Change in Landscape Greenness: Anthropogenic or Natural Proof of Concept: selected study areas

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November 18th 2014

Washington DC, US EPA, William Jefferson Clinton West Bldg

1300 Constitution Ave

• The primary objectives of the presentation/study is to present New Mexico (detecting greenness (NDVI*) changes as related to climatic factors) over 18 years (1989-2006) **

•Demonstrate the applicability of model that used in New Mexico to other study areas (as Proof of Concept)

• Modified NM_NDVI model by incorporating RF, Tmin, and PET .

•We selected four National Forest areas that span east to west of USA to conduct the study over the 25-year period from 1989 through 2013

- •GWJ (Virginia)
- •Chatt-O (Georgia)
- •Kisatchie (Louisiana)
- •Hemlock Restoration (California)

•**The Normalized Difference Vegetation Index (NDVI), derived from the Advanced Very High Resolution Radiometer (AVHRR), can be used as a means to monitor vegetation. NDVI data is per 1 km^2 pixel.*

•***Maliha S. Nash, David F. Bradford, James Wickham and Timothy Wade. 2014. Detecting Change in Landscape Greenness over Large Areas: An Example for New Mexico, USA. Remote Sensing of Environment. http://dx.doi.org/10.1016/j.rse.2014.04.023***

In this work, we use the phrase "climate change" to refer to the association between NDVI and the climate variables used in our analyses.

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Our approach for the New Mexico study

Univariate Autoregression

$$NDVI_t = \theta_o + \theta_1 * Time + \mu_t$$

Multivariate Autoregression

$$NDVI_t = \beta_o + \beta_1 RF_t + \beta_2 RF_{t-1} + \beta_3 T\min_t + \beta_4 T\max_t + \beta_5 DP_t + \beta_6 Time_t + \mu_t$$

Comparison

- Univariate time trend (θ_1) vs. multivariate time trend (β_6)
- improvement in detection of a significant NDVI trend
- significant NDVI trend is consistent with climate change as the cause of the trend (i.e., for the climate variables in the analysis)
- significant NDVI trend is consistent with change in more local factors as the cause.

•we examined several areas with known land cover history to help understand the likely causes of NDVI change at these localities.

Data

Normalized Difference Vegetation Index (NDVI), derived from the Advanced Very High Resolution Radiometer (AVHRR), can be used as a means to monitor vegetation. NDVI data is per 1 km^2 pixel.

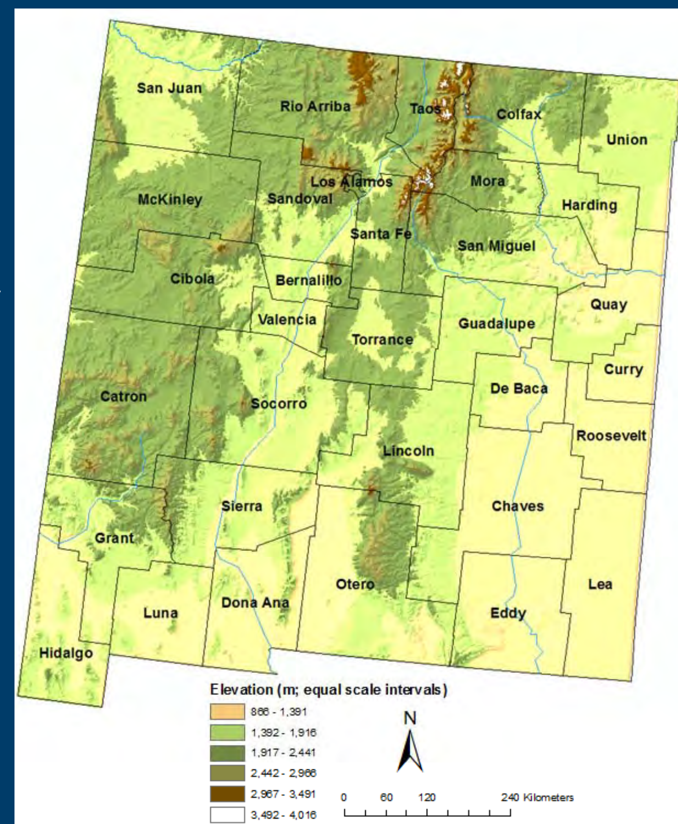
We used five climate variables, monthly averages of precipitation, maximum temperature, minimum temperature, and dew point temperature. (Parameter-elevation Regressions on Independent Slopes Model (PRISM; http://www.prism.oregonstate.edu/products/matrix.phtml, accessed March 2012).

PRISM 4-km^2 grid cells and were gridded into 1-km^2 grid cells using the inverse distance weighted method in ARC-GIS 9.3.1 (ESRI, Redlands, California) to match the NDVI resolution.

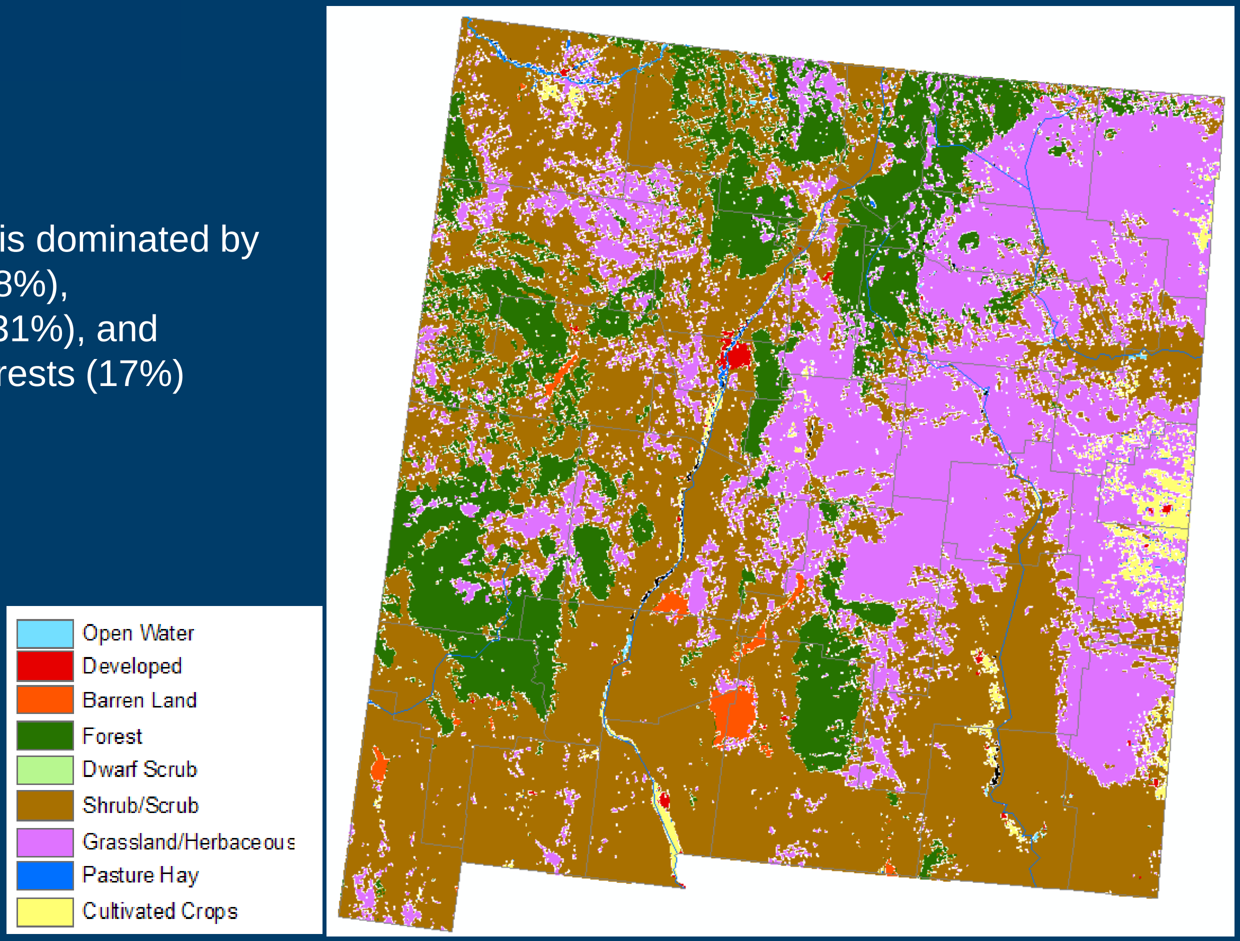
For the model, we used the monthly NDVI, which is the maximum NDVI value of the biweekly NDVI derived by applying MapAlgebra in ARC-GIS 9.3.1.

The New Mexico study was build on an earlier study of change in the NDVI over time that accounted for temporal dependencies (Nash, et al., 2006) by including climate factors that may influence the NDVI.

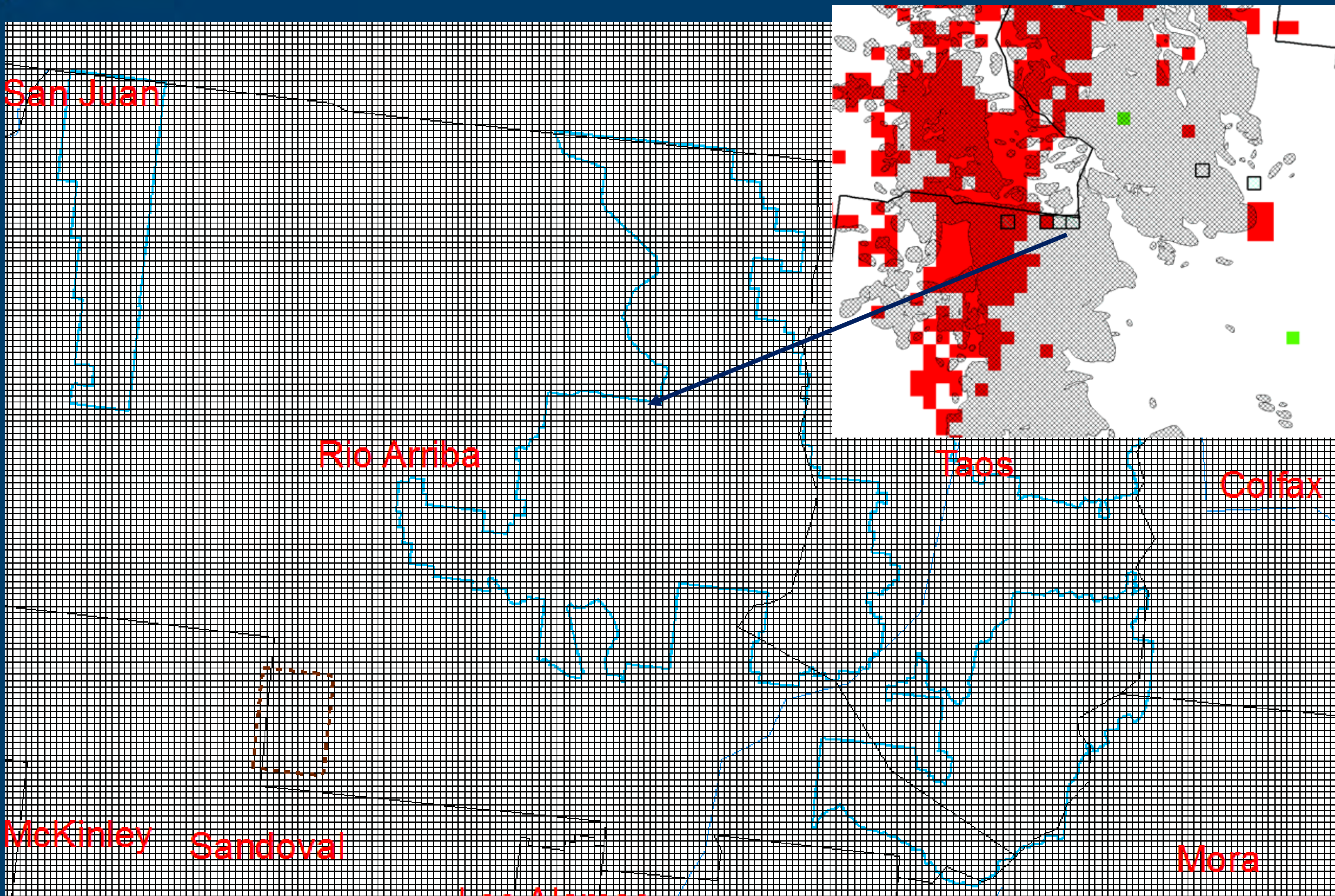
Area: 314,460 km^2
Diverse topography: high plain plateaus (mesas) with numerous mountain ranges, canyon, valleys, and normally dry arroyos and playas.
Elevation: 859 to 4011 m.
Climate: arid to semi-arid.
Annual precipitation varies with elevation and season: averaging 500 mm at higher elevations and 250 mm at lower elevations.



Land covers is dominated by shrubland (48%), grasslands (31%), and evergreen forests (17%)



My analyses were done per 1-km^2 area (pixel)
~ 314,000 pixels



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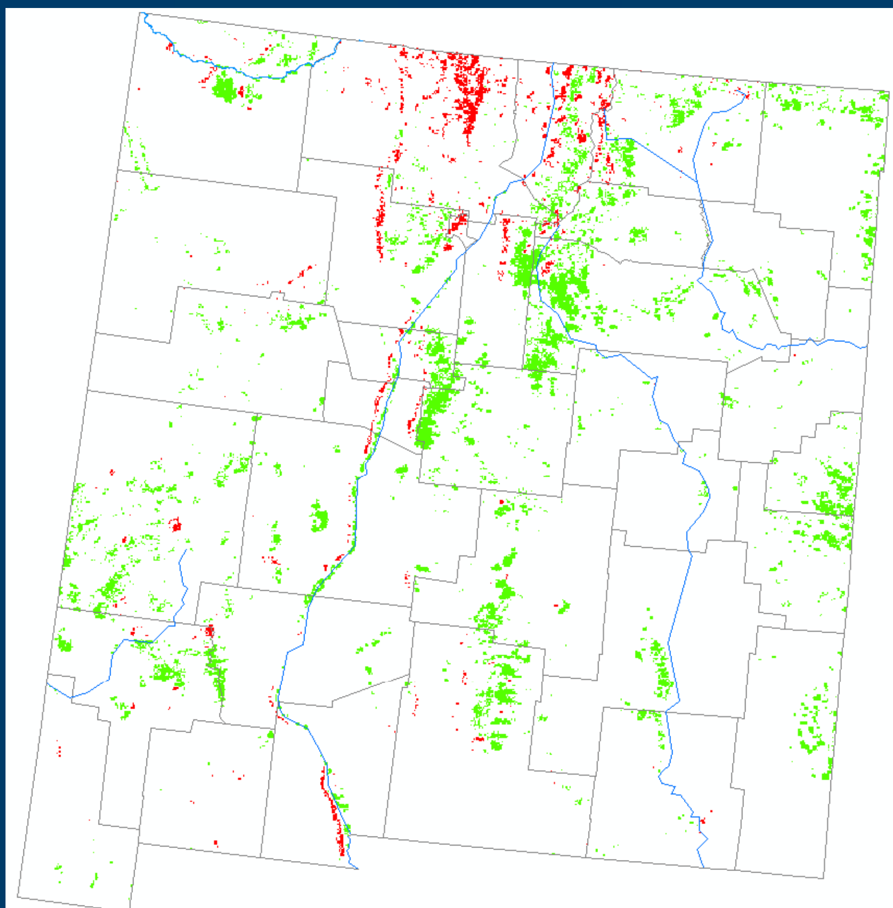
Statistical methods
Univariate Autoregression

Greenness; NDVI
Measure of significant changes is Probability of increase or decrease

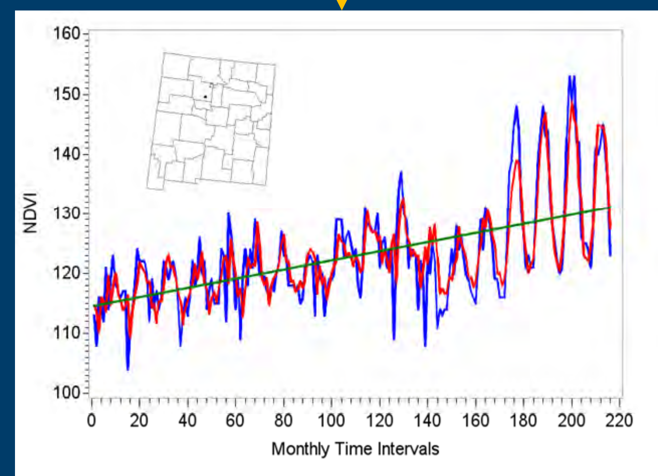


Green indicates significant increase
Red indicates significant decrease

$$NDVI_t = \theta_o + \theta_1 * Time + \mu_t \qquad 1a$$

$$\mu_t = \sum_{t=1}^{k} \rho_i \mu_{t-i} + \varepsilon_t \qquad 1b$$

$$\varepsilon_t \sim IN(0,\sigma^2) \qquad 1c$$



monthly NDVI (n=216 months; 1989-2006).
The slope/coefficient of *Time* (θ_1) quantifies the rate and direction of change for each variable over 18 years (1989-2006).

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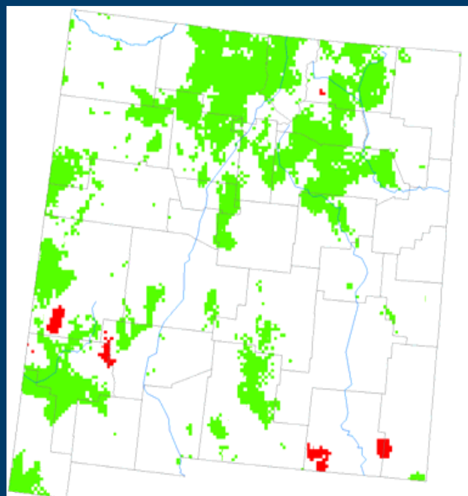
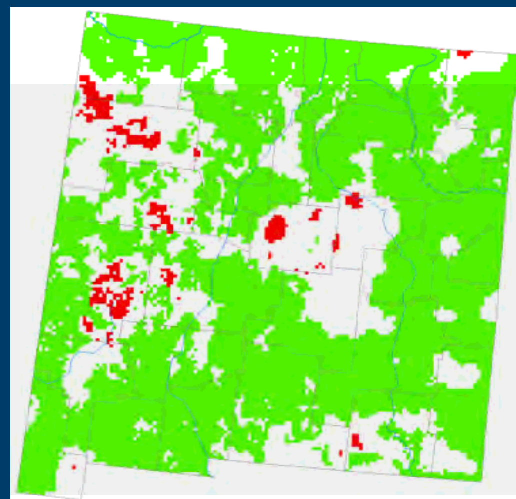
Statistical methods

Univariate Autoregression

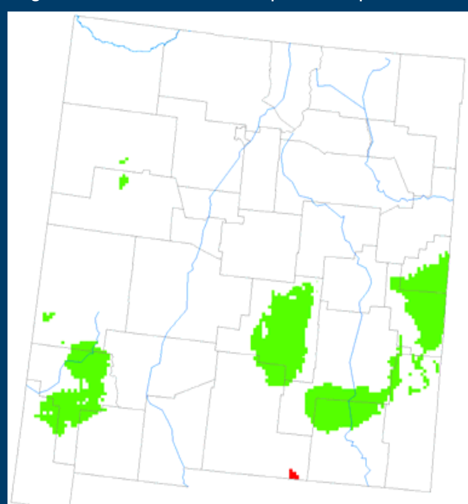
Significant increase in maximum temperature



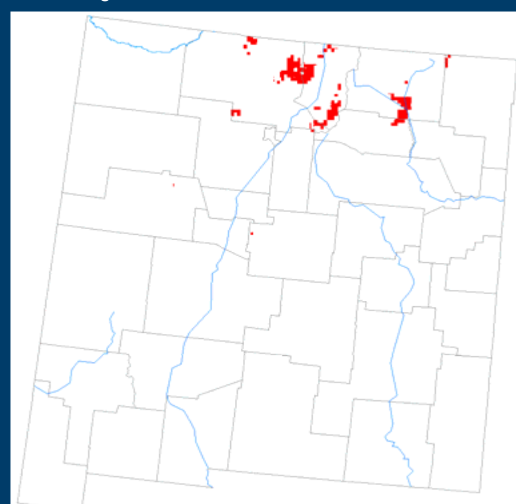
Significant increase in minimum temperature



Significant increase in dew point temperature



Significant decrease in rainfall



Green indicates significant increase
Red indicates significant decrease

$$Y_t = \theta_o + \theta_1 * Time + \mu_t \qquad 1a$$

$$\mu_t = \sum_{t=1}^{k} \rho_i \mu_{t-i} + \varepsilon_t \qquad 1b$$

$$\varepsilon_t \sim IN(0, \sigma^2) \qquad 1c$$

monthly maximum, minimum temperature, Dew point temperatures, monthly Rainfall (n=216 months; 1989-2006).
The slope/coefficient of *Time* (θ_1) quantifies the rate and direction of change for each variable over 18 years (1989-2006).

