Combining tree species models from the Climate Change Tree Atlas with traits to assess vulnerability to climate change

Louis Iverson

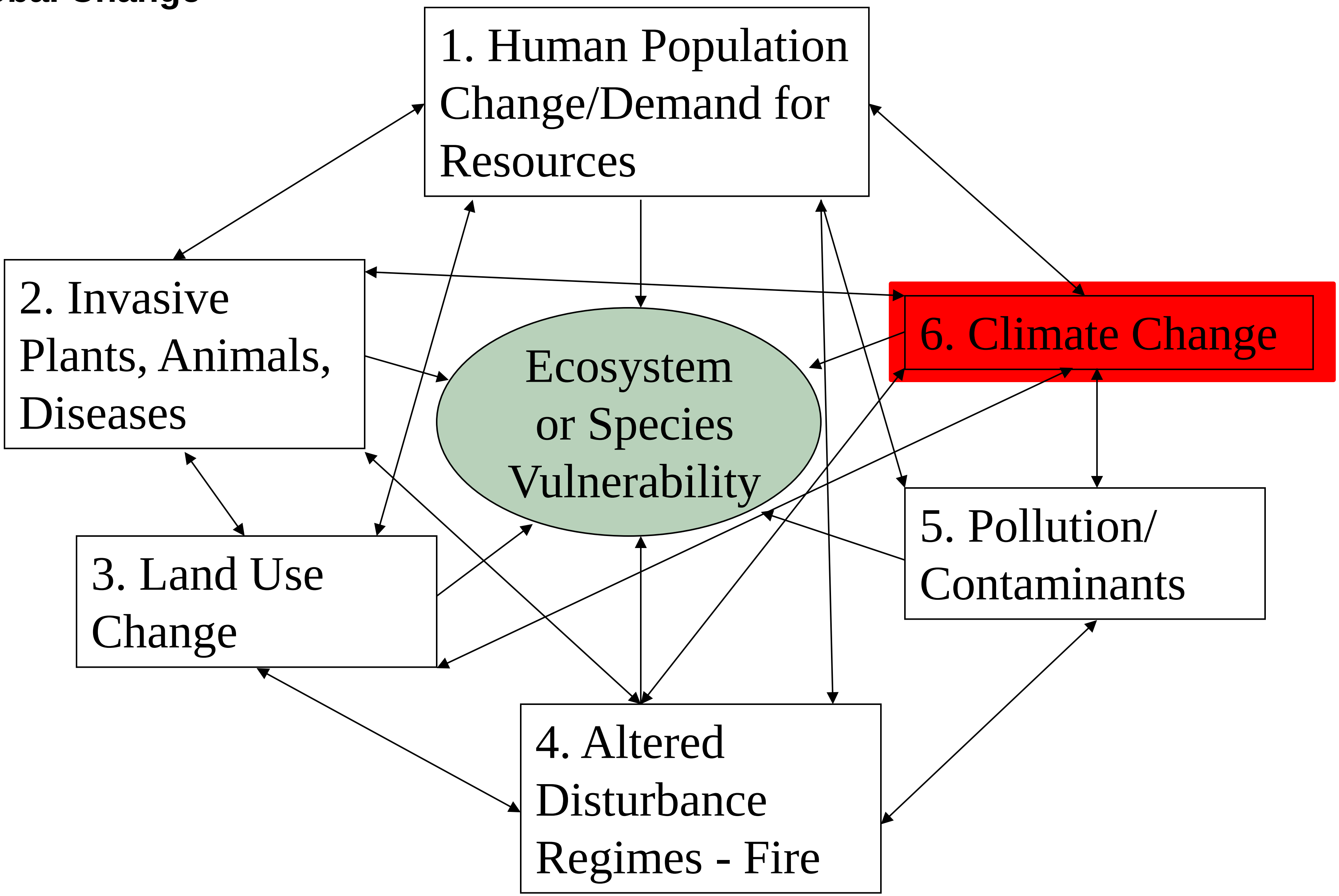
US Forest Service, Delaware, OH

Major contributions by Maria Janowiak, Stephen Handler (NIACS), Stephen Matthews, Matthew Peters, Anantha Prasad, (NRS-Delaware)

Impacts of Climate Change on Forests

- What evidence do we have that the global climate has changed over the last century? How might it change further?
- In what ways would we expect species to respond to changes in climate?
- How can we begin to integrate climate change impacts into the complicated realm of forest management?

Climate Change is Part of Complicated Network of Interconnected Issues =
Global Change



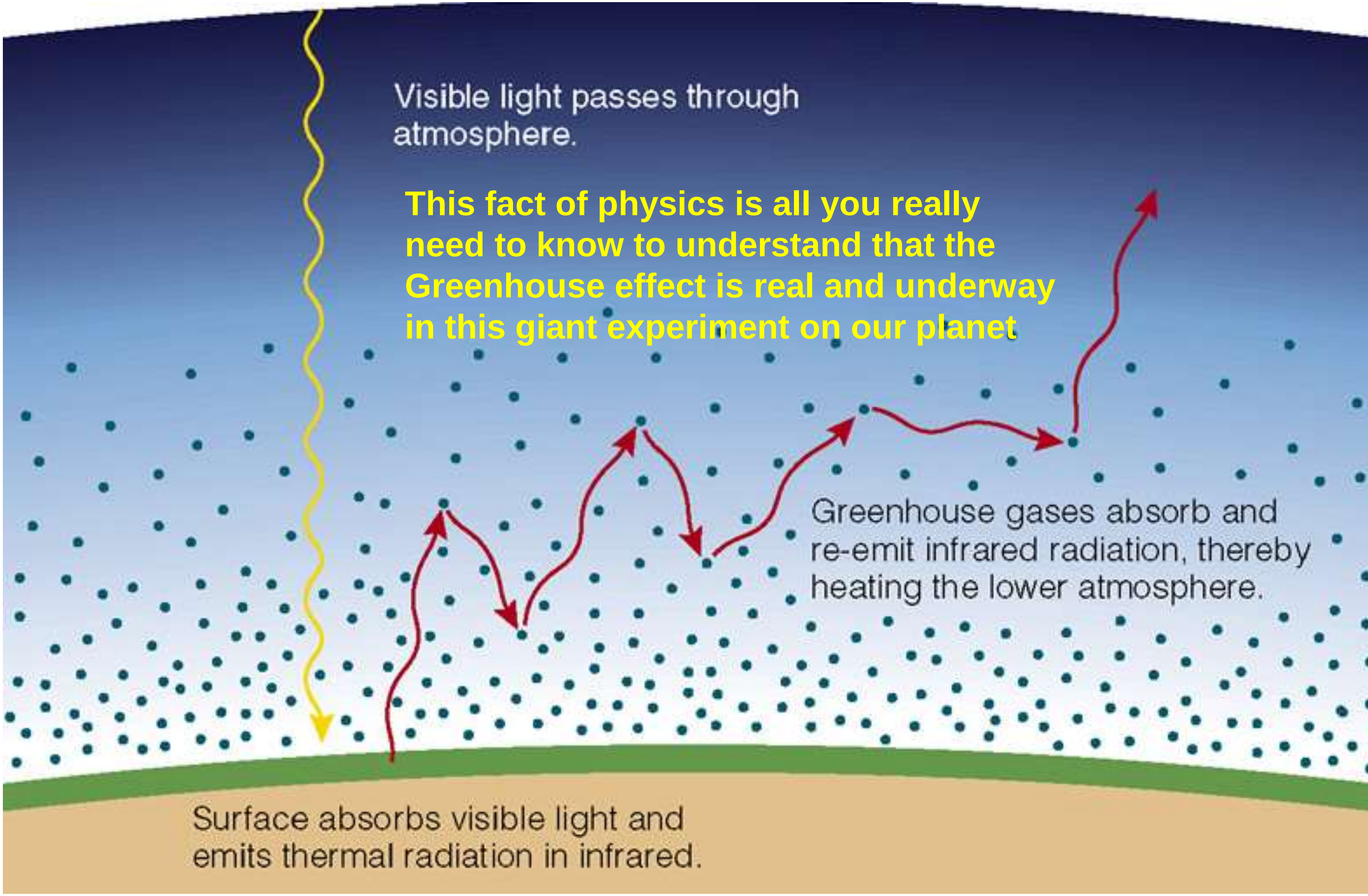
From T. Stohlgren

Greenhouse effect known a long time

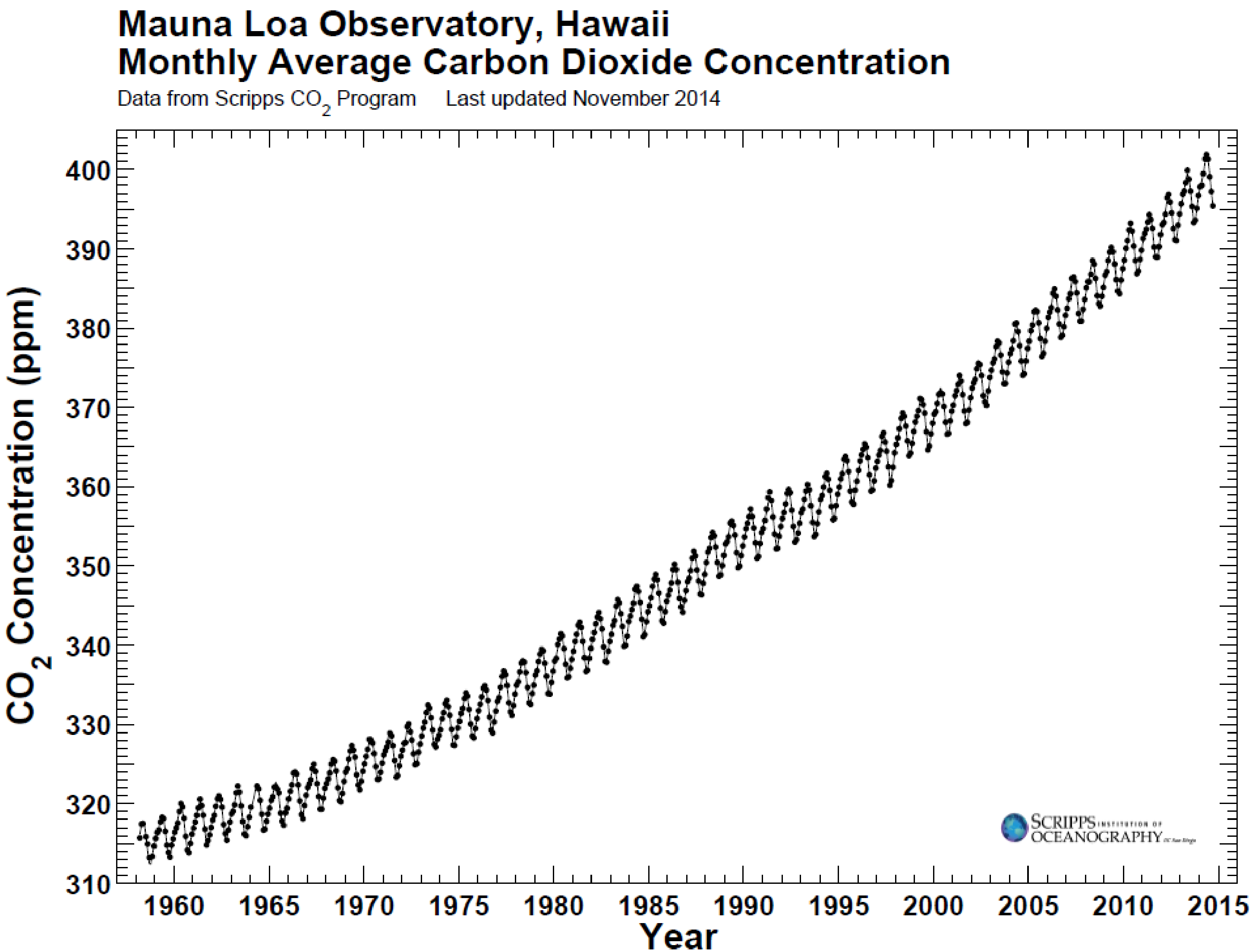
Joesph Fourier in 1824 was first to propose that the Earth's atmosphere acts to raise the planet's temperature

Svante Arrhenius in 1896 first claimed that fossil fuel combustion would eventually lead to global warming

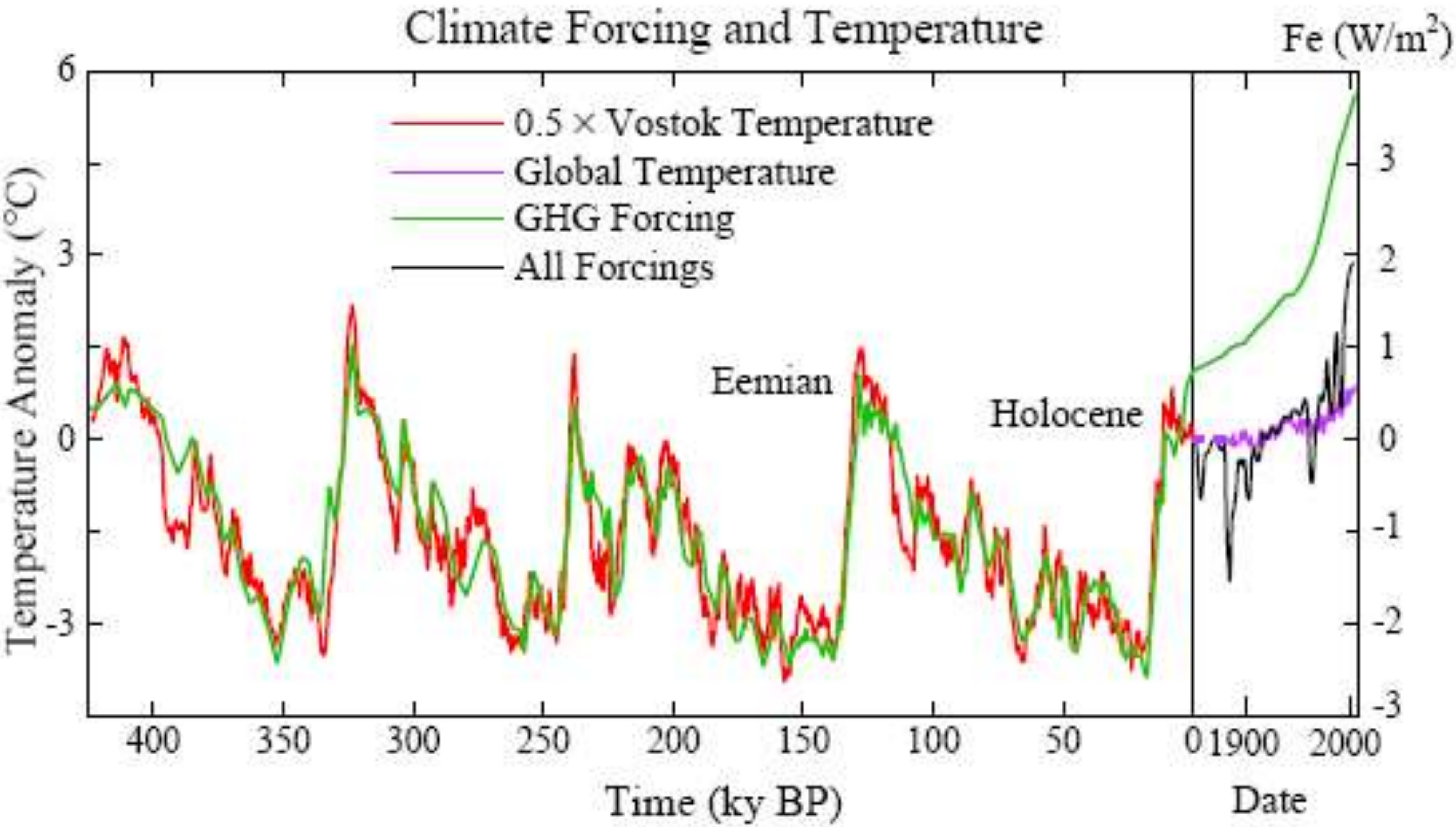
The Greenhouse Effect



~2 ppm rise per year, just crossed 400ppm = 120 ppm more than in 1860

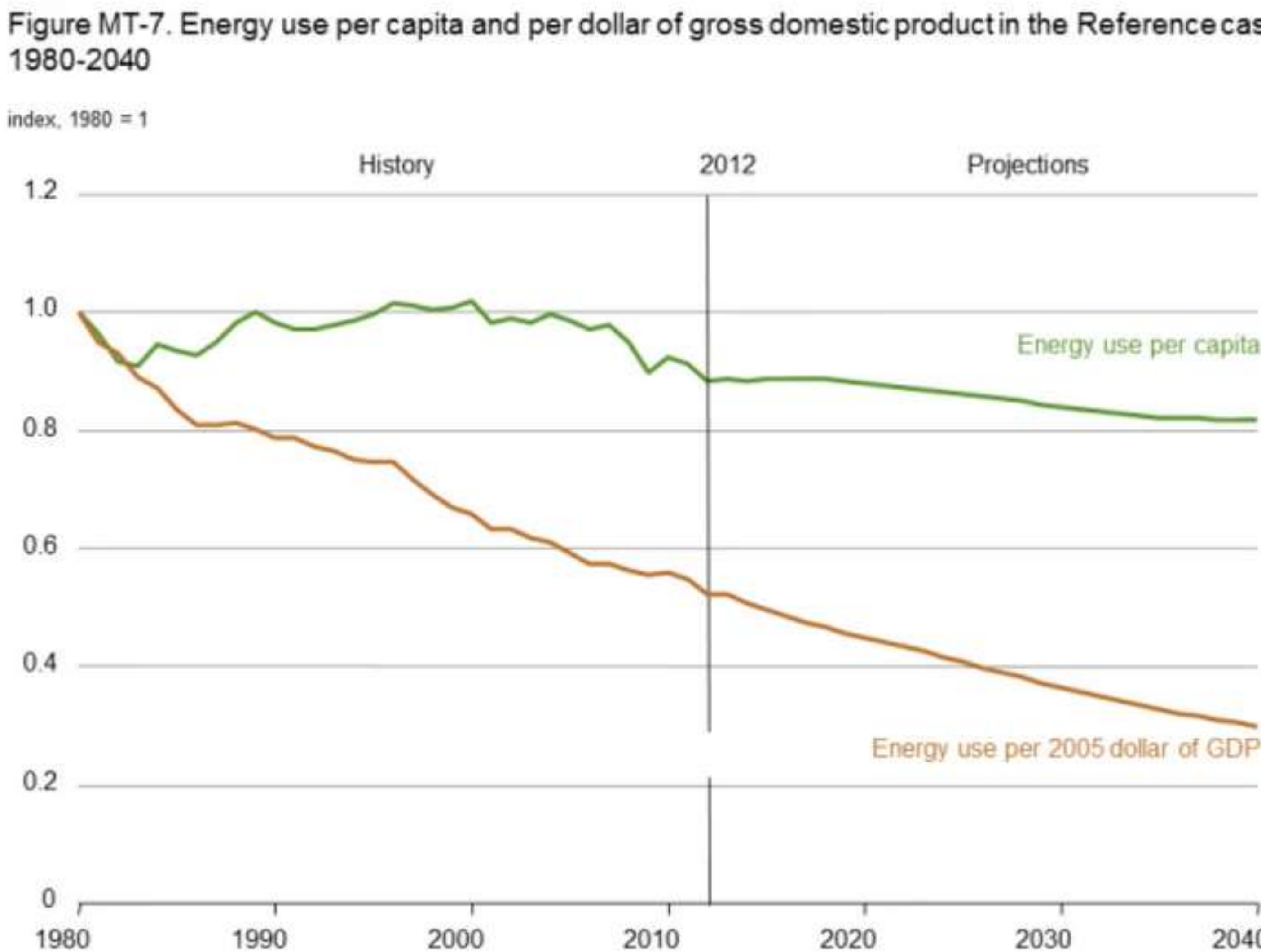


Greenhouse gases higher now than past 400,000 years



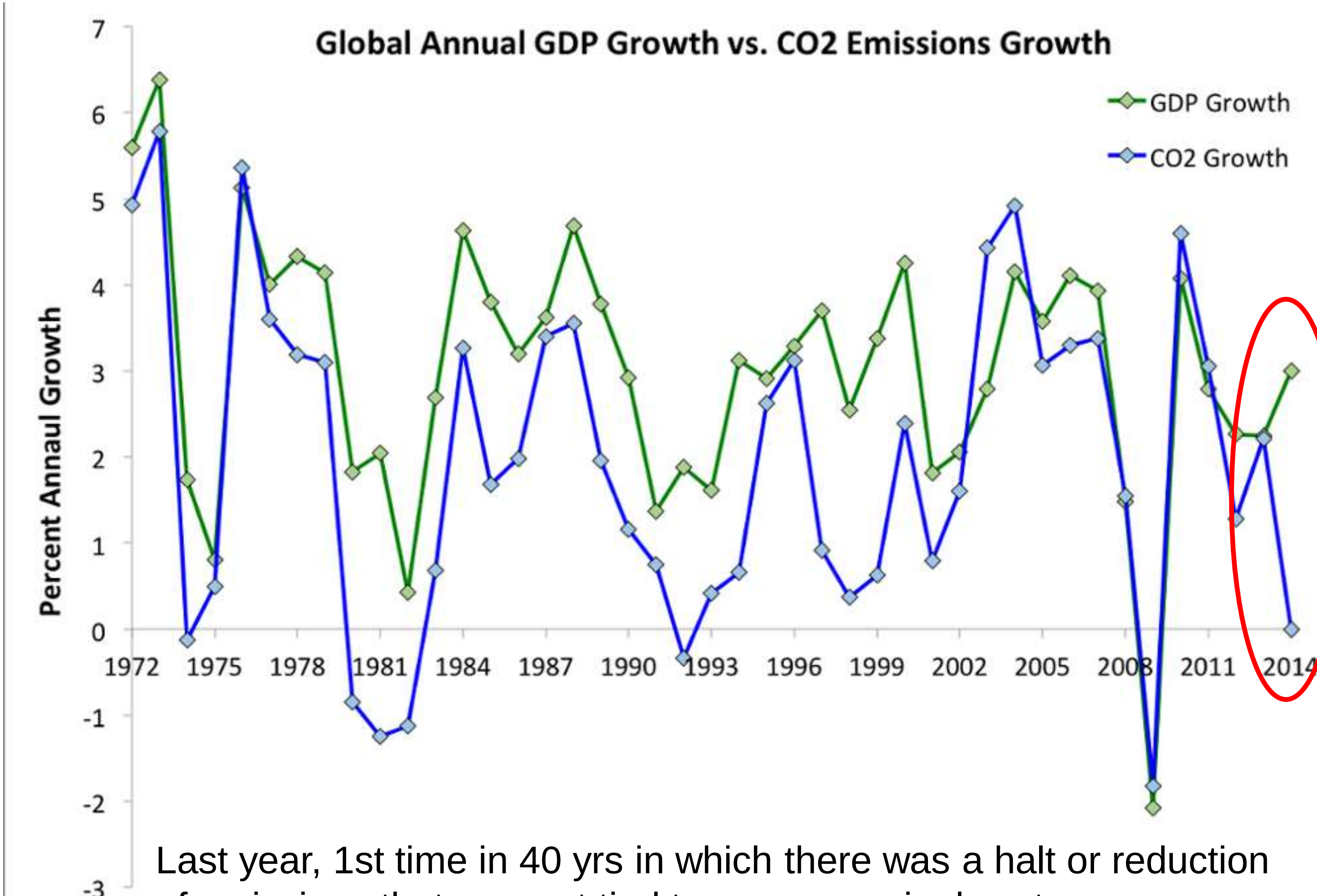
Hansen 2008

Some good news!



Energy use per capita and per dollar of GDP is dropping!

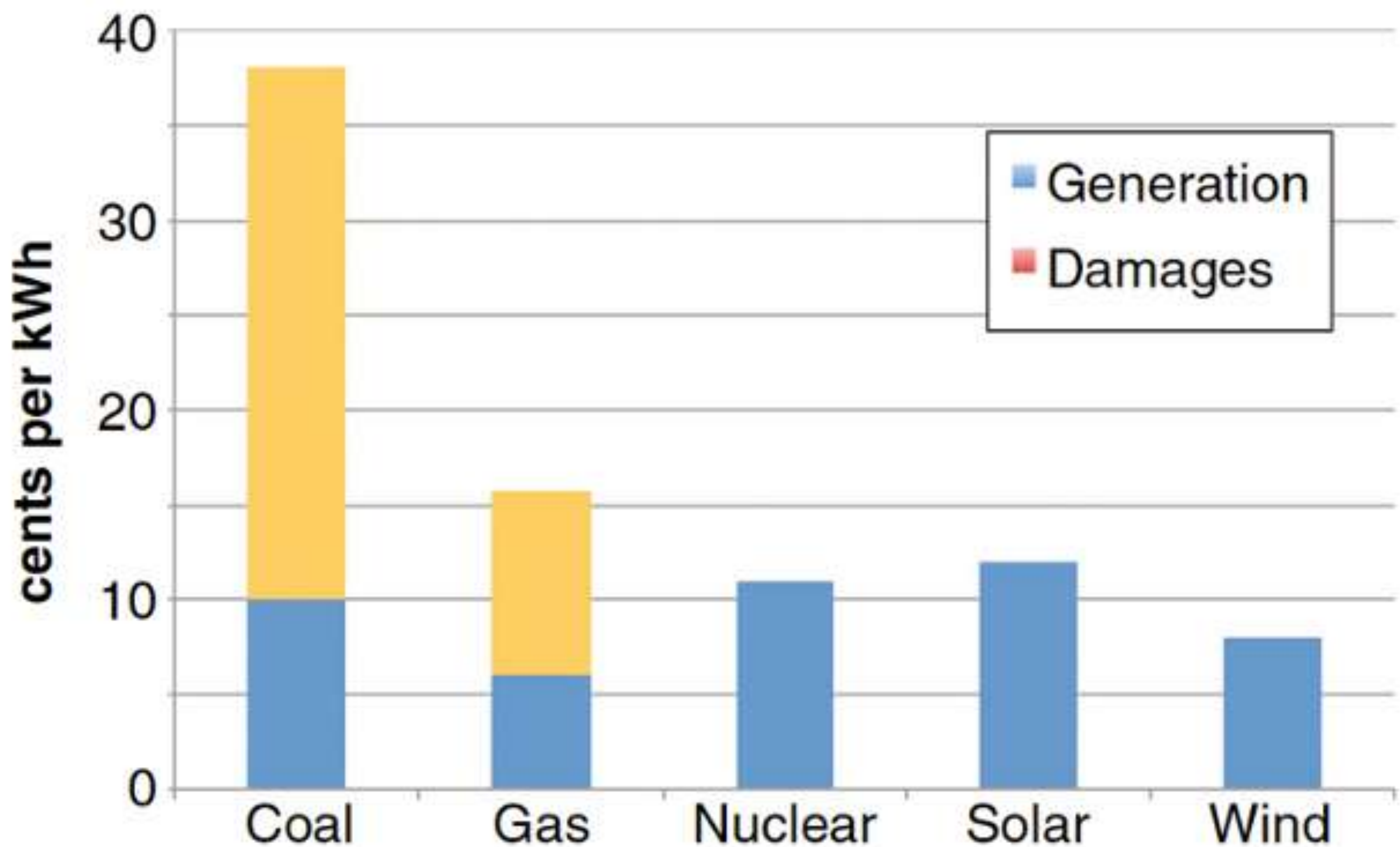
Some more good news!



Last year, 1st time in 40 yrs in which there was a halt or reduction of emissions that was not tied to an economic downturn

A ways to go…and more reasons to reduce fossil fuels

A new paper published in *Climatic Change* estimates that when we account for the pollution costs associated with our energy sources, gasoline costs an extra $3.80 per gallon, diesel an additional $4.80 per gallon, coal a further 24 cents per kilowatt-hour, and natural gas another 11 cents per kilowatt-hour that we don't see in our fuel or energy bills.



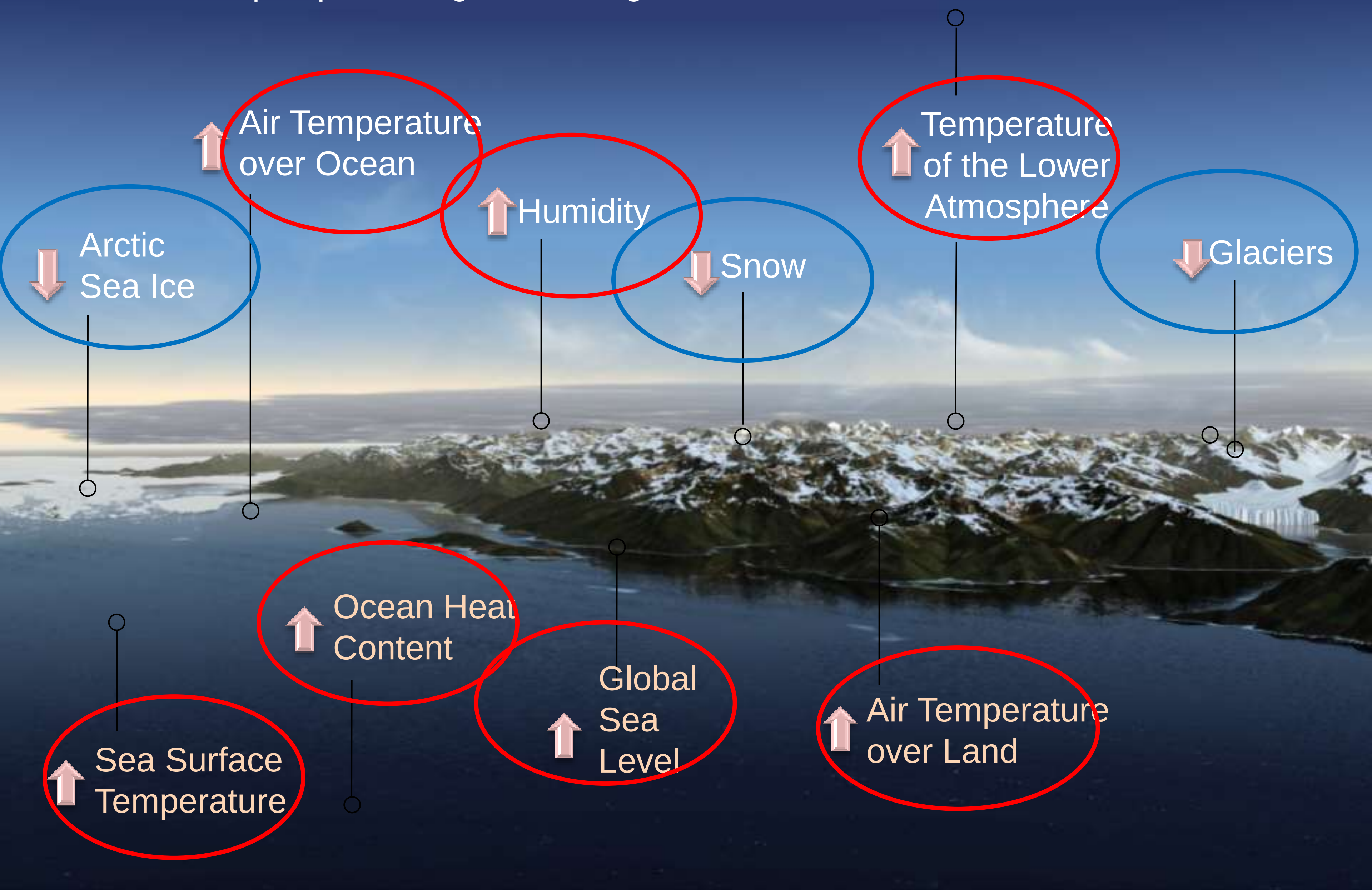
Levelized generation costs for new US electricity generation and environmental damages by fuel type. Source: Climatic Change, Shindell (2015).

