Testing Climate SI for Douglas-fir Diameter Growth

Greg Johnson, Aaron Weiskittel, and David Marshall

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Model

$$\Delta dbh = e^{(\beta_0+\beta_1 log(\frac{(dbh+1)^2}{(cr*ht+1)^{\beta_4}})+\beta_2 \frac{bal^{\beta_5}}{dbh+2.7}+\beta_3 log(csi+1.37))} \quad (1)$$

where:

- `dbh` = diameter at breast height (inches),
- `bal` = basal area per acre in larger trees ($feet^2/ac$),
- `cr` = crown ratio (fraction of total height),
- `ht` = total height (feet),
- `csi` = climate site index (meters), and
- $\beta_0 - \beta_5$ are parameters to be estimated.

Climate site index (`csi`) was developed by Aaron Weiskittel and represents a CONUS-wide consistent estimate of productivity.

Nonlinear regression was used with an integrated fitting approach such that individual observations can have differing remeasurement intervals. The error to be minimized is ending `dbh`.

Data

We extracted and processed Forest Inventory and Analysis (FIA) data from 11 states listed in the native range of Douglas-fir in the Silvics of North America.[1]

[1] Burns, Russell M., and Barbara H. Honkala, tech. coords. 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 p.

After subsetting the data to censor observations with missing data, limiting the species to Douglas-fir (FIA species code 202), and remeasurement intervals ≥ 5 years we get the observations in Table 1.

Table 1: Douglas-fir Growth Observations by State

State	Observations
AZ	1143
CA	18360
CO	6774
ID	13789
MT	23645
NM	2440
NV	27
OR	68702
UT	2348
WA	46594
WY	865

Equation Parameter Estimates

	Coef.	Std. error	t-stat.	p
B0	-14.2622438	0.1272246	-112.10285	0
B1	-0.6703803	0.0036881	-181.76972	0
B2	-0.0978492	0.0074911	-13.06201	0
B3	3.5792363	0.0404204	88.55029	0
B4	2.0777500	0.0082683	251.29007	0
B5	0.5714310	0.0134300	42.54891	0

```
Residual Standard Error: 1.119424928078 on 184681 degrees of freedom, AIC: 565798
```

Comparison to Simplified Model without Climate SI

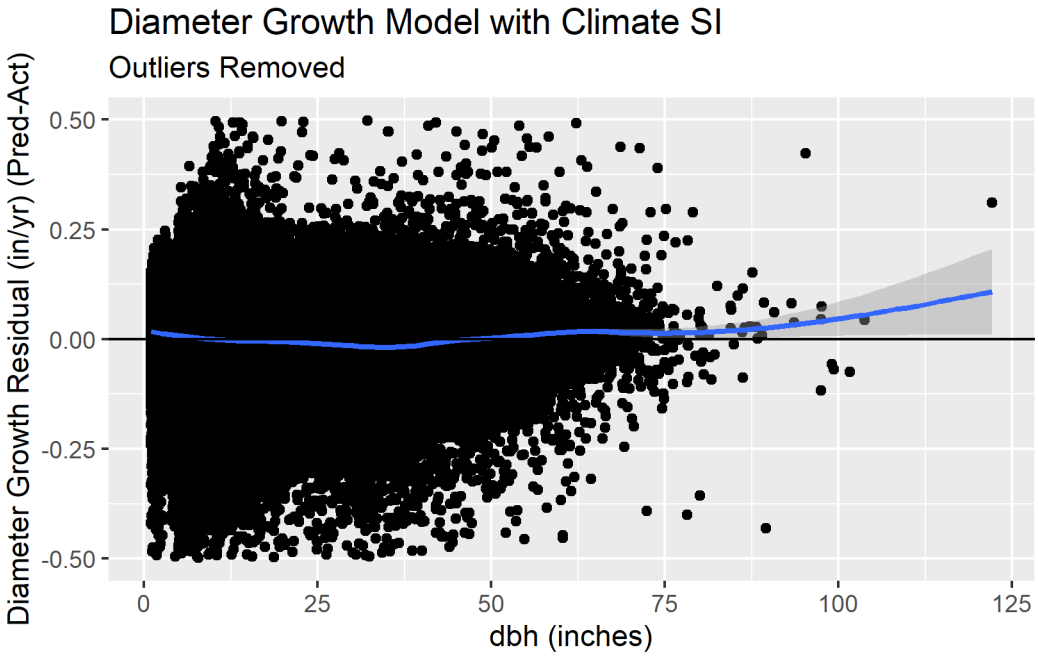
	Coef.	Std. error	t-stat.	p
B0	-3.4564861	0.0250123	-138.19136	0
B1	-0.7101748	0.0039153	-181.38255	0
B2	-0.0885761	0.0080010	-11.07058	0
B4	2.2088177	0.0083208	265.45686	0