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Statistical methods

Multivariate Autoregression

$$NDVI_t = \beta_o + \beta_1 RF_t + \beta_2 RF_{t-1} + \beta_3 T\min_t + \beta_4 T\max_t + \beta_5 DP_t + \beta_6 Time_t + \mu_t \qquad 2a$$

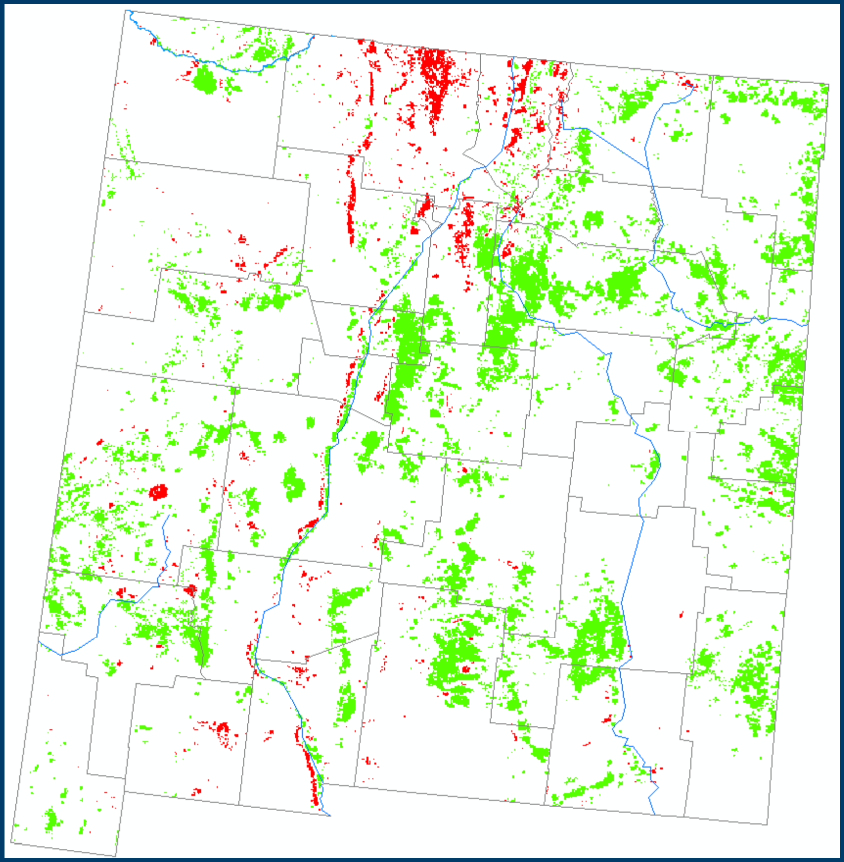
$$\mu_t = \sum_{t=1}^{k} \rho_i \mu_{t-i} + \varepsilon_t \qquad 2b$$

$$\varepsilon_t \sim IN(0, \sigma^2) \qquad 2c$$

where RF_t is rainfall at month t, RF_{t-1} is rainfall for previous month (i.e., one-month lag precipitation), *Tmin* is minimum temperature, *Tmax* is maximum temperature, *DP* is dew point temperature, and ε is the error term., autoregression error (μ_t).

The slope/coefficient of *Time* (β_6) is the temporal trend of the NDVI after accounting for climate variables.

Multivariate Autoregression



A

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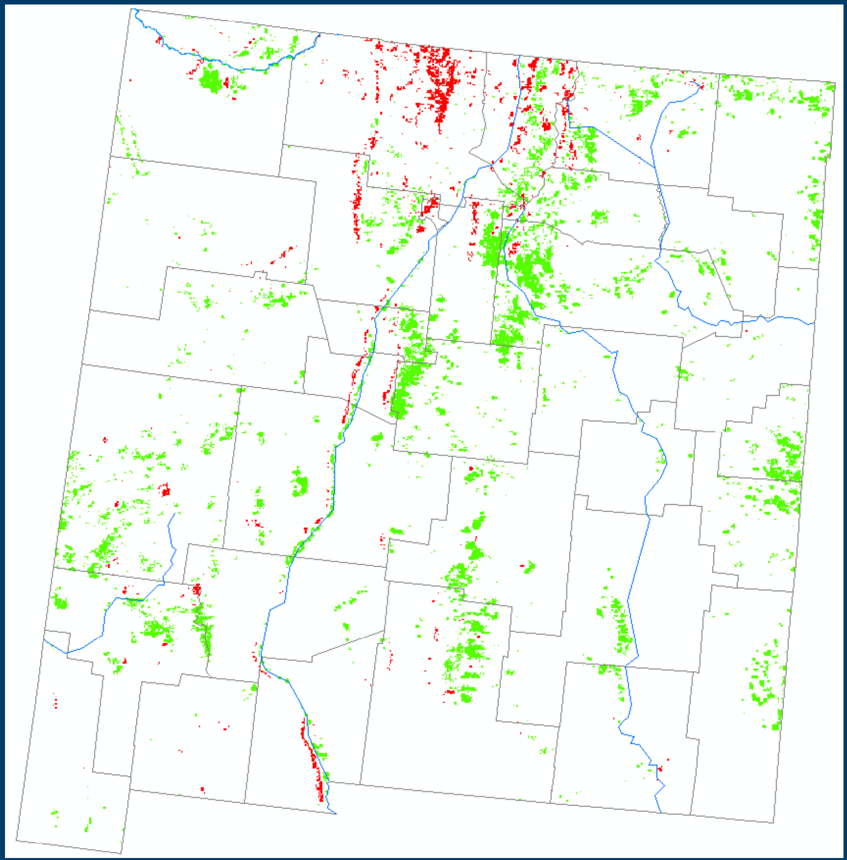
Comparison

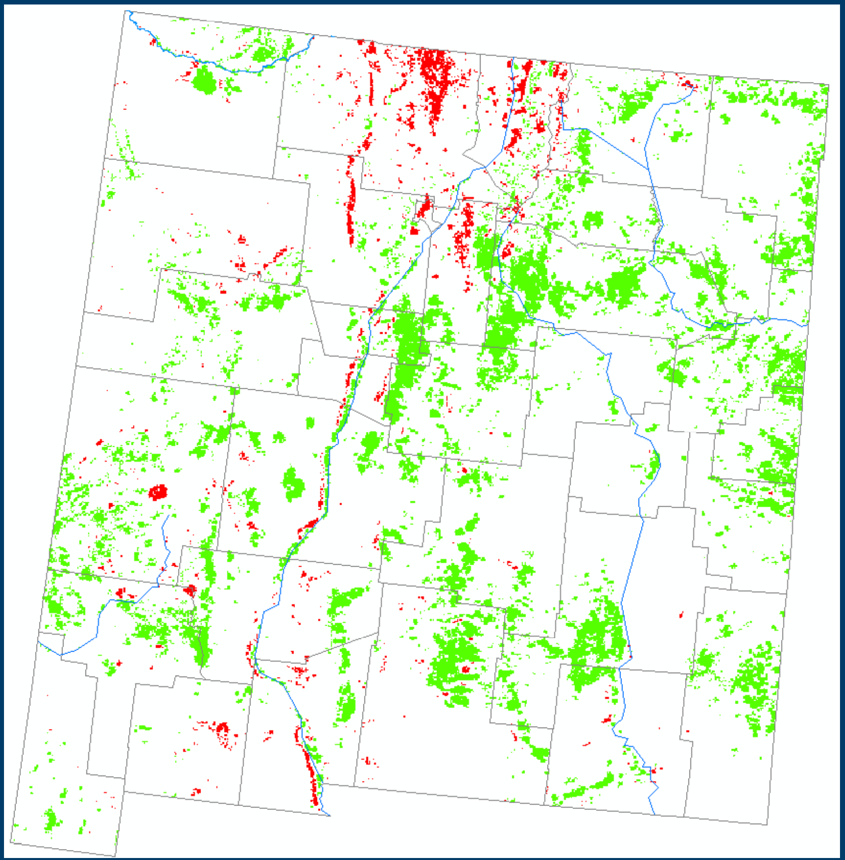
$$NDVI_t = \theta_o + \theta_1 * Time + \mu_t$$

$$NDVI_t = \beta_o + \beta_1 RF_t + \beta_2 RF_{t-1} + \beta_3 T\min_t + \beta_4 T\max_t + \beta_5 DP_t + \beta_6 Time_t + \mu_t$$

Univariate Autoregression (θ_1)

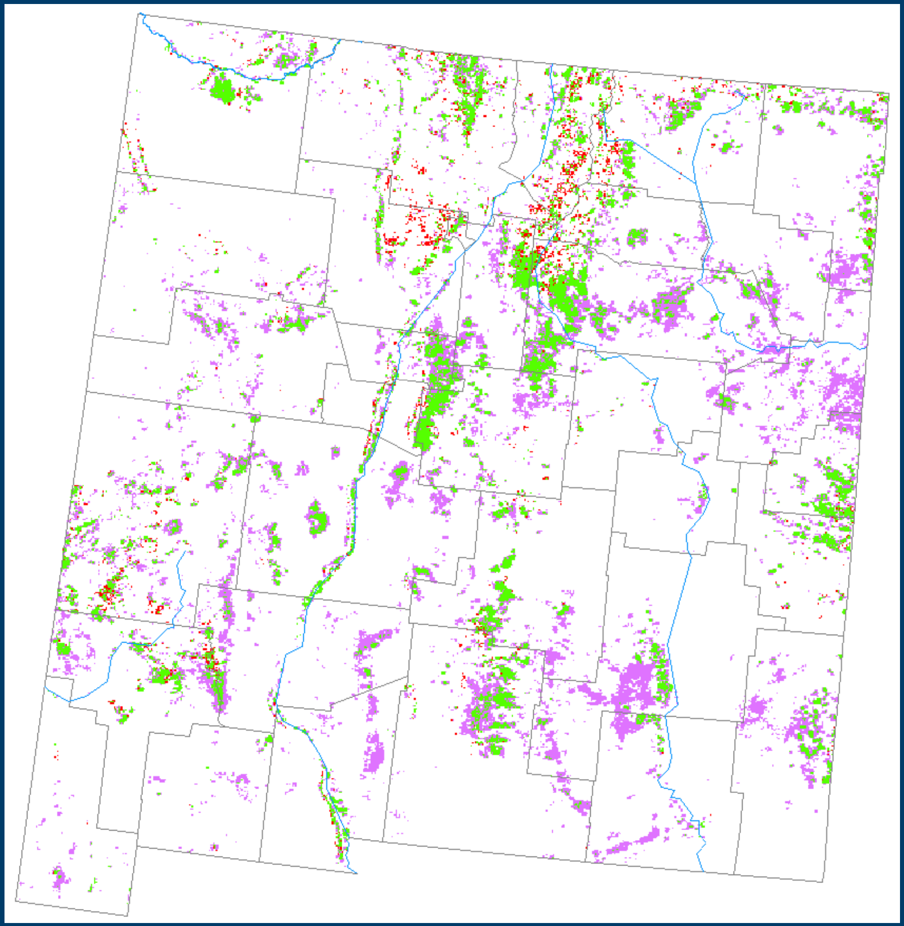


Multivariate Autoregression (β_6)



Pixels (1 km^2) with significant temporal trend for the monthly NDVI from 1989 to 2006 in New Mexico. Sample size is 216 for each pixel. Green indicates significant (p<0.05) increase in greenness (i.e., NDVI); red indicates significant decrease in greenness.

Comparison, two way contingency table



Multivariate Regression

Univariate Regression	S	NS
S	A Local Change	B Climate Change
NS	C Local Change	D No Change

Comparisons of the NDVI trend significance between the univariate and multivariate autoregression analyses for each pixel. Outcomes (A-D) are defined in the Table.

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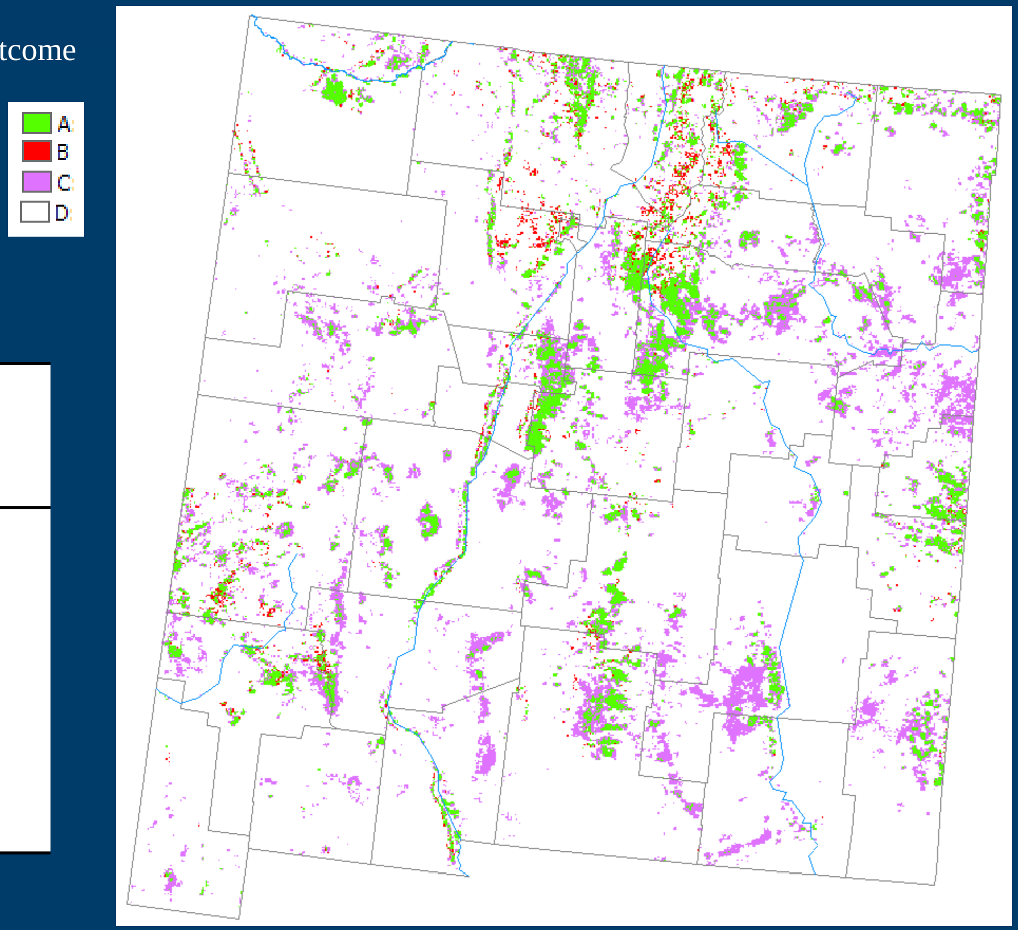
NDVI Trends in Univariate Analysis	NDVI Trends in Multivariate Analysis		
	Significant	Not Significant	Total
Significant	Outcome A 4.43%	**Outcome B 0.77%**	5.20%
Not Significant	Outcome C 7.44%	Outcome D 87.37%	94.80%
Total	11.86%	88.14%	100.00%

Outcome



Comparisons of the NDVI trend significance between the univariate and multivariate autoregression analyses for each pixel. Outcomes (A-D) are defined in the Table.

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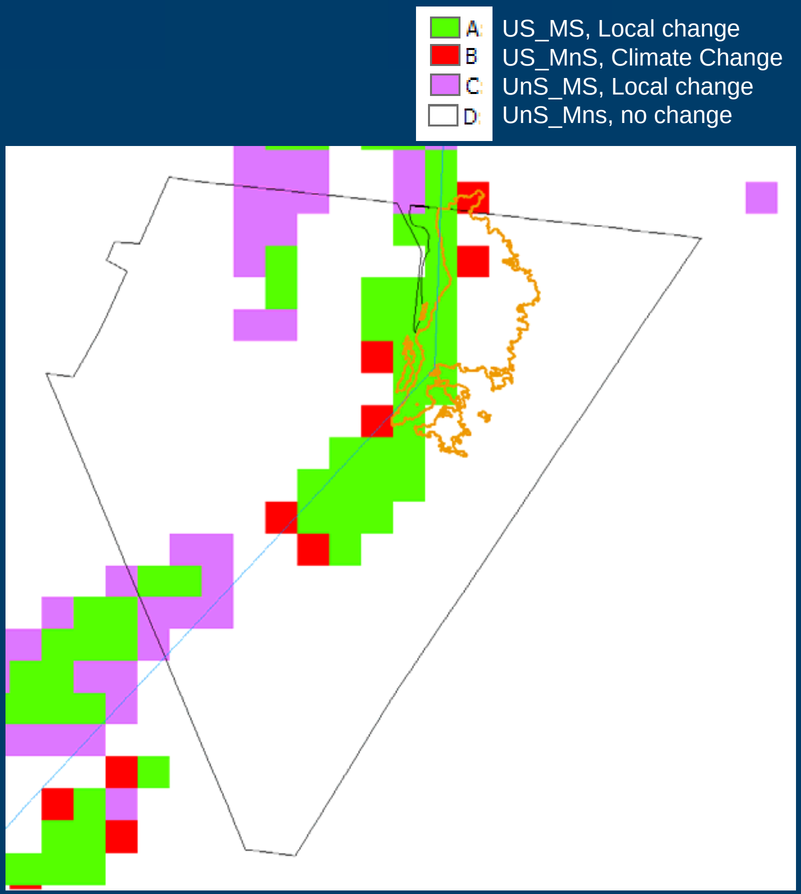
Examining and Validating Results
Field, Publications, Expert Knowledge, etc.

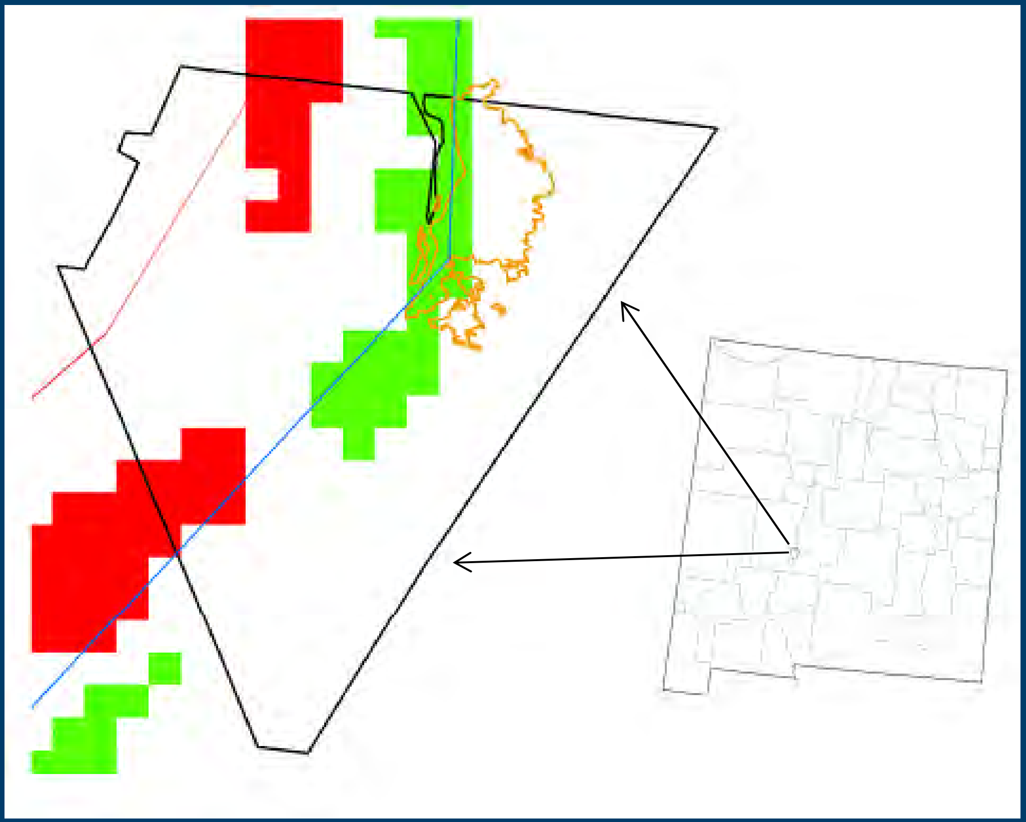
- ***Invasive species and restoration*** (Bosque del Apache NWR)
- ***Fires and post fire greenness gains*** **(**Cerro Grande Fire**)**
- ***Tree mortality due to insect infestation*** (Carson National Forest)
- Rio Grande River water level (Elephant Butte Reservoir) (this was not included the published article)

Invasive species and restoration

Climate Change

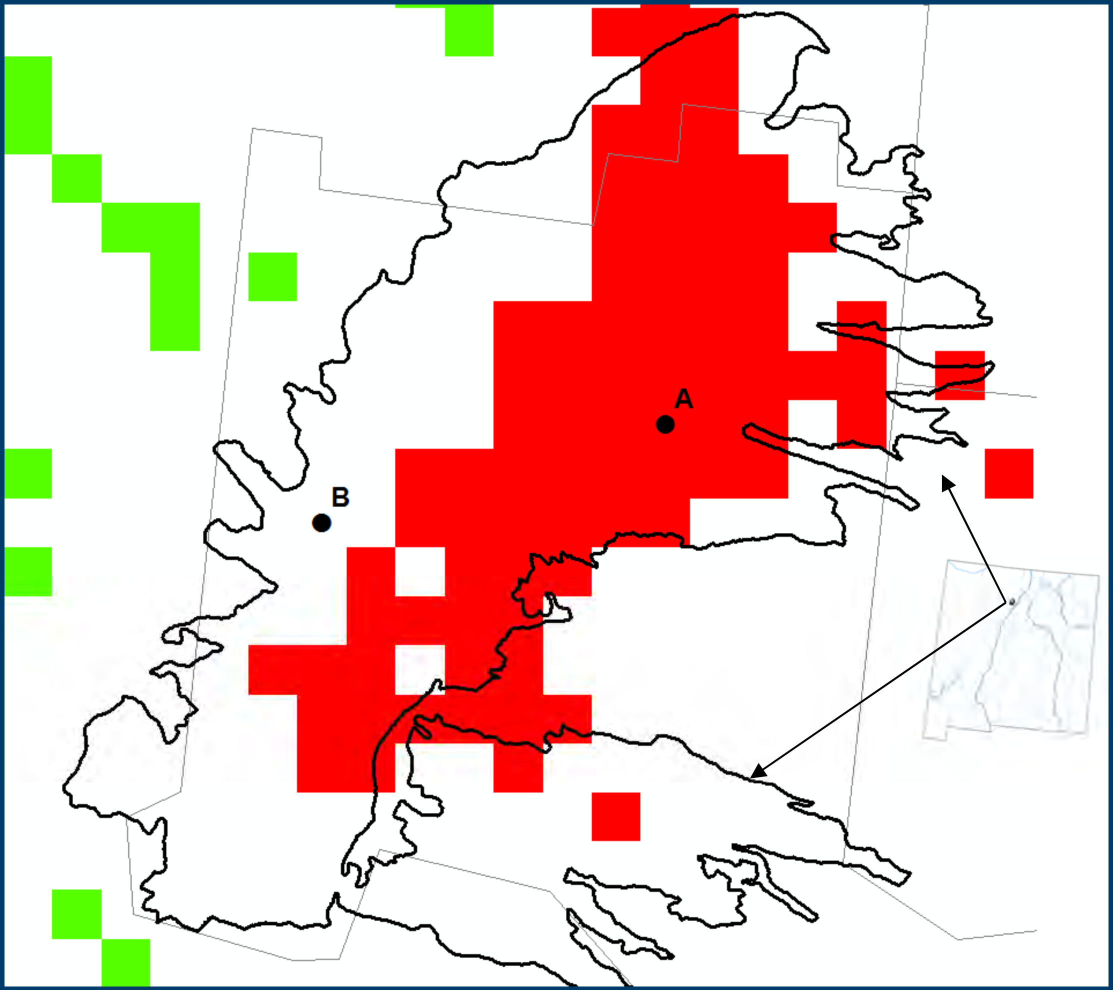


Green indicates significant increase in NDVI
Red indicates significant decrease in NDVI



