USDA Northern Forests Climate Hub
U.S. DEPARTMENT OF AGRICULTURE

Mid-Atlantic Climate Change Vulnerability Assessment: Climate Change Effects on Forest Ecosystems

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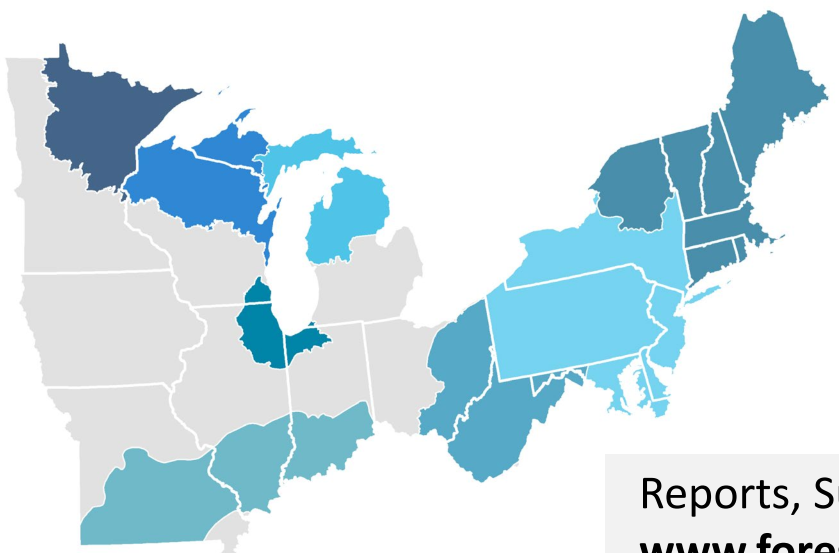
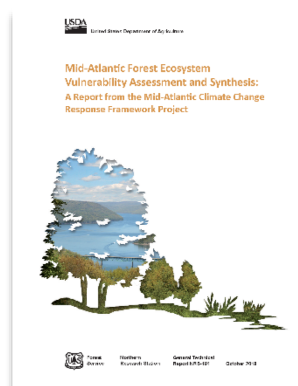
Climate Change and Pennsylvania's Forests
State College, PA

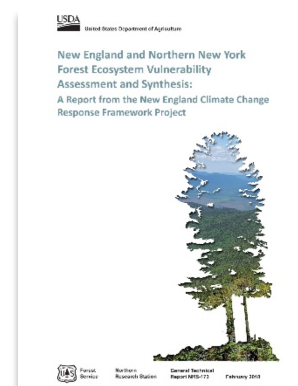
NIACS Northern Institute of Applied Climate Science

Vulnerability Assessment

- Series of reports for **natural resource professionals**
- Focus on **tree species and forest ecosystems**
- Examine a **range** of future climates
- Evaluate **key ecosystem vulnerabilities** to climate change
- Does **not make recommendations** or assess vulnerability to changes in mgmt., land use, policy





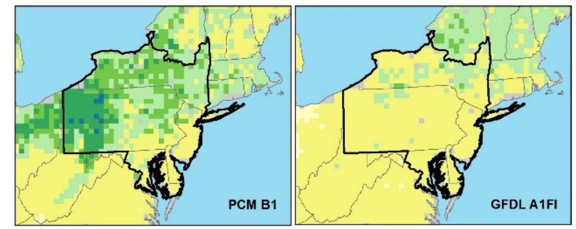


Reports, Summaries and StoryMaps:
www.forestadaptation.org/vulnerability-assessment

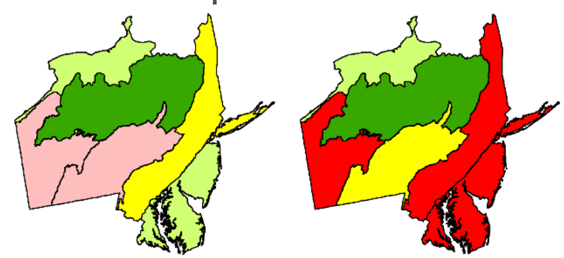
Vulnerability Assessment

- Current Forest Condition
- Observed Climate Change
- Future Climate Change
- Climate Change Impacts on Forests
- Forest Ecosystem Vulnerability
- Implications for Forest Management

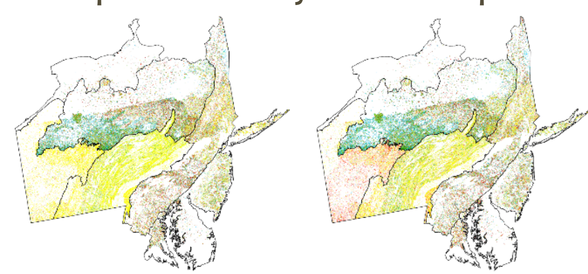
Climate Change Tree Atlas: suitable habitat



LINKAGES: species establishment



LANDIS: productivity and composition



https://tinyurl.com/EVAS-MAR

Observed Climate Trends

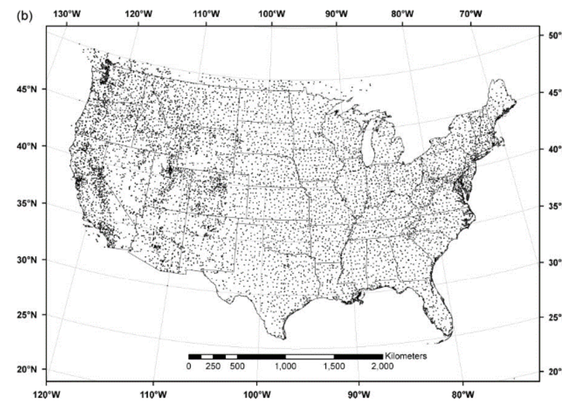
ClimateWizardcustom.org

- PRISM (Parameter-elevation Regressions on Independent Slopes Model)
- 2.5-mile grid

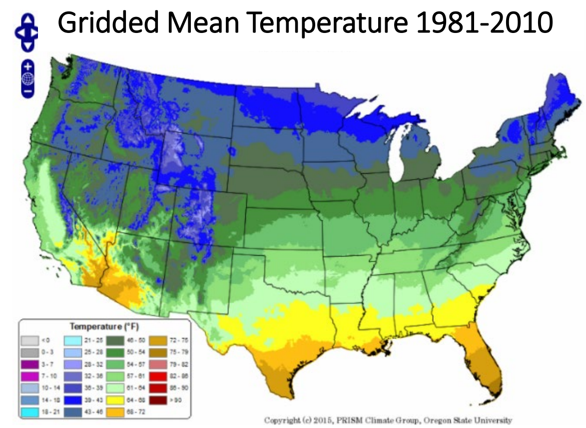
1901 to 2011 departure analysis

- Mean, Min, Max Temperatures
- Precipitation
- Yearly, seasonally

Weather Stations



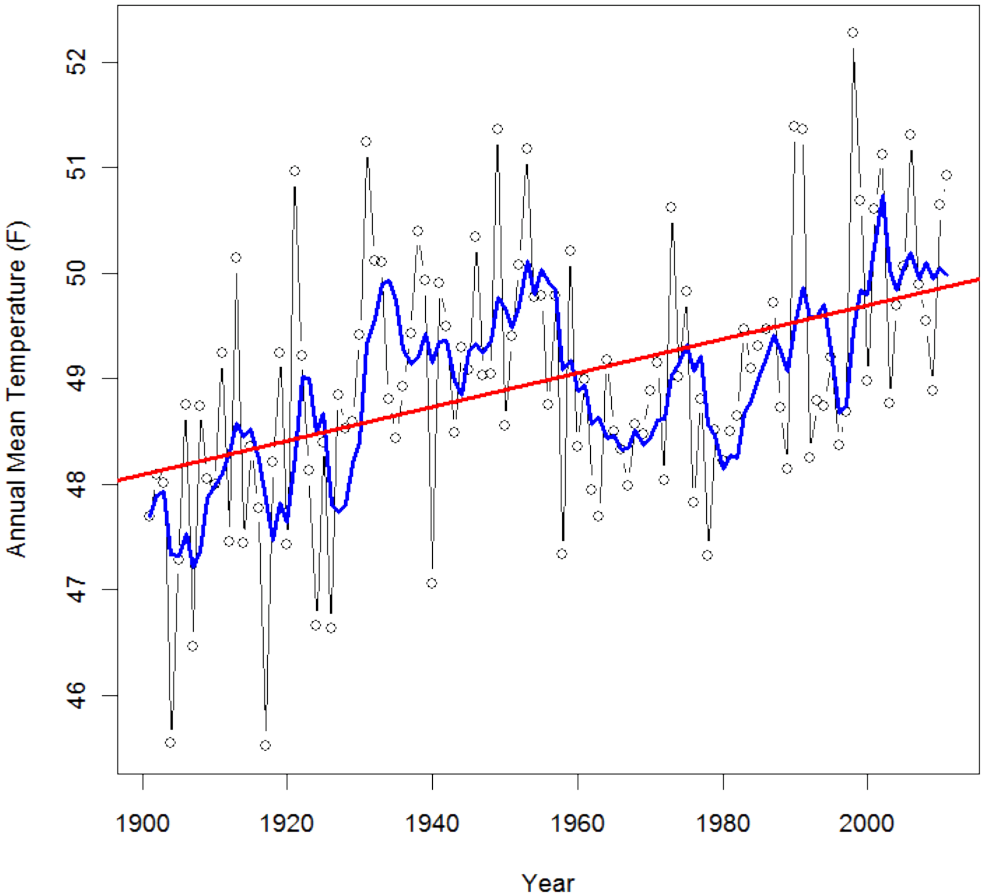
Gridded Mean Temperature 1981-2010



(ClimateWizard 2012, Girvetz et al. 2009, Gibson et al. 2002)

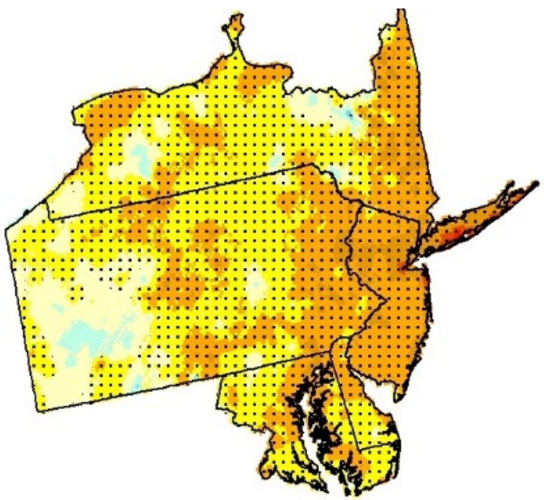
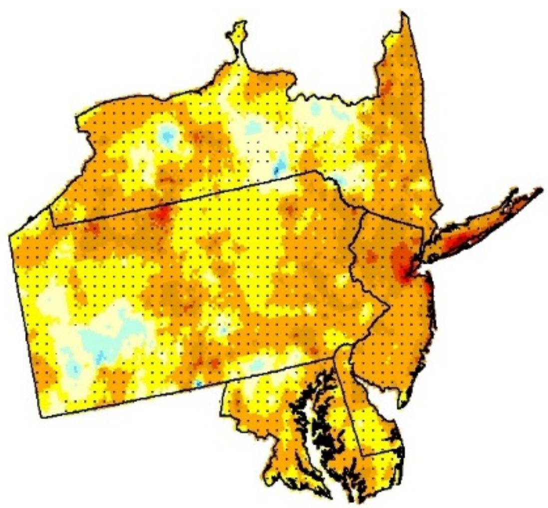
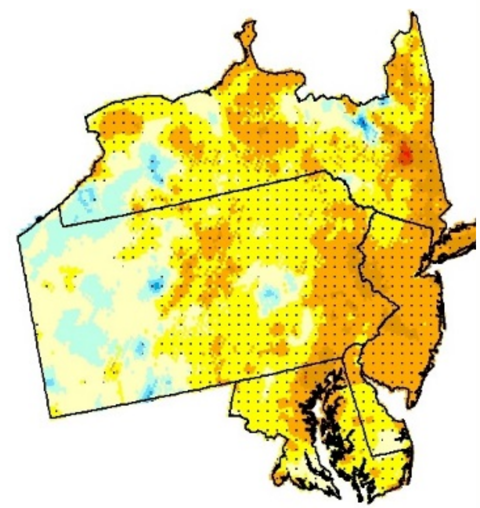
Observed Annual Temperature

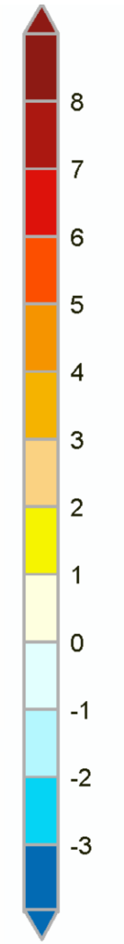
- 0.016 °F per year = 1.8 °F
- Substantial inter-annual fluctuation