"The social cost of atmospheric release"

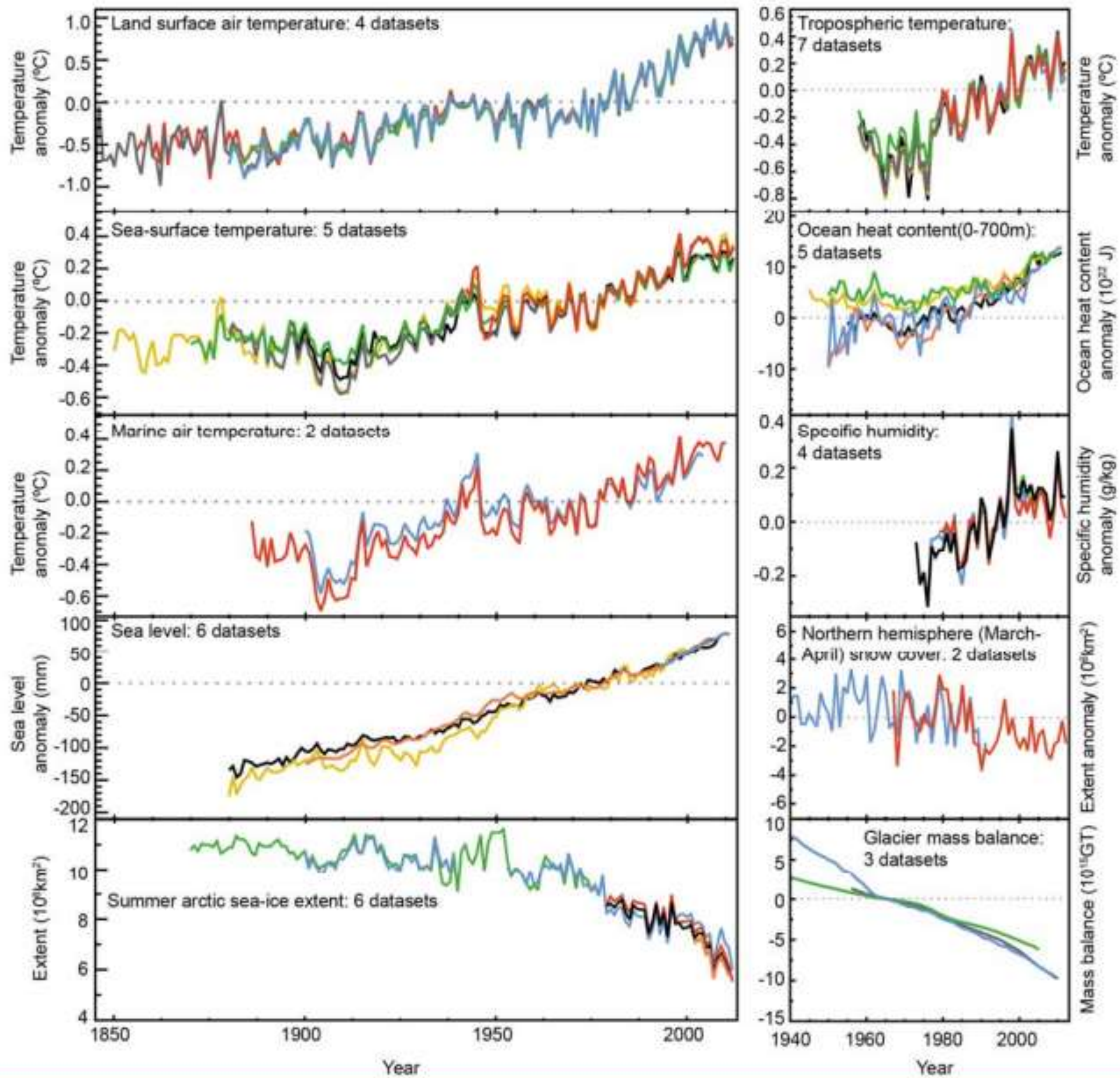
How do we know the world is warming?

http://cpo.noaa.gov/warmingworld/

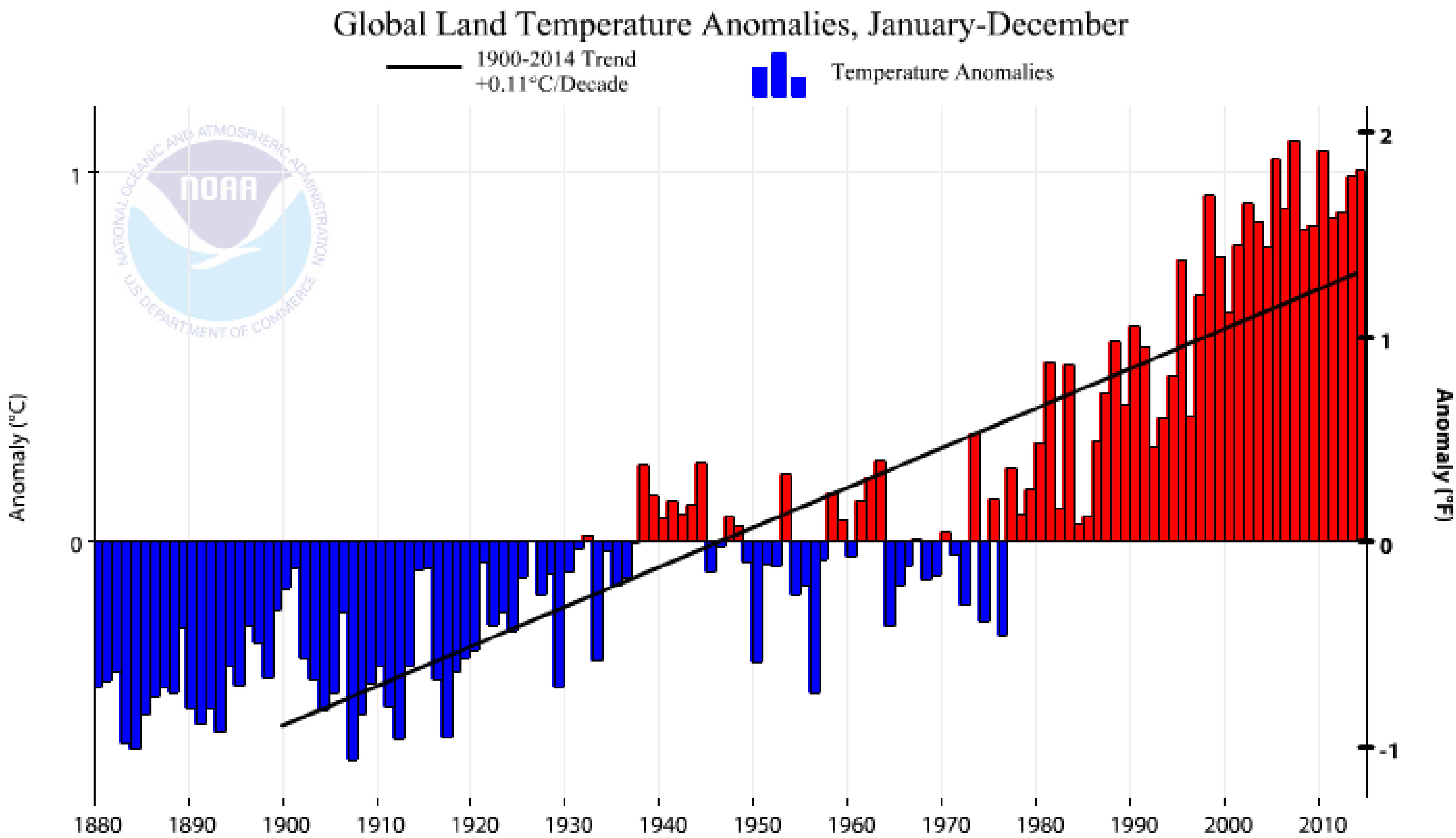
Climate change will have consequences for the Earth system and human lives.
Explore further information and the data sets that support each of these statements at:
www.climate.noaa.gov/warmingworld



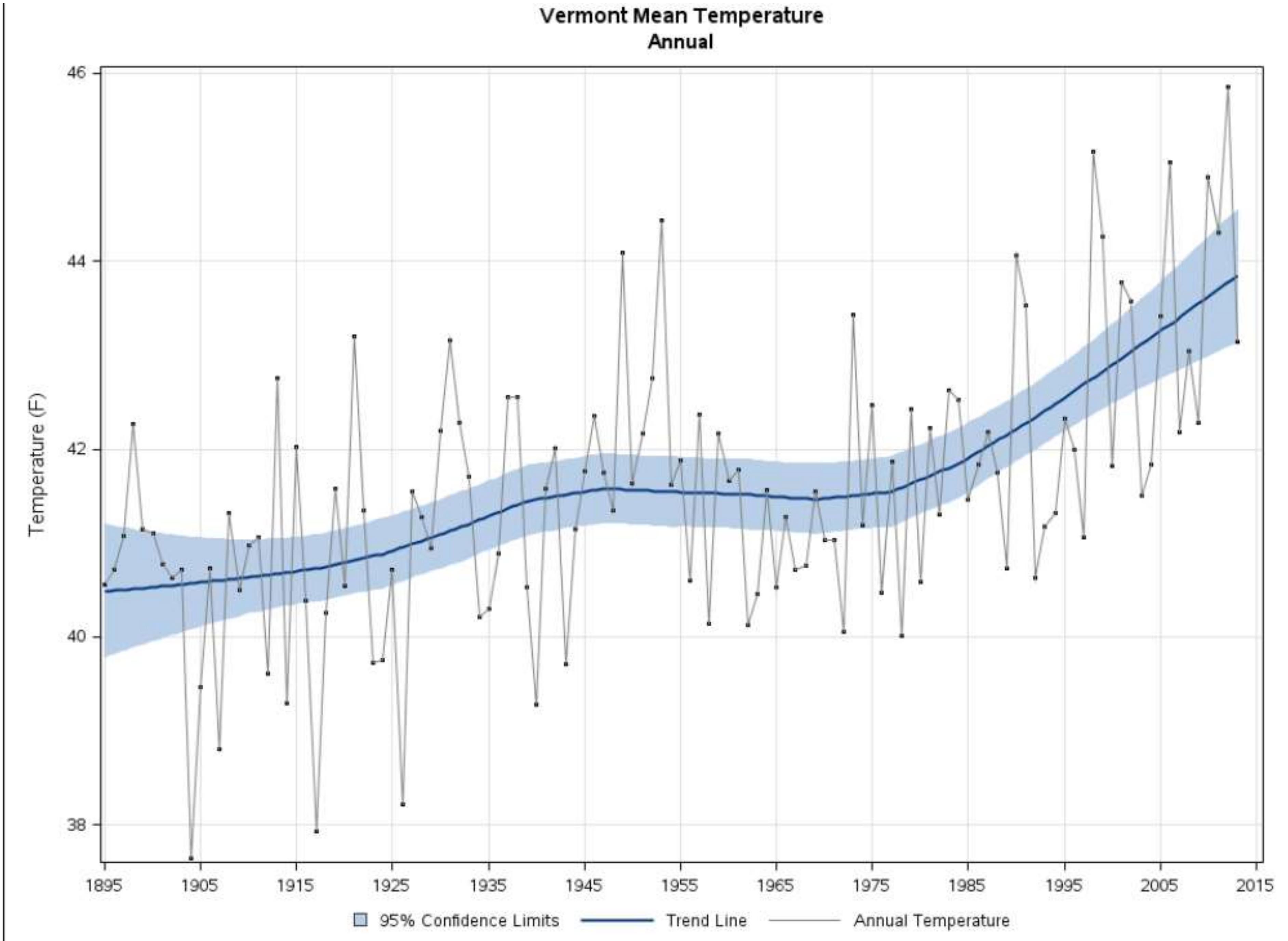
10 indicators of climate change



State of the Climate, NOAA



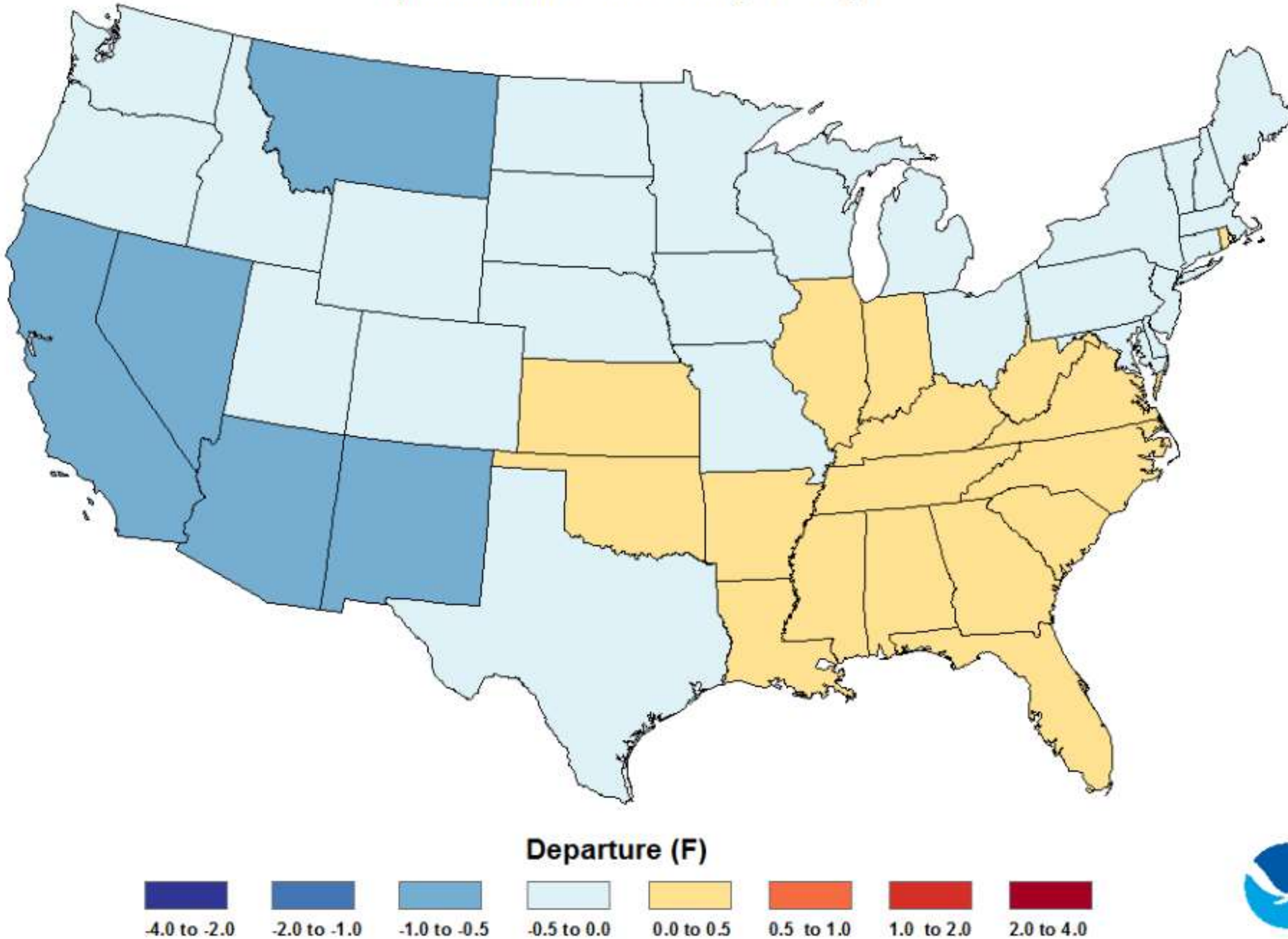
Global Land Temperature Anomalies, January-December
1900-2014 Trend
+0.11°C/Decade
Temperature Anomalies
Anomaly (°C)
Anomaly (°F)
1
0
2
1
0
-1
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

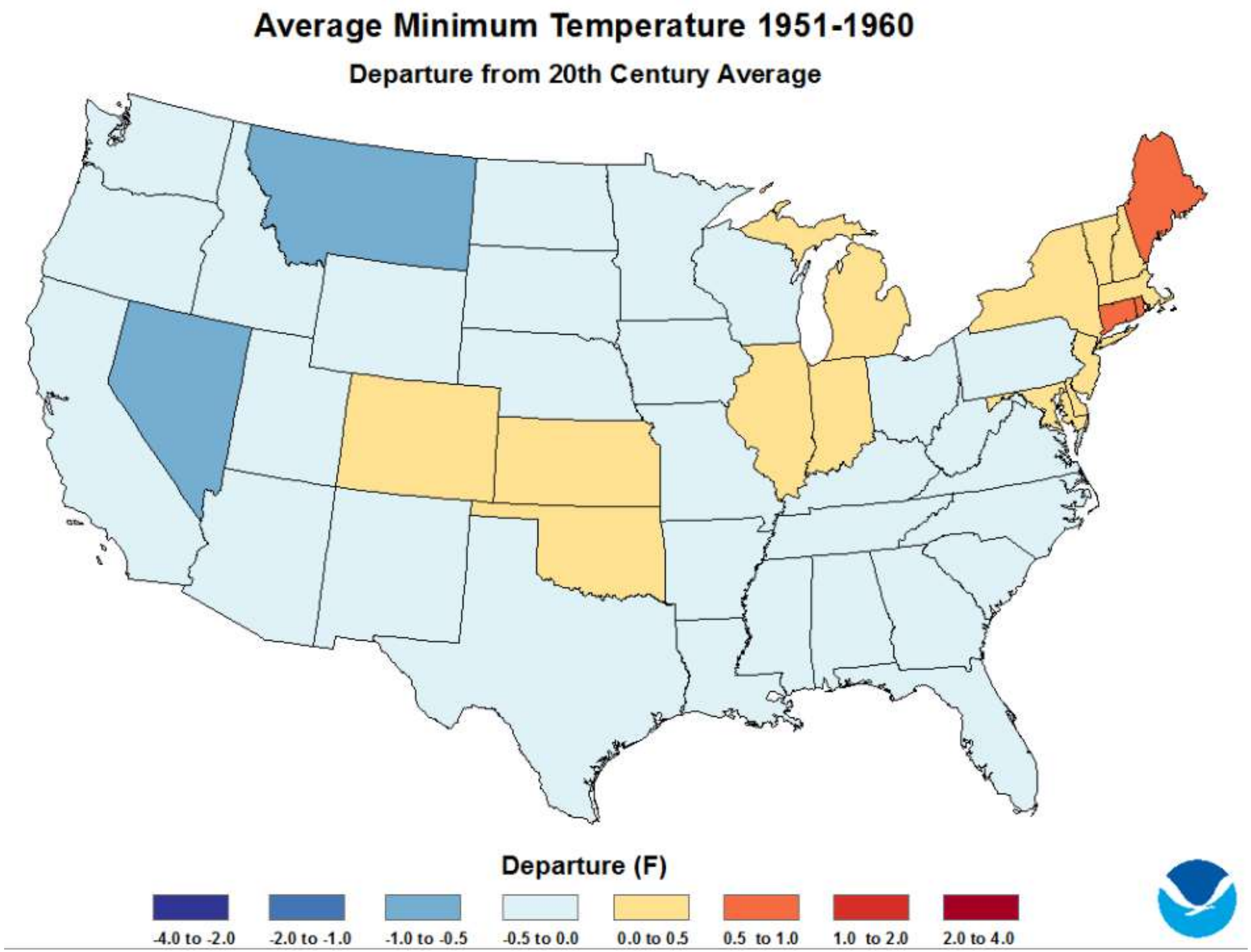


Vermont Mean Temperature
Annual
Temperature (F)
46
44
42
40
38
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
2005
2015
95% Confidence Limits
Trend Line
Annual Temperature

Average Minimum Temperature 1941-1950

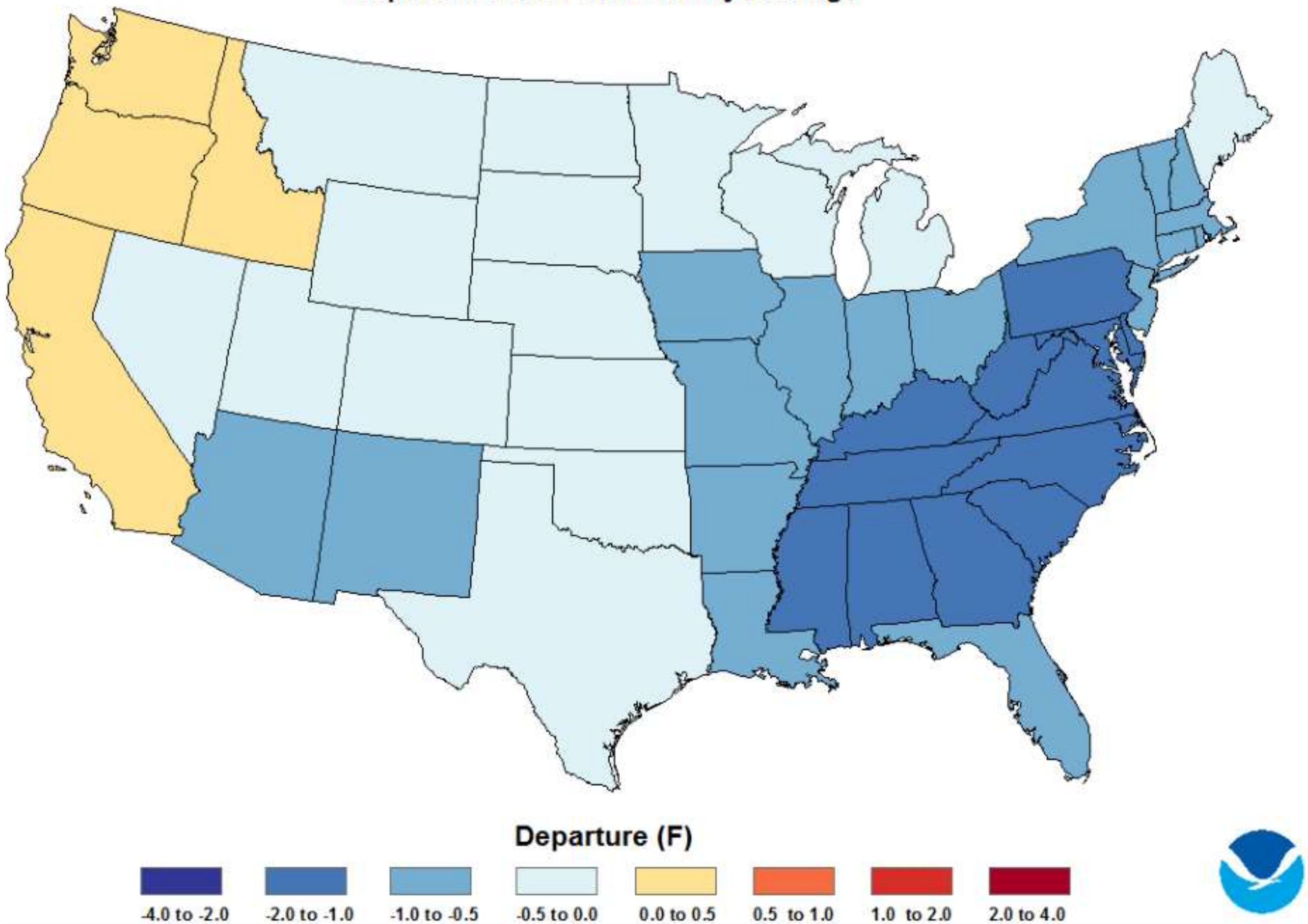
Departure from 20th Century Average




Average Minimum Temperature 1951-1960
Departure from 20th Century Average
Departure (F)
-4.0 to -2.0
-2.0 to -1.0
-1.0 to -0.5
-0.5 to 0.0
0.0 to 0.5
0.5 to 1.0
1.0 to 2.0
2.0 to 4.0

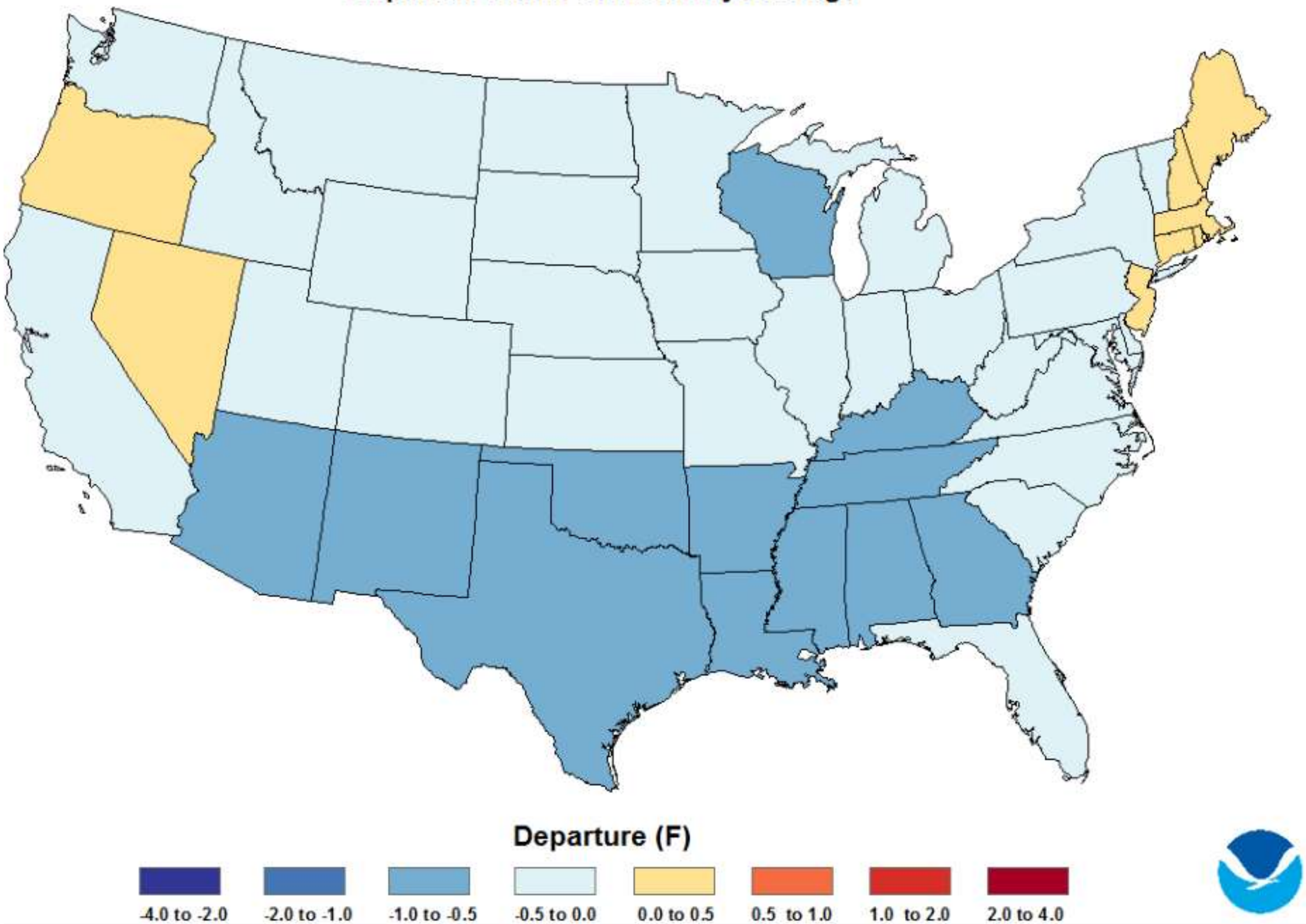
Average Minimum Temperature 1961-1970

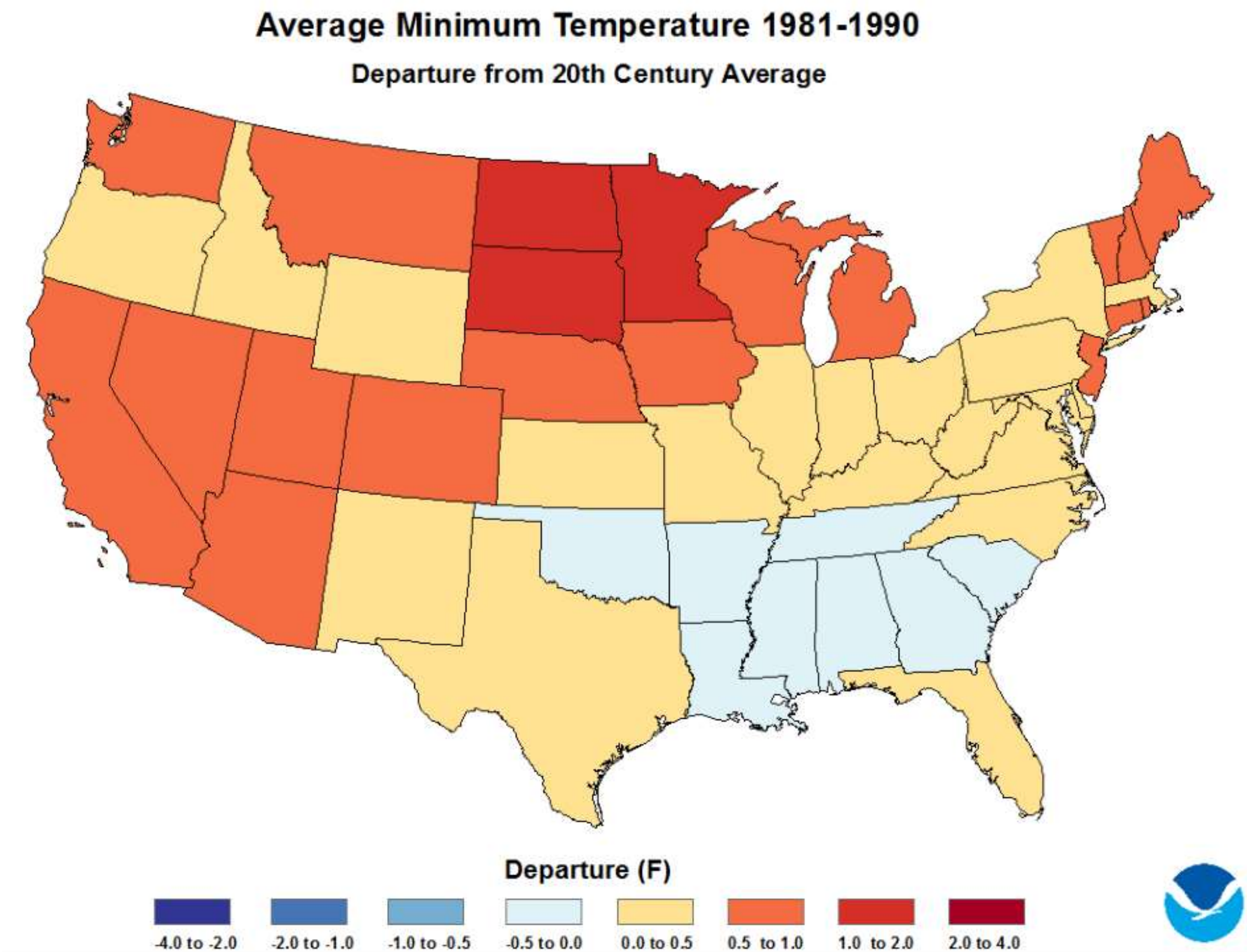
Departure from 20th Century Average



Average Minimum Temperature 1971-1980

Departure from 20th Century Average

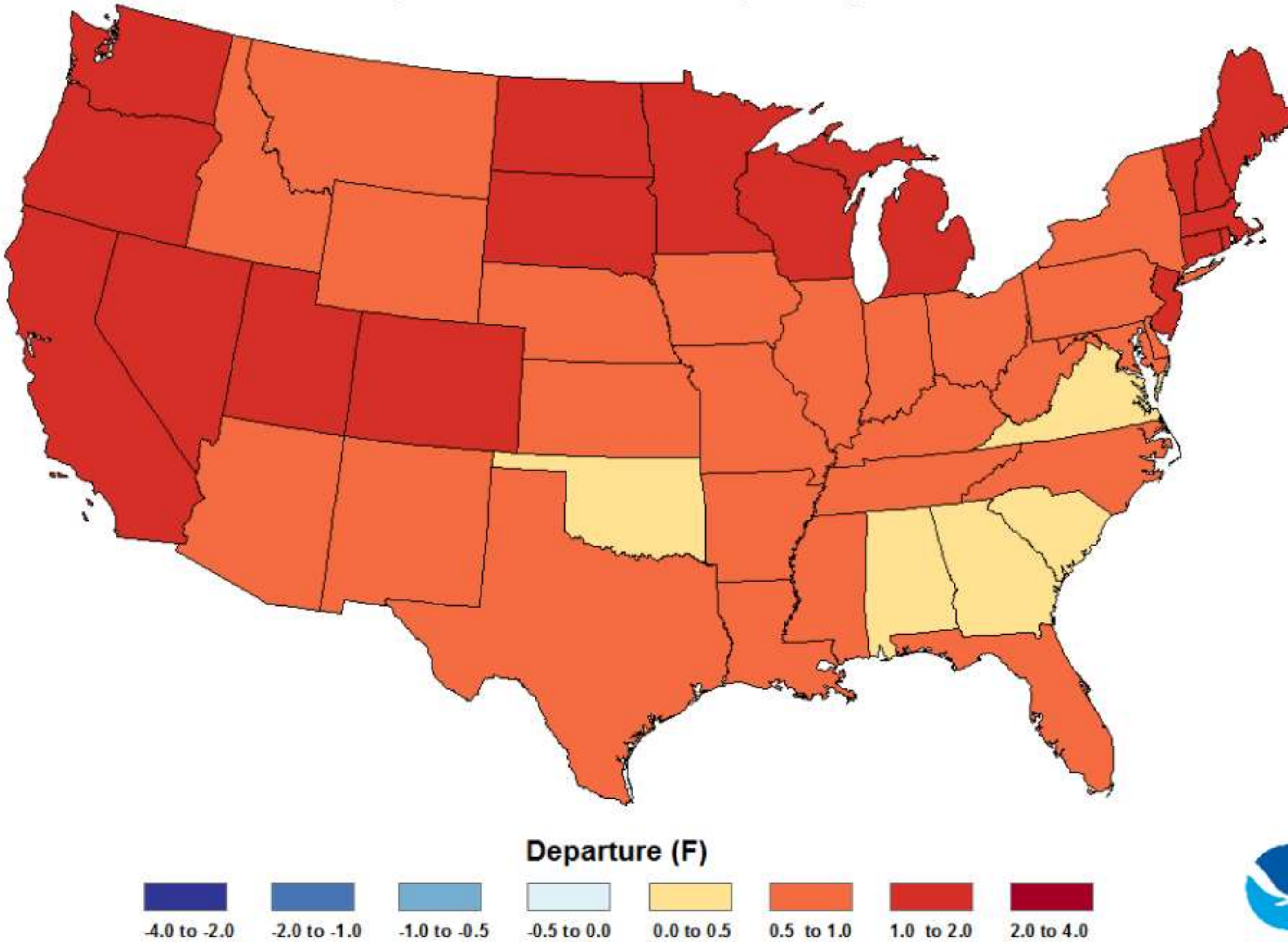




Average Minimum Temperature 1981-1990
Departure from 20th Century Average
Departure (F)
-4.0 to -2.0
-2.0 to -1.0
-1.0 to -0.5
-0.5 to 0.0
0.0 to 0.5
0.5 to 1.0
1.0 to 2.0
2.0 to 4.0

