



# Developing Resilient Forests

## *Tools and management practices*

MICHELLE THOMPSON, STEVE MCNULTY, MICHAEL GAVAZZI, AND  
PUSKAR KHANAL, MAY 2, 2025

US Department of Agriculture Southeast Climate Hub & Clemson University

# Introduction

---

- Michelle Thompson
- Climate Science Communication Specialist
- Clemson University Department of Forestry & Environmental Conservation/ United States Forest Service Southeast Climate Hub



Climate Hubs  
U.S. DEPARTMENT OF AGRICULTURE

# Outline

1. Resilient forestry in the U.S.

2. What is the Climate Hub?

3. Overview of the Climate Hub tools and resources



# Resilient forestry in the U.S.

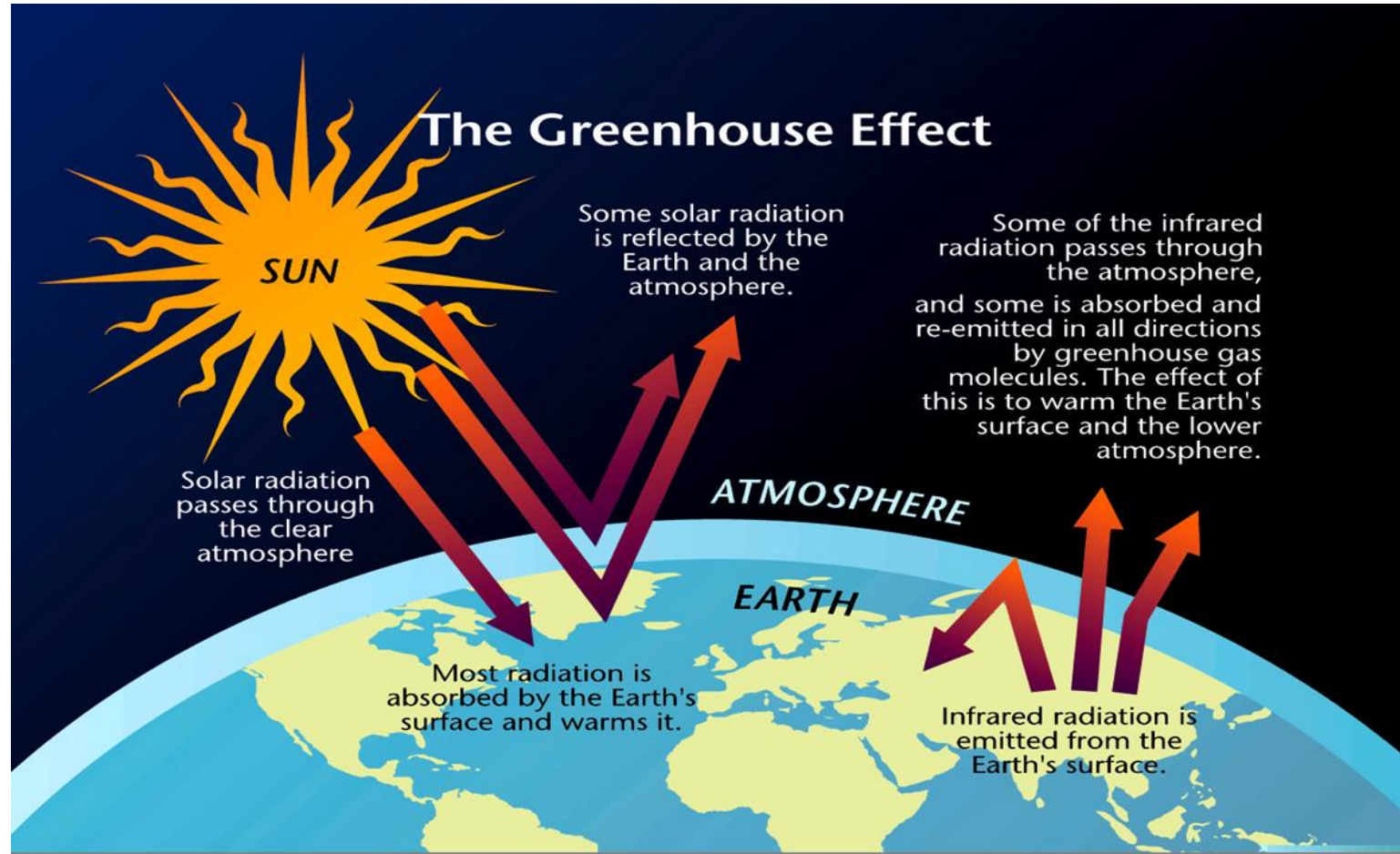
---

# Key moments in U.S. resilient forest management

---

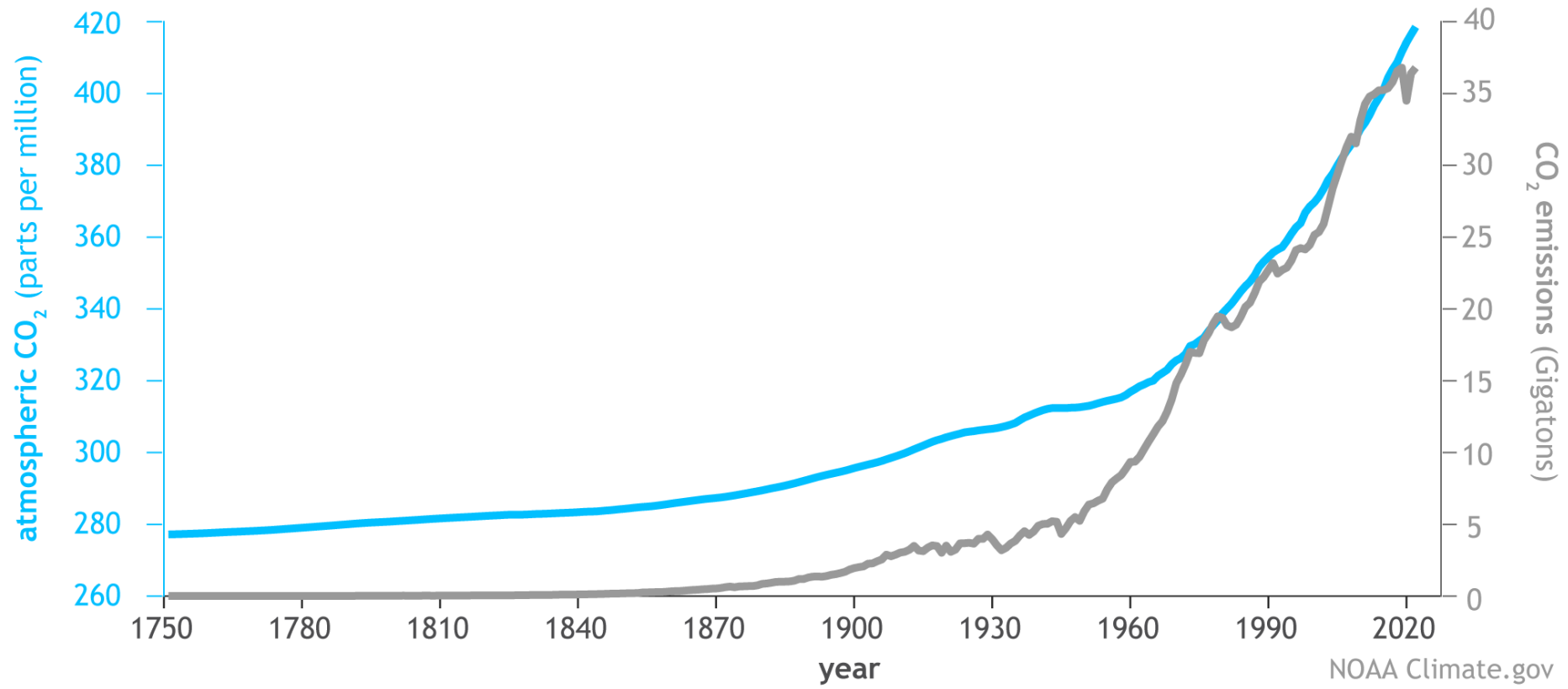
- 1713- Origin of sustainable forest management concept by Carl von Carlowitz
- Founding of U.S., intense and unsustainable logging followed
- 1904-1940 Chestnut blight destroyed chestnut populations
- 1930s CCC planted trees, U.S. became more sustainable
- Climate change

# The Greenhouse Effect



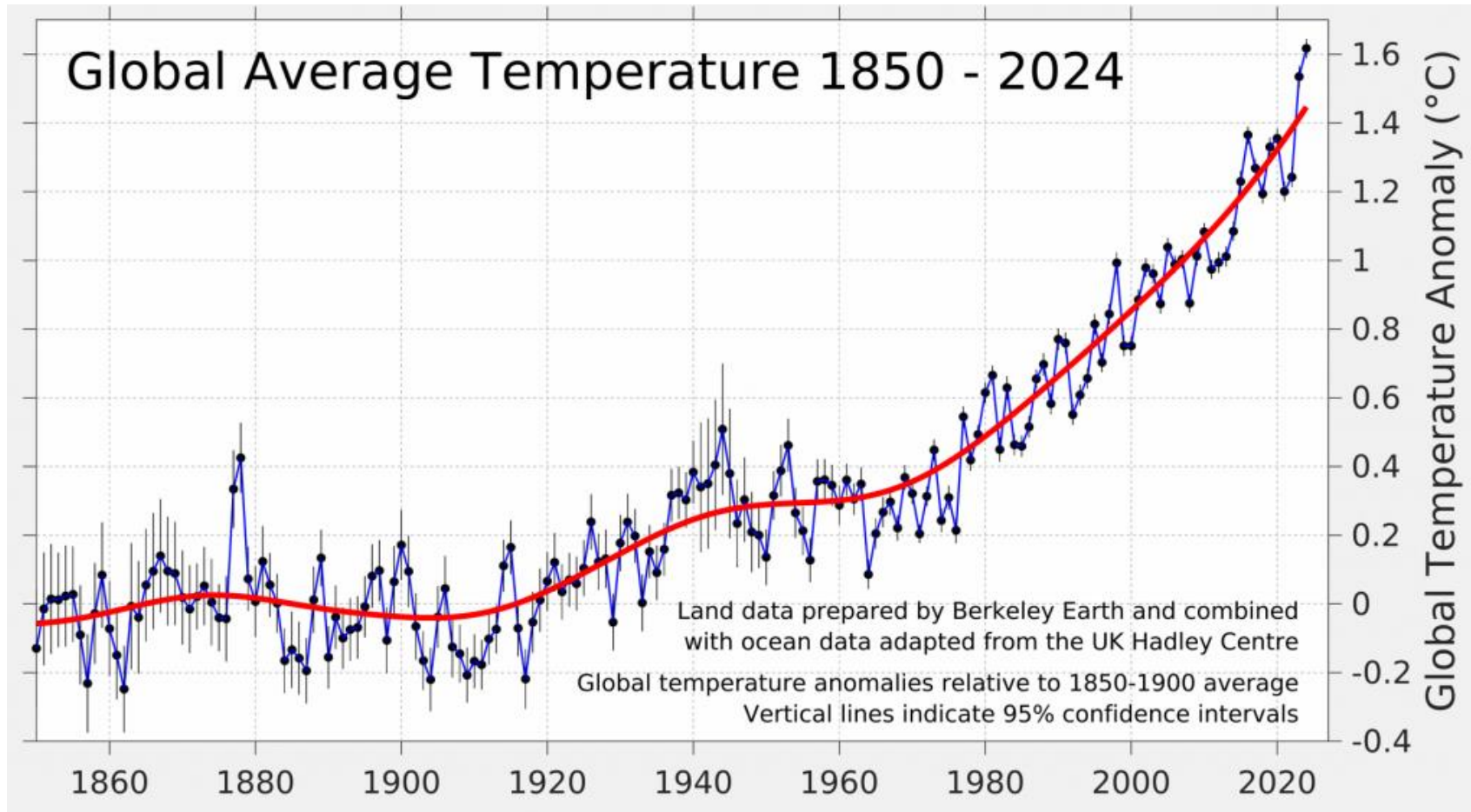
# Historical Atmospheric Carbon Dioxide

Global atmospheric carbon dioxide compared to annual emissions (1751-2022)