ClimateWizard 2012

Observed Annual Temperatures

Mean	Minimum	Maximum
		
1.8 °F	2.1 °F	1.5 °F

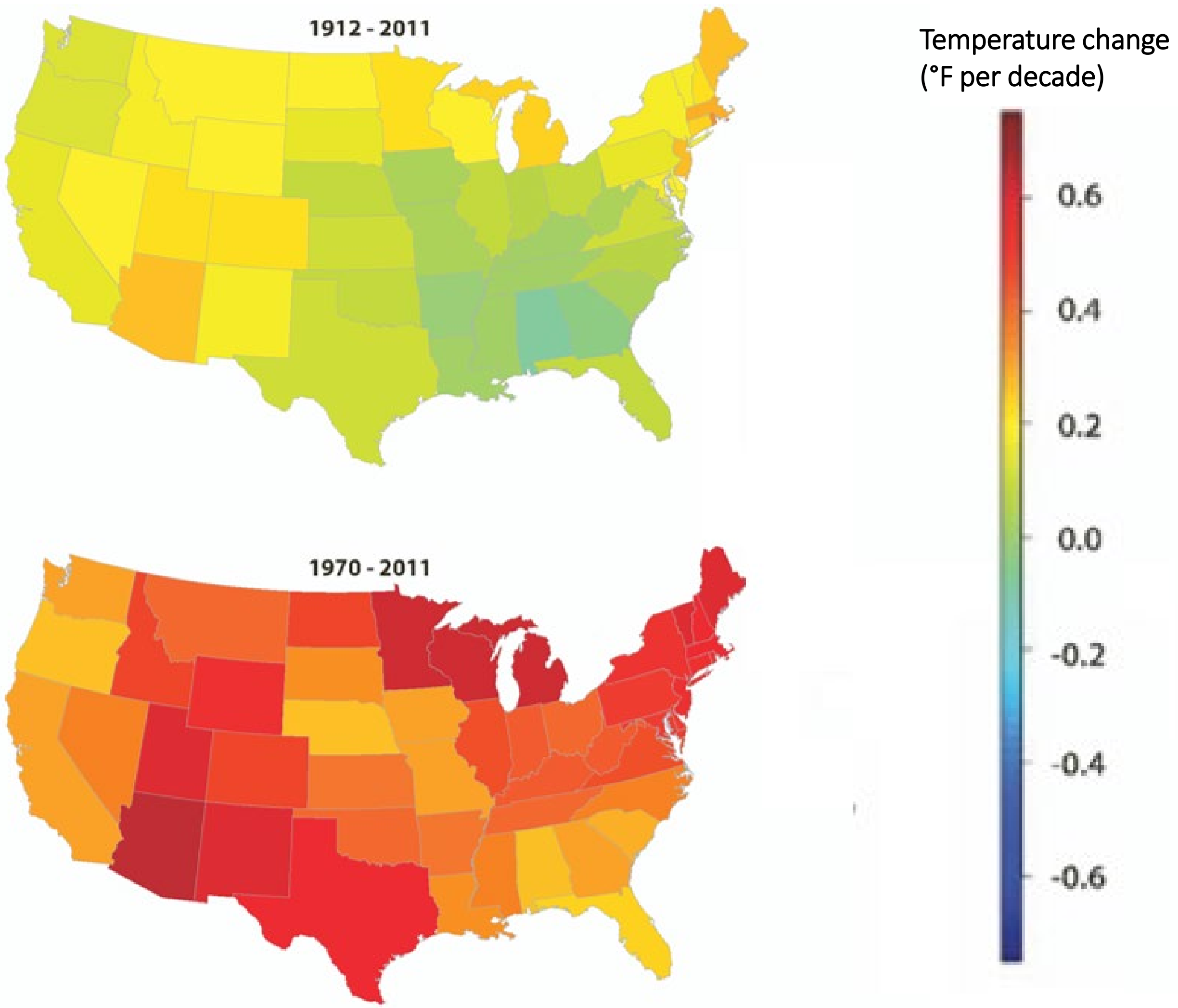


Statistically significant trend

P-value < 0.1

ClimateWizard 2012

Shifting rates of change

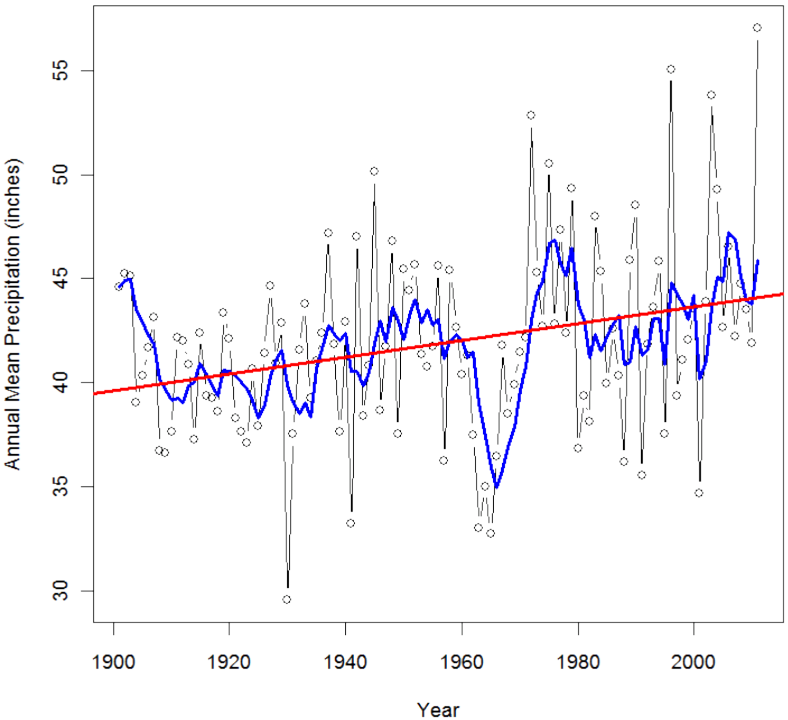


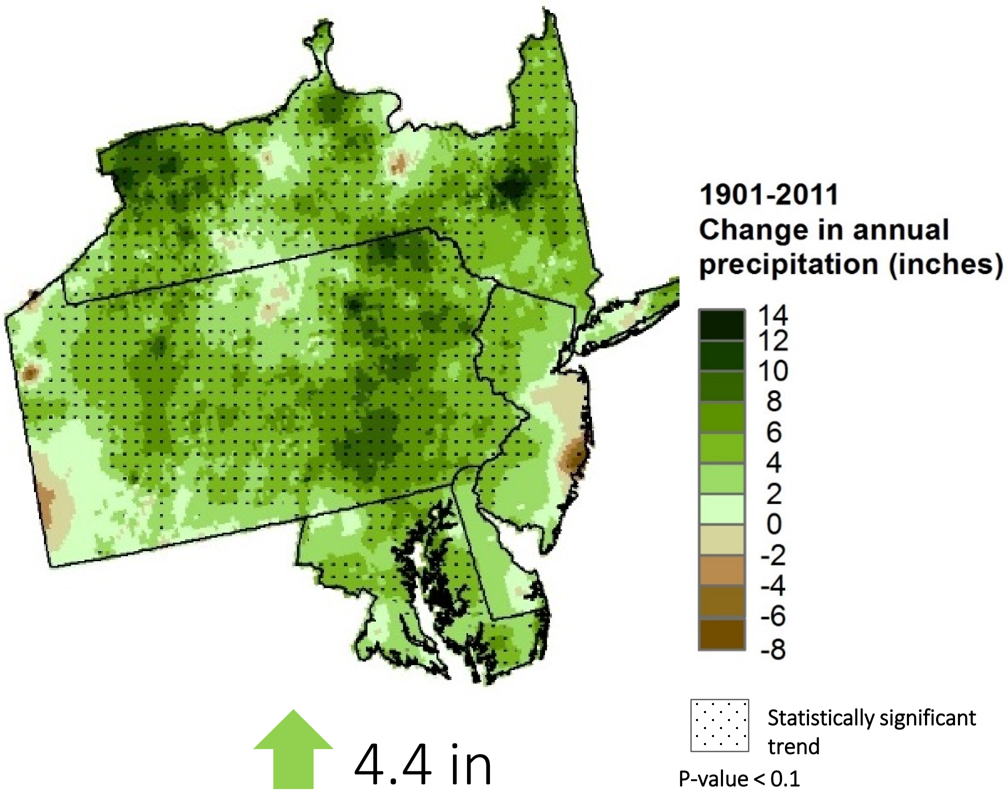
www.climatecentral.org/news/the-heat-is-on/