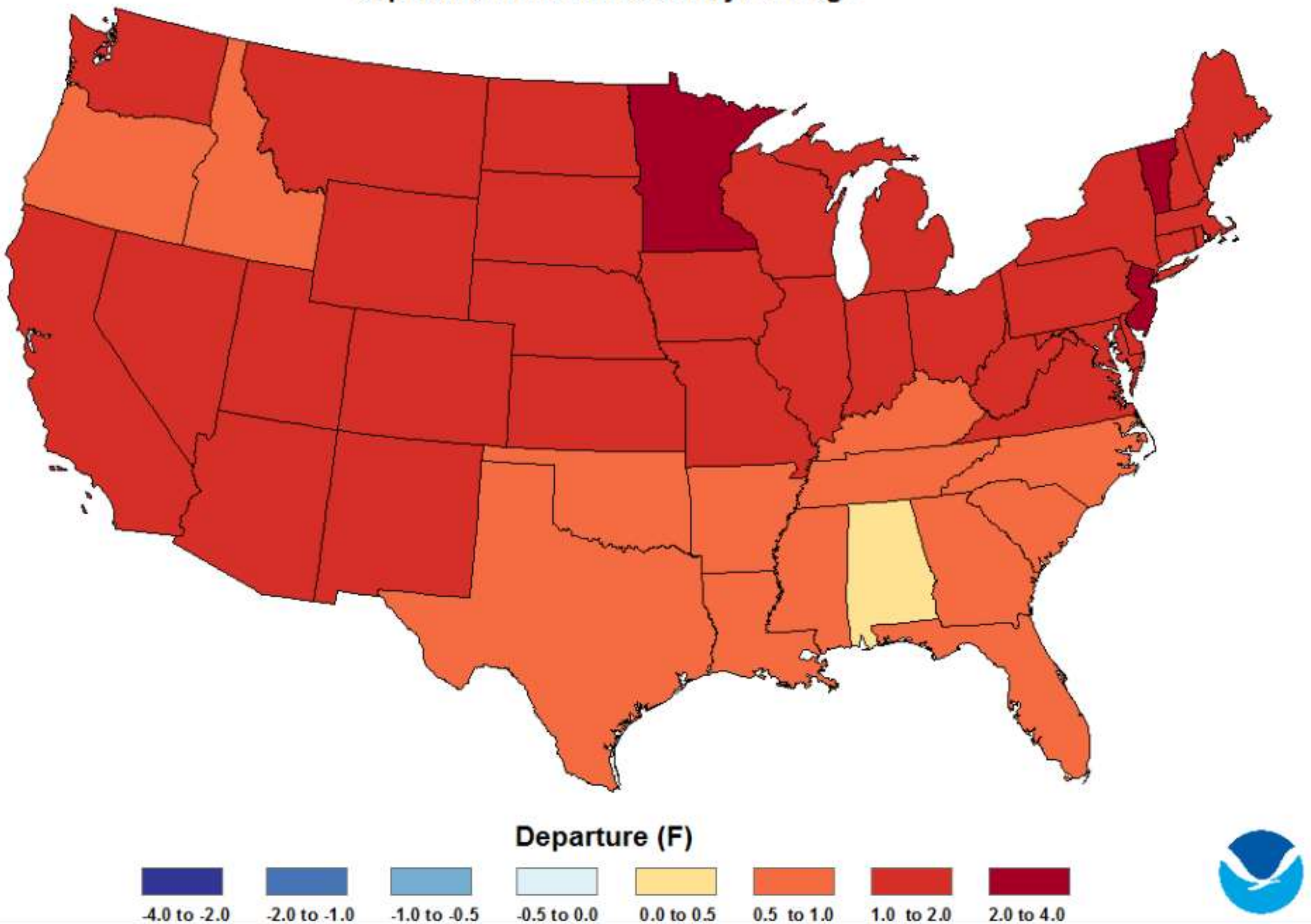
Average Minimum Temperature 1991-2000

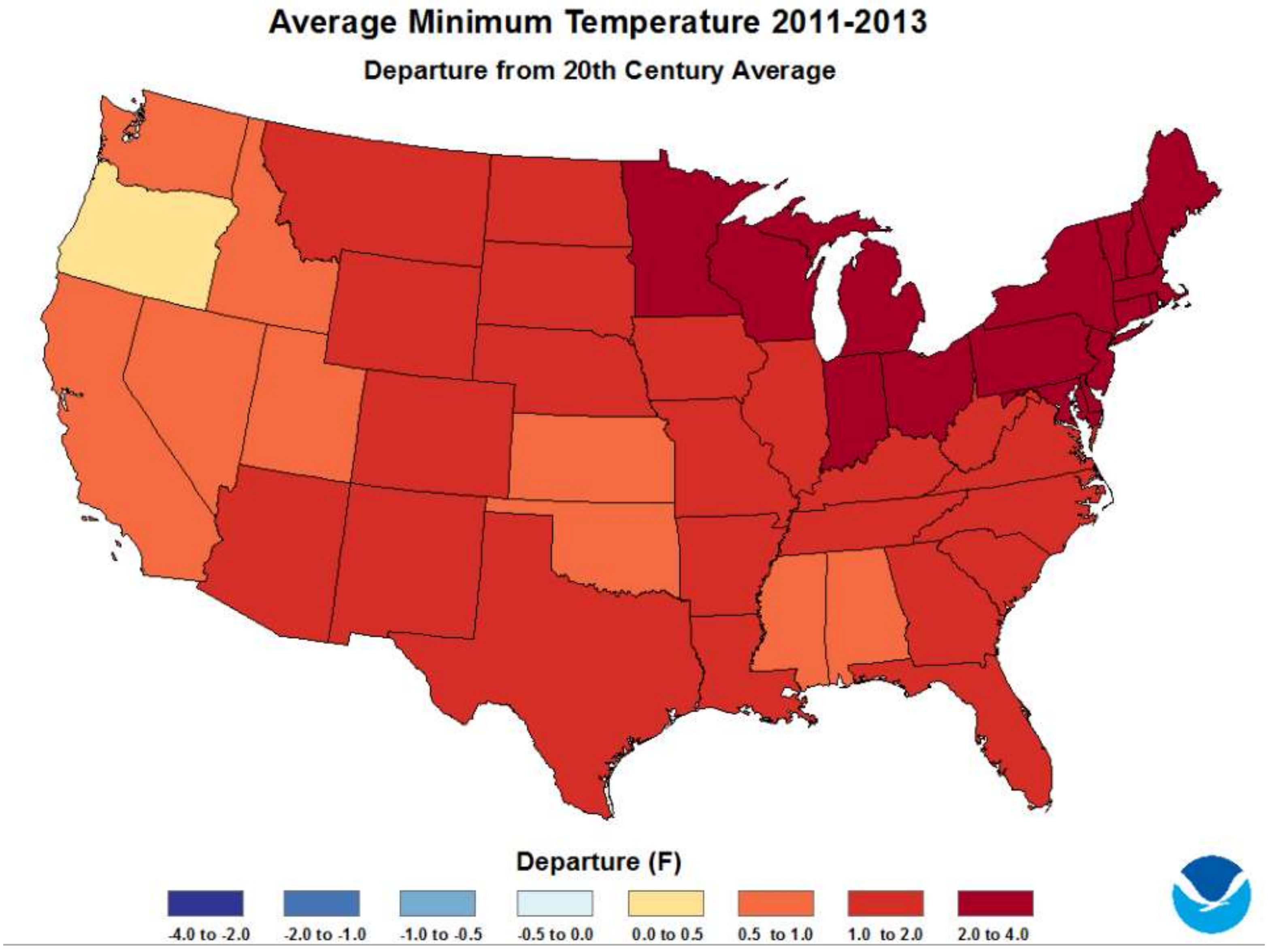
Departure from 20th Century Average

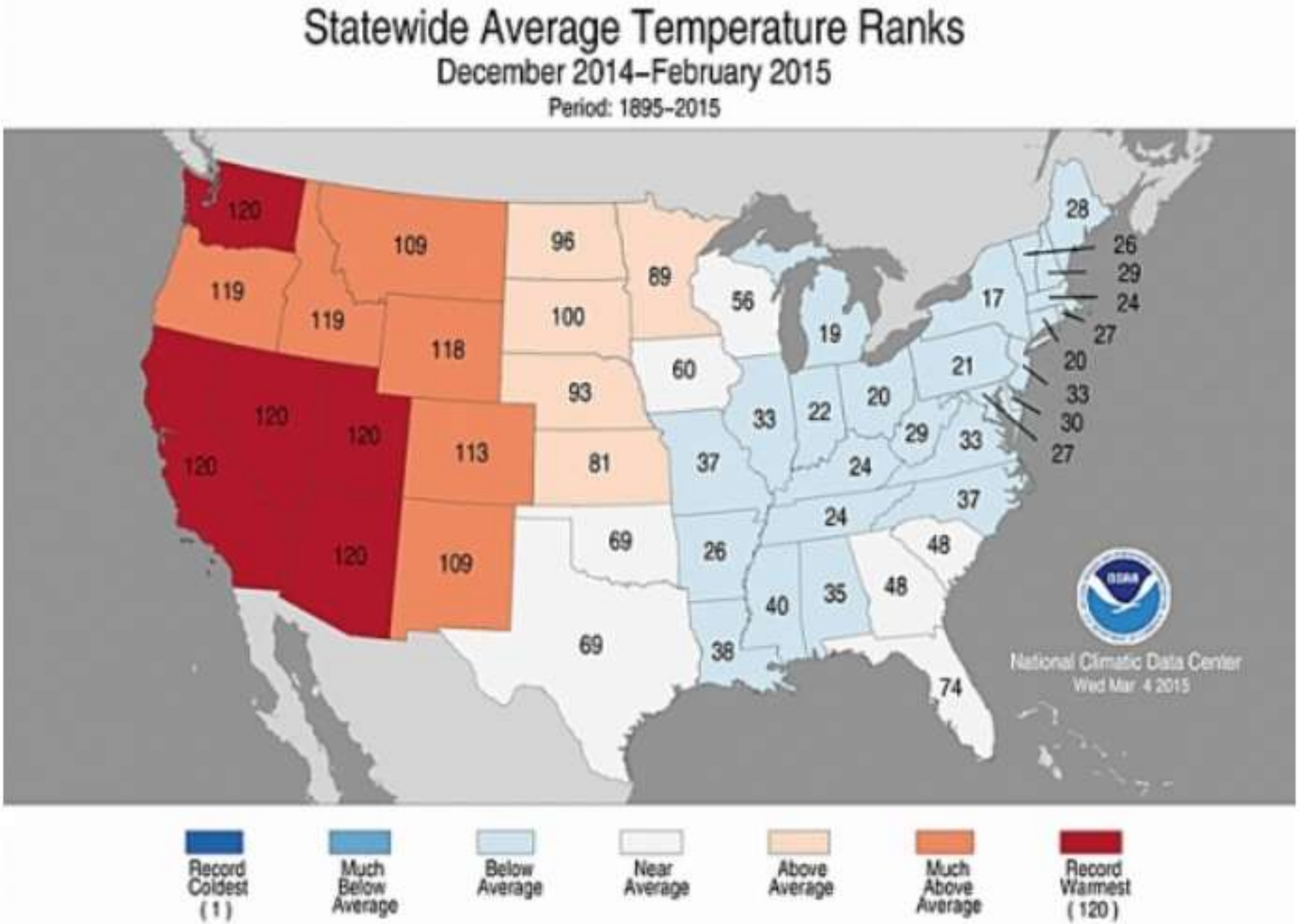


Average Minimum Temperature 2001-2010

Departure from 20th Century Average




Average Minimum Temperature 2011-2013
Departure from 20th Century Average
Departure (F)
-4.0 to -2.0
-2.0 to -1.0
-1.0 to -0.5
-0.5 to 0.0
0.0 to 0.5
0.5 to 1.0
1.0 to 2.0
2.0 to 4.0



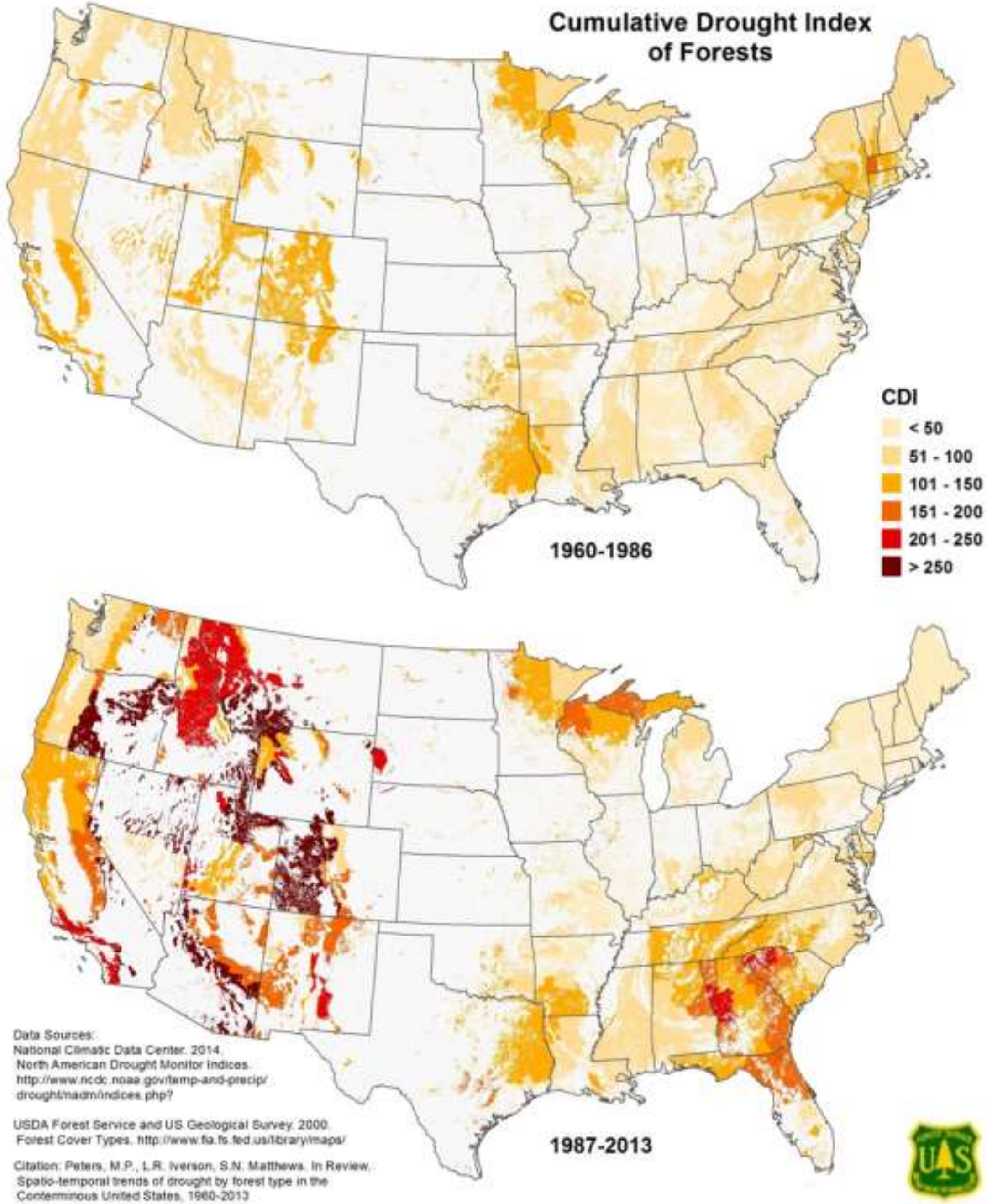
Statewide Average Temperature Ranks
December 2014–February 2015
Period: 1895–2015
120
109
96
89
119
119
56
28
26
29
24
17
27
100
118
19
60
21
20
93
120
120
33
22
20
33
30
29
33
27
120
113
81
37
24
37
24
69
48
26
120
109
35
48
40
69
38
74
National Climatic Data Center
Wed Mar 4 2015
Record Coldest (1)
Much Below Average
Below Average
Near Average
Above Average
Much Above Average
Record Warmest (120)

Bring in snow for the Iditarod in Anchorage

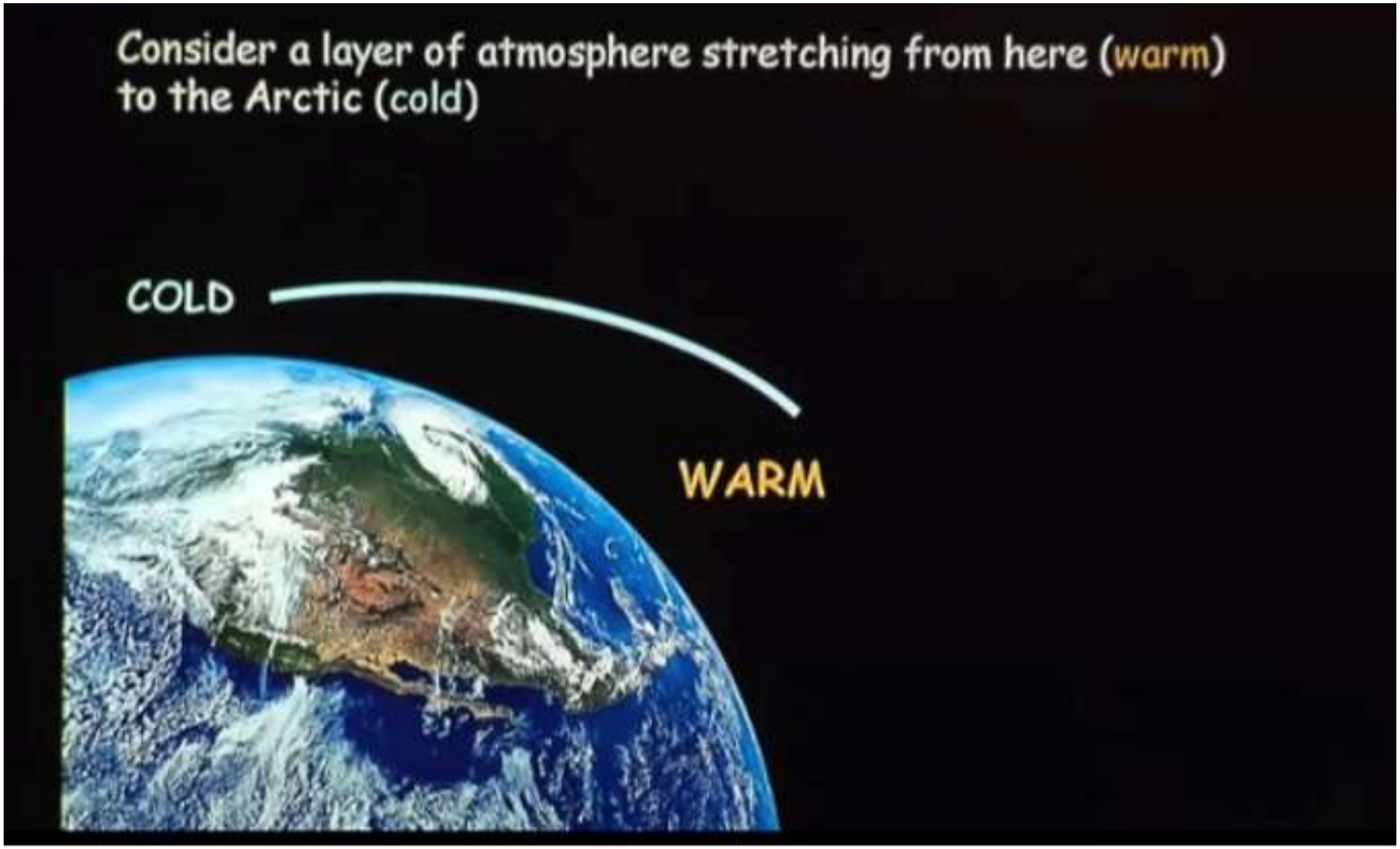
Snow is trucked in on March 7, 2015, for the ceremonial Iditarod start in Anchorage, Alaska.

Photo by David Hulen/Twitter

--While in Boston, where to put it?


Cumulative Drought Index
of Forests
1960-1986
CDI
< 50
51 - 100
101 - 150
151 - 200
201 - 250
> 250
1987-2013
Data Sources:
National Climatic Data Center. 2014.
North American Drought Monitor Indices.
http://www.ncdc.noaa.gov/temp-and-precip/
drought/nadm/indices.php?
USDA Forest Service and US Geological Survey. 2000.
Forest Cover Types. http://www.fia.fs.fed.us/library/maps/
Citation: Peters, M.P., L.R. Iverson, S.N. Matthews. In Review.
Spatio-temporal trends of drought by forest type in the
Conterminous United States, 1960-2013

Theory for weather extremes in mid-latitudes – Francis and others

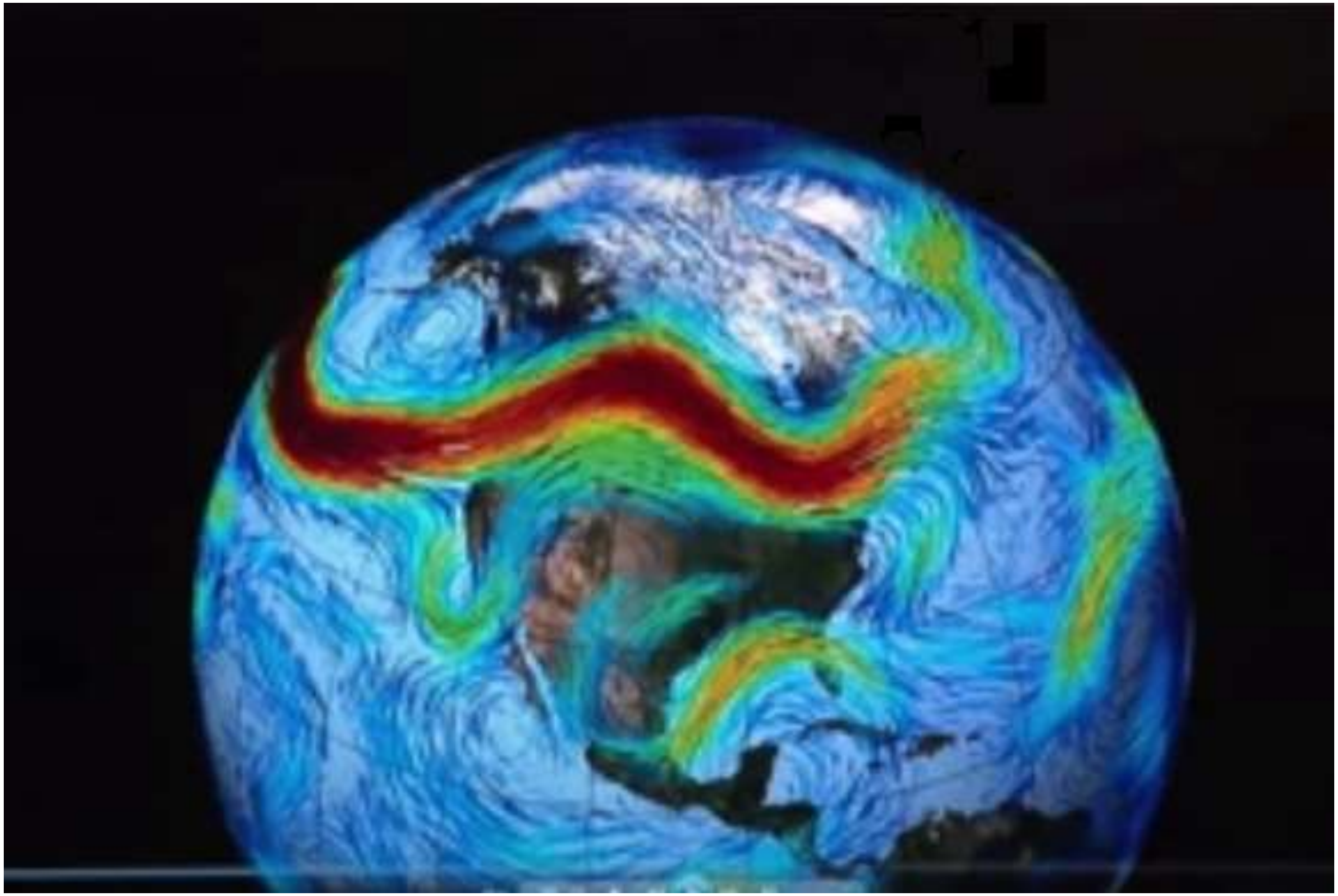


Francis, J. A. and S. J. Vavrus. 2015. Evidence for a wavier jet stream in response to rapid Arctic warming. Environmental Research Letters 10:014005.

Normal jet stream behavior

Francis, J. A. and S. J. Vavrus. 2015. Evidence for a wavier jet stream in response to rapid Arctic warming. Environmental Research Letters 10:014005.

“Normal jet stream – fast moving systems – less extreme weather

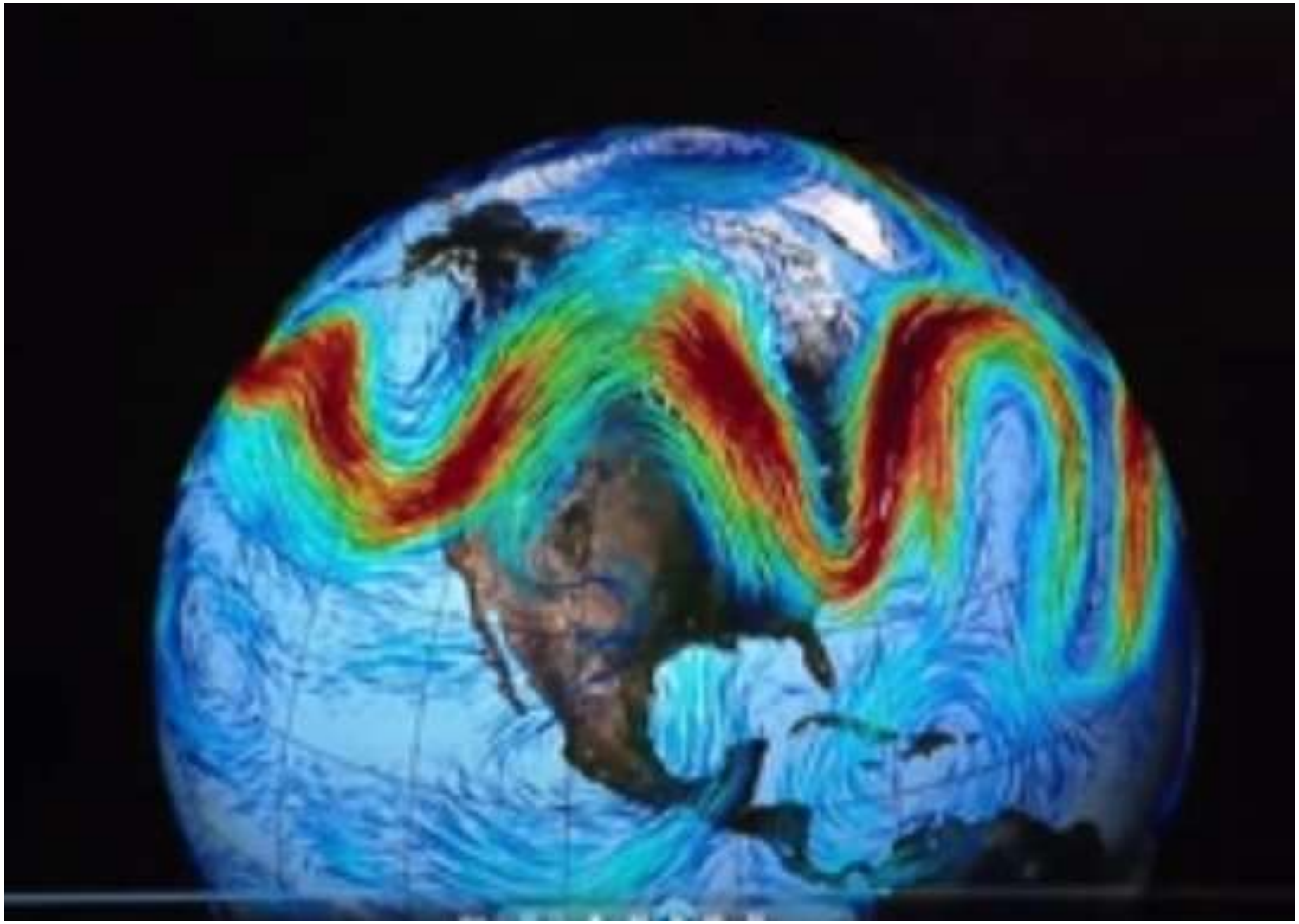


Francis, J. A. and S. J. Vavrus. 2015. Evidence for a wavier jet stream in response to rapid Arctic warming. Environmental Research Letters 10:014005.

Since ~1990 – Arctic amplification – weakens jet stream

Francis, J. A. and S. J. Vavrus. 2015. Evidence for a wavier jet stream in response to rapid Arctic warming. Environmental Research Letters 10:014005.

“Wavier” jet stream – slow moving systems - more extremes

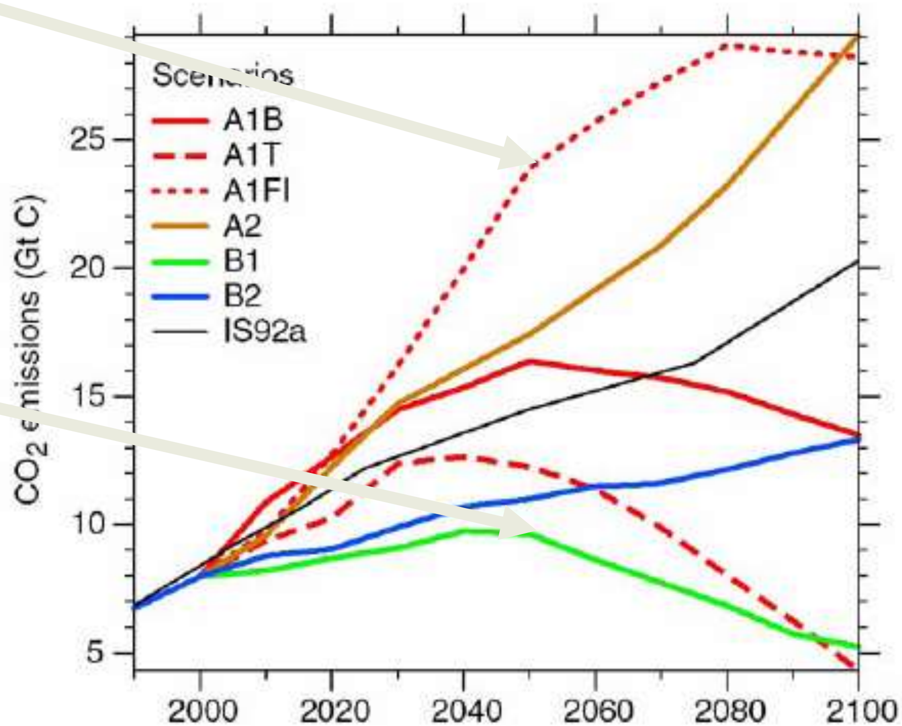


Francis, J. A. and S. J. Vavrus. 2015. Evidence for a wavier jet stream in response to rapid Arctic warming. Environmental Research Letters 10:014005.

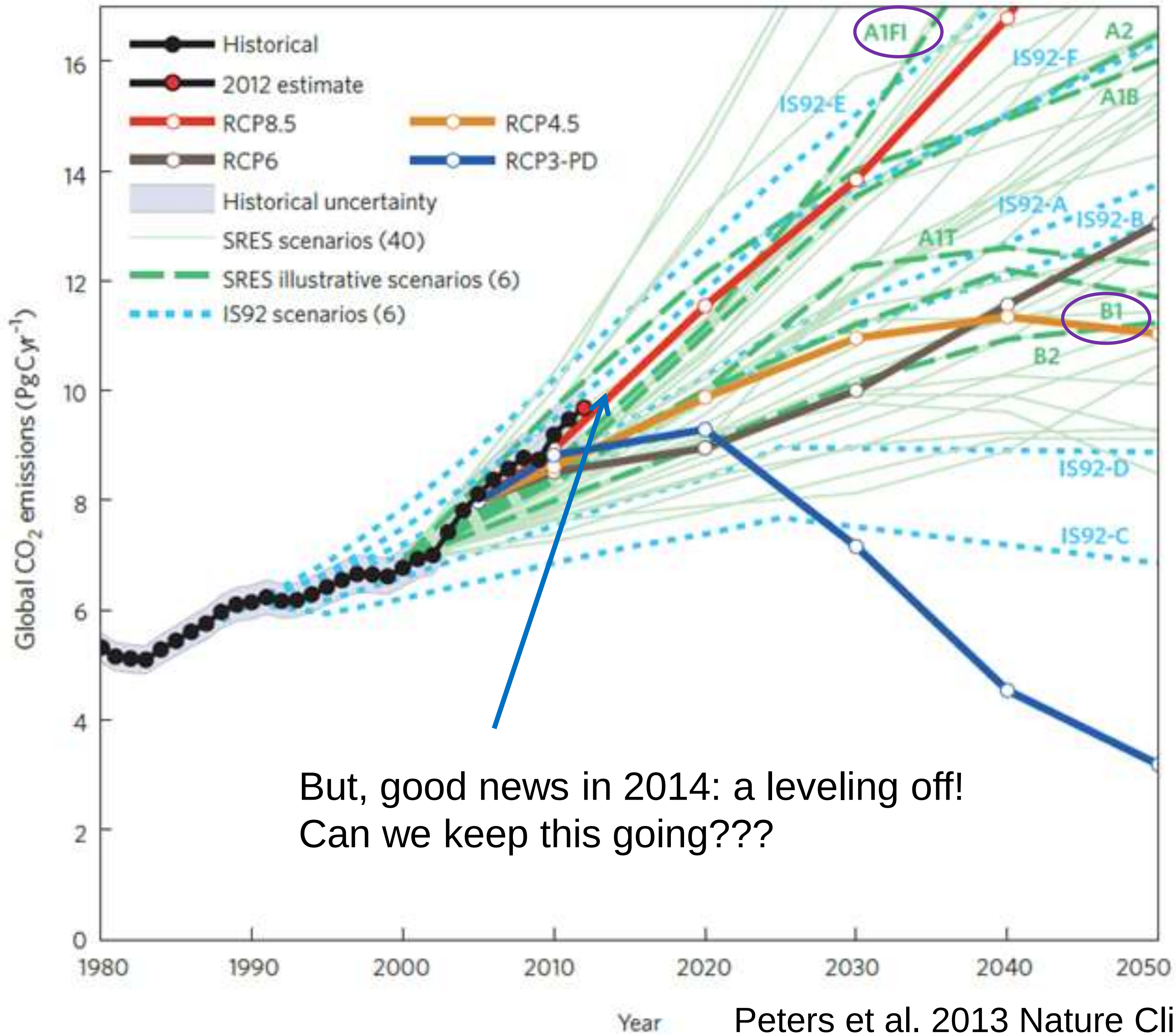
The Future Climate – Depends on what we humans decide!

