Climate-driven individual tree growth modeling fusing diameter tape measurement and increment core data

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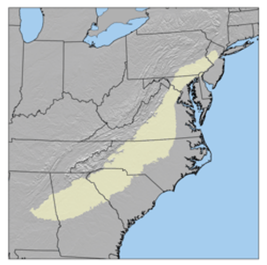
Duke Forest

Duke Forest is a forest managed by Duke University for research, teaching, and recreation.
Located at edge of the Piedmont - 7,060 acres



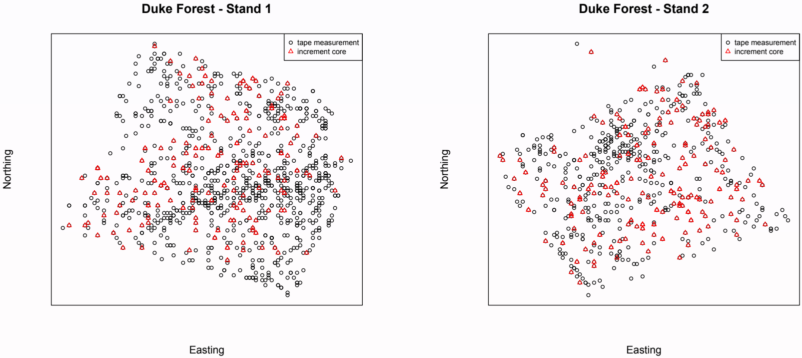
Motivation

Model individual-level tree growth in the Duke Forest

- Fuse two datasets - tape measurement data and increment core data
- Use climate variables to explain annual growth and variability between years
- Model spatial correlation in individual-level growth

Tape measurement and increment core data

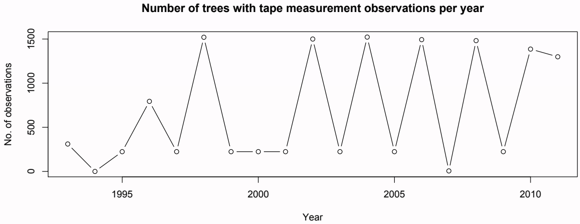
Duke Forest Plots



Stands established in 1991 to study forest dynamics.
Both stands are approximately 5000m^2
Stand 1 is 200 meters north of Stand 2

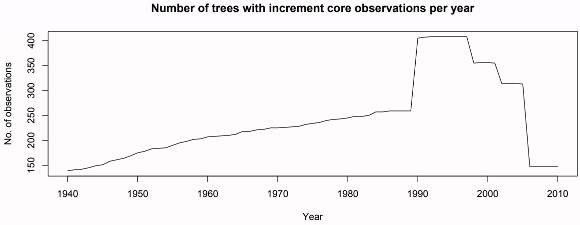
Tape measurement data

- Diameter measurements conducted at intervals of one to four years starting in 1993
- 1583 unique trees with diameters