Observed Annual Precipitation

0.04 inches/year = 4.4 inches = 11% increase

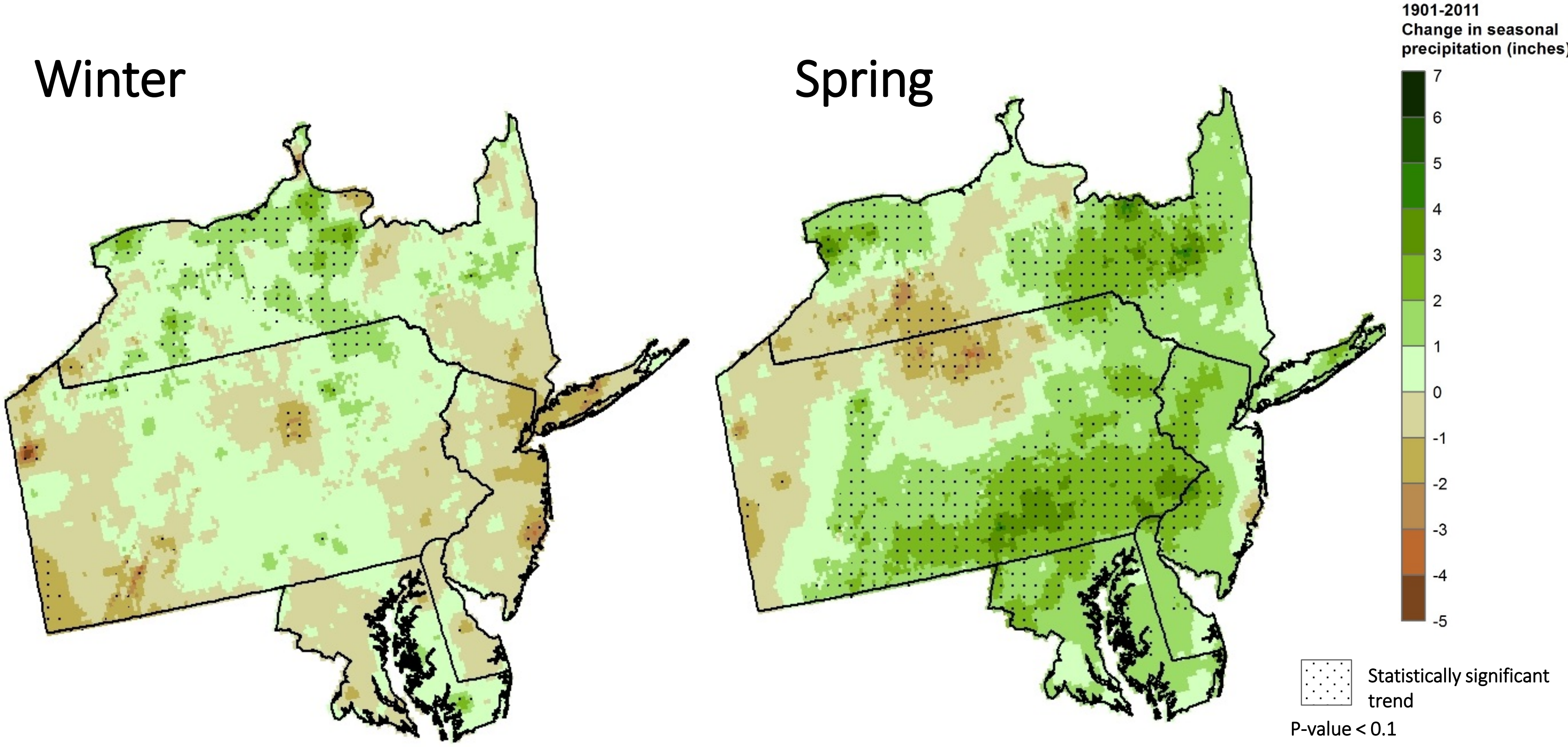
Substantial inter-annual fluctuation





ClimateWizard 2012

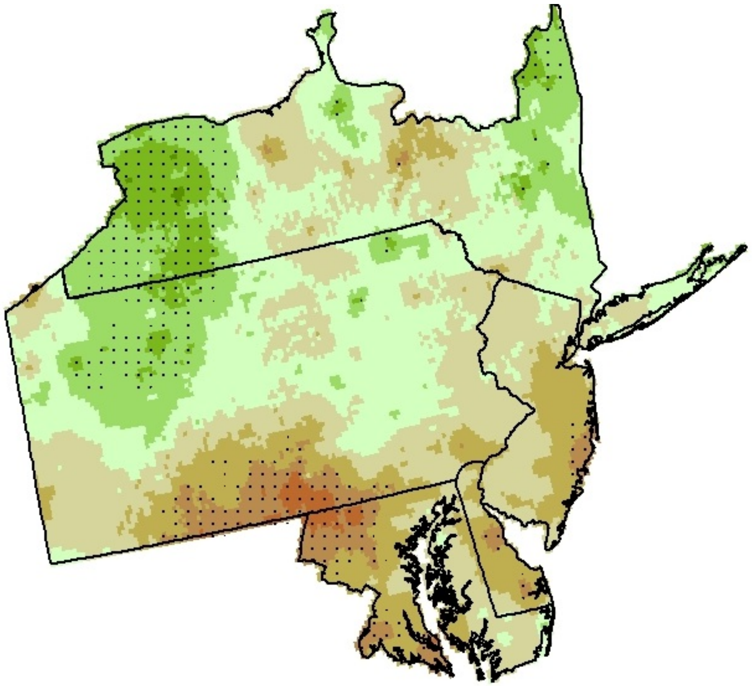
Observed Seasonal Trends



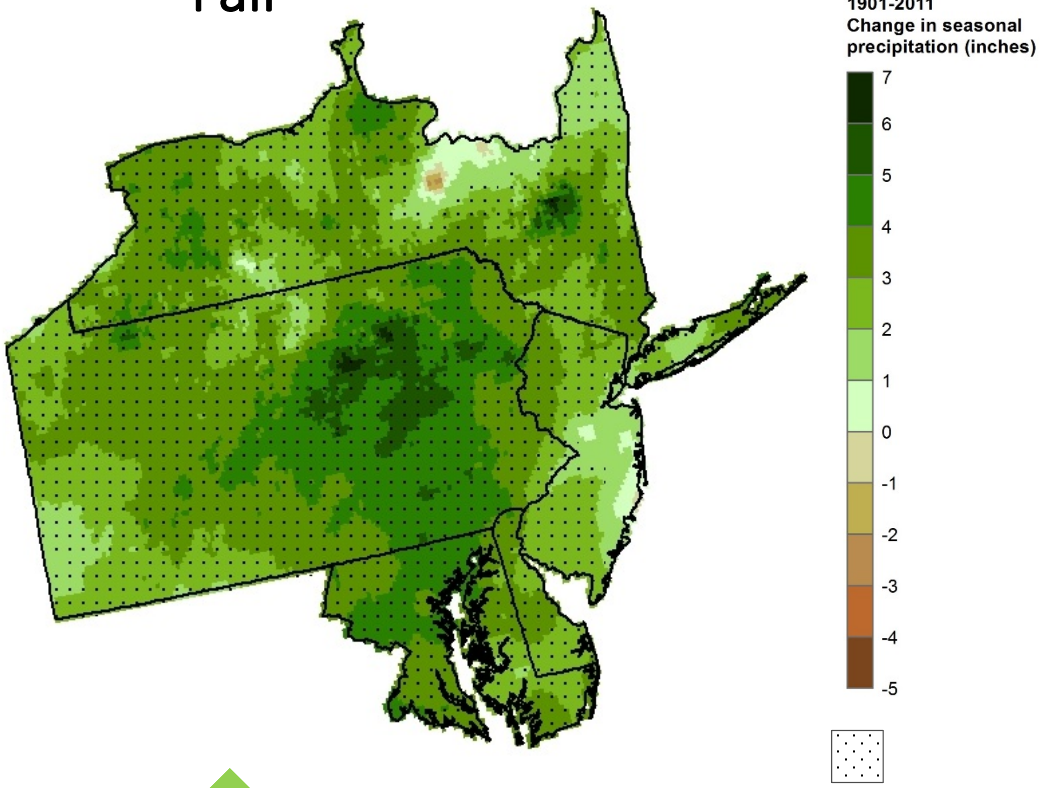
ClimateWizard 2012

Observed Seasonal Trends

Summer



Fall

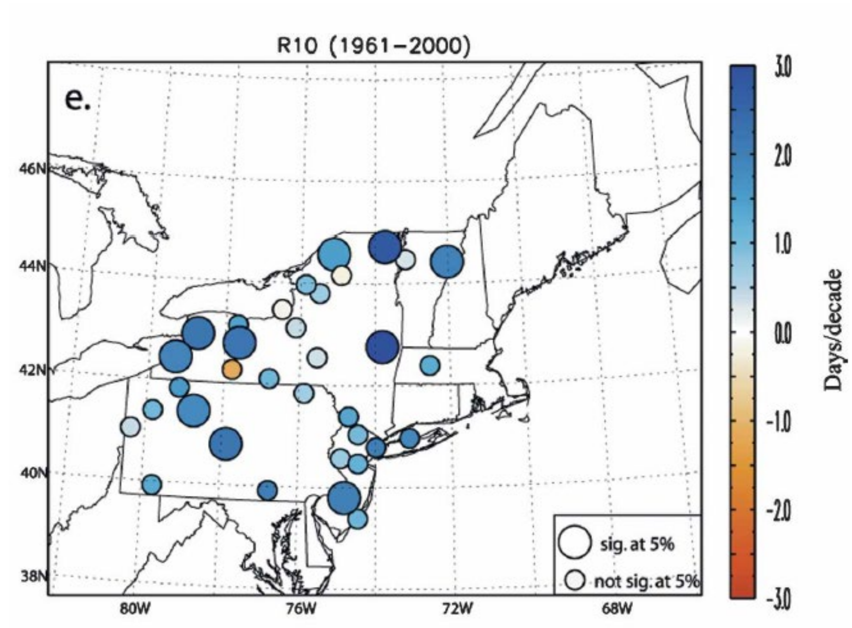


3.2 inches

ClimateWizard 2012

Additional Observations

- More days with heavy precipitation >1 inch (1926 to 2000)
- More very wet days (exceeding 95th percentile) (1961 to 2000)
- Less consecutive dry days in some areas (1961 to 2000)
- Occurrence of 1-inch events correlated with temperature (1948 to 2007)

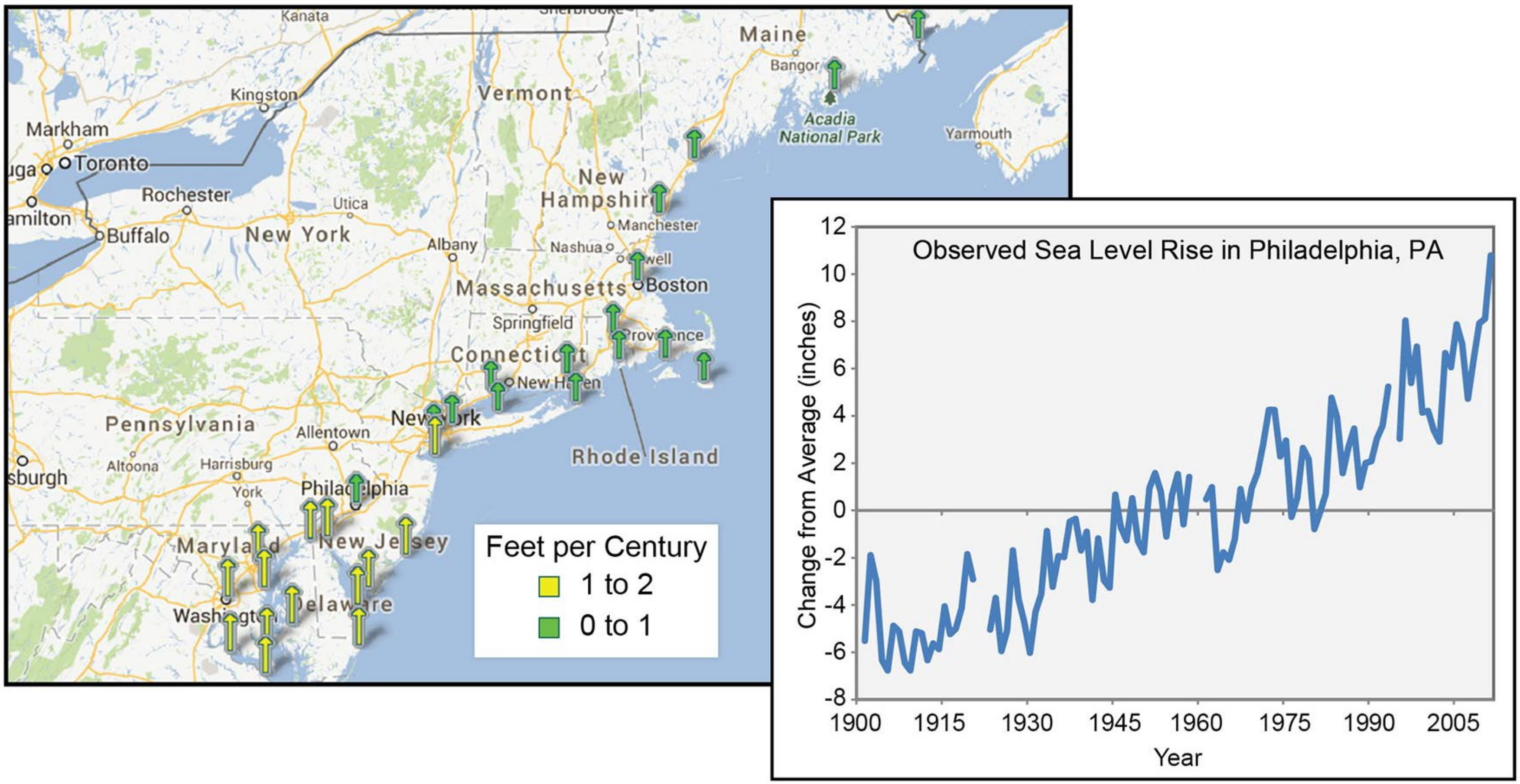


Griffiths & Bradley 2007; Spierre & Wake 2010

Sea-level Rise

1901 to 2012

From Cape Hatteras to Boston, sea-level rates are 3 to 4 times larger than global average

