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Climate Change and the Highway System: Impacts and Adaptation Approaches

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Objectives:

1) synthesize the current state of knowledge on the range of impacts of climate change on the highway system by region of the United States for the period 2030-2050

2) recommend institutional arrangements, tools, approaches and strategies that state DOTs can use during the different stages of planning and project development and system management to adapt both infrastructure and operations to these impacts

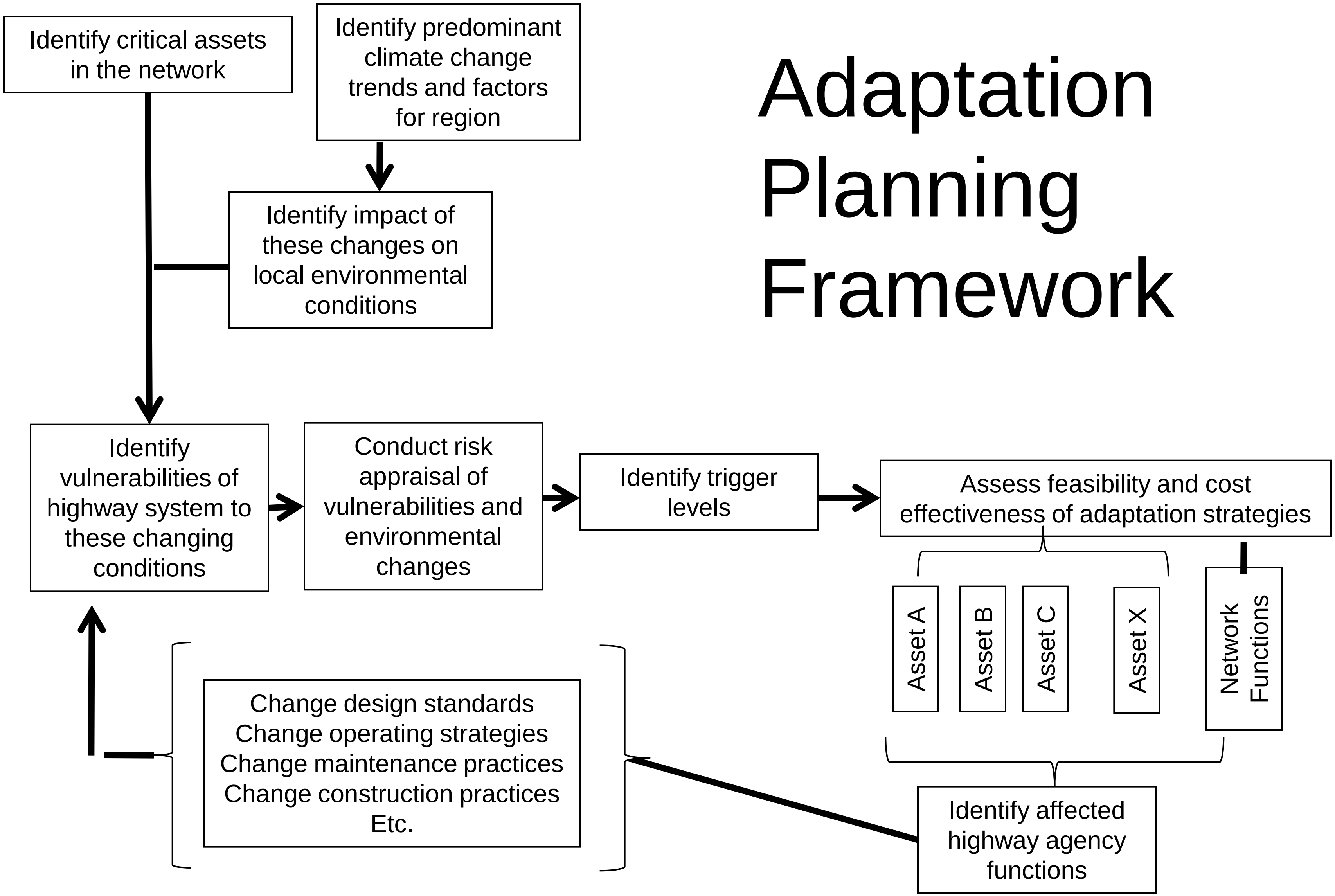
3) prepare guidance, materials and methods for dealing with these impacts, and

Climate Change and Adaptive Transportation Management: xxxxx (e.g., Maintenance)

1. How might climate change affect xxxxx?
2. What is the adaptive transportation system management approach to considering climate change?
3. What are the elements of an adaptive xxxxx program?
4. What strategies can be considered as part of the adaptive xxxxx program?
5. What is the process for considering the analysis of such strategies as part of decision making?
6. What are the risk assessment and cost effectiveness tools that can be used to analyze possible strategies?
7. How is a adaptive xxxxx program established?
8. Technical references

4) Identify future research and activities needed to improve our understanding of possible impacts and on the steps needed for adaptive system management.