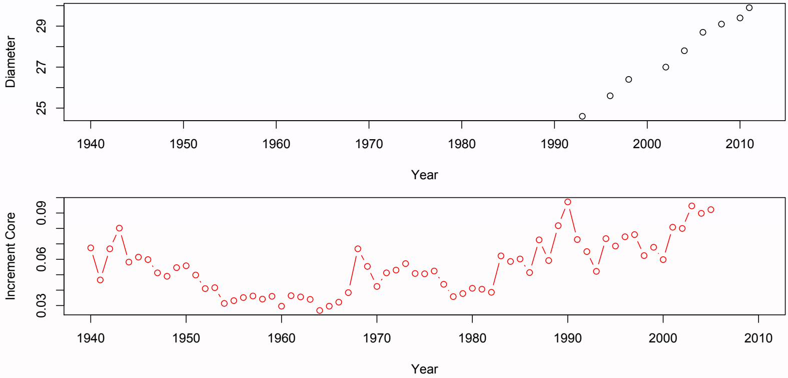


Core increment data

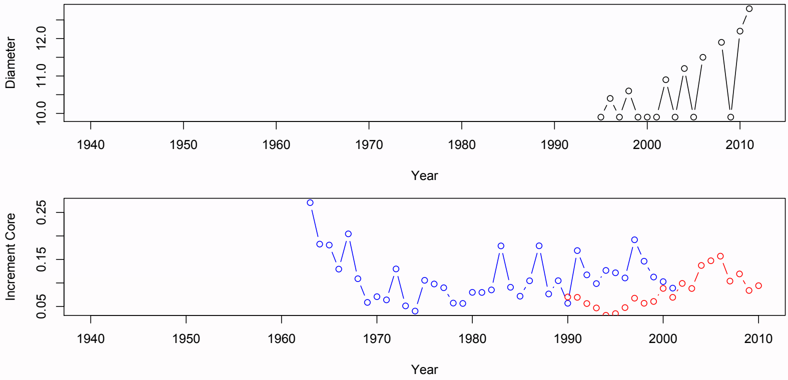
- Increment cores were collected in 1998, 2001, 2006, and 2009
- Some trees sampled in multiple years resulting in more than one set of increments observed for the tree
- 324 unique trees with increment cores



Tape measurement and core increment data



Tape measurement and core increment data



Clearly both datasets are noisy!
The hope is that by merging the two datasets we are able to improve estimates of annual growth

Tape measurement model

$Y_{i,t}$ be the observed diameter of tree i at year t
$Y_{i,0}$ is the first observation for tree i

$$Y_{i,t} = \mu_{i,t} + \epsilon_{i,t}, \quad \epsilon_{i,t} \sim \mathrm{N}(0, \sigma^2)$$

$\mu_{i,t}$ be the true diameter of tree i in year t
$\epsilon_{i,t}$ is measurement error

$$\log(\mu_{i,t} - \mu_{i,t-1}) = \mathbf{X}'_{it}\beta + \omega_i$$

$\mathbf{X}_{it}$ denote a vector of climate covariate data for tree i and year t
ω_i is a tree specific random effect

Fusion model

$Z_{i,t,j}$ be the jth observed radius increment of tree i and year t

Re-write growth between years $t-1$ and t as

$$\mu_{i,t} - \mu_{i,t-1} = \exp(\mathbf{X}'_{it}\boldsymbol{\beta} + \omega_i)$$

$$Y_{i,t} \sim \mathrm{N}\left(\mu_{i,0} + \sum_{k=1}^{t} \exp(\mathbf{X}'_{ik}\boldsymbol{\beta} + \omega_i),\ \sigma^2\right)$$

$$Z_{i,t,j} \sim \mathrm{N}\left(\frac{1}{2}\exp(\mathbf{X}'_{it}\boldsymbol{\beta} + \omega_i),\ \gamma^2\right)$$

Modeling the tree-specific random effect

ω_i is the random effect for tree *i* used to capture the variation in response to weather at the tree level.

$$\omega_i \overset{iid}{\sim} \mathrm{N}(\nu, \tau^2) \quad \textit{or} \quad \boldsymbol{\omega} \sim \mathrm{GP}(\mathbf{1}\nu, \Sigma)$$

Spatial correlation within stand, not across

$$\boldsymbol{\omega}_k \sim GP(\nu\mathbf{1}, \Sigma_k)$$

Assume an exponential covariance for Σ_k, which is a function of distance and the parameters τ^2 and ϕ_k.