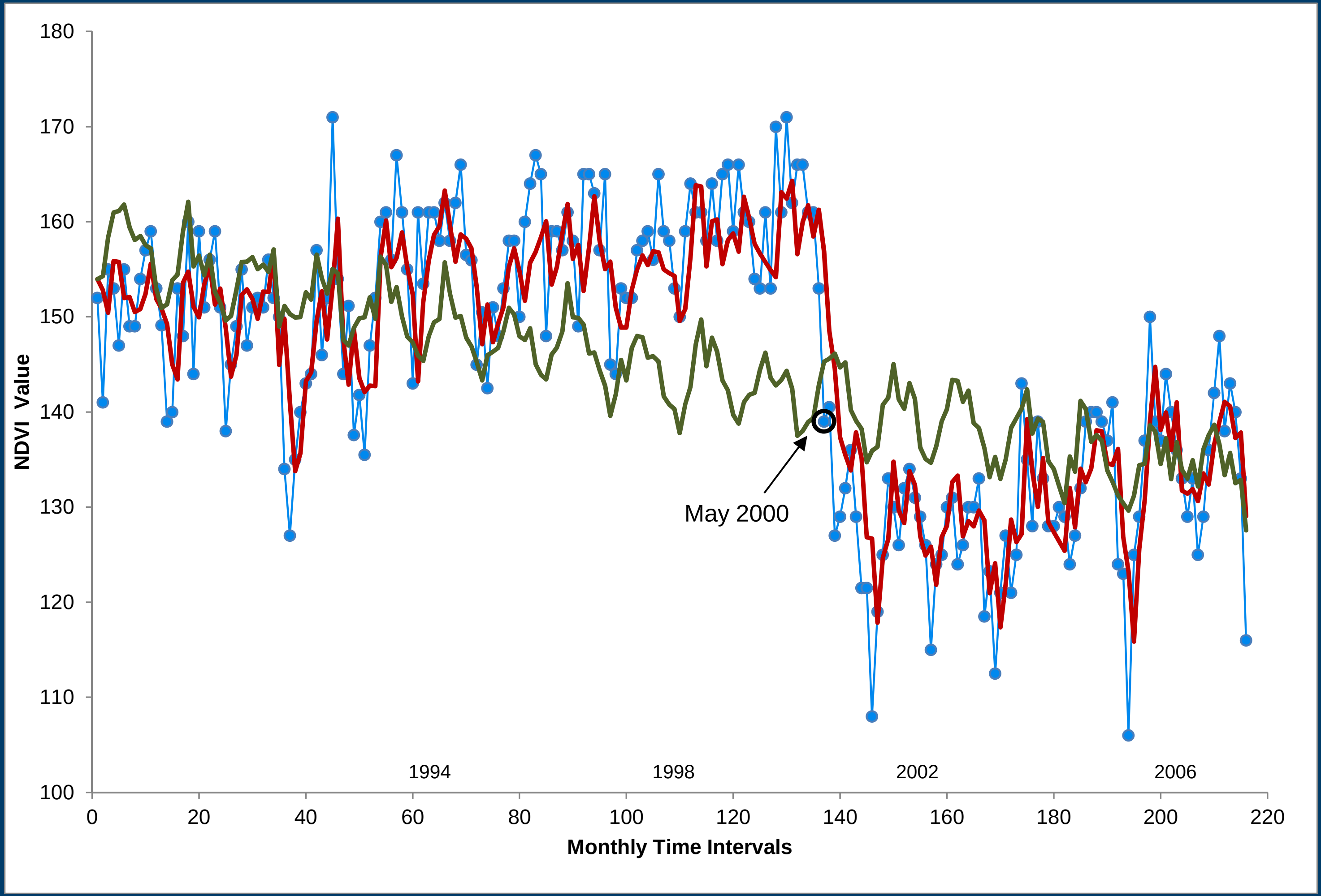
Change in greenness in the Bosque del Apache National Wildlife Refuge (black polygon) in Socorro County. Blue line is the Rio Grande River; red line is Interstate Highway 25; brown polygon indicates boundaries of the 1996 wildfire (provided by Mara Weisenberger, U.S. Fish and Wildlife Service, Las Cruces, New Mexico). Inset map shows the location of the Refuge.

Fires and post fire greenness gains

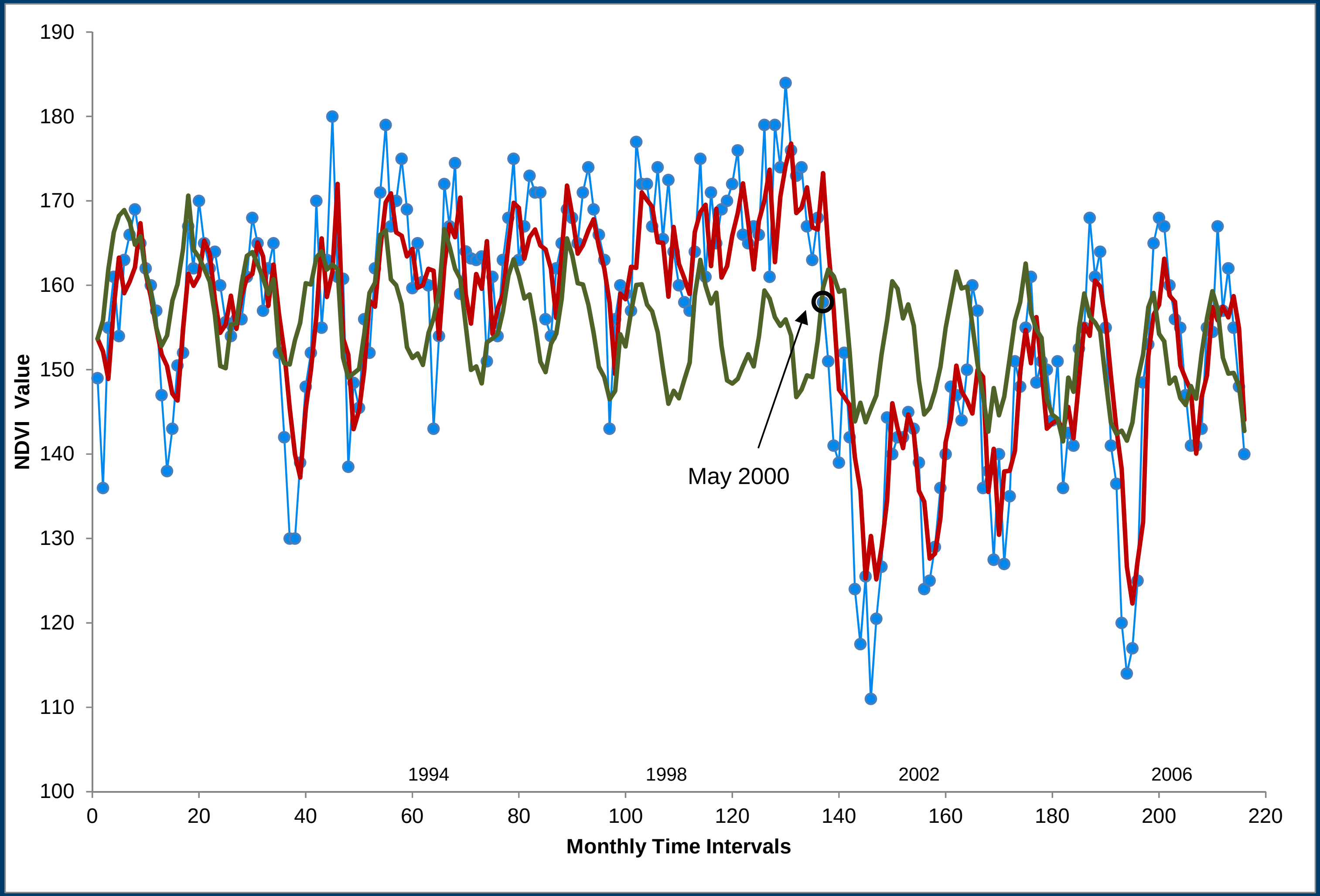


The 2000 Cerro Grande Fire polygon (heavy black outline; from http://www.fs.usda.gov/detail/r3/landmanagement/gis/, Santa Fe fire history). The fire polygon lies mostly in Los Alamos County (light black lines). Green pixels indicate significant increase in the NDVI over time (multivariate autoregression); red pixels indicate significant decrease in the NDVI over time (multivariate autoregession).

Cerro Grande Fire, Pixel A



Cerro Grande Fire, Pixel B



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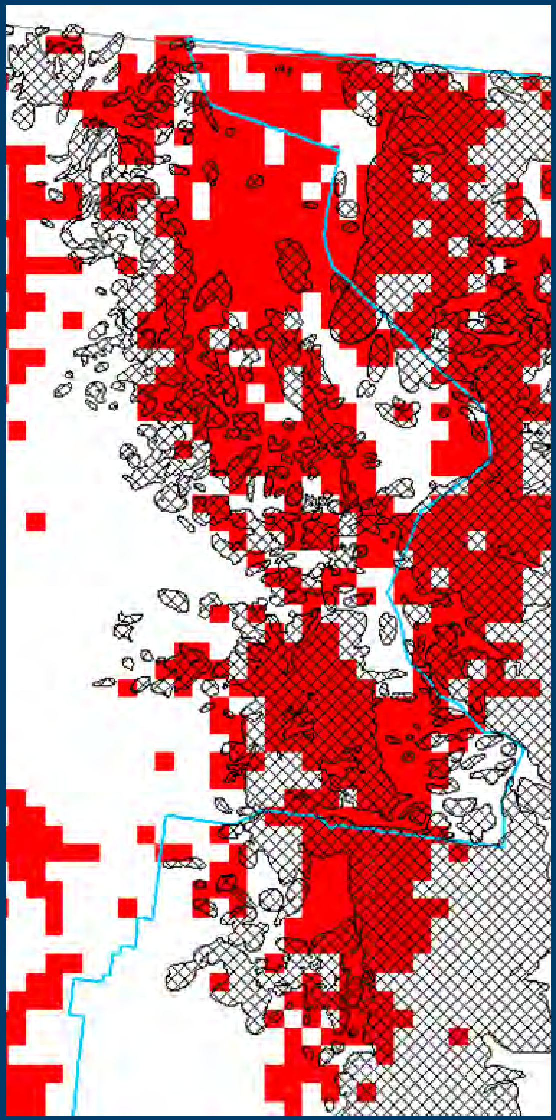
Tree mortality due to insect infestation



Tree mortality from insect infestation in 1998 to 2006 (black hatching), and pixels with significant decrease in the NDVI (red color) in multivariate autoregression

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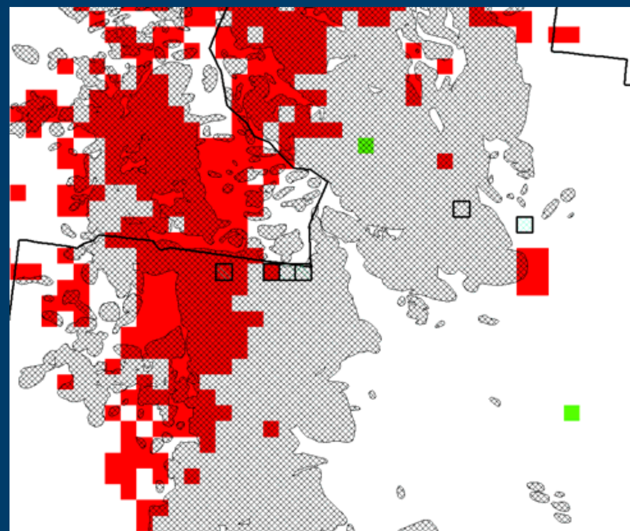
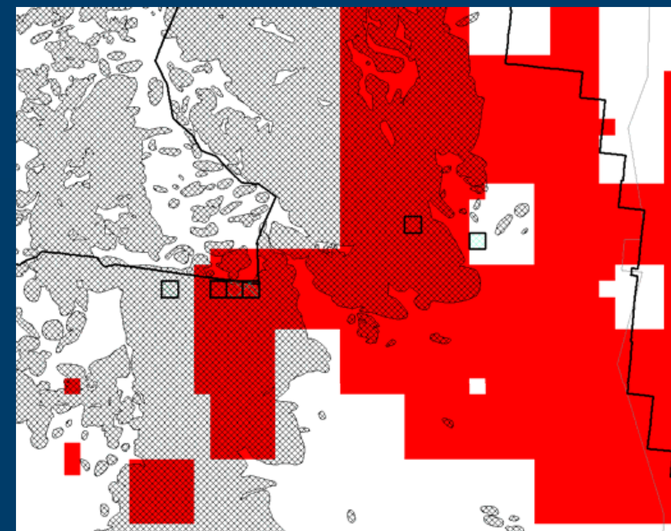
Green: significant (p<0.05) increase
Red: significant decrease

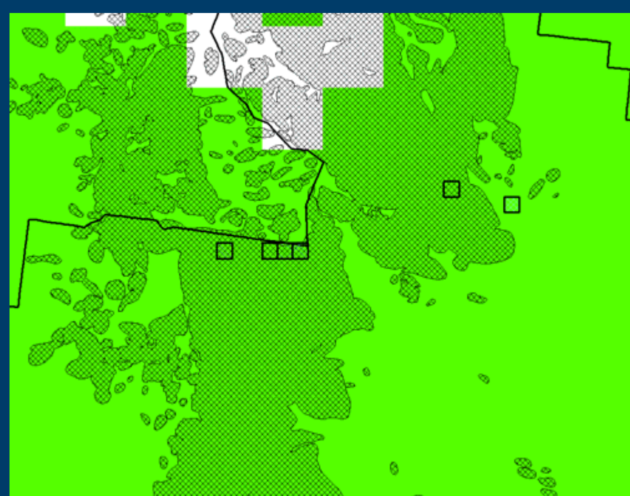
Significant decrease in greenness (NDVI)



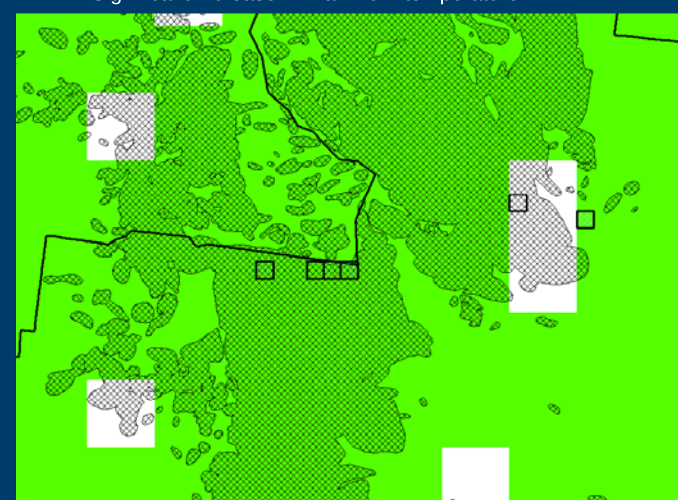
Significant decrease in rainfall



Significant increase in maximum temperature



Significant increase in maximum temperature



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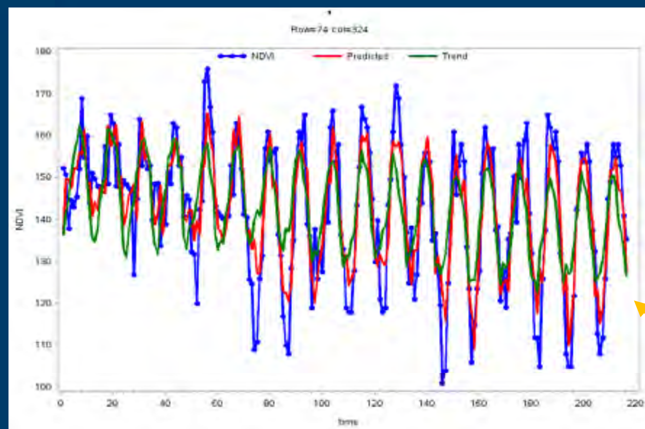
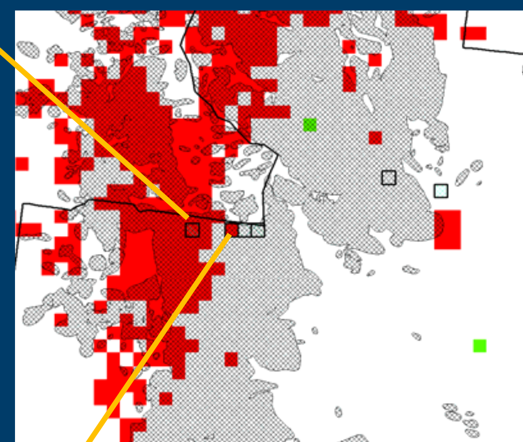
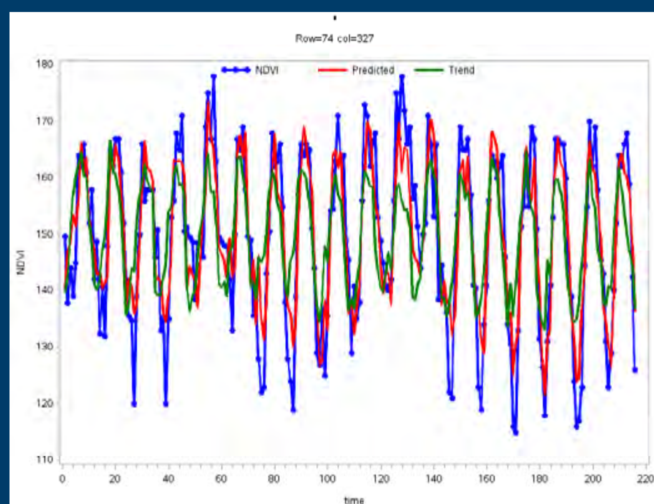


Red: greenness (NDVI) Decrease





Insect infestation in 1998 to 2006 (black hatching)