Adaptation Planning Framework



Message 1: The U.S. population will continue to grow with most of this growth occurring in urban areas, and in parts of the country expecting notable changes in climate.

Message 2: The composition of this population will be very different than it is today, with more diverse populations and elderly in the nation’s population mix.

Message 3: Significant levels of housing and corresponding development will be necessary to provide places to live and work for this population, with much of this development likely to occur in areas subject to changing environmental conditions.

Message 4: Increasing population growth will create new demands for transportation infrastructure and services, once again in areas that are vulnerable to changing climate conditions.

Message 5: The nation’s highway system will be facing increasing demands for reconstruction and rehabilitation over the next 40 years (to 2050), which provides an opportunity to incorporate climate adaptation strategies into such efforts, if appropriate.

Message 6: New vehicle, fuel and system management technologies will likely be more widely used in 2050 than they are today, but the net effect of such technologies will be to make travel easier and more environmentally benign. This along with increasing travel demand will result in higher levels of vehicle miles traveled, and result in need for more infrastructure.

Temperature	Change in temperature	Models project an average increase in temperature for the continental United States of 1.6°C (2.9°F) from 2010 to 2050 (range is from 0.3 to 3.8°C (0.5 to 6.9°F).
	Change in range of maximum and minimum temperatures	On average, minimum temperatures are projected to increase more than maximum temperatures.

Precipitation	Overall changes in precipitation levels	On average, precipitation in the United States is projected to increase 2.3% from 2010 to 2050, but model results vary widely, ranging from –11 to +10%.
	Precipitation changes by season	On average, precipitation in the United States is projected to increase 2.4% in the winter from 2010 to 2050, but model results vary widely, ranging from -10% to +15%. Summer precipitation is projected to decrease 1.6%, with model results ranging from +15% to -21%.
	Increased intense precipitation and other changes in storm intensity (except hurricanes).	The most intense storms will likely increase. The increase in intensity is projected to be 7%/°C (4%/°F).

Sea Level Rise	Sea level rise	Sea level is projected to rise 0.5 to 2 ft by 2050; the most likely increase is about 10 in; 100-year and 500-year storm expected flood heights would increase accordingly.

Need to account for local subsidence or uplift. Examples of such rates are (negative is uplift offsetting sea level rise, positive I> that is > 3 is subsidence; all measures in mm/yr): San Francisco: 0.21; Los Angeles: -0.97; Grand Isle, LA: 7.44; Charleston, SC: 1.35; Boston, MA: 0.83.

Hurricanes	Increased hurricane intensity	The total number of hurricanes could decrease. The intensity of the strongest storms (Categories 4 and 5) are projected to increase.