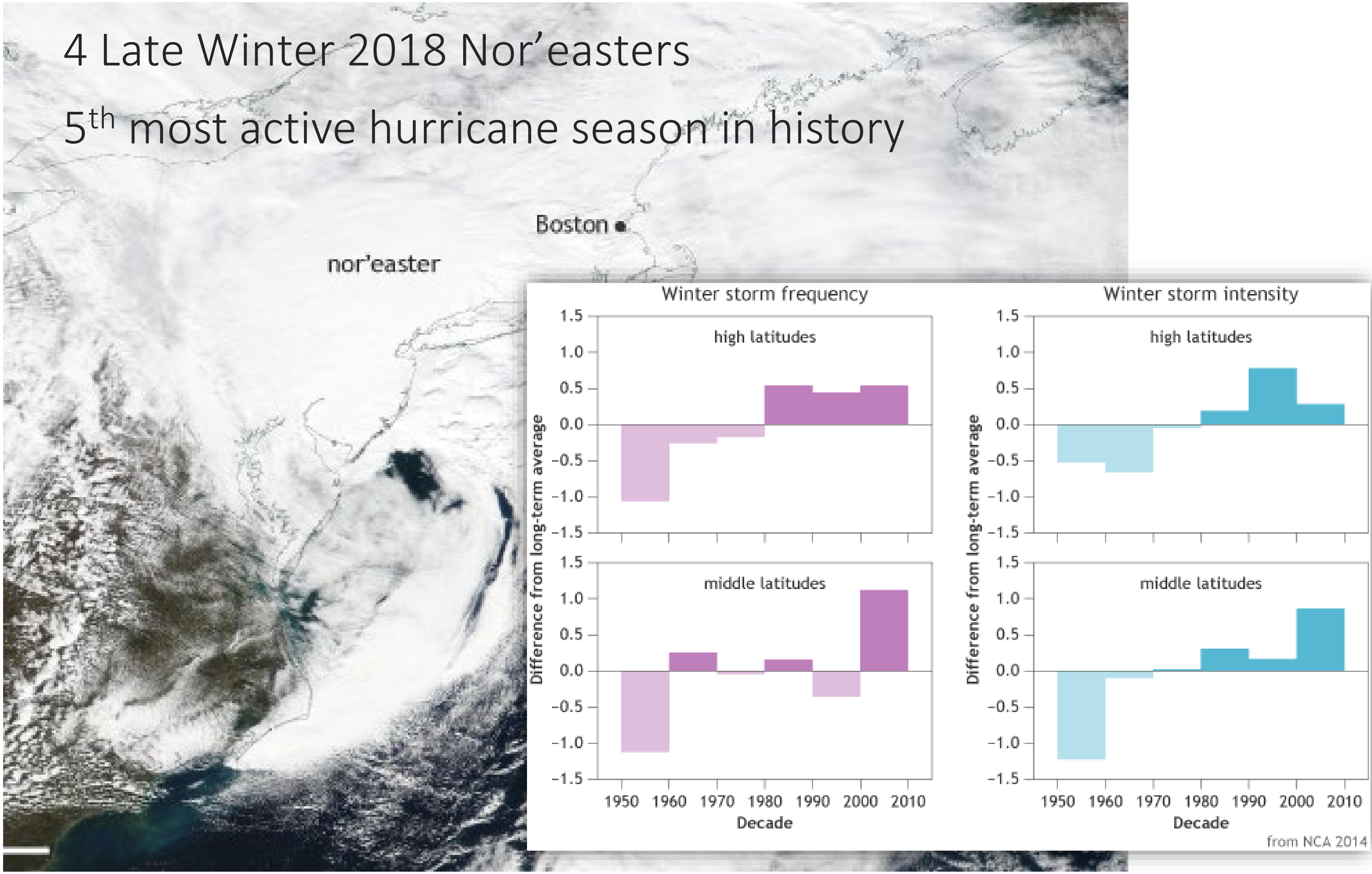


NOAA 2013

Regionally Observed Extremes

4 Late Winter 2018 Nor'easters

5th most active hurricane season in history



NOAA 2018

Future Modeling Introduction

We used climate data that was downscaled by ATMOS/K.Hayhoe

Three time periods

- 2010 to 2039
- 2040 to 2069
- 2070 to 2099

7.5-mile grid

Annual and Seasonal changes

Temperature: Mean, Minimum, Maximum

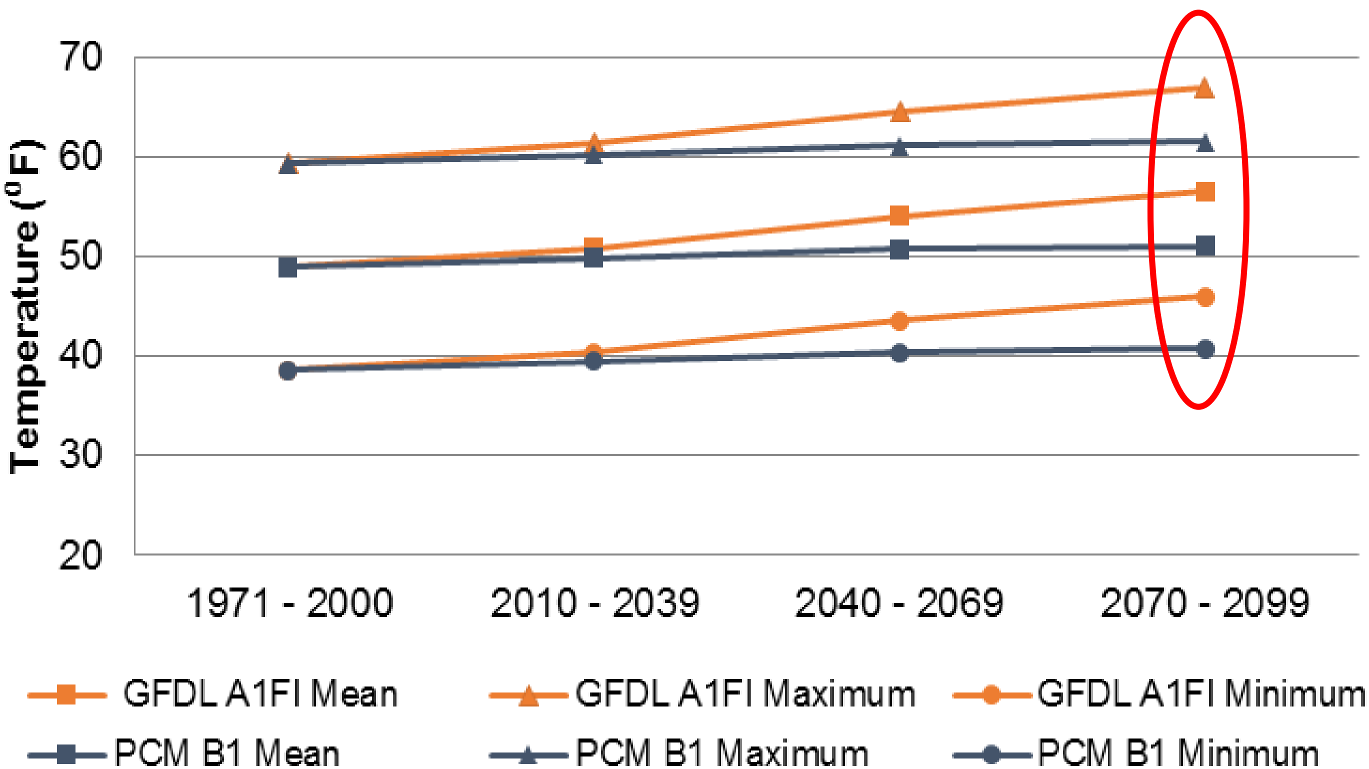
Precipitation

Stoner et al. 2012

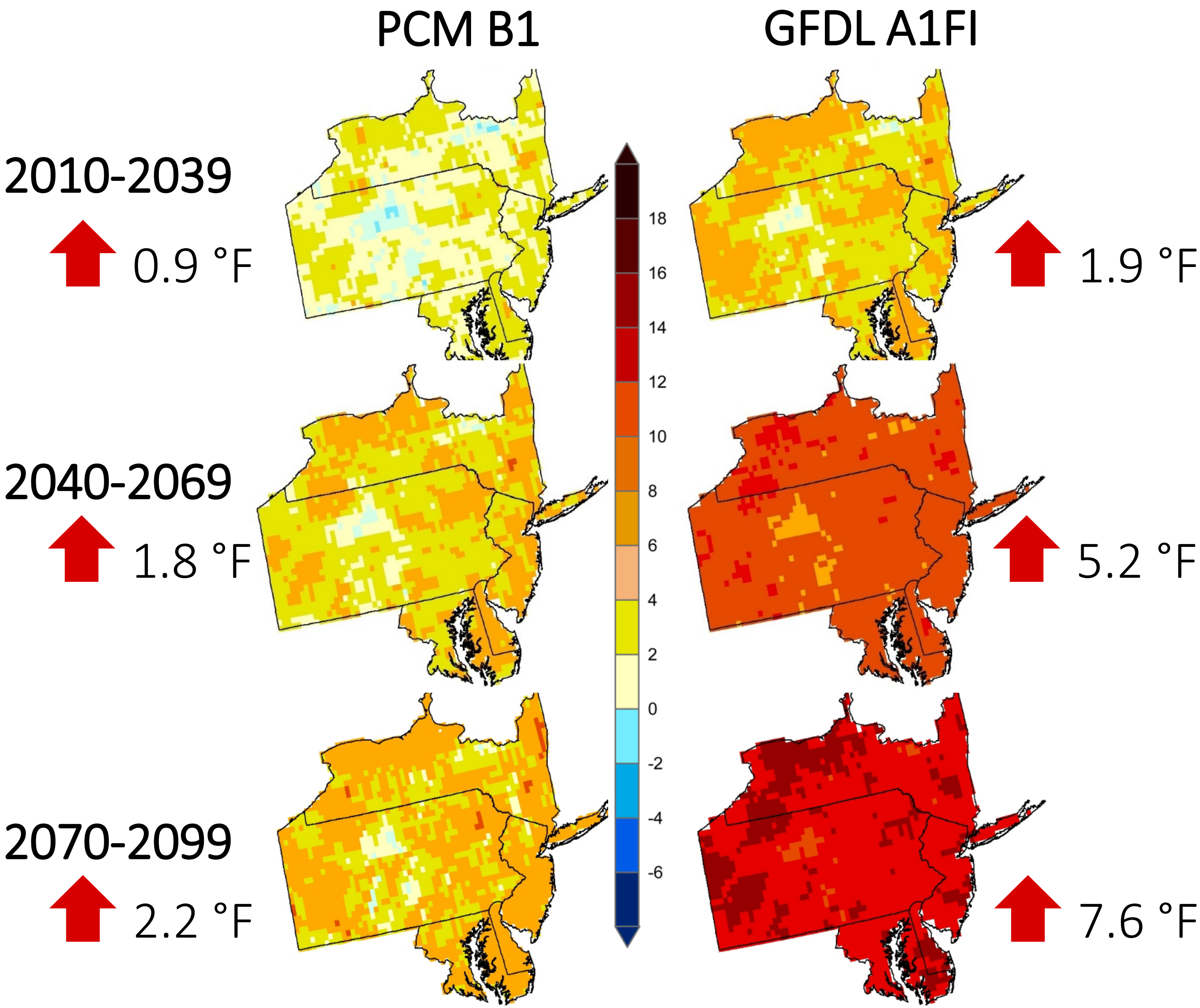
Projected Annual Temperature

PCM B1 and GFDL A1FI diverge more as time progresses

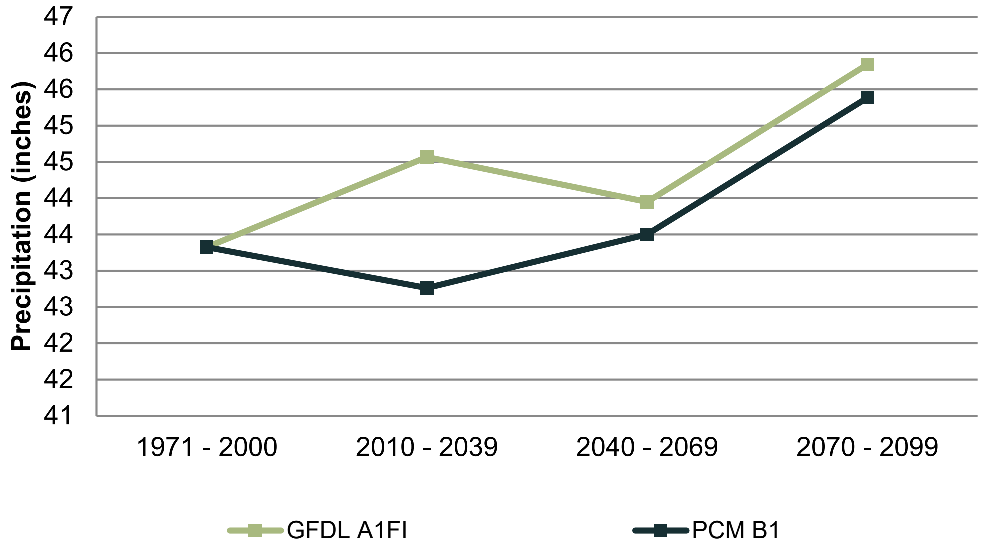
Similar patterns across seasons



Projected Changes in Annual Temperature

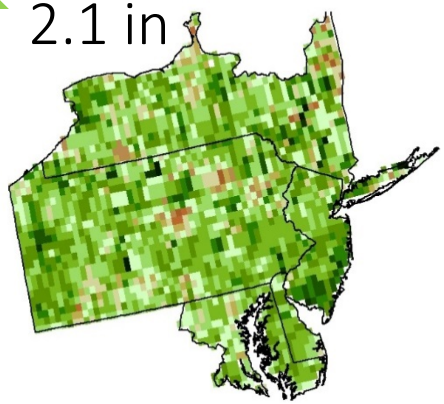


Projected Annual Precipitation



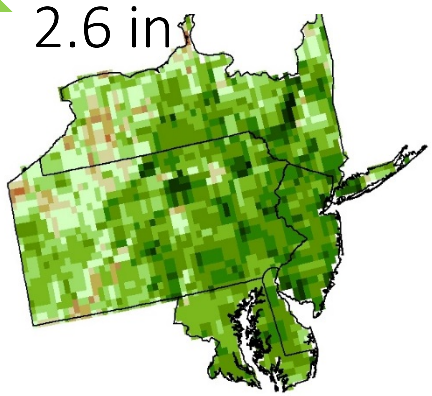
PCM B1: 2070-2099

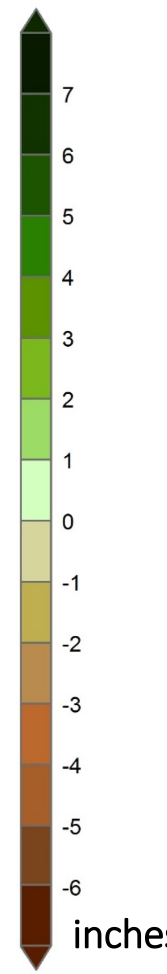
2.1 in



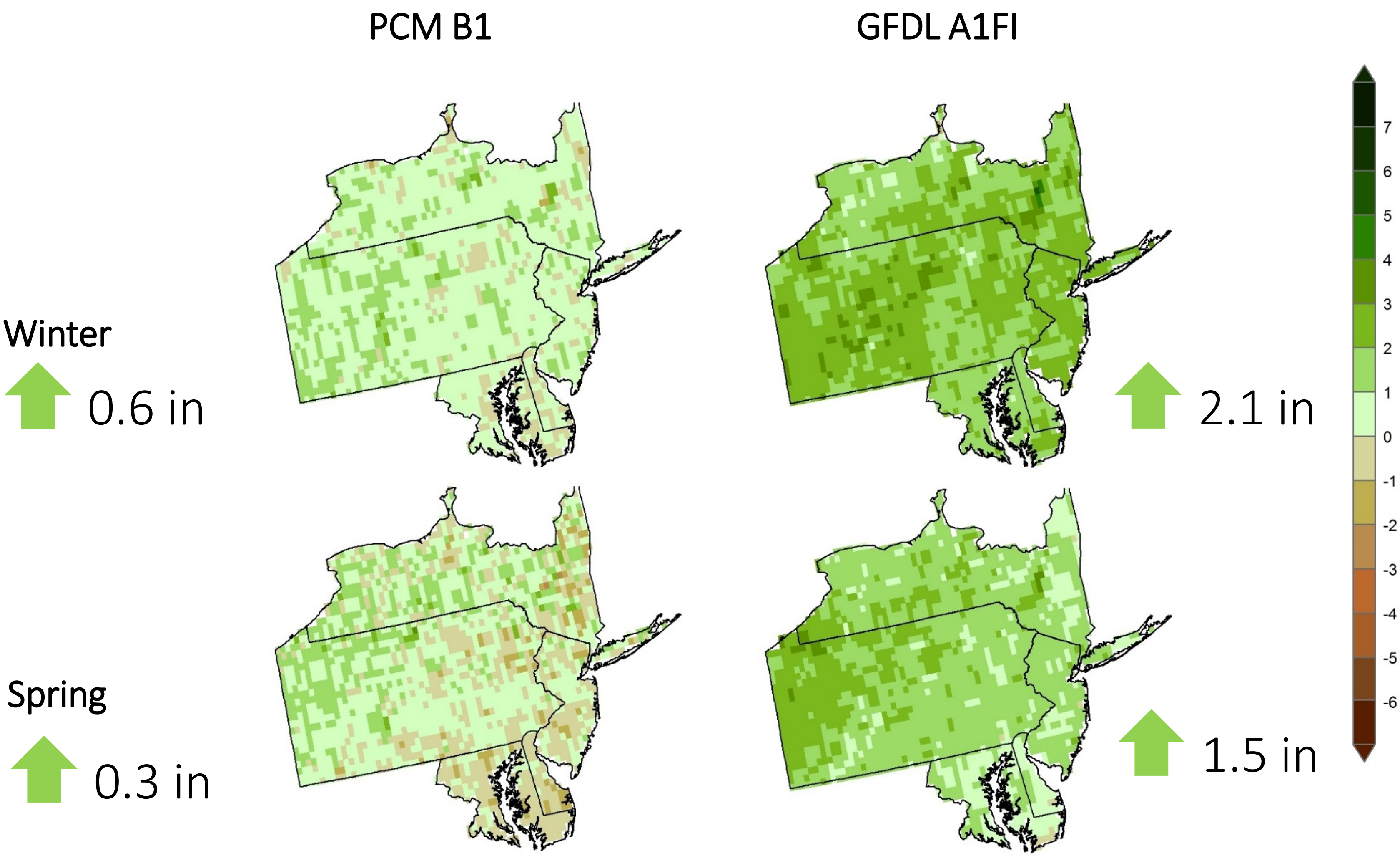
GFDL A1FI: 2070-2099

2.6 in

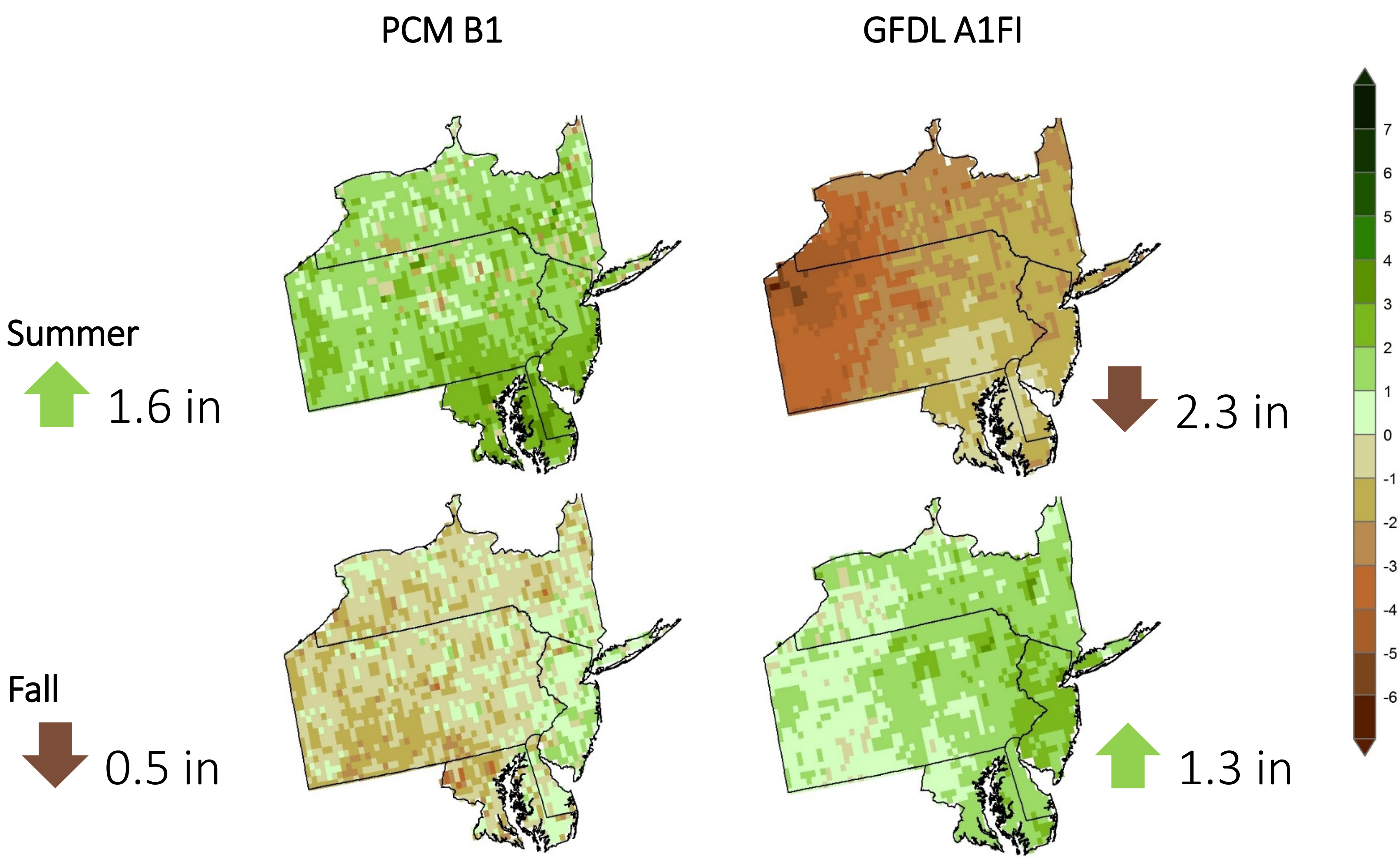




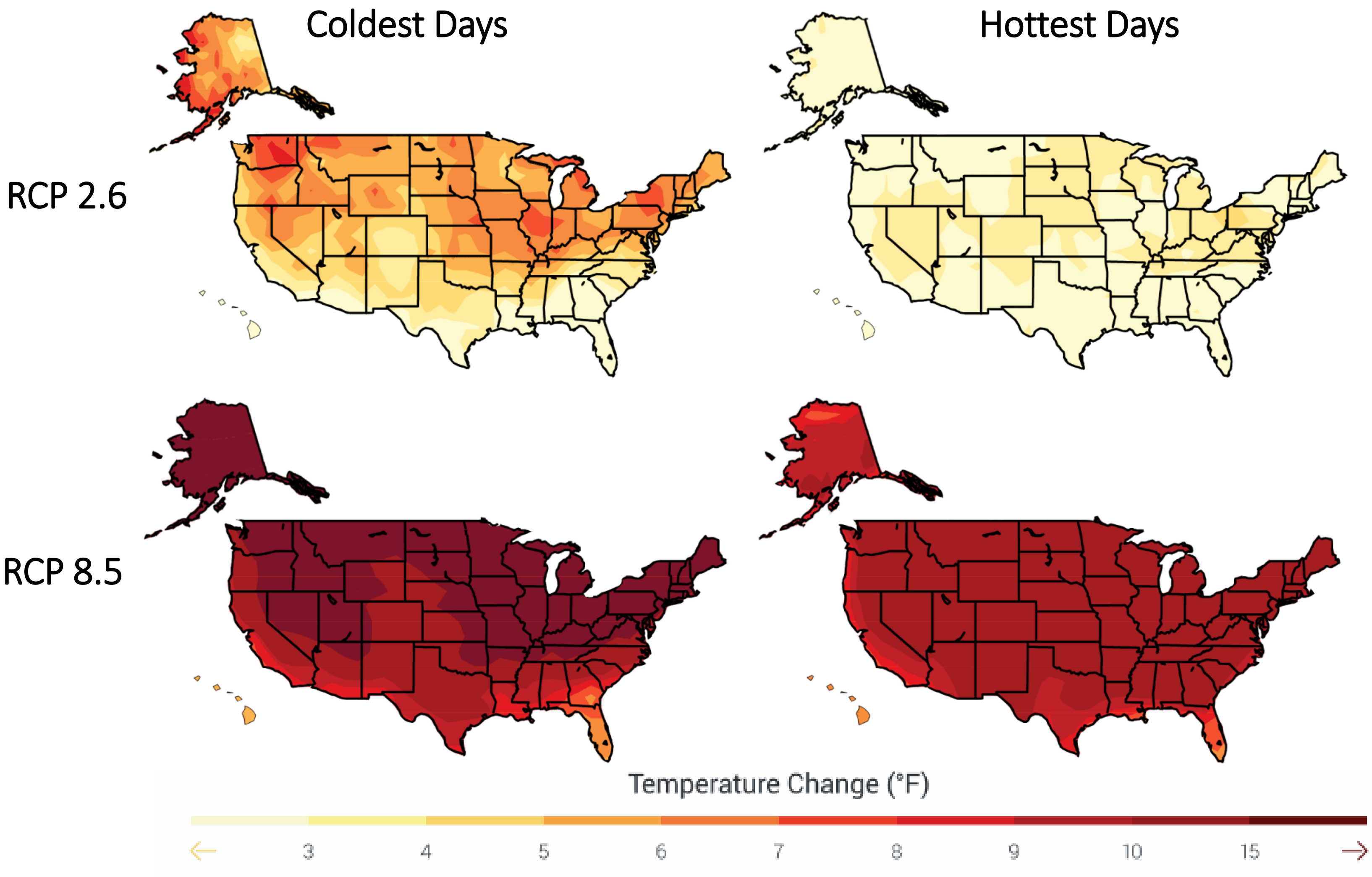
Seasonal Precipitation 2070-2099



Seasonal Precipitation 2070-2099



Extreme Temperatures



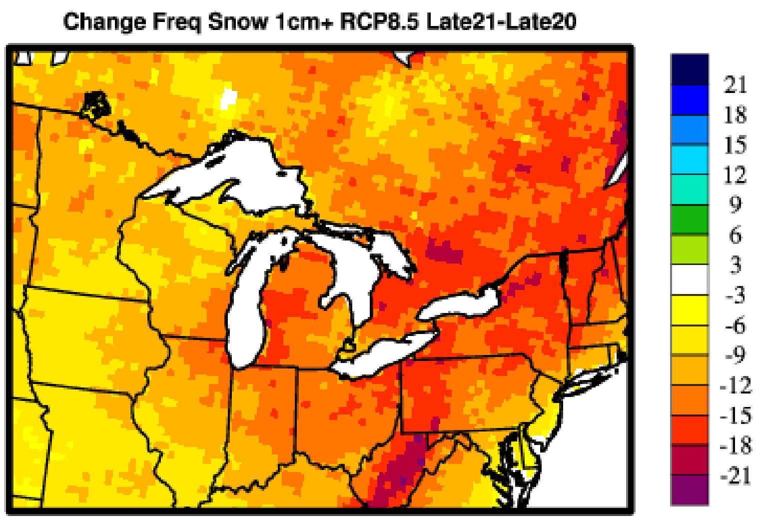
NCA 2014

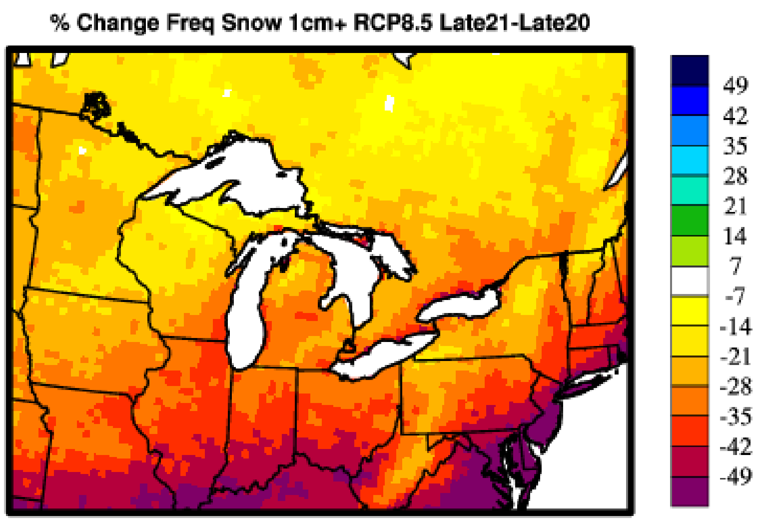
What does this mean for forests?

Shorter Winter (Less Snow)

Projected decreases in snow fall, cover, and depth

- 20-50% decrease in Days with Snowfall
- 20-50% decrease in amount
- Greatest loss in December/January





https://nelson.wisc.edu/ccr/resources/dynamical-downscaling/index.php

Shorter Winter (Less Snow)

Projected decreases in snow fall, cover, and depth

- 20-50% decreases in snowfall
- Greatest loss in December/January

Decreased snowpack

- Increased soil freeze-thaw cycles can damage roots and alter soil processes

What may be at risk: The ability to do winter timber harvest when it is preferred to prevent damage to forest soils and residual forest; tree species sensitive to soil freeze-thaw

Shorter Winter (More Rain)

More rain

- Warmer temperatures
- Increased precipitation
- Extreme rain events

Earlier peak stream flows

- Flashiness and episodic high flows may increase

Dale et al 2001, Huntingon 2004, Parmesan 2006

Shorter Winter (More Rain)

More rain

- Warmer temperatures
- Increased precipitation
- Extreme rain events

Earlier peak stream flows

- Flashiness and episodic high flows may increase

What may be at risk: Increased erosion/sedimentation on susceptible sites; culvert washouts and road damage from extreme events; aquatic habitats and species