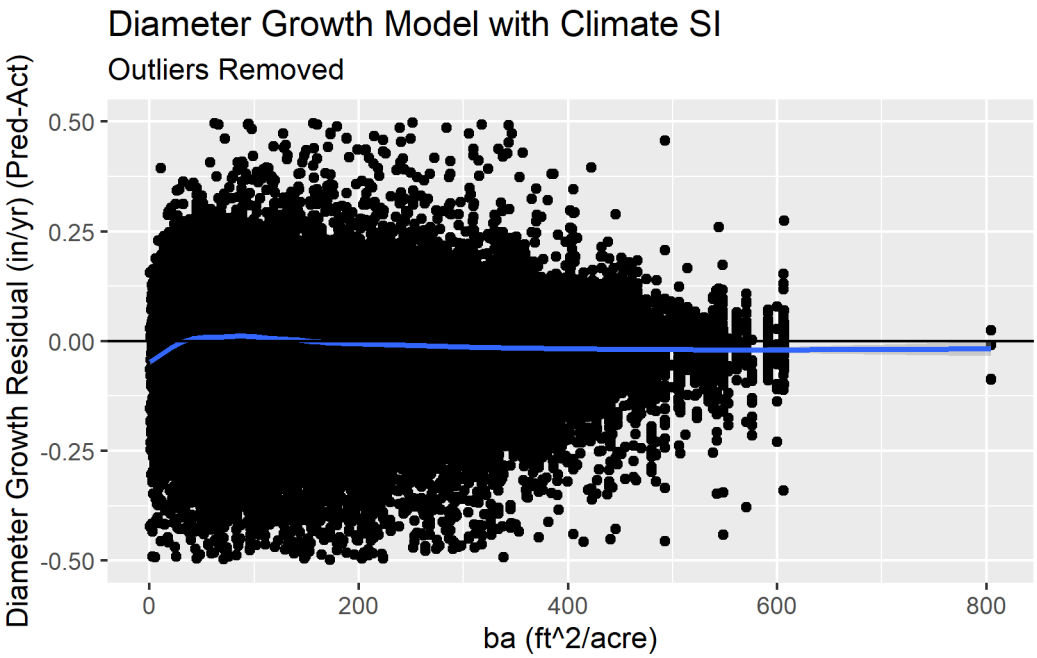
	Coef.	Std. error	t-stat.	p
B5	0.5639511	0.0158093	35.67219	0