Impact to Operations/Maintenance

Actual Change

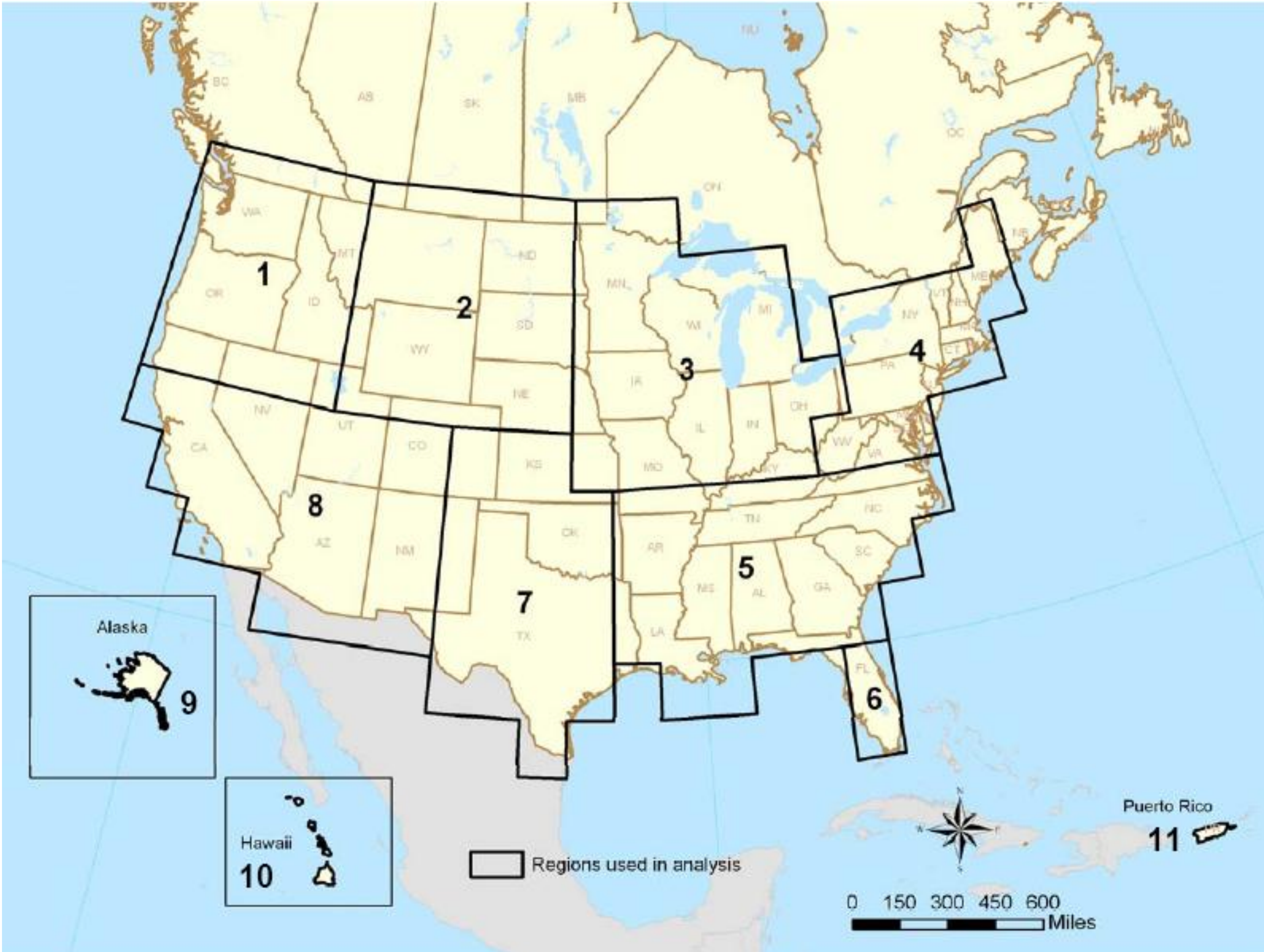
	Clima[illegible] Weather [illegible]e	*Impact to Infrastructure*	*Impact[illegible]erations/ Maintenance*
Temperature	Change i[illegible] extrem[illegible] maximu[illegible] temperatur[illegible]	• Premature deterioration of infrastructure; • Damage to roads from buckling and rutting; • Bridges subject to extra stresses through thermal expansion and increased movement.	• Safety concerns for hi[illegible] workers limiting construction activities; • Thermal expansion of [illegible] joints, adversely affecting bridge operations and increasi[illegible]ntenance costs; • Vehicle overheating an[illegible]d risk of tire bow-outs; • Rising transportation cos[illegible]crease need for refrigeration); • Materials and load restrictions can limit transportation operations; • Closure of roads because of increased wildfires
	Change in range of maximum and minimum temperatures	• Fewer days with snow and ice on roadways; • Reduced frost heave and road damage; • Structures will freeze later and thaw earlier with shorter freeze season lengths • Increased freeze-thaw conditions creating frost heaves and potholes on road and bridge surfaces; • Permafrost thawing leads to increased slope instability, landslides and shoreline erosion damaging roads and bridges due to foundation settlement (bridges and large culverts are particular[illegible]sitive to movement caused by thawing permaf[illegible] • Hotter summers in Al[illegible]ad to increased glacial melting and longer per[illegible]f high stream flows, causing both increased [illegible]ent in rivers and scouring of bridge supporting pi[illegible]d abutments.	• Decrease in frozen precipitation would improve mobility and safety of travel through reduced winter hazards, reduce snow and ice removal costs, decrease need for winter road maintenance, result in less pollution from road salt, and decrease corrosion of infrastructure and vehicles; • Longer road construction season in colder locations. • Vehicle load restrictions in place on roads to minimize structural damage due to subsidence and the loss of bearing capacity during spring thaw period (restrictions likely to expand in areas with shorter winters but longer thaw seasons); • Roadways built on permafrost likely to be damaged due to lateral spreading and settlement of road embankments; • Shorter season for ice roads.