Emissions of CO_2 – range of scenarios over next 100 years

- A1fi (high)-fossil fuel intensive until later century
- B1 (low)-shift to resource efficient technology

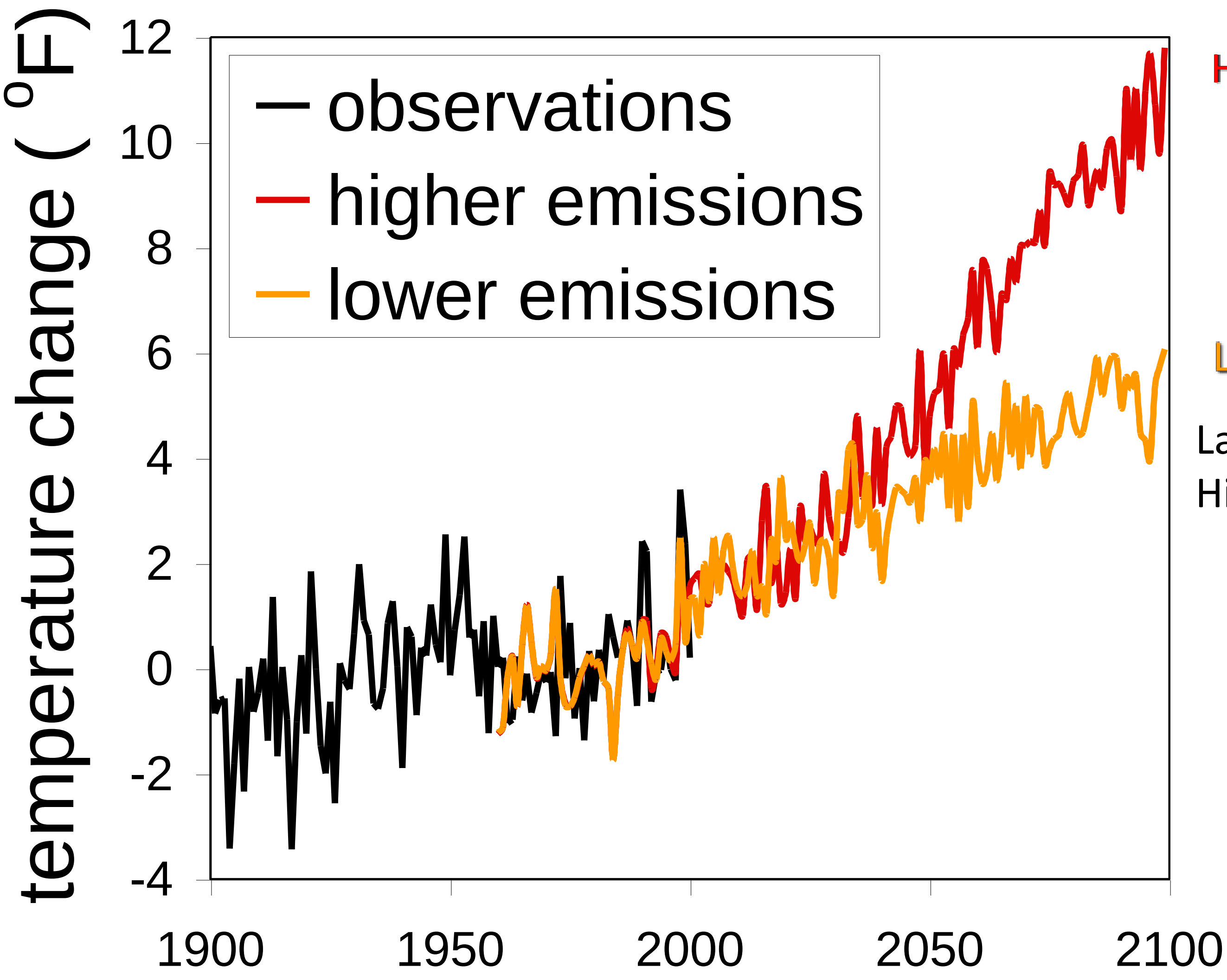


Past and potential future trends in annual CO2 emissions



Peters et al. 2013 Nature Climate Change

Rising Temperatures in NE. US
(annual average)



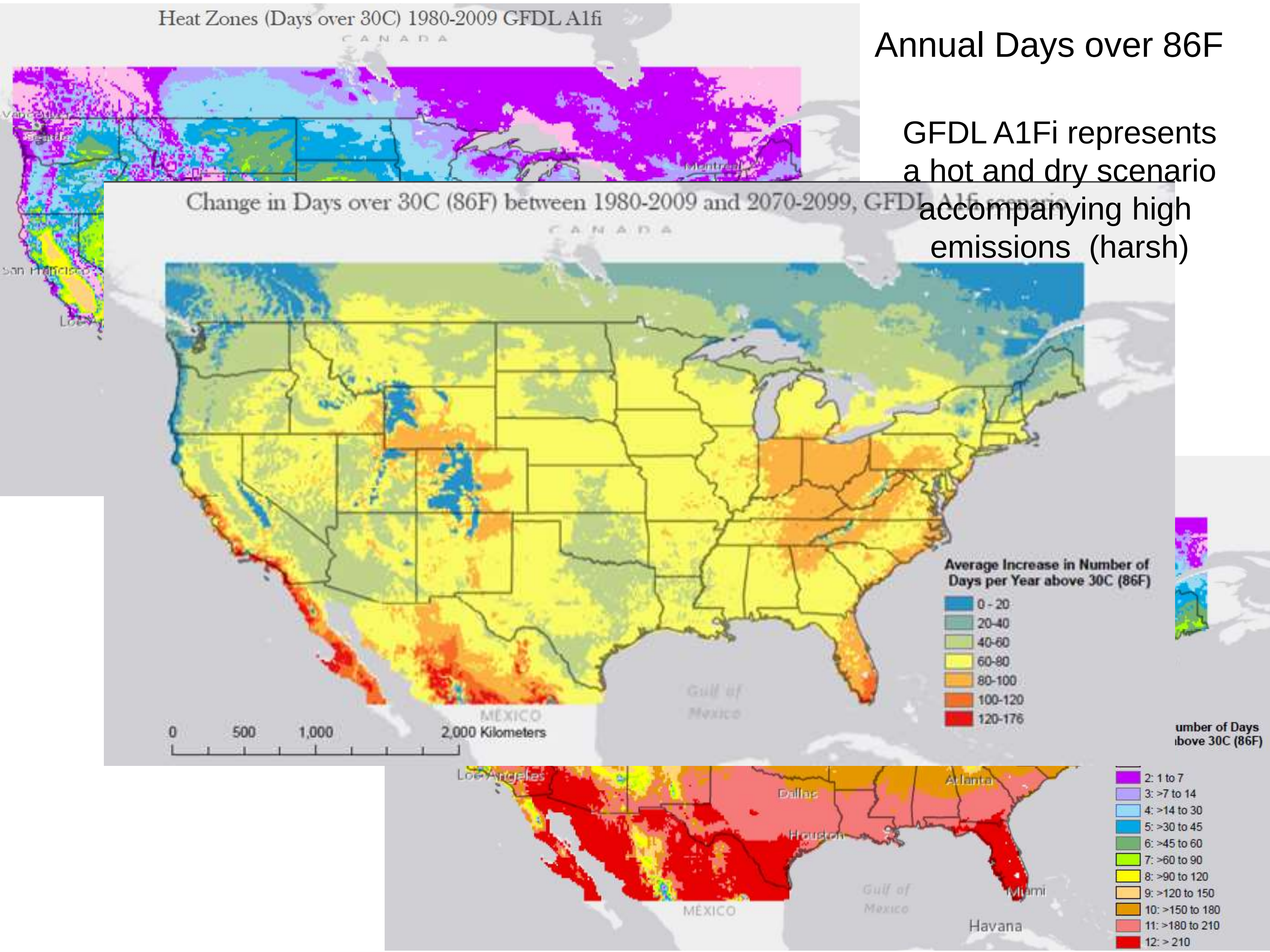
Higher: 6.5-12.5°F

Lower:3.5-6.5°F

Large difference between High and Low emissions!

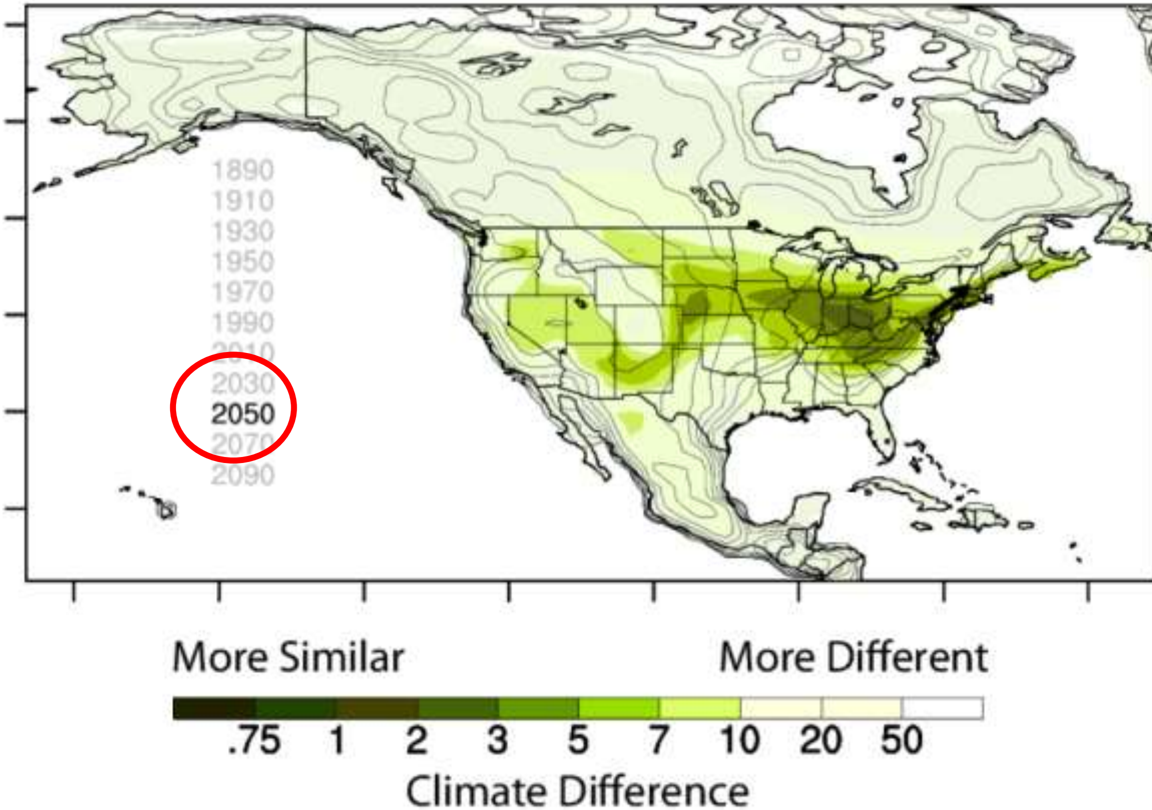
Annual Days over 86F

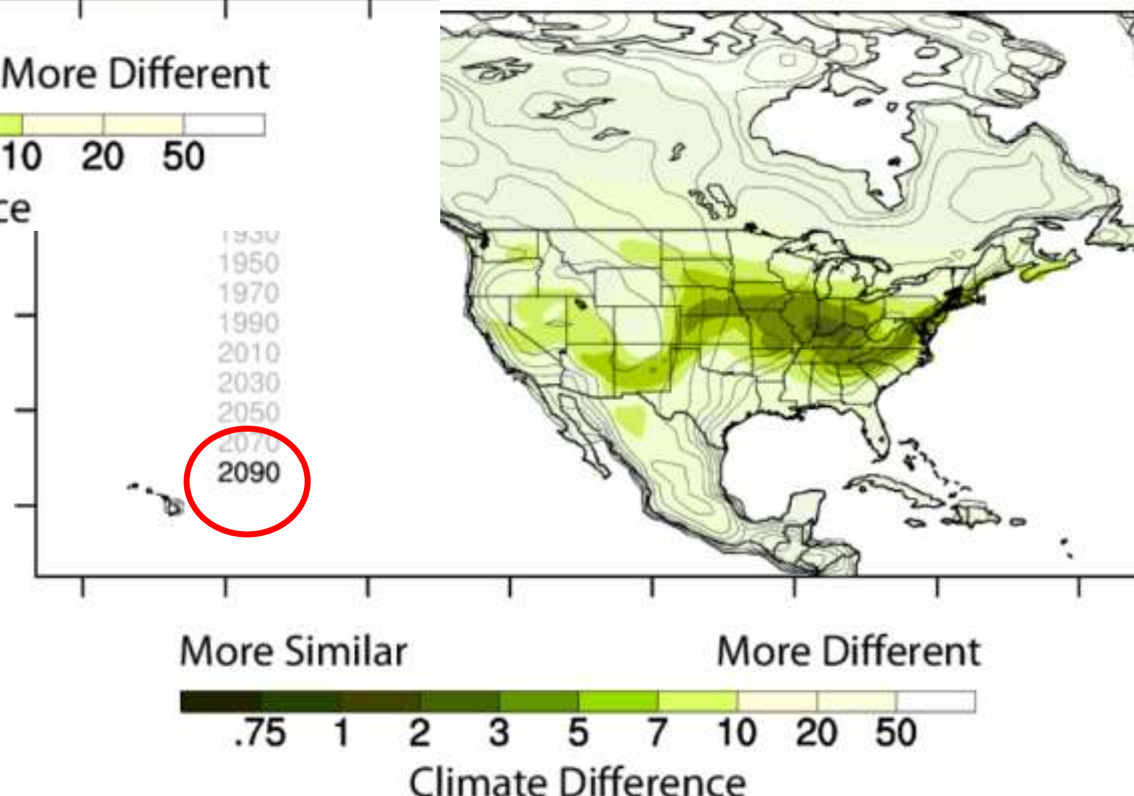
GFDL A1Fi represents a hot and dry scenario accompanying high emissions (harsh)



What are most similar climates now to Vermont climate in 2050, 2090?

Medium emissions
(RCP4.5)
2050-2090





U.S. DEPARTMENT OF ENERGY

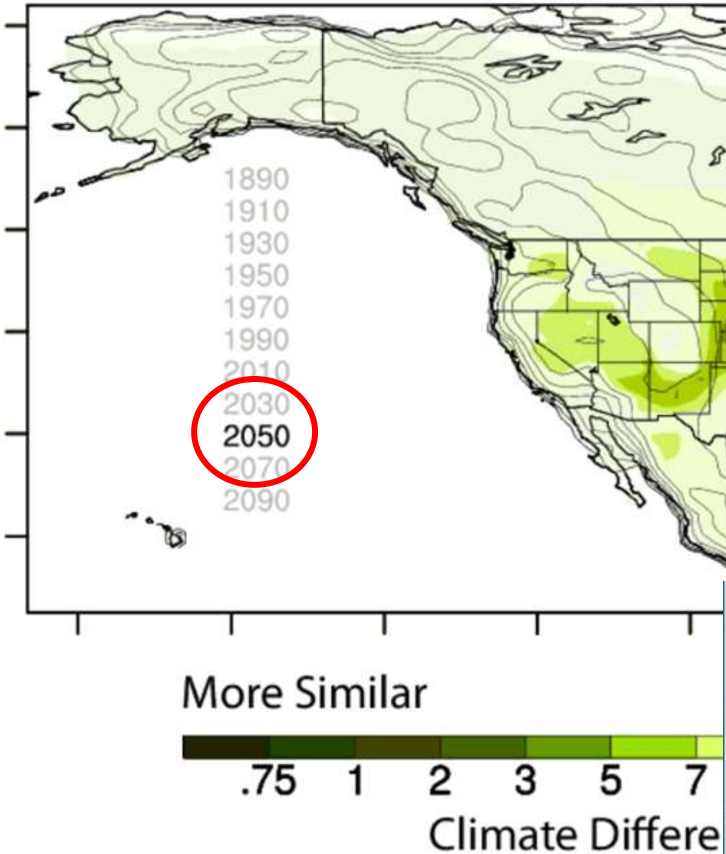
BERKELEY LAB

http://esd.lbl.gov/about/staff/charleskoven/climate_vectors.html

Top 20 species now in Southeast Pennsylvania according to Ecoregion 221D

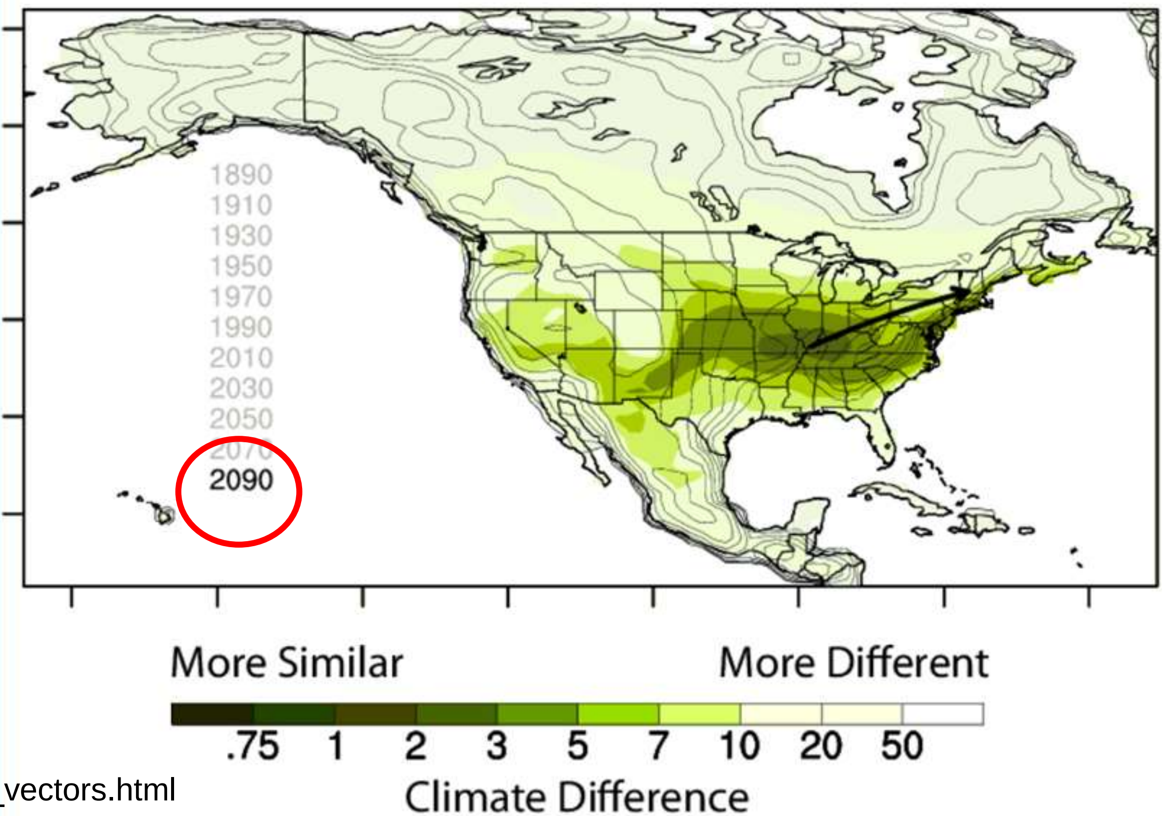
red maple
white ash
black cherry
yellow-poplar
chestnut oak
northern red oak
black oak
blackgum
flowering dogwood
American beech
white oak
sassafras
sugar maple
sweet birch
pignut hickory
eastern redcedar
scarlet oak
black walnut
mockernut hickory
boxelder

Medium emissions
(RCP4.5)
2090



What are most similar climates now to Vermont climate in 2050, 2090?

High emissions
(RCP8.5)
2050-2090



http://esd.lbl.gov/about/staff/charleskoven/climate_vectors.html

Top 20 species now in Southern Illinois according to Ecoregion 223G

American elm
white oak
hackberry
sassafras
shagbark hickory
silver maple
white ash
red maple
black oak
green ash
shingle oak
sugar maple
black cherry
pignut hickory
pin oak
boxelder
black walnut
sycamore
slippery elm
northern red oak

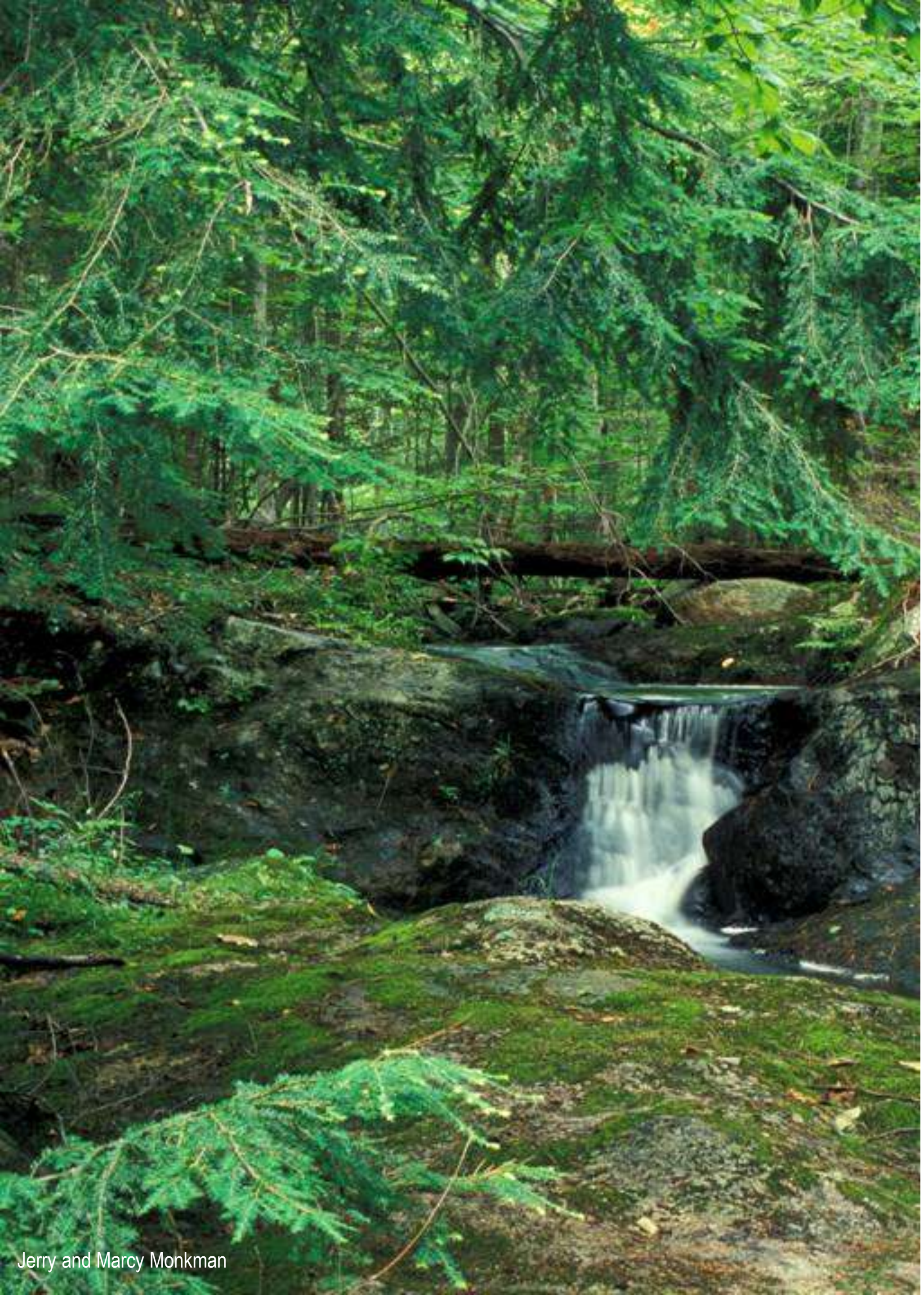
High emissions
(RCP8.5)
2050-2090


Invasives
Natural Forest Dynamics
Landowner Objectives
Timber Sale Revenue
Forest Health
Past Management History
Wildlife Habitat
Disturbance: Past + Future
Certification Requirements
Climate Change
And more!!
Deer

Climate-Informed Forest Management?

All forest managers should…

- argue about the causes and solutions to global climate change
- take the same actions to respond to climate change
- acknowledge climate change as a legitimate risk to forests in our region
- consider the best available information on climate change impacts to forests
- incorporate a range of adaptation ideas into planning goals and objectives



Impacts on Tree Species Suitable Habitats

Climate has always been changing

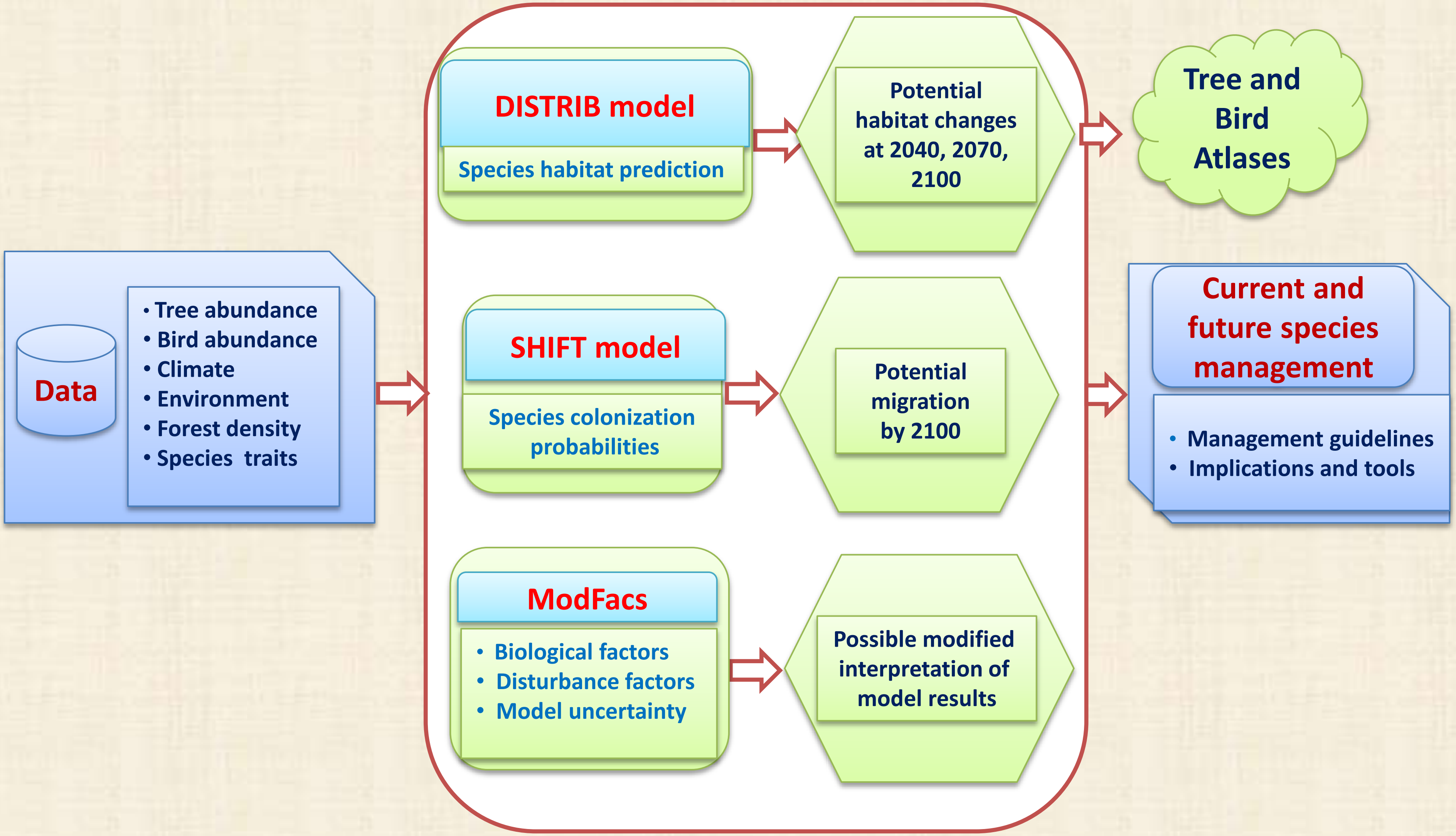
~ 13,000 years ago

Today

http://www.esd.ornl.gov/projects/qen/nercNORTHAMERICA.html

MODELING POTENTIAL CHANGES IN TREE SPECIES HABITATS

Multi-stage modeling scheme



Iverson et al. 2011 Ecosystems

Atlas ingredients (DISTRIB model)

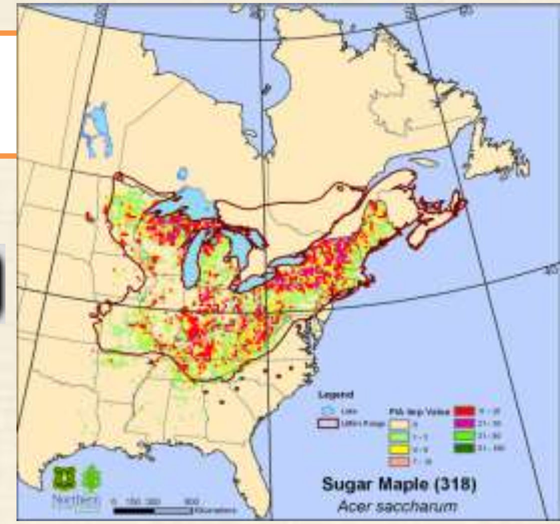
Modeled responses

Trees: Forest Inventory -> Importance Value (IV) -> measure of abundance
Birds: Breeding Bird Survey -> Incidence -> measure of abundance

Forest Inventory and Analysis (FIA)
- Eastern US extent (37 states)
- 134 tree taxa
- > 100,000 plots
- ~ 3 million tree records

→ **Importance value (IV)**
for 134 tree species
(Range: 0-100)

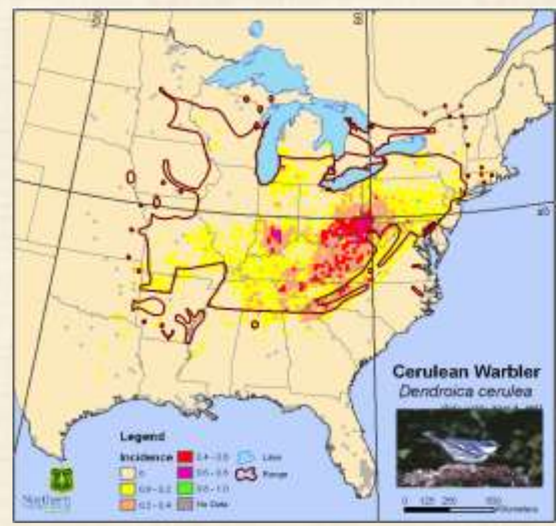
Abundance & Little's Range Maps



Breeding Bird Survey (BBS)
- Eastern US extent (37 states)
- 147 bird species
- ~ 1000 BBS routes

→ **Incidences**
for 147 bird species
(Range of incidences: 0-1)

Abundance & NatureServe Maps



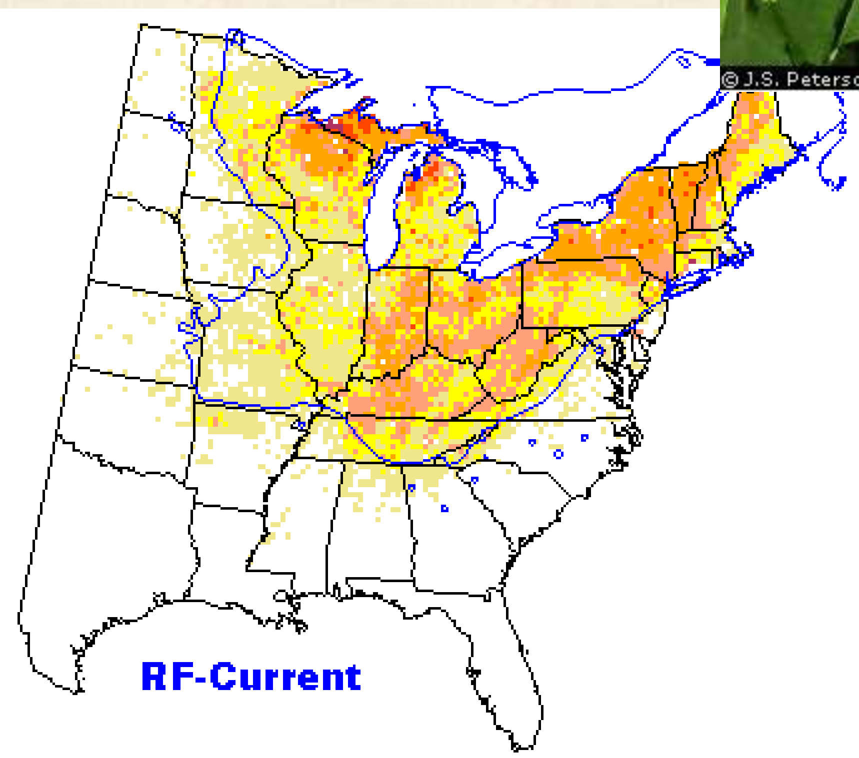
Check out Steven Matthews talk in next session to dive into birds and trees interactions!

Rate each species model for reliability

Model Reliability: High Medium Low

Iverson et al. 2011 Ecosystems

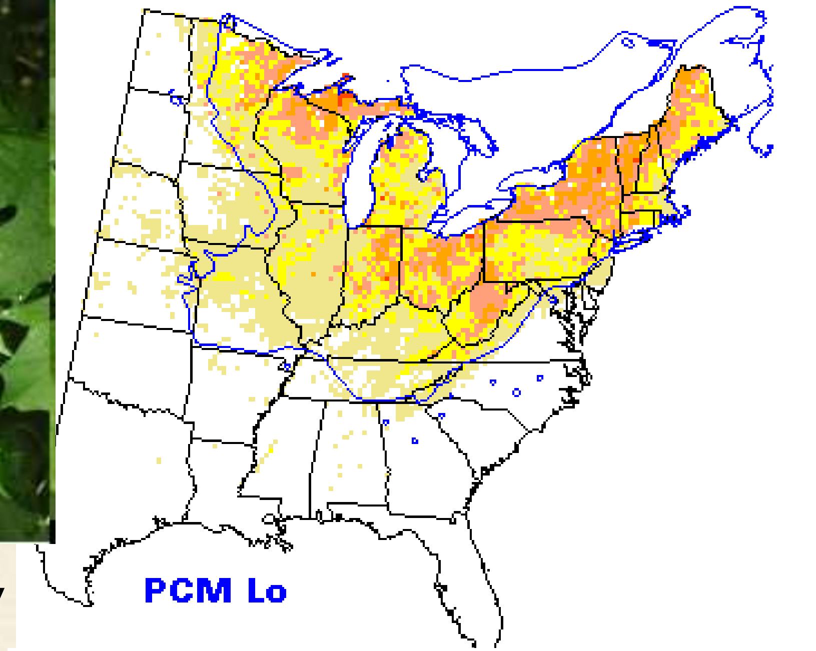
Sugar Maple
Habitat Changes by 2100

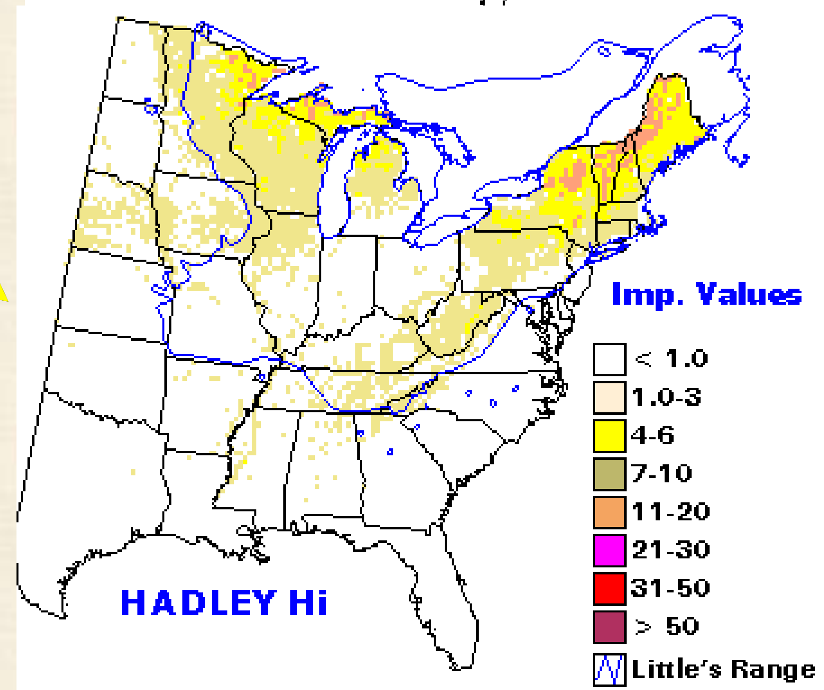


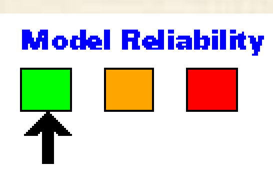
Low

?