Longer Growing Season

Warmer temps result in longer growing seasons

- Evidence of phenological shifts
- Projected to increase 3-7+ more weeks

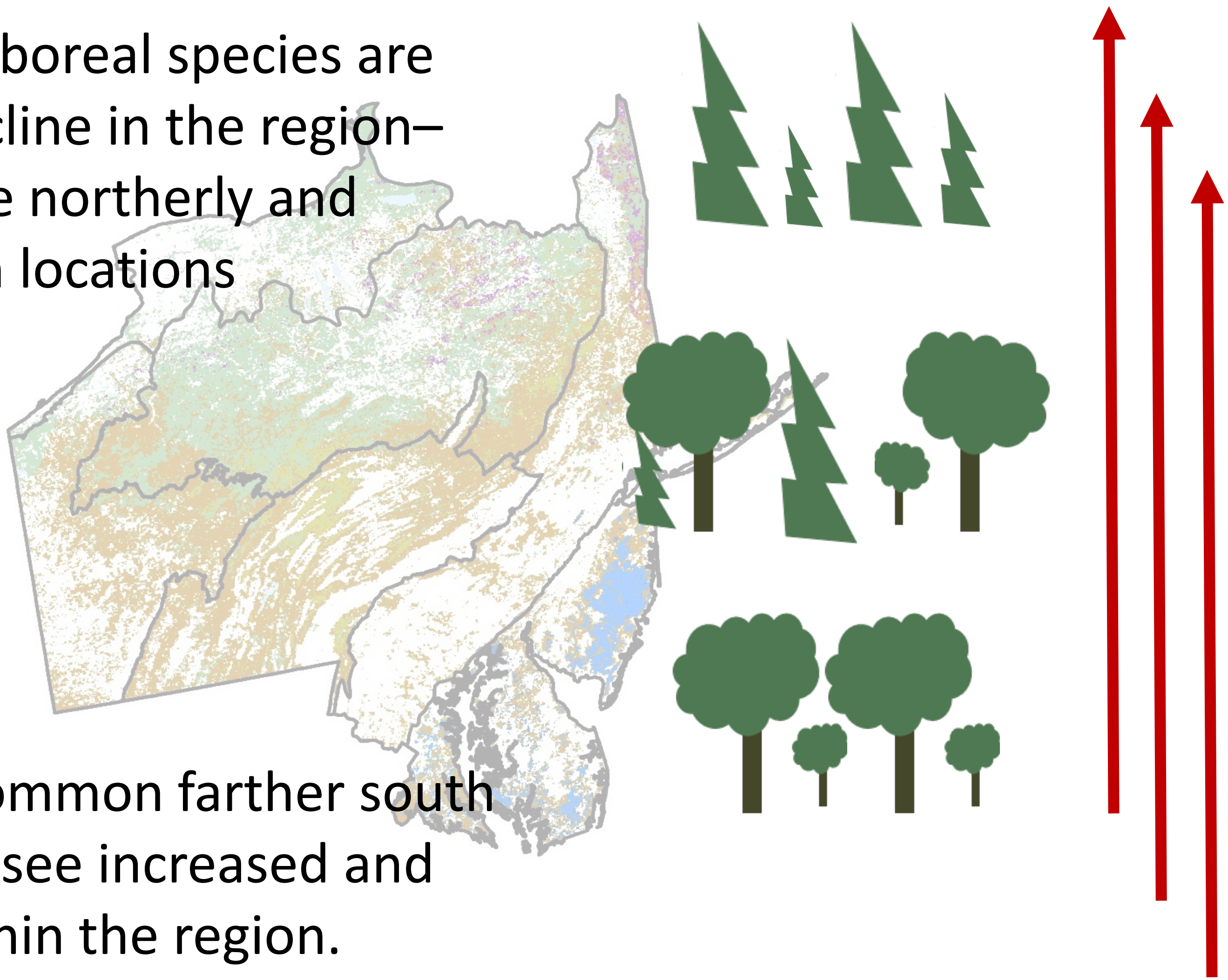
Longer period for plant growth

What may be at risk: Early bud break and frost damage from increased freeze-thaw cycles

Ainsworth and Long 2005, Ainsworth and Rogers 2007, Norbyand Zak 2011

Changes in Forest Composition

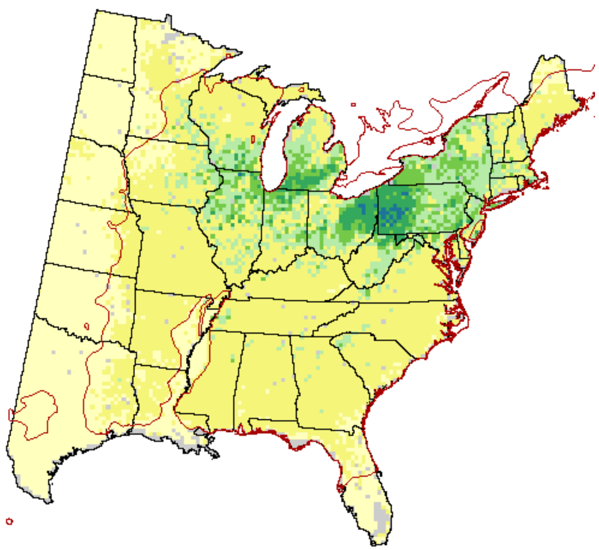
Many northern/boreal species are projected to decline in the region–contract to more northerly and higher-elevation locations



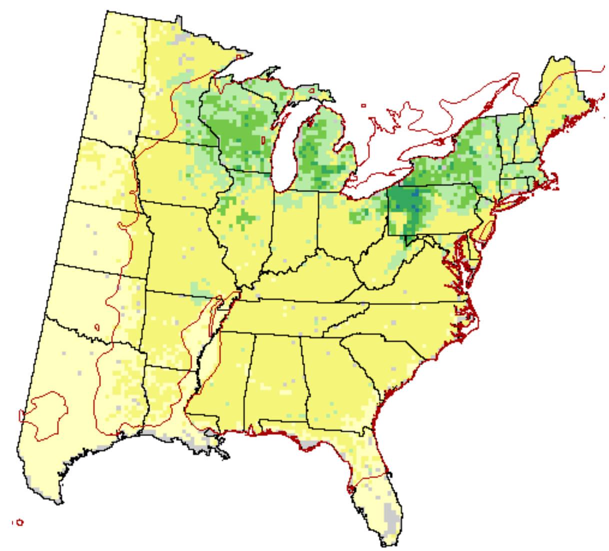
Many species common farther south are expected to see increased and new habitat within the region.

Changes in Forest Composition

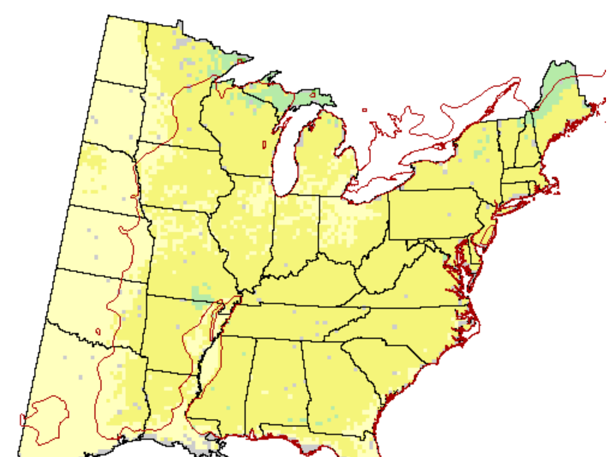
Current Habitat

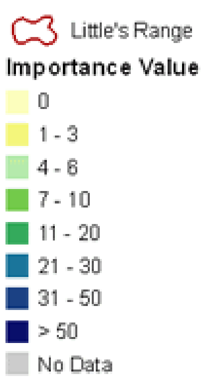


Low Emissions



High Emissions





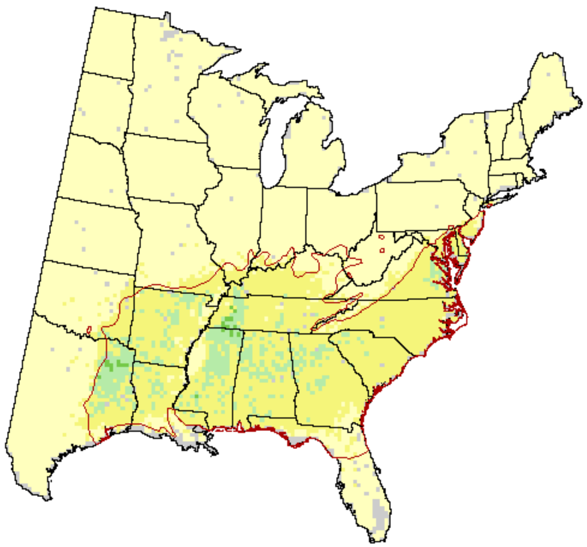
Black Cherry: Decline

2070-2099

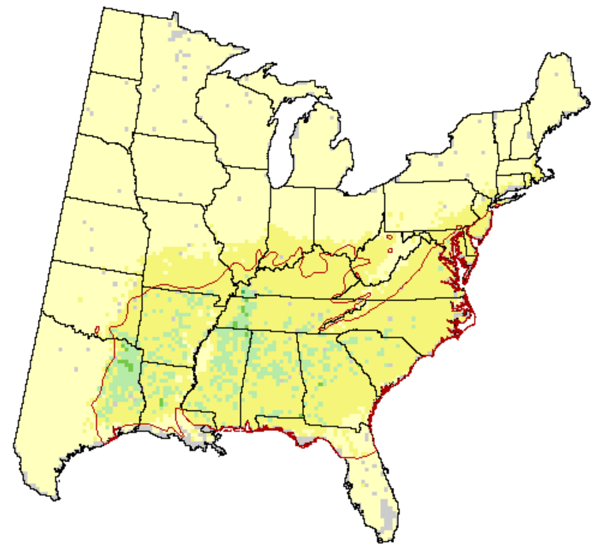
fs.fed.us/nrs/atlas

Changes in Forest Composition

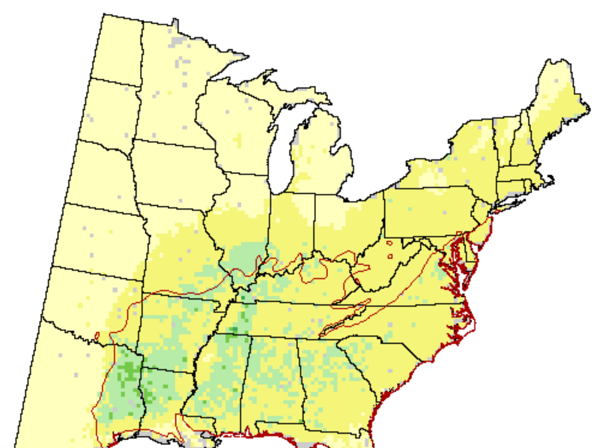
Current Habitat

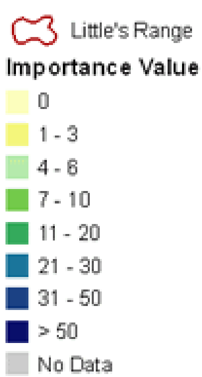


Low Emissions



High Emissions





Southern Red Oak: Increase

2070-2099

fs.fed.us/nrs/atlas

Changes in Forest Composition

CLIMATE CHANGE PROJECTIONS FOR INDIVIDUAL TREE SPECIES

MID-ATLANTIC REGION

The region's forests will be affected by a changing climate during this century. A team of forest managers and researchers created an assessment that describes the vulnerability of forests in the Mid-Atlantic region (Butler-Leopold et al. in review). This report includes information on the current landscape, observed climate trends, and a range of projected future climates. It also describes many potential climate change impacts to forests and summarizes key vulnerabilities for major forest types. This handout is summarized from the full assessment.

TREE SPECIES INFORMATION:
This assessment uses two climate scenarios to "bracket" a range of possible futures. These future climate projections were used with two forest impact models (Tree Atlas and LANDIS) to provide information about how individual tree species may respond to a changing climate. More information on the climate and forest impact models can be found in the assessment. Results for "low" and "high" climate scenarios can be compared on page 2 of this handout.

Remember that models are just tools, and they're not perfect. Model projections don't account for some factors that could be modified by climate change, like droughts, wildfire activity, and invasive species. If a species is rare or confined to a small area, Tree Atlas results may be less reliable. These factors, and others, could cause a particular species to perform better or worse than a model projects. Human choices will also continue to influence forest distribution, especially for tree species that are projected to increase. Planting programs may assist the movement of future-adapted species, but this will depend on management decisions.

Despite these limits, models provide useful information about future expectations. It's perhaps best to think of these projections as indicators of possibility and potential change. The model results presented here were combined with information from published reports and local management expertise to draw conclusions about potential risk and change in the region's forests.

SPECIES	ADDITIONAL CONSIDERATIONS - 30 MOST COMMON SPECIES
MAY DECREASE	
American basswood	Tolerates shade, susceptible to fire
American beech	Susceptible to beech bark disease, very shade tolerant
Bigtooth aspen	Early-successional colonizer, susceptible to drought
Black cherry	Susceptible to insects and fire, mildly drought-tolerant
Eastern hemlock	Hemlock woolly adelgid causes mortality
Eastern white pine	Good disperser, but susceptible to drought and insects
Quaking aspen	Early-successional colonizer, susceptible to heat & drought
Serviceberry	Competitive colonizer, susceptible to drought
Striped maple	Shade tolerant, easily established, susceptible to drought
Sugar maple	Grows across a variety of sites, tolerates shade
Sweet birch	Susceptible to drought, fire topkill, and insects
Yellow birch	Good disperser, susceptible to fire, insects, and disease
NO CHANGE	
American hornbeam	Tolerates shade, susceptible to fire and drought
Eastern hophornbeam	Grows across a variety of sites, tolerates shade
Pitch pine	Early-successional colonizer, susceptible to insect pests

SPECIES	ADDITIONAL CONSIDERATIONS - 30 MOST COMMON SPECIES
MIXED MODEL RESULTS	
Chestnut oak	Establishes from seed or sprout, adapted to fire
Red maple	Competitive colonizer, tolerant of disturbance
Scarlet oak	Seeds and sprouts, susceptible to fire and disease
Tulip tree	Competitive colonizer tolerant of diverse sites
White ash	Emerald ash borer causes mortality
MAY INCREASE	
American elm	Susceptible to Dutch elm disease
Black locust	Early-successional colonizer, susceptible to insect pests
Black oak	Drought tolerant, susceptible to insect pests & diseases
Blackgum	Shade tolerant, fire adapted
Flowering dogwood	Shade tolerant
Northern red oak	Susceptible to insect pests
Pignut hickory	Susceptible to insect pests and drought
Sassafras	Early-successional colonizer, susceptible to fire topkill
Sweetgum	Seeds and sprouts,susceptible to fire and drought
White oak	Fire-adapted, grows on a variety of sites

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FUTURE PROJECTIONS
Data for the end of the century are summarized for two forest impact models under two climate change scenarios. The Climate Change Tree Atlas (www.fs.fed.us/nrs/atlas) models future suitable habitat, while LANDIS models changes in forest growth over time (future tree density presented in this table; additional data are available in the assessment).