Model results

We compare the following four models:

1. Diameter only, non-spatial model (referred to as non-fusion, non-spatial)
2. Diameter only, spatial model (referred to as non-fusion, spatial)
3. Fusion, non-spatial model
4. Fusion, spatial model

Model comparison: Out-of-sample-prediction

Two types of out-of-sample prediction

1. Fill in missing observations of trees
2. Predict trees not observed - perhaps more interesting!

Model comparison: Out-of-sample-prediction

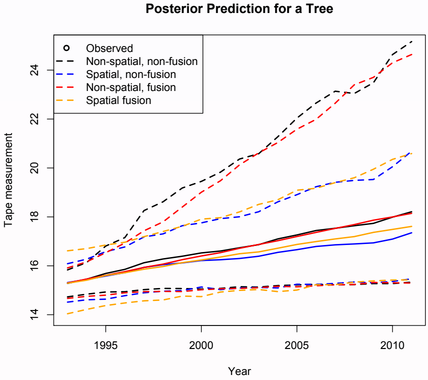
- Model fitted using 1,080 trees, 228 having 1 or more increment core
- Out-of-sample prediction on 500 trees, 96 having 1 or more increment core

Comparison based on:

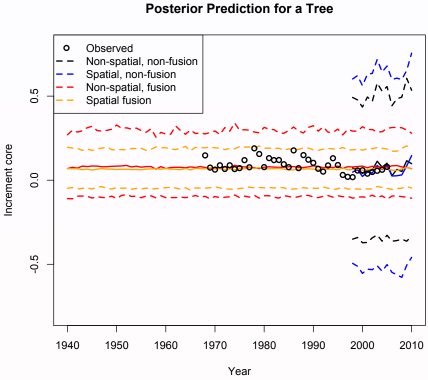
- root mean square perdition error (RMSPE)
- continuous rank probability score (CRPS)

***Comparing models based on prediction of out-of-sample trees is difficult due to the variability of the “true value” between datasets.

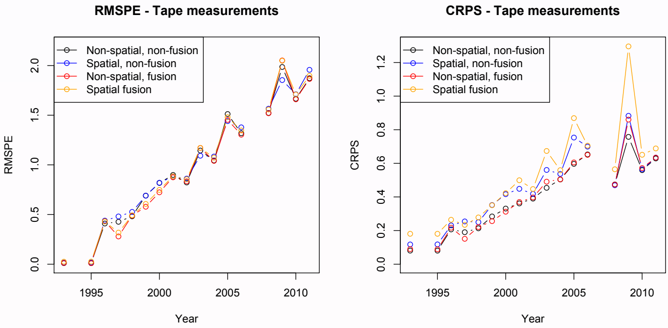
Model comparison: Out-of-sample-prediction



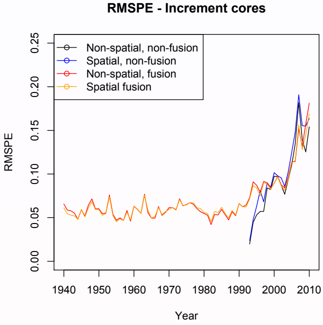
Model comparison: Out-of-sample-prediction

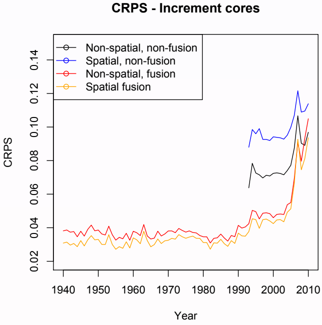


Model comparison: Out-of-sample-prediction



Model comparison: Out-of-sample-prediction





Model comparison: Out-of-sample-prediction

Table: CRPS and empirical coverage of 90% credible intervals for out-of-sample prediction of tape measurements and increment cores.

	CRPS		90% CI Empirical Coverage	
	Tape Measurements	Increment Cores	Tape Measurements	Increment Cores
Diameter only, nonspatial	0.554	0.074	96.83	99.55
Diameter only, spatial	0.601	0.096	87.55	99.73
Fusion, nonspatial	0.555	0.051	96.49	94.41
Fusion, spatial	0.626	0.046	89.64	87.81

Summary and future work

- Prediction very similar between models
- Spatial models have lower prediction standard deviations

- Comparison across species
- Joint species modeling
- Use these tree diameter estimates in future modeling of individual and plot-level biomass