High







Iverson et al. 2008, Forest Ecology and Management

USDA United States Department of Agriculture
Forest Service

Landscape Change Research Group LCRG

Northern Research Station

Forest Service Home | About the Agency | Contact the National Office

You are here: Northern Research Station Home / Tools & Applications / Climate Change Atlas / Tree Atlas / red maple *(Acer rubrum)*

red maple (*Acer rubrum*)

Model Reliability: High

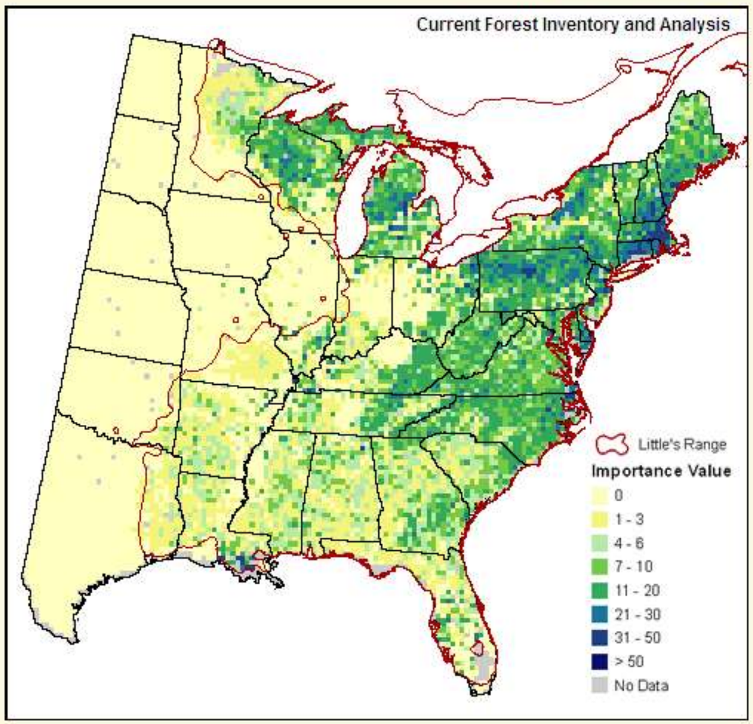
Current Distribution | Climate Scenarios | Predictor Maps

Current Distribution Maps for red maple

Help »

Current Forest Inventory and Anal

Compare Two Species



View All Climate Scenarios in Google Earth (259 KB)

About red maple

Climate Change Adaptability

What traits will impact red maple's ability to adapt to climate change, and in what way?:

Positive Traits

- Seedling establishment
- Environment habitat specificity
- Edaphic specificity
- Shade tolerance
- Dispersal

Negative Traits

- None

More on these traits and MODFACT

Range and Niche Maps

Search for Trees & Birds:

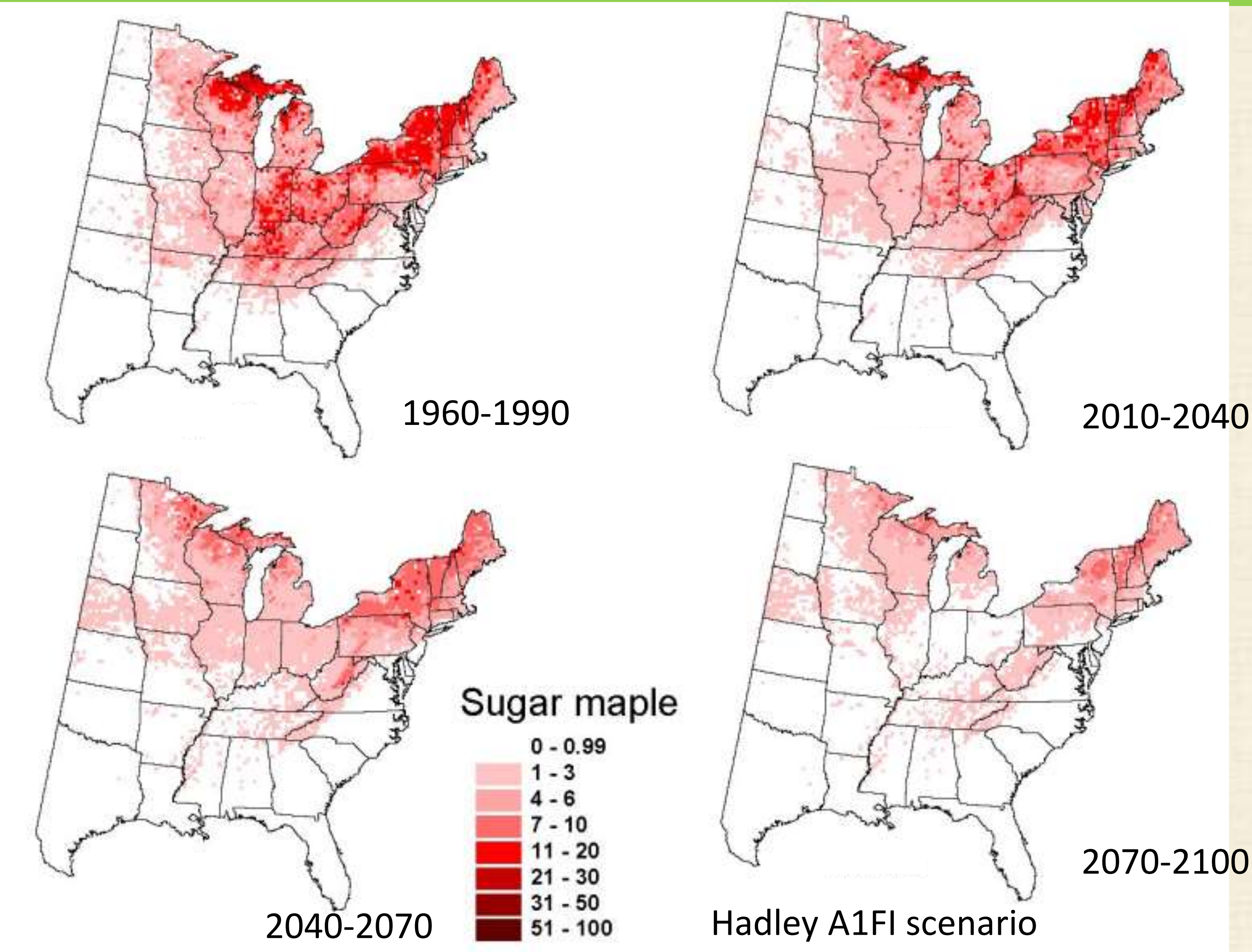
Enter a common or scientific name

List of Trees | List of Birds

http://www.nrs.fs.fed.us/atlas

Climate Change Atlases | Learn About the Models | Products | Get Help

Sugar Maple Habitat – change through time



Modifying Factors (ModFacs)

- We rate biological and disturbance characteristics for positive or negative impacts
- We also quantify some aspects of uncertainty
- Goal was to evaluate more realistic outcomes at regional and local levels

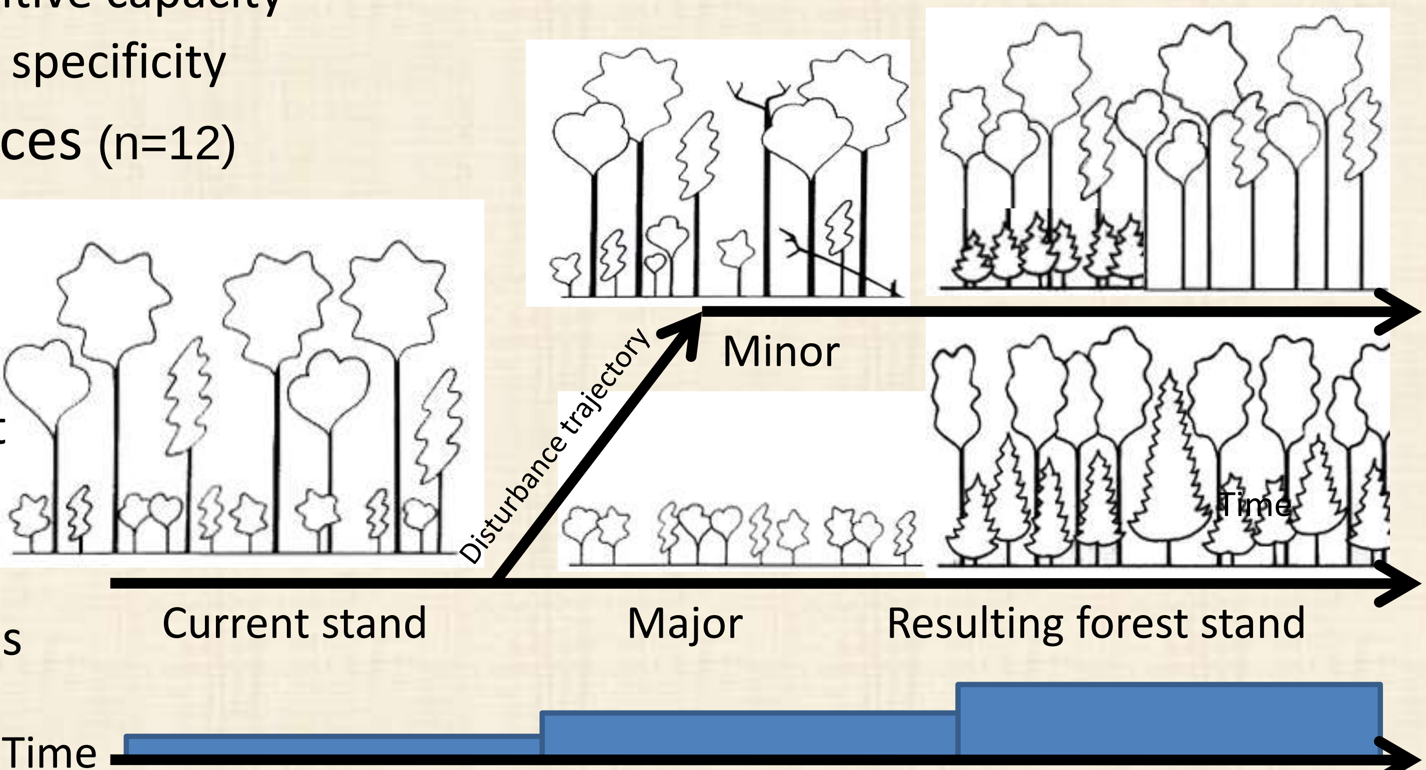


Matthews et al. 2011, For. Ecol.. Manage.

Modification Factors help in interpretation of potential futures

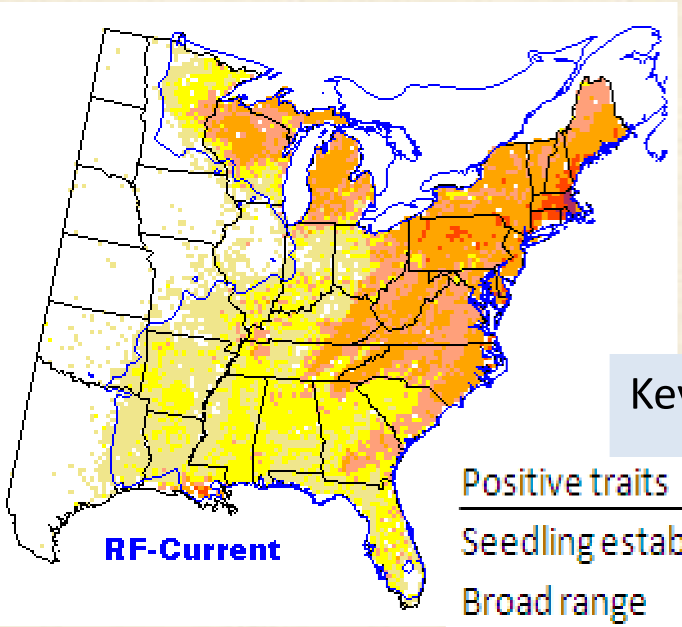
<u>Some of the ModFacs</u>

- Biological traits (n=9)
  - Competitive capacity
  - Edaphic specificity
- Disturbances (n=12)
  - Insects
  - Disease
  - Fire
  - Drought
  - Flood
  - Wind
  - Invasives
  - Browse



Climate change pressure and disturbance intensity increases thus altering habitat suitability of species

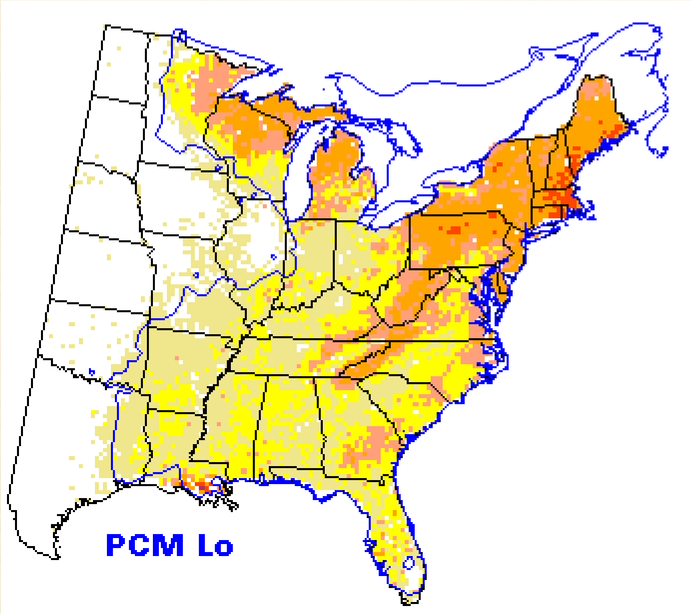
Red Maple

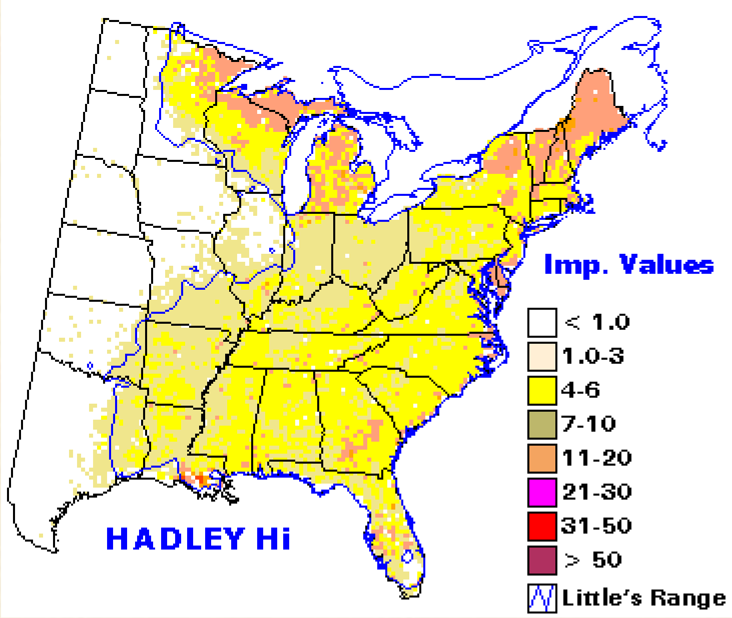


Low

?

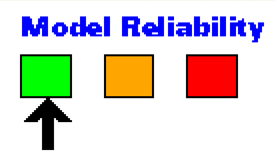
High



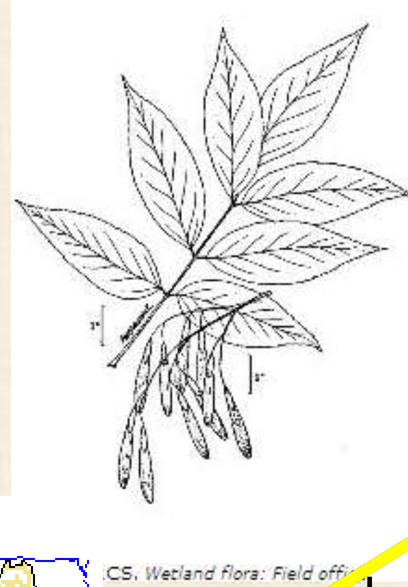


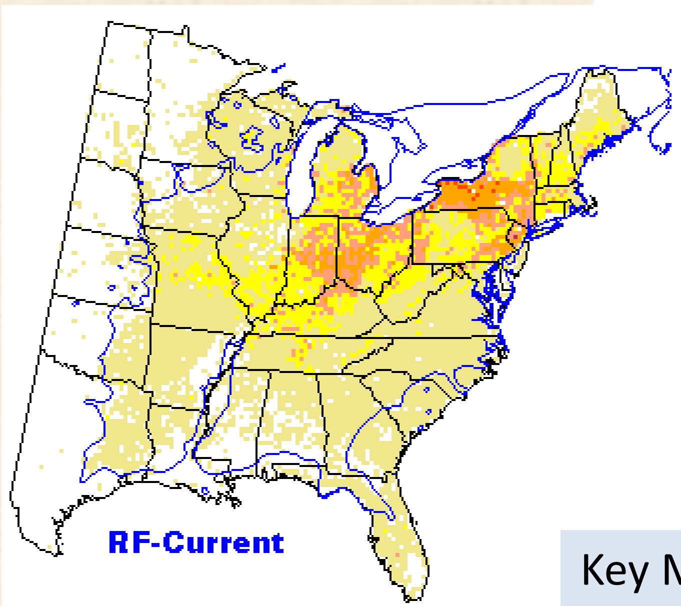
Key ModFacs

Positive traits	Negative traits
Seedling establishment	None
Broad range	
Broad soil tolerance	
Shade tolerance	
Dispersal	



White Ash

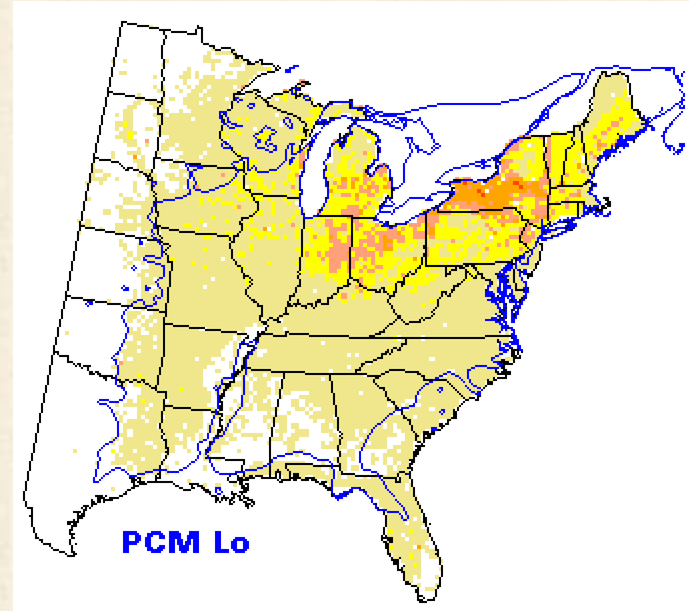


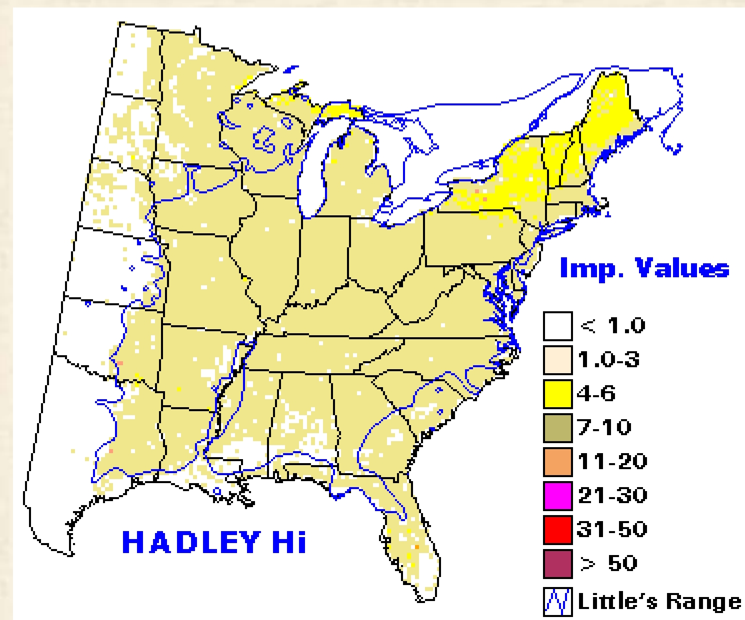


Low

?

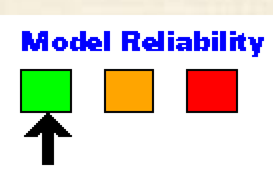
High





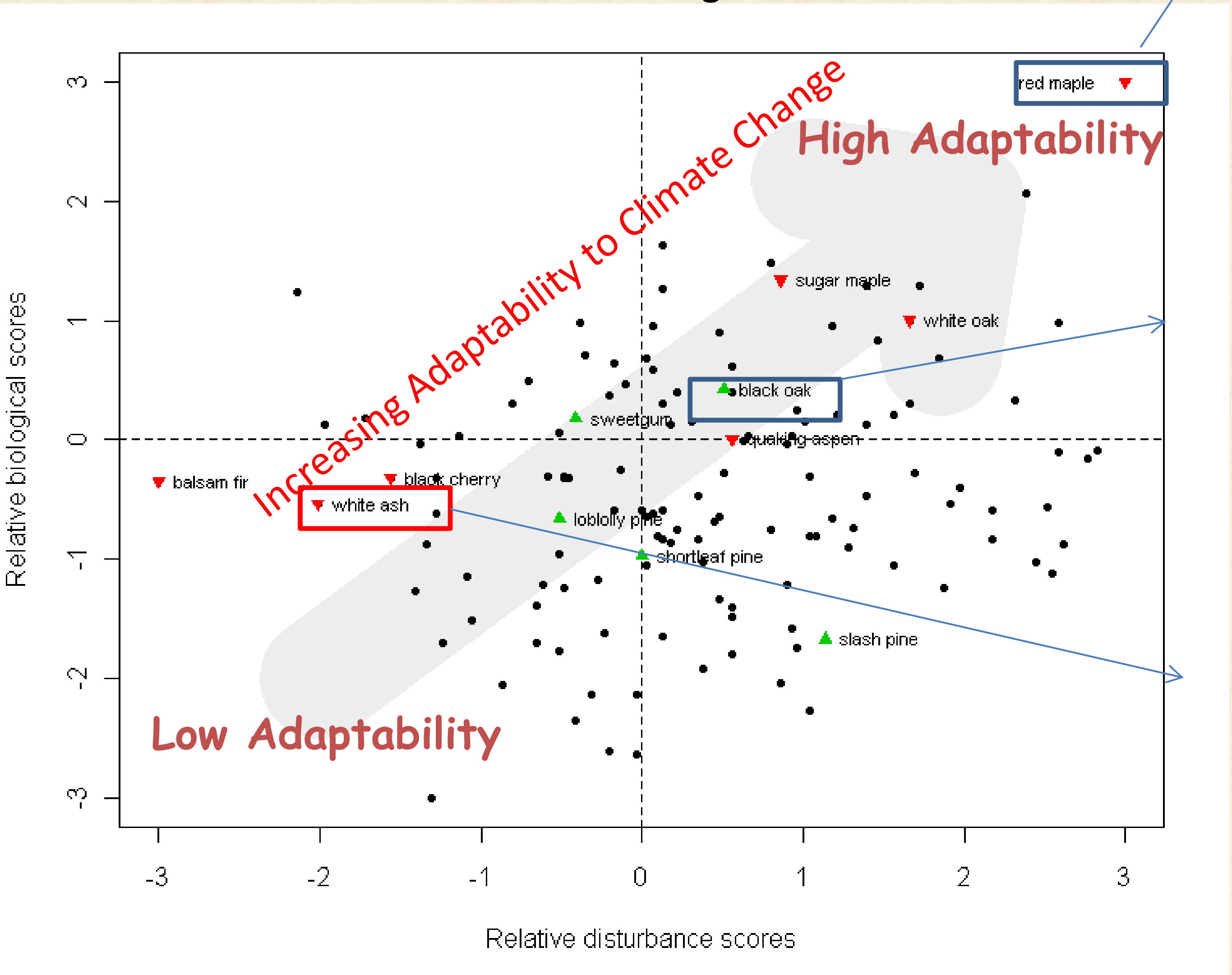
Key ModFacs

Positive Traits	Negative Traits
None	Insect pest (EAB) Competition – light Fire - topkill



Modification Factors

12 Disturbance Factors and 9 Biological Factors considered



Red Maple:

- Projected habitat declines
- Characteristics suggest high adaptability

Black Oak:

- Projected habitat increases
- Positive ModFac profile suggests it may be able to persist in harsh areas

White Ash:

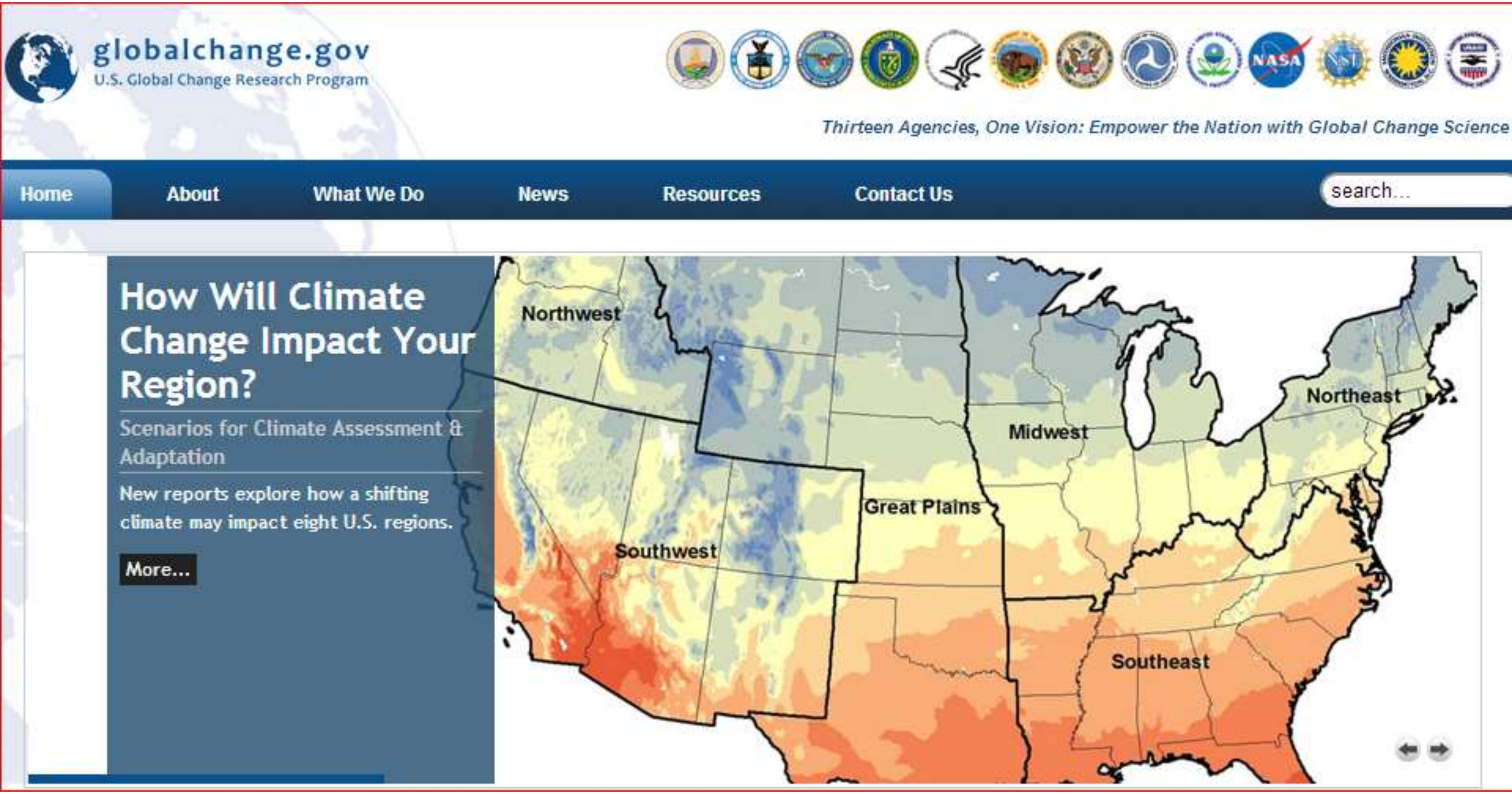
- Projected habitat declines
- Negative ModFac
- Metrics suggest it will likely face severe limits in eastern US

Matthews et al. 2011, For. Ecol. Manag.; Iverson et al. 2011 Ecosystems

U.S. Global Change Research Program
National Climate Assessment
http://assessment.globalchange.gov

Preparing the Nation for Change

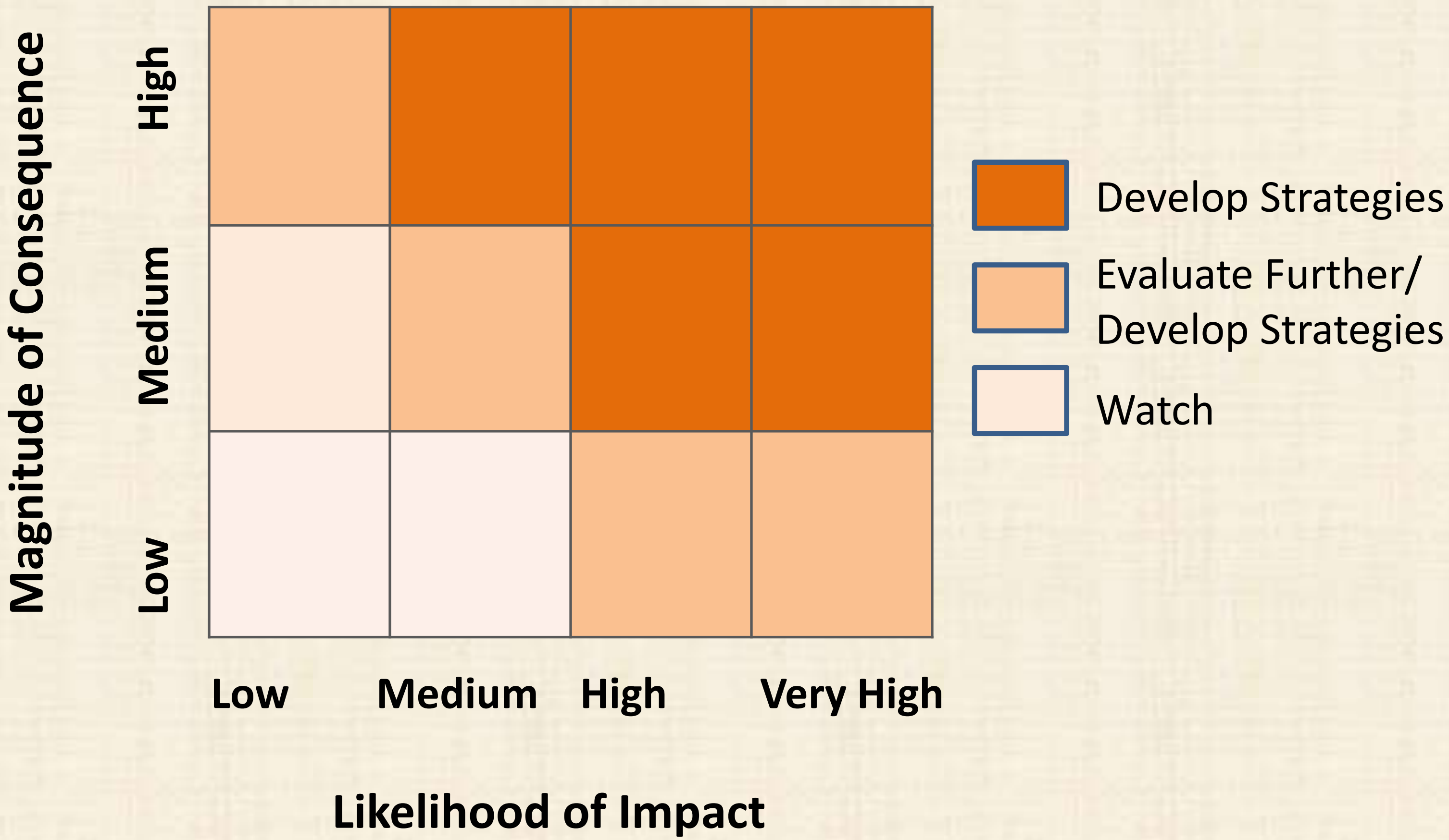
Introduction to the National Climate Assesement



Mandated by Congress every four years -
to include methods to document climate-related risks and opportunities

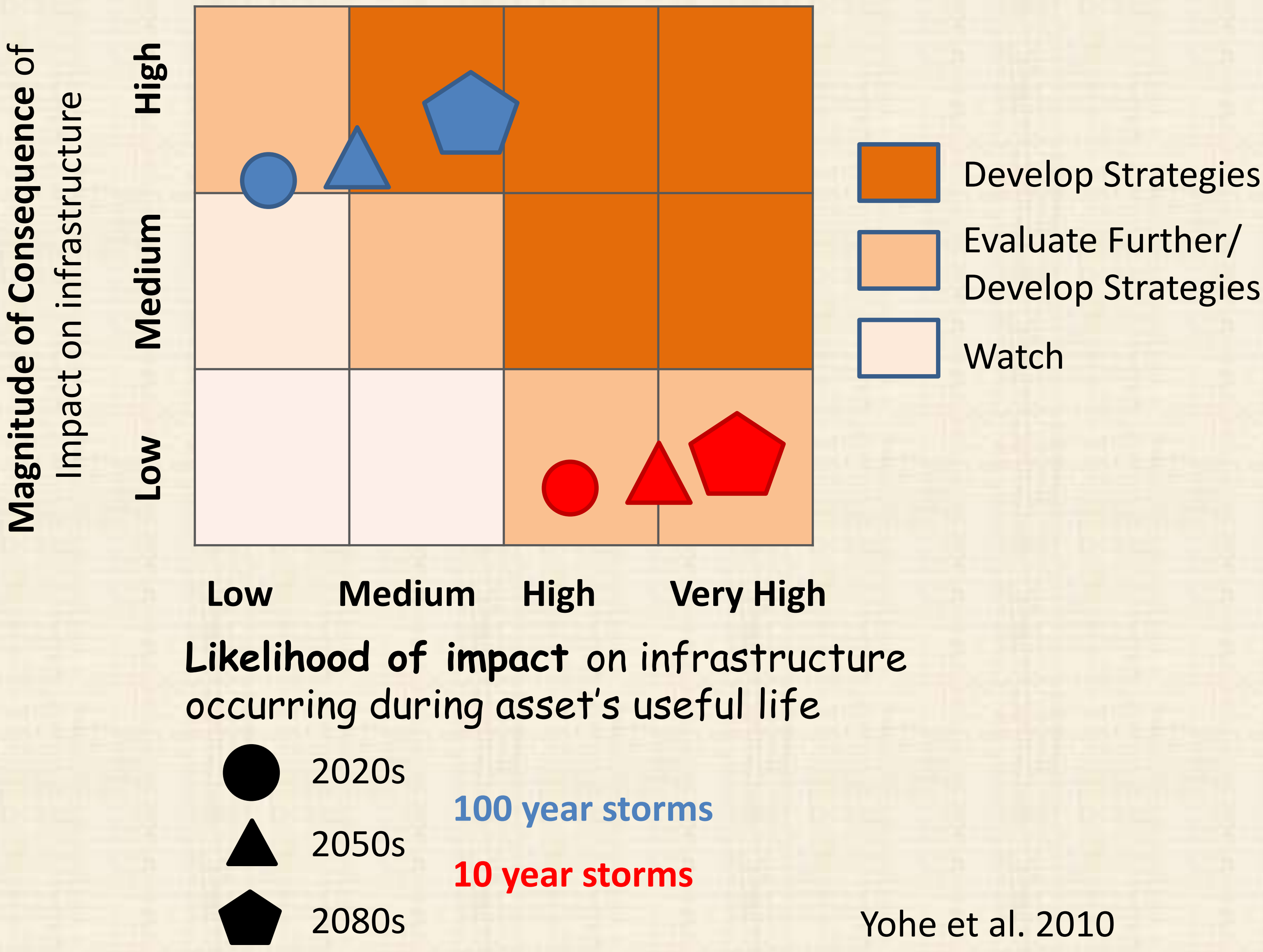
The Risk Matrix of the National Climate Assessment