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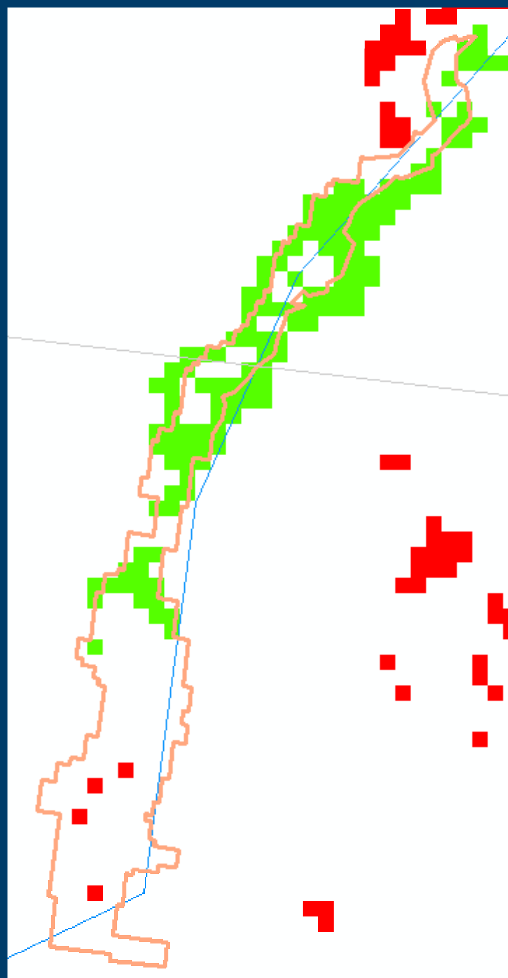
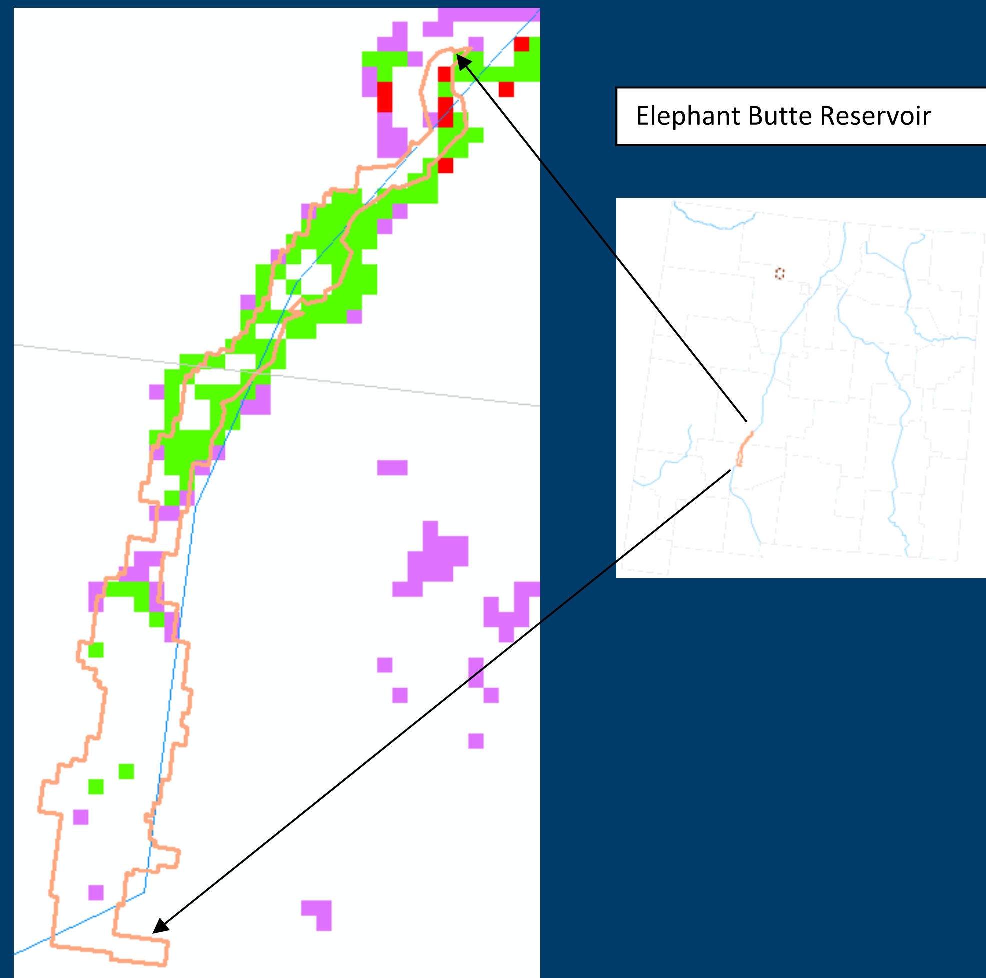
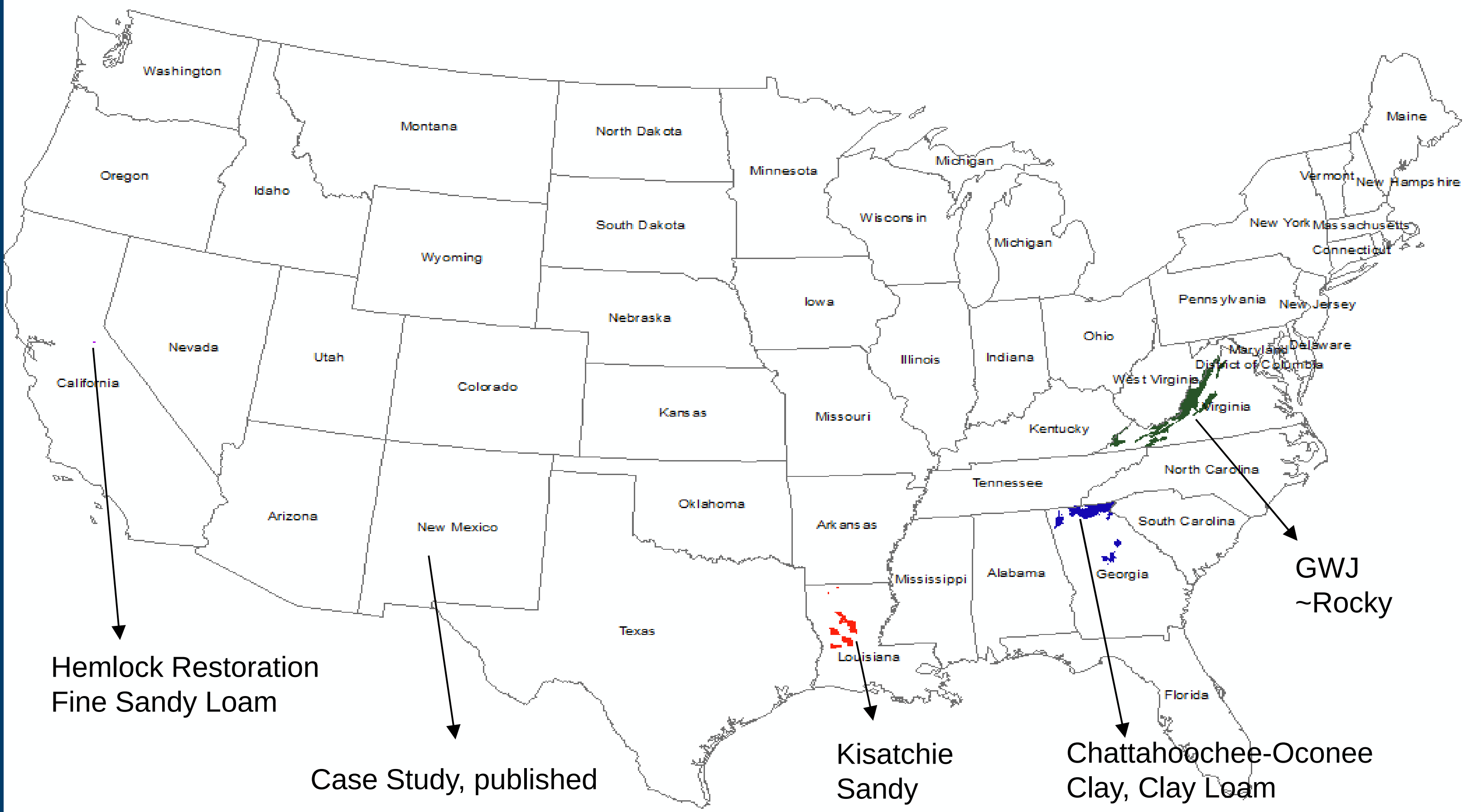
Climate Change

Sig. Increase in Greenness from
Mult. Autoregression model



A	US_MS, Local change
B	US_MnS, Climate Change
C	UnS_MS, Local change
D	UnS_Mns, no change




Washington
Montana
North Dakota
Minnesota
Oregon
Idaho
South Dakota
Wisconsin
Michigan
Maine
Vermont
New Hampshire
New York
Massachusetts
Connecticut
Wyoming
Iowa
Nebraska
Pennsylvania
New Jersey
Nevada
Utah
Colorado
Illinois
Indiana
Ohio
Maryland
Delaware
District of Columbia
California
Kansas
Missouri
West Virginia
Virginia
Kentucky
North Carolina
Tennessee
Oklahoma
Arkansas
South Carolina
Arizona
New Mexico
Mississippi
Alabama
Georgia
Texas
Louisiana
Florida
GWJ
~Rocky
Hemlock Restoration
Fine Sandy Loam
Case Study, published
Kisatchie
Sandy
Chattahoochee-Oconee
Clay, Clay Loam

Data (1989-2013) per 1-km^2 pixel:

- NDVI monthly (remote sensing)
- (PRISM) monthly
  - Precipitation (mm/month)
  - Minimum Temperature (^oC)
  - Maximum Temperature (^oC)
    - Average Temperature (^oC)

- Potential Evapotranspiration (mm/month) (Hamon, 1961)

$$PET = 13.97 d D^2 W_t$$

  - d is number of days in a month
  - D is mean monthly hours of daylight (in unit of 12 hours)
  - W_t is saturated water vapor density (= $0.0495e^{0.062T}$)
    - T is the monthly mean temperature in Celsius

- Ongoing
  - Actual Evapotranspiration
  - Water Balance, follow Thornthwaite & Mather (1957) algorithm to calculate water Surplus, Deficit and future prediction (on going)

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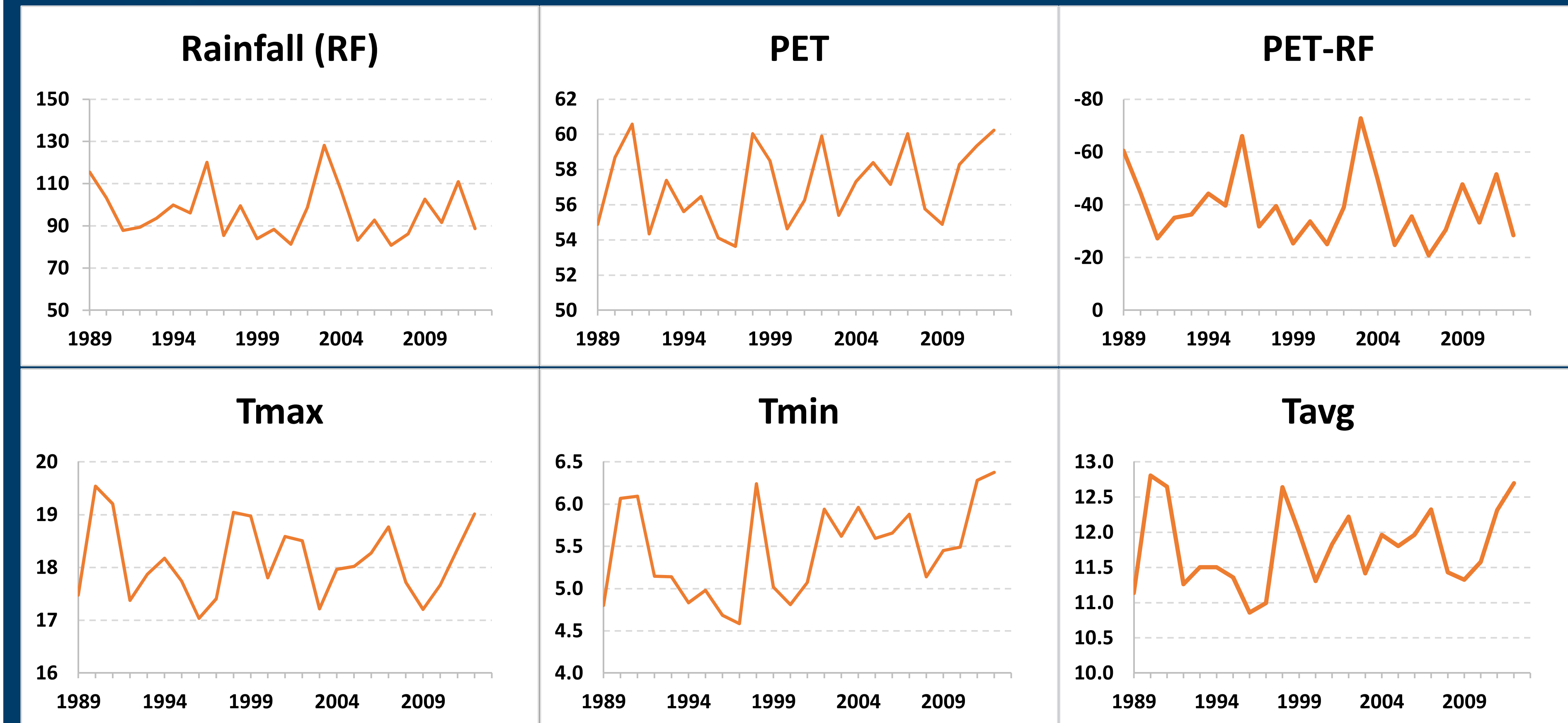
GWJ; Yearly Mean Values of Variables



T in ºC, RF and PET in mm/month

**2013 data is not included

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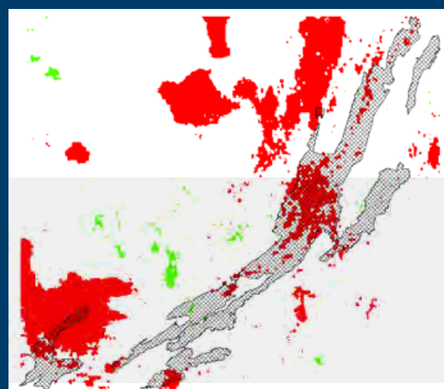
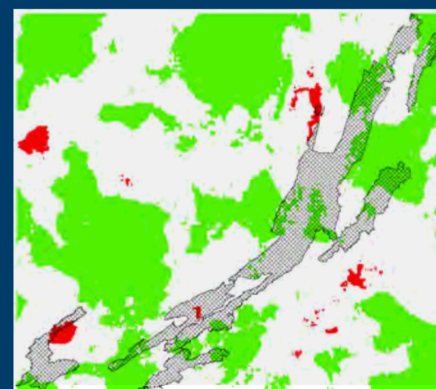
Spatial distribution of changes (trend): GWJ

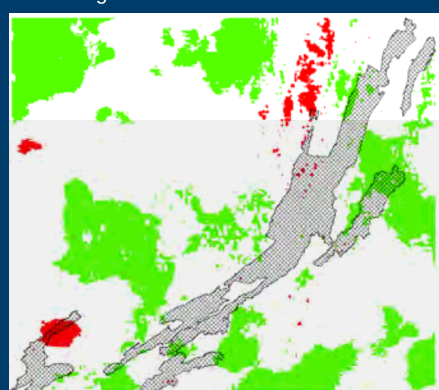
Significant decrease in maximum temperature



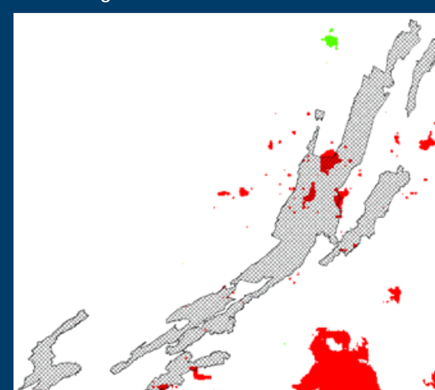
Significant increase in minimum temperature



Significant increase in PET



Significant decrease in rainfall



Green: Significant increase
Red: Significant decrease

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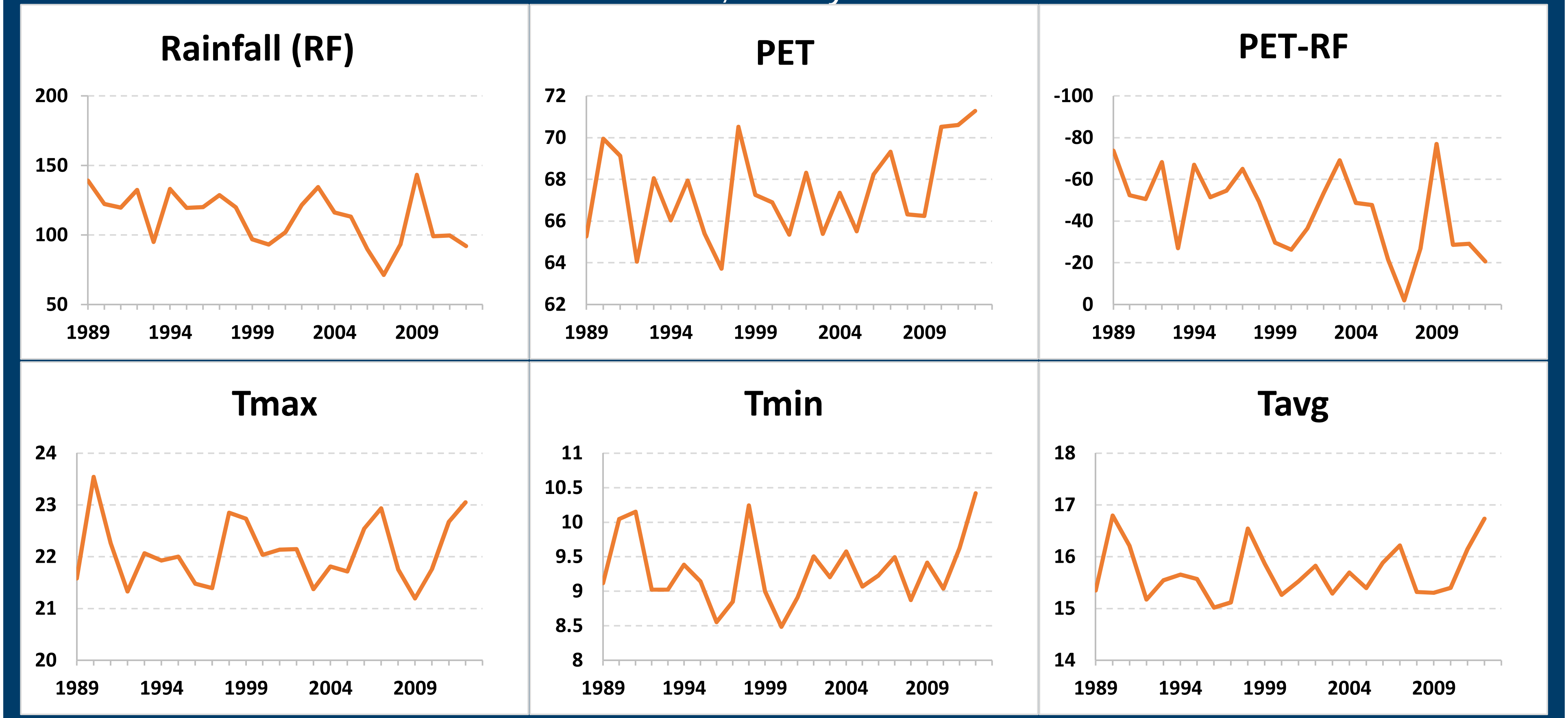
Chattahoochee-Oconee; Yearly Mean Values of Variables



T in ºC, RF and PET in mm/month

**2013 data is not included

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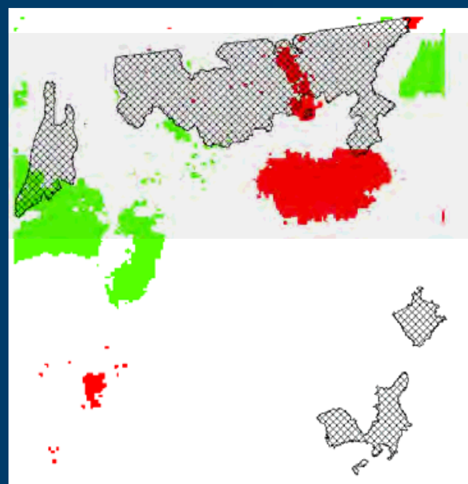
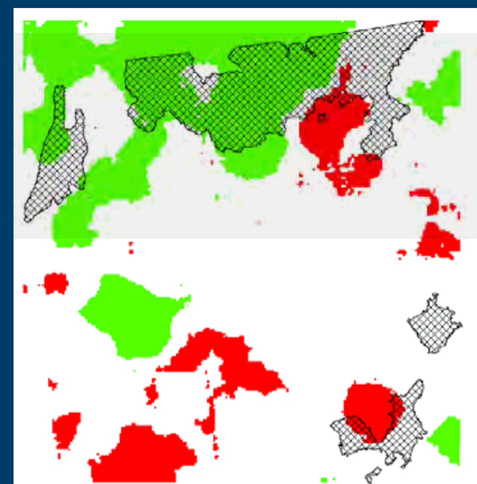
Spatial distribution of changes (trend): Chattahoochee-Oconee

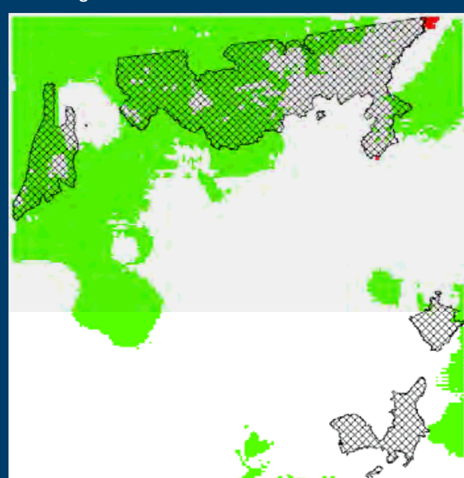
Significant increase/decrease in maximum temperature



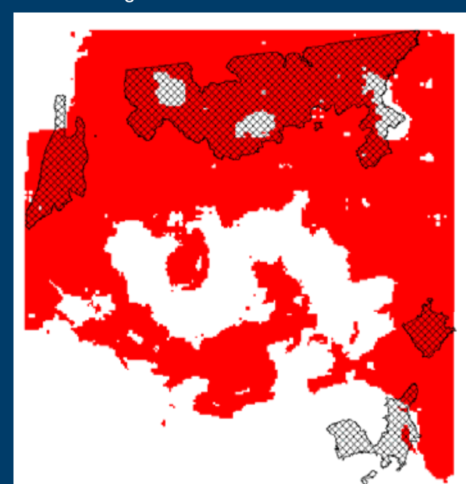
Significant increase in minimum temperature



Significant increase in PET



Significant decrease in rainfall



Green: Significant increase
Red: Significant decrease

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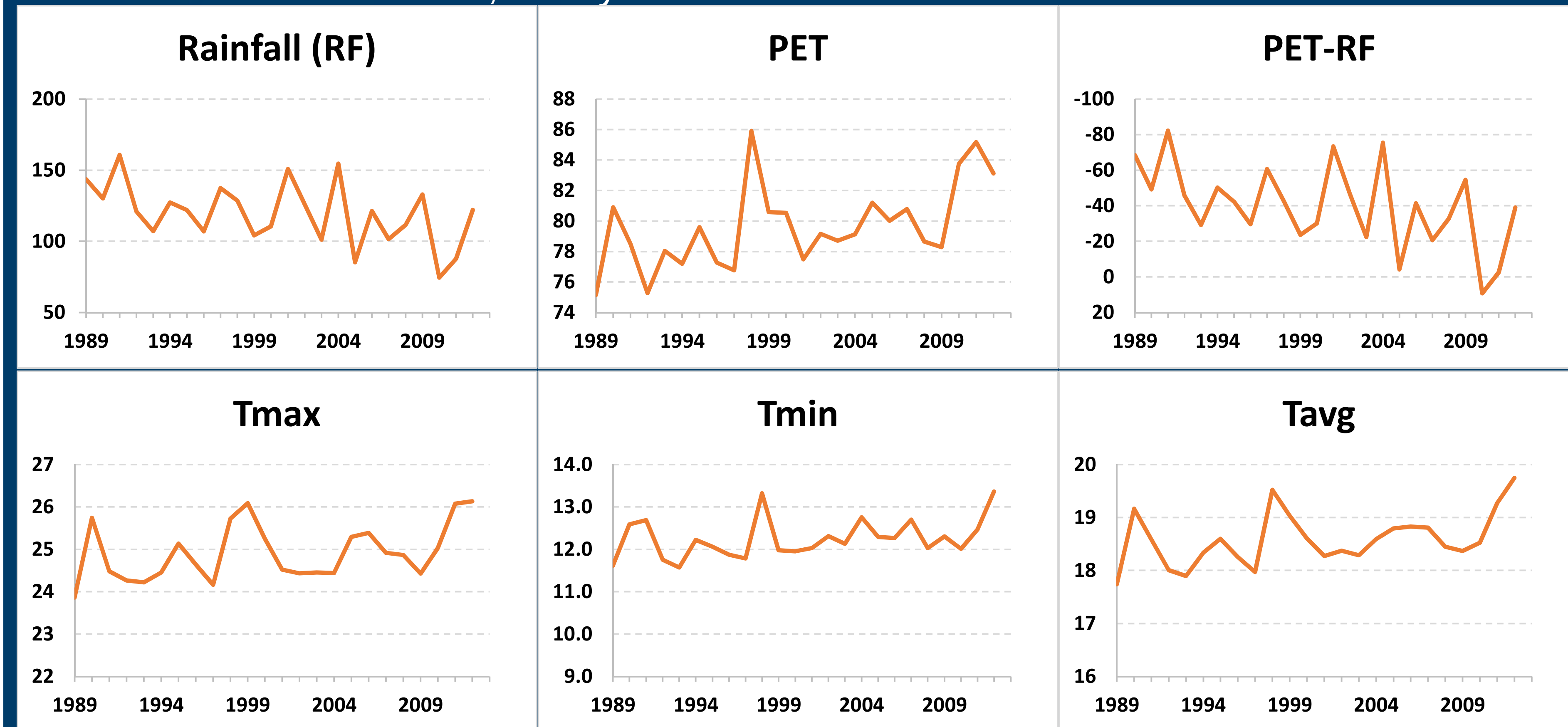
Kisatchie; Yearly Mean Values of Variables