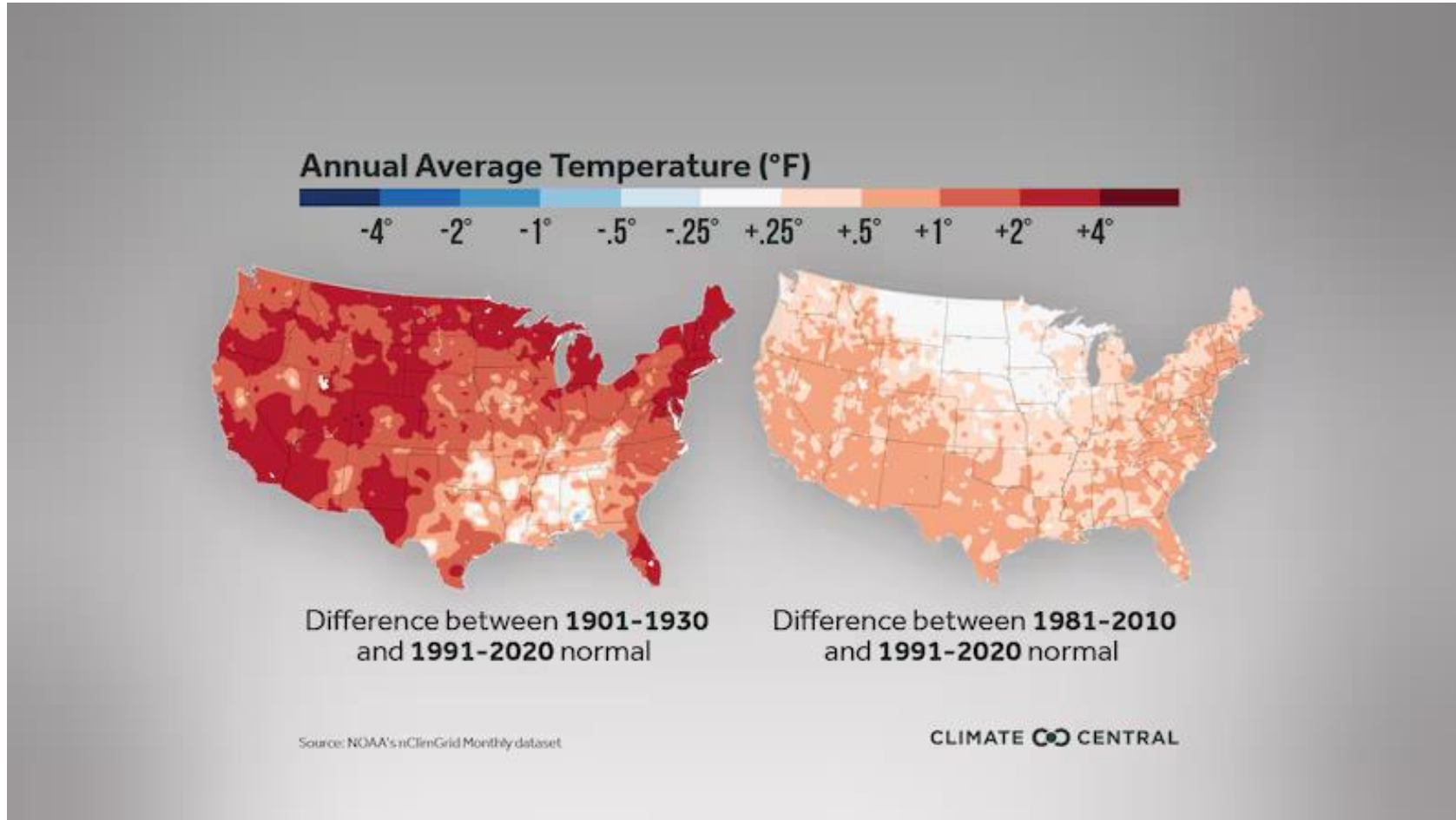


NOAA Climate.gov  
Data: NOAA, ETHZ, Our World in Data

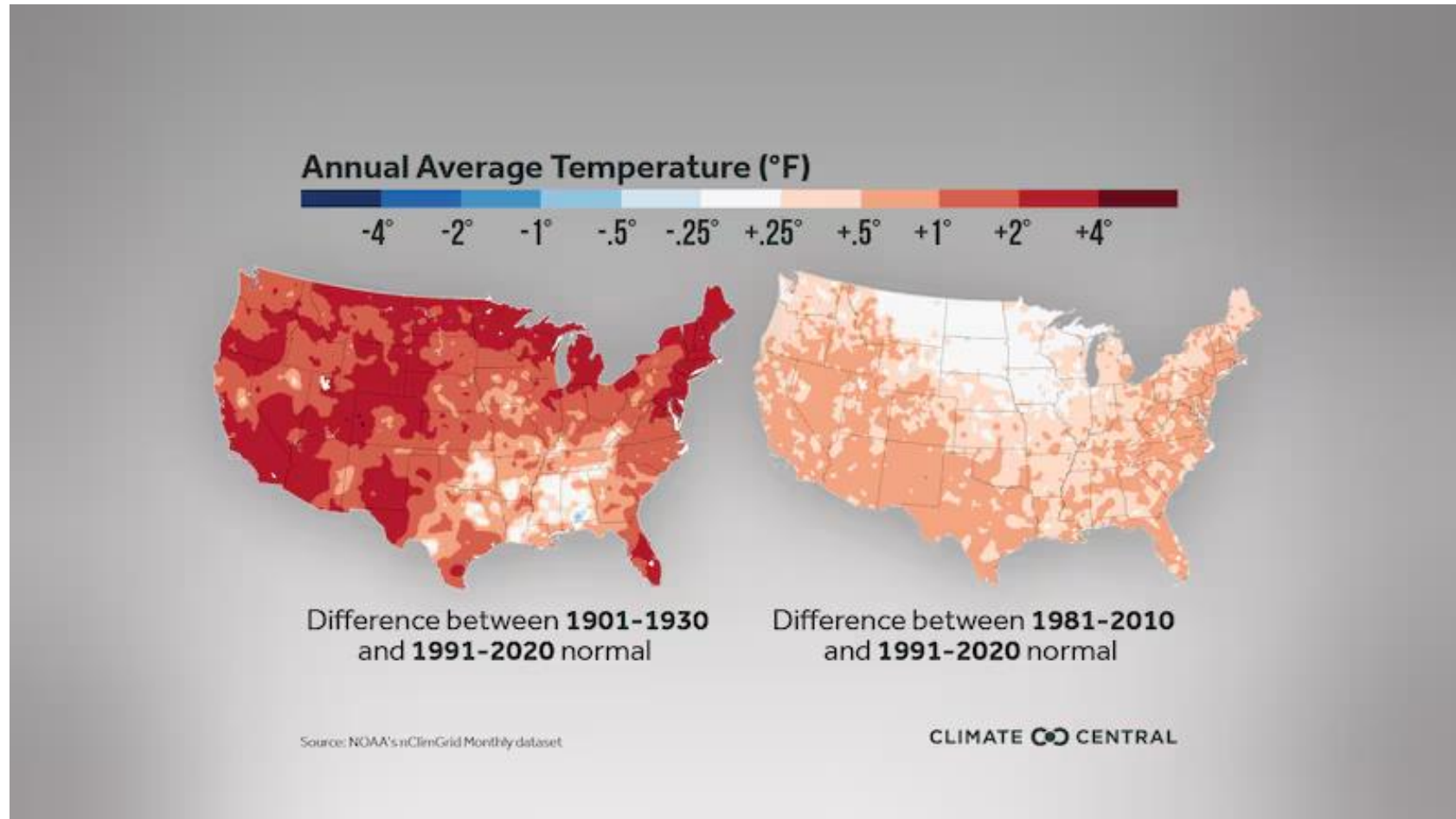
# Global Temperature



# Climate trends in the US: Warming



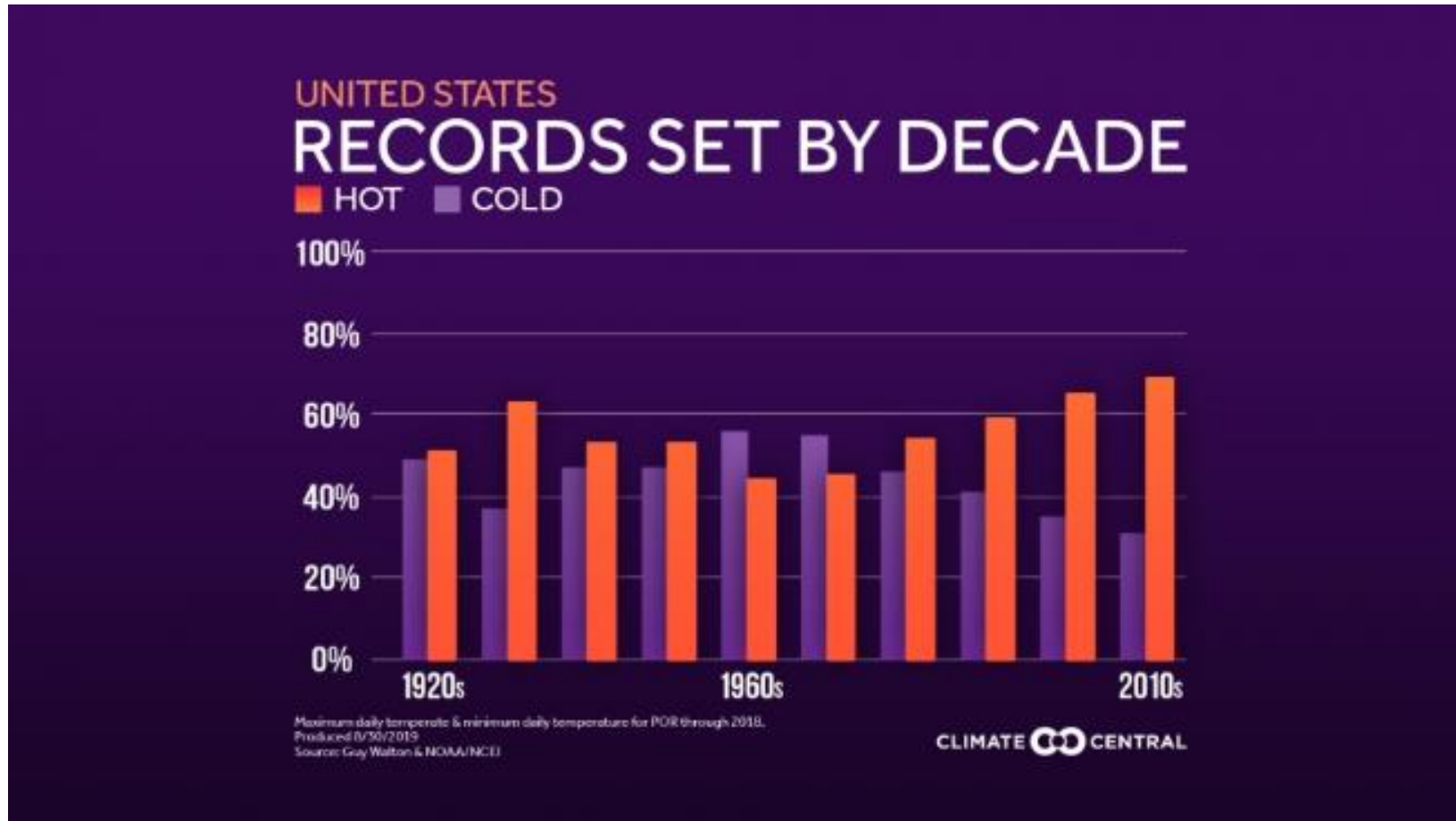
# Climate trends in the US: Warming



## Impacts

- Soil moisture stress
- Heat stress
- Weed and pest pressure
- Lower productivity
- Increased mortality
- Species & habitat migration

# Climate trends in the US: Warming



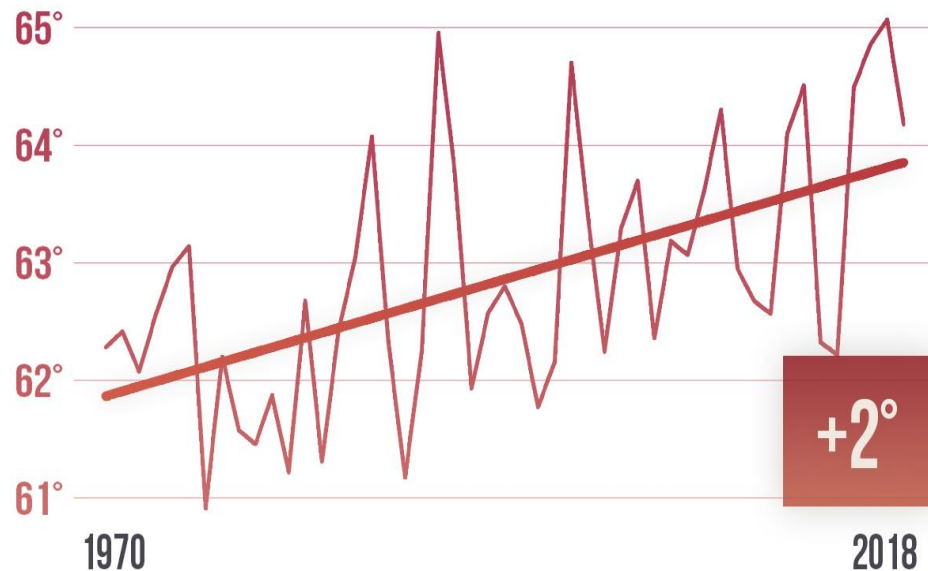
## Impacts

Changes to fruit set and growing degree days

# South Carolina climate trends: Warming

## South Carolina Warming

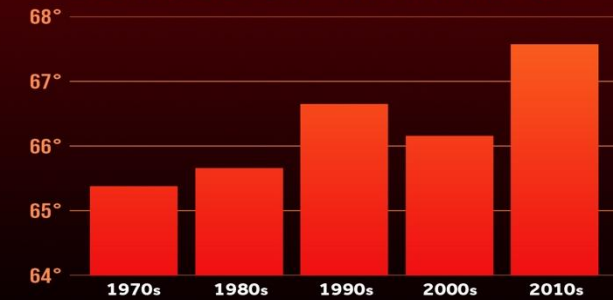
Average annual temperature



Based on linear trends of average annual temperature  
Source: NCEI Climate at a Glance. Produced 4/17/2019