Risk = Likelihood * Consequences



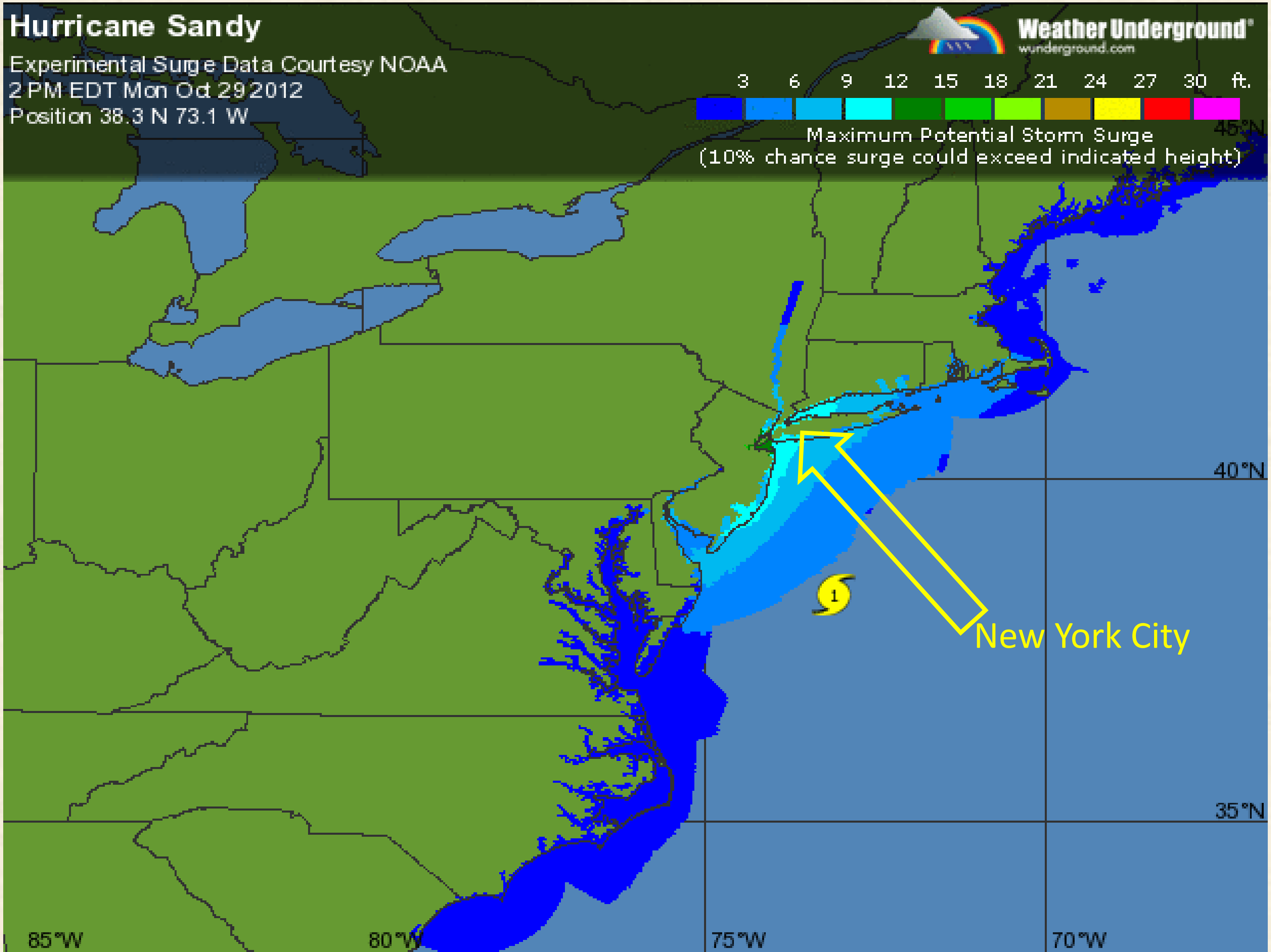
Risk of Flood Damage to Infrastructure

New York City: 2020s, 2050s, 2080s for 10- and 100-year floods

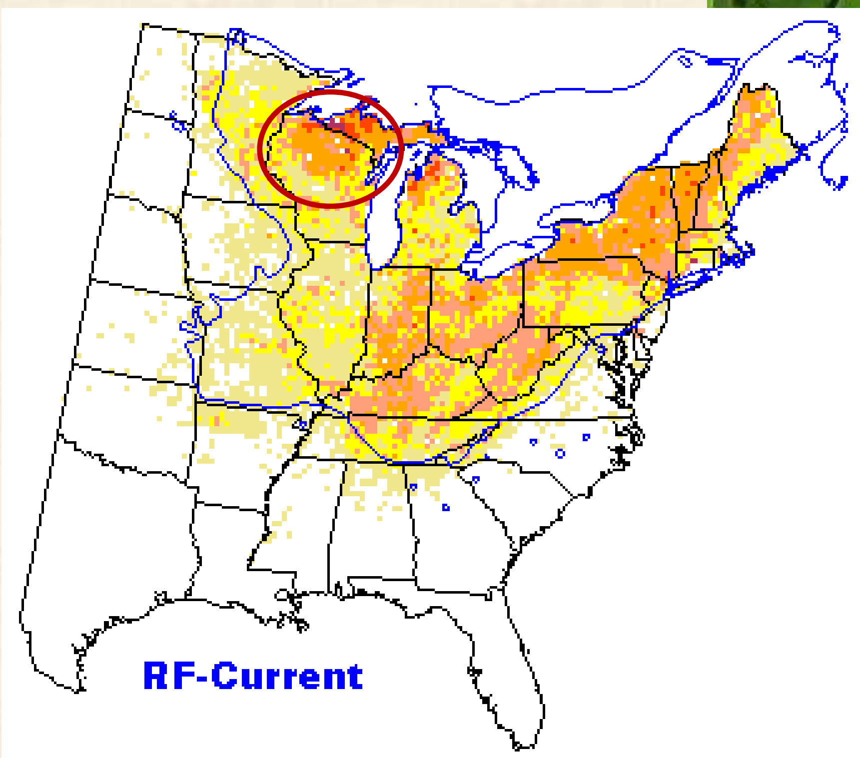


Yohe et al. 2010

Storm Surge from Sandy, Oct 29-31,2012



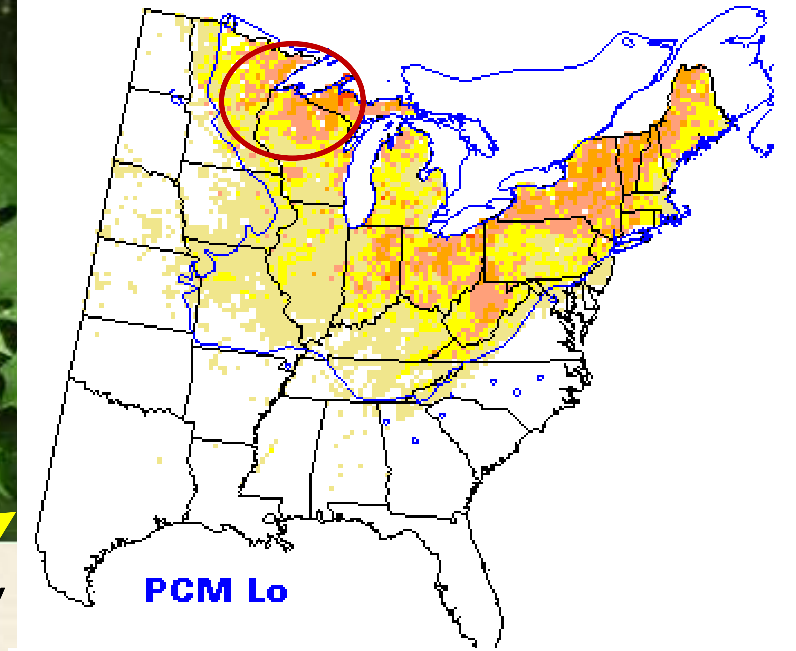
Sugar Maple
Habitat Changes by 2100

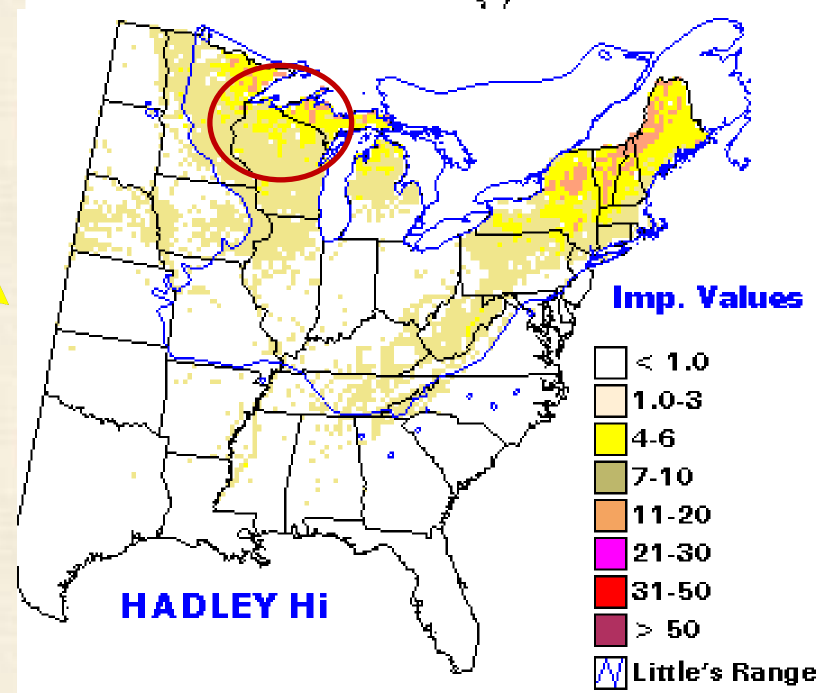


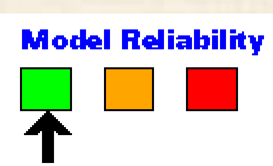
Low

?

High



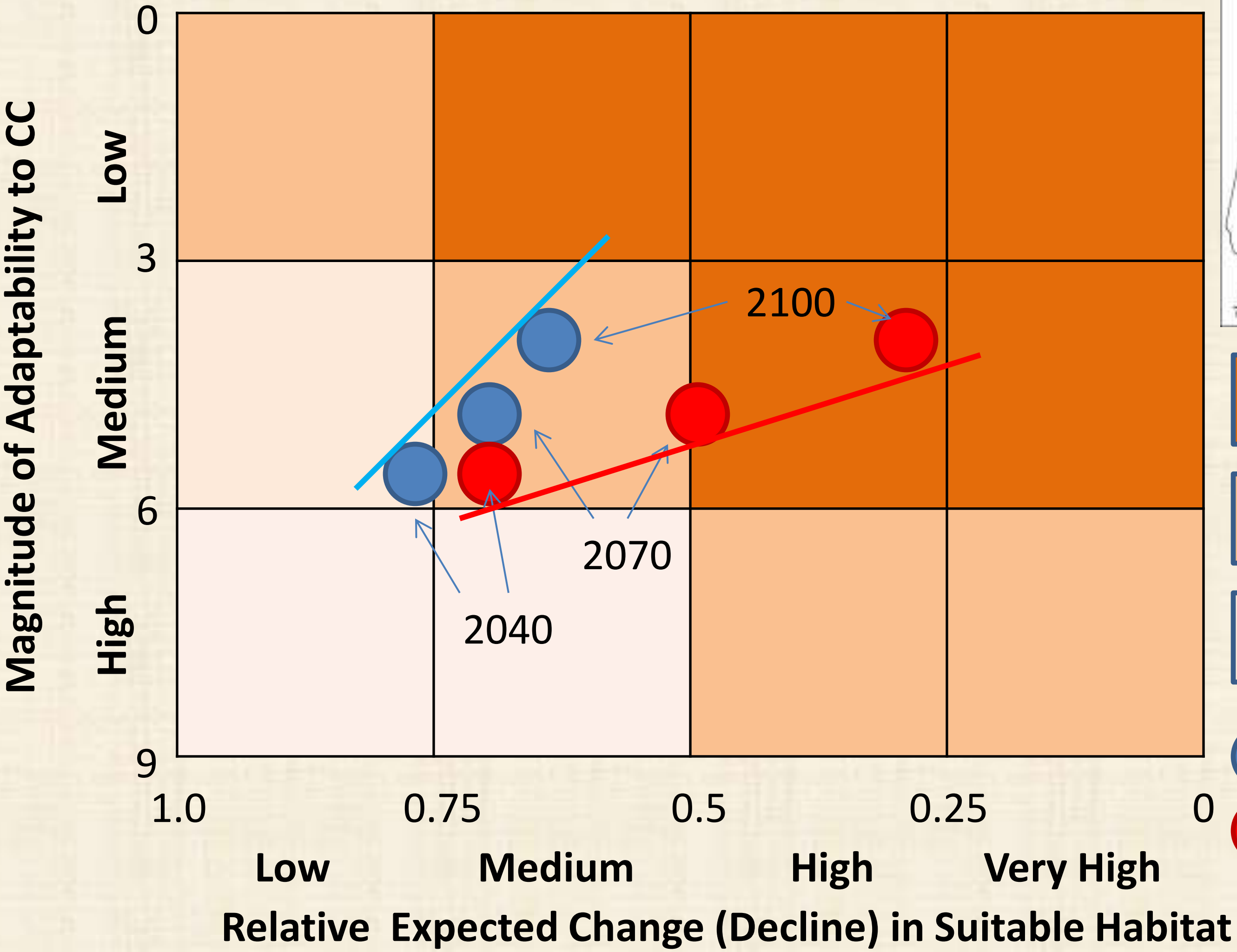




Iverson et al. 2008, Forest Ecology and Management

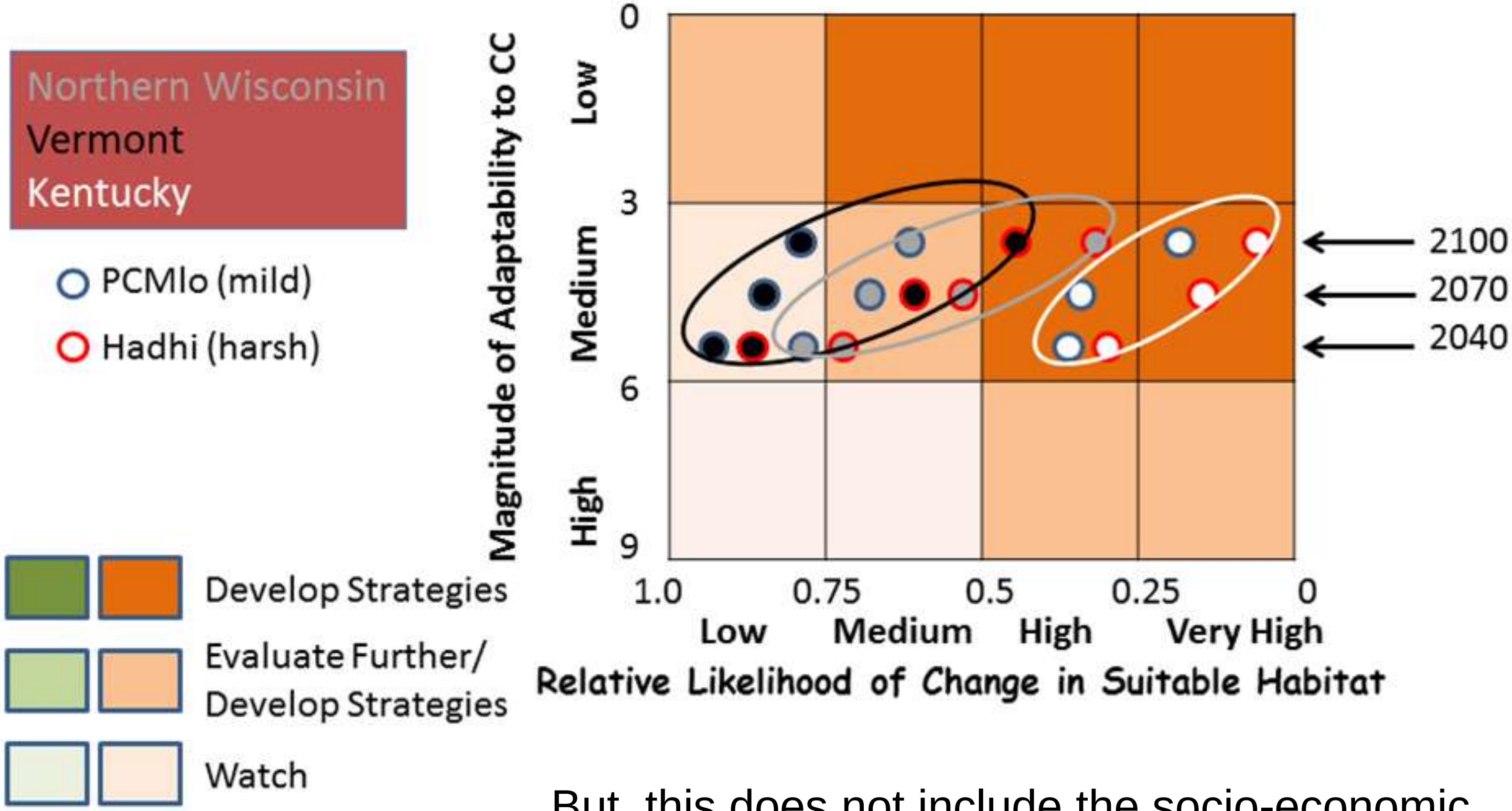
Risk of Habitat Decline in Sugar Maple

Northern Wisconsin



Iverson et al., Climatic Change, 2012

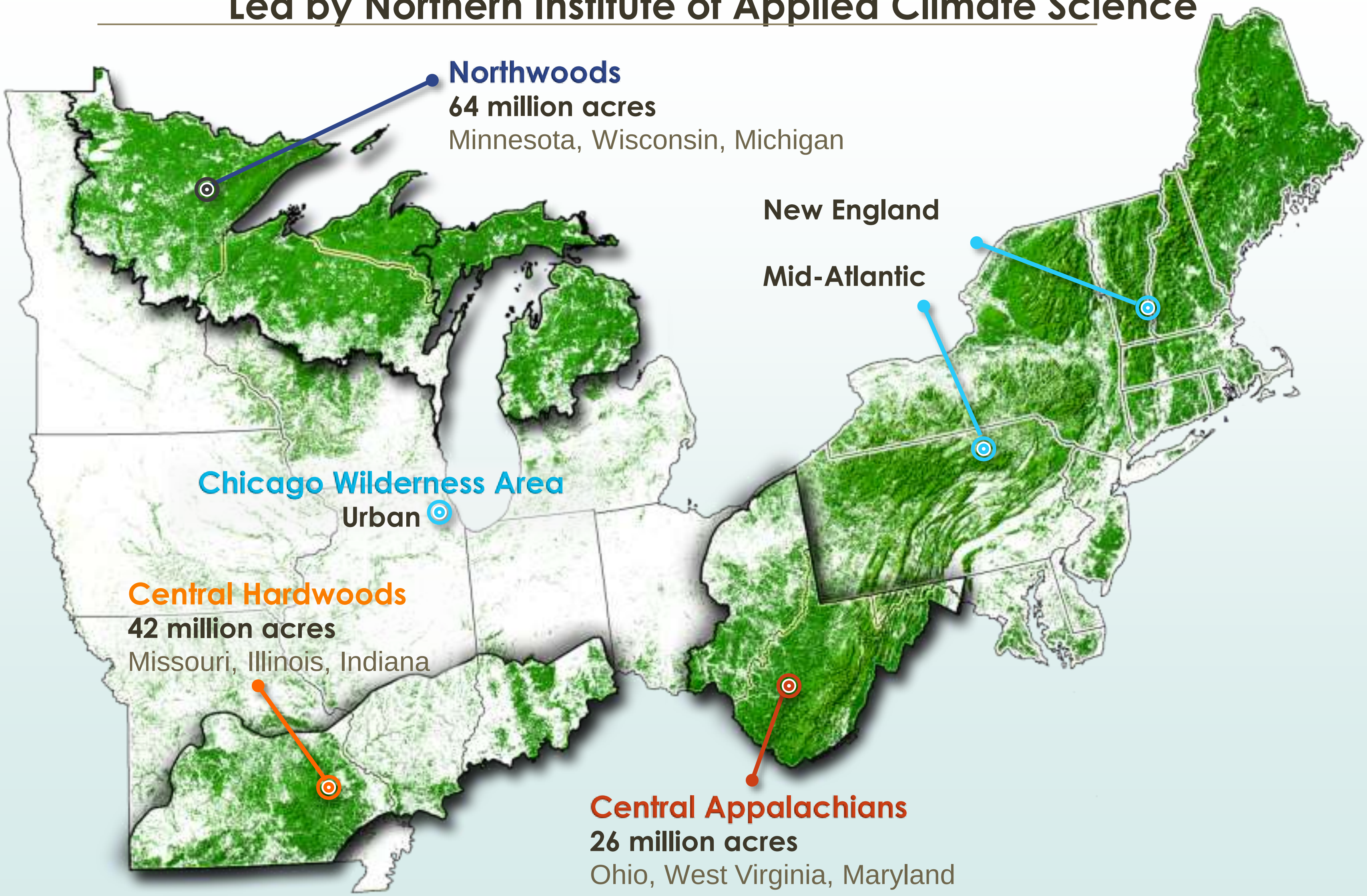
Risk of Habitat Change in Sugar Maple



But, this does not include the socio-economic component of risk – because Vermont has the highest US production of maple syrup, it will have more serious human consequences should the industry decline from climate change.

CLIMATE CHANGE **RESPONSE** FRAMEWORK

Led by Northern Institute of Applied Climate Science



Climate-Informed Conservation and Forest Management

forestadaptation.org

Climate Change Response Framework

Structured, process-oriented, works on multiple scales

Components:	Progress:
Partnerships	75+ partner organizations (and counting)
Vulnerability Assessment	6 published assessments
Forest Adaptation Resources	Published in 2012, updated and online versions in prep
Adaptation Demonstrations	60+ demonstrations underway

Vulnerability Assessment

Ecoregional Vulnerability Assessments

Audience: Land managers

Scope: Forest ecosystems

Vulnerability of:

- Tree species
- Forest/natural communities
- Does not make recommendations

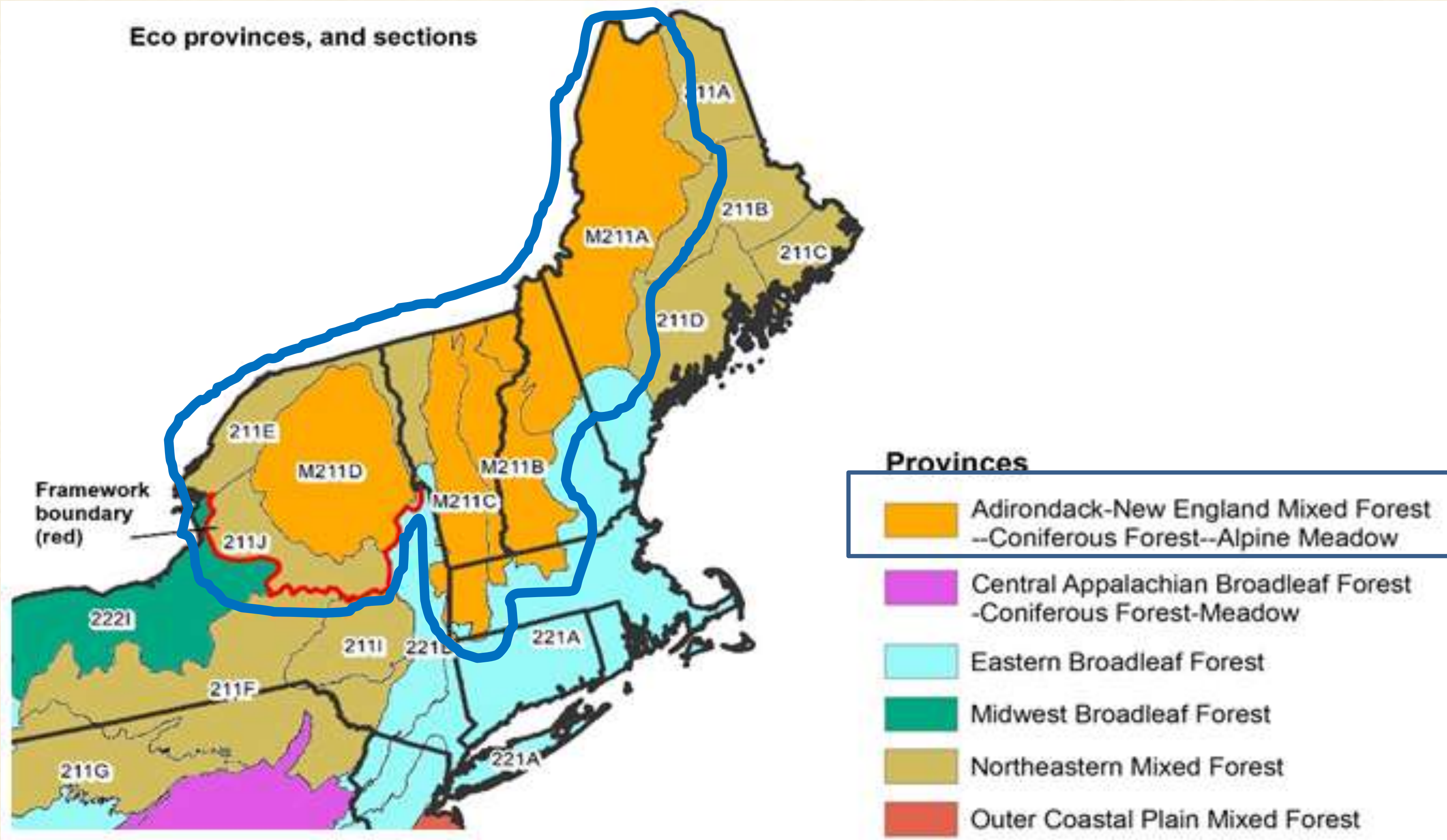
Vulnerability Assessment

Local Info → Potential Forest Change →

→ **Vulnerability** *(& Confidence)*

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

NE Analysis


Eco provinces, and sections
Framework boundary (red)
M211A
211B
211C
211D
211E
M211D
M211B
M211C
211J
222I
211I
221A
211F
211G
221A
Provinces
Adirondack-New England Mixed Forest --Coniferous Forest--Alpine Meadow
Central Appalachian Broadleaf Forest -Coniferous Forest-Meadow
Eastern Broadleaf Forest
Midwest Broadleaf Forest
Northeastern Mixed Forest
Outer Coastal Plain Mixed Forest

Species Importance – **FIA IV** is the importance value as reported from FIA; **Current Modeled** is our model to replicate FIA based on 38 environmental variables . These are area-weighted numbers, meaning it is the **sum** of the average IV for each of the 20x20 km pixels in the study area.

Adirondack-New England Mixed Forest

FIA #	Common name	FIA IV	Current IV	Model Reliability	Modeled IV 2010 - 2039 PCM B1	Modeled IV 2010 - 2039 GFDL A1FI	Modeled IV 2040 - 2069 PCM B1	Modeled IV 2040 - 2069 GFDL A1FI	Modeled IV 2070 - 2099 PCM B1	Modeled IV 2070 - 2099 GFDL A1FI	Future : Current Suitable Habitat 2010 - 2039 PCM B1	Future : Current Suitable Habitat 2010 - 2039 GFDL A1FI	Future : Current Suitable Habitat 2040 - 2069 PCM B1	Future : Current Suitable Habitat 2040 - 2069 GFDL A1FI	Future : Current Suitable Habitat 2070 - 2099 PCM B1	Future : Current Suitable Habitat 2070 - 2099 GFDL A1FI	Change Class 2070 - 2099 PCM B1	Change Class 2070 - 2099 GFDL A1FI	Modifying Factors DistFact	Modifying Factors BioFact	Modifying Factors Adapt
951	American basswood	255	311	Medium	254	413	287	529	301	637	0.82	1.33	0.92	1.70	0.97	2.05	No change	Large increase	0.31	0.16	4.6
531	American beech	3543	3659	High	3670	3333	3554	2609	3513	2086	1.00	0.91	0.97	0.71	0.96	0.57	No change	Decrease	-1.14	0.03	3.6
421	American chestnut	27	9	Medium	15	12	15	8	16	7	1.67	1.33	1.67	0.89	1.78	0.78	No change	No change	0.13	0.3	4.5
972	American elm	581	662	Medium	657	942	724	1344	823	1662	0.99	1.42	1.09	2.03	1.24	2.51	Increase	Large increase	-0.8	0.3	4.0
591	American holly	7	4	High	5	8	5	40	5	55	1.25	2.00	1.25	10.00	1.25	13.75	No change	Large increase	-0.1	0.47	4.5
391	American hornbeam	188	248	Medium	250	286	273	470	291	546	1.01	1.15	1.10	1.90	1.17	2.20	No change	Large increase	0.56	0.62	5.1
935	American mountain-ash	77	33	Medium	43	22	28	5	21	2	1.30	0.67	0.85	0.15	0.64	0.06	No change	Large decrease	-0.23	-1.62	3.1
43	Atlantic white-cedar	31	36	Low	35	34	33	29	35	28	0.97	0.94	0.92	0.81	0.97	0.78	No change	No change	-0.61	-1.21	3.0
221	Baldcypress	0	24	Medium	25	40	24	53	41	91	1.04	1.67	1.00	2.21	1.71	3.79	New habita	New habitat	0.38	-1.02	3.9
12	Balsam fir	5334	5255	High	4501	3445	3713	1457	3313	1175	0.86	0.66	0.71	0.28	0.63	0.22	Decrease	Large decrease	-3	-0.35	2.7
741	Balsam poplar	131	125	High	82	73	68	33	73	39	0.66	0.58	0.54	0.26	0.58	0.31	Decrease	Large decrease	0.13	-0.59	4.0
816	Bear oak:scrub oak	6	14	Low	10	14	12	17	13	16	0.71	1.00	0.86	1.21	0.93	1.14	No change	No change	1.04	-0.81	4.6
743	Bigtooth aspen	507	613	High	550	628	589	562	606	461	0.90	1.02	0.96	0.92	0.99	0.75	No change	Decrease	1.01	0.16	5.1
402	Bitternut hickory	46	21	Low	36	116	36	280	54	420	1.71	5.52	1.71	13.33	2.57	20.00	No change	Large increase	2.17	-0.83	5.6
543	Black ash	313	436	High	298	394	290	322	296	297	0.68	0.90	0.67	0.74	0.68	0.68	Decrease	Decrease	-1.31	-3	1.7
762	Black cherry	1355	1561	High	1630	1889	1752	2160	1807	2175	1.04	1.21	1.12	1.38	1.16	1.39	No change	Increase	-1.56	-0.32	3.0
408	Black hickory	0	0	High	0	6	0	188	0	588	0.00	Migrate	0.00	Migrate	0.00	Migrate	NA	New habitat	1.04	-2.27	4.1
901	Black locust	40	79	Low	101	234	143	508	182	768	1.28	2.96	1.81	6.43	2.30	9.72	Large incre	Large increase	0	-0.59	3.8
314	Black maple	5	1	Low	1	1	1	1	1	0	1.00	1.00	1.00	1.00	1.00	0.00	No change	No change	0.48	0.9	5.2
837	Black oak	473	563	High	654	964	803	1627	900	2059	1.16	1.71	1.43	2.89	1.60	3.66	Increase	Large increase	0.51	0.42	4.9
95	Black spruce	475	537	High	345	294	266	30	222	5	0.64	0.55	0.50	0.06	0.41	0.01	Large decre	Large decrease	-2.14	1.24	4.3
602	Black walnut	9	31	Medium	40	204	99	587	138	801	1.29	6.58	3.19	18.94	4.45	25.84	Increase	Large increase	0.35	-0.83	4.0

Model Reliability–the reliability of the model – green=good; orange=fair; red=poor. It represents the 'trust' you can put in the model results ("all models are wrong; some are useful").

Adirondack-New England Mixed Forest

					Modeled IV						Future : Current Suitable Habitat						Change Class		Modifying Factors		
					2010 - 2039		2040 - 2069		2070 - 2099		2010 - 2039		2040 - 2069		2070 - 2099		2070 - 2099				
FIA #	Common name	FIA IV	Current IV	Model Reliability	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	DistFact	BioFact	Adapt
951	American basswood	255	311	Medium	254	413	287	529	301	637	0.82	1.33	0.92	1.70	0.97	2.05	No change	Large increase	0.31	0.16	4.6
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421	American chestnut	27	9	Medium	15	12	15	8	16	7	1.67	1.33	1.67	0.89	1.78	0.78	No change	No change	0.13	0.3	4.5
972	American elm	581	662	Medium	657	942	724	1344	823	1662	0.99	1.42	1.09	2.03	1.24	2.51	Increase	Large increase	-0.8	0.3	4.0
591	American holly	7	4	High	5	8	5	40	5	55	1.25	2.00	1.25	10.00	1.25	13.75	No change	Large increase	-0.1	0.47	4.5
391	American hornbeam	188	248	Medium	250	286	273	470	291	546	1.01	1.15	1.10	1.90	1.17	2.20	No change	Large increase	0.56	0.62	5.1
935	American mountain-ash	77	33	Medium	43	22	28	5	21	2	1.30	0.67	0.85	0.15	0.64	0.06	No change	Large decrease	-0.23	-1.62	3.1
43	Atlantic white-cedar	31	36	Low	35	34	33	29	35	28	0.97	0.94	0.92	0.81	0.97	0.78	No change	No change	-0.61	-1.21	3.0
221	Baldcypress	0	24	Medium	25	40	24	53	41	91	1.04	1.67	1.00	2.21	1.71	3.79	New habita	New habitat	0.38	-1.02	3.9
12	Balsam fir	5334	5255	High	4501	3445	3713	1457	3313	1175	0.86	0.66	0.71	0.28	0.63	0.22	Decrease	Large decrease	-3	-0.35	2.7
741	Balsam poplar	131	125	High	82	73	68	33	73	39	0.66	0.58	0.54	0.26	0.58	0.31	Decrease	Large decrease	0.13	-0.59	4.0
816	Bear oak:scrub oak	6	14	Low	10	14	12	17	13	16	0.71	1.00	0.86	1.21	0.93	1.14	No change	No change	1.04	-0.81	4.6
743	Bigtooth aspen	507	613	High	550	628	589	562	606	461	0.90	1.02	0.96	0.92	0.99	0.75	No change	Decrease	1.01	0.16	5.1
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314	Black maple	5	1	Low	1	1	1	1	1	0	1.00	1.00	1.00	1.00	1.00	0.00	No change	No change	0.48	0.9	5.2
837	Black oak	473	563	High	654	964	803	1627	900	2059	1.16	1.71	1.43	2.89	1.60	3.66	Increase	Large increase	0.51	0.42	4.9
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602	Black walnut	9	31	Medium	40	204	99	587	138	801	1.29	6.58	3.19	18.94	4.45	25.84	Increase	Large increase	0.35	-0.83	4.0

Modeled IV – Estimates of future area-weighted IV for three time periods: 2010-2039, 2040-2069, and 2070-2099 (compare to current IV, previous columns).

