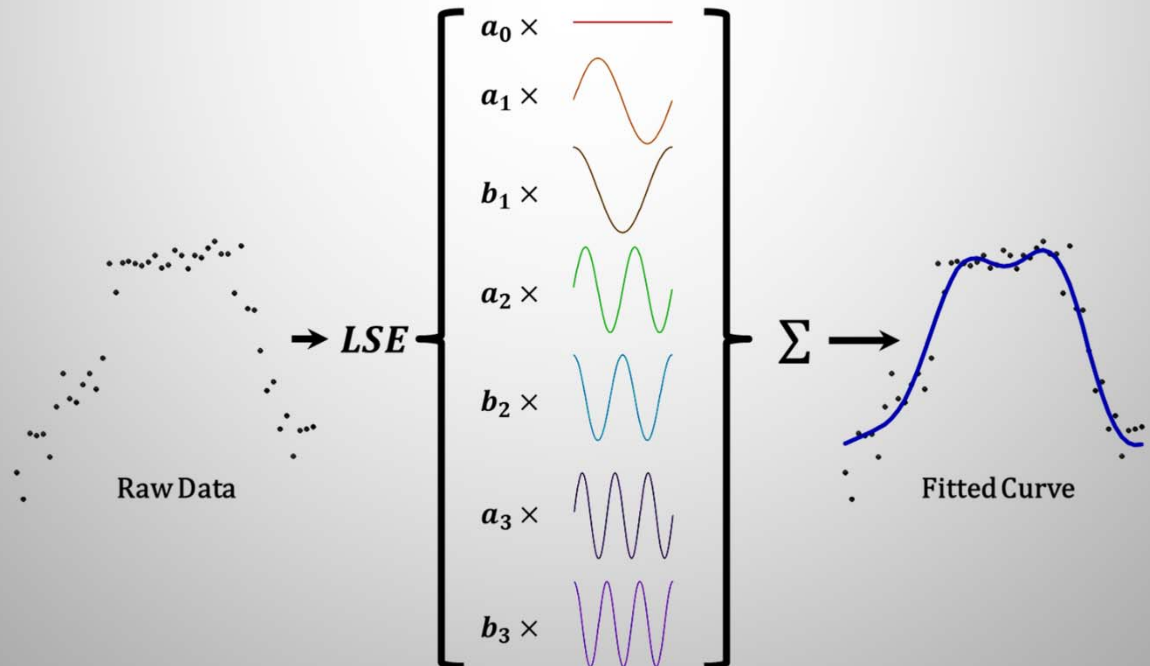
Shifts to this...

# Preparation of Data

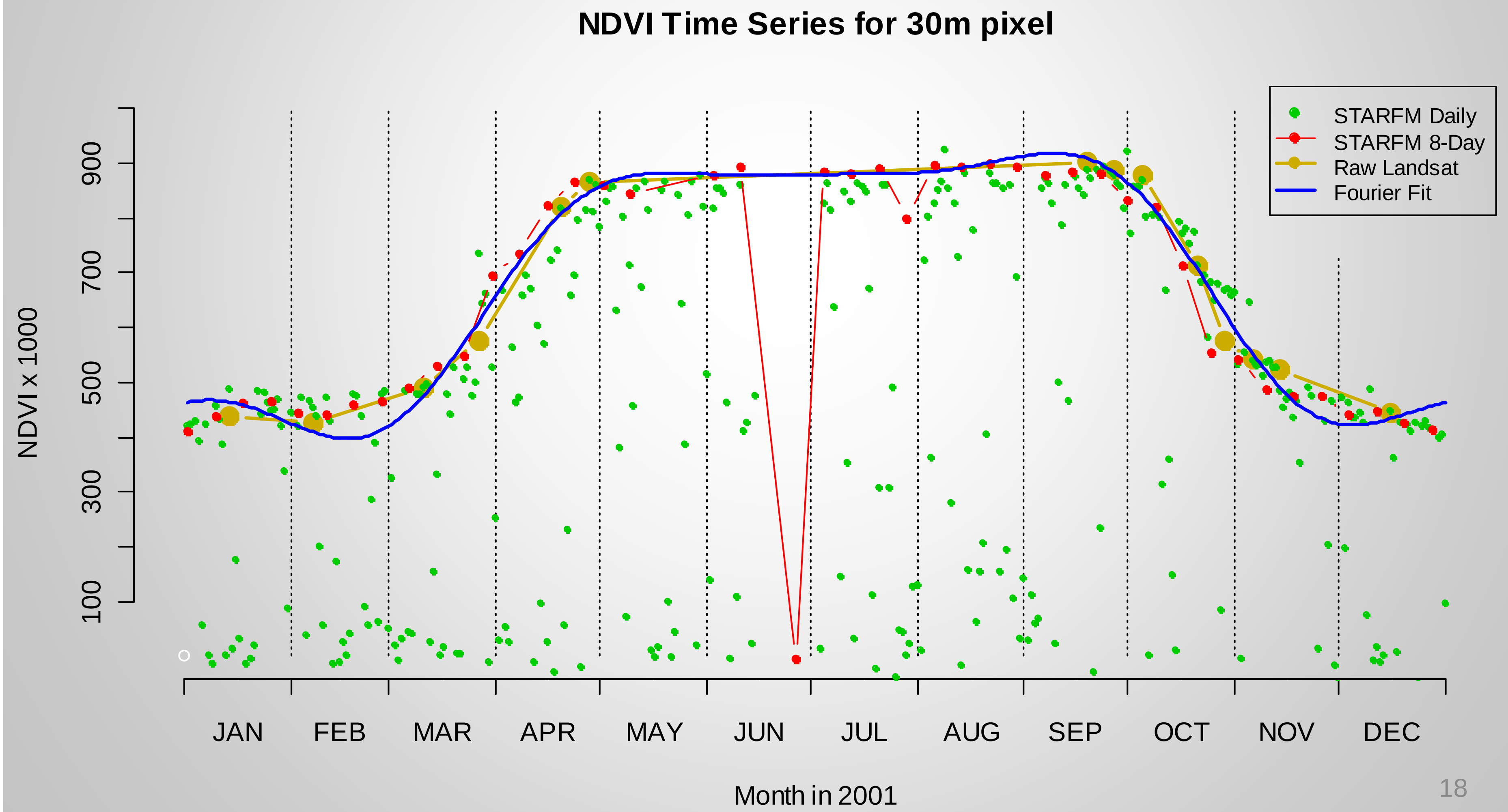
- While Landsat images come in every 16 days, not all images provide clear land surface features
  - e.g., clouds may obscure parts or all of multiple images
- In order to apply methods relying on long histories of data, we need to find a way to fill these gaps back in

# Enter Harmonic Regression

- Assumptions
  - Any pixel on January 1st is roughly equal to that pixel on December 31st in terms of its brightness vector
  - Changes from one date to another for that pixel are relatively linear with no sudden shifts in direction



Harmonic regression approximates seasonal features for vegetated pixels as well as STAR-FM does, with much lighter computational costs

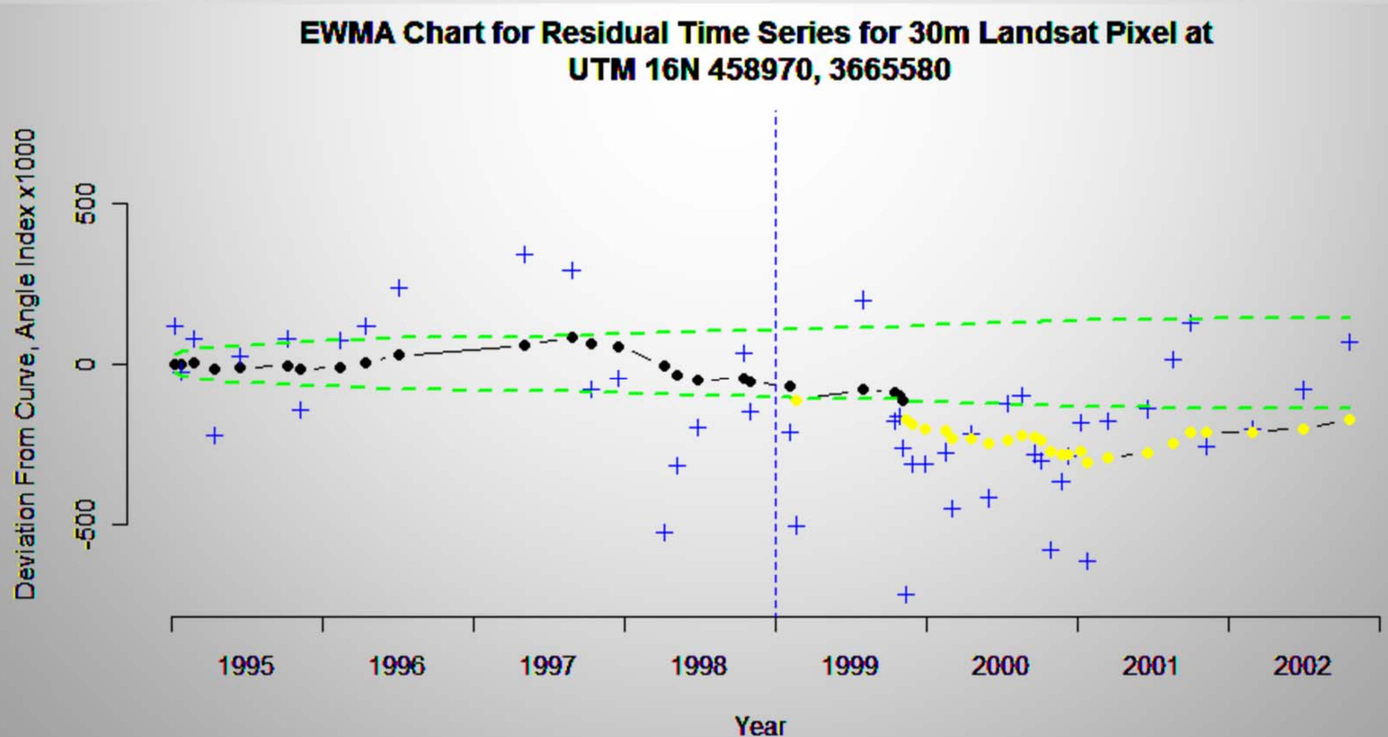


# Using Regression to Detect Changes

- What happens when the assumptions behind harmonic regression fail?
  - Sudden change in the time series
  - Gradual aperiodic element present in the series
  - In short, the forest changes or gets disturbed

- “Failed” assumptions in harmonic regression show up most clearly in the residuals
  - Residuals supposed to be 0 on the average
  - Detect when residuals’ average shifts from 0 to detect shifts in forest pixels

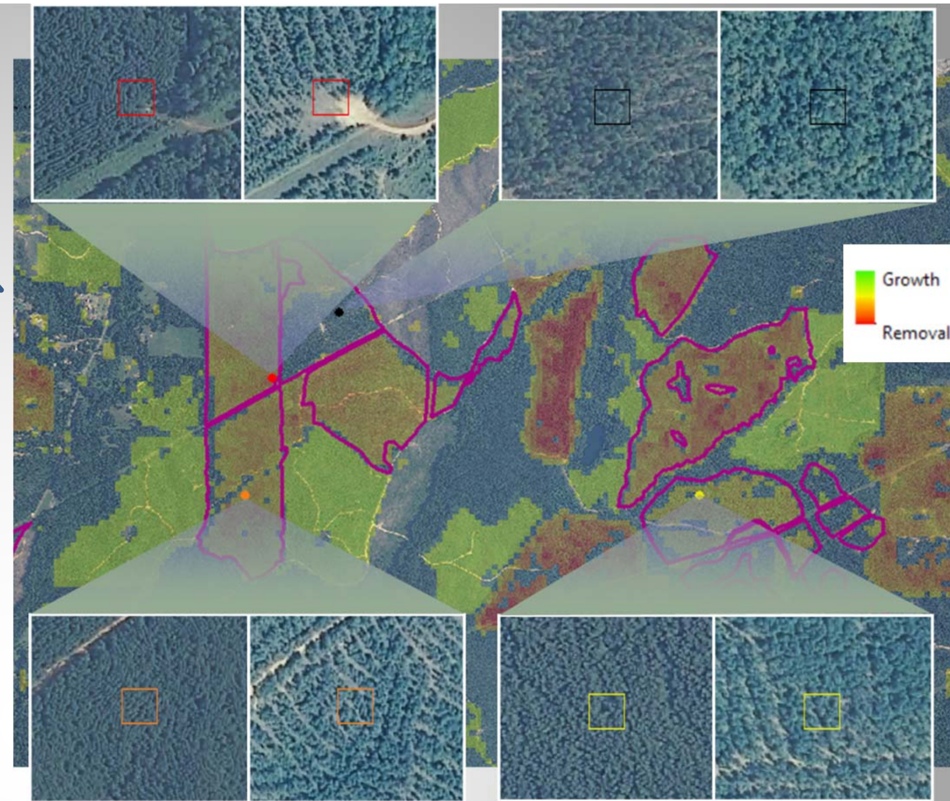
- Exponentially weighted moving average (EWMA) charts can detect subtle shifts
  - Weights current observation against entire history or observations
    - Changing the weight parameter adjusts the target shift the chart will signal for