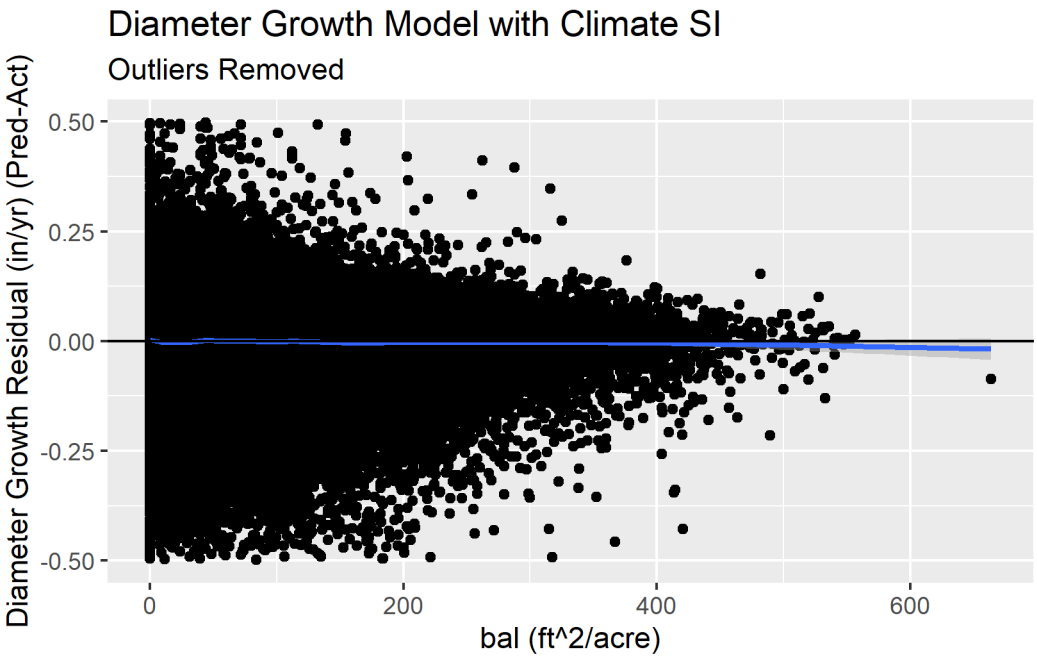
```
Residual Standard Error: 1.14563104993115 on 184682 degrees of freedom, AIC: 574344.5
```

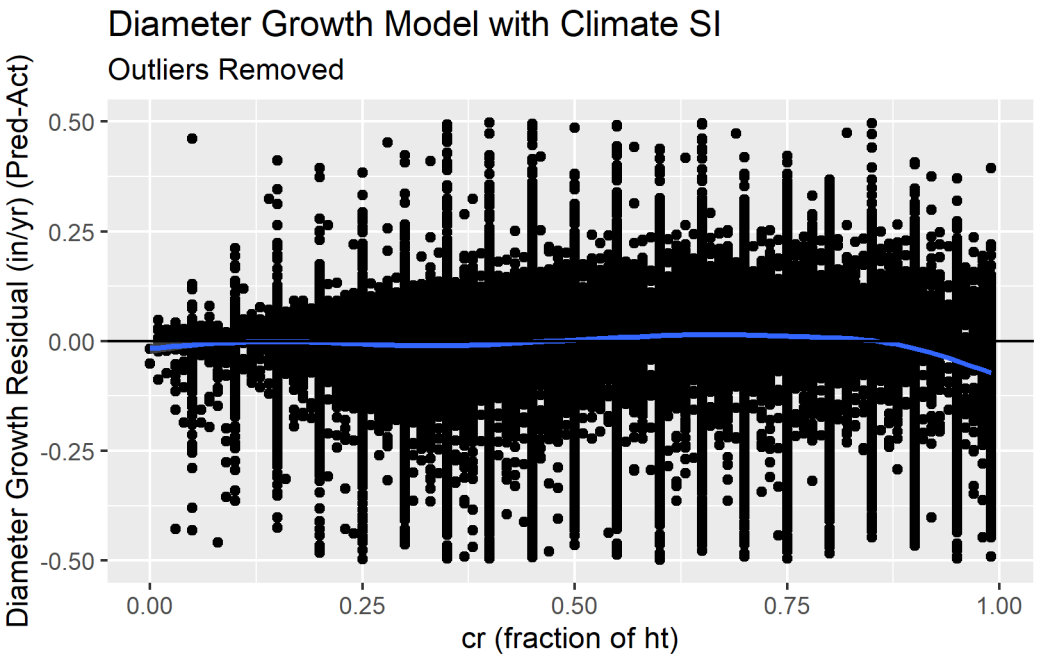
While `csi` improves the fit significantly, it does not remove the geographic residuals patterns in the residuals (see the last graph below).