T in ºC, RF and PET in mm/month

**2013 data is not included

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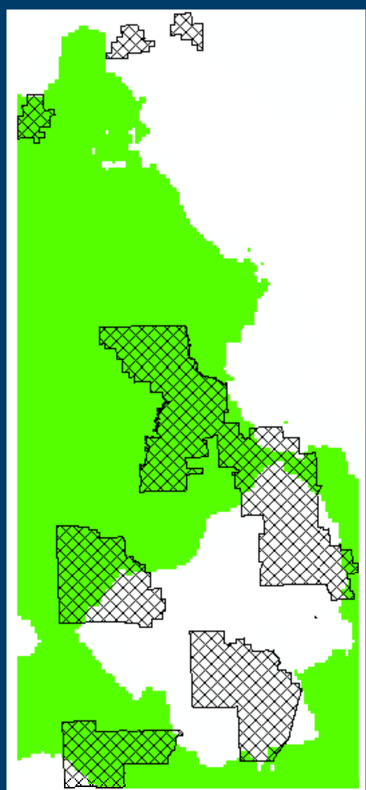
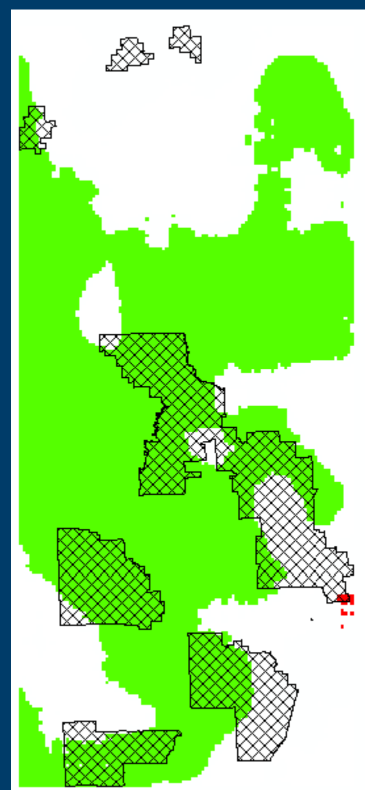
Spatial distribution of changes (trend): Kisatchie

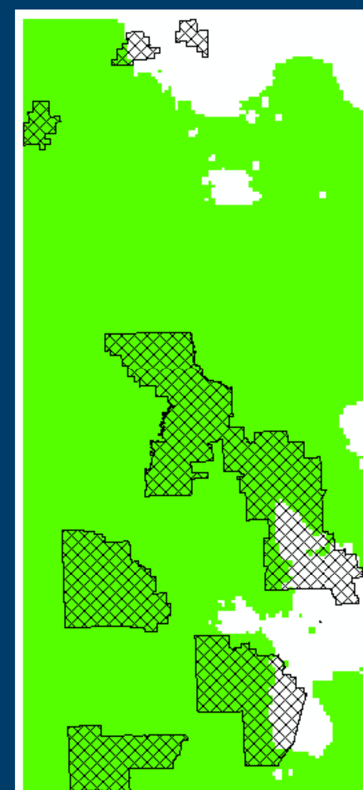
Significant increase in maximum temperature



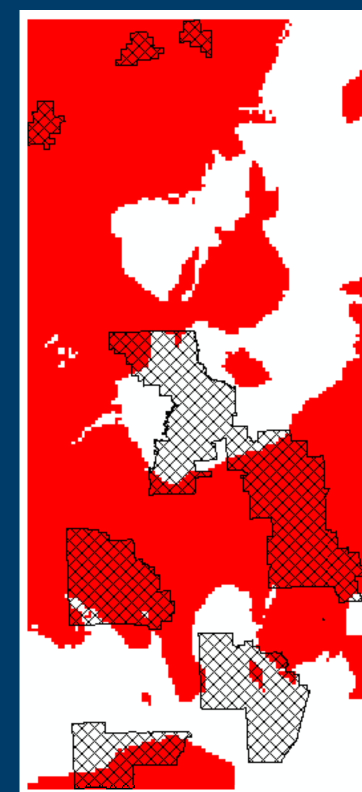
Significant increase in minimum temperature



Significant increase in PET



Significant decrease in rainfall



Green: Significant increase
Red: Significant decrease

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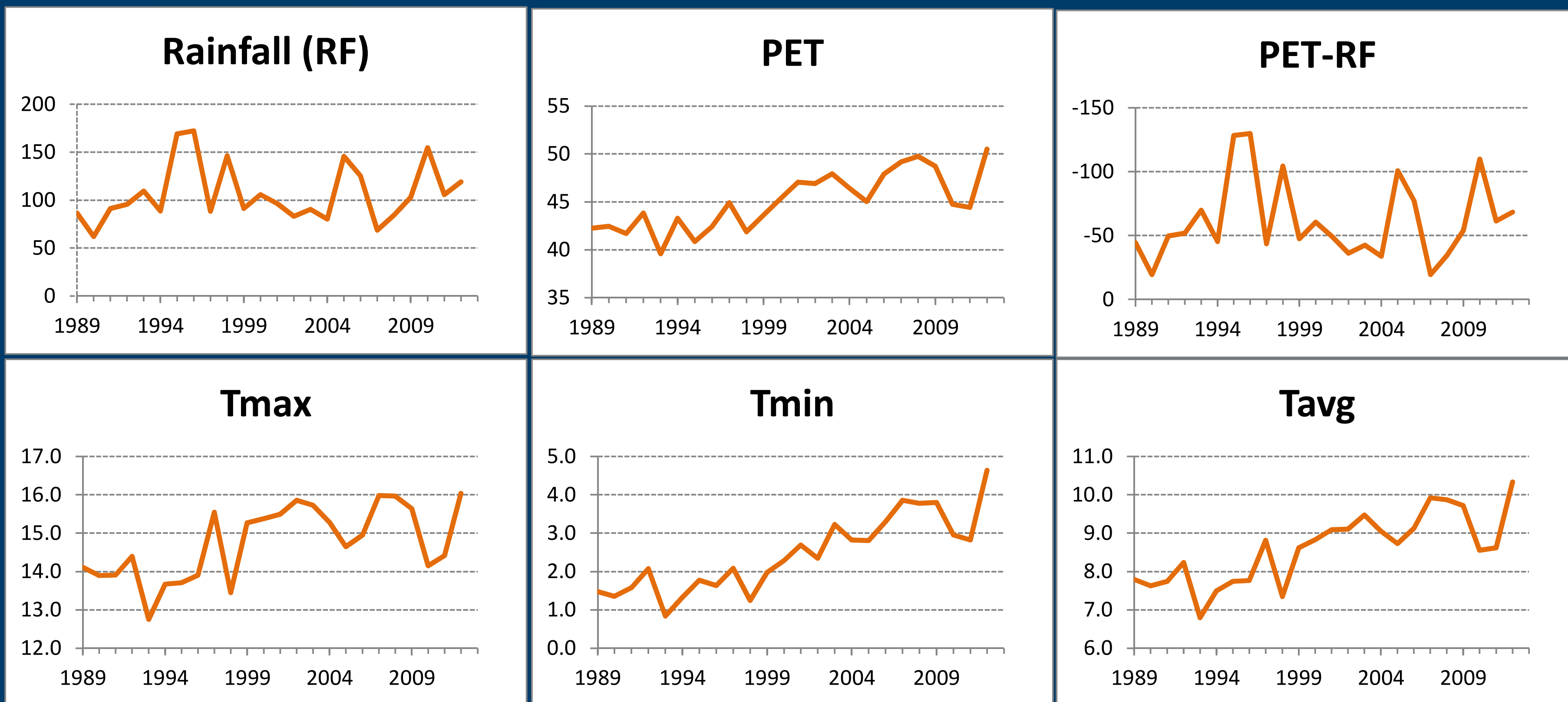
Hemlock; Yearly Mean Values of Variables



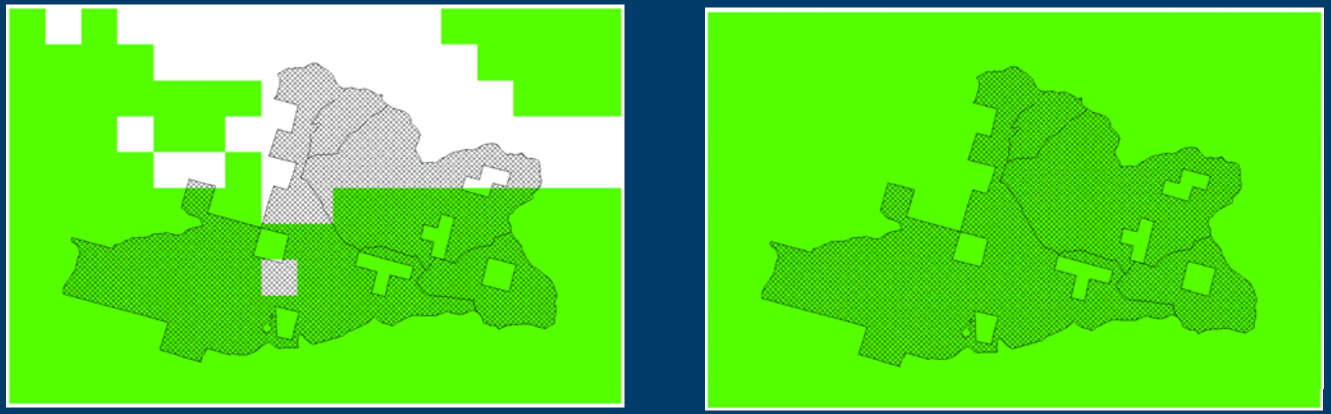
T in ºC, RF and PET in mm/month

**2013 data is not included

Spatial distribution of changes (trend): Hemlock

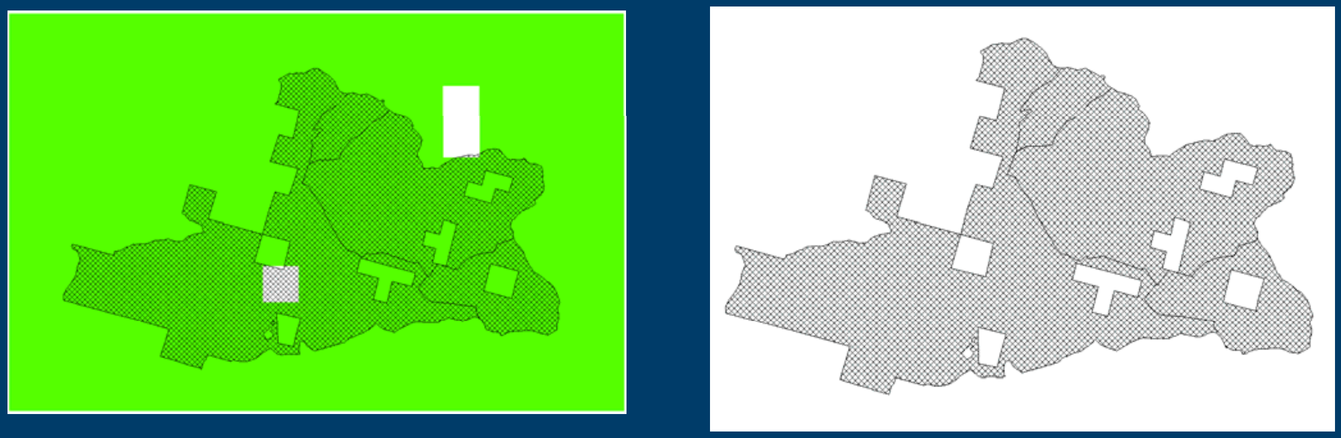
Significant increase in maximum temperature

Significant increase in minimum temperature



Significant increase in PET

No significant change in rainfall



Green: Significant increase
Red: Significant decrease

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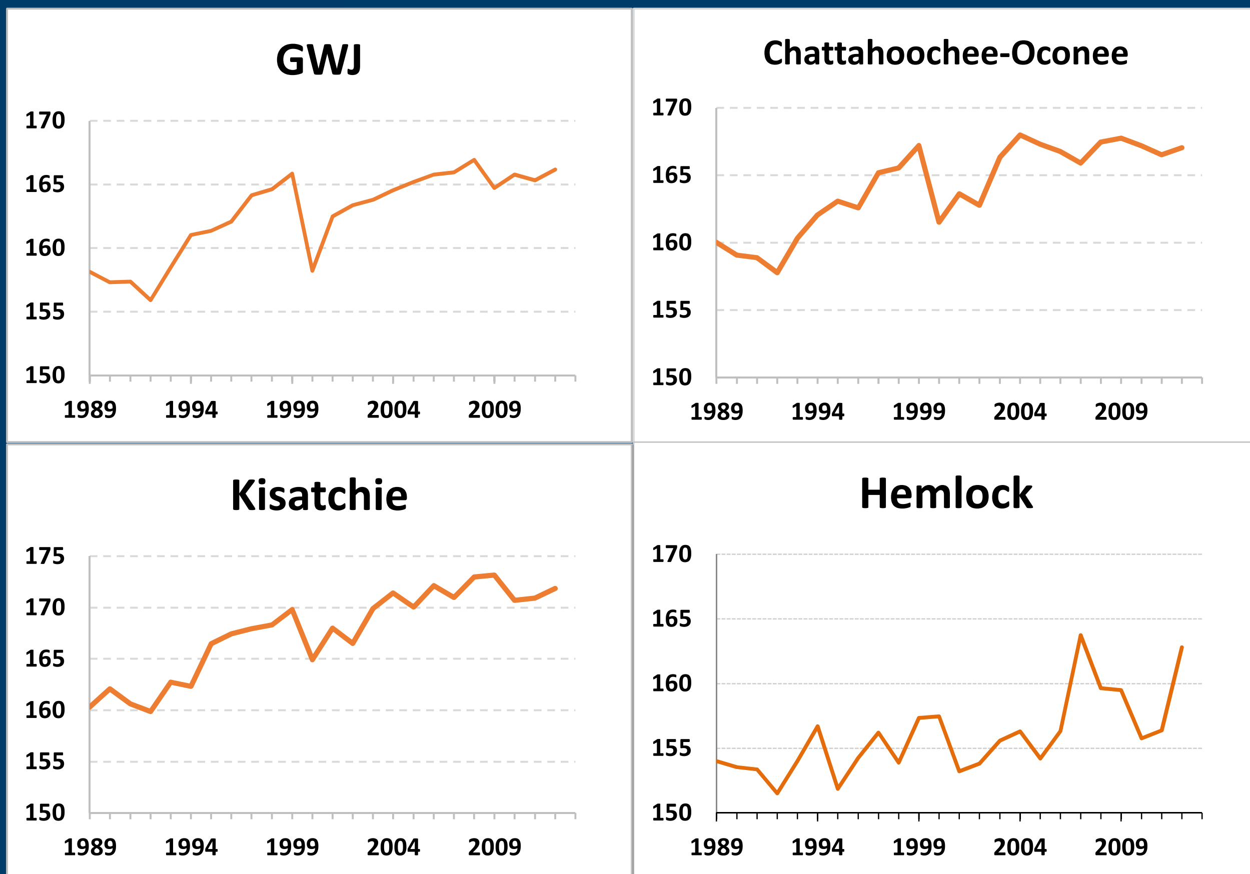
Greenness (NDVI) Change



East Coast: Drought 1999, 2007
West Coast: Drought last 3-5 year (~2012-2014)

http://www.ncdc.noaa.gov/sotc/drought/1999/16

Statistical methods

Univariate Autoregression

$$NDVI_t = \theta_o + \theta_1 * Time + \mu_t \qquad 1a$$

$$\mu_t = \sum_{t=1}^{k} \rho_i \mu_{t-i} + \varepsilon_t \qquad 1b$$

$$\varepsilon_t \sim IN(0, \sigma^2) \qquad 1c$$

monthly NDVI, monthly rainfall, monthly minimum temperature, or monthly PET (n = 294 months).
The slope (θ_1) quantifies the rate and direction of change for each variable over 25 years.

Multivariate Autoregression

$$NDVI_t = \beta_o + \beta_1 RF_{t-6} + \beta_2 T\min_t + \beta_3 PET_t + \beta_4 Time_t + \mu_t \qquad 2a$$

$$\mu_t = \sum_{t=1}^{k} \rho_i \mu_{t-i} + \varepsilon_t \qquad 2b$$

$$\varepsilon_t \sim IN(0, \sigma^2) \qquad 2c$$

Where RF_{t-6} is rainfall for previous 6 month, *Tmin is monthly minimum temperature*, *PET is monthly potential evapotranspiration,* ε is the error term, and autoregression error (μ_t).
The coefficient of Time (β_4) is the temporal trend of the NDVI after accounting for climate variables.

All statistical analyses are carried on each 1-km^2 pixel.

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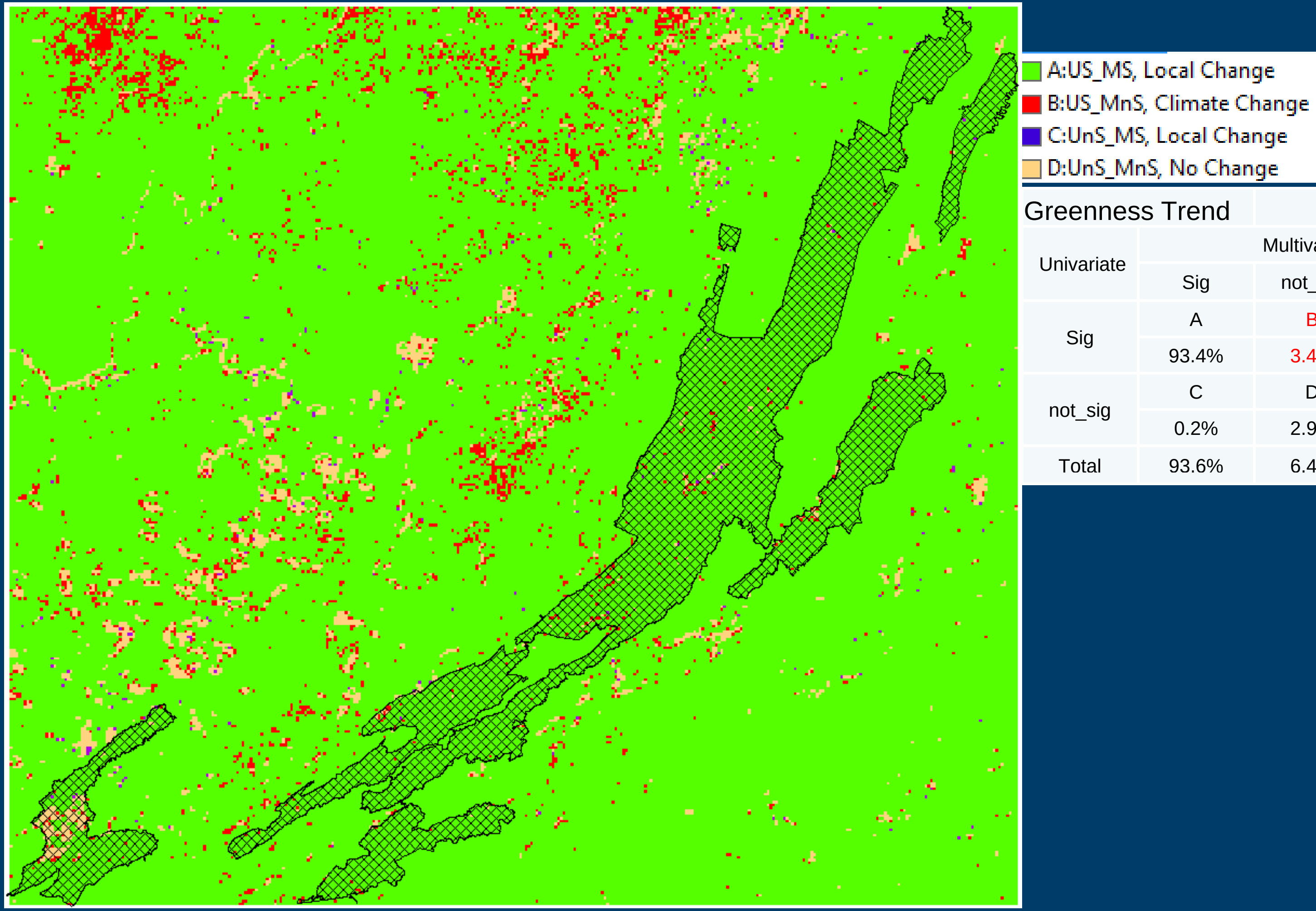
Cause of greenness changes: is it anthropogenic? Natural?