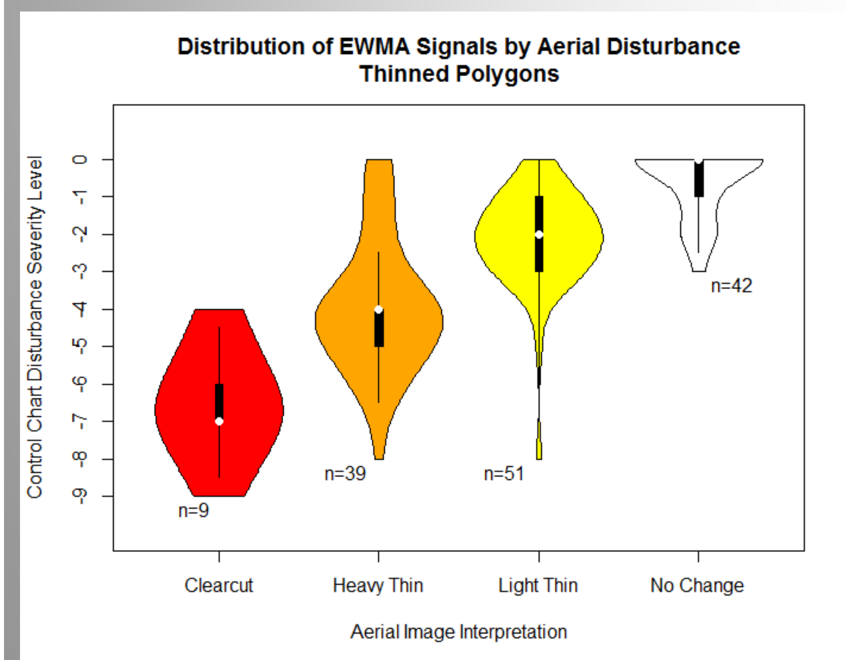


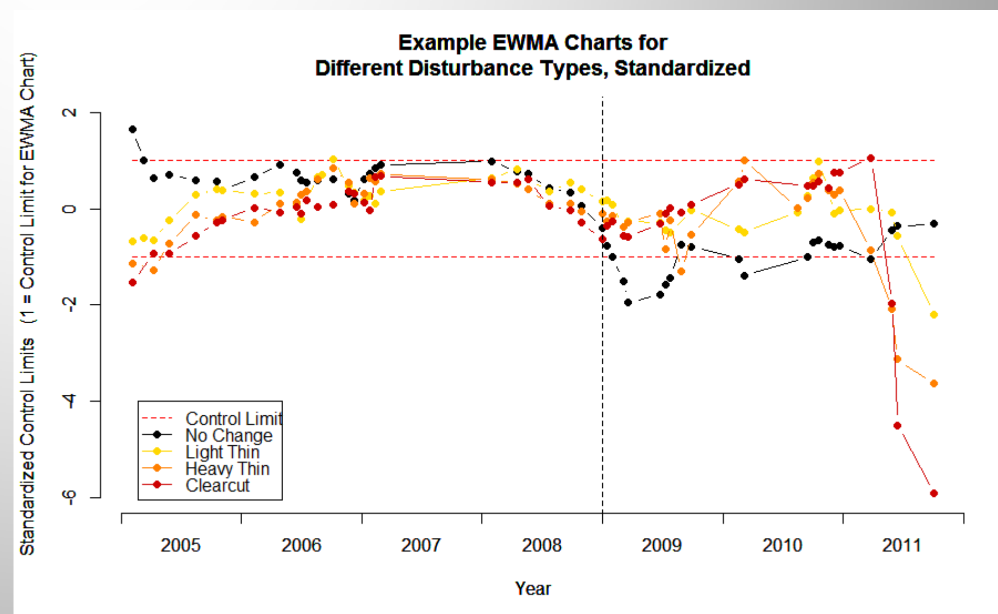
We compared the algorithm's output to ***aerial images*** of polygons where ***stand harvesting*** was known to have taken place over a timeframe

Disturbances are signaled ***shortly after they occur***

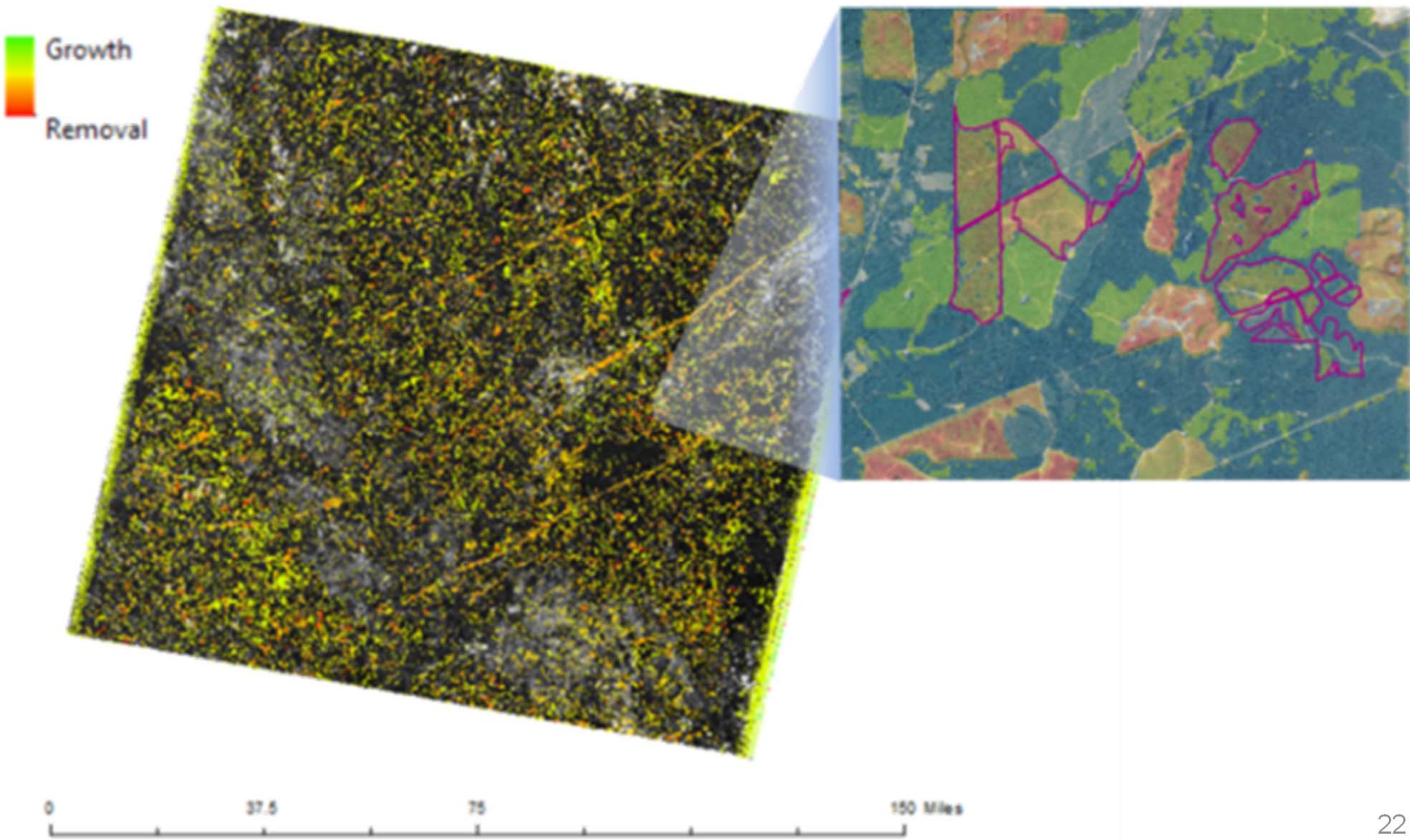
There was a ***clear positive association*** between the output and the aerial photos