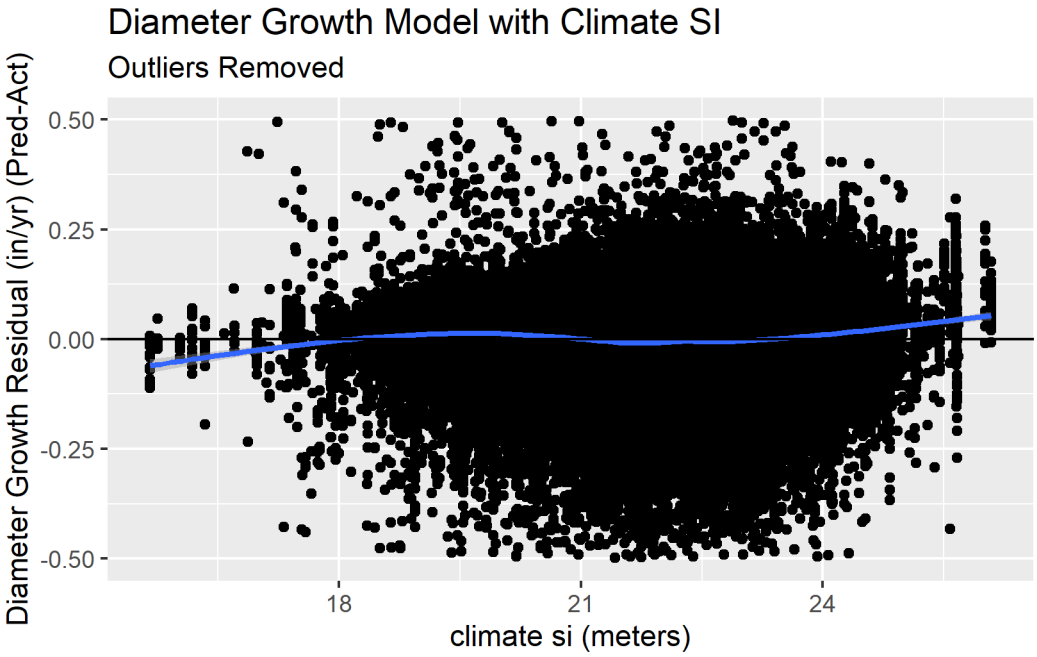
Residual Analysis for Equation 1

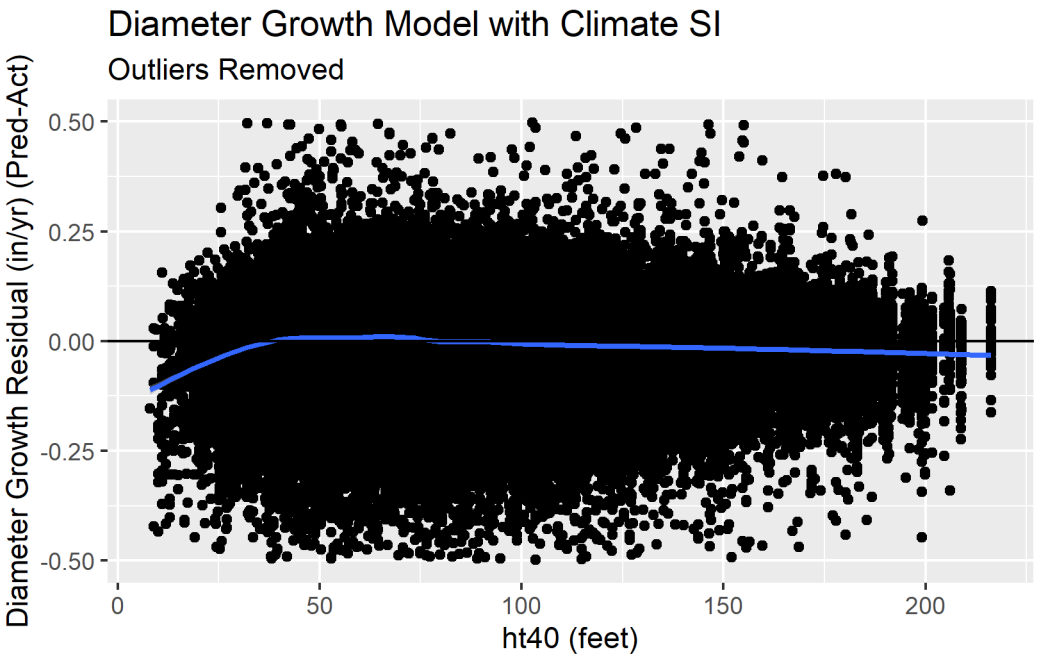


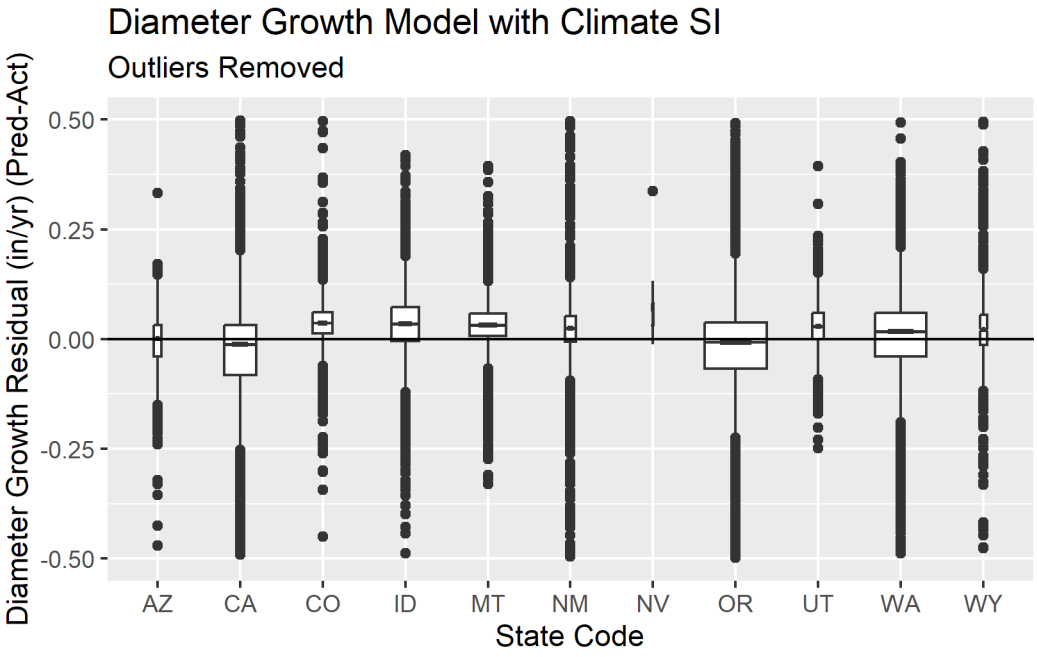

Diameter Growth Model with Climate SI
Outliers Removed
Diameter Growth Residual (in/yr) (Pred-Act)
0.50
0.25
0.00
-0.25
-0.50
0
200
400
600
800
ba (ft^2/acre)