Greenness Trend

Univariate	Multivariate		
	Sig	not_sig	Total
Sig	A 93.4%	B 3.4%	96.8%
not_sig	C 0.2%	D 2.9%	3.2%
Total	93.6%	6.4%	100%

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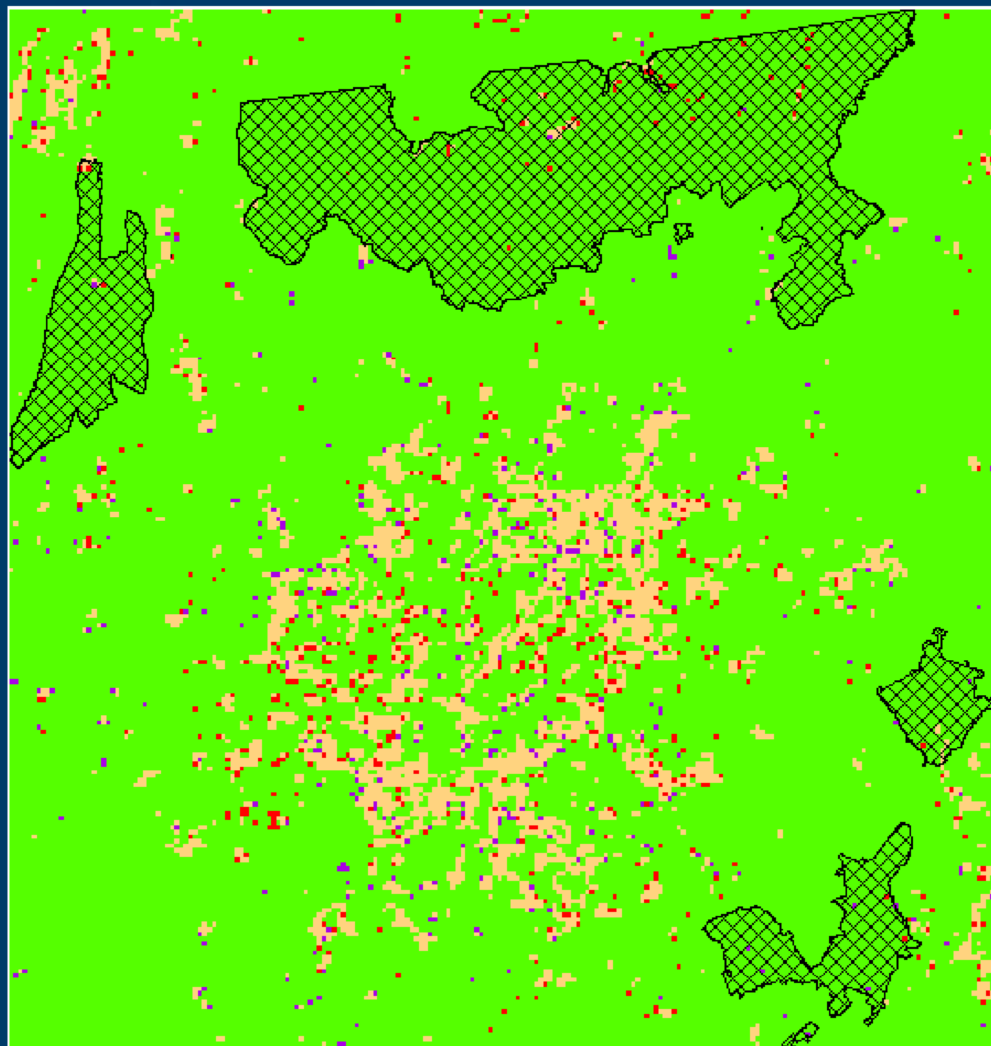

Greenness Trend			
Univariate	Multivariate		
	Sig	not_sig	Total
Sig	A	B	91.3%
	90.0%	1.3%	
not_sig	C	D	8.7%
	0.8%	8.0%	
Total	90.8%	9.2%	100.00%

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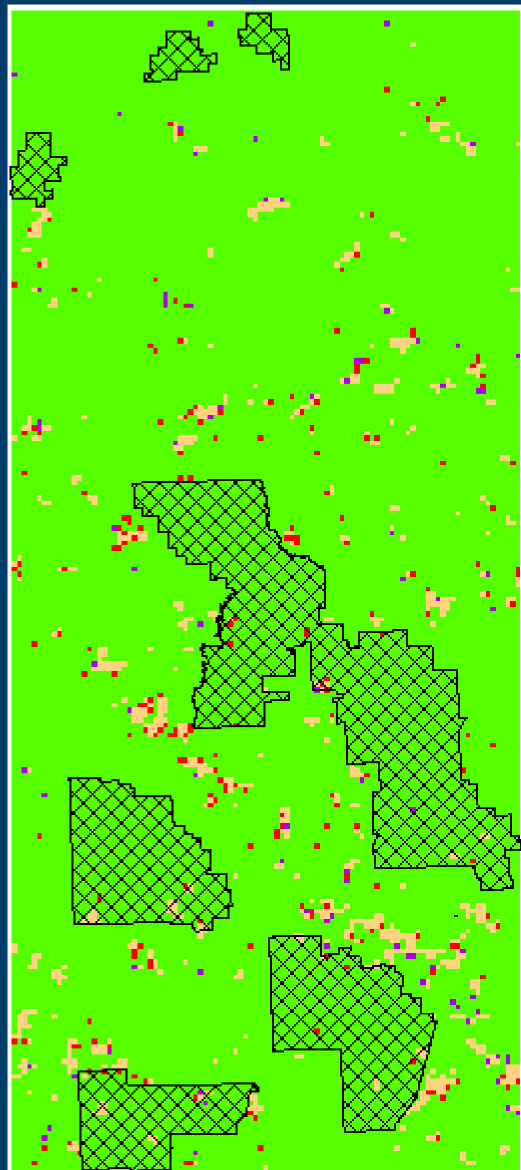
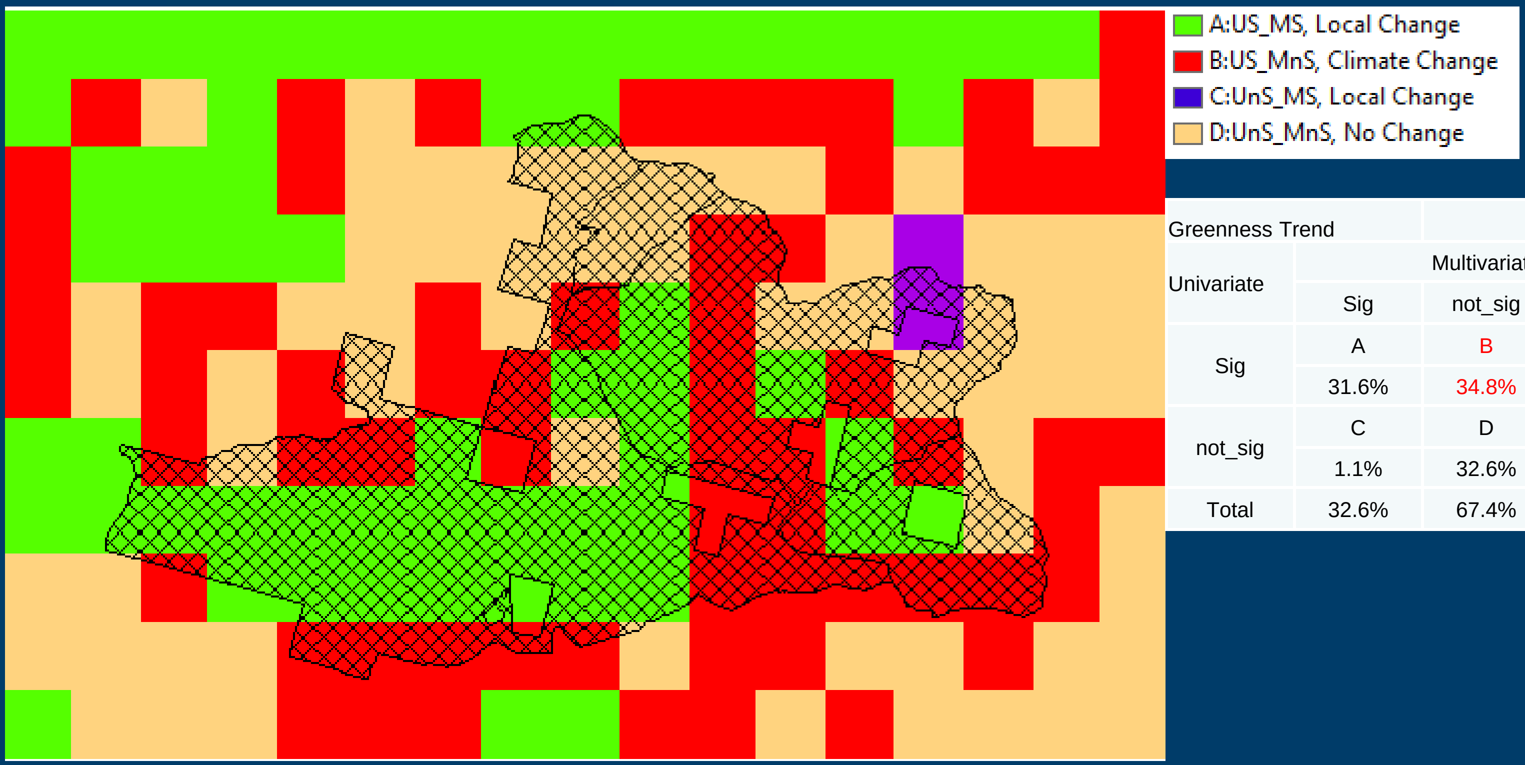


Greenness Trend			
Univariate	Multivariate		
	Sig	not_sig	Total
Sig	A	B	96.6%
	95.6%	0.9%	
not_sig	C	D	3.4%
	0.4%	3.1%	
Total	96.0%	4.0%	100.0%



Greenness Trend			
Univariate	Multivariate		
	Sig	not_sig	Total
Sig	A 31.6%	B 34.8%	66.3%
not_sig	C 1.1%	D 32.6%	33.7%
Total	32.6%	67.4%	100.0%

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Q&A

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Supplementary, if needed

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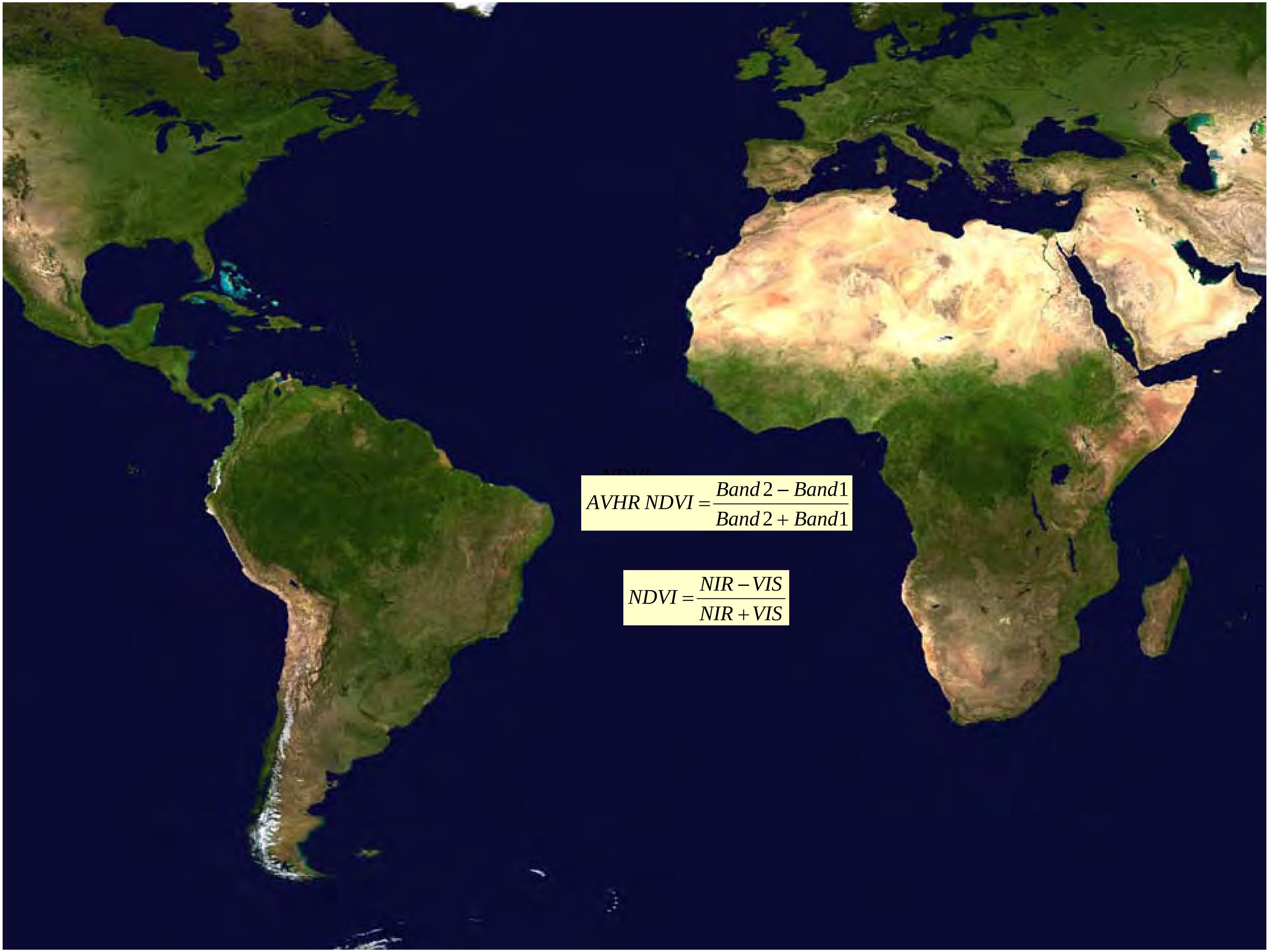
On going (EPA),

Changes in Landscape Greenness, Climatic Factors, Water Stress and Dew Point Depression over 25 Years (1989-2013) in USA, Maliha S. Nash, James Wickham, Jay Christensen, and Timothy Wade

- **Relate NDVI to precipitation, water stress, dew point depression, and time (univ- and multiple autoregression)**

- **Long (slow) term and short (fast) term**
  - **Non-significant (slow) vs. significant (fast) trend in time coefficient**
    - **Non-significant decrease**
    - **Non-significant increase**

- **etc**


$AVHR\ NDVI = \frac{Band\,2 - Band\,1}{Band\,2 + Band\,1}$
$NDVI = \frac{NIR - VIS}{NIR + VIS}$

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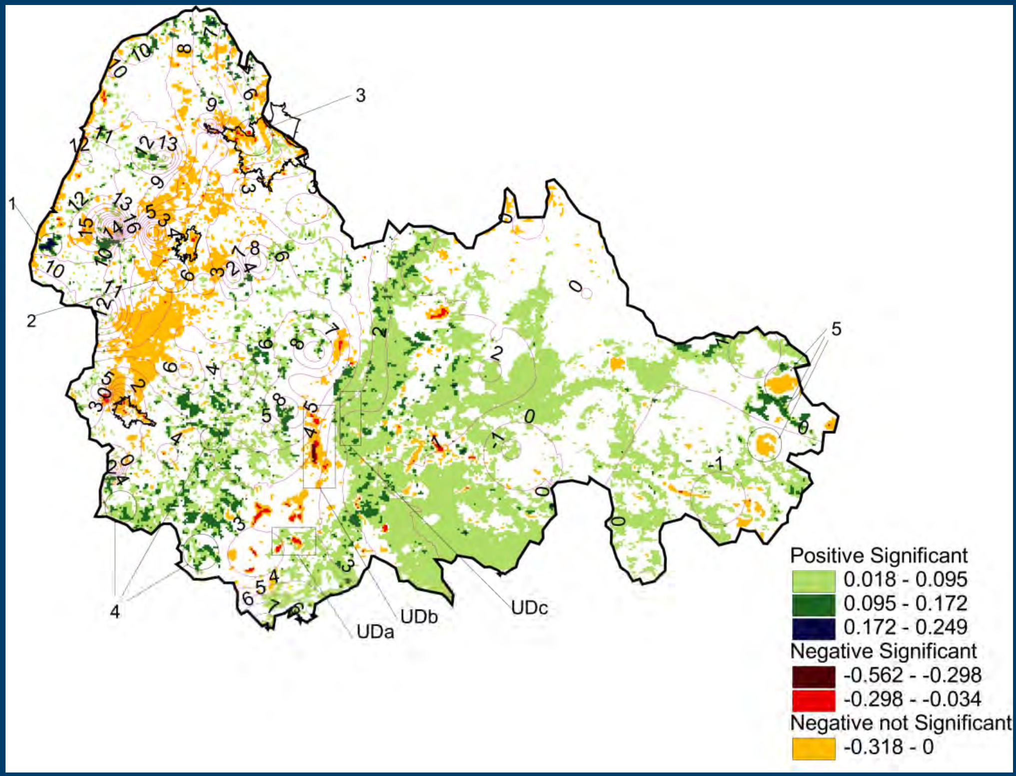
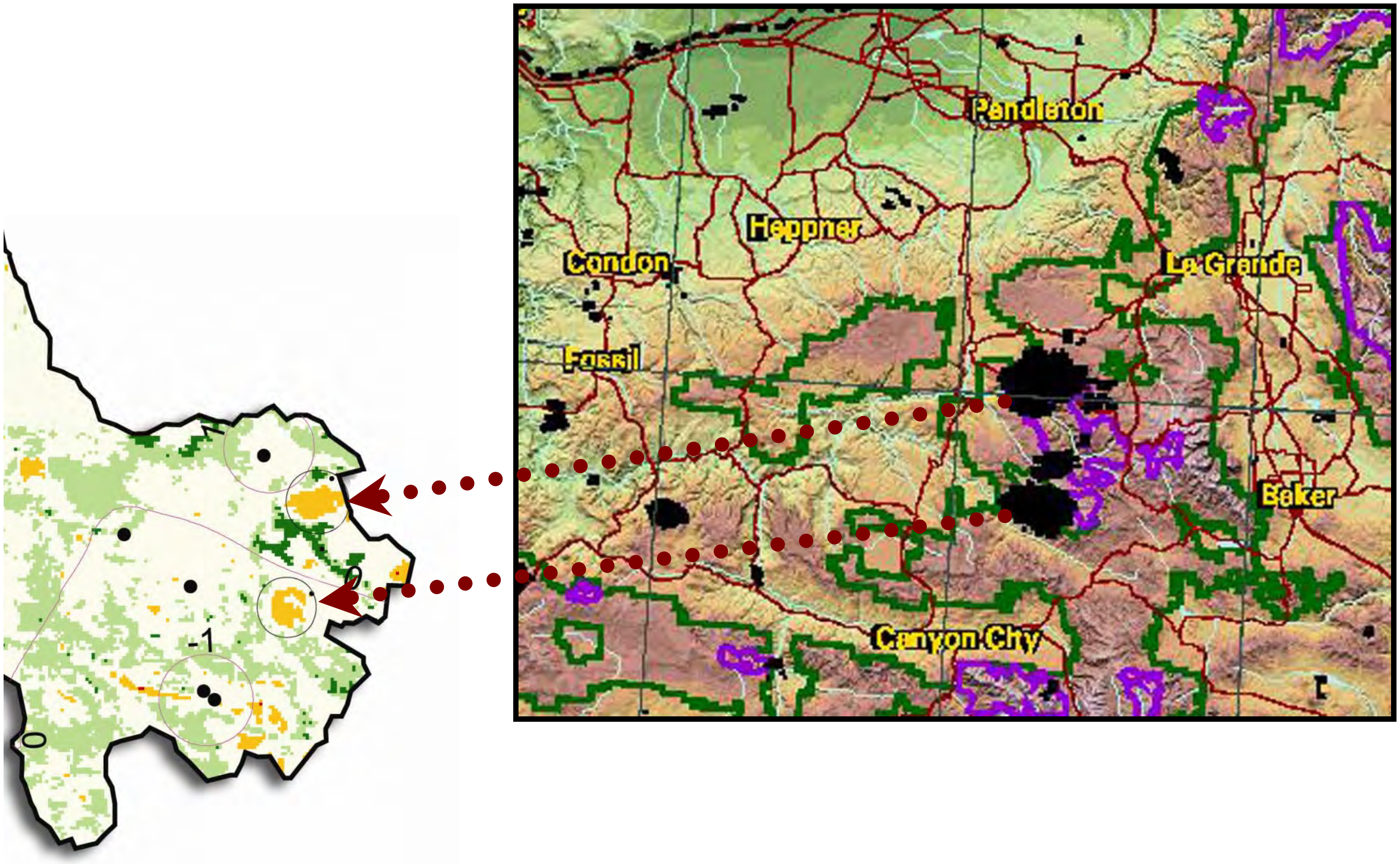
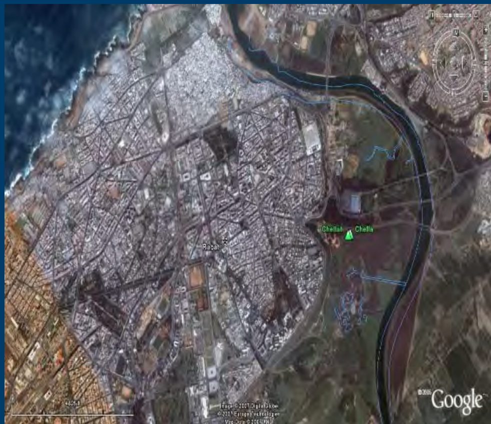
1- reforestation following high intensity timber harvest. In 1995, a report by the Coastal Landscape Analysis and Modeling Study indicated that 65% of the area was covered by 10″ diameter at breast height (DBH) and 18% of the basin lands was covered by conifer or mixed stands (> 20″, in DBH)

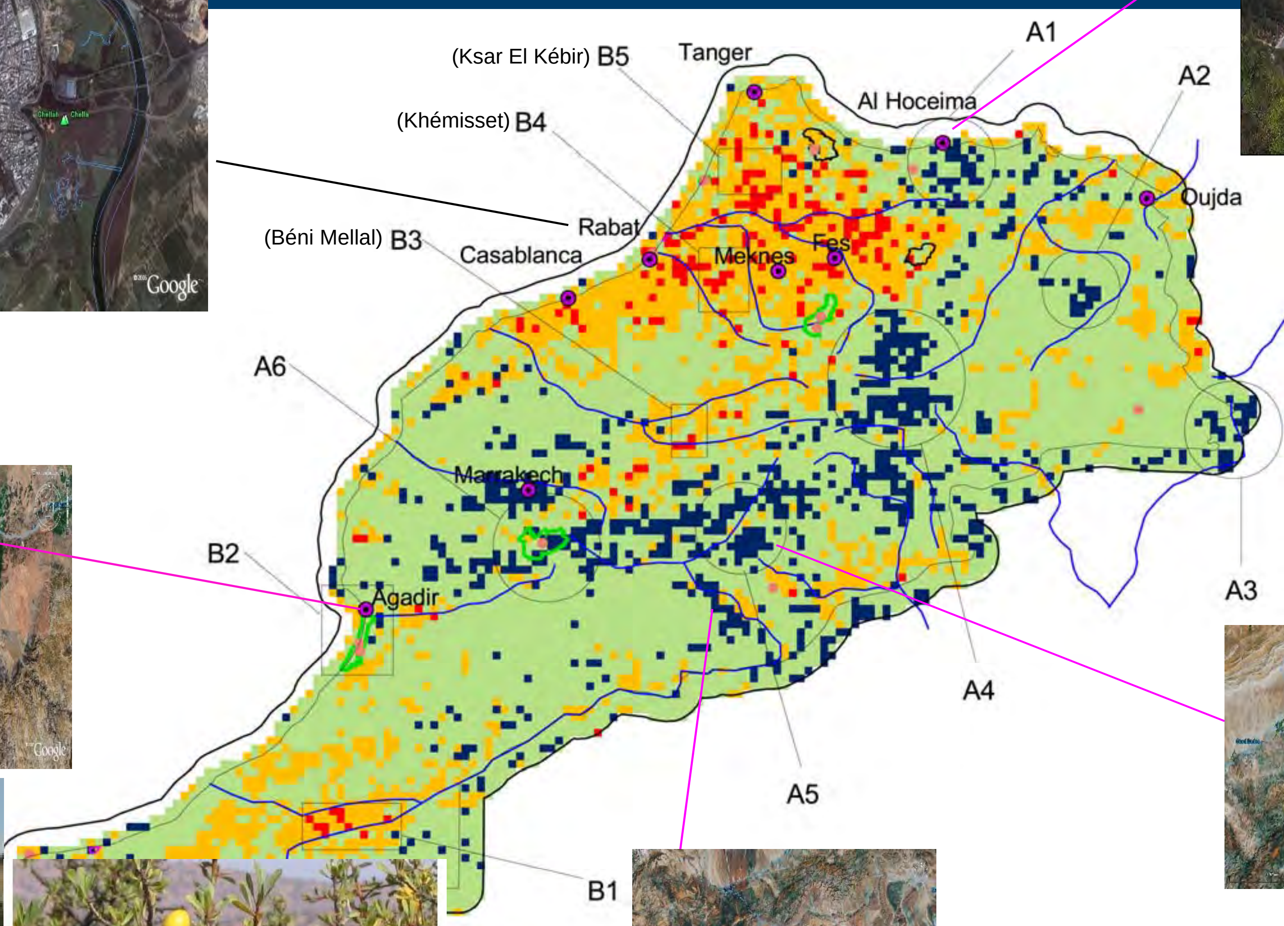
4- in the Cascade Mountain Range show a positive greenness. Perhaps a major recovery in the last decade from heavy timber harvests of the 1980s, the spotted owl rulings, and the North West Forest Plan may have contributed to a decreasing amount of forest harvest (personal communication, G. Bishop).

