The Effect of Minimum Winter Temperatures on Pine Growth

Alfredo Farjat, Fikret Isik, Ross Whetten, Steve McKeand
NC State University - Cooperative Tree Improvement Program

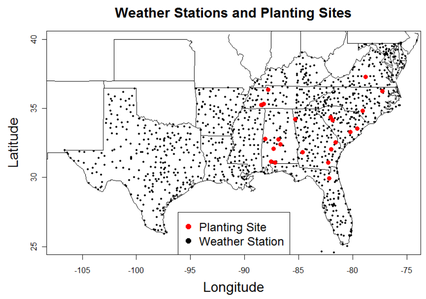
Plantation Selection Seed Source Study (PSSSS)

- Designed to determine the pattern of geographic variation in plantation selections and to assess pine genotypes by environment interactions
- Seedlings from 180 families were planted at 22 test locations throughout the southeastern US.
- Wide range of genetic entries (Piedmont and Coastal) that represent the whole pine population
- Growth, stem quality and fusiform rust disease were measured at tree ages 4 and 8 years

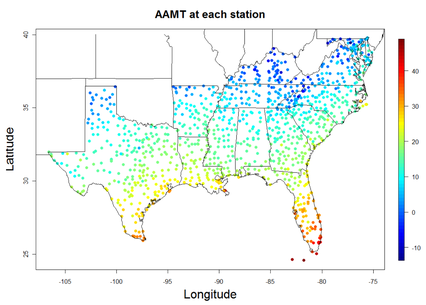
Research Objectives

- Understand the effect of climate variables on the growth of different families (genetic entries)
- Assess pine genotypes by environment interactions (e.g. minimum temperature)
- Develop guidelines for future breeding and deployment decisions

Location of PSSSS Trials

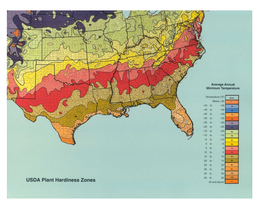


Annual Average Minimum Temperatures (AAMT) - (1994-2005)



Method

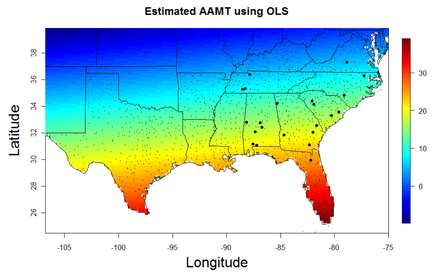
- Explain variation in Average Annual Minimum Temperature (AAMT) through geographical variables (e.g. latitude, longitude, elevation)
- Latitude and longitude are obviously related to temperature
- Ultimately we want to estimate AAMT at the plantation sites along with the corresponding measures of uncertainty.

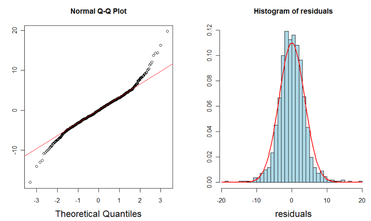


Ordinary Least Squares (OLS)

$$AAMT(s) = \beta_0 + \beta_1 LONG + \beta_2 LAT + \varepsilon$$

OLS Parameter Estimates of First Order Model				
Parameter	Estimate	Std Error	t Value	Pr > t
Intercept	134.3	2.20	60.8	<.0001
Longitude	0.28	0.01	17.9	<.0001
Latitude	-2.87	0.03	-76.4	<.0001

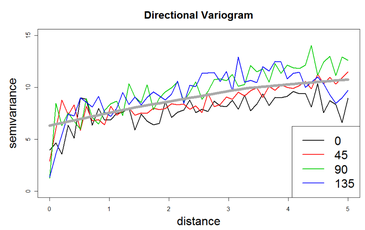




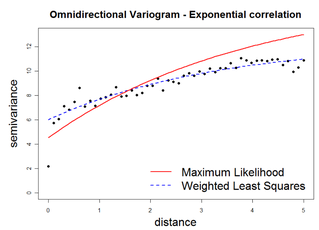
Pearson chi-square normality test: P = 61.1, p-value = 0.00099
Cramer-Von Mises normality test: W = 0.4526, p-value < 0.0001

Spatial Statistical Approach

- A variogram might be thought of as a measure of the dissimilarity between point values as a function of distance. Is the representation of the variability between pairs of data at certain distances and directions.