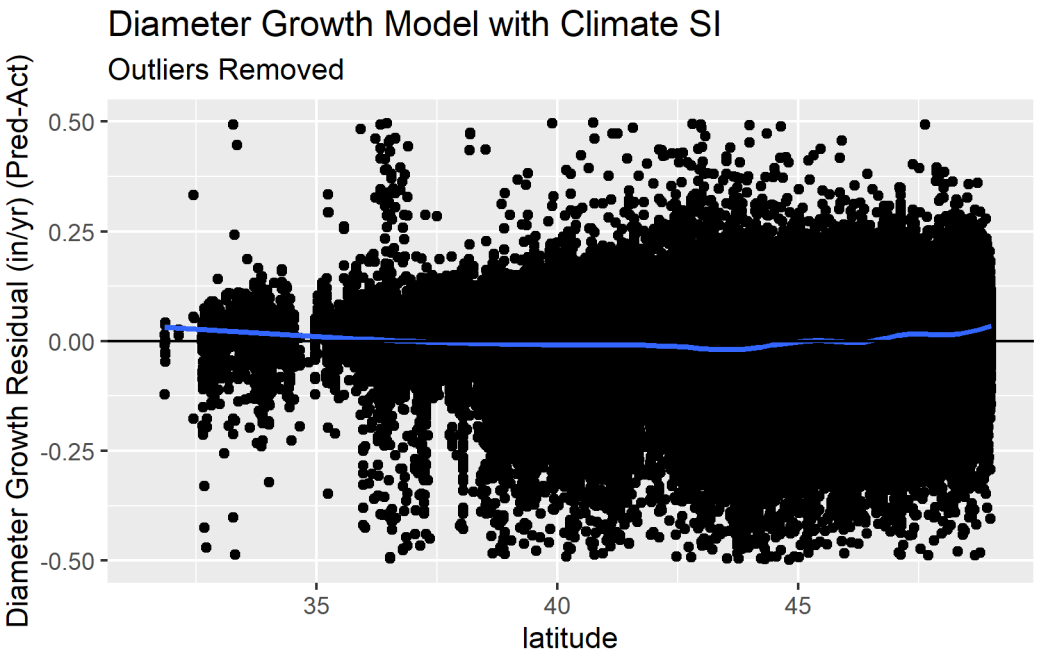

Diameter Growth Model with Climate SI
Outliers Removed
Diameter Growth Residual (in/yr) (Pred-Act)
0.50
0.25
0.00
-0.25
-0.50
0
200
400
600
bal (ft^2/acre)

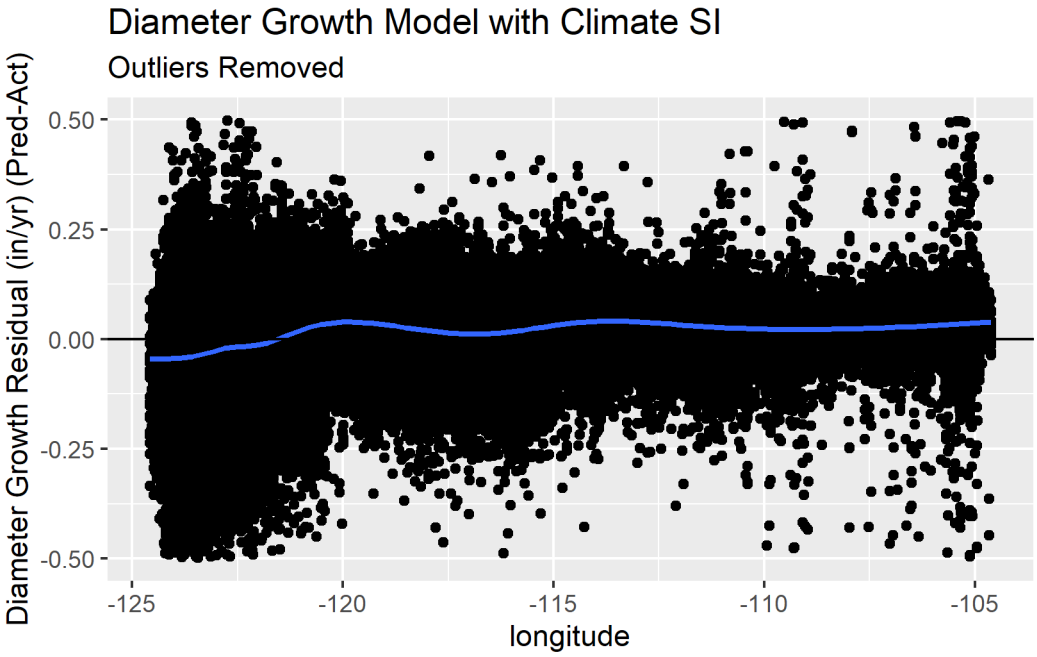

Diameter Growth Model with Climate SI
Outliers Removed
Diameter Growth Residual (in/yr) (Pred-Act)
0.50
0.25
0.00
-0.25
-0.50
0.00
0.25
0.50
0.75
1.00
cr (fraction of ht)