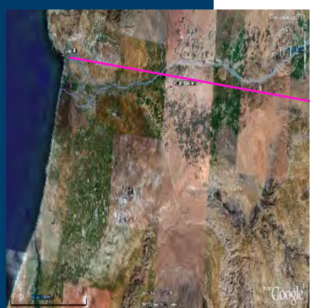


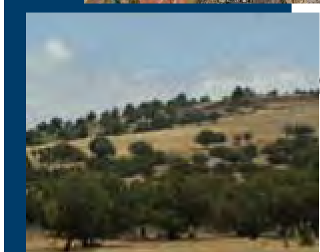


http://www.fs.fed.us/r4/rsgis_fire/images/firehist20yr.jpg









Argan Tree

Drâa Valley

Pixels with significant gain (blue) and loss (red), non-significant gain (green) and loss (orange) in greenness for Morocco between 1981- 2003. Marked areas A1-A6 (increasing NDVI) and B1-B5 (decreasing NDVI) are for evaluation using an ancillary data.

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Argania Spinosa

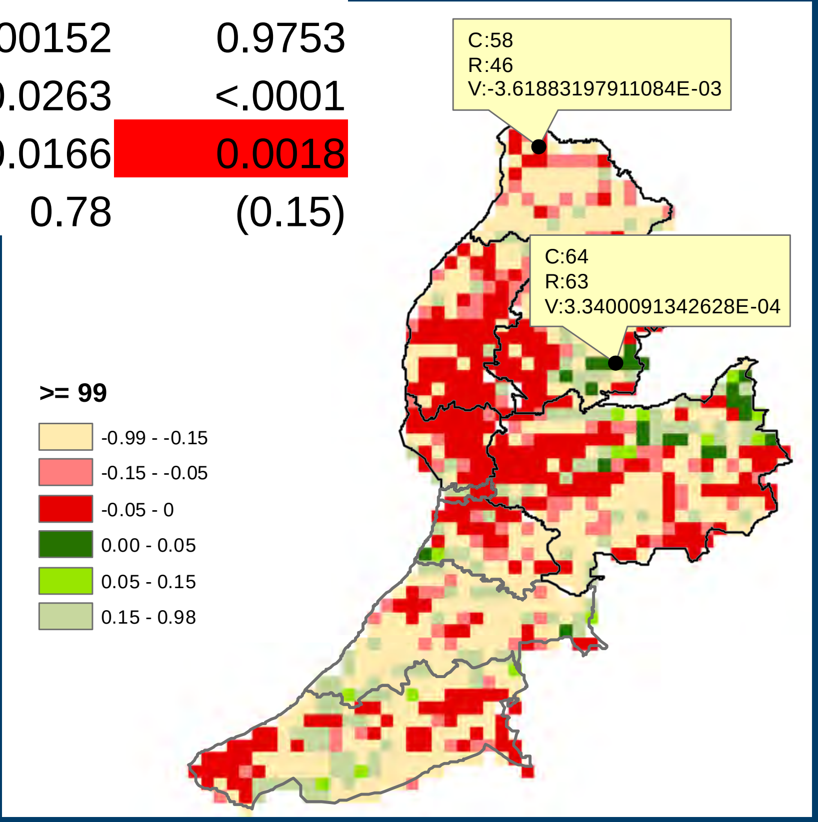
Keepers of tradition

Argan oil from unroasted seeds is a popular cosmetic, said to be useful for dry skin, wrinkles and blemishes.

Land Sustainability

BelYazid (2000) reported that as a result of overgrazing, deforestation, and conversion to agriculture to meet the needs of the population, the sustainability of the Argan forest will not last more than two decades if proper management steps are not taken.

Pixel:	(58,46)		(63,58)	
	Coef.	p-value	Coef.	p-value
Intercept	25.2225	<.0001	63.8743	<.0001
Rain	-0.022	0.1443	-0.0111	0.3897
CumRain	0.018	0.003	0.0127	0.0105
CumRain(t-1) X Dry	0.000822	0.8843	0.000152	0.9753
Trend X Wet	0.0342	0.0003	-0.0263	<.0001
Trend X Dry	0.0424	<.0001	-0.0166	0.0018
Total R^2 (w/o AR)	0.77	(0.12)	0.78	(0.15)



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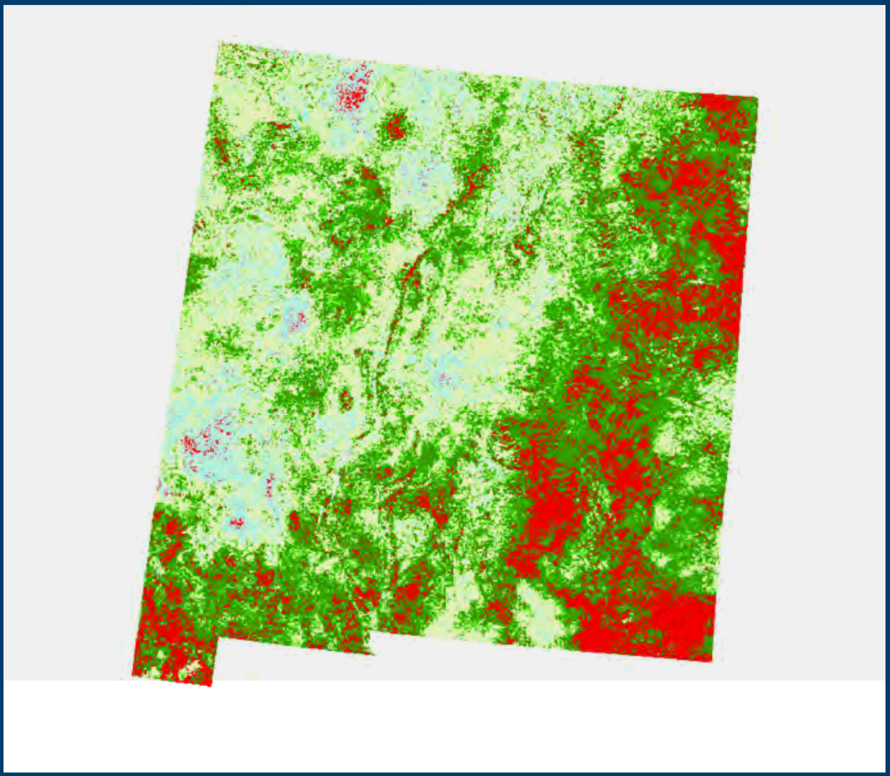
Maximum Temperature



Direction/Probability of slope

	-1.00 - -0.10
	-0.10 - -0.05
	-0.05 - 0.00
	0.00 - 0.05
	0.05 - 0.10
	0.10 - 1.00

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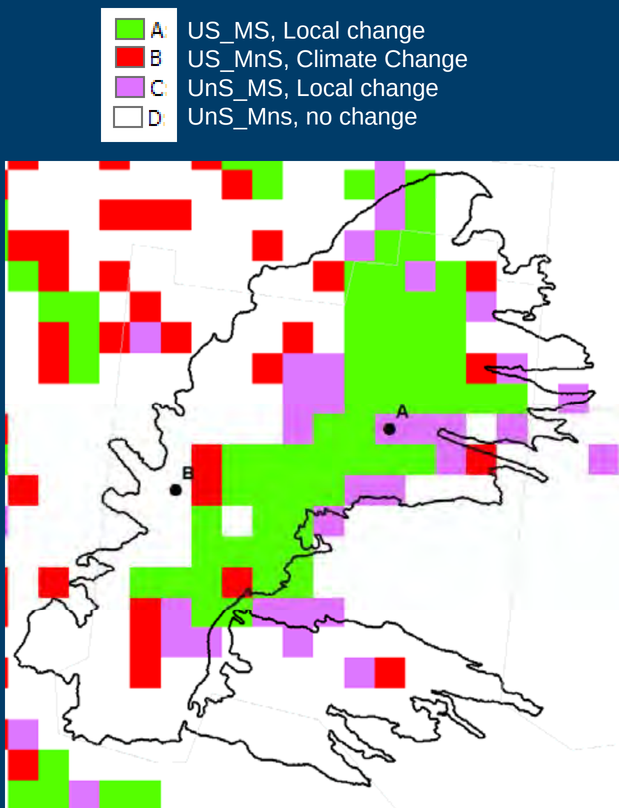
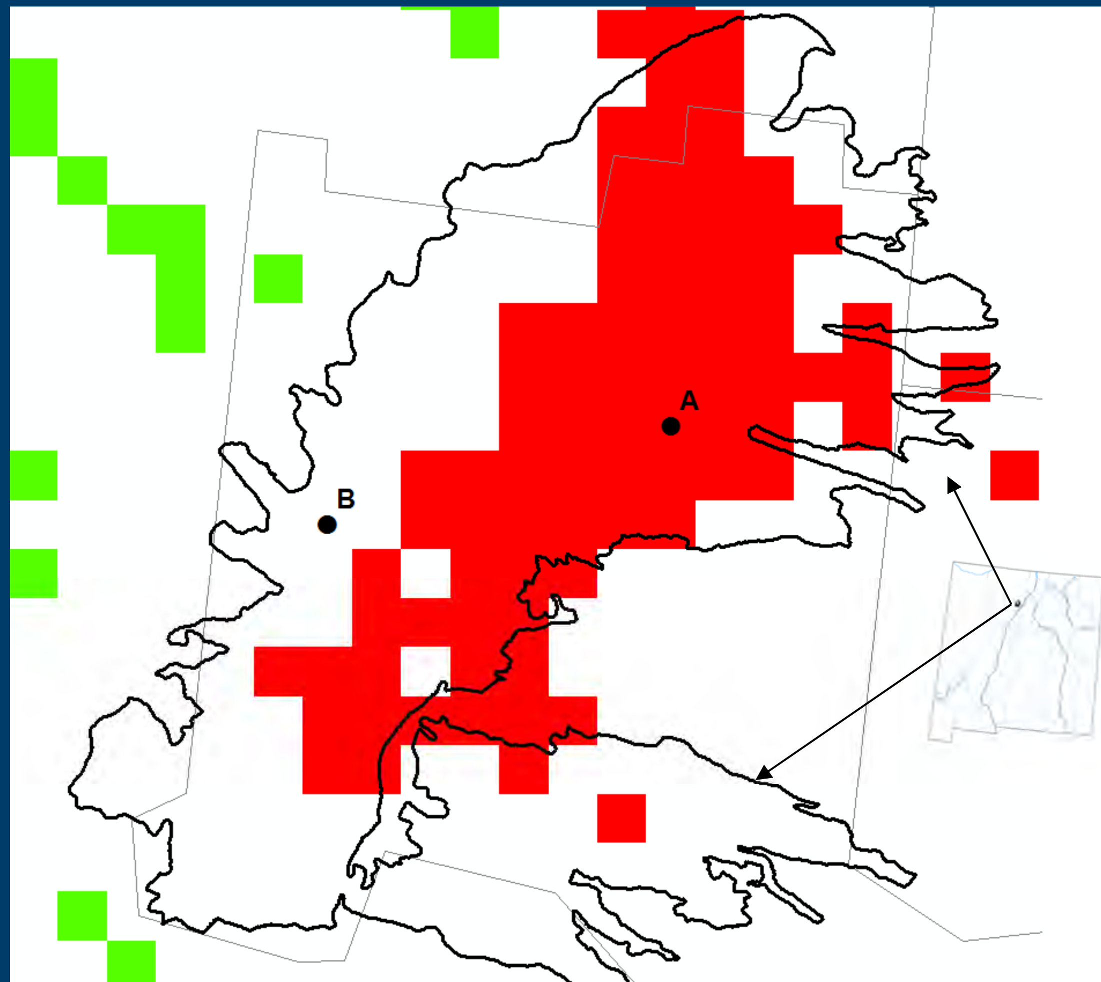
Fires and post fire greenness gains

Climate Change





The 2000 Cerro Grande Fire polygon (heavy black outline; from http://www.fs.usda.gov/detail/r3/landmanagement/gis/, Santa Fe fire history). The fire polygon lies mostly in Los Alamos County (light black lines). Green pixels indicate significant increase in the NDVI over time (multivariate autoregression); red pixels indicate significant decrease in the NDVI over time (multivariate autoregession).

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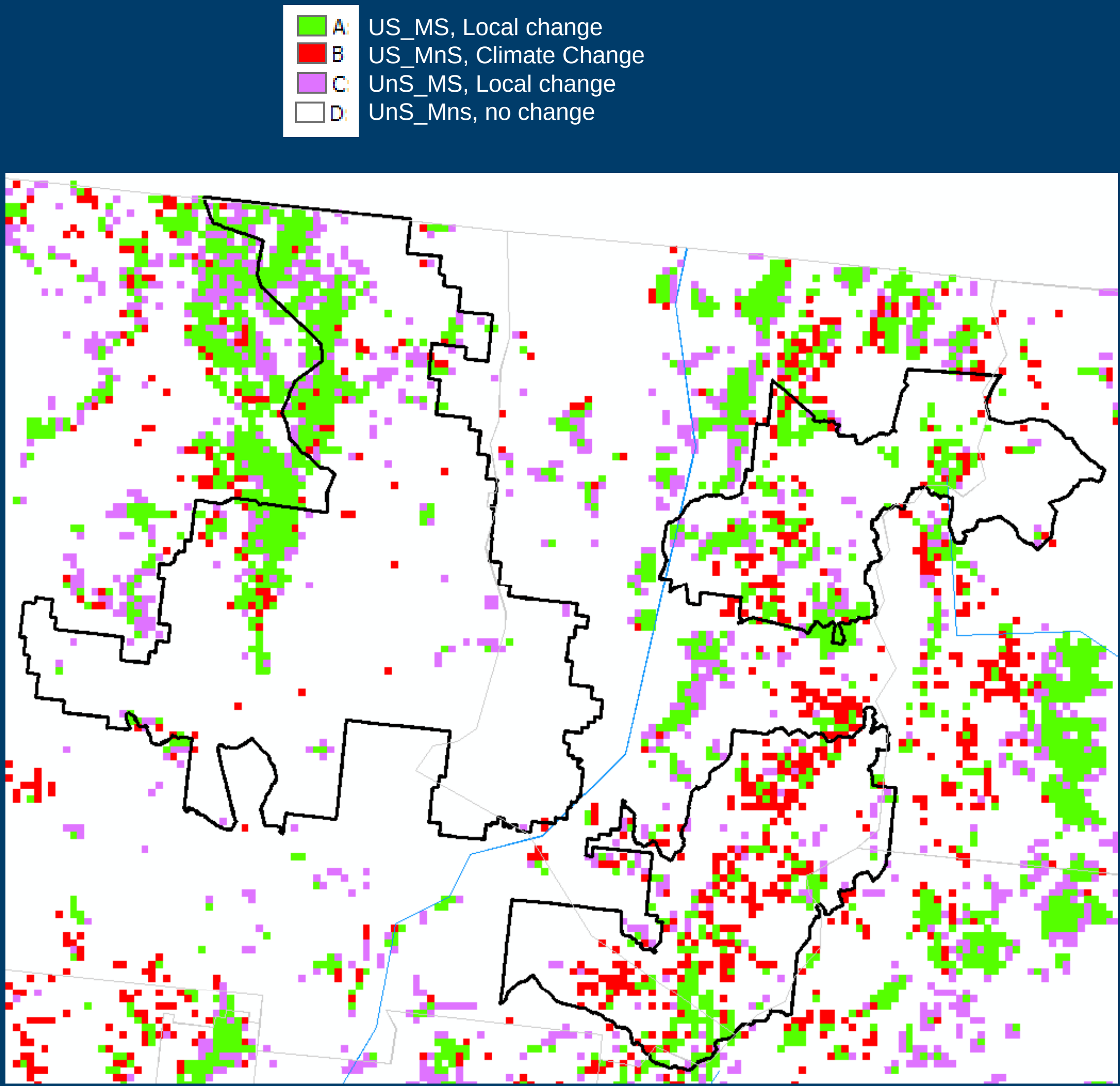
Climate Change



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$$PET = 13.97dD^2W_t$$

$$\theta = 0.2163108 + 2 * Arctan[0.9617396 * \mathrm{TAN}[0.00860 * (J - 186)]]$$

$$\varphi = Arcsin(0.39795 * cos\theta)$$

$$D = 24 - \frac{24}{\pi} Arcsin\left[\frac{sin\frac{\rho\pi}{180} + sin\frac{L\pi}{180} sin\varphi}{cos\frac{L\pi}{180} cos\varphi}\right]$$

θ is revolution angle (radians)
φ is sun's declination angle (radians)
p is daylight coefficient (degrees) (=0.8333; Forsythe et al 1995)
L is latitude
D is daylight length