CLIMATE CENTRAL

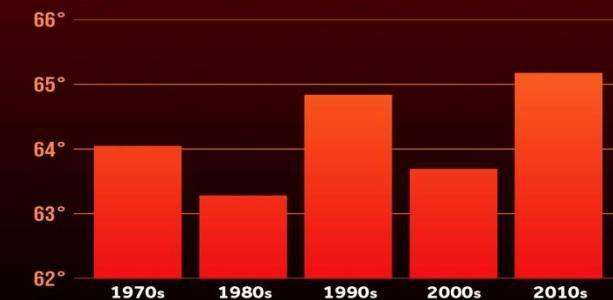
## CHARLESTON, SC DECADES OF WARMING



Average decadal temperature (°F). Data through 12/1/2019.  
Source: RCC-ACIS.org

CLIMATE CENTRAL

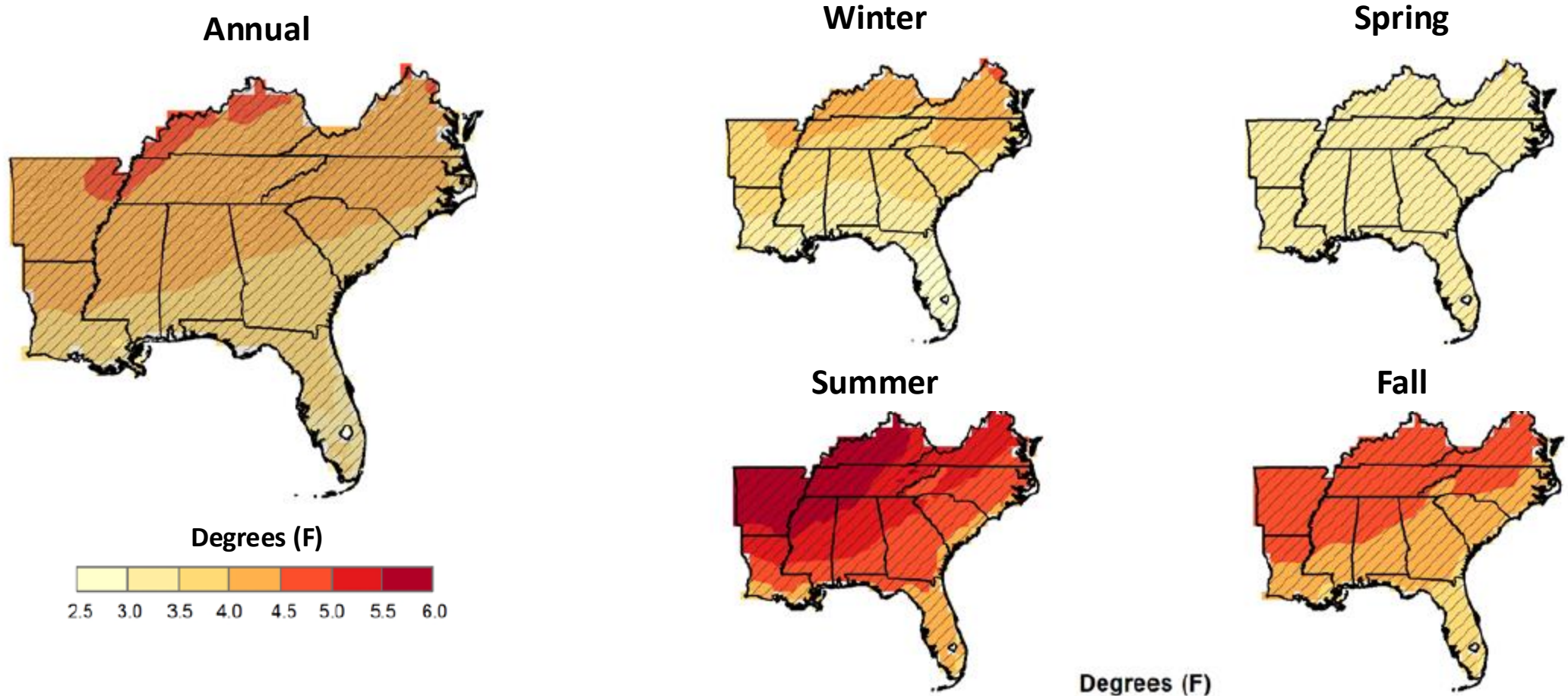
## FLORENCE DECADES OF WARMING



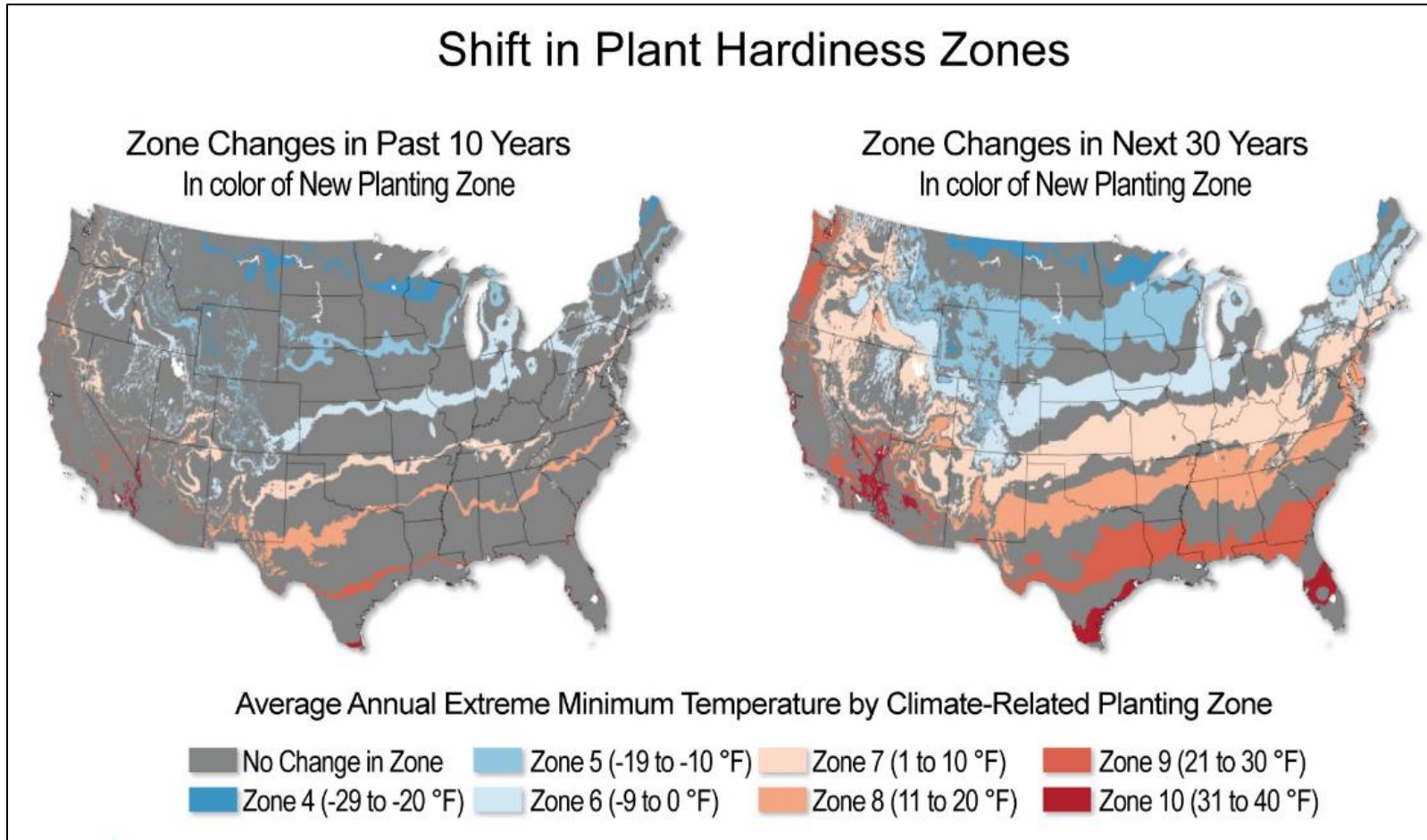
Average decadal temperature (°F). Data through 12/1/2019.  
Source: RCC-ACIS.org

CLIMATE CENTRAL

# South Carolina climate forecasting: Warming (2041-2070)

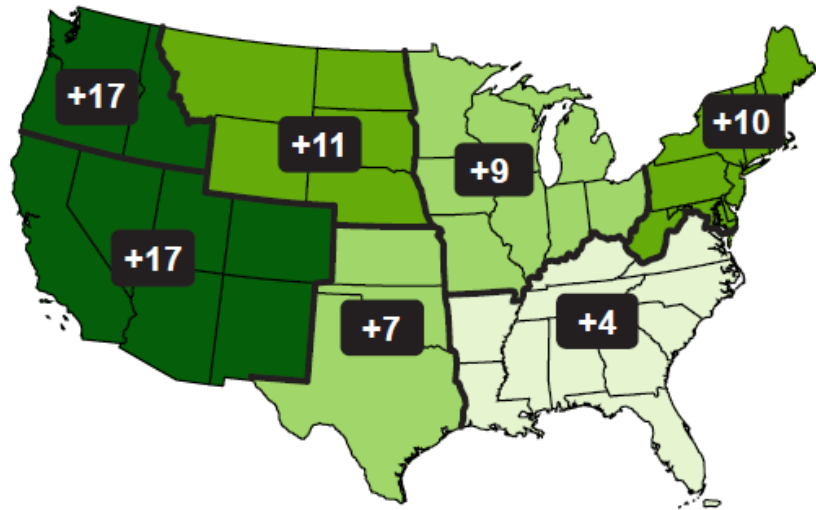


# Climate trends in the US

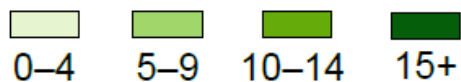


# Climate trends in the US: Frost-free season

Observed Increase in Frost-Free Season Length

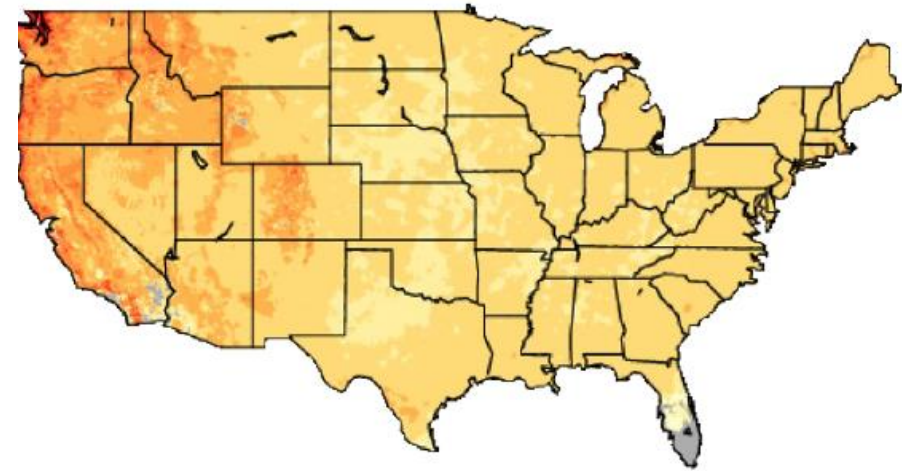


Change in Annual Number of Days

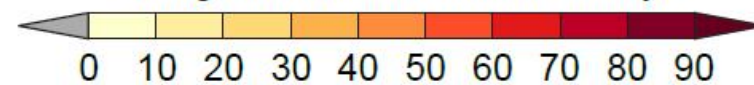


1901 - 2015

Projected Changes in Frost-free Season Length



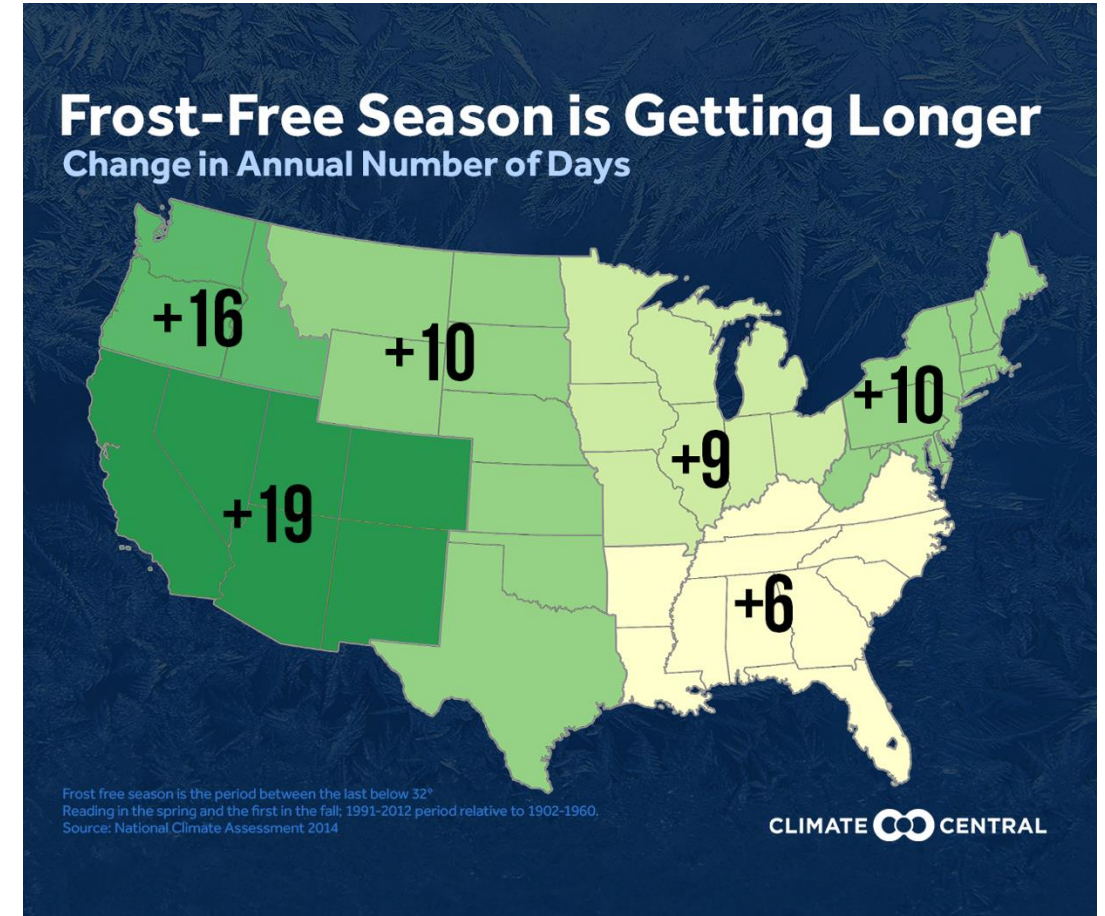
Change in Annual Number of Days



2036 - 2065

# Climate trends in the US: Frost-free season

- Frost-free season impacts
  - Last spring frost is earlier
  - First fall frost is later
  - Growing season ~ 1 week longer
- Benefits
  - Longer growing season
  - More time for photosynthesis
- Challenges
  - More insect generations or growth
  - Late freezes
  - Potential phenological mismatches



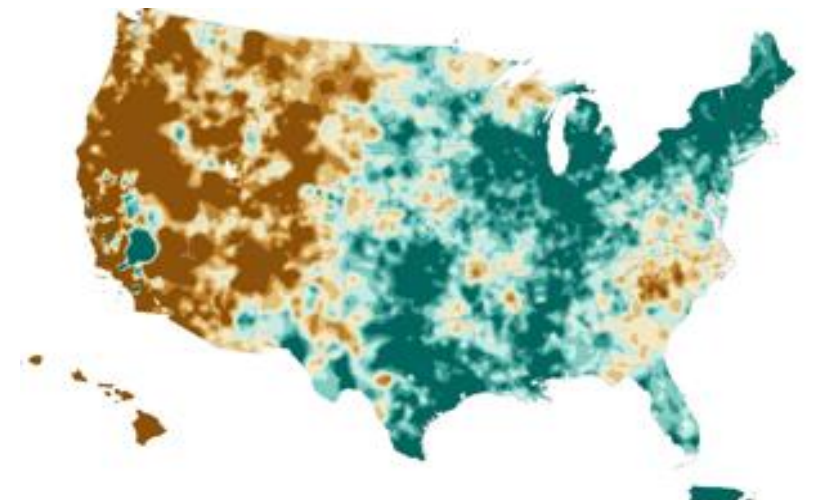
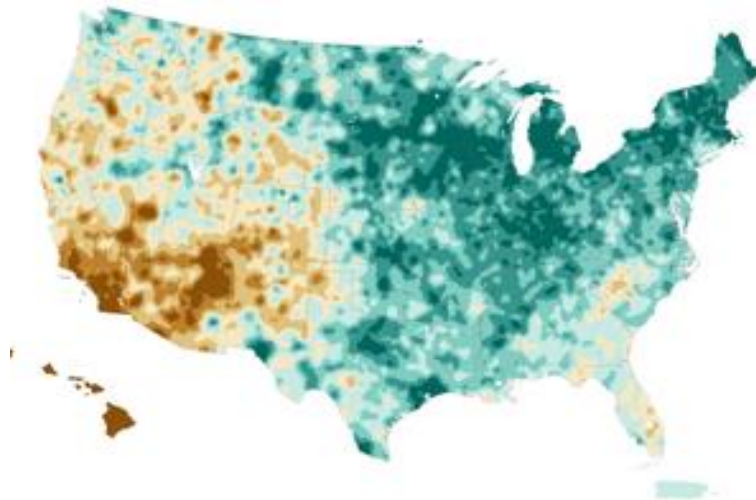
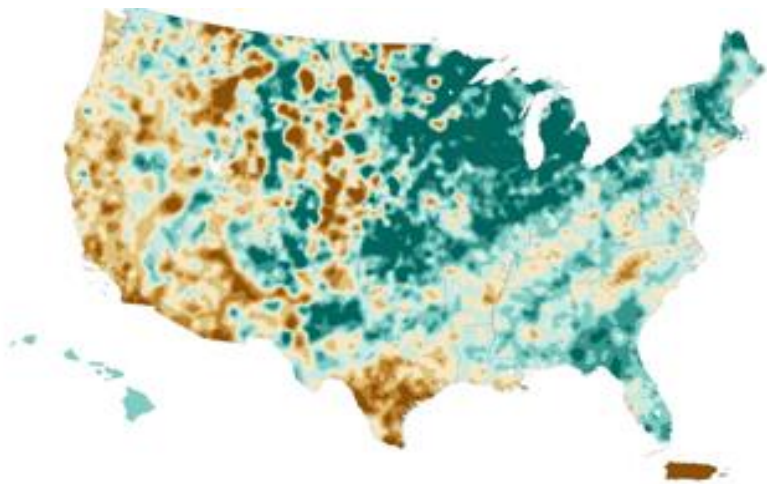
# Climate trends in the US: Precipitation