PCM B1 is a mild scenario

GFDL A1FI is a harsh scenario

The idea is to create 'bookends' on what may happen to tree species habitats.

Adirondack-New England Mixed Forest

					Modeled IV						Future : Current Suitable Habitat						Change Class		Modifying Factors		
					2010 - 2039		2040 - 2069		2070 - 2099		2010 - 2039		2040 - 2069		2070 - 2099		2070 - 2099				
FIA #	Common name	FIA IV	Current IV	Model Reliability	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	DistFact	BioFact	Adapt
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421	American chestnut	27	9	Medium	15	12	15	8	16	7	1.67	1.33	1.67	0.89	1.78	0.78	No change	No change	0.13	0.3	4.5
972	American elm	581	662	Medium	657	942	724	1344	823	1662	0.99	1.42	1.09	2.03	1.24	2.51	Increase	Large increase	-0.8	0.3	4.0
591	American holly	7																		0.47	4.5
391	American hornbeam	188																		0.62	5.1
935	American mountain-ash	77																		-1.62	3.1
43	Atlantic white-cedar	31																		-1.21	3.0
221	Baldcypress	0																		-1.02	3.9
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741	Balsam poplar	131																		-0.59	4.0
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314	Black maple	5	1	Low	1	1	1	1	1	0	1.00	1.00	1.00	1.00	1.00	0.00	No change	No change	0.48	0.9	5.2
837	Black oak	473	563	High	654	964	803	1627	900	2059	1.16	1.71	1.43	2.89	1.60	3.66	Increase	Large increase	0.51	0.42	4.9
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602	Black walnut	9	31	Medium	40	204	99	587	138	801	1.29	6.58	3.19	18.94	4.45	25.84	Increase	Large increase	0.35	-0.83	4.0

Remember: this represents modeled potential for changes in suitable habitat by 2039, 2069, 2099; not what the composition will necessarily look like by those times.

Trees live a long time; migration takes a long time unassisted.

Future:Current– Ratio of future estimate of habitat to current estimate of habitat (not where the species will be!), for three time periods in future.

A ratio of ~ 1 = no change; a ratio < 1 = decrease; a ratio >1 = increase in future..

Adirondack-New England Mixed Forest

					Modeled IV						Future : Current Suitable Habitat						Change Class		Modifying Factors		
					2010 - 2039		2040 - 2069		2070 - 2099		2010 - 2039		2040 - 2069		2070 - 2099		2070 - 2099				
FIA #	Common name	FIA IV	Current IV	Model Reliability	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	DistFact	BioFact	Adapt
951	American basswood	255	311	Medium	254	413	287	529	301	637	0.82	1.33	0.92	1.70	0.97	2.05	No change	Large increase	0.31	0.16	4.6
531	American beech	3543	3659	High	3670	3333	3554	2609	3513	2086	1.00	0.91	0.97	0.71	0.96	0.57	No change	Decrease	-1.14	0.03	3.6
421	American chestnut	27	9	Medium	15	12	15	8	16	7	1.67	1.33	1.67	0.89	1.78	0.78	No change	No change	0.13	0.3	4.5
972	American elm	581	662	Medium	657	942	724	1344	823	1662	0.99	1.42	1.09	2.03	1.24	2.51	Increase	Large increase	-0.8	0.3	4.0
591	American holly	7	4	High	5	8	5	40	5	55	1.25	2.00	1.25	10.00	1.25	13.75	No change	Large increase	-0.1	0.47	4.5
391	American hornbeam	188	248	Medium	250	286	273	470	291	546	1.01	1.15	1.10	1.90	1.17	2.20	No change	Large increase	0.56	0.62	5.1
935	American mountain-ash	77	33	Medium	43	22	28	5	21	2	1.30	0.67	0.85	0.15	0.64	0.06	No change	Large decrease	-0.23	-1.62	3.1
43	Atlantic white-cedar	31	36	Low	35	34	33	29	35	28	0.97	0.94	0.92	0.81	0.97	0.78	No change	No change	-0.61	-1.21	3.0
221	Baldcypress	0	24	Medium	25	40	24	53	41	91	1.04	1.67	1.00	2.21	1.71	3.79	New habita	New habitat	0.38	-1.02	3.9
12	Balsam fir	5334	5255	High	4501	3445	3713	1457	3313	1175	0.86	0.66	0.71	0.28	0.63	0.22	Decrease	Large decrease	-3	-0.35	2.7
741	Balsam poplar	131	125	High	82	73	68	33	73	39	0.66	0.58	0.54	0.26	0.58	0.31	Decrease	Large decrease	0.13	-0.59	4.0
816	Bear oak:scrub oak	6	14	Low	10	14	12	17	13	16	0.71	1.00	0.86	1.21	0.93	1.14	No change	No change	1.04	-0.81	4.6
743	Bigtooth aspen	507	613	High	550	628	589	562	606	461	0.90	1.02	0.96	0.92	0.99	0.75	No change	Decrease	1.01	0.16	5.1
402	Bitternut hickory	46	21	Low	36	116	36	280	54	420	1.71	5.52	1.71	13.33	2.57	20.00	No change	Large increase	2.17	-0.83	5.6
543	Black ash	313	436	High	298	394	290	322	296	297	0.68	0.90	0.67	0.74	0.68	0.68	Decrease	Decrease	-1.31	-3	1.7
762	Black cherry	1355	1561	High	1630	1889	1752	2160	1807	2175	1.04	1.21	1.12	1.38	1.16	1.39	No change	Increase	-1.56	-0.32	3.0
408	Black hickory	0	0	High	0	6	0	188	0	588	0.00	Migrate	0.00	Migrate	0.00	Migrate	NA	New habitat	1.04	-2.27	4.1
901	Black locust	40	79	Low	101	234	143	508	182	768	1.28	2.96	1.81	6.43	2.30	9.72	Large incre	Large increase	0	-0.59	3.8
314	Black maple	5	1	Low	1	1	1	1	1	0	1.00	1.00	1.00	1.00	1.00	0.00	No change	No change	0.48	0.9	5.2
837	Black oak	473	563	High	654	964	803	1627	900	2059	1.16	1.71	1.43	2.89	1.60	3.66	Increase	Large increase	0.51	0.42	4.9
95	Black spruce	475	537	High	345	294	266	30	222	5	0.64	0.55	0.50	0.06	0.41	0.01	Large decre	Large decrease	-2.14	1.24	4.3
602	Black walnut	9	31	Medium	40	204	99	587	138	801	1.29	6.58	3.19	18.94	4.45	25.84	Increase	Large increase	0.35	-0.83	4.0

Change Class – our interpretation of potential habitat changes by 2100. This is based on a set of rules for the ratios .

Adirondack-New England Mixed Forest

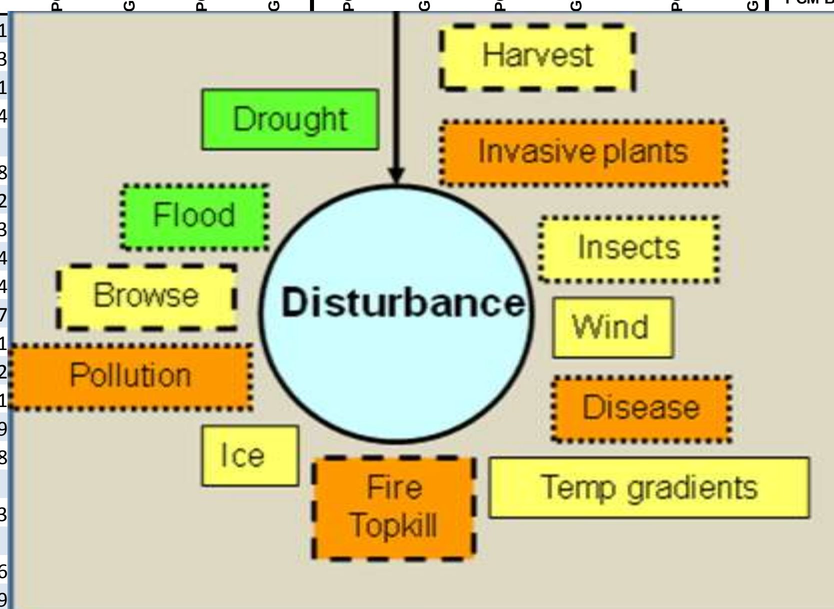
					Modeled IV						Future : Current Suitable Habitat						Change Class		Modifying Factors		
					2010 - 2039		2040 - 2069		2070 - 2099		2010 - 2039		2040 - 2069		2070 - 2099		2070 - 2099				
FIA #	Common name	FIA IV	Current IV	Model Reliability	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	PCM B1	GFDL A1FI	DistFact	BioFact	Adapt
951	American basswood	255	311	Medium	254	413	287	529	301	637	0.82	1.33	0.92	1.70	0.97	2.05	No change	Large increase	0.31	0.16	4.6
531	American beech	3543	3659	High	3670	3333	3554	2609	3513	2086	1.00	0.91	0.97	0.71	0.96	0.57	No change	Decrease	-1.14	0.03	3.6
421	American chestnut	27	9	Medium	15	12	15	8	16	7	1.67	1.33	1.67	0.89	1.78	0.78	No change	No change	0.13	0.3	4.5
972	American elm	581	662	Medium	657	942	724	1344	823	1662	0.99	1.42	1.09	2.03	1.24	2.51	Increase	Large increase	-0.8	0.3	4.0
591	American holly	7	4	High	5	8	5	40	5	55	1.25	2.00	1.25	10.00	1.25	13.75	No change	Large increase	-0.1	0.47	4.5
391	American hor																				5.1
935	American mo																				3.1
43	Atlantic white																				3.0
221	Baldcypress																				3.9
12	Balsam fir																				2.7
741	Balsam popla																				4.0
816	Bear oak:scru																				4.6
743	Bigtooth aspe																				5.1
402	Bitternut hick																				5.6
543	Black ash																				1.7
762	Black cherry																				3.0
408	Black hickory																				4.1
901	Black locust																				3.8
314	Black maple																				5.2
837	Black oak																				4.9
95	Black spruce																				4.3
602	Black walnut																				4.0

Future:Current	Class
<0.5	Large decrease
0.5 to 0.8	Decrease [Small decrease]
>0.8 to <1.2	No change
1.2 to 2.0	Increase [Small increase]
>2	Large increase
If Current modeled AWIV is 0 and future AWIV>0, then "New habitat"	
If Current modeled AWIV is >0 and future AWIV=0, then "Extirpated"	

DistFact – average score of 12 disturbance factors and the capacity of the species to withstand them, scaled -3 to +3. See Matthews et al (2011) publication (Publications on the website) for full explanation of Modifying Factors.

Adirondack-New England Mixed Forest

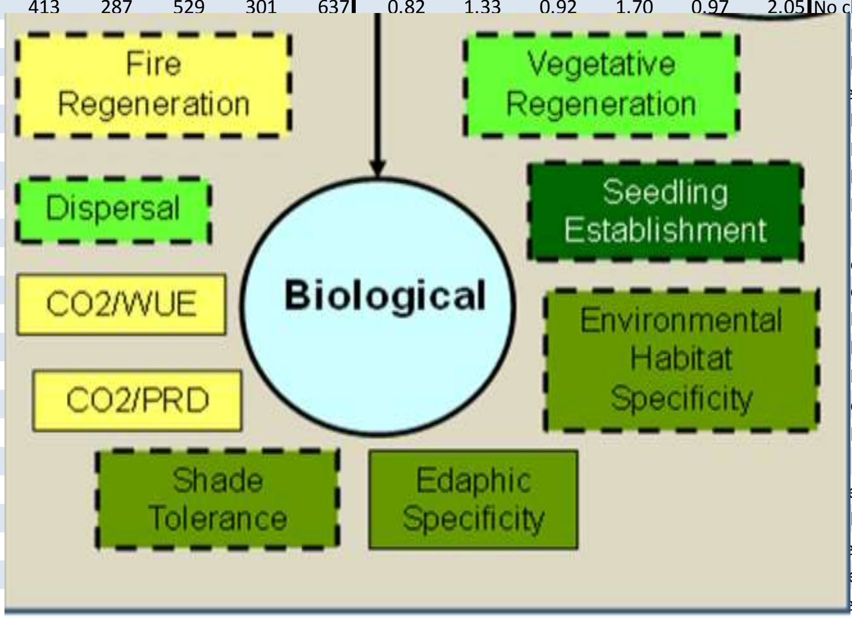
FIA #	Common name	FIA IV	Current IV	Model Reliability	Modeled IV 2010 - 2039 PCM B1	Modeled IV 2010 - 2039 GFDL A1FI	Modeled IV 2040 - 2069 PCM B1	Modeled IV 2040 - 2069 GFDL A1FI	Modeled IV 2070 - 2099 PCM B1	Modeled IV 2070 - 2099 GFDL A1FI	Future : Current Suitable Habitat 2010 - 2039 PCM B1	Future : Current Suitable Habitat 2010 - 2039 GFDL A1FI	Future : Current Suitable Habitat 2040 - 2069 PCM B1	Future : Current Suitable Habitat 2040 - 2069 GFDL A1FI	Future : Current Suitable Habitat 2070 - 2099 PCM B1	Future : Current Suitable Habitat 2070 - 2099 GFDL A1FI	Change Class 2070 - 2099 PCM B1	Change Class 2070 - 2099 GFDL A1FI	Modifying Factors DistFact	Modifying Factors BioFact	Modifying Factors Adapt
951	American basswood	255	311	Medium	254	41												Large increase	0.31	0.16	4.6
531	American beech	3543	3659	High	3670	333												Decrease	-1.14	0.03	3.6
421	American chestnut	27	9	Medium	15	1												No change	0.13	0.3	4.5
972	American elm	581	662	Medium	657	94												Large increase	-0.8	0.3	4.0
591	American holly	7	4	High	5													Large increase	-0.1	0.47	4.5
391	American hornbeam	188	248	Medium	250	28												Large increase	0.56	0.62	5.1
935	American mountain-ash	77	33	Medium	43	2												Large decrease	-0.23	-1.62	3.1
43	Atlantic white-cedar	31	36	Low	35	3												No change	-0.61	-1.21	3.0
221	Baldcypress	0	24	Medium	25	4												New habitat	0.38	-1.02	3.9
12	Balsam fir	5334	5255	High	4501	344												Large decrease	-3	-0.35	2.7
741	Balsam poplar	131	125	High	82	7												Large decrease	0.13	-0.59	4.0
816	Bear oak:scrub oak	6	14	Low	10	1												No change	1.04	-0.81	4.6
743	Bigtooth aspen	507	613	High	550	62												Decrease	1.01	0.16	5.1
402	Bitternut hickory	46	21	Low	36	11												Large increase	2.17	-0.83	5.6
543	Black ash	313	436	High	298	39												Decrease	-1.31	-3	1.7
762	Black cherry	1355	1561	High	1630	188												Increase	-1.56	-0.32	3.0
408	Black hickory	0	0	High	0													New habitat	1.04	-2.27	4.1
901	Black locust	40	79	Low	101	23												Large increase	0	-0.59	3.8
314	Black maple	5	1	Low	1													No change	0.48	0.9	5.2
837	Black oak	473	563	High	654	96												Large increase	0.51	0.42	4.9
95	Black spruce	475	537	High	345	29												Large decrease	-2.14	1.24	4.3
602	Black walnut	9	31	Medium	40	204	99	587	138	801	1.29	6.58	3.19	18.94	4.45	25.84	Increase	Large increase	0.35	-0.83	4.0



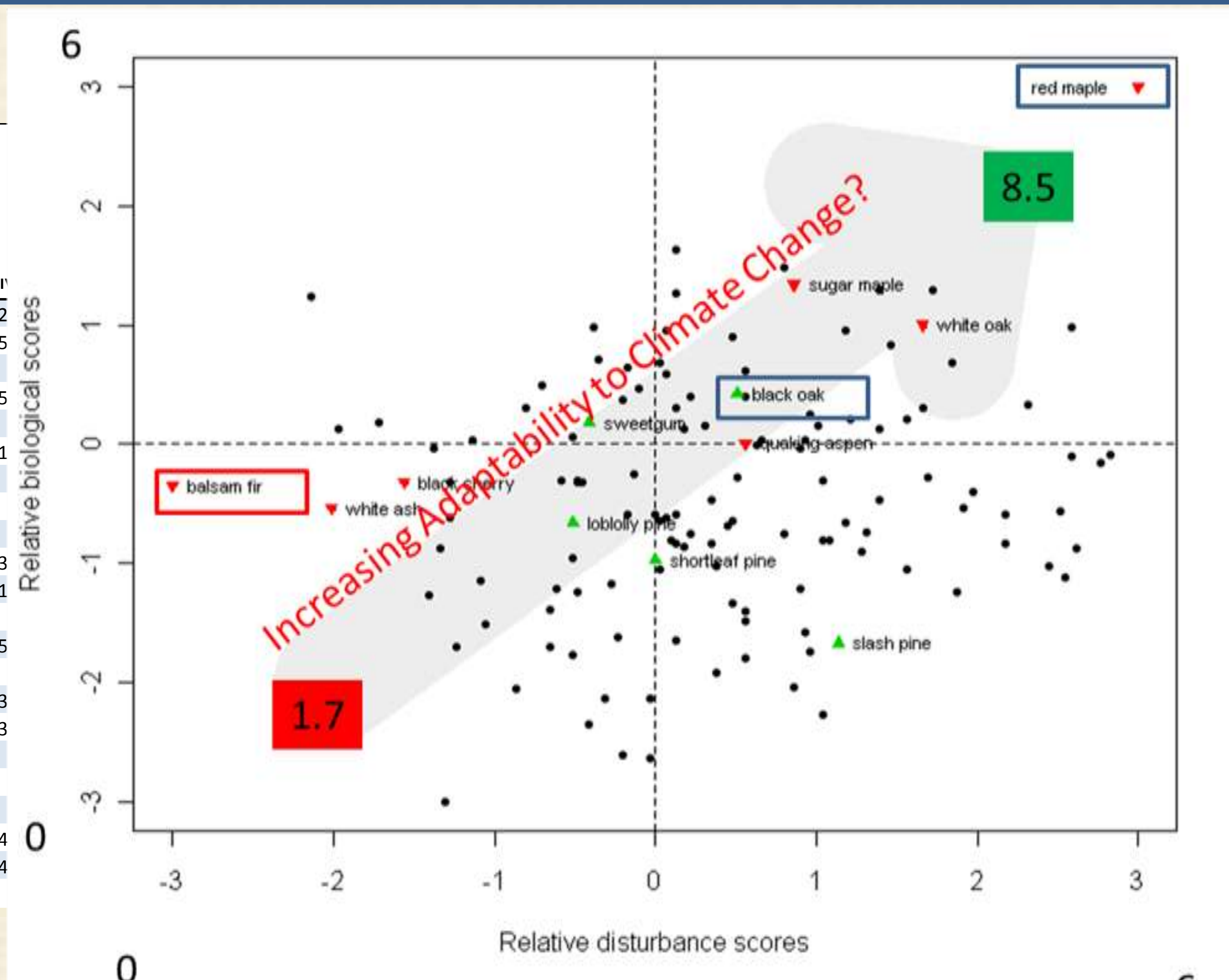
BioFact – average score of 9 biological factors and the capacity of the species to withstand them, scaled -3 to +3. See Matthews et al (2011) publication (Publications on the website) for full explanation of Modifying Factors.

Adirondack-New England Mixed Forest

FIA #	Common name	FIA IV	Current IV	Model Reliability	Modeled IV 2010 - 2039 PCM B1	Modeled IV 2010 - 2039 GFDL A1FI	Modeled IV 2040 - 2069 PCM B1	Modeled IV 2040 - 2069 GFDL A1FI	Modeled IV 2070 - 2099 PCM B1	Modeled IV 2070 - 2099 GFDL A1FI	Future : Current Suitable Habitat 2010 - 2039 PCM B1	Future : Current Suitable Habitat 2010 - 2039 GFDL A1FI	Future : Current Suitable Habitat 2040 - 2069 PCM B1	Future : Current Suitable Habitat 2040 - 2069 GFDL A1FI	Future : Current Suitable Habitat 2070 - 2099 PCM B1	Future : Current Suitable Habitat 2070 - 2099 GFDL A1FI	Change Class 2070 - 2099 PCM B1	Change Class 2070 - 2099 GFDL A1FI	Mo[illegible]ctors DistFact	Mo[illegible]ctors BioFact	Mo[illegible]ctors Adapt
951	American basswood	255	311	Medium	254	413	287	529	301	637	0.82	1.33	0.92	1.70	0.97	2.05	No change	Large increase	0.31	0.16	4.6
531	American beech	3543	3659	High	3670												hange	Decrease	-1.14	0.03	3.6
421	American chestnut	27	9	Medium	15												hange	No change	0.13	0.3	4.5
972	American elm	581	662	Medium	657												ease	Large increase	-0.8	0.3	4.0
591	American holly	7	4	High	5												hange	Large increase	-0.1	0.47	4.5
391	American hornbeam	188	248	Medium	250												hange	Large increase	0.56	0.62	5.1
935	American mountain-ash	77	33	Medium	43												hange	Large decrease	-0.23	-1.62	3.1
43	Atlantic white-cedar	31	36	Low	35												hange	No change	-0.61	-1.21	3.0
221	Baldcypress	0	24	Medium	25												habita	New habitat	0.38	-1.02	3.9
12	Balsam fir	5334	5255	High	4501												ease	Large decrease	-3	-0.35	2.7
741	Balsam poplar	131	125	High	82												ease	Large decrease	0.13	-0.59	4.0
816	Bear oak:scrub oak	6	14	Low	10												hange	No change	1.04	-0.81	4.6
743	Bigtooth aspen	507	613	High	550												hange	Decrease	1.01	0.16	5.1
402	Bitternut hickory	46	21	Low	36												hange	Large increase	2.17	-0.83	5.6
543	Black ash	313	436	High	298												ease	Decrease	-1.31	-3	1.7
762	Black cherry	1355	1561	High	1630												hange	Increase	-1.56	-0.32	3.0
408	Black hickory	0	0	High	0													New habitat	1.04	-2.27	4.1
901	Black locust	40	79	Low	101												e incre	Large increase	0	-0.59	3.8
314	Black maple	5	1	Low	1												hange	No change	0.48	0.9	5.2
837	Black oak	473	563	High	654												ease	Large increase	0.51	0.42	4.9
95	Black spruce	475	537	High	345												e decre	Large decrease	-2.14	1.24	4.3
602	Black walnut	9	31	Medium	40												ease	Large increase	0.35	-0.83	4.0



Adapt – index of biological and disturbance factors, range 1.7-8.5.
Low values < 3.3 (red) – species likely to do worse than DISTRIB projects;
Medium values (orange) 3.3-5.2 – species may do roughly as modeled;
High values (green) > 5.2 – species likely to do better than DISTRIB projects



			Modifying Factors			
FIA #	Common name	FIA I'	FI	DistFact	BioFact	Adapt
951	American basswood	2	ase	0.31	0.16	4.6
531	American beech	35		-1.14	0.03	3.6
421	American chestnut			0.13	0.3	4.5
972	American elm	5	ase	-0.8	0.3	4.0
591	American holly		ase	-0.1	0.47	4.5
391	American hornbeam	1	ase	0.56	0.62	5.1
935	American mountain-ash		ease	-0.23	-1.62	3.1
43	Atlantic white-cedar			-0.61	-1.21	3.0
221	Baldcypress		at	0.38	-1.02	3.9
12	Balsam fir	53	ease	-3	-0.35	2.7
741	Balsam poplar	1	ease	0.13	-0.59	4.0
816	Bear oak:scrub oak			1.04	-0.81	4.6
743	Bigtooth aspen	5		1.01	0.16	5.1
402	Bitternut hickory		ase	2.17	-0.83	5.6
543	Black ash	3		-1.31	-3	1.7
762	Black cherry	13		-1.56	-0.32	3.0
408	Black hickory		at	1.04	-2.27	4.1
901	Black locust		ase	0	-0.59	3.8
314	Black maple			0.48	0.9	5.2
837	Black oak	4	ase	0.51	0.42	4.9
95	Black spruce	4	ease	-2.14	1.24	4.3
602	Black walnut		ase	0.35	-0.83	4.0

Declines under Both Scenarios

Balsam fir (–)
Balsam poplar
Black ash (–)
Black spruce
Mountain maple (+)
Northern white-cedar
Paper birch
Red spruce (–)
White spruce

Declines under High Emissions

American beech
Chokecherry
Pin cherry
Quaking aspen
Striped maple
Sugar maple (+)
Yellow birch
American mountain-ash (–)

No Change under Both Scenarios

American chestnut
Atlantic white-cedar (–)
Bear oak/Scrub oak
Bigtooth aspen
Eastern hemlock (–)
Eastern white pine
Gray birch
Pitch pine
Red maple (+)
White ash (–)

Based on end of century models
(–) ModFacs reduce species adaptability
(+) ModFacs increase species adaptability

Increases under Both Scenarios

Black oak
Black willow (–)
Blackgum (+)
Chestnut oak (+)
Eastern cottonwood
Eastern redbud
Eastern redcedar
Flowering dogwood
Northern red oak (+)
Pignut hickory
Pin oak (–)
Scarlet oak
Serviceberry
Shagbark hickory
Silver maple (+)
Slippery elm
Sweet birch (–)
White oak (+)
Yellow-poplar (+)

Increases under High Emissions

American basswood
American elm
American hornbeam
Bitternut hickory (+)
Black cherry (–)
Black locust
Black walnut
Boxelder (+)
Bur oak (+)
Eastern hophornbeam (+)
Green ash
Honeylocust (+)
Mockernut hickory (+)
Northern pin oak** (+)
Ohio buckeye
Red pine
Sassafras
Swamp white oak
Sycamore

Mixed Results

Tamarack (native) (–)
Butternut (–)
Jack pine

New Suitable Habitat – Both

Hackberry** (+)
Red mulberry**

New Suitable Habitat – High

American holly
Black hickory
Blackjack oak (+)
Chinkapin oak**
Common persimmon (+)
Loblolly pine
Osage-orange (+)
Pawpaw**
Post oak (+)
Rock elm (–)
Shellbark hickory
Shingle oak
Shortleaf pine
Southern red oak (+)
Sugarberry
Sweetgum
Virginia pine
Wild plum
Winged elm

Do we have some evidence of change so far, or that the models have merit?

- Difficulties:
  - Trees live a long time! Natural composition changes via death/re-establishment or migration take a long time.
  - Sampling at appropriate scale (temporal or spatial) is rare. Can't expect annualized FIA (since ~2000) to detect much yet.
  - Where is the current boundary? Little's boundaries are not appropriate for this type of analysis. We have developed Generalized Species Boundaries based on FIA and modeled current distributions, that are used in our SHIFT models, but still coarse.
  - Latitude vs. altitude? In flat terrain, species must move 145 km to reach zones 1C cooler (in mountains, 175m upslope).
  - Confounded by land use history, disturbance, and succession

Selected Studies showing evidence:

- Reich, P. B., K. M. Sendall, K. Rice, R. L. Rich, A. Stefanski, S. E. Hobbie, and R. A. Montgomery. 2015. Geographic range predicts photosynthetic and growth response to warming in co-occurring tree species. Nature Clim. Change **5**:148-152. (**11 spp in MN**)
- Monleon, V. J. and H. E. Lintz. 2015. Evidence of Tree Species' Range Shifts in a Complex Landscape. Plos One **10**:e0118069. (**46 spp in CA, OR, WA**)
- Boisvert-Marsh, L., C. Périé, and S. de Blois. 2014. Shifting with climate? Evidence for recent changes in tree species distribution at high latitudes. Ecosphere **5**:art83. (**11 spp in Quebec**)
- Treyger, A. L. and C. A. Nowak. 2011. Changes in tree sapling composition within powerline corridors appear to be consistent with climatic changes in New York State. Global Change Biology **17**:3439-3452. (**14 spp in NY**)
- Woodall, C., C. M. Oswalt, J. A. Westfall, C. H. Perry, M. D. Nelson, and A. O. Finley. 2009. An indicator of tree migration in forests of the eastern United States. Forest Ecology and Management **257**:1434-1444. (**40 spp in eastern US**)
- Schuster, W. S. F., K. L. Griffin, H. Roth, M. H. Turnbull, D. Whitehead, and D. T. Tissue. 2008. Changes in composition, structure and aboveground biomass over seventy-six years (1930–2006) in the Black Rock Forest, Hudson Highlands, southeastern New York State. Tree Physiology **28**:537-549. (**57 spp in NY**)

Selected Studies showing evidence:

- Reich, P. B., K. M. Sendall, K. Rice, R. L. Rich, A. Stefanski, S. E. Hobbie, and R. A. Montgomery. 2015. Geographic range predicts photosynthetic and growth response to warming in co-occurring tree species. Nature Clim. Change **5**:148-152. (11 spp in MN)
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- Treyger, A. L. and C. A. Nowak. 2011. Changes in tree sapling composition within powerline corridors appear to be consistent with climatic changes in New York State. Global Change Biology **17**:3439-3452. (14 spp in NY)
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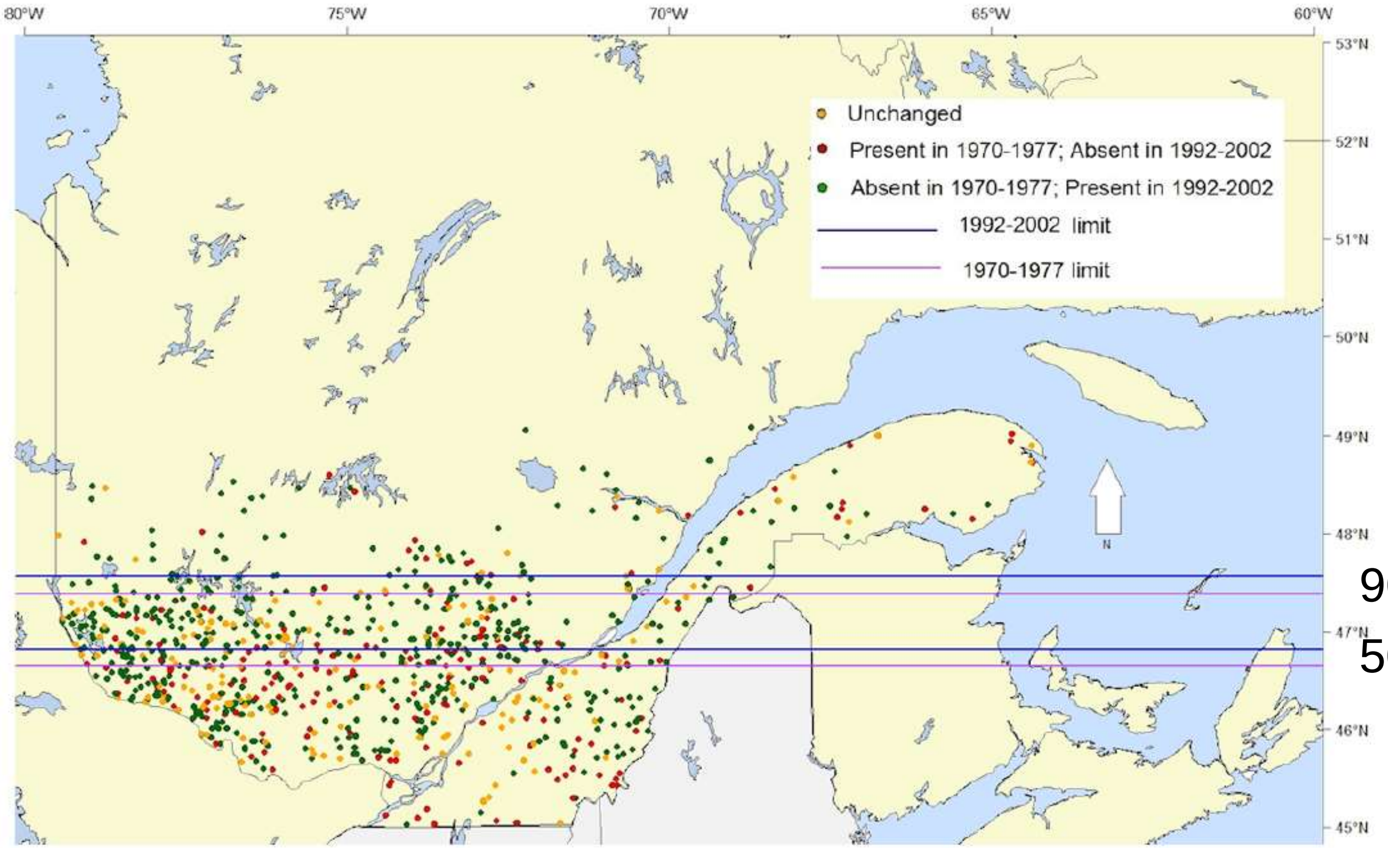
- Schuster, W. S. F., K. L. Griffin, H. Roth, M. H. Turnbull, D. Whitehead, and D. T. Tissue. 2008. Changes in composition, structure and aboveground biomass over seventy-six years (1930–2006) in the Black Rock Forest, Hudson Highlands, southeastern New York State. Tree Physiology **28**:537-549. (57 spp in NY)

Boisvert-Marsh et al. study using 6456 plots in Quebec (1970s to ~2000). Red Maple saplings



90th percentile

50th percentile

Fig. A3. Species map for saplings of *Acer rubrum*. The lower pair of lines represent the 50th percentile while the upper pair represents the 90th.