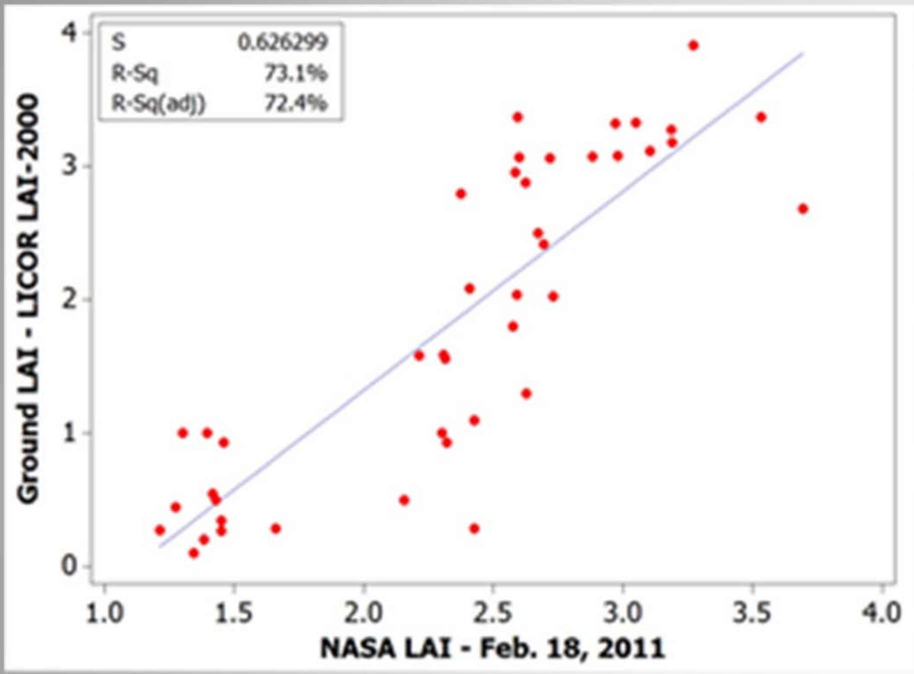


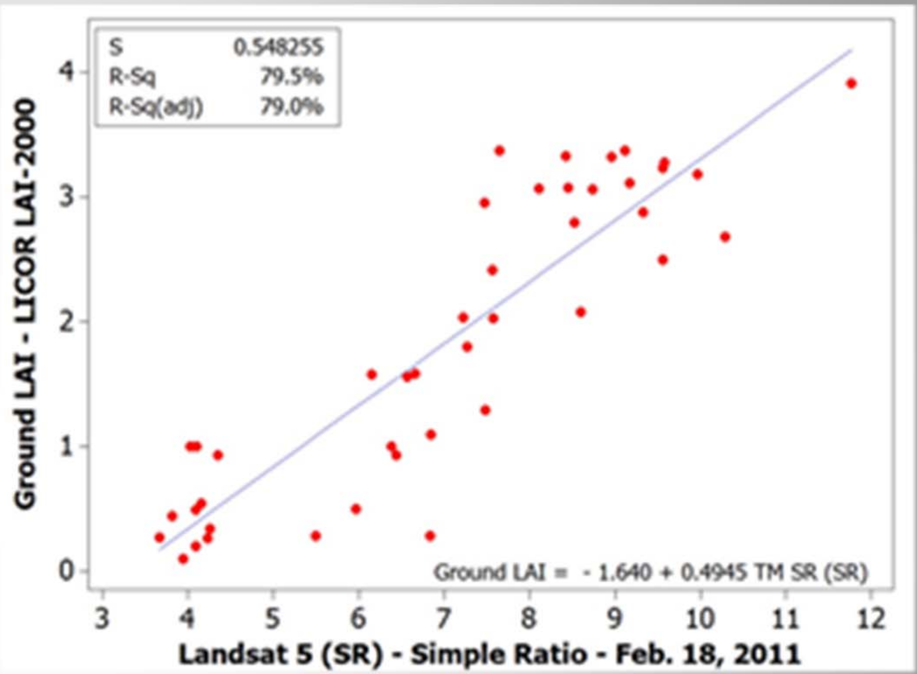



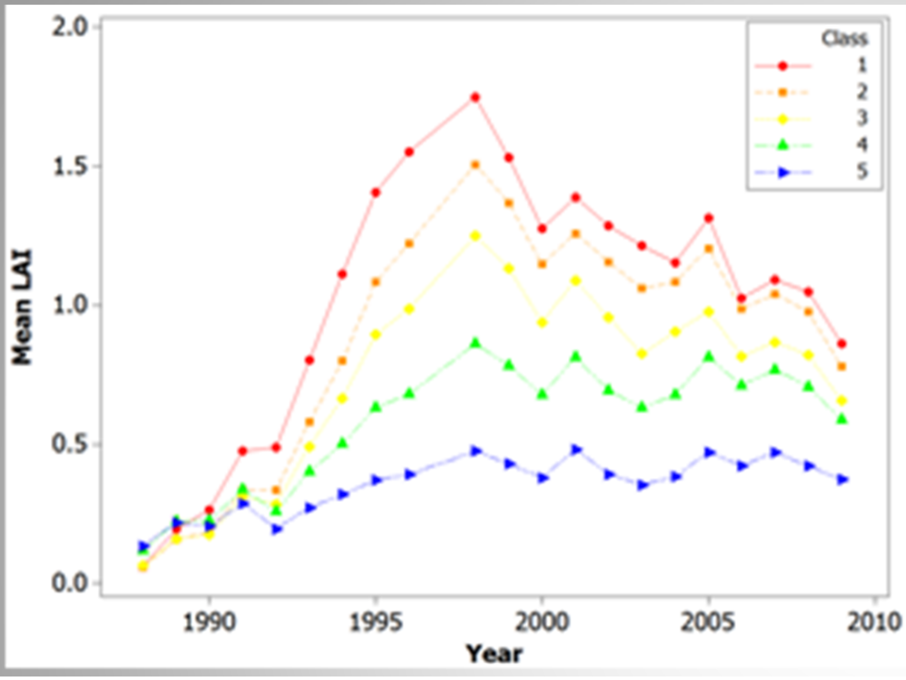



# The algorithm can detect both increase and decrease in vegetation, on varying levels of subtlety

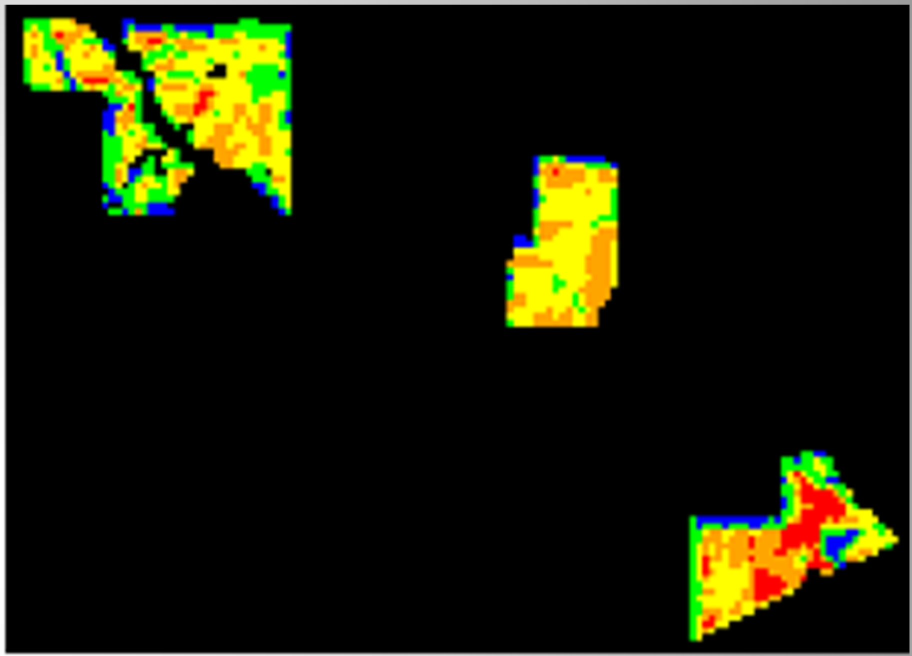



S 0.626299
R-Sq 73.1%
R-Sq(adj) 72.4%
Ground LAI - LICOR LAI-2000
NASA LAI - Feb. 18, 2011

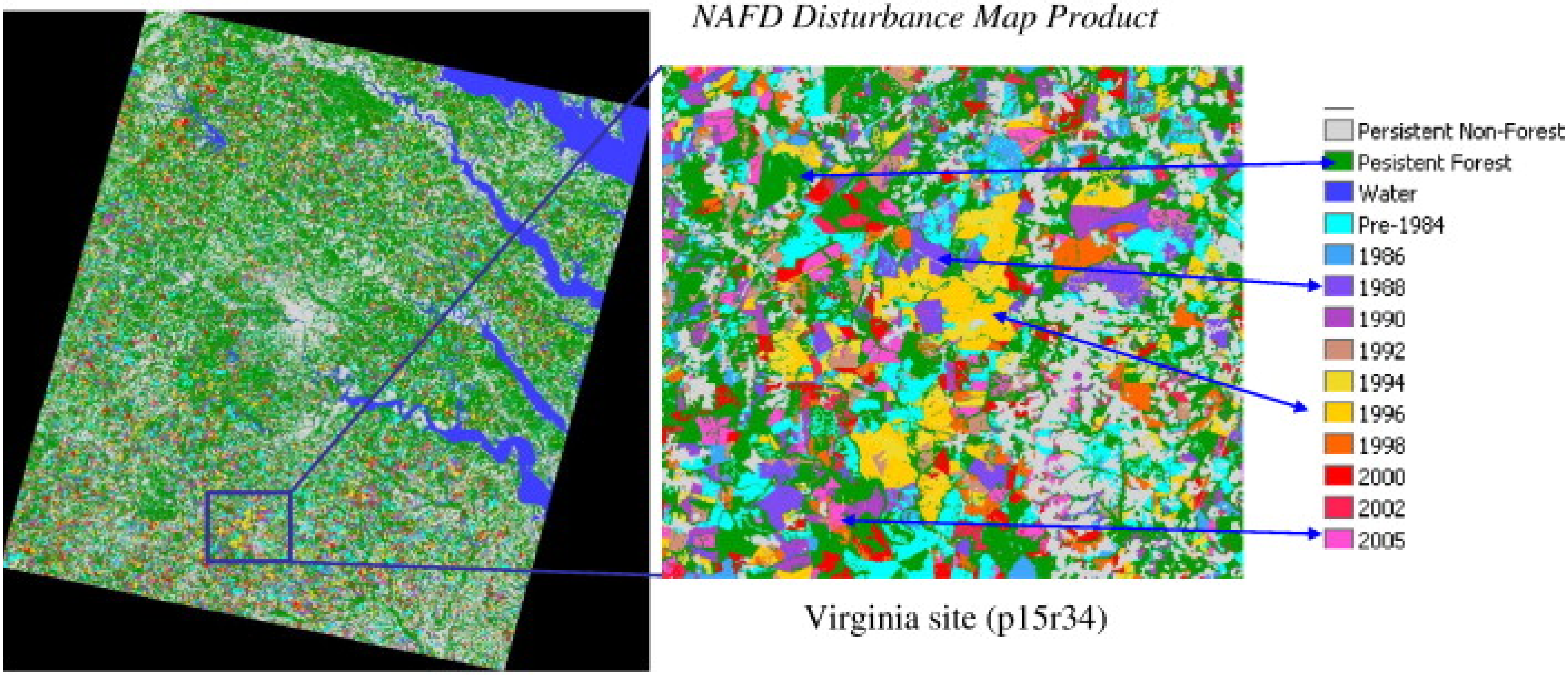

S 0.548255
R-Sq 79.5%
R-Sq(adj) 79.0%
Ground LAI = - 1.640 + 0.4945 TM SR (SR)
Ground LAI - LICOR LAI-2000
Landsat 5 (SR) - Simple Ratio - Feb. 18, 2011



Mean LAI
Year
Class
1
2
3
4
5
2.0
1.5
1.0
0.5
0.0
1990
1995
2000
2005
2010

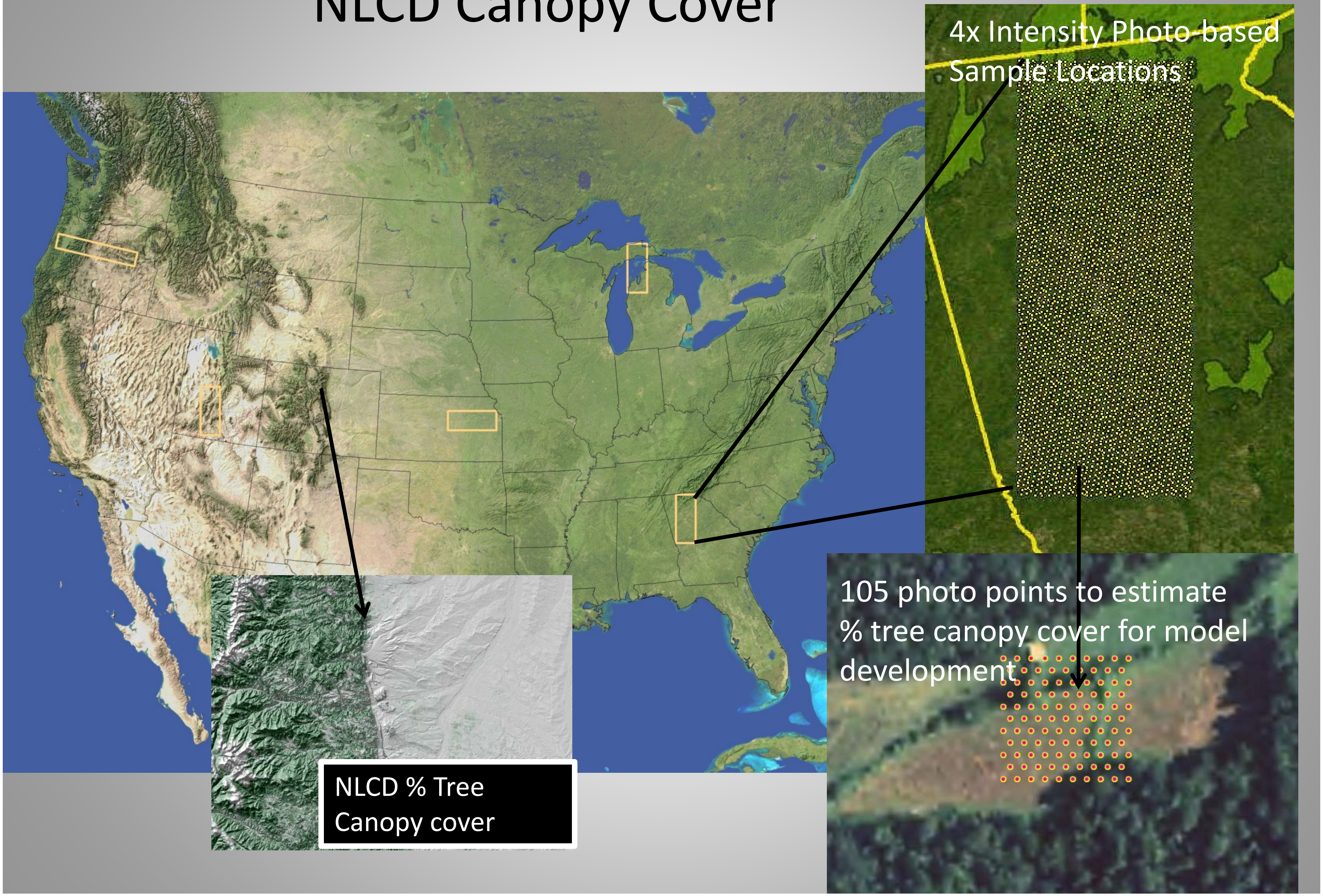



*NAFD Disturbance Map Product*




Virginia site (p15r34)