---

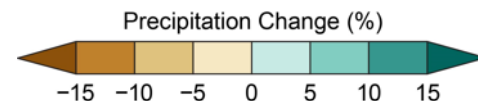
Winter Precipitation

Annual Precipitation

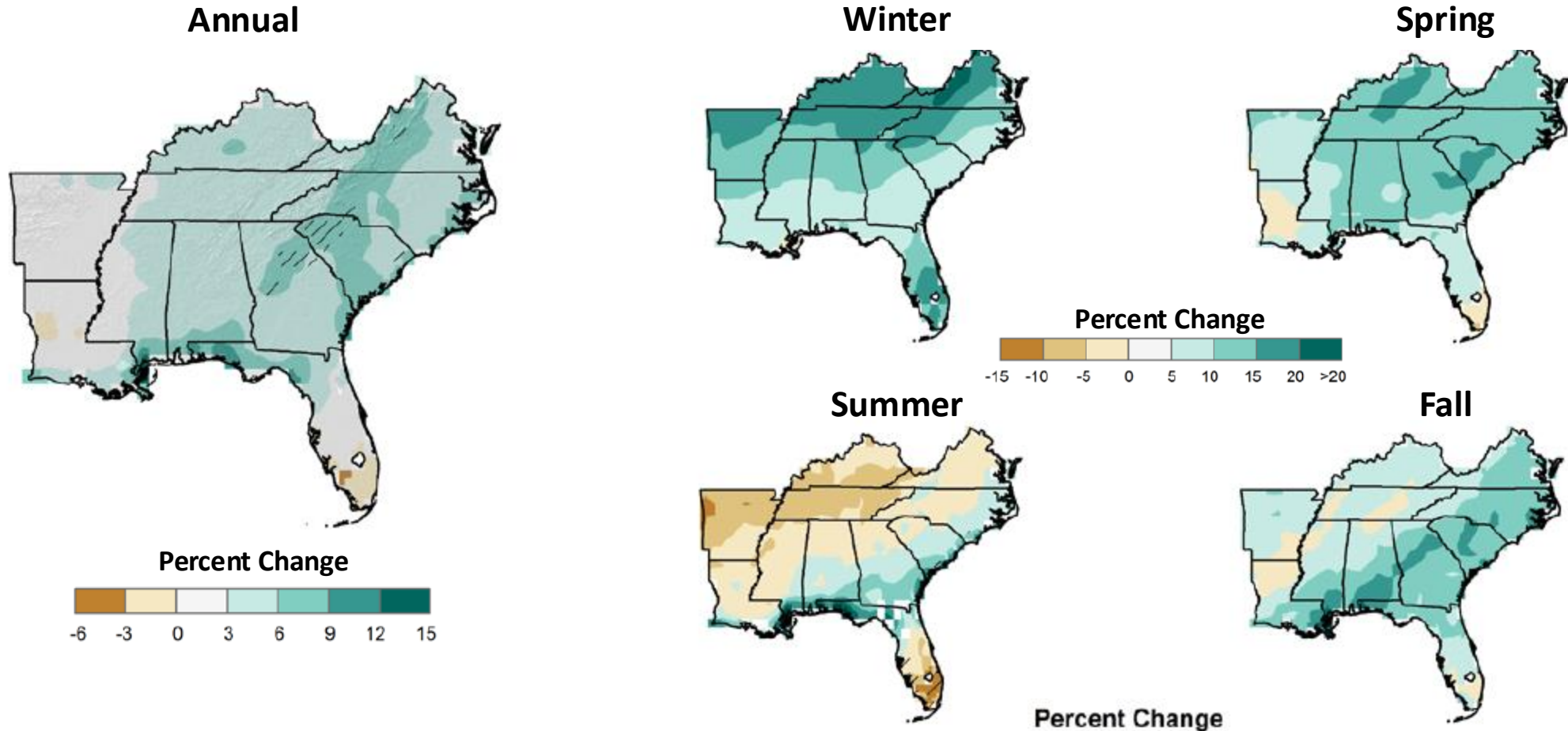
Summer Precipitation



**Comparing 2002-2021 to 1901-1960**

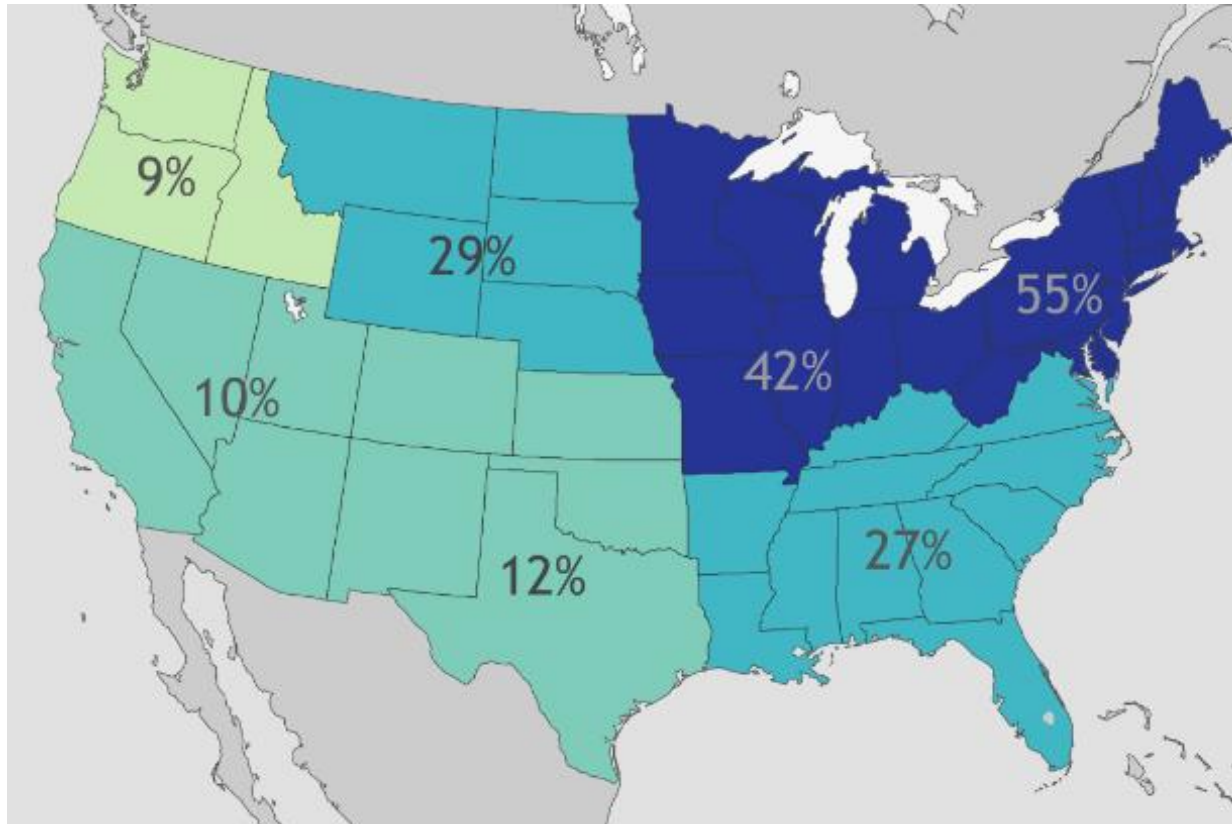


# South Carolina climate forecast: Precipitation (2041-2070)

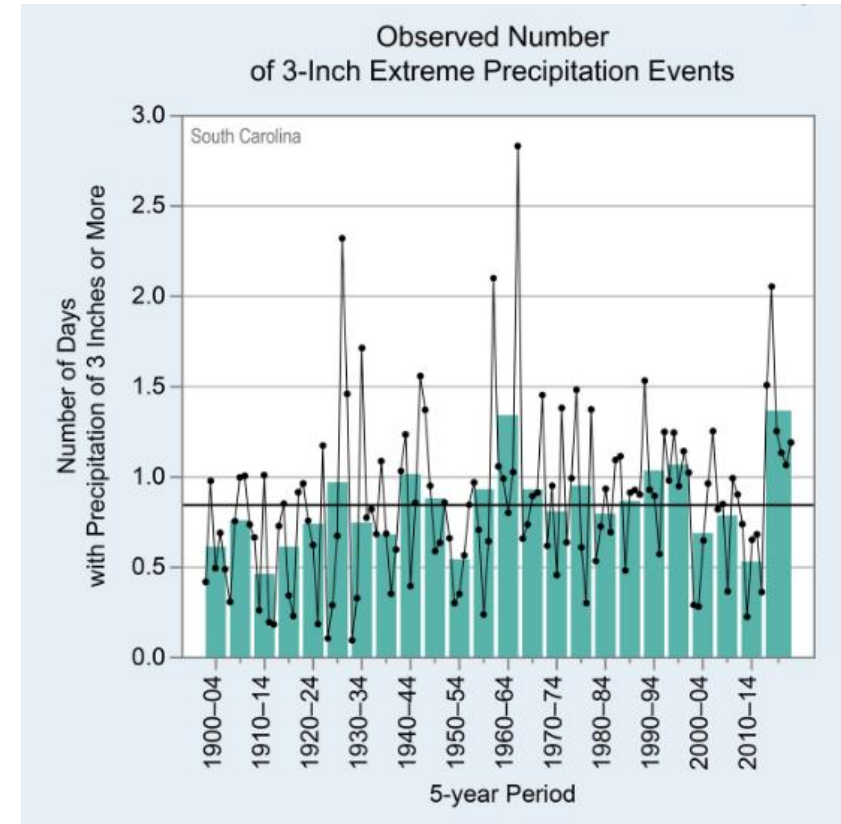


# Climate trends in the US: Precipitation Variability

Observed change in extreme precipitation (1958 – 2016)



Observed change (1900 - 2020)



# Climate trends in the US: Precipitation

---

- Decreased Storm Frequency
  - Drought
  - Water supply
  - Wildfire
  - Pests/ insects
- Increased Storm Intensity
  - Flooding
  - Wind damage
  - Soil erosion
  - Damage to infrastructure
  - Delayed planting/ harvesting



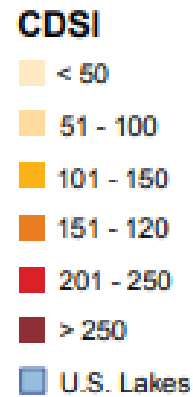
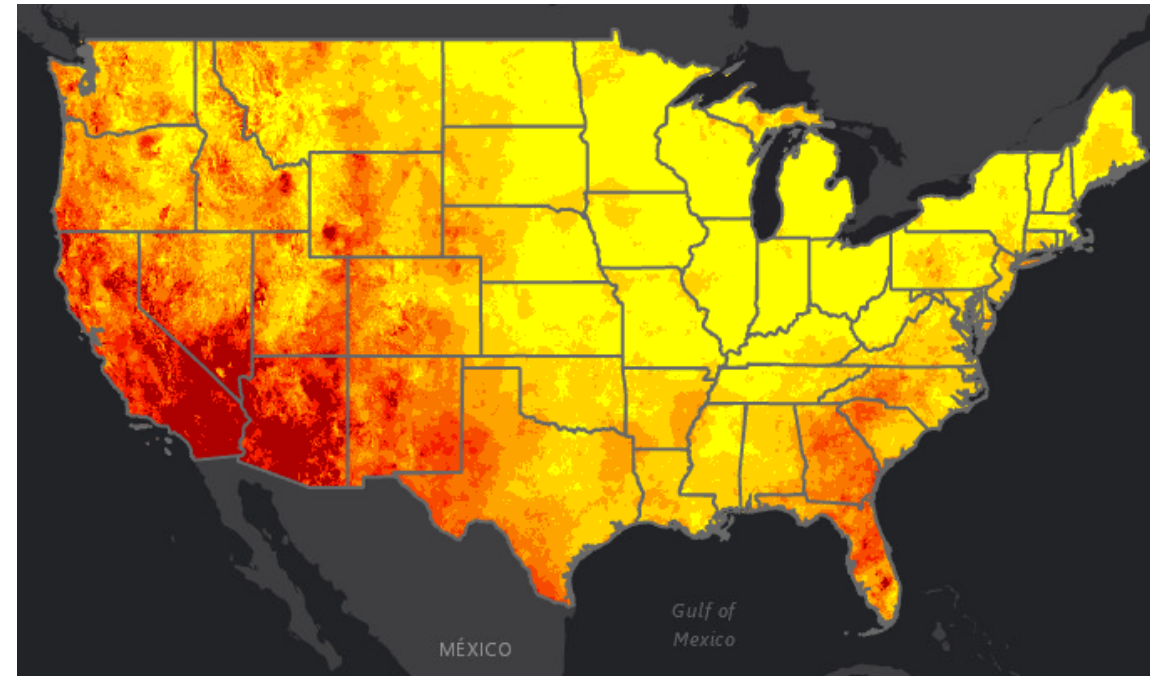
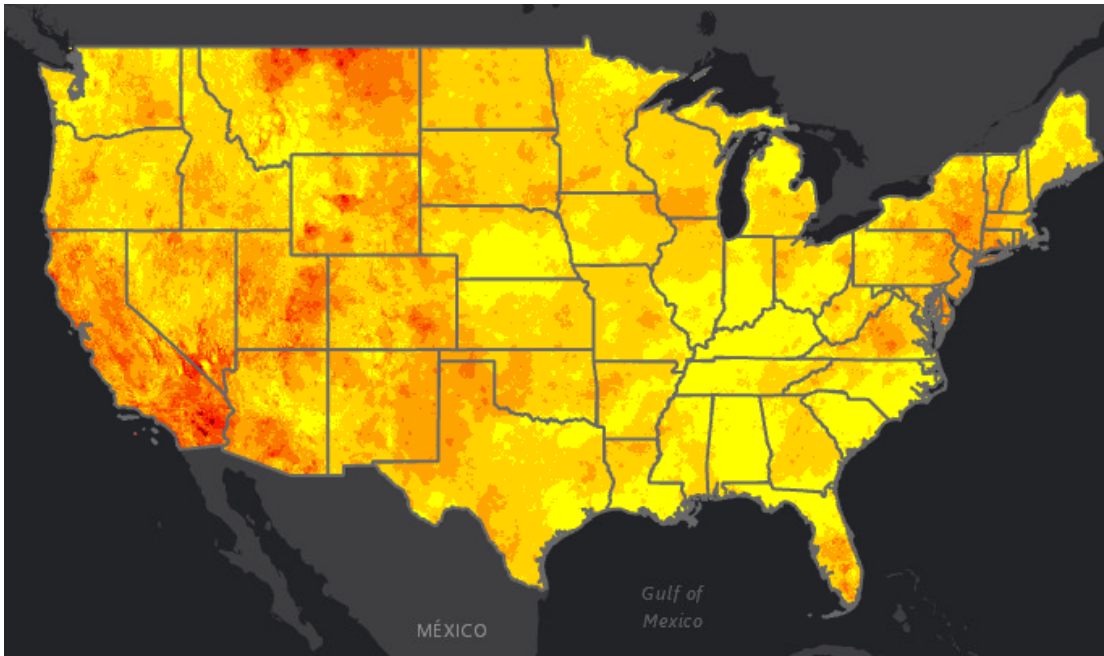
Drought stricken longleaf pine. Photo credit: Andrew J. Boone, South Carolina Forestry Commission, Bugwood.org