▲ **INCREASE** *Projected increase of >20% by 2100*

● **NO CHANGE** *Little change (<20%) projected by 2100*

▼ **DECREASE** *Projected decrease of >20% by 2100*

★ **NEW HABITAT** *Tree Atlas projects new habitat for species not currently present*

ADAPTABILITY
Factors not included in the Tree Atlas model, such as the ability to respond favorably to disturbance, may make a species more or less able to adapt to future stressors (see reverse page for considerations for the 30 most common species).

- \+ high *Species may perform better than modeled*
- · medium
- – low *Species may perform worse than modeled*

	LOW CLIMATE CHANGE (PCM B1)		HIGH CLIMATE CHANGE (GFDL A1FI)		
SPECIES	TREE ATLAS	LANDIS	TREE ATLAS	LANDIS	ADAPT
American basswood	●		▼		·
American beech	▼	●	▼	▼	·
American chestnut	●		●		·
American elm	●		▲		·
American holly	●		▼		·
American hornbeam	●		●		·
Balsam fir	▼	▼	▼	▼	–
Balsam poplar	▼		▼		·
Bigtooth aspen	●		▼		·
Black ash	▼		▼		–
Black cherry	●	●	▼	●	–
Black oak	●	●	▲	●	·
Black spruce	▼	▼	▼	▼	·
Black walnut	▲		▲		·
Blackgum	▲		▲		+
Blackjack oak	●		▲		+
Boxelder	●		▲		+
Bur oak	●		▲		+
Chestnut oak	●	▼	●	▲	+
Cucumbertree	▲		▼		·
Eastern hemlock	▼	●	▼	▼	–
Eastern hophornbeam	●		●		+
Eastern red cedar	▲		▲		·
Eastern redbud	●		▲		·
Eastern white pine	▼	●	▼	▼	·
Flowering dogwood	▲		▲		·
Gray birch	▼		▼		·
Green ash	●		▲		·
Hackberry	▲		▲		+
Jack pine	▼		▼		·
Loblolly pine	▲	●	▲	●	·
Longleaf pine	★		★		·
Mockernut hickory	●		▲		+
Mountain maple	▼		▼		+
Northern red oak	●	●	●	▲	+
Northern white-cedar	▼	▼	▼	▼	·
Osage-orange	●		▲		+
Paper birch	▼		▼		·
Persimmon	▲		▲		+
Pignut hickory	●	●	▲	●	·
Pin cherry	▼		▼		·
Pin oak	▲		▲		–
Pitch pine	●	●	●	●	·
Pond pine	▲		▲		–
Post oak	▲		▲		+
Quaking aspen	▼	▼	▼	▼	·
Red maple	●	●	▼	▲	+
Red pine	▼		▼		·
Red spruce	▼	▼	▼	▼	–
Redbay	★				+
Sassafras	▲		▲		·
Scarlet oak	▲	●	▲	▼	·
Serviceberry	●		▼		·
Shagbark hickory	▲	●	▲	●	·
Shingle oak	●		▲		·
Shortleaf pine	●		▲		·
Silver maple	▼		▲		+
Slippery elm	●		▲		·
Sourwood	▲		●		+
Southern red oak	▲		▲		+
Striped maple	●		▼		·
Sugar maple	●	●	▼	▼	+
Swamp chestnut oak	●		●		·
Swamp tupelo	▲		▲		–
Sweet birch	●		▼		–
Sweetbay	●		●		·
Sweetgum	▲		▲		·
Sycamore	▲		▲		·
Tamarack	▼		▼		–
Tulip tree	▲	●	▼	▲	+
Turkey oak	★		★		+
Virginia pine	●	●	●	▼	·
Water oak	●		▲		·
Water tupelo	●		●		–
White ash	●	●	▼	▲	–
White oak	●	●	▲	▲	+
White spruce	▼		▼		·
Willow oak	●		▲		·
Yellow birch	●	●	▼	▼	·
Yellow buckeye	●		●		–

SOURCE: Butler-Leopold et al. (in review). Mid-Atlantic forest ecosystem vulnerability assessment and synthesis: a report from the Mid-Atlantic Climate Change Response Framework, Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. **www.forestadaptation.org/mid-atlantic/vulnerability-assessment**

www.forestadaptation.org

https://tinyurl.com/Mid-Atlantic-Species

Changes in Forest Composition


CLIMATE CHANGE PROJECTIONS FOR INDIVIDUAL TREE SPECIES
WESTERN ALLEGHENY PLATEAU (PENNSYLVANIA SUBREGION 1)

Pennsylvania's forests will be affected by a changing climate during this century. A team of forest managers and researchers created an assessment that describes the vulnerability of forests in the Mid-Atlantic region (https://forestadaptation.org/mid-atlantic/vulnerability-assessment). This handout is summarized from the full assessment, but focuses on one region in Pennsylvania. Model results for additional regions can be found online at (https://forestadaptation.org/PA-DISTRIB).

CLIMATE CHANGE PROJECTIONS FOR INDIVIDUAL TREE SPECIES
NORTHERN ALLEGHENY PLATEAU (PENNSYLVANIA SUBREGION 3)

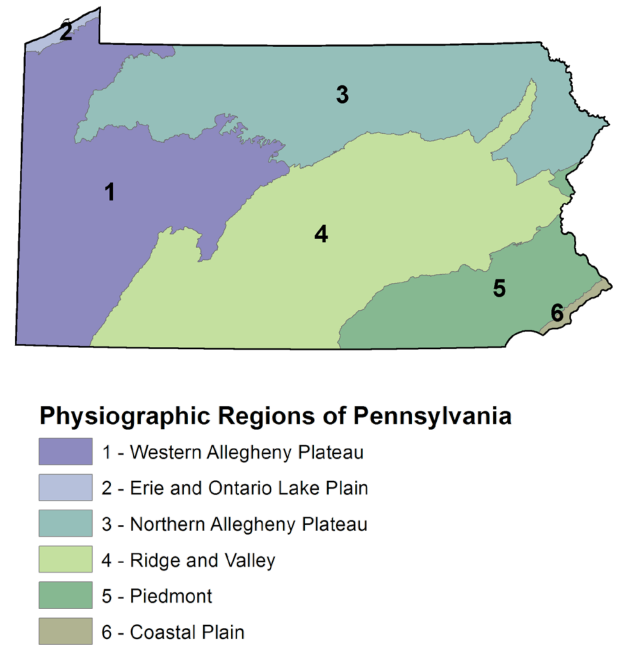
Pennsylvania's forests will be affected by a changing climate during this century. A team of forest managers and researchers created an assessment that describes the vulnerability of forests in the Mid-Atlantic region (https://forestadaptation.org/mid-atlantic/vulnerability-assessment). This handout is summarized from the full assessment, but focuses on one region in Pennsylvania. Model results for additional regions can be found online at (https://forestadaptation.org/PA-DISTRIB).

CLIMATE CHANGE PROJECTIONS FOR INDIVIDUAL TREE SPECIES
RIDGE AND VALLEY (PENNSYLVANIA SUBREGION 4)

Pennsylvania's forests will be affected by a changing climate during this century. A team of forest managers and researchers created an assessment that describes the vulnerability of forests in the Mid-Atlantic region (https://forestadaptation.org/mid-atlantic/vulnerability-assessment). This handout is summarized from the full assessment, but focuses on one region in Pennsylvania. Model results for additional regions can be found online at (https://forestadaptation.org/PA-DISTRIB).

CLIMATE CHANGE PROJECTIONS FOR INDIVIDUAL TREE SPECIES
PIEDMONT (PENNSYLVANIA SUBREGION 5)

Pennsylvania's forests will be affected by a changing climate during this century. A team of forest managers and researchers created an assessment that describes the vulnerability of forests in the Mid-Atlantic region (https://forestadaptation.org/mid-atlantic/vulnerability-assessment). This handout is summarized from the full assessment, but focuses on one region in Pennsylvania. Model results for additional regions can be found online at (https://forestadaptation.org/PA-DISTRIB).



Forestadaptation.org/PA

Changes in Forest Composition

Ridge and Valley and Piedmont

- Bitternut hickory
- Black oak
- Boxelder
- Chinkapin oak
- Eastern hophornbeam
- Eastern redbud
- Hackberry
- Mockernut hickory
- Persimmon
- Pin oak
- Red mulberry
- Scrub oak
- Shagbark hickory
- Pin oak
- Red mulberry
- Scrub oak
- Shagbark hickory
- Shortleaf pine
- Southern red oak
- Sweetgum
- Sycamore
- White oak

- Basswood
- American beech
- Balsam poplar
- Bigtooth aspen
- Black cherry
- Butternut
- Chestnut oak
- Chokecherry
- Cucumbertree
- Eastern hemlock
- Eastern white pine
- Northern red oak
- Paper birch
- Pin cherry
- Quaking aspen
- Red maple
- Red pine
- Red spruce
- Serviceberry
- Striped maple
- Sugar maple
- Swamp white oak
- Sweet birch
- Tamarack
- White ash
- Yellow birch

Forestadaptation.org/pa

Changes in Forest Composition

- Many common tree species are projected to have reduced suitability in the future
- Changes will occur slowly—not instant dieback
- Mature and established trees should fare better
- Immense lags to occupy habitats
- Critical factors: competition, management, & disturbance

Risk may be greatest:

- Location is relatively near the southern extent of species range
- Trees are projected to decline and located on a marginal site
- Forest is composed of few species, esp. those projected to decline
- Something is “missing” from the ecosystem
- Other factors cause additional stress

Interactions make all the difference.

- Chronic stress
- Disturbances
- Invasive species
- Insect pests
- Forest diseases