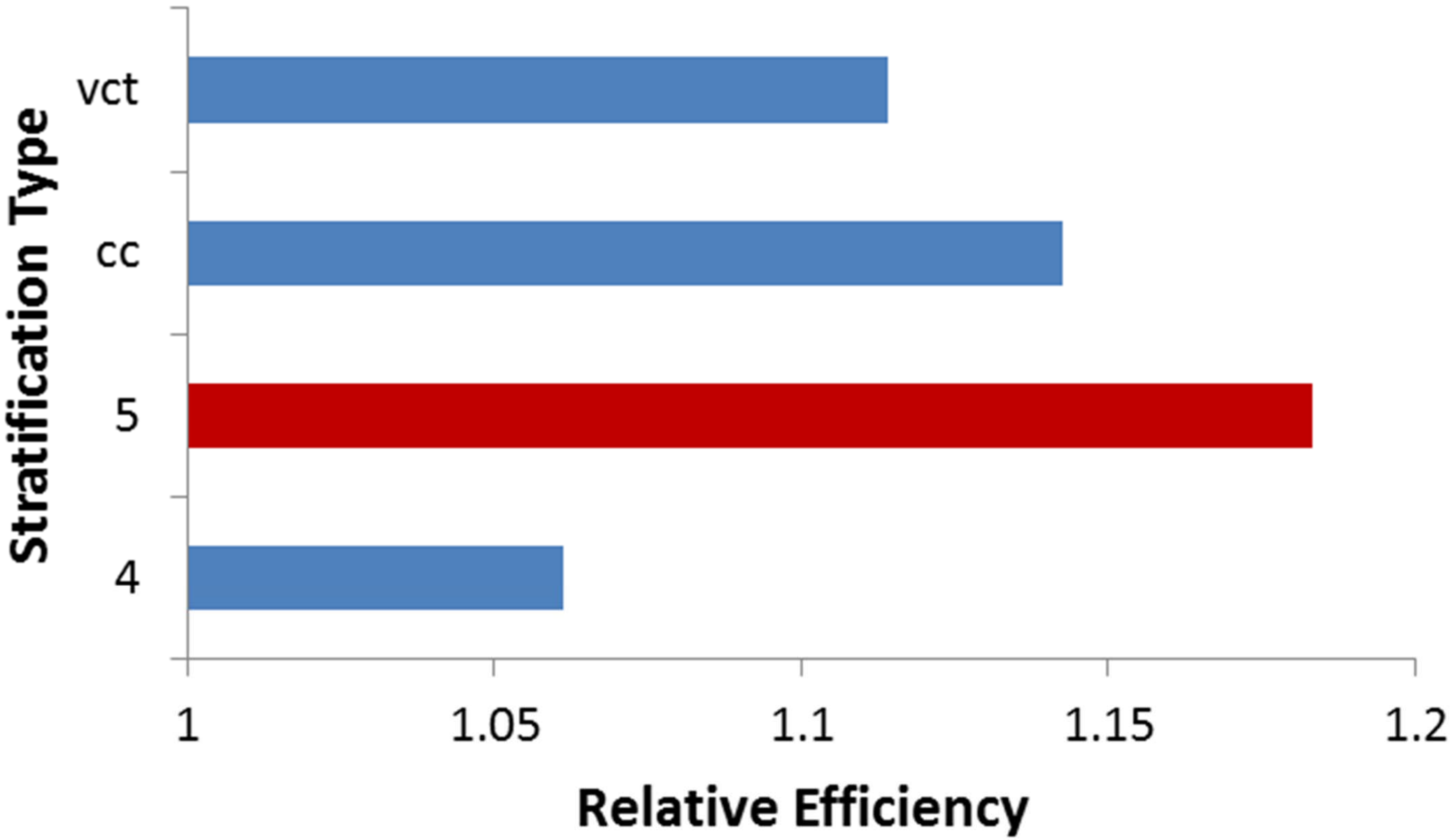
# NLCD Canopy Cover



# VCT and Canopy Cover Strata

- **VCT**
  - persisting non-forest
  - persisting forest
  - disturbed from 0-10 years ago
  - disturbed from 11 to 22 years ago

- **Canopy**
  - 0-5% canopy cover
  - 6-25%
  - 26-50%
  - 51-75%
  - 76-100%


Stratification Type
vct
cc
5
4
1
1.05
1.1
1.15
1.2
Relative Efficiency

# Productivity Mapping

- Multitemporal clustering using Fourier series shows promise to map productivity and as a stratification tool for forest growth
- Prior classification of forest area needed
- Larger, potentially multi-scene, areas will enable larger number of clusters when using FIA P2 data or PINEMAP Tier 1 data

- Forest / Nonforest ⇨ (Age) ⇨ Growth

# Project Title

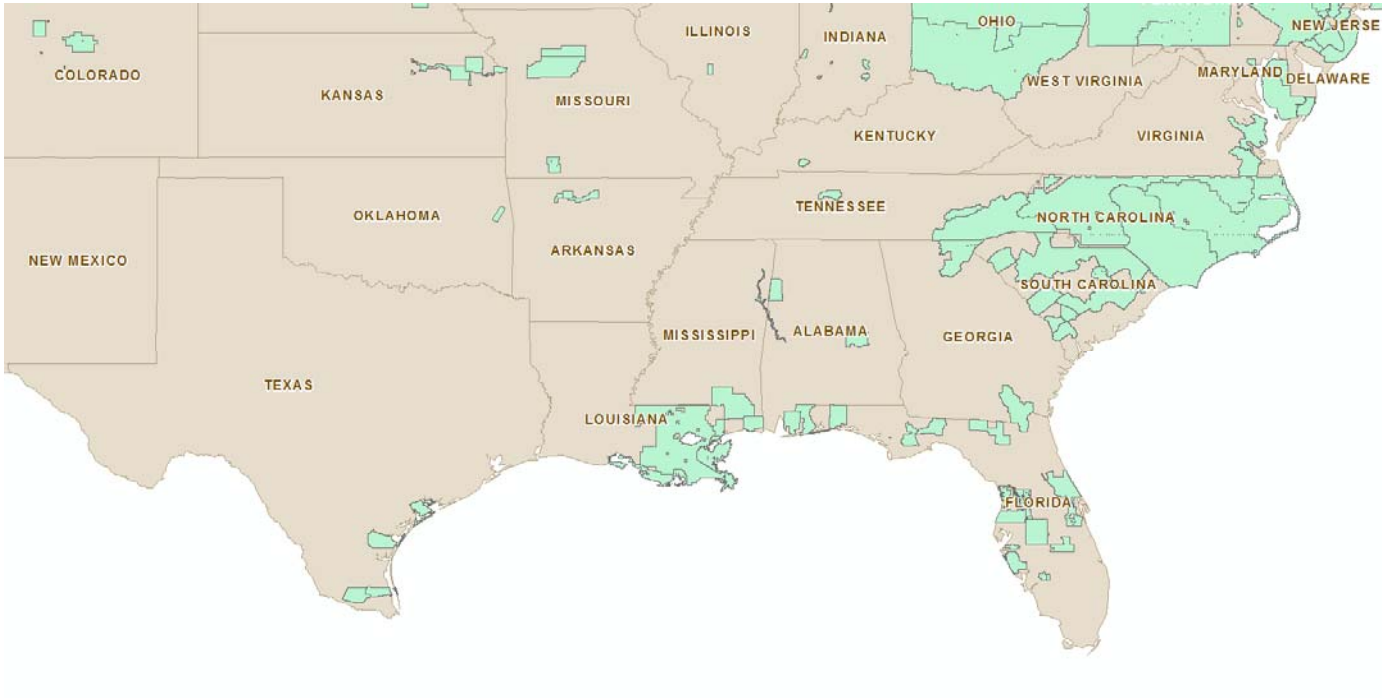
- “Effective characterization of fuel load and its impact on future fire regimes in managed loblolly pine plantations of South-east USA”

# Project objectives

- To quantify canopy and understory fuel load characteristics in managed loblolly pine plantations using three dimensional light detection and ranging (LIDAR) data
- To identify the relations between fuel load and management practices, in such plantations
- To estimate future fuel load trajectories, in the face of climate change and planned management strategies

# Mapping fuel loading using LIDAR

- Step1:
  - LIDAR data acquired from USGS
  - Coverage fair for South-east US



# Mapping fuel loading using LIDAR (contd.)

- Step2:
  - LIDAR data spatially “joined” with FIA plot location information
  - Created over 6000 geographically dereferenced plots (each encompasses an FIA plot), spanning large area
  - These plots have both:
    - LIDAR data
    - FIA field data
- Step3:
  - Establish correlations between these two (ongoing)

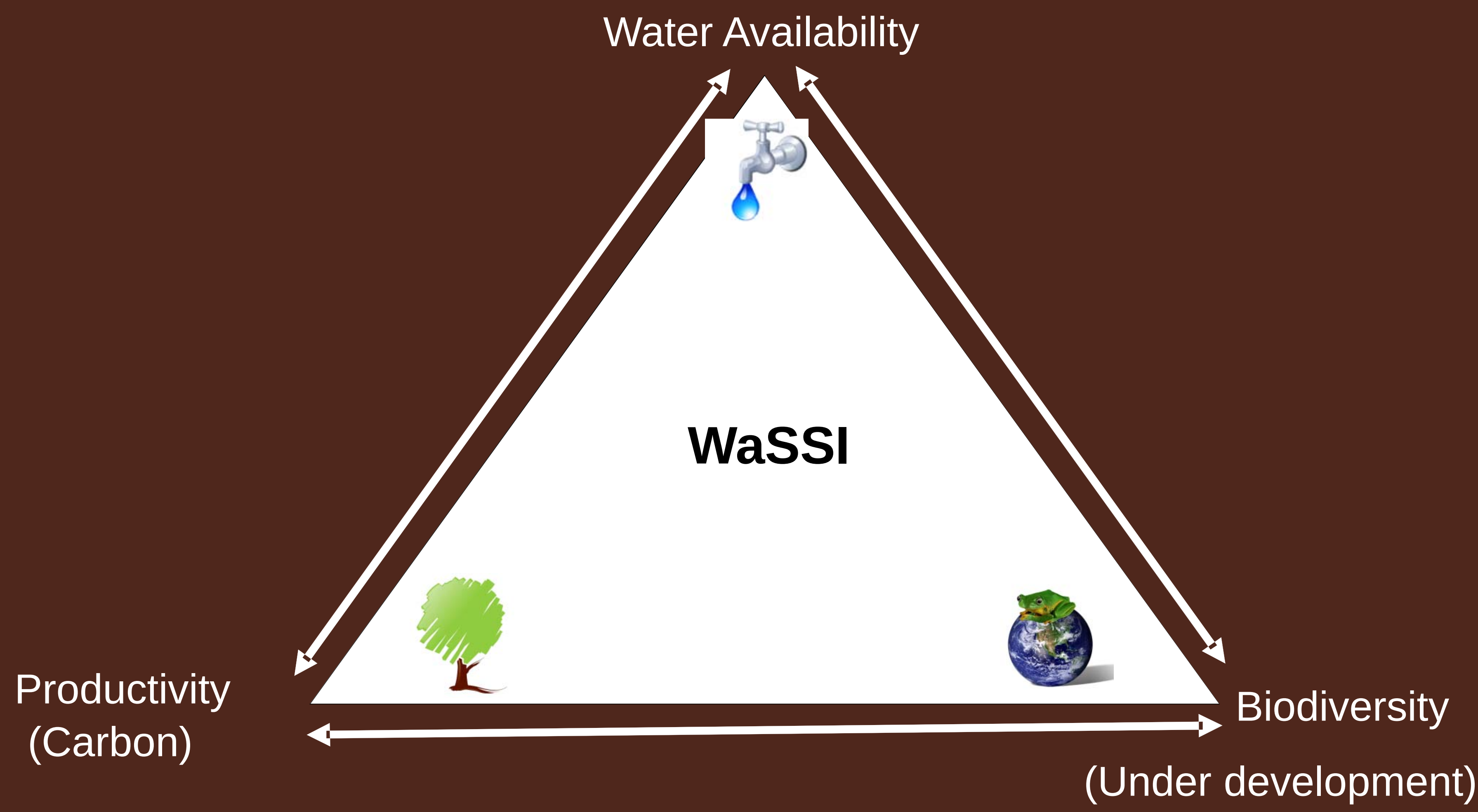
# WaSSI: Using a Water Model to Project Forest Carbon Sequestration

S. McNulty, G. Sun, P. Caldwell, E. Cohen, J. Moore Myers
USDA Forest Service
Eastern Forest Environmental Threat Assessment Center
Raleigh, NC