# Climate trends in the US: Drought

---

1960 - 1986

1987 - 2013



# Climate trends in the US: Hurricane Risk

---

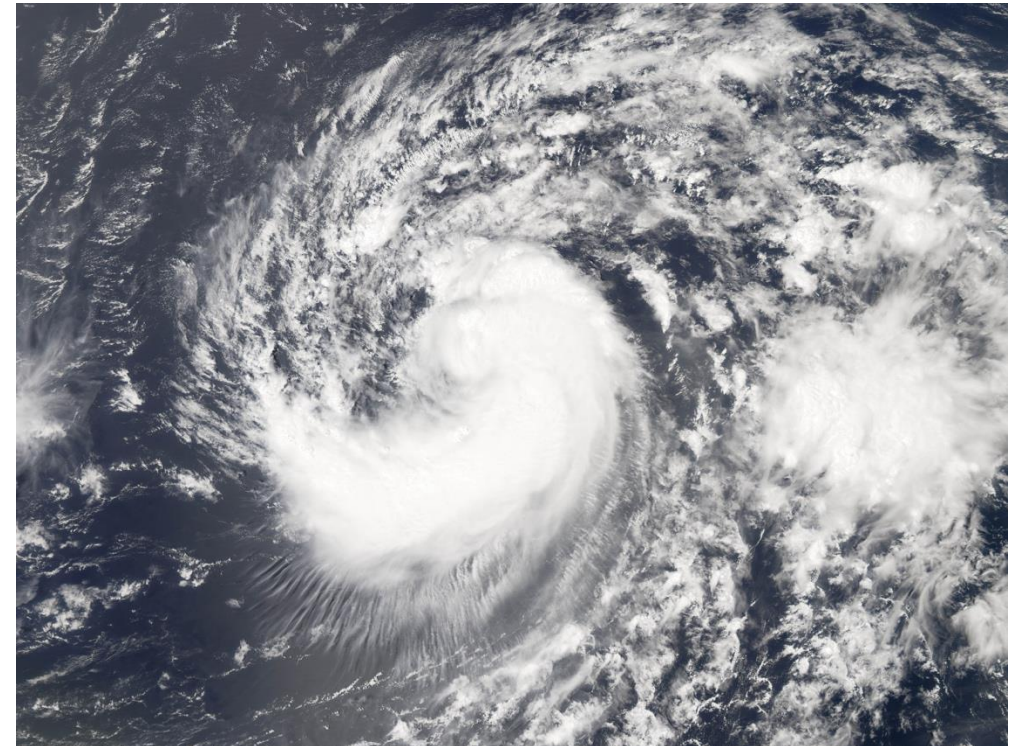
## Trends and Forecasts

- Frequency may not change
- Shift toward more higher category storms (4 & 5)
- Higher rainfall/event

## Impacts

- Increased fuel loading
- Increased invasives and pests
- Increased flooding
- Carbon Sequestration
- Productivity?

Sources: Myers & van Lear 1998, Verbout et al 2007, McNulty 2002



# Climate trends in the US: Hurricane Risk

---

## Trends and Forecasts

- Frequency may not change
- Shift toward more higher category storms (4 & 5)
- Higher rainfall/event

## Impacts

- Increased fuel loading
- Increased invasives and pests
- Increased flooding
- Carbon Sequestration
- Productivity?

Sources: Myers & van Lear 1998, Verbout et al 2007, McNulty 2002



# Climate trends in the US: Invasive Species

---

## Plants:

### Trends and Forecasts

- Increased stress
- Northward expansion
- Disturbance

### Impacts

- Tree mortality
- Habitat destruction/fragmentation
- Decreased species richness
- Increased fuel loading



# Climate trends in the US: Invasive Species

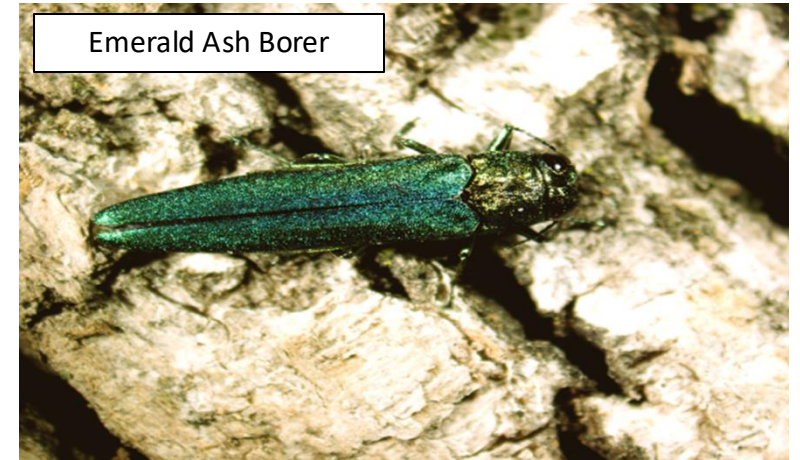
## Insects:

### Trends and Forecasts

- Longer breeding season
- Higher winter temperatures
- Increased over-winter larva survival rate
- Northward expansion
- Drought stress
- Disturbance

### Impacts

- Tree mortality
- Habitat destruction/fragmentation
- Decreased species richness



# Climate trends in the US: Wildfire

---

## Cross-cutting Impacts

- Decreased:
  - Aesthetics
  - Productivity
  - Carbon Sequestration & Storage
  - Culturally important species
- Increased:
  - Mortality
  - Habitat destruction
  - Fragmentation



# Climate trends in the US: Sea Level Rise, Soil Salinization and Saltwater Intrusion/ Inundation

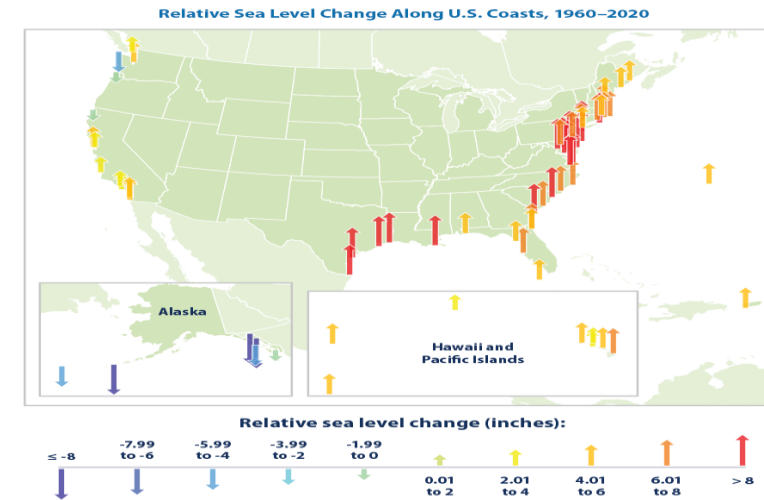
## Trends and Forecasts

- SLR rate: 3.8 mm/yr (1.5 in/decade)
- High variability
- Timing of salinization events depends on tropical storm occurrence and SLR



## Impacts

- Decreased vigor and growth
- Increased mortality and insect problems
- Culturally important sites, working lands threatened

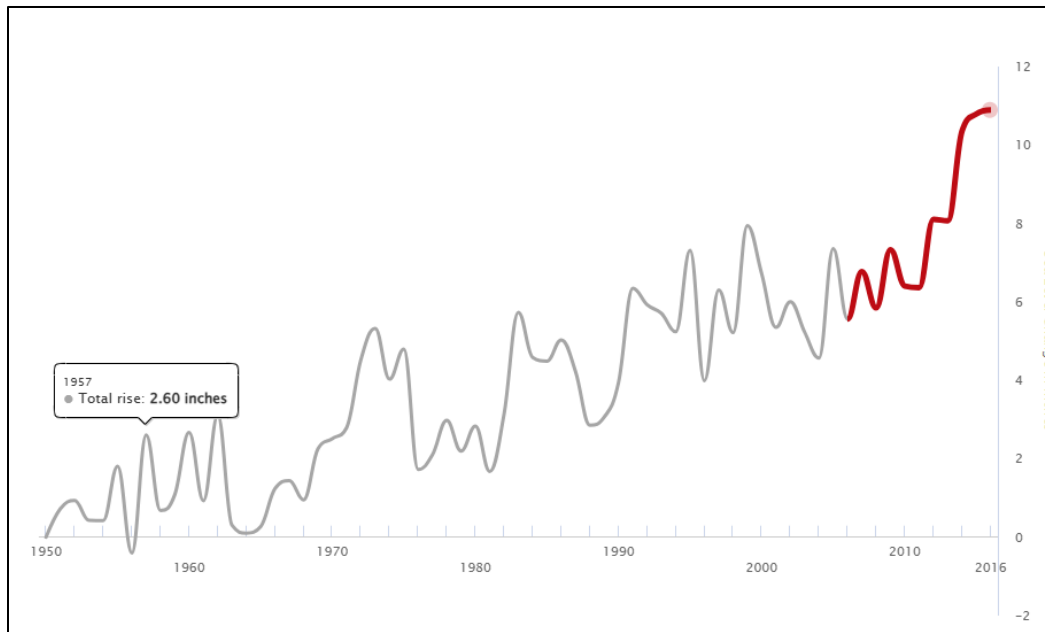


Data source: NOAA (National Oceanic and Atmospheric Administration). 2021 update to data originally published in: NOAA, 2009. Sea level variations of the United States 1854–2006. NOAA Technical Report NOS CO-OPS 053. [www.tidesandcurrents.noaa.gov/publications/Tech\\_rpt\\_53.pdf](http://www.tidesandcurrents.noaa.gov/publications/Tech_rpt_53.pdf).

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at [www.epa.gov/climate-indicators](http://www.epa.gov/climate-indicators).

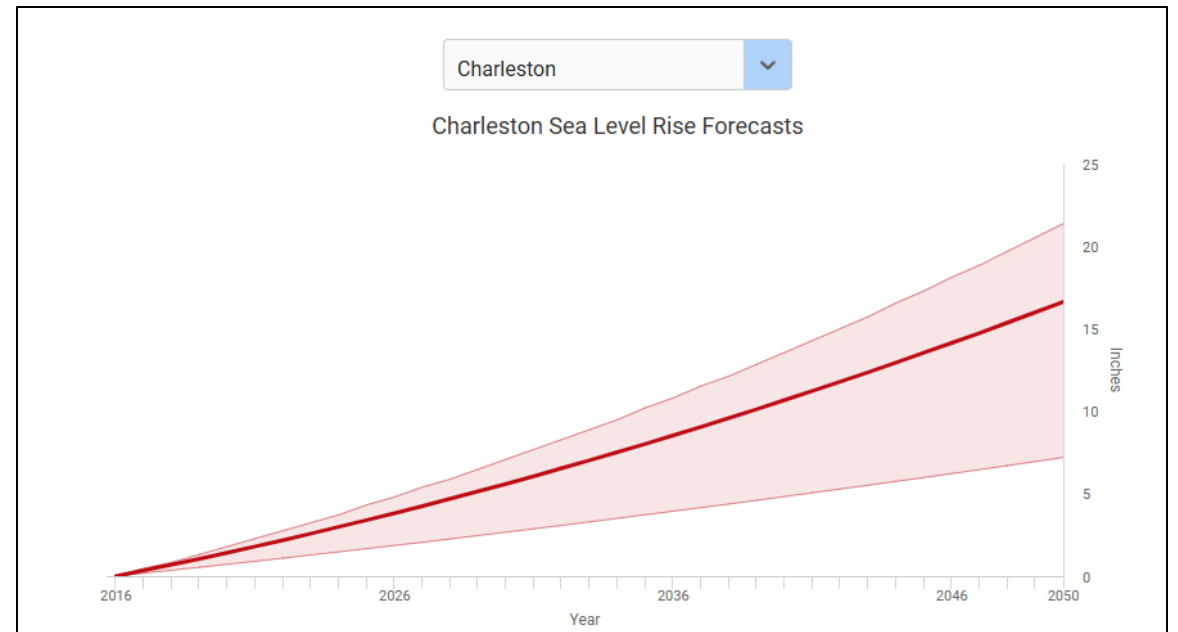
# South Carolina climate trends: Sea Level Rise