Boisvert-Marsh, L., C. Périé, and S. de Blois. 2014. Shifting with climate? Evidence for recent changes in tree species distribution at high latitudes. Ecosphere 5:art83.

Boisvert-Marsh et al. study in Quebec Paper Birch saplings

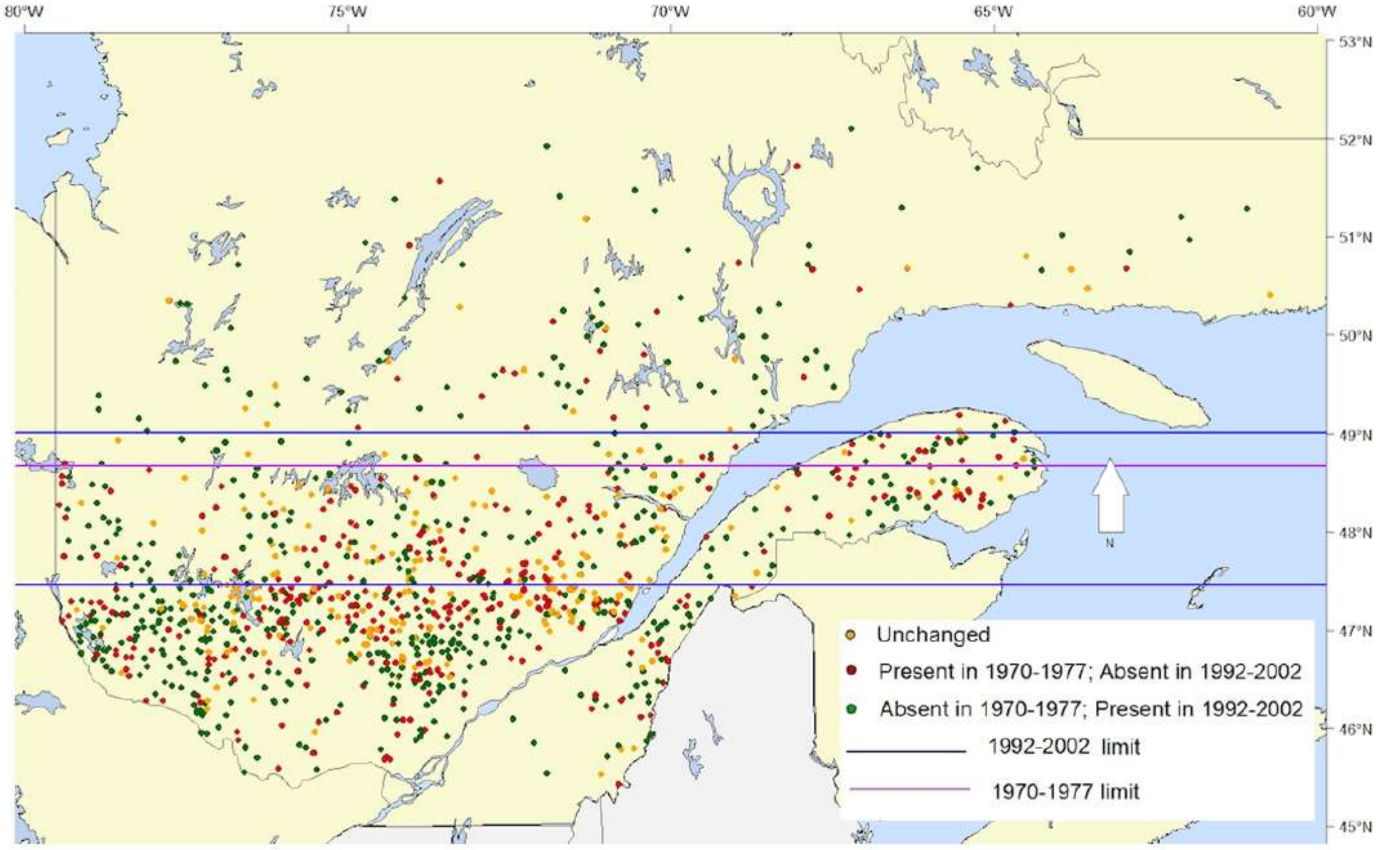
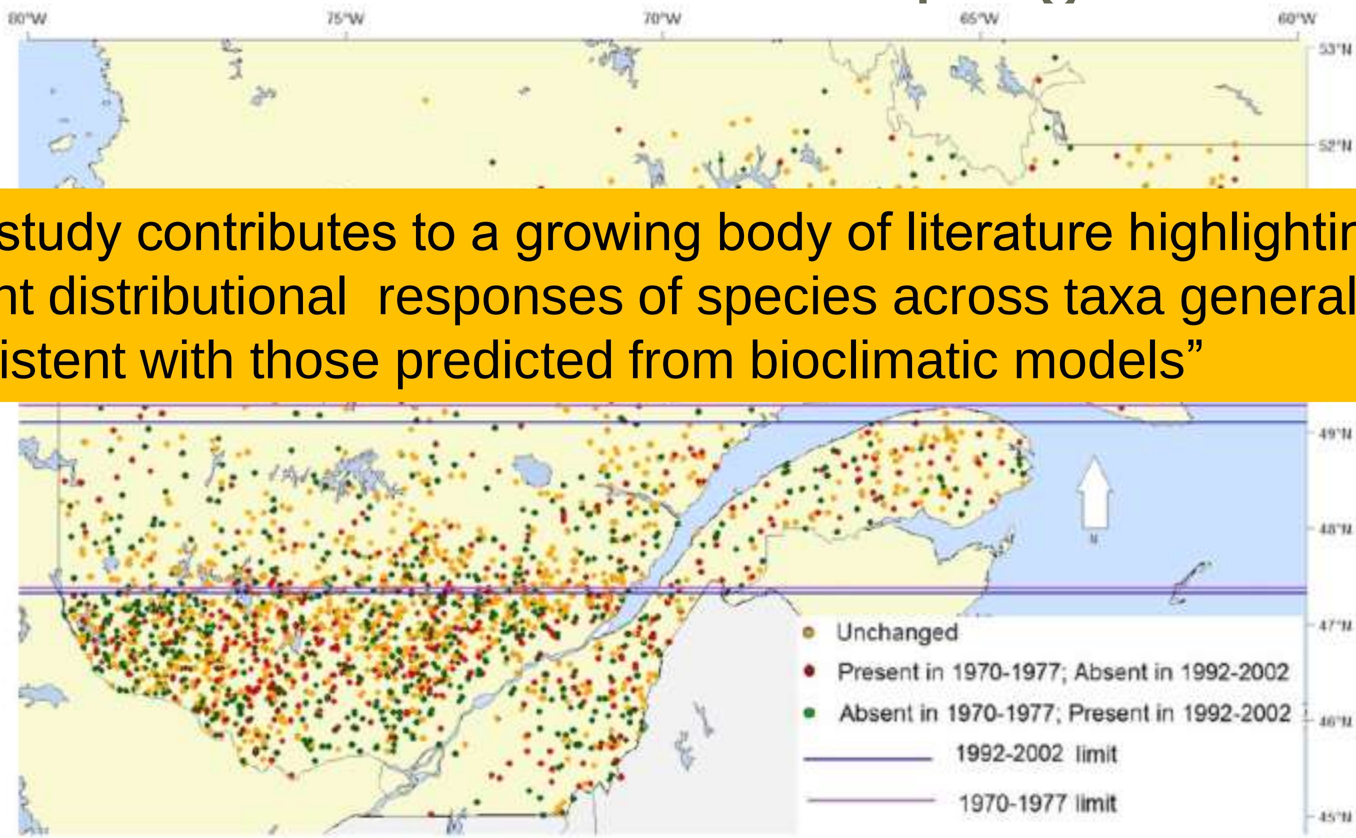


Fig. A9. Species map for saplings of *Betula papyrifera*. The lower pair of lines represent the 50th percentile while the upper pair represents the 90th.

Northward shift also seen for sugar maple, Am. beech, quaking aspen

Boisvert-Marsh et al. study in Quebec
Balsam Fir saplings



“our study contributes to a growing body of literature highlighting recent distributional responses of species across taxa generally consistent with those predicted from bioclimatic models”

Fig. A1. Species map for saplings of *Abies balsamea*. The lower pair of lines represent the 50th percentile while the upper pair represents the 90th.

- Balsam fir, white spruce, black spruce appeared to regenerate better in southern portion of range
  - But affected by recent disturbances (ice storm, spruce budworm outbreaks, northward progression of timber harvest and fires)

Reich et al. warming experiment on 11 spp. in N. MN

- 2 species nearest warm edge limit (balsam fir and white spruce) most adversely affected by warming
- Several temperate species (sugar maple, red maple, bur oak, northern red oak) had 30% more growth in warmed conditions
- Paper birch, quaking aspen, eastern white pine, and jack pine were intermediate
- "..southern boreal forests ....replacement by temperate species could take decades to centuries. There is considerable uncertainty about this timing, however, because climate change could also affect natural (e.g., fire, windstorm, herbivory) and anthropogenic (e.g., timber harvest) disturbance regimes that could contribute to the rate and direction of compositional change"
  - "at least for this set of important North American cold temperate and boreal species, climate-envelope models may accurately project future forests in the ecotone"

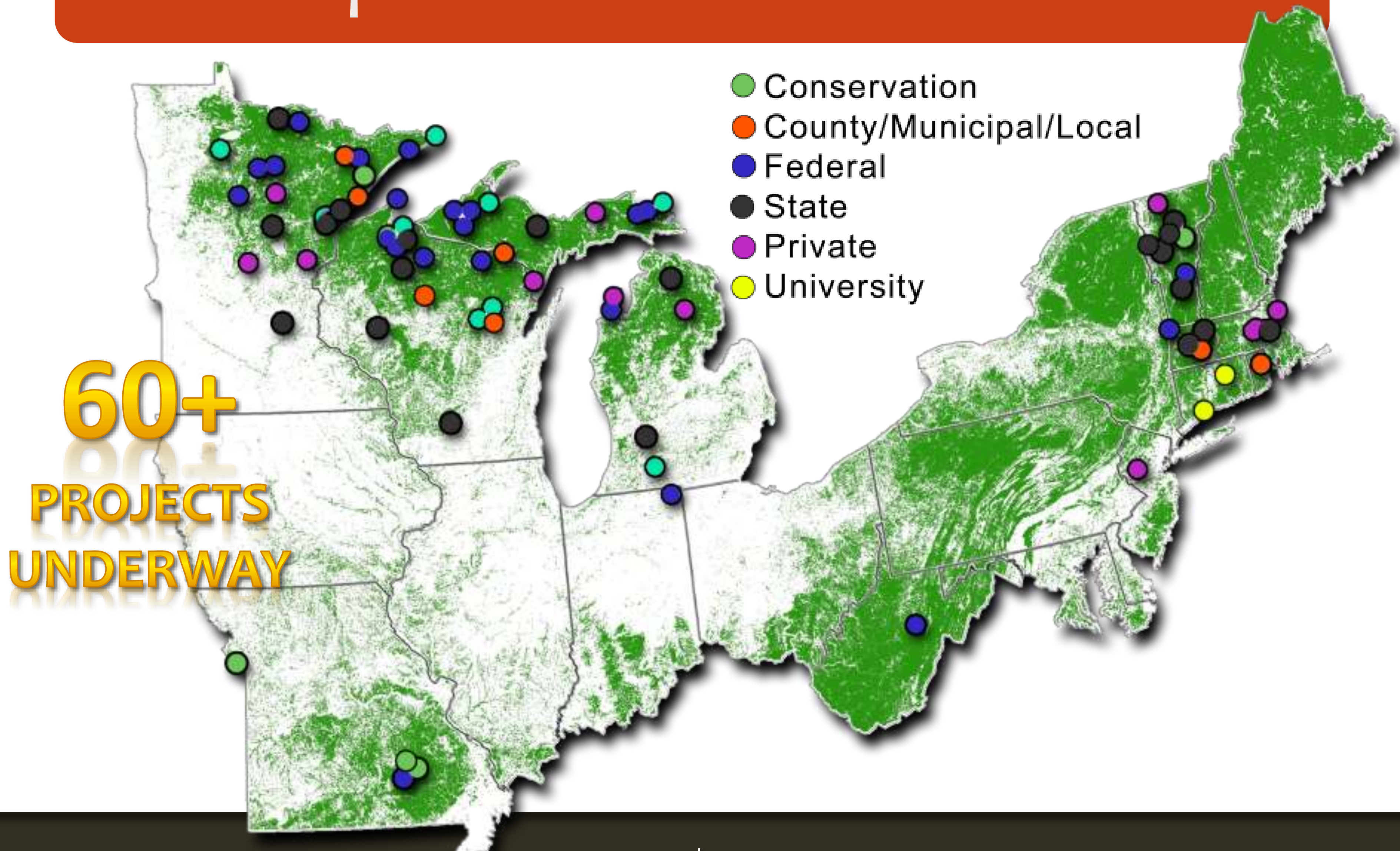
Reich, P. B., K. M. Sendall, K. Rice, R. L. Rich, A. Stefanski, S. E. Hobbie, and R. A. Montgomery. 2015. Geographic range predicts photosynthetic and growth response to warming in co-occurring tree species. Nature Clim. Change **5**:148-152.

CLIMATE CHANGE RESPONSE FRAMEWORK

Structured, process-oriented, works on multiple scales

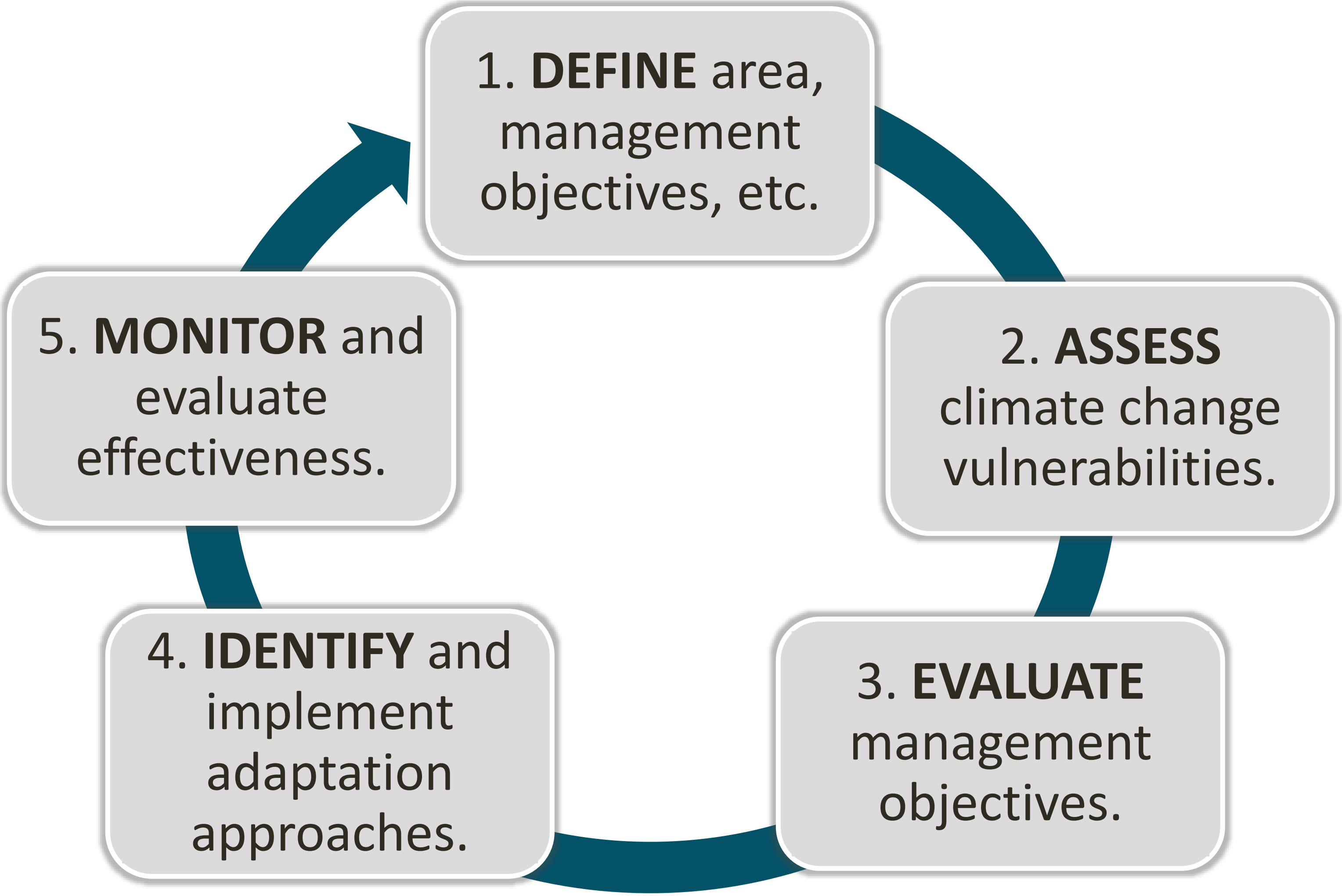
Components:	**Progress:**
Partnerships	75+ partner organizations (and counting)
Vulnerability Assessment	6 published assessments
Forest Adaptation Resources	Published in 2012, updated and online versions in prep
Adaptation Demonstrations	60+ demonstrations underway

Adaptation Demonstrations

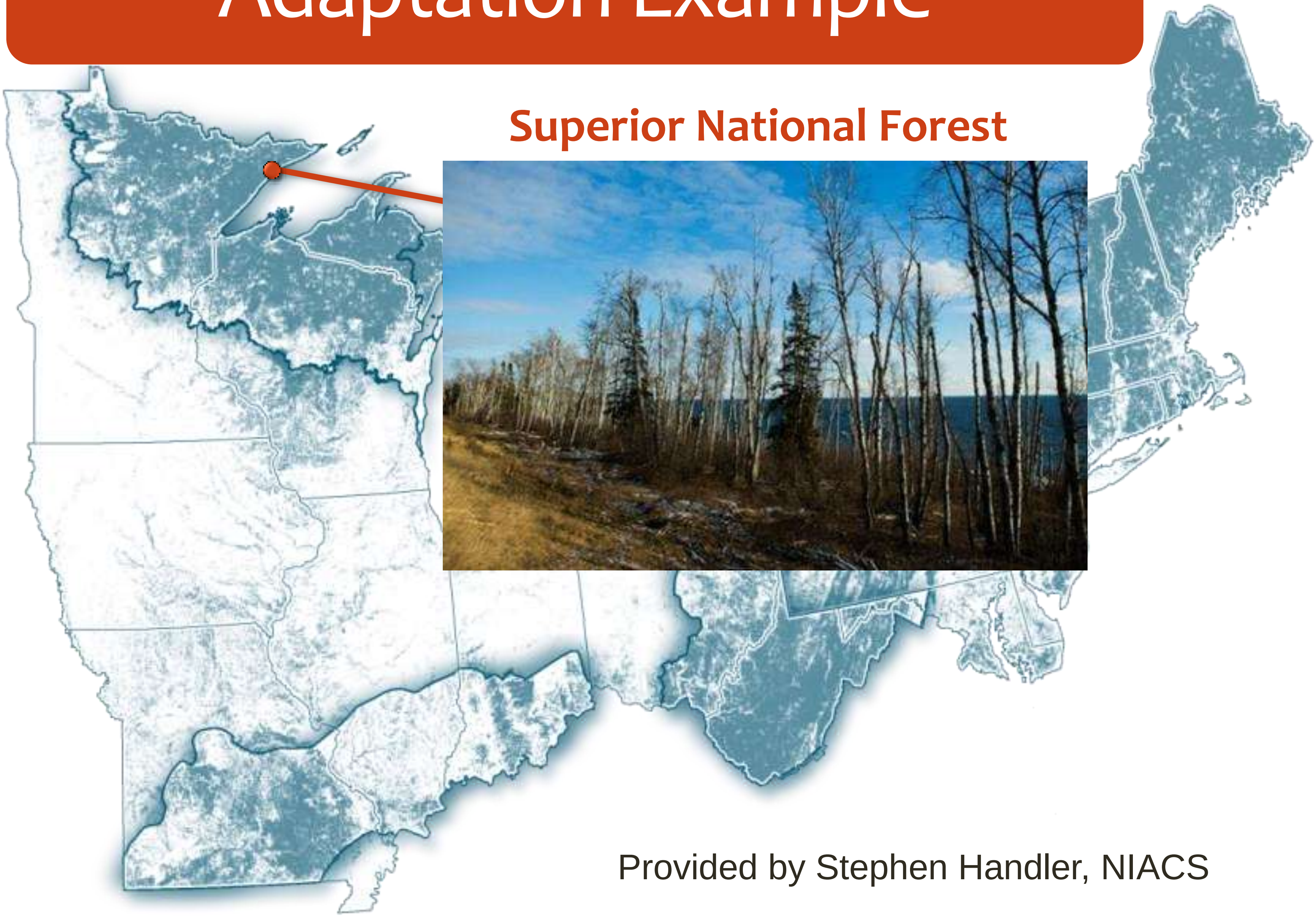


www.forestadaptation.org | *Coordinated by NIACS*

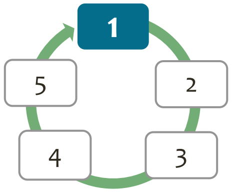
Forest Adaptation Process



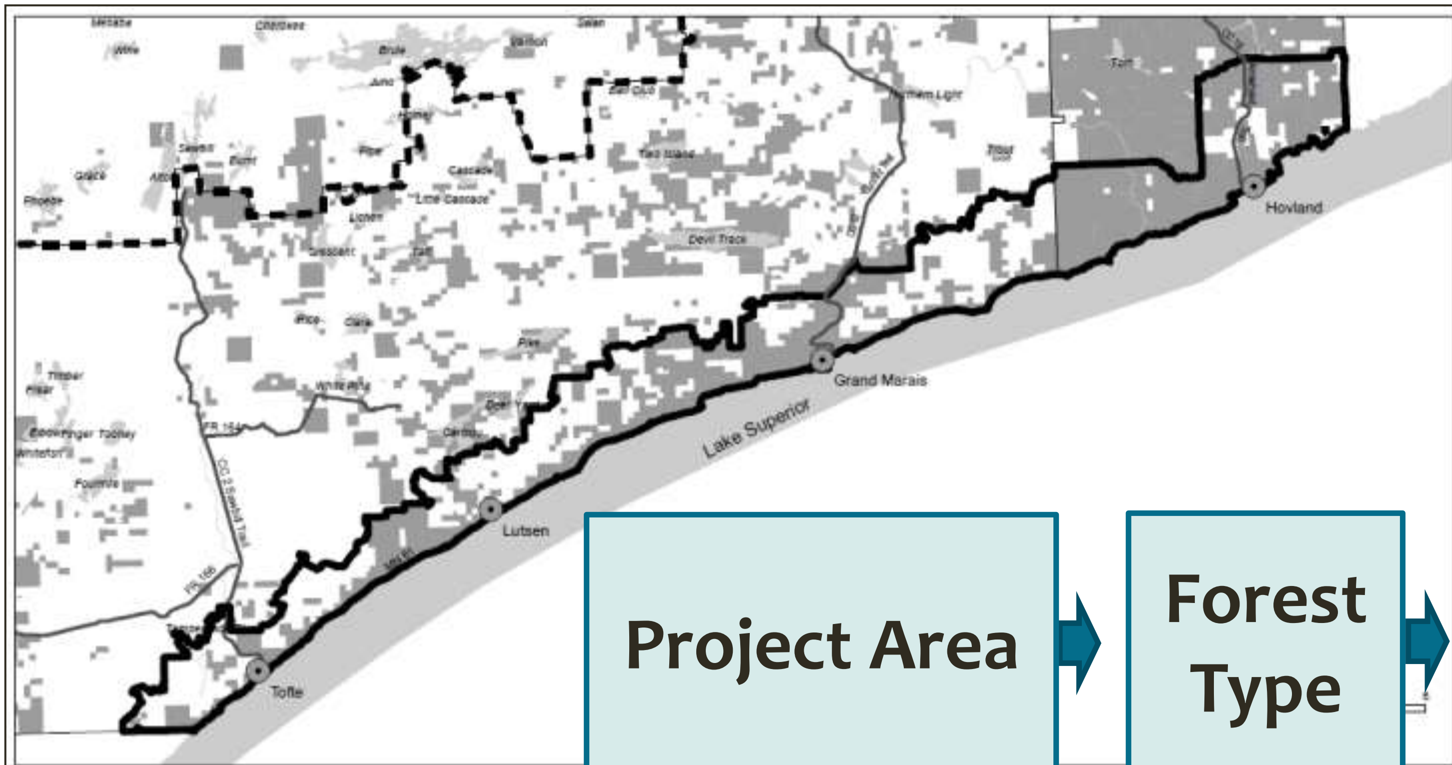
Adaptation Example



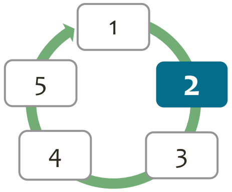
Provided by Stephen Handler, NIACS



Step 1: DEFINE area of interest, management goals and objectives, and time frames.



Project Area	Forest Type	Mgmt. Obj.
Corridor along N shore of Lake Superior	Paper birch	Regenerate paper birch, other spp.

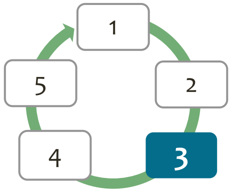


Step 2: ASSESS climate change impacts and vulnerabilities for the area of interest.

How might the area be affected by climatic change and subsequent impacts?

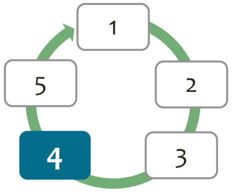
Data from Inventory and Tree Atlas

TREES			At Risk?		At Risk BA	
Species	**BA/Ac**	**TPA**	**Low**	**High**	**Low**	**High**
Balsam Fir	2.3	11.8	yes	yes	2.3	2.3
Basswood	5.1	9.3			0.0	0.0
Black Ash	0.6	0.4		yes	0.0	0.6
Black Spruce	0.6	0.4	yes	yes	0.6	0.6
Hemlock	4.0	5.7			0.0	0.0
Ironwood	0.6	2.1			0.0	0.0
Paper Birch	0.6	0.8	yes	yes	0.6	0.6
Quaking Aspen	4.6	8.5	yes	yes	4.6	4.6
Red Maple	22.2	59.9			0.0	0.0
Red Oak	1.1	0.5			0.0	0.0
Sugar Maple	38.2	76.9		yes	0.0	38.2
White Cedar	5.7	8.3		yes	0.0	5.7
Yellow Birch	14.8	23.4		yes	0.0	14.8
Grand Total	**100.4**	**207.9**		**At-Risk Value:**	8.0	67.3
				Proportion at Risk:	8%	67%



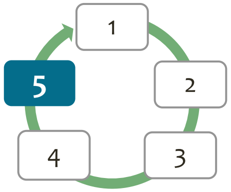
Step 3: EVALUATE management objectives given projected impacts and vulnerabilities.

Mgmt. Obj.	Challenges	Opportunities	Feasibility of Meeting Obj. (Current Mgmt)
• Regenerate paper birch	• On-going succession • Brush, grass comp. • Productivity issues • Paper birch projected to decline long-term	• Lake effect = moderation • Healthy pockets of birch • Range of micro-sites	• Short term: Med • Long-term: Low



Step 4: IDENTIFY and adaptation approaches and tactics for implementation.

Adaptation Approach	Tactic	Consider:
• Match species to sites that are likely to provide future habitat	• Focus on wetter, north-facing sites	• Benefits • Drawbacks • Barriers • Practicability
• Encourage a range of native species	▪ Plant higher % of white pine, lower % of white spruce ▪ Additional species (bur oak, red oak, jack pine, red maple)	



Step 5: MONITOR and evaluate effectiveness of implemented actions.

Monitoring Item	Monitoring Metric	Criteria for Evaluation	Implement
Post harvest stocking*	Stems/acre	Established criteria	Stocking surveys
Survival of planted trees*	Seedling survival	Established criteria	Survival surveys

This kind of approach can work most anywhere without large changes in modes of operation.

Maria Janowiak will discuss in greater detail in next session.

**Standard monitoring item*

Conclusions

- We have challenges posed by a changing climate, which also brings many opportunities.
- Management of our forest resources need not change drastically, but being ‘climate informed’ in management decisions will enhance the likelihood of sustained ecosystem services.
- The time to act, each in our own ways, is now.

My personal way to act, and a dream for nearly 2 decades, is finally going to come true!

32 solar panels now in garage; will power house heat and lights and local travel.

~13K kwh/yr for
~$16K after
30% fed rebate

Might something like this work for you or someone you have influence with?

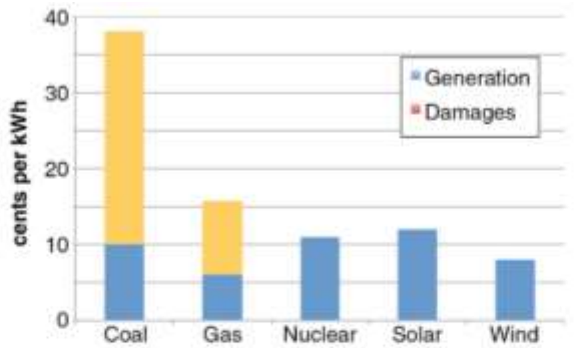
Electric car (Ford Focus Electrc)
($7500 fed rebate and 0% for 60 mo)

~$19.5K after rebate

Still will have long-distance car travel and airplane flights….

Thank you!

- USFS Northern Research Station
  - A. Prasad, M. Peters, S. Matthews
  - FIA folks: R. McCullough, all field crews!
  - Web folks: J. Lootens-White, D. Deitzman
- Northern Global Change Res. Program
  - D. Hollinger, R. Birdsey

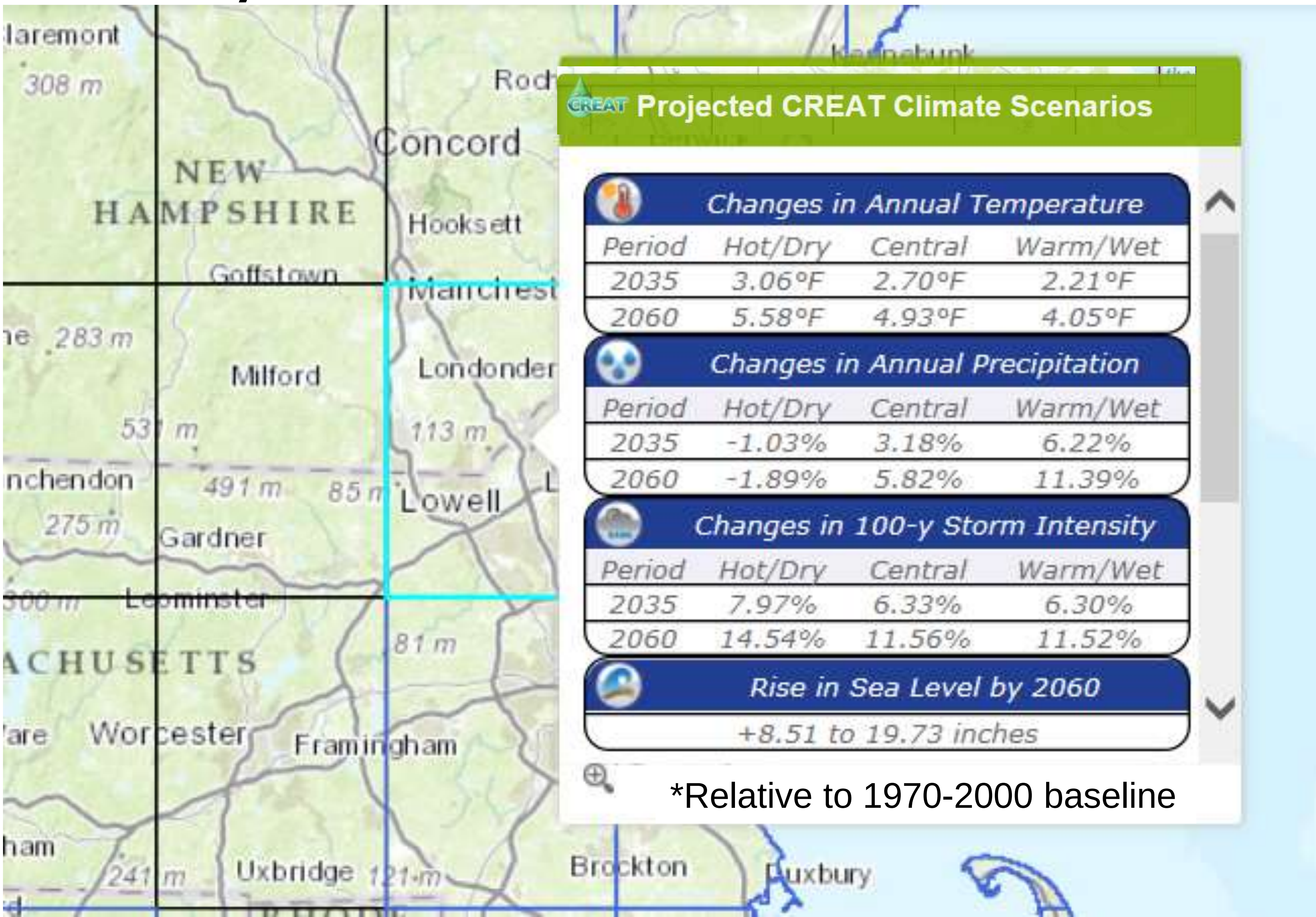


- National Climate Assessment
  - G. Yohe, T. Patel-Weynand, S. Pryor , D. Scavia
- Northern Institute of Applied Climate Science
  - C. Swanston, M. Janowiak, S. Handler, L. Brandt, P. Butler, K. Schmitt

Louis Iverson, Anantha Prasad, Stephen Matthews, Matthew Peters
liverson@fs.fed.us 740-368-0097

All publications available at http://www.treesearch.fs.fed.us/ or
Google Scholar or Web of Science or ResearchGate: 'louis iverson'
Atlas web site http://www.nrs.fs.fed.us/atlas

Projected temperature, precipitation and 100 yr storm intensity with 3 scenarios*, ~2035 and ~2060.



Projected CREAT Climate Scenarios

Changes in Annual Temperature			
Period	Hot/Dry	Central	Warm/Wet
2035	3.06°F	2.70°F	2.21°F
2060	5.58°F	4.93°F	4.05°F

Changes in Annual Precipitation			
Period	Hot/Dry	Central	Warm/Wet
2035	-1.03%	3.18%	6.22%
2060	-1.89%	5.82%	11.39%

Changes in 100-y Storm Intensity			
Period	Hot/Dry	Central	Warm/Wet
2035	7.97%	6.33%	6.30%
2060	14.54%	11.56%	11.52%

Rise in Sea Level by 2060

+8.51 to 19.73 inches

*Relative to 1970-2000 baseline