# Key Issues for climate change

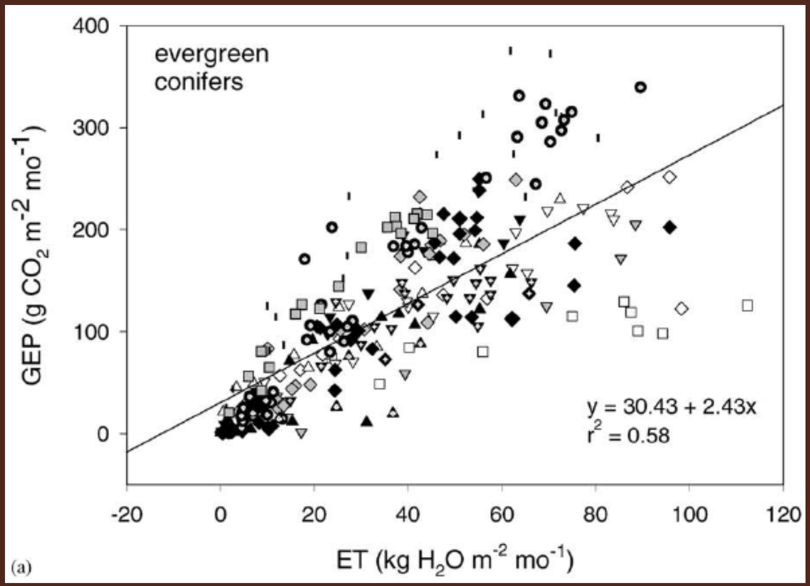
- Adaptation
  - Options for increasing water availability
- Mitigation
  - Opportunities to increase carbon sequestration
- Tradeoffs between managing for water or for carbon

# WaSSI Ecosystem Services Model

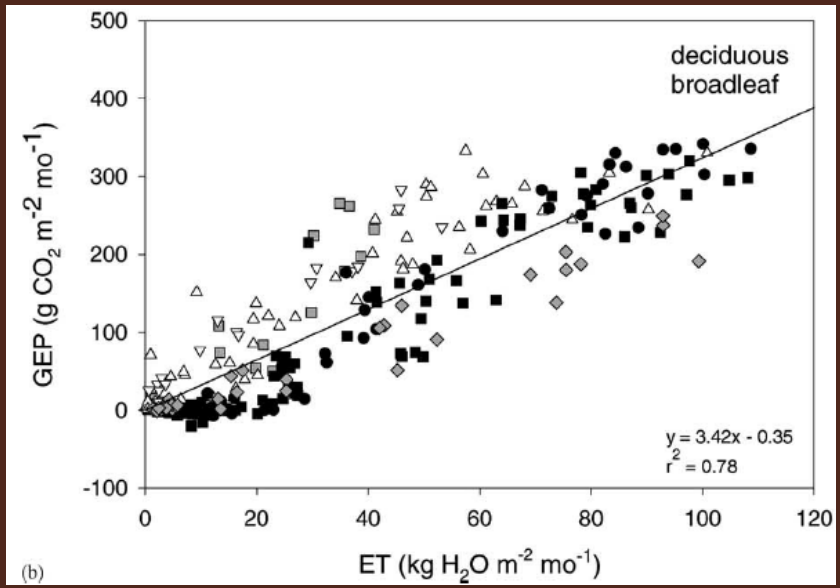


# Carbon & Water Relationships

## Evergreen Conifers



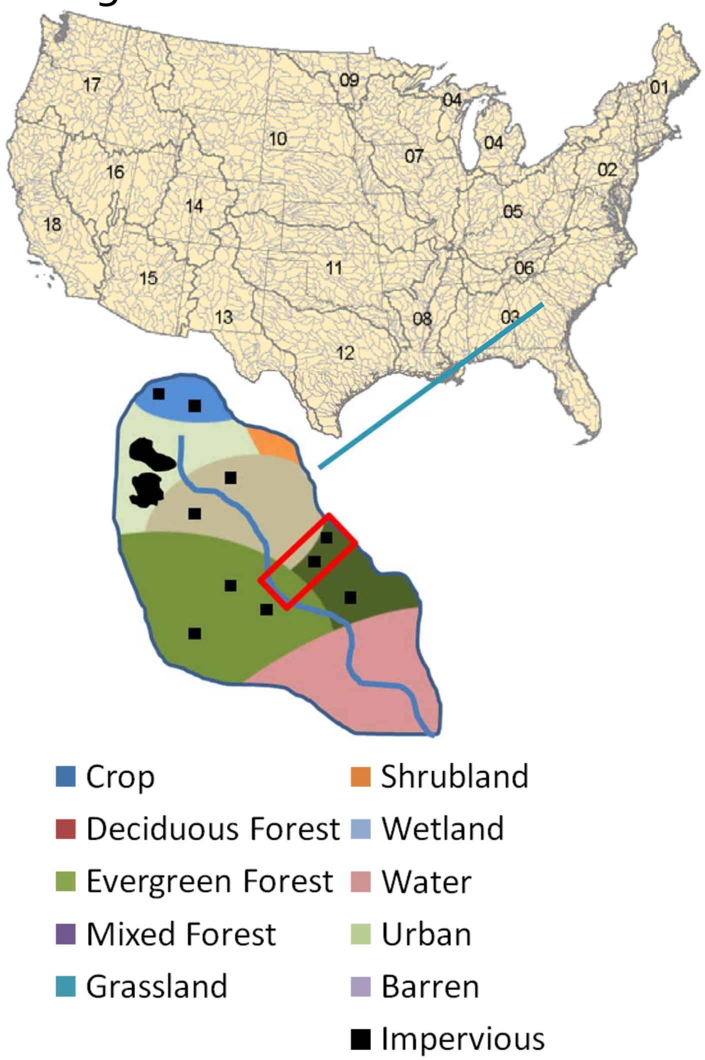

## Deciduous Broadleaf




(Law et al., 2002)

# Watershed and Land Cover Based

8-digit HUC Watersheds of the U.S.




**Water**

ET=f(PET, PPT, LAI, SM)

*Sun et al., Ecohydrology, 2011*

$Q_{out} = Q_{in} + Q_{gen} - WU$

*Caldwell et al., HESS, 2012*

**Carbon**

NEE=f(ET)

*Sun et al., JGR, 2011*

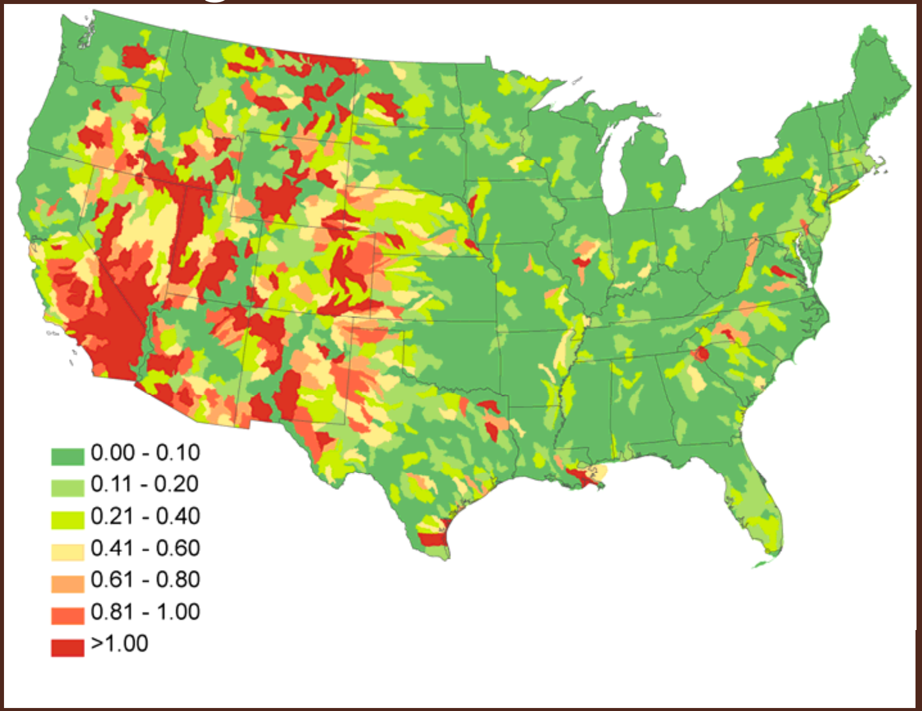
# Water Supply Stress Index (WaSSI)

$$\text{WaSSI} = \frac{\text{Demand}}{\text{Supply}}$$

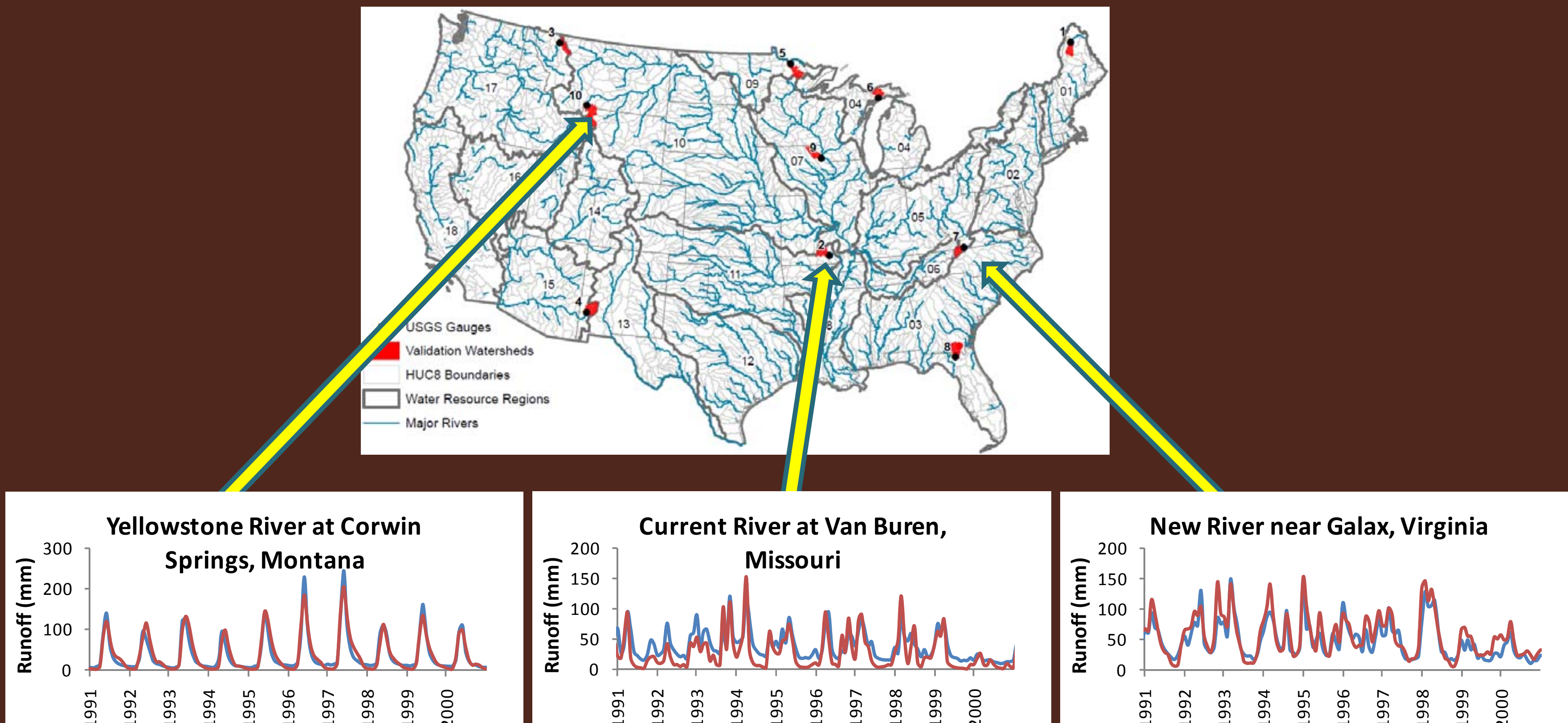
Sectors

1. Domestic
2. Industrial
3. Irrigation
4. Thermopower
5. Mining
6. Livestock
7. Public Supply
8. Aquaculture

1981-2000 WaSSI



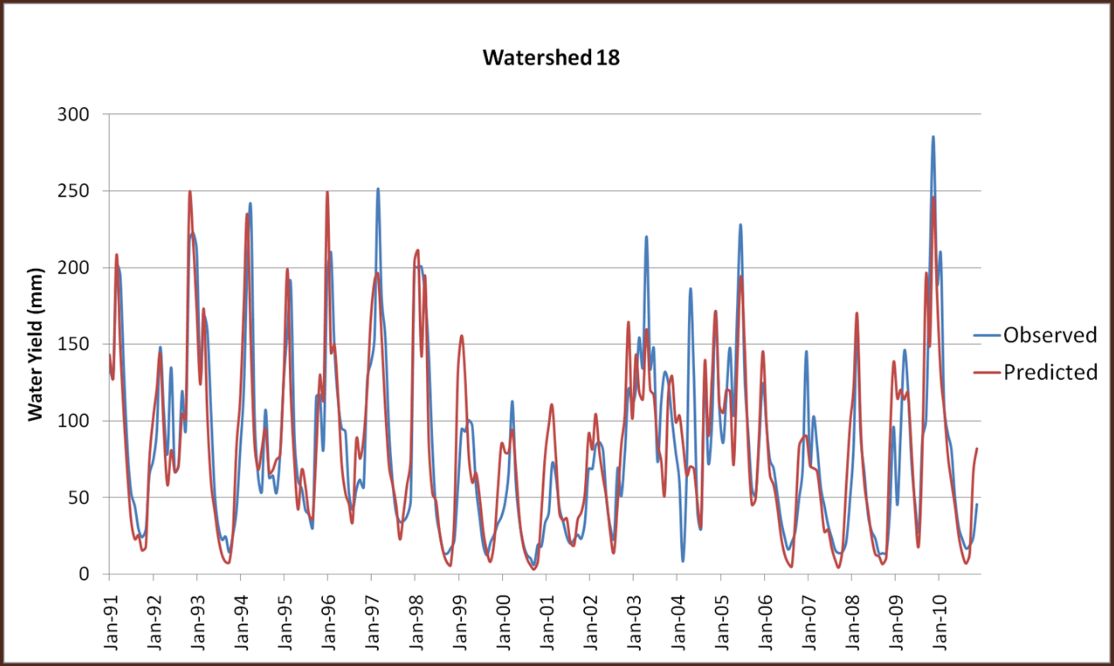
# Continental scale validation (~850 km²)