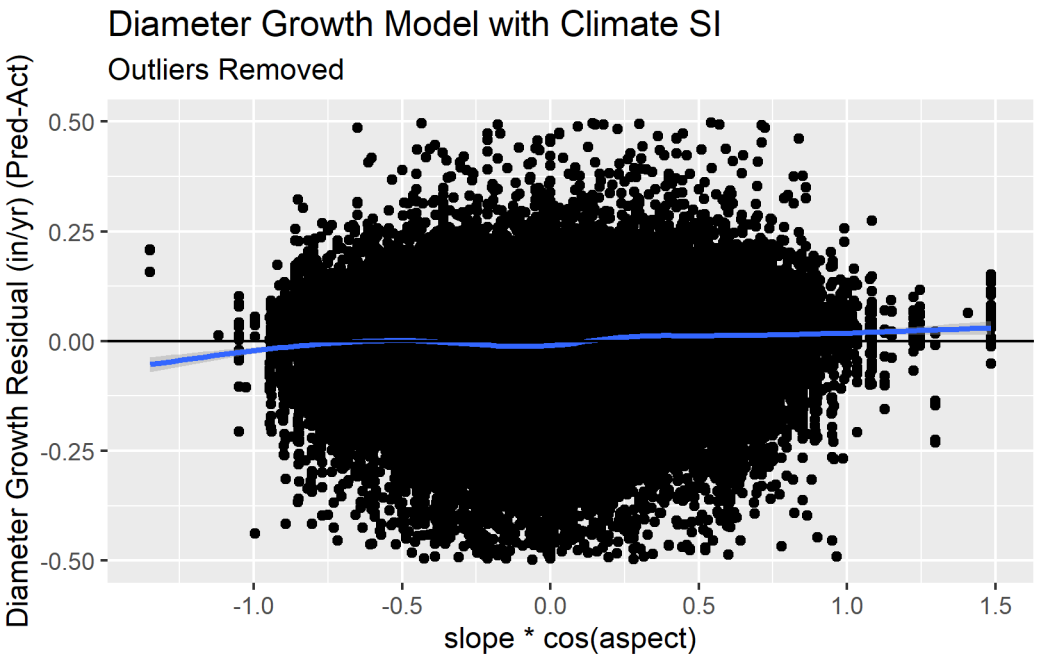

Diameter Growth Model with Climate SI
Outliers Removed
Diameter Growth Residual (in/yr) (Pred-Act)
0.50
0.25
0.00
-0.25
-0.50
18
21
24
climate si (meters)

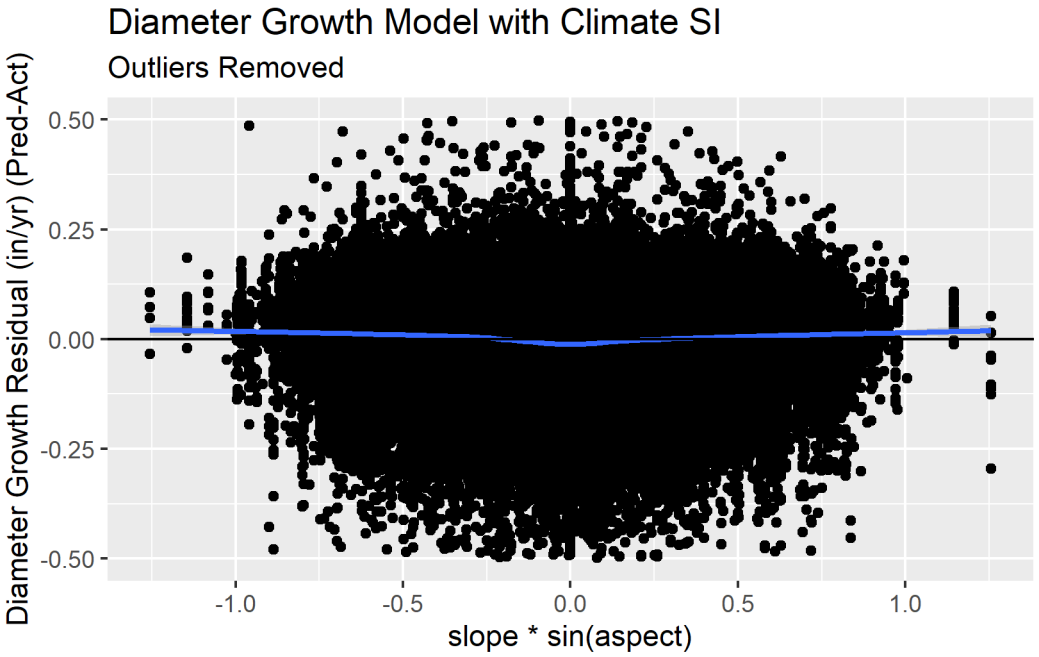

Diameter Growth Model with Climate SI
Outliers Removed
Diameter Growth Residual (in/yr) (Pred-Act)
0.50
0.25
0.00
-0.25
-0.50
0
50
100
150
200
ht40 (feet)