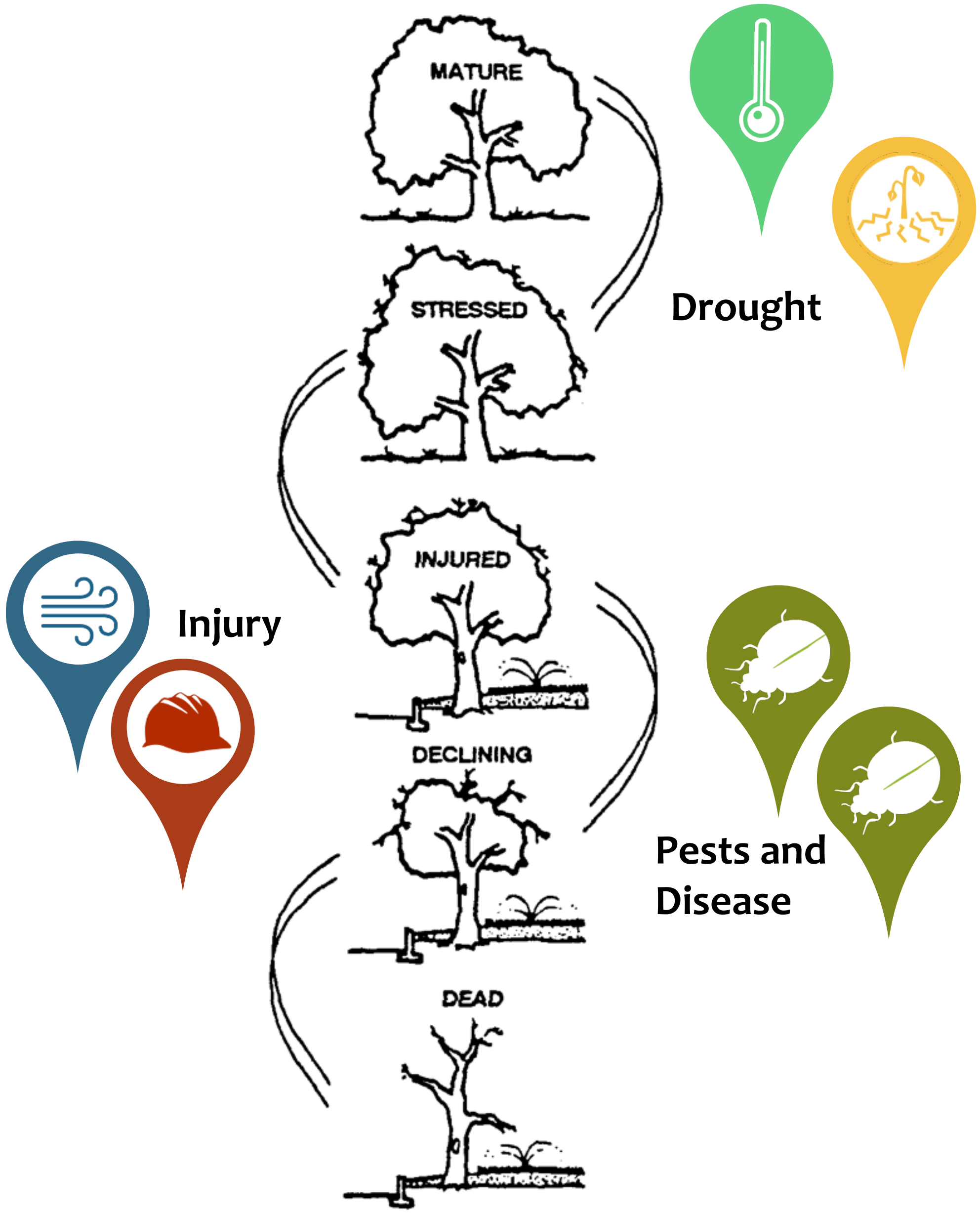


Image: Bartlett Tree Experts

Extreme Weather Events

Extreme events may become more frequent or severe

Heavy precipitation

Flooding

Ice storms

Heat waves/droughts

Wind storms

Hurricanes

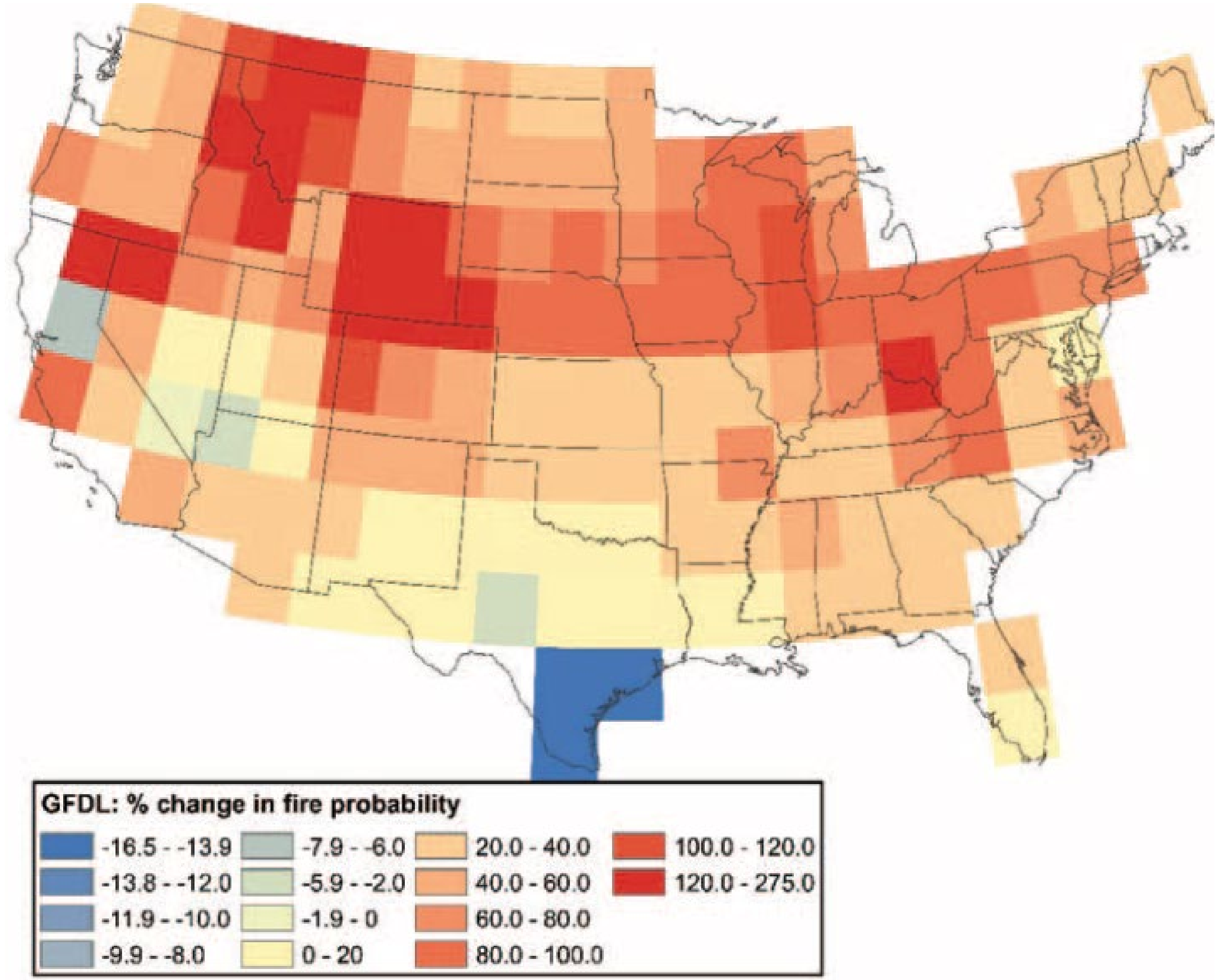
"Events" are not well modeled

Loyalsock State Forest; PA DCNR

Sean Simmers, PennLive

What may be at risk: Depends greatly on site conditions and susceptibility to different types of disturbance

Wildfire Probability



Guyette et al. 2007

Interactions: Wildfire

Future climate conditions suggest increased risk of fire.

Wildfire may increase:

- Warmer/drier summers
- Increased stress or mortality from less suitable conditions
- Shift toward fire-associated species like oaks and pines

Wildfire may not change:

- Spring/early summer moisture
- Current regeneration of more mesic species
- Spatial patterns of land use and fragmentation
- Fire suppression

What may be at risk: Fire-dependent forests or areas of tree mortality when fire is not suppressed.

Clark et al. 2014, Guyette et al. 2014

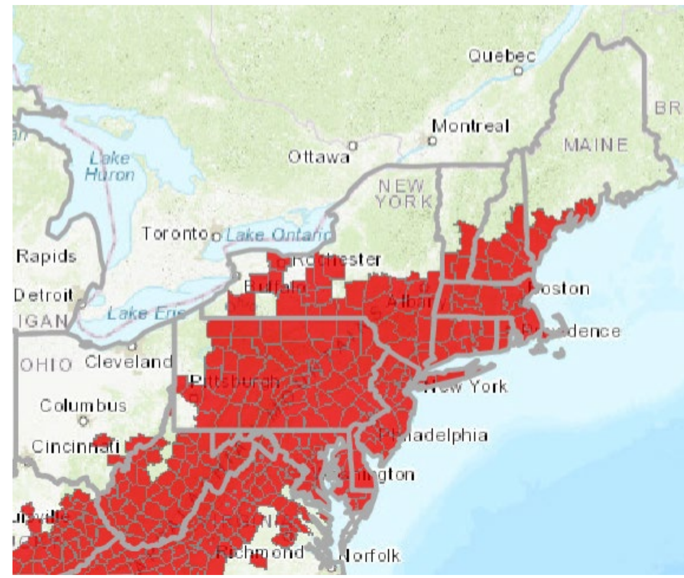
Interactions: Forest Health

Increased damage from forest insects & diseases

Indirect: Stress from other impacts increases susceptibility

Direct:

- Pests migrating northward
- Decreased probability of cold lethal temperatures
- Accelerated lifecycles



Hemlock woolly adelgid incidence ~2015

Risk may be greatest: Presence of host species; pest is nearby; other factors reduce that forest vigor

Ayres and Lombardero 2000, Parmesan 2006, Dukes et al. 2009, Weed et al. 2013, Sturrock et al. 2011

Interactions: Invasive Plants

Increased habitat for many noxious plants

<u>Indirect:</u> Stress or disturbance from other impacts can affect the potential for invasion or success

<u>Direct:</u>

- Expanded ranges under warmer conditions
- Increased competitiveness from ability of some plants to take advantage of elevated CO_2

Risk may be greatest: Presence of invasive species nearby; other factors that reduce forest/understory vigor

Dukes et al. 2009, Hellman et al. 2008; Images: Invasives Plants Atlas of New England (www.eddmaps.org)

Ecosystem Vulnerability

Vulnerability Process

Place-based, model-informed, expert driven, transparent

Modified from [Swanston and Janowiak 2012]

Mid-Atlantic Vulnerability Ratings

Forest community	Potential impacts	Adaptive capacity	Vulnerability
Montane Spruce-Fir	Negative	Low	High
Northern Hardwood	Moderate-Negative	Moderate	Moderate-High
Central Oak-Pine	Moderate-Positive	Moderate-High	Moderate-Low
Woodland, Glades, and Barrens	Positive	Moderate-High	Low
Lowland and Riparian Hardwood	Moderate	Moderate	Moderate
Lowland Conifer	Negative	Moderate-Low	High
Forest community	**Potential impacts**	**Adaptive capacity**	**Vulnerability**
Coastal Plain Swamp	Moderate	Moderate-High	Moderate-Low
Coastal Plain Tidal Swamp	Moderate-Negative	Moderate-Low	Moderate-High
Coastal Plain Oak-Pine-Hardwood	Moderate-Positive	High	Moderate-Low
Coastal Plain Pine-Oak Barrens	Moderate	Moderate	Moderate-Low
Coastal Plain Maritime Forest	Negative	Moderate-Low	High

High Vulnerability: Lowland Conifer

- Changes in hydrologic regime: floods *and* droughts
- Tree susceptibility to insect infestations may increase as trees become moisture-stressed
- Most species projected to decline, including balsam fir, black ash, black spruce, eastern hemlock, eastern white pine, red spruce, tamarack, and northern white-cedar
- As the keystone conifers decline, the identity of this forest community may be severely compromised

Low Vulnerability: Woodland, glades, barrens

- Exist in the hottest, driest, and most exposed sites
- Warmer, drier summers are likely to increase the risk of drought and fire in these locations, which could help maintain open conditions
- Most dominant species are projected to increase or remain stable, including eastern redcedar, eastern redbud, hackberry, northern red oak, pignut hickory, pitch pine, scrub oak, Virginia pine, and white oak.

Recreation/Infrastructure

Flood Impacts

Heavy rain events

Rain on snow

Earlier snowmelt

Overwhelmed infrastructure

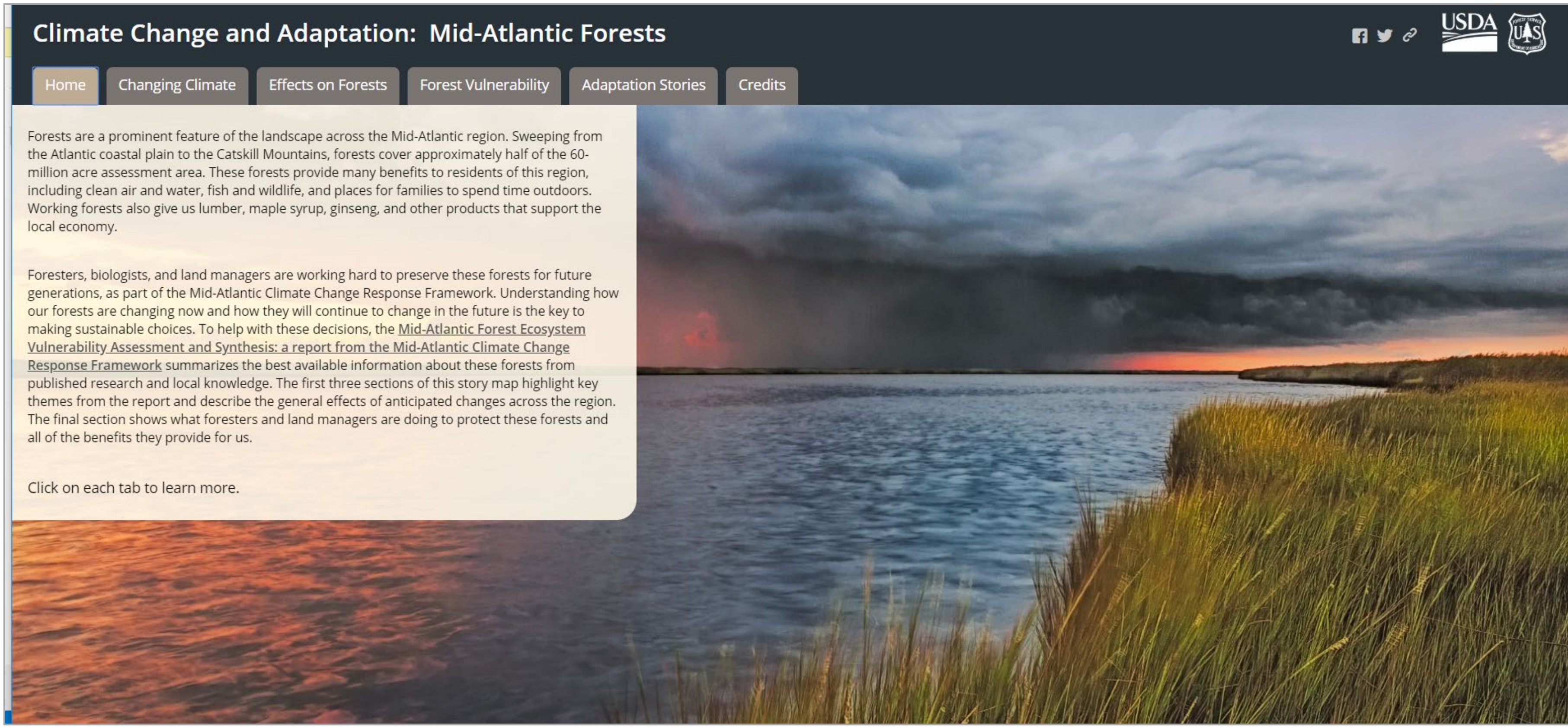
More maintenance and repairs

Recreation/Infrastructure

Changing Use Trends

- Shifting “shoulder seasons
- Longer warm-weather seasons
- Increasing visitor use
- Shifting visitor use

Story Map: Mid-Atlantic Forests & CC



Online Now! https://tinyurl.com/MAstorymap

Last Slide: **Location, Location, Location**

Research and assessments describe **broad trends** but **local conditions** and **management** make the difference.

Questions???