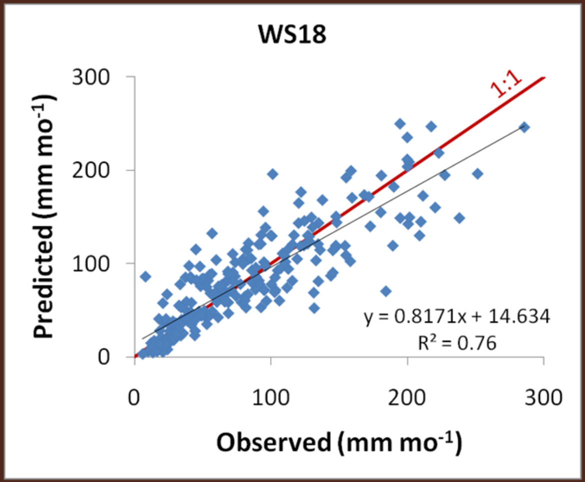


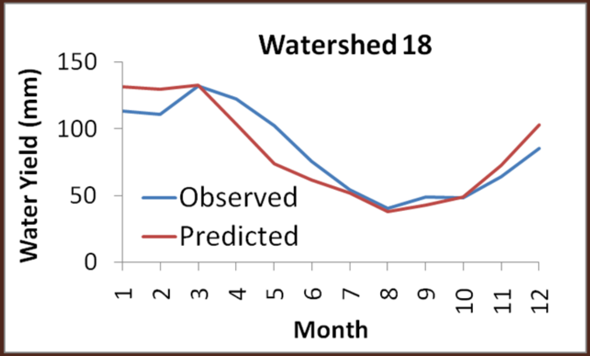

Caldwell et al., HESS, 2012

# Fine-scale validation (~0.1 km²)

## Watershed 18, Coweeta, NC



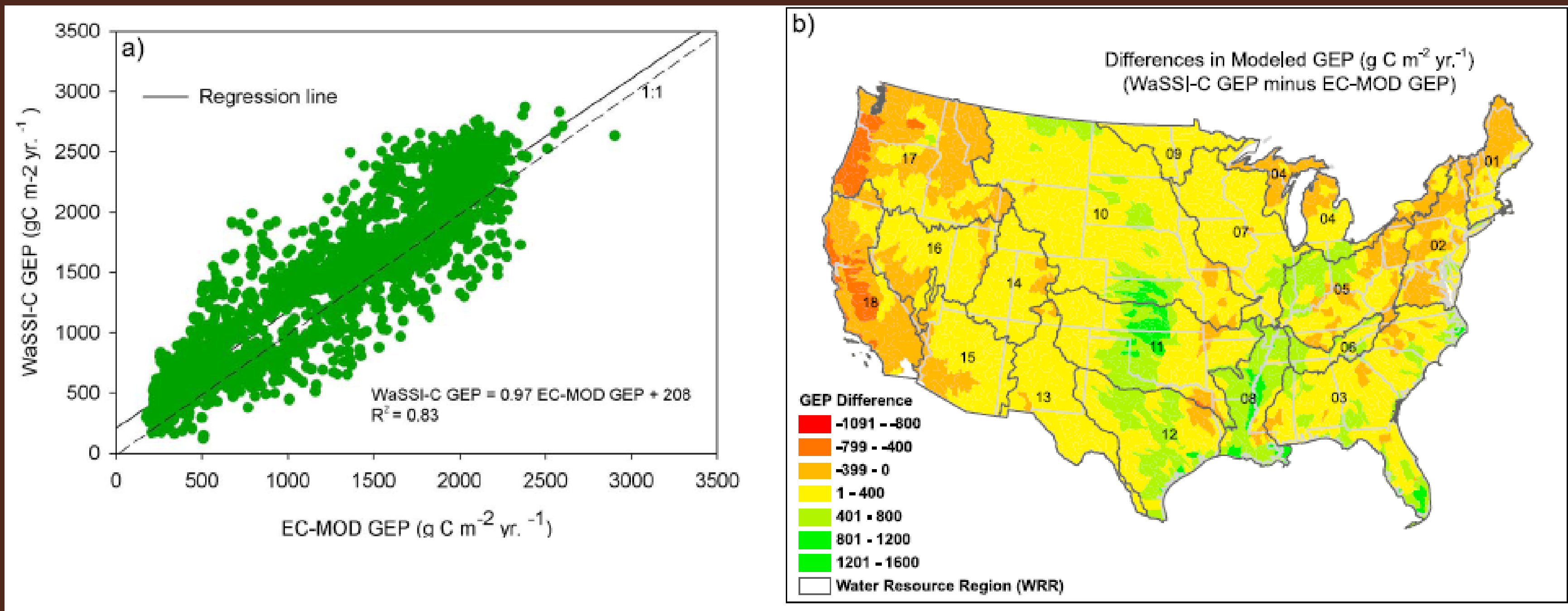




Mean Annual Bias: -6.6 mm (-0.7%)

Monthly NSE: 0.75

# Carbon Validation




Sun et al., JGR, 2011

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, G00J05, doi:10.1029/2010JG001573, 2011

# Upscaling key ecosystem functions across the conterminous United States by a water-centric ecosystem model

Ge Sun,[1] Peter Caldwell,[1] Asko Noormets,[2] Steven G. McNulty,[1] Erika Cohen,[1] Jennifer Moore Myers,[1] Jean-Christophe Domec,[2,3] Emrys Treasure,[1] Qiaozhen Mu,[4] Jingfeng Xiao,[5] Ranjeet John,[6] and Jiquan Chen[6]

Received 1 October 2010; revised 19 February 2011; accepted 7 March 2011; published 21 May 2011.

[1] We developed a water-centric monthly scale simulation model (WaSSI-C) by integrating empirical water and carbon flux measurements from the FLUXNET network and an existing water supply and demand accounting model (WaSSI). The WaSSI-C model was evaluated with basin-scale evapotranspiration (ET), gross ecosystem productivity (GEP), and net ecosystem exchange (NEE) estimates by multiple independent methods across 2103 eight-digit Hydrologic Unit Code watersheds in the conterminous United States from 2001 to 2006. Our results indicate that WaSSI-C captured the spatial and temporal variability and the effects of large droughts on key ecosystem fluxes. Our modeled mean (±standard deviation in space) ET (556 ± 228 mm $yr^{-1}$) compared well to Moderate Resolution Imaging Spectroradiometer (MODIS) based (527 ± 251 mm $yr^{-1}$) and watershed water balance based ET (571 ± 242 mm $yr^{-1}$). Our mean annual GEP estimates (1362 ± 688 g C $m^{-2}$ $yr^{-1}$) compared well ($R^2 = 0.83$) to estimates (1194 ± 649 g C $m^{-2}$ $yr^{-1}$) by eddy flux-based EC-MOD model, but both methods led significantly higher (25–30%) values than the standard MODIS product (904 ± 467 g C $m^{-2}$ $yr^{-1}$). Among the 18 water resource regions, the southeast ranked the highest in terms of its water yield and carbon sequestration capacity. When all ecosystems were considered, the mean NEE (−353 ± 298 g C $m^{-2}$ $yr^{-1}$) predicted by this study was 60% higher than EC-MOD's estimate (−220 ± 225 g C $m^{-2}$ $yr^{-1}$) in absolute magnitude, suggesting overall high uncertainty in quantifying NEE at a large scale. Our water-centric model offers a new tool for examining the trade-offs between regional water and carbon resources under a changing environment.

**Citation:** Sun, G., et al. (2011), Upscaling key ecosystem functions across the conterminous United States by a water-centric ecosystem model, *J. Geophys. Res.*, *116*, G00J05, doi:10.1029/2010JG001573.

## 1. Introduction

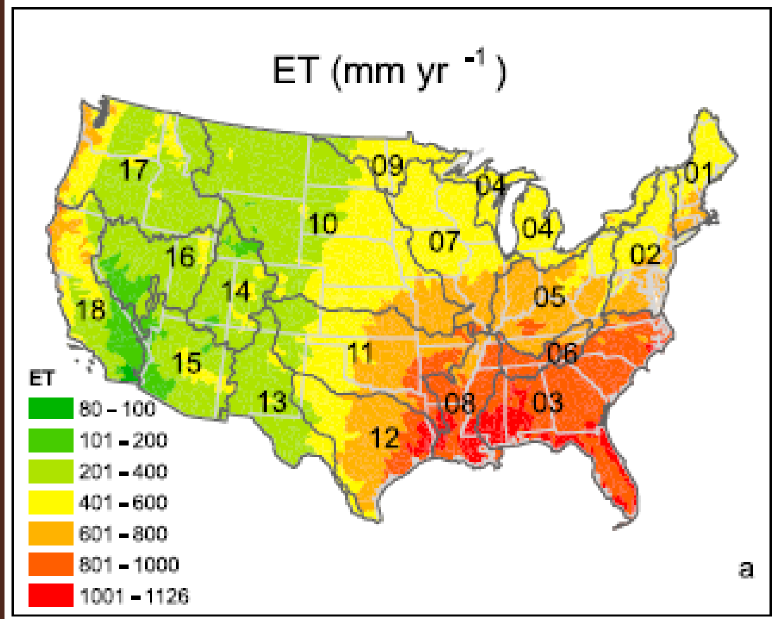
[2] Evapotranspiration (ET), water yield, gross ecosystem productivity (GEP), net primary productivity (NPP), ecosystem respiration (Re), and net ecosystem exchange (NEE) (i.e., NEE = -NEP, where NEP is net ecosystem productivity) are the key ecosystem functions [*Xiao et al.*, 2008, 2010; *Beer et al.*, 2010; *Jung et al.*, 2010; *Tian et al.*, 2010; *Xiao et al.*, 2010] that directly affect many ecosystem services, including providing stable and high quality water, moderating climate, sequestering atmospheric carbon dioxide, and protecting biodiversity. Understanding the tightly coupled water and carbon cycles is critical to evaluating regional and global biogeochemical cycles under a changing climate [*Law et al.*, 2002; *Nemani et al.*, 2003; *Beer et al.*, 2007, 2010]. Quantifying water and carbon balances at regional and continental scales is essential for land managers and policy makers to develop sound mitigation and adaptation strategies in response to global change.