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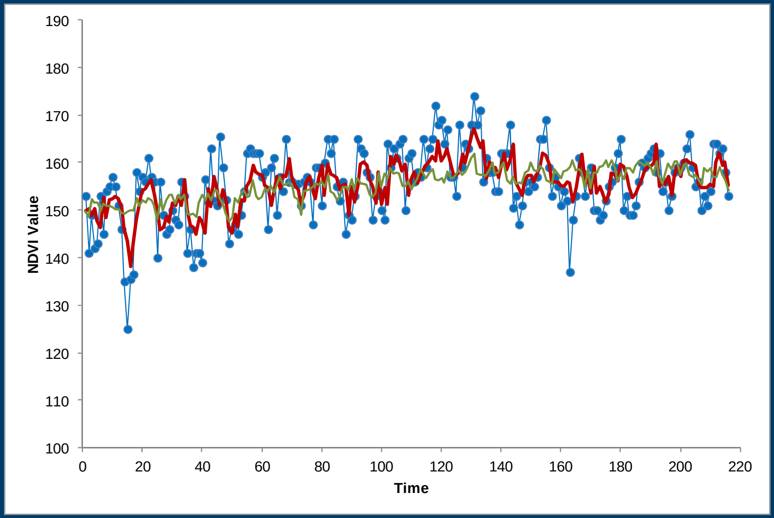
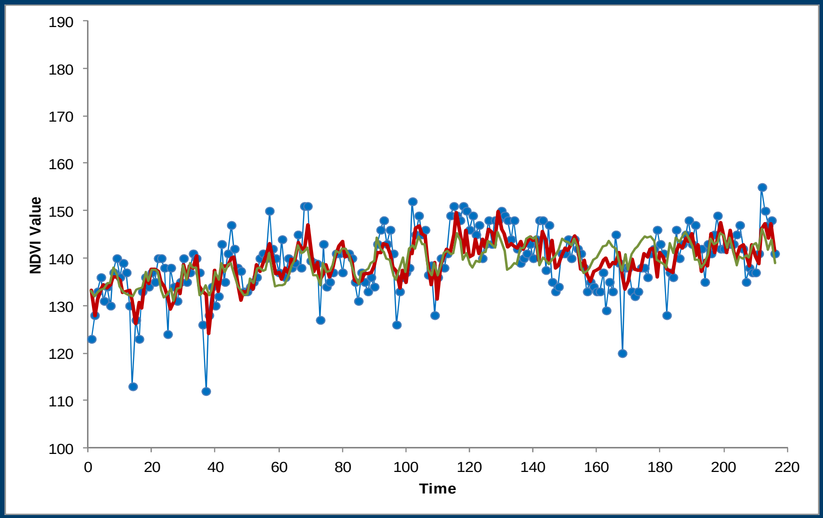
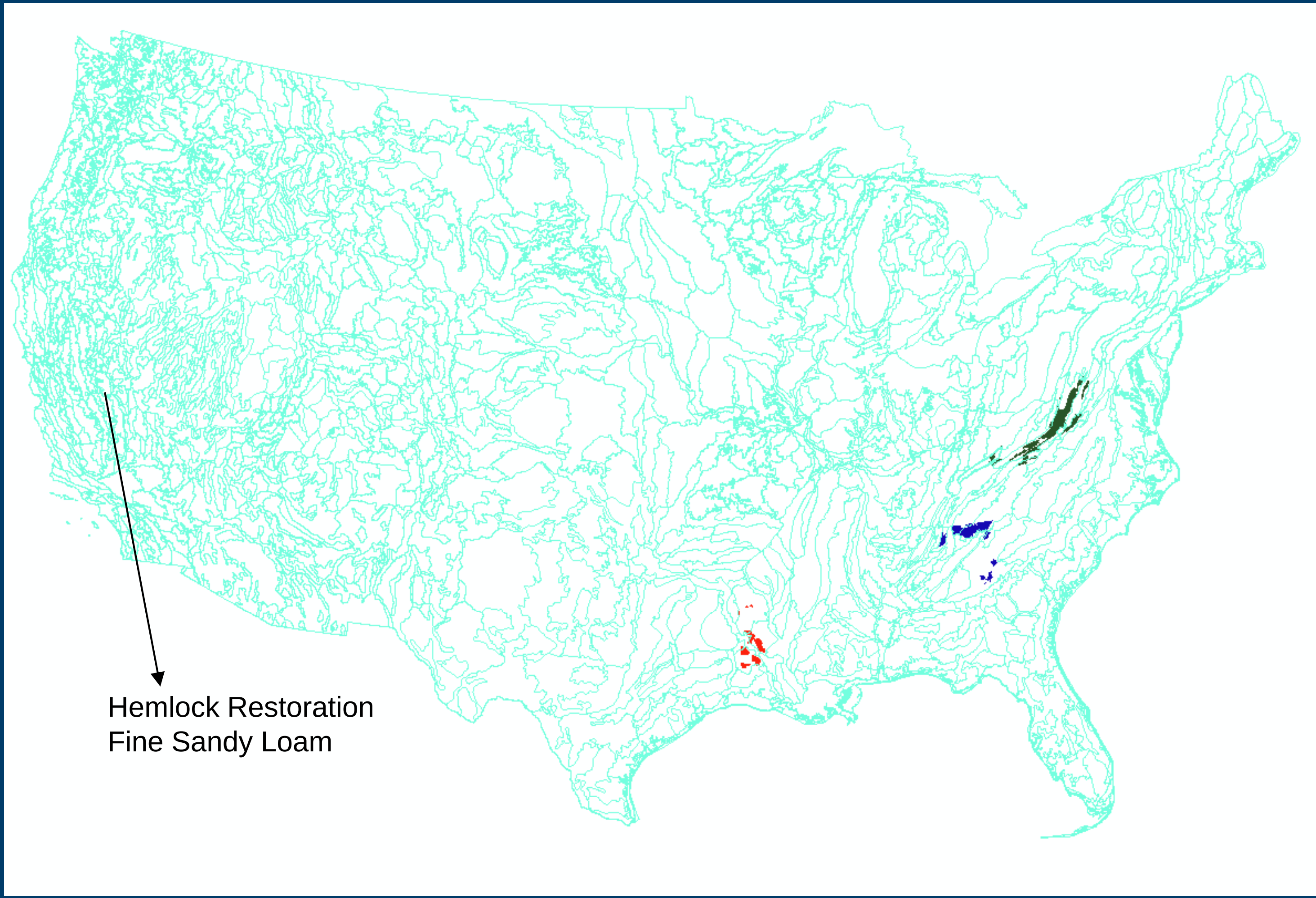
West San Miguel



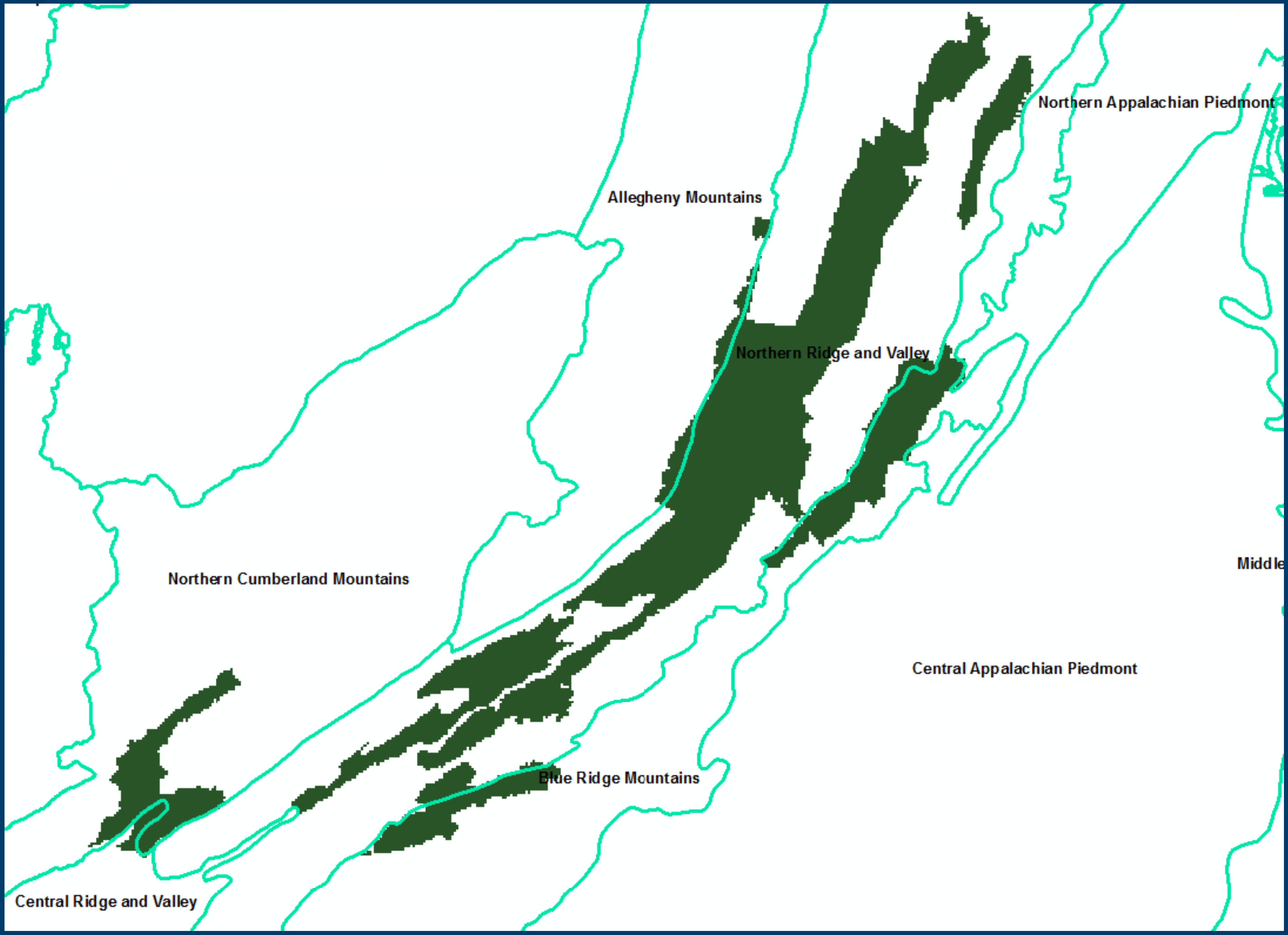
East Bernalillo

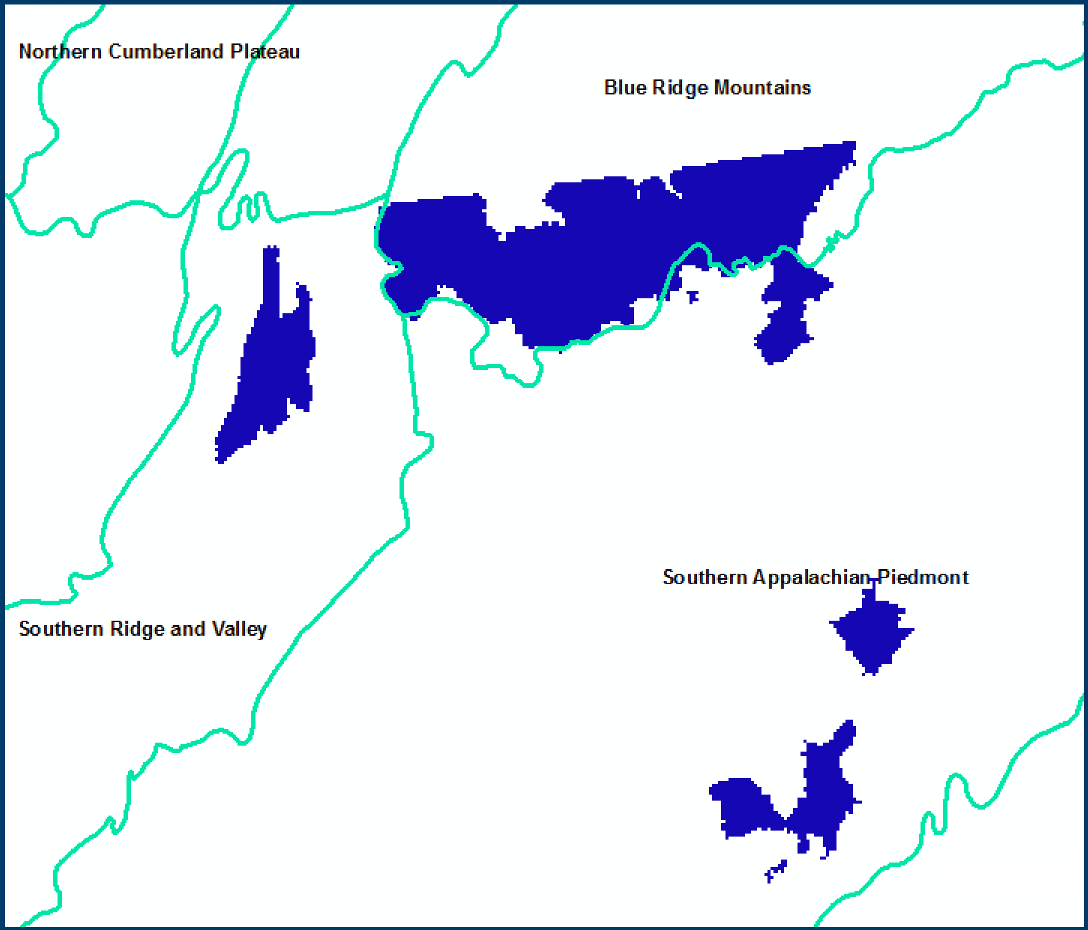


SoilsSubsections
http://data.fs.usda.gov/geodata/edw/datasets.php



Soils Sections;
http://data.fs.usda.gov/geodata/edw/datasets.php




Northern Cumberland Plateau
Blue Ridge Mountains
Southern Appalachian Piedmont
Southern Ridge and Valley

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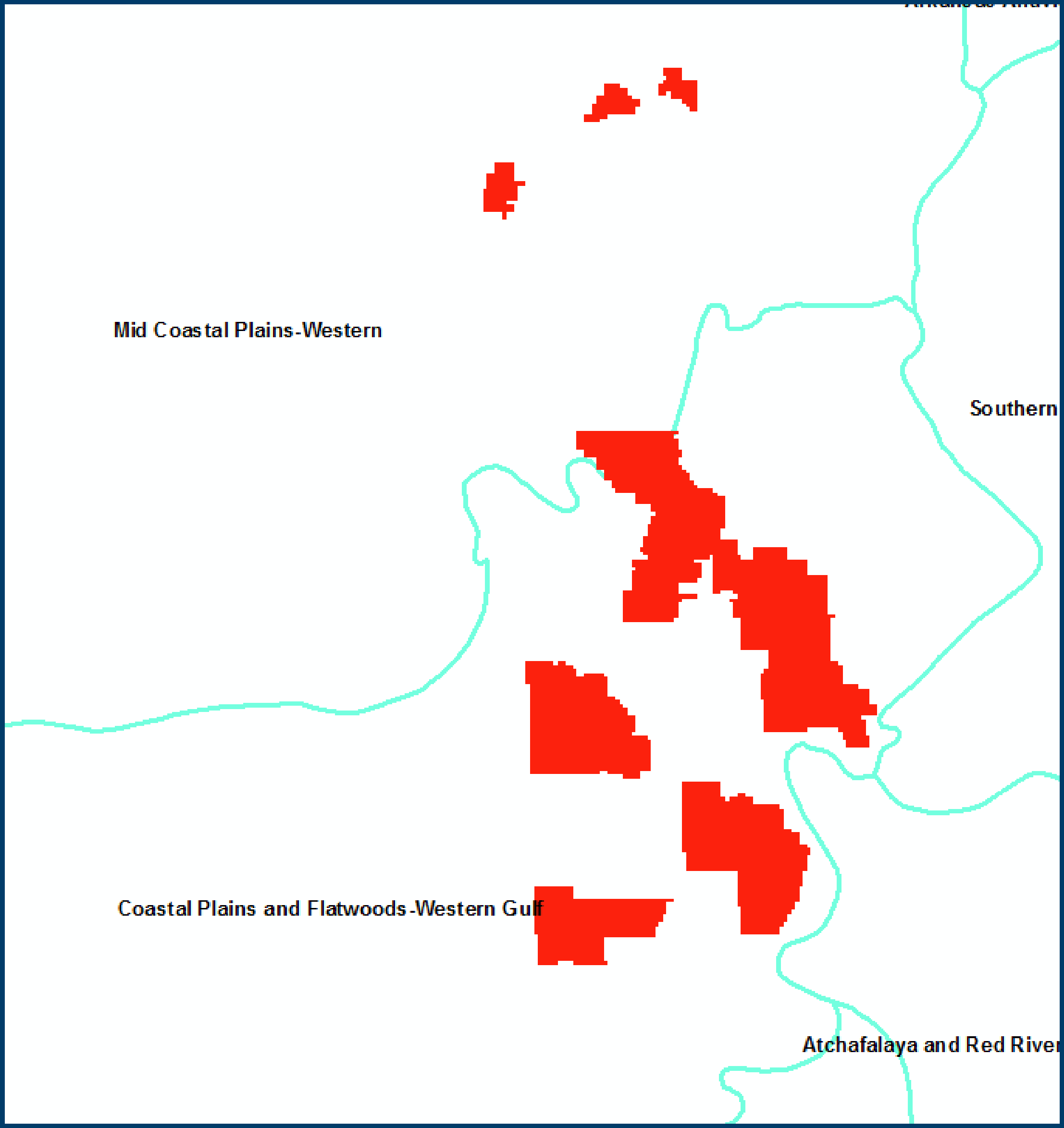
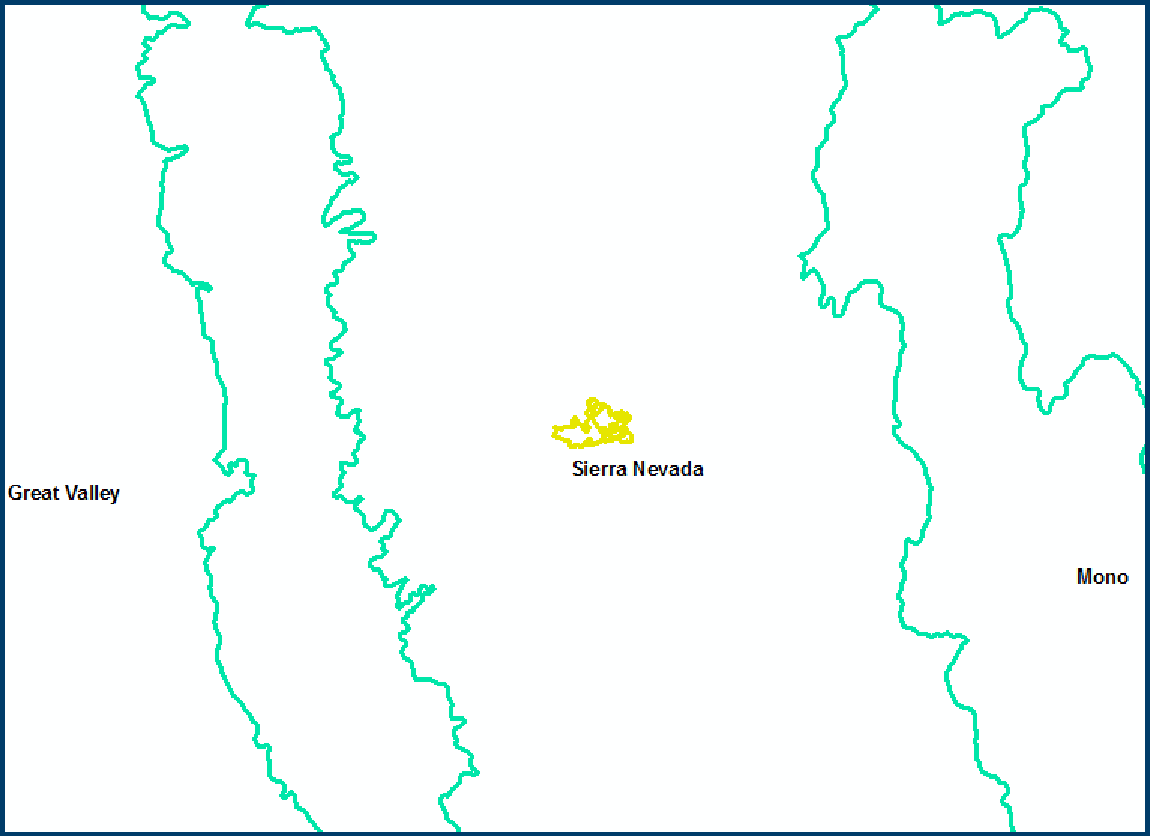
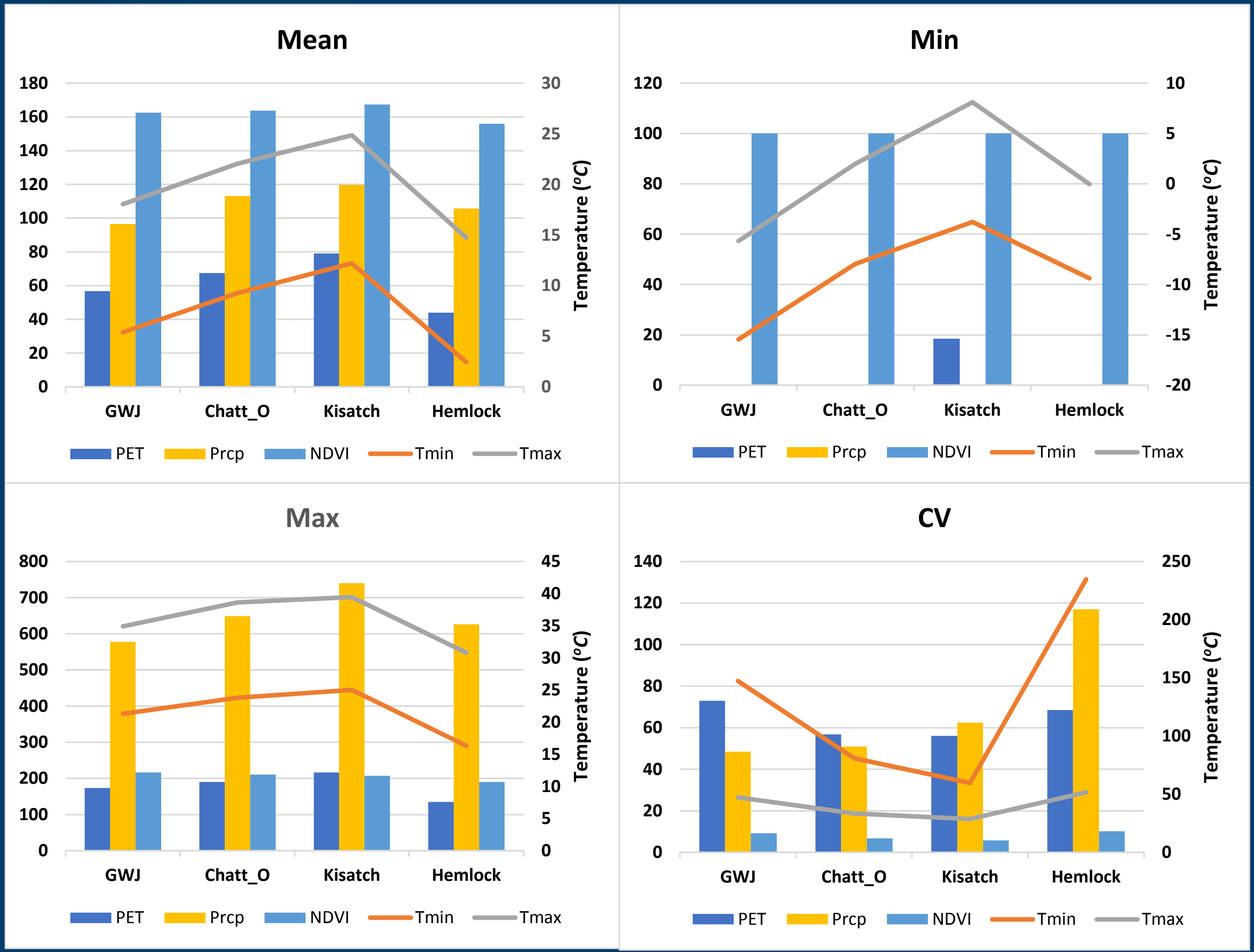



Great Valley
Sierra Nevada
Mono

United States Environmental Protection Agency

Comparing Statistics between areas



T in °C, RF and PET in mm/month