Historical SLR: 1950 - 2016



Charleston, SC

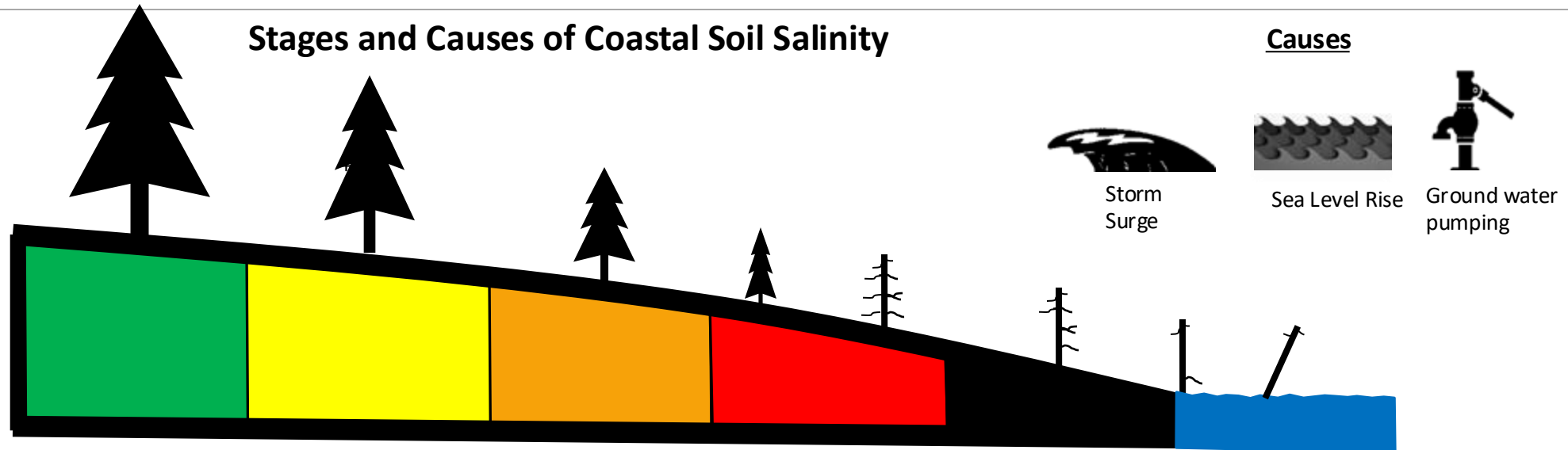
Projected: 2016 - 2050



Charleston, SC

# Soil Salinization

## Stages and Causes of Coastal Soil Salinity



Stage 0 Non-Impacted	Stage 1 Sporadic Salinity	Stage 2 Reoccurring Episodic Salinity	Stage 3 Low Chronic Salinity	Stage 4 High Chronic Salinity	Stage 5 Chronic Surface Water
EC = < 2 dS m <sup>-1</sup>	EC = 2 < 4 dS m <sup>-1</sup>	EC = 4 < 8 dS m <sup>-1</sup>	EC = 8 < 16 dS m <sup>-1</sup>	EC = 16 < 25 dS m <sup>-1</sup>	EC = >25 dS m <sup>-1</sup>

Commercial	Commercial	Commercial	Non-Commercial	Non-Commercial	Saltwater Marsh	Uses
No	Yes	No	No	No	No	<b>Mitigation?</b>
No	Yes	Yes	Yes	No	No	<b>Adaptation?</b>
No	No	No	No	Yes	Yes	<b>Wetland Restoration/Easement?</b>

# Management considerations

- Climate variation is a threat to forest management and productivity
- Leads to disturbances including droughts, hurricanes, wildfires, sea level rise, invasive species, and changes to precipitation patterns
- Each of these causes secondary effects including increased risk of other disturbances, decreases in growth and carbon storage, and adds complications/unknowns to management
- Resilient forestry is a method that can be used to support adaptive management decisions

# Resilient Forestry

---

“The ability of communities, economies, and ecosystems within South Carolina to anticipate, absorb, recover, and thrive when presented with environmental change and natural hazards.”

- South Carolina Office of Resilience

# Resilient Forestry: Synergies & Conflicts

---

- Many goals to manage for, some will be in conflict
  - i.e. a lower stand density protects against wildfire, drought, and insects, and higher stand density is beneficial for hurricanes

The best resilient forestry management will depend on where you are, what the risks are, and what you want from your forests

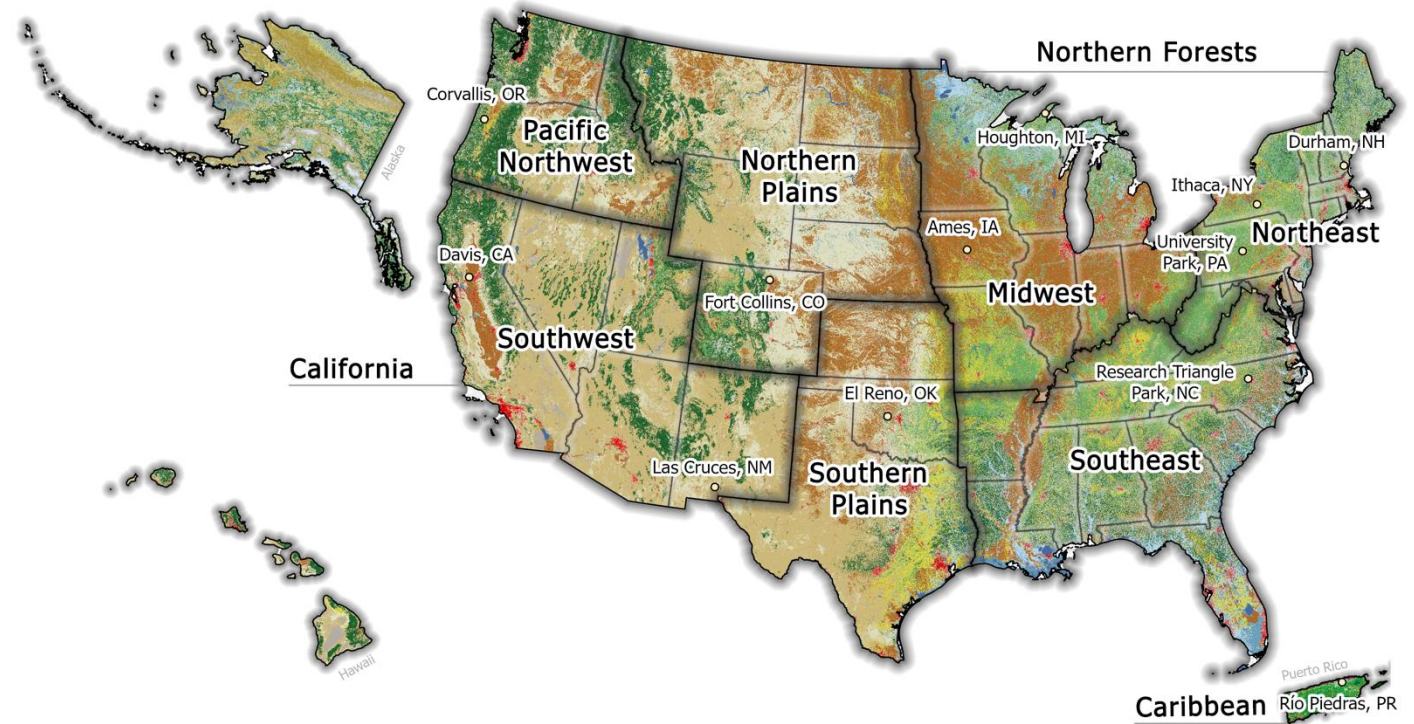
An aerial photograph of a vast, dense evergreen forest, likely a coniferous forest, covering a hillside. The trees are tightly packed, creating a textured, green surface. The lighting is soft, suggesting an overcast day or early morning/late afternoon. The overall tone is natural and serene.

# What is the Climate Hub?

---

# History of the Climate Hubs

- Created in 2014 by the U.S. Department of Agriculture to address risks posed by climate change to working lands
- Consists of 10 regional hubs
- Southeast Regional Climate Hub covers AL, AK, GA, FL, KY, LA, MS, NC, SC, TN, and VA
- Rich history of working lands, important to U.S. economy
- Facing pressures



## Our Mission:

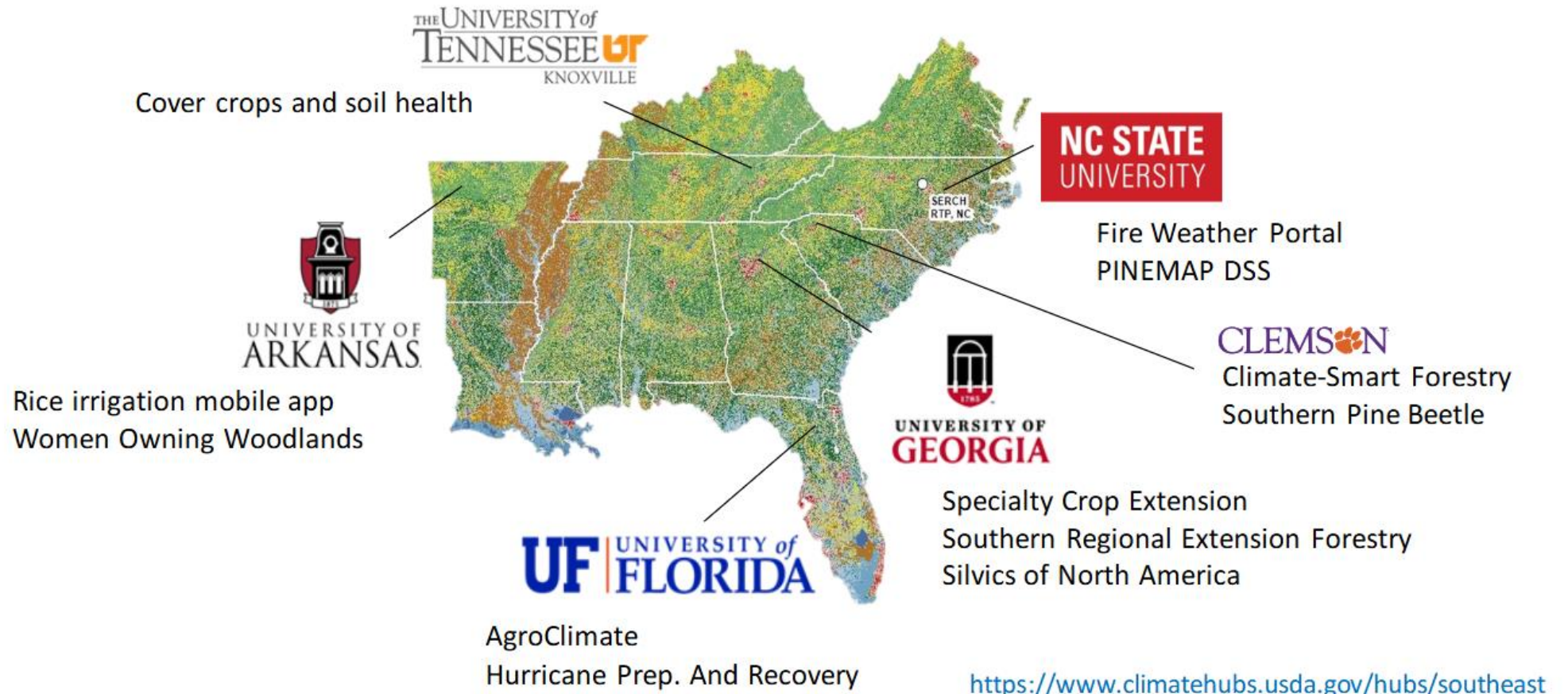
“The mission of the Climate Hubs is to develop and deliver science-based, region-specific information and technologies, with USDA agencies and partners, to agricultural and natural resource managers that enable climate-informed decision-making, and to provide access to assistance to implement those decisions.”

# What are Climate Hubs doing?

---

- Develop and deliver tools
  - Connect land managers with tools to assist adaptation/ mitigation
- Regional Vulnerability Assessment
  - Connect land managers to science
- Partner with LGUs and Extension
- Outreach and Education
  - Leading workshops and continuing education
  - Outreach to extension, farm groups, forestry groups, tribal groups

# What are Climate Hubs doing?



# Current Projects

---

- Drought Preparation and Recovery Guides in the Southeastern United States, for 14 different commodities
- Disturbance Guides for the Southeast by disturbance type
- Updating TACCIMO to be more effective for users
- Salinization on working lands guide

# Southeast Topics

Explore content from the Southeast Climate Hub that pertains to specific topics within climate change.



# Overview of tools and resources



Climate Science

Crops

Economics

Bioenergy

Carbon & Greenhouse Gases

# Emerging Forest Threats Fact Sheets



## SOUTH CAROLINA'S EMERGING FOREST THREATS

Healthy Forests Management Options

### WHY DOES IT MATTER TO ME?

It is important for private forest landowners to prepare for the likelihood of increasing threats to their forest lands. Private forests make up the largest holdings of forestlands in the southeastern U.S. These properties collectively will be crucial in protecting the overall health of our landscape. Management that uses the most current forest science will better enable landowners to protect their land and resources, and to contribute positively to the conservation and productivity of South Carolina's forestlands.

## EMERGING THREATS & HEALTHY FOREST MANAGEMENT

events. Adaptation options include thinning to reduce stand water stress, maintaining a canopied riparian zone to reduce stream temperatures, incorporation of drought-resistant species, and using prescribed burns to reduce fuel loads and wildfire risk. Monitoring for signs of disease or pest activity will alert landowners to the problem and allow for actions for stopping outbreaks early.



**Threats from Wildfire** - Increased fuel loads and more frequent droughts could increase wildfire frequency and intensity within the southeast, with South Carolina already experiencing \$1 million of fire caused forest damage each year. Other impacts include habitat destruction and fragmentation, and biodiversity decline. Prescribing burning to reduce fuel loads and periodic thinning are important control methods. Salvage logging after extreme weather events or significant timber losses reduces fuel loads and the chances for pest or disease outbreaks. Incorporating fire-resistant species such as longleaf pine may also mitigate wildfire risks.



**Threats from Flooding** - Extreme precipitation events from storms and hurricanes can harm coastal and inland forests, especially recently established plantations. Flooding is a common disturbance within the Southeast U.S. due to the frequency of extreme (more than 2.5" in a day)

rainfall events. Floods impact forest productivity by altering soil conditions and exposing or burying root systems. Reductions in stream water quality, aquatic habitat, the aesthetic value of recreational areas, and soil productivity can all occur after floods. Management practices to mitigate damages include post-disturbance revegetation, maintaining the areas natural hydrology and riparian zone health, planting flood-tolerant tree species, monitoring susceptible trees for outbreaks or fungal growth, and implementing proper erosion control structures such as culverts and drainage ditches where needed.