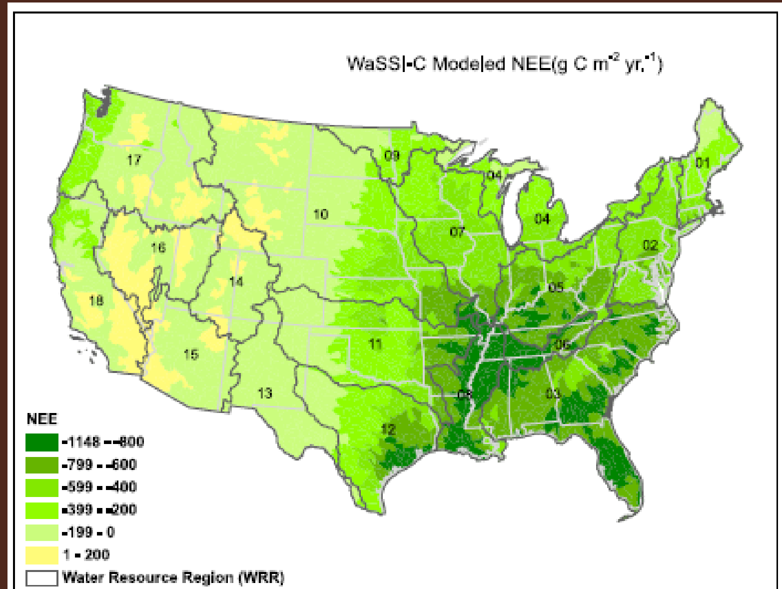
[3] Although it is well known in ecology that water is a major control to plant growth and productivity [*Chapin et al.*, 2004; *Noormets et al.*, 2008; *Domec et al.*, 2009], water and carbon have long been treated as two separated entities. Many existing ecosystem models have some forms of coupling between carbon and water, mostly related to the effects of soil moisture on photosynthesis process. However, these models have rarely been validated with both carbon and water flux measurements [*Hanson et al.*, 2004; *Noormets et al.*, 2006; *Domec et al.*, 2010; *Tian et al.*, 2010]. Similarly, the hydrologic community has long ignored the feedbacks

[1] Eastern Forest Environmental Threat Assessment Center, Forest Service, U.S. Department of Agriculture, Raleigh, North Carolina, USA.
[2] Department of Forestry and Environmental Resources, North Carolina State University at Raleigh, Raleigh, North Carolina, USA.
[3] ENITA de Bordeaux, UMR TCEM, Gradignan, France, .
[4] Numerical Terradynamic Simulation Group, University of Montana, Missoula, Montana, USA.
[5] Complex Systems Research Center, University of New Hampshire, Durham, New Hampshire, USA.
[6] Department of Environmental Sciences, University of Toledo, Toledo, Ohio, USA.


0148-0227/11/2010JG001573



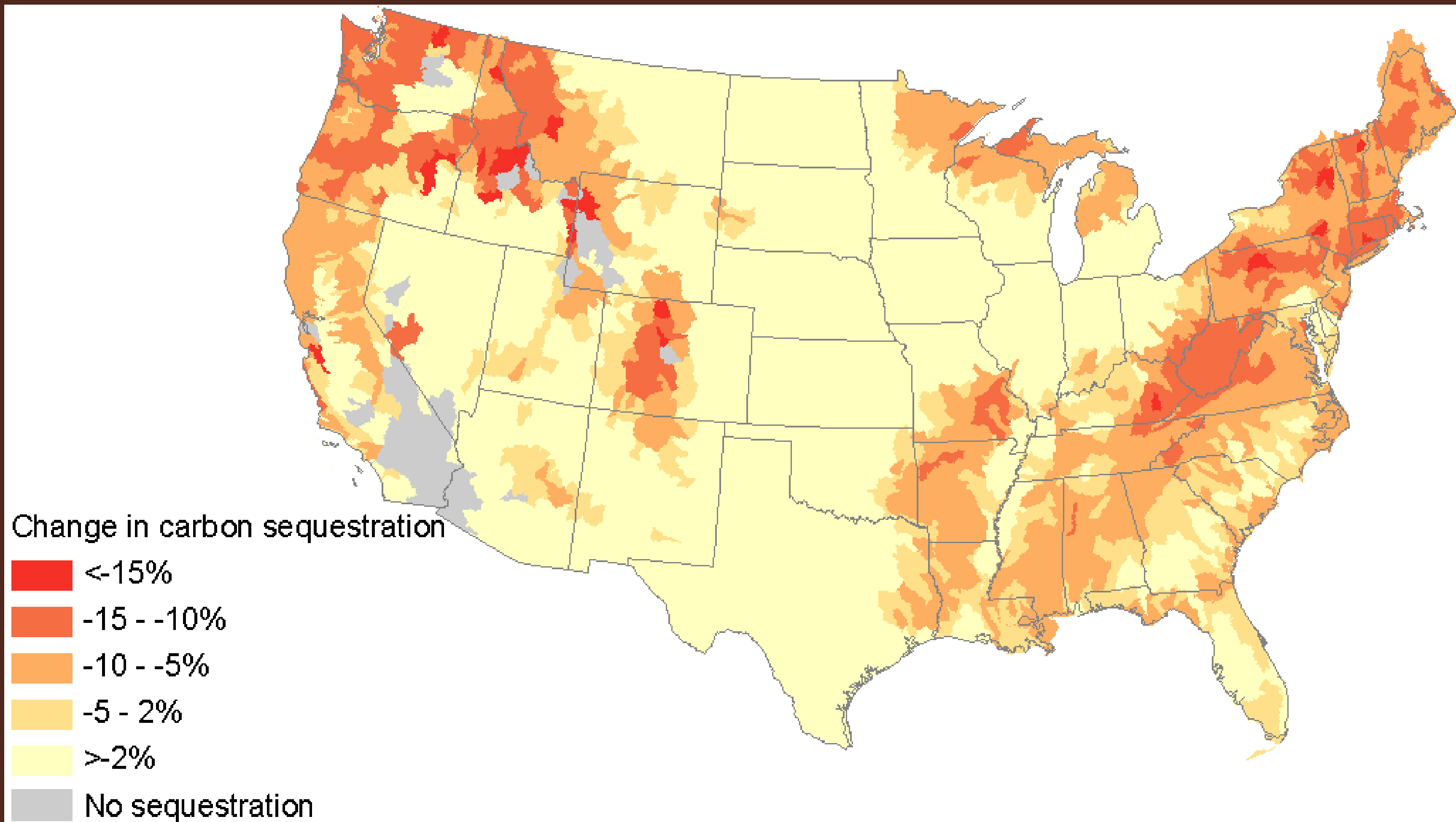


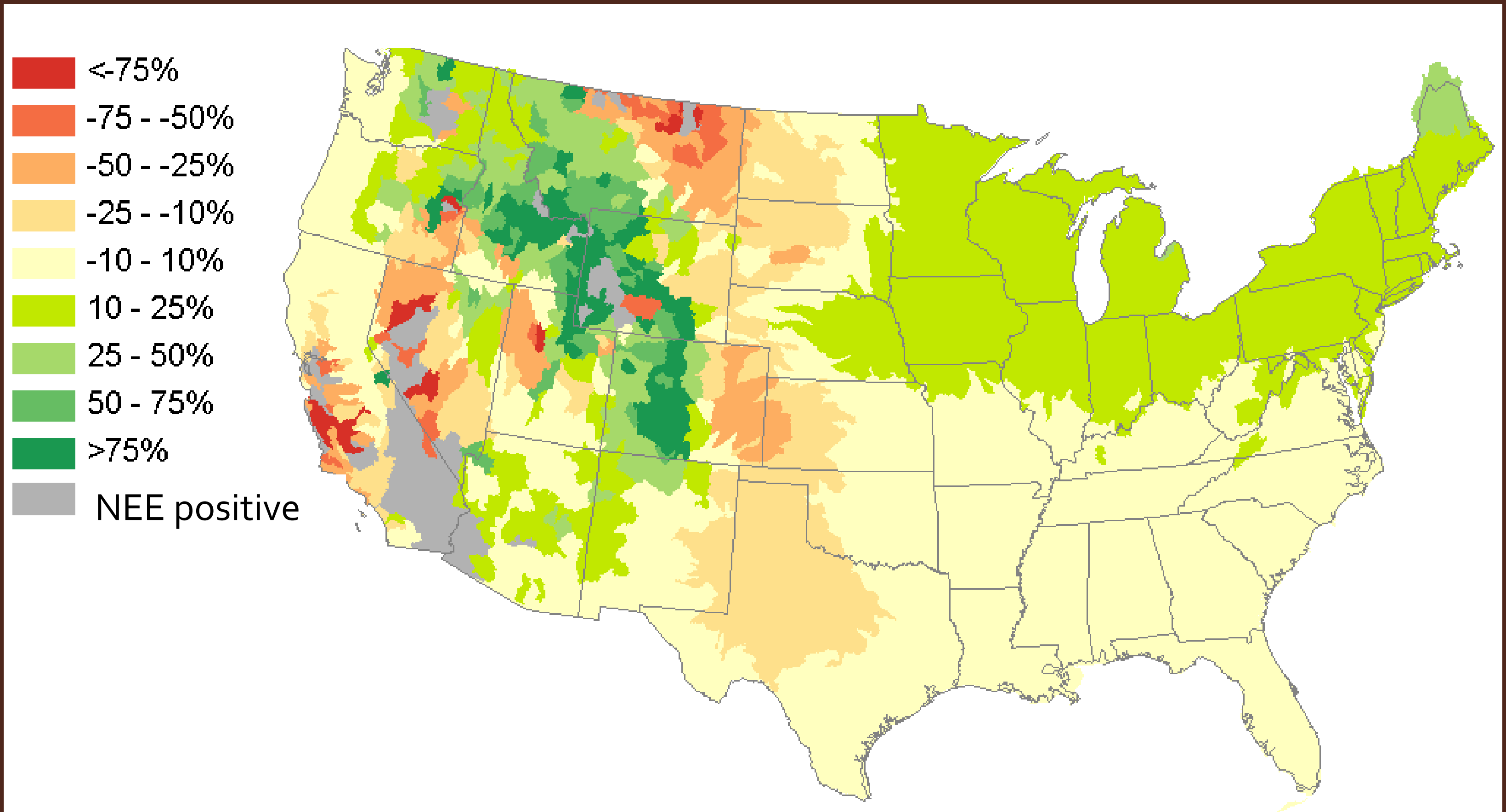
# How WaSSI can be useful for resource management?

- Help answer the “So what?” questions of climate predictions
  - What effect might climate change have on magnitude and timing of water yield?
  - Carbon sequestration?
- Assess sensitivity to management options for climate change mitigation and adaptation
  - How can forest management mitigate climate change impacts on water supply?
  - What are the tradeoffs of water management with carbon sequestration?
  - What is the effect of forest land conversion to other uses on water yield and carbon?
- And many others…

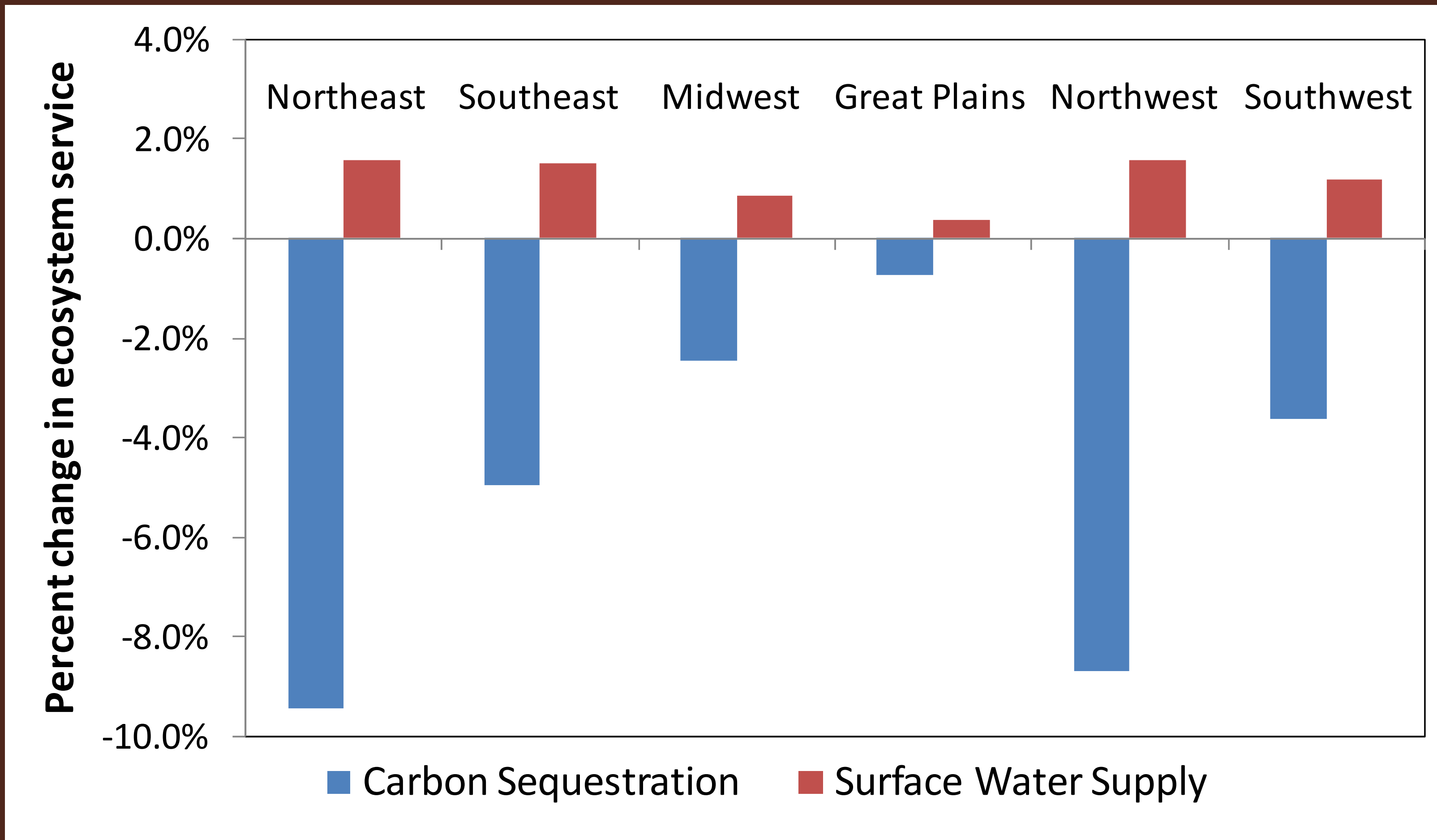
# Sensitivity of NEE to a 20% forest conversion to shrubland