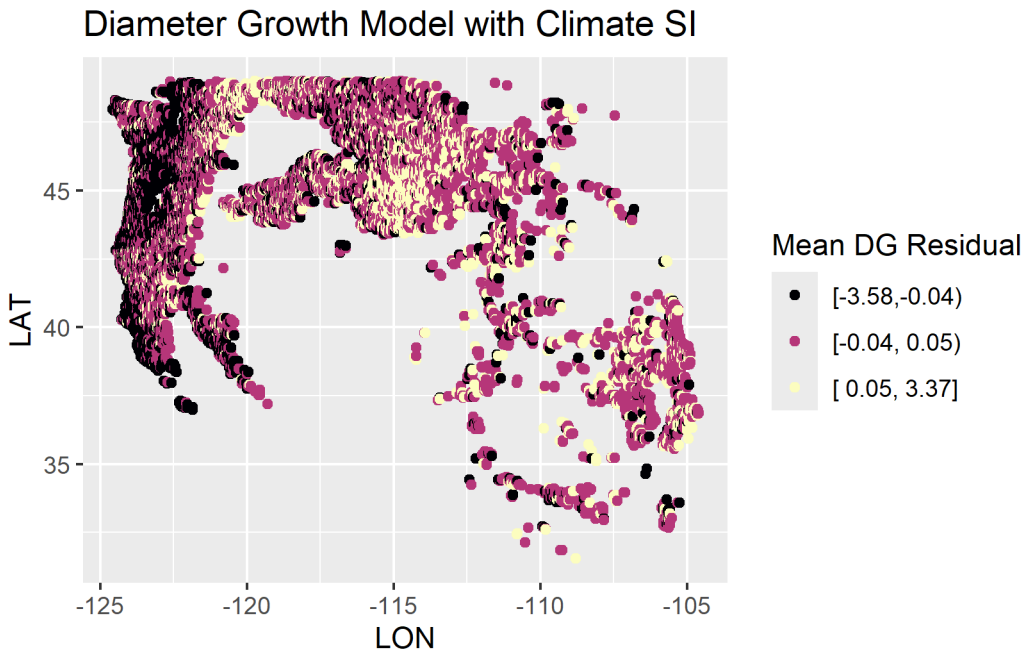

Diameter Growth Model with Climate SI
Outliers Removed
Diameter Growth Residual (in/yr) (Pred-Act)
0.50
0.25
0.00
-0.25
-0.50
AZ
CA
CO
ID
MT
NM
NV
OR
UT
WA
WY
State Code


Diameter Growth Model with Climate SI
Outliers Removed
Diameter Growth Residual (in/yr) (Pred-Act)
0.50
0.25
0.00
-0.25
-0.50
35
40
45
latitude


Diameter Growth Model with Climate SI
Outliers Removed
Diameter Growth Residual (in/yr) (Pred-Act)
0.50
0.25
0.00
-0.25
-0.50
-125
-120
-115
-110
-105
longitude


Diameter Growth Model with Climate SI
Outliers Removed
Diameter Growth Residual (in/yr) (Pred-Act)
0.50
0.25
0.00
-0.25
-0.50
-1.0
-0.5
0.0
0.5
1.0
1.5
slope * cos(aspect)


Diameter Growth Model with Climate SI
Outliers Removed
Diameter Growth Residual (in/yr) (Pred-Act)
0.50
0.25
0.00
-0.25
-0.50
-1.0
-0.5
0.0
0.5
1.0
slope * sin(aspect)


Diameter Growth Model with Climate SI
LAT
45
40
35
-125
-120
-115
-110
-105
LON
Mean DG Residual
[-3.58,-0.04)
[-0.04, 0.05)
[0.05, 3.37]