**Threats from Hurricanes/Tornadoes** - Hurricane Matthew caused \$200 million in forest damage across the state in 2019. Additionally, tornadoes can be locally destructive and cause up to \$5 million per year in forest damage. Increases in hurricane intensity and storm frequency are related to warming air and water temperatures. Therefore, annual forest damage is likely to increase in the coming years. Hurricanes and tornadoes cause habitat and recreational area destruction, reduce biodiversity and water quality, and can cause inland soil salinization from storm surges. Adaptation practices to reduce wind damage impacts include rotational harvesting to reduce stand age uniformity, incorporating wind resistant tree species, and modifying thinning frequencies.



**Threats from Ice Storms** - Ice storms are another, lesser known threat to southeastern forests. The most likely area to see ice storms is northern South Carolina. However, this area could shift northward with warming winters. As ice builds on branches, the weight of the ice exceeds the carrying capacity of the branch and it breaks. Pines collect more ice compared to hardwoods because they retain their needles year-round, and the needles hold the ice. Additionally, pines branches break under less weight than hardwoods, so pines are particularly vulnerable to ice storms. As little as 1" of ice can cause breakage. Adaptation practices include decreasing tree density, adjusting thinning timing frequencies to reduce the probability of damage after fresh thinning, and planting/regenerating breakage-resistant tree species. Post-disturbance monitoring will aid in preventing pest outbreaks and attacks on green timber.



**Threats from Sea Level Rise** - Accelerated sea level rise has been correlated with warming sea surface and air temperatures. Due to this trend, southeastern coastal states like South Carolina have experienced soil salinity issues moving further inland, resulting in severe forest damage and the overall loss of workable lands. Other impacts include vegetation changes, biodiversity, habitat loss, water quality declines, and increased invasive species outbreaks. Planting more salt-tolerant species is one adaptation option for creating salt-tolerant forest stands that are more resilient to storm surge. As soil salinity becomes a chronic issue, implementing short-rotation woody crops may help retain profits while decreasing risks from storm surge events. Drainage system installation may reduce the probability of developing salinity issues by lowering the height of the soil water table.



**Summary**— Many threats impact the economic and ecosystem value of South Carolina's forestland. Threats such as wildfires, hurricanes, soil salinization from storm surge and sea-level rise, and insect and invasive species outbreaks have always existed, but are now being amplified by warming temperatures and changes in rainfall frequency and amounts. The adaptation methods listed on this sheet are just a few of the available options that help forest land managers improve resilience and reduce risk. Consult your local forest extension agent or a county forester for more information about threats and corrective measures appropriate for your forest.

FOR MORE INFORMATION ON  
MANAGEMENT OPTIONS FOR YOUR  
WOODLANDS:

Contact the South Carolina Forestry  
Commission Office at 803-896-8800  
[www.trees.sc.gov](http://www.trees.sc.gov)

# Silvics of North America: Updated

## New to SNA

- Forecasted Distribution
- Urban Forestry
- Invasive Species
- Indigenous Uses?

The screenshot shows the website interface for *Ailanthus altissima* (Mill.) Swingle. The header includes logos for USDA, U.S. Forest Service, Canada, and CONAFOR, along with the text "SILVICS OF NORTH AMERICA". A navigation bar contains "Home", "Chapters", "About", and "Acknowledgments", with a search icon and a "Search" button. The main content area features a grid of icons representing different topics: Introduction, Distribution and Environmental Associations, Life History Traits, Reproduction, and Early Growth, Tree Growth and Stand Dynamics, Management, Genetics, Disturbance Regime: Insects and Diseases, Disturbance Regime: Wildland Fire, Disturbance Regime: Drought, Additional Disturbances, Goods and Services, and Urban Forestry. Below the grid is a large photograph of the plant's green, pinnately compound leaves.

# Climate Change Tree Atlas

- Updated model results
- Results in several formats (State, EcoMap, HUC6 watersheds, 1° x 1°, etc.)
- **New information** about colonization potential (SHIFT) and overall ability to tolerate future conditions (Capability)
- **Better tutorials and explanations** throughout the site.

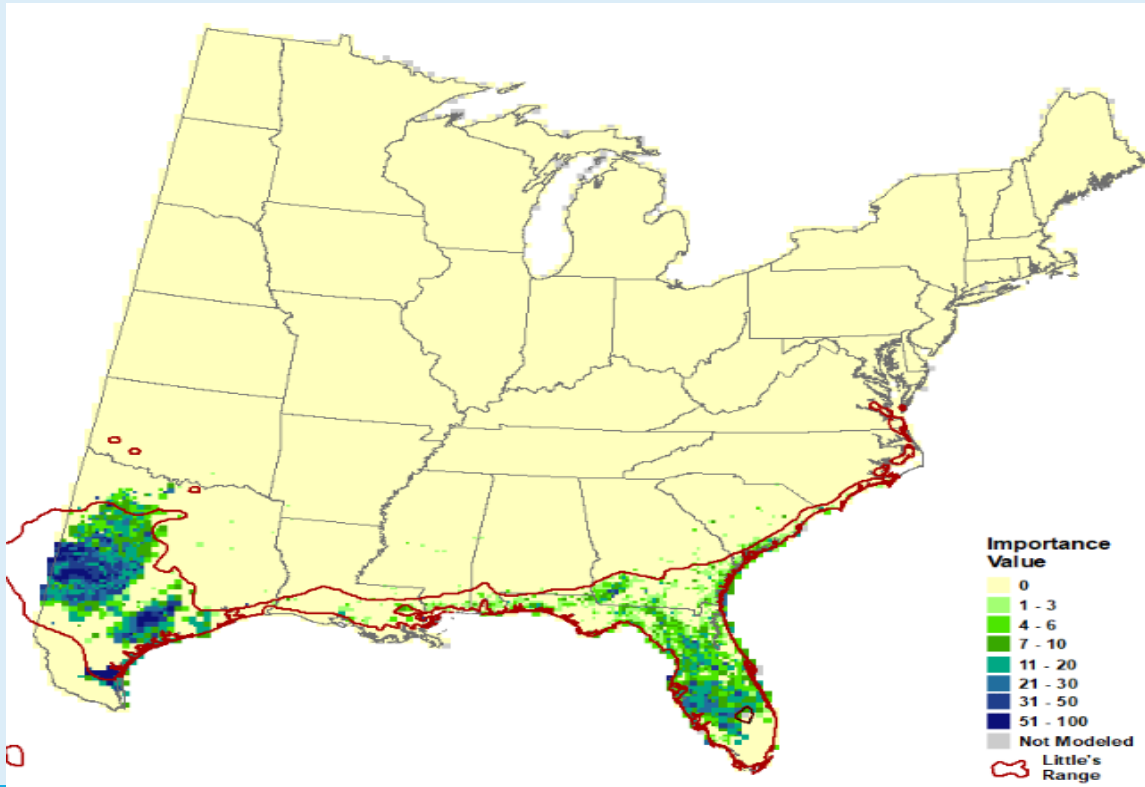
<https://www.fs.fed.us/nrs/atlas/tree/>

The screenshot displays the 'Climate Change Atlas' website. At the top, the title 'Climate Change Atlas' is centered. Below it, there are two main featured sections: 'Tree Atlas' (Version 4) and 'Bird Atlas' (Version 2). The 'Tree Atlas' section includes a map of the Eastern United States showing modeled potential suitable habitat for 125 tree species, with an additional 23 species with current information only. The 'Bird Atlas' section features a photograph of a blue jay and text indicating potential changes in abundance and range for 147 bird species in the East. To the right of these sections is a search and navigation area with a search bar for trees or birds, buttons for 'Browse Previous Tree Atlas' (Version 3, Version 2) and 'Browse Previous Bird Atlas' (Version 1), and a 'Publications' section with a 'Browse Publications' button. Below the main content is a 'Regional Summary Tree Tables' section with a sub-header 'Current and Potential Future Habitat, Capability, and Migration'. This section provides a summary of available data for various geographies in PDF and Excel formats, based on Version 4 of the atlas. A list of links includes National Forest Summaries, National Park Summaries, HUC6 Watersheds, Ecoregional Vulnerability Assessments (EVAS), USDA Forest Service EcoMap 2007 Sections, National Climate Assessment (NCA) 2016 Regional Summaries, 1 x 1° Grid Summaries, Eastern United States, and Urban Areas. On the far right, there is a 'Featured Publication' section with a book cover titled 'Assessing Potential Climate Change Impacts across the Conterminous United States: Mapping Plant Hardiness Zones, Heat Days, Growing Degree Days, and Cumulative Drought Severity Throughout the Century'.

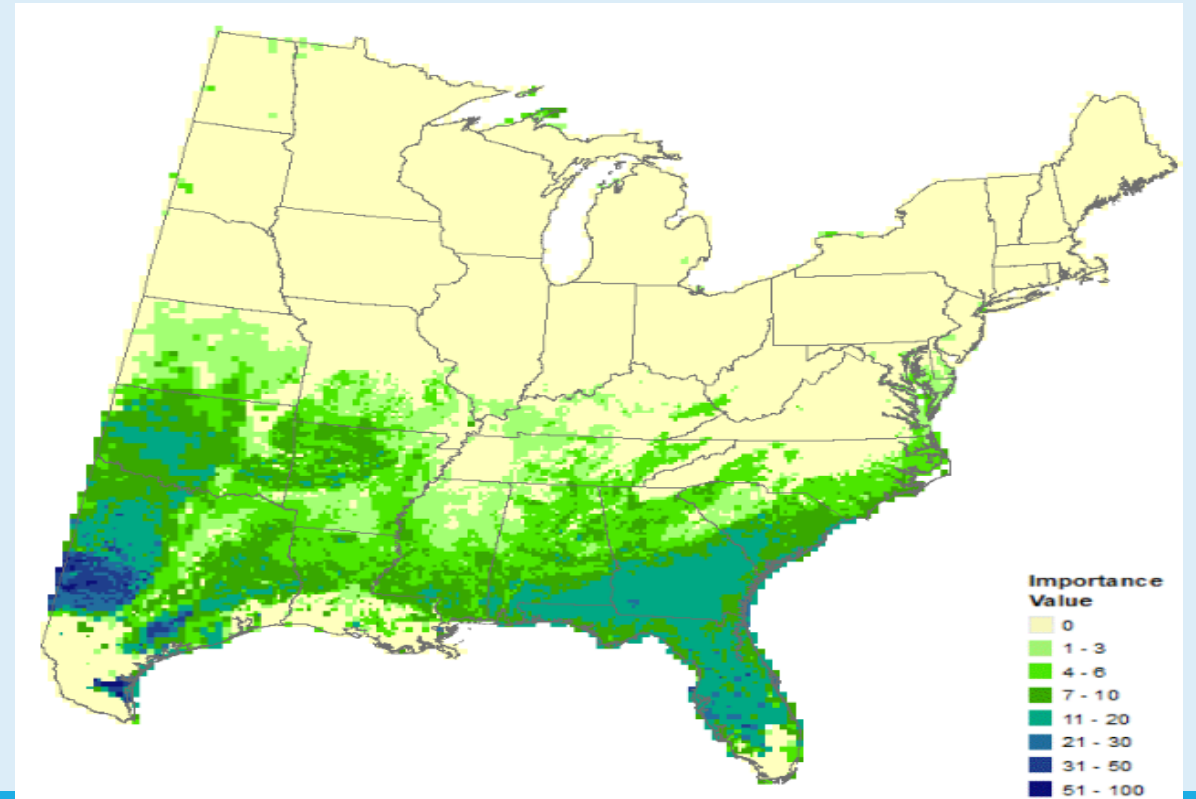
# Climate Change Tree Atlas

Live Oak – *Quercus virginiana*

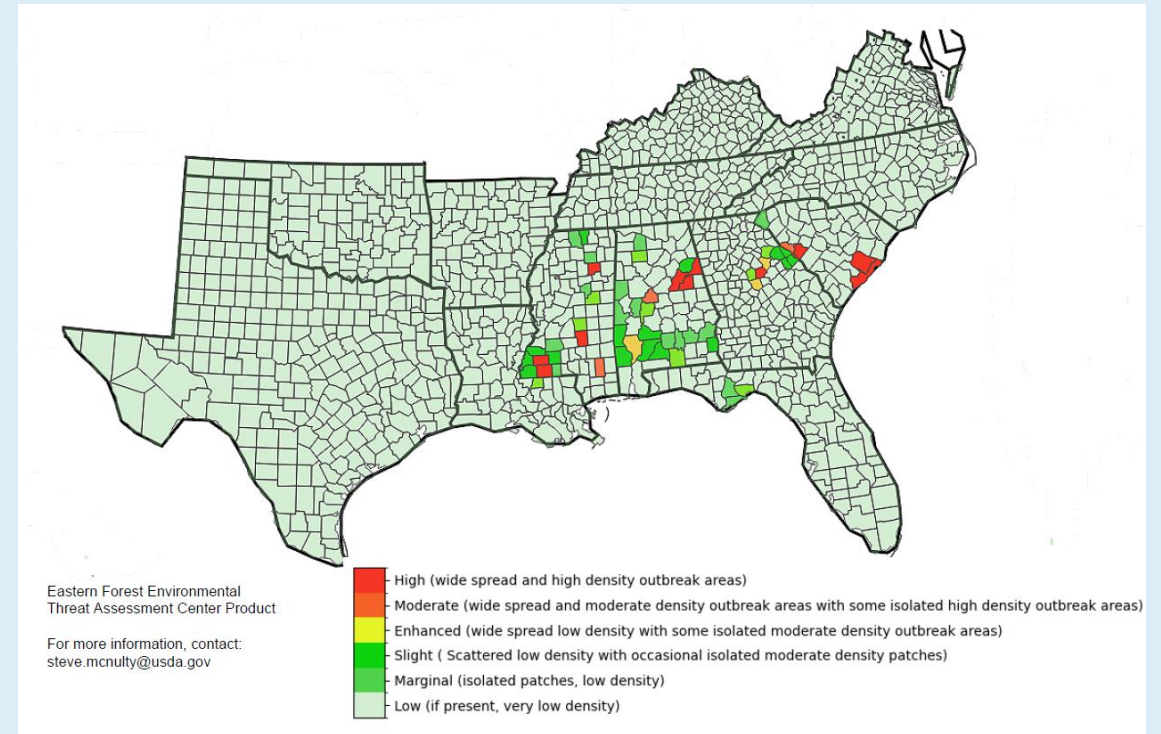
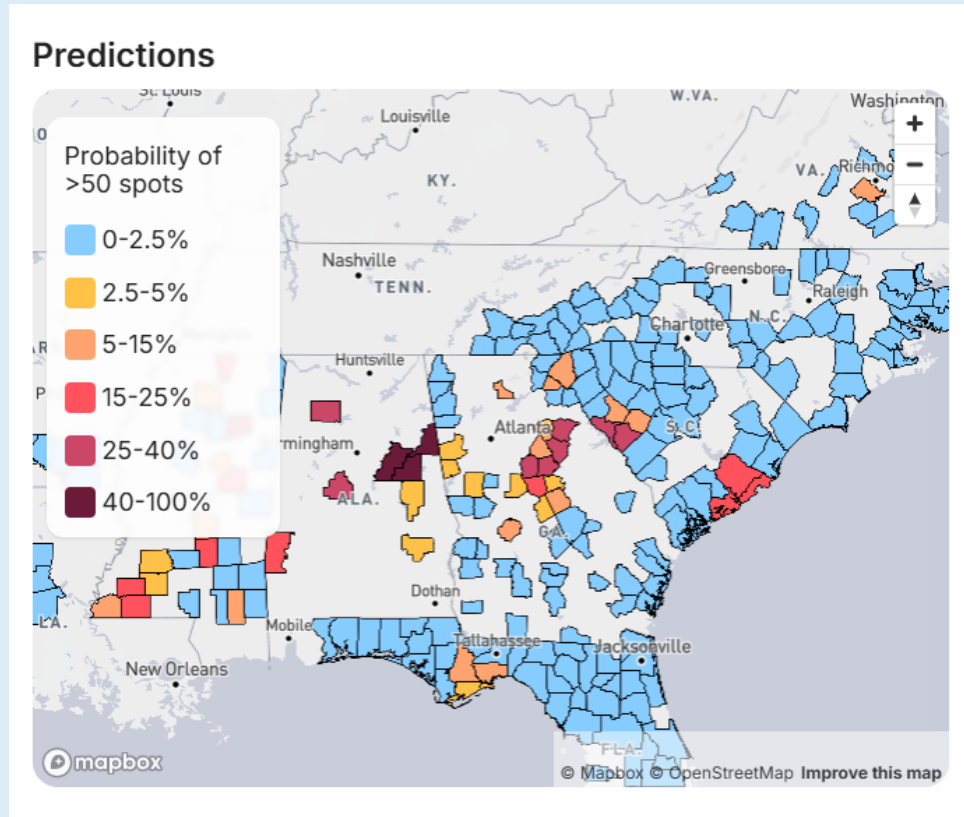
Current Range