# Mean change in NEE due to climate change



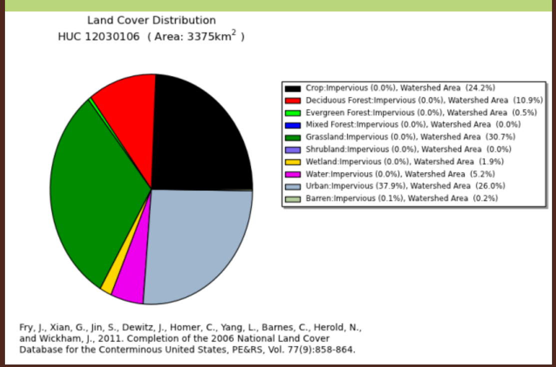
# Tradeoffs between water and carbon due to 20% forest conversion



# www.forestthreats.org/research/tools/WaSSI

## Create Scenario

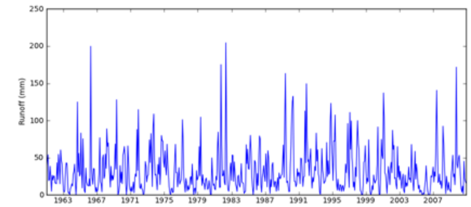

## View Inputs




## WaSSI Ecosystem Services Model

## View Outputs

### Time Series




### Map View

# What is 3-PG?

- 3-PG stands for Physiological Processes Predicting Growth

- It is a model that uses simple representations of physiological processes so that it can be more easily parameterized than a standard process model, and requires only a limited amount of site and weather data to run.

# Model Inputs

- Site factors: soil type, maximum and minimum available soil water holding capacity, stocking density and site fertility rating (0 to 1 index).
- Monthly mean weather data: Rainfall, max and min temperature, solar radiation and frost days.
- Values for physiological parameters of loblolly pine.

# Species Physiological Parameters

- Allometric relationships and partitioning
- Canopy structure and processes (SLA, k, alpha)
- Canopy conductance
- Tree mortality
- Rate and timing of litter fall and root turnover
- Effects of tree age, temperature and frost on growth rate
- Ratio of NPP/GPP

# Model Outputs (yearly, monthly)

- Biomass (stem, branch, root, foliage)
- DBH
- Stand Volume
- Basal Area
- Live Tree Density
- Mean Annual Increment
- Numerous Biological Components of Stand Growth (stand water use, leaf area index, etc.)

# Model Modifications

- We have made a number of refinements and modifications to optimize it for loblolly pine plantations (3-$PG_{lob}$).

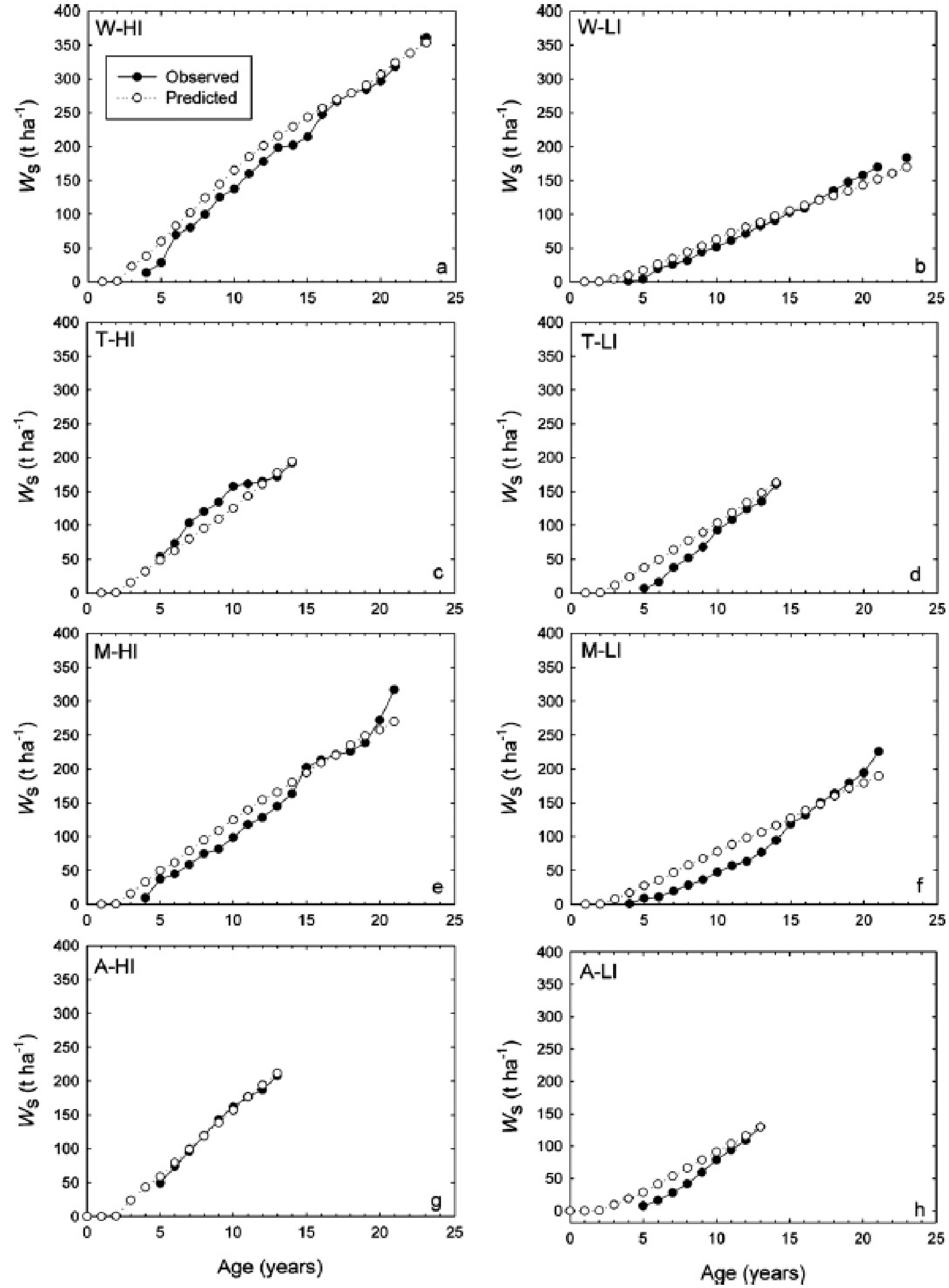
- PINEMAP researchers are working on how to predict the Fertility Index and how to incorporate fertilization and competition into the model.

# How well does the model work?

- Comparing Model Output to Growth Measurements

- Comparison of predicted and observed biomass growth (Ws) in plantations in GA.

Bryars et al. (2013) *Forest Ecology and Management* 289: 501-514 .



# ASSESSMENT OF PERFORMANCE

Once the initial parameterization was complete, 3-$PG_{lob}$ was able to simulate the growth of loblolly pine stands reasonably well, using only a limited amount of weather and site data.

We are now testing 3-$PG_{lob}$ using PINEMAP Tier I datasets across the loblolly pine range.

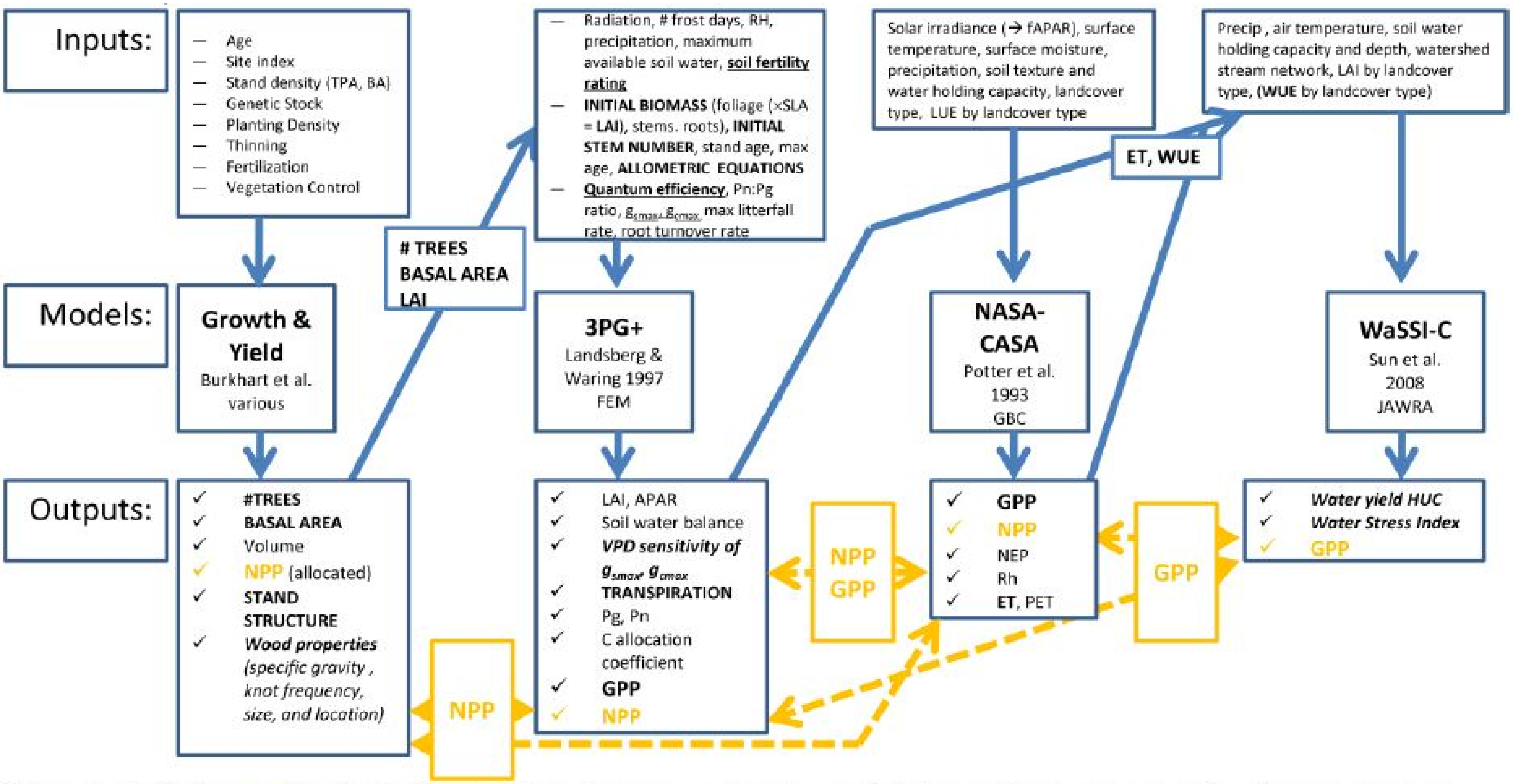



**Figure 6.** Schematic depiction of the inputs, outputs, and interactions among the four primary models. Solid blue arrows indicate data flow between models, yellow dashed arrows and variable names indicate cross comparison of common model outputs, **BOLD CAPS** input & output parameters indicate variables transferred among models, underlining indicates key sources of stand-level variability, and *italics* indicates terminal outputs unique in scale.