- Observations are not independent, there is a non-negligible spatial correlation
- Directional variograms are similar (there is no privileged direction)
- The isotropy assumption is reasonable
- We can model the correlations among observations only through their relative distance

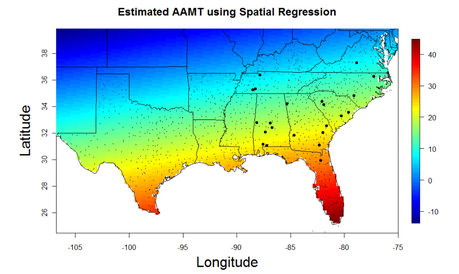


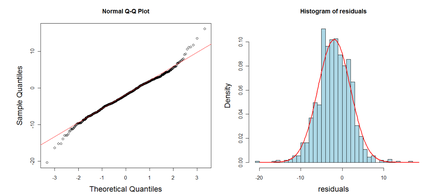
Spatial Statistical Approach

Exponential correlation : $C(h) = \begin{cases} \tau^2 + \sigma^2 & h = 0 \\ \sigma^2 \exp(-\frac{h}{\phi}) & h > 0 \end{cases}$

Estimated Parameters			
Method	τ2 (nugget)	σ2 (partial sill)	ϕ (range)
MLE	4.52	11.69	3.88

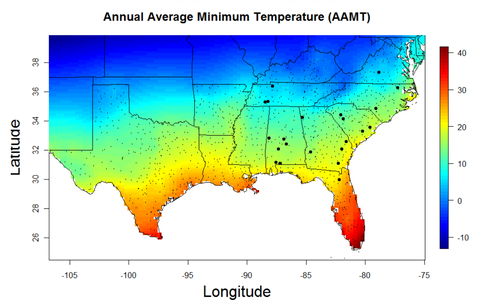
MLE Estimates of First Order Spatial Regression Model				
Parameter	Estimate	Std Error	Z Score	Pr > Z
Intercept	164.2	13.41	12.2	<.0001
Longitude	0.48	0.11	4.2	<.0001
Latitude	-3.18	0.20	-15.1	<.0001



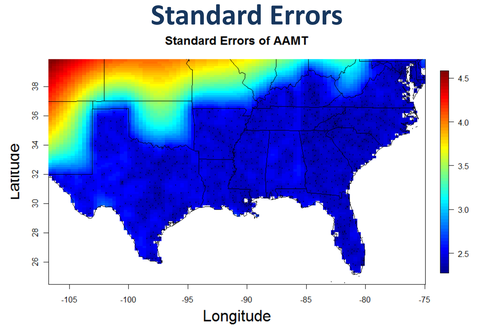


Pearson chi-square normality test: P = 39.18, p-value = 0.1485
Cramer-Von Mises normality test: W = 0.1197, p-value = 0.06048

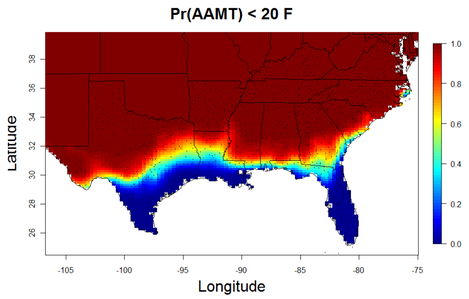
Kriging Interpolation Predicted Values



Standard Errors



Kriging Interpolation: Application



Statistical Analysis: Linear Mixed Model

$$HT_2 = \beta_0 + \beta_1 HT_1 + \beta_2 LONG + \beta_3 LAT + \beta_4 AAMT + \beta_5 FAM + \beta_6 (FAM \times AAMT) + \epsilon$$

HT_2 : Height at age 8
HT_1 : Height at age 4
LAT : Latitude
$LONG$: Longitude
$AAMT$: Annual Average Minimum Temperature
FAM : Family (random)

$FAM \sim N(0, \sigma_F^2)$
$FAM \times AAMT \sim N(0, \sigma_{FT}^2)$
$\epsilon \sim N(0, \sigma^2)$

Covariance Parameter Estimates				
Cov Parm	Estimate	Std Error	Z Value	Pr > Z
Family	5.1398	0.6257	8.22	<.0001
AAMT*Family	0.01330	0.001870	7.11	<.0001
Residual	11.3824	0.07540	150.95	<.0001

Solution for Fixed Effects					
Effect	Estimate	Std Error	DF	t Value	Pr > |t|
Intercept	-108.62	2.6310	178	-41.28	<.0001
Height1	1.1662	0.004647	46E3	250.98	<.0001
Latitude	1.8575	0.04678	46E3	39.70	<.0001
Longitude	-0.6293	0.01088	46E3	-57.85	<.0001
AAMT	0.7258	0.02103	151	34.51	<.0001

- The variance associated to *Family* is relatively high compared to the total variance, ICC=0.31
- The interaction term between *AAMT* and *Family* is highly significant. Although the associated variance is relatively small cannot be neglected
- Likelihood Ratio Test for interaction: C=626.4, p-value ≈ 0
- Different families (pine genotypes) respond differently depending on the AAMT that are exposed.
- An increase of 1 F degree in the AAMT (keeping all the other variables constant) result in an average height increase of 0.72 feet at age 8 years.

Conclusions

- We have found strong evidence that pine genotypes respond differently to AAMT
- This approach can be easily extended to other climate variables of interest (e.g. precipitation)
- Spatial regression and Kriging interpolation are suitable tools for fitting models with geographical variables.
- These tools could be used to model response functions for future deployment breeding guidelines