Projected (RCP 4.5)



# Southern Pine Beetle Forecasts

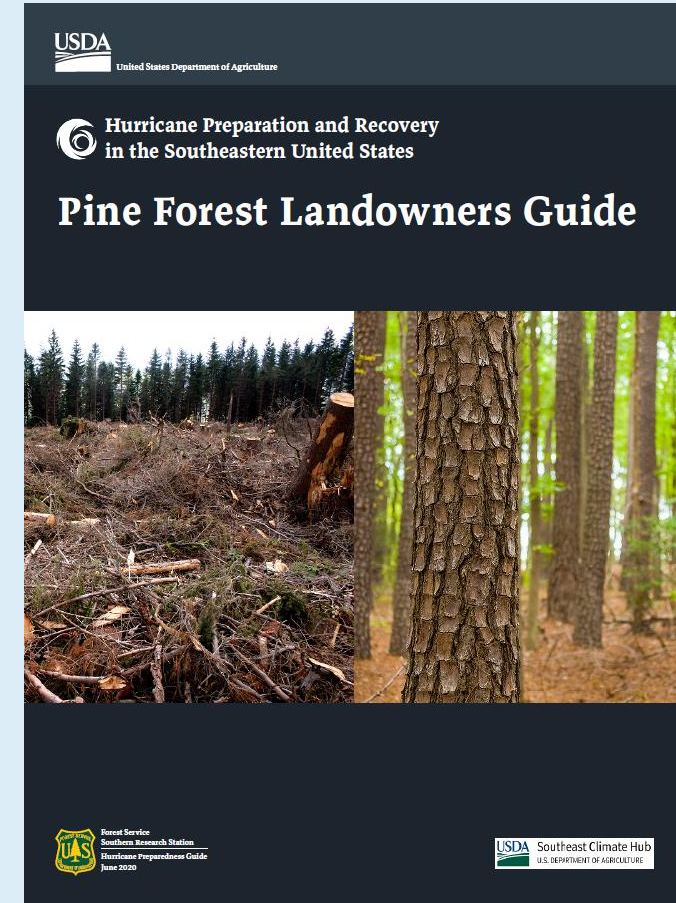
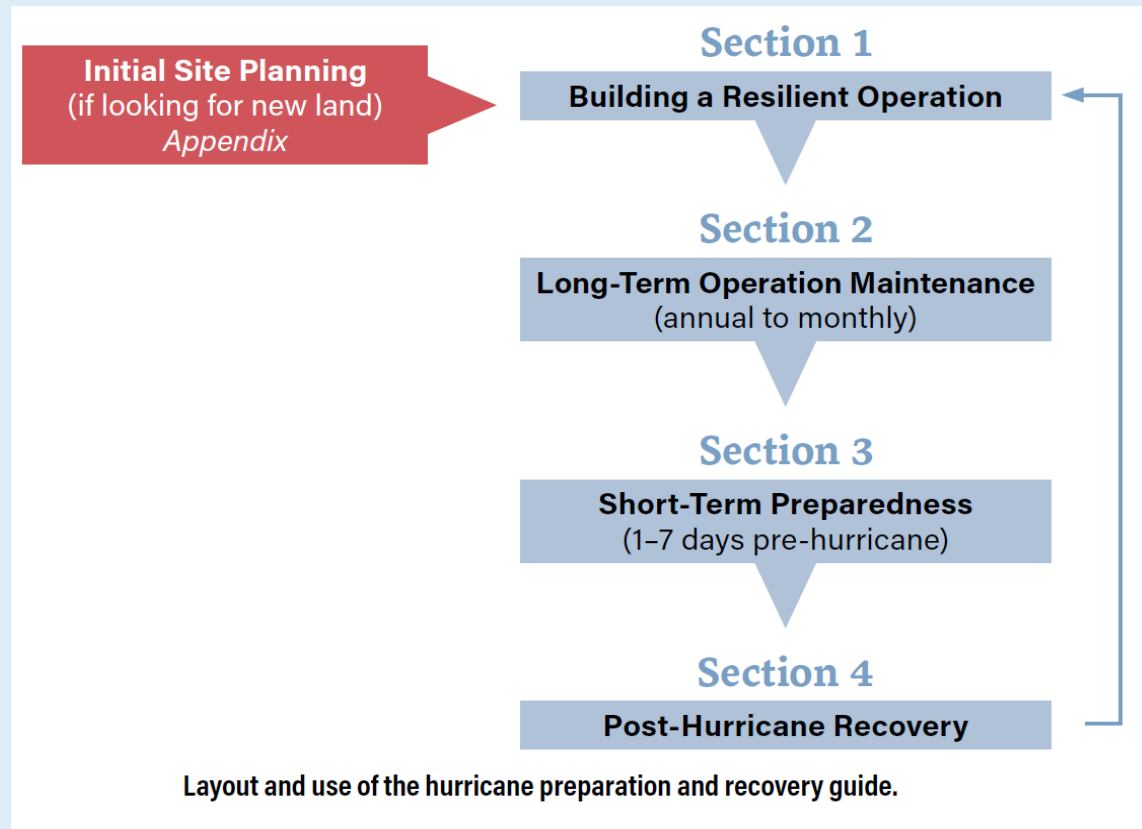


Available in 2025

[spbpredict.com](http://spbpredict.com)

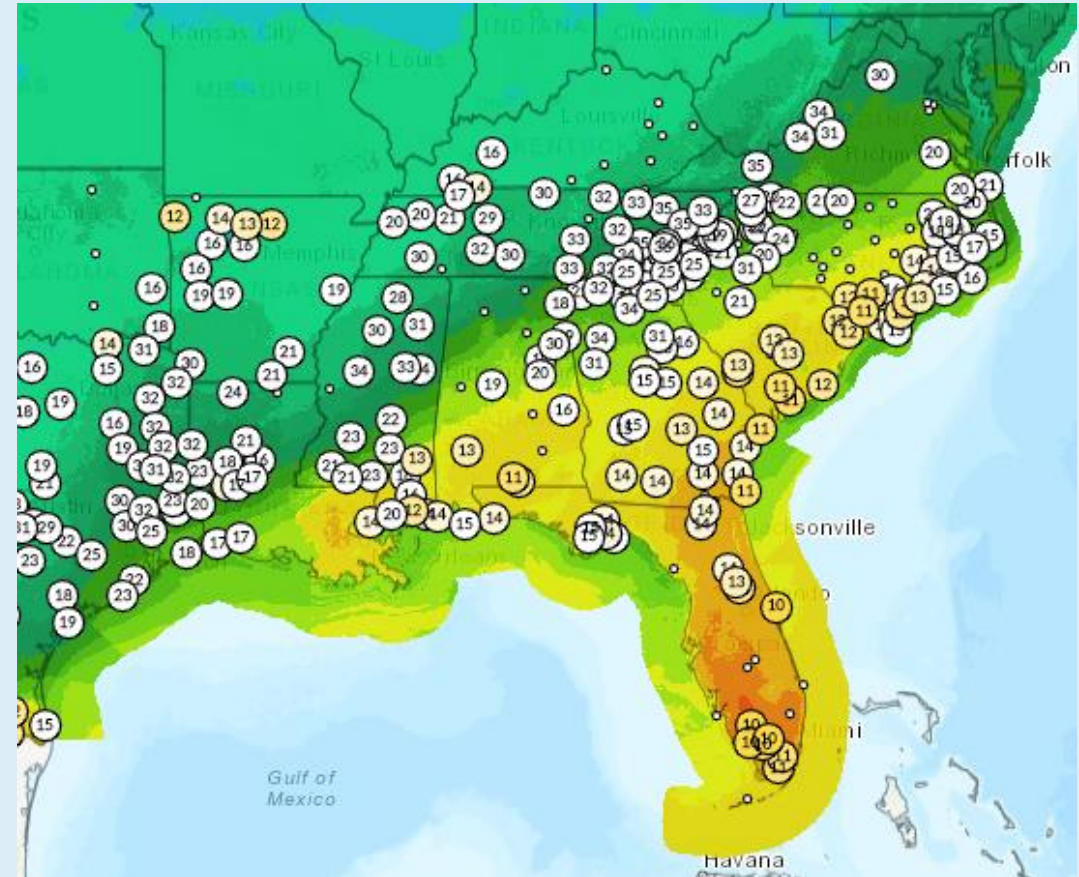
Designed and developed in the DALI Lab with USFS and state partners

# Hurricane Preparation & Recovery



# Fire Weather Intelligence Portal

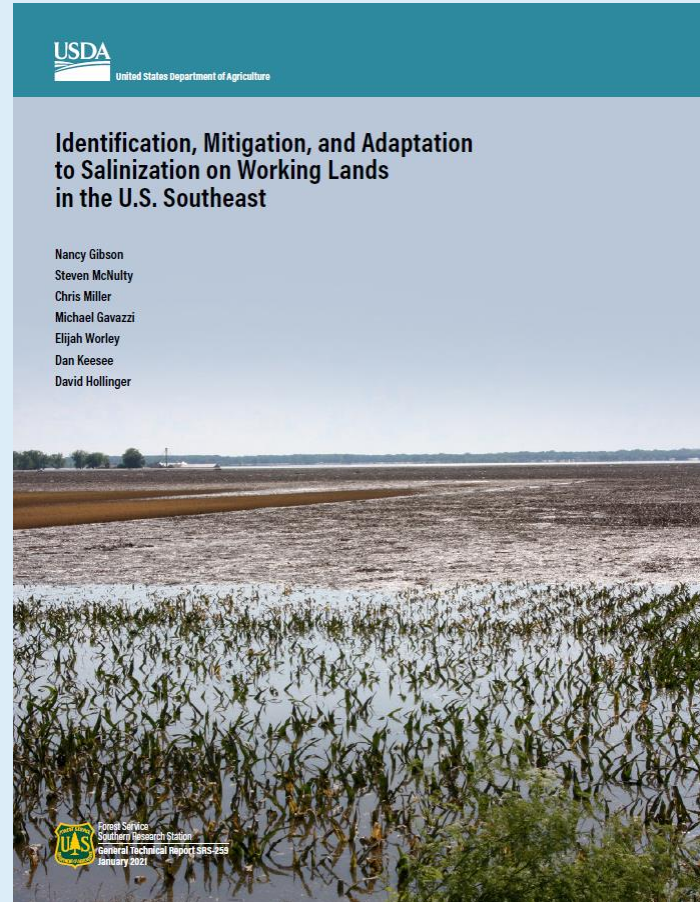
- State Climate Office of NC
- Expand out of NC
- Modified based on stakeholder feedback



<https://products.climate.ncsu.edu/fwip/>

# Soil Salinization Guide

---



# Seedlot Selection Tool

- Local ~~is best~~ might not be best?

Identify suitable seed collection zones  
for your planting site

**OR**

Identify suitable planting sites for your  
seed

- Map “climate analogs” based on  
different climate scenarios,  
timeframes, and ecosystem  
parameters

The screenshot displays the 'Seedlot Selection Tool' interface. The top navigation bar includes 'About', 'Tool', 'Layers', and 'Saved Runs'. The main control panel on the left is divided into four steps:

- 1 Select objective**: Includes buttons for 'Find seedlots' and 'Find planting sites'. A 'Units' dropdown is set to 'Metric'.
- 2 Select planting site location**: Includes a 'Location' field with a description 'Locate your planting site by using the map or entering coordinates.' Below this are input fields for 'Lat' (35.2456) and 'Lon' (-80.0684), and an 'Elevation' field showing '338 ft (103 m)'.
- 3 Select region**: Includes buttons for 'Automatic' and 'Custom'. The 'Region' is set to 'Eastern US'.
- 4 Select climate scenarios**: Includes a dropdown menu for 'Which climate are the seedlots adapted to?' currently set to '1961 - 1990'.

The right side of the interface shows a map of the Eastern United States. A heatmap overlay indicates climate analogs, with a color gradient from green (low similarity) to red (high similarity). A blue location pin is placed on the map, corresponding to the coordinates entered in step 2.

[seedlotselectiontool.org/sst/](https://seedlotselectiontool.org/sst/)

# Take home message

- For working land managers, climate variability is more important than climate change
- The climate is and will always be variable
- Climate variability is increasing and will likely continue to increase
- **Increasing climate variability is a problem that can be addressed, by organizations and land managers**
- Check the Climate Hub for resources and tools to make informed decisions

Thank you!

---

Questions?

[Michelle.Thompson@usda.gov](mailto:Michelle.Thompson@usda.gov)