Category

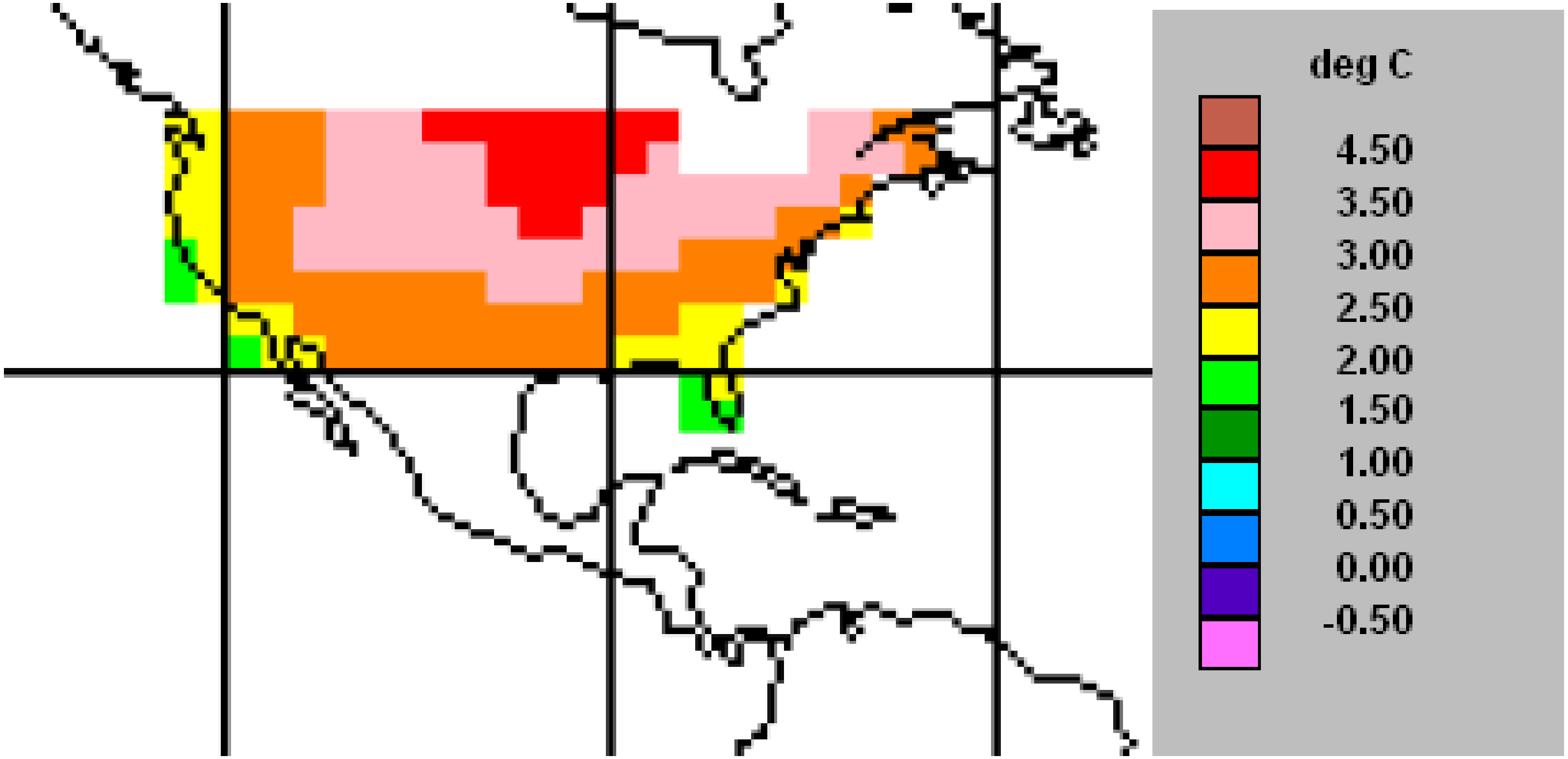
Impact to Infrastructure

Summary of Emissions Scenarios

SRES Scenario	*Key Assumptions*	*CO_2 Concentration in 2050 (ppmv)*	*Projected Increase in Global Mean from 2010 to 2050 (°F)*
A1FI	Very high rates of growth in global income, moderate population growth, and very high fossil fuel	562–574	1.7–3.0
A2	Moderate rates of economic growth, but very high rates of population growth	527–537	1.2–2.6
A1B	Same economic and population assumptions as the A1FI scenario, but assumes more use of low-carbon emitting power sources and clean technologies	527–541	1.5–2.6
B1	Same population growth as A1FI and A1B, but assumes a more service-oriented economy and much more use of low-carbon emitting power sources and clean technologies	482–491	0.8–1.9


1
2
3
4
5
6
7
8
Alaska
9
Hawaii
10
Puerto Rico
11
Regions used in analysis
0 150 300 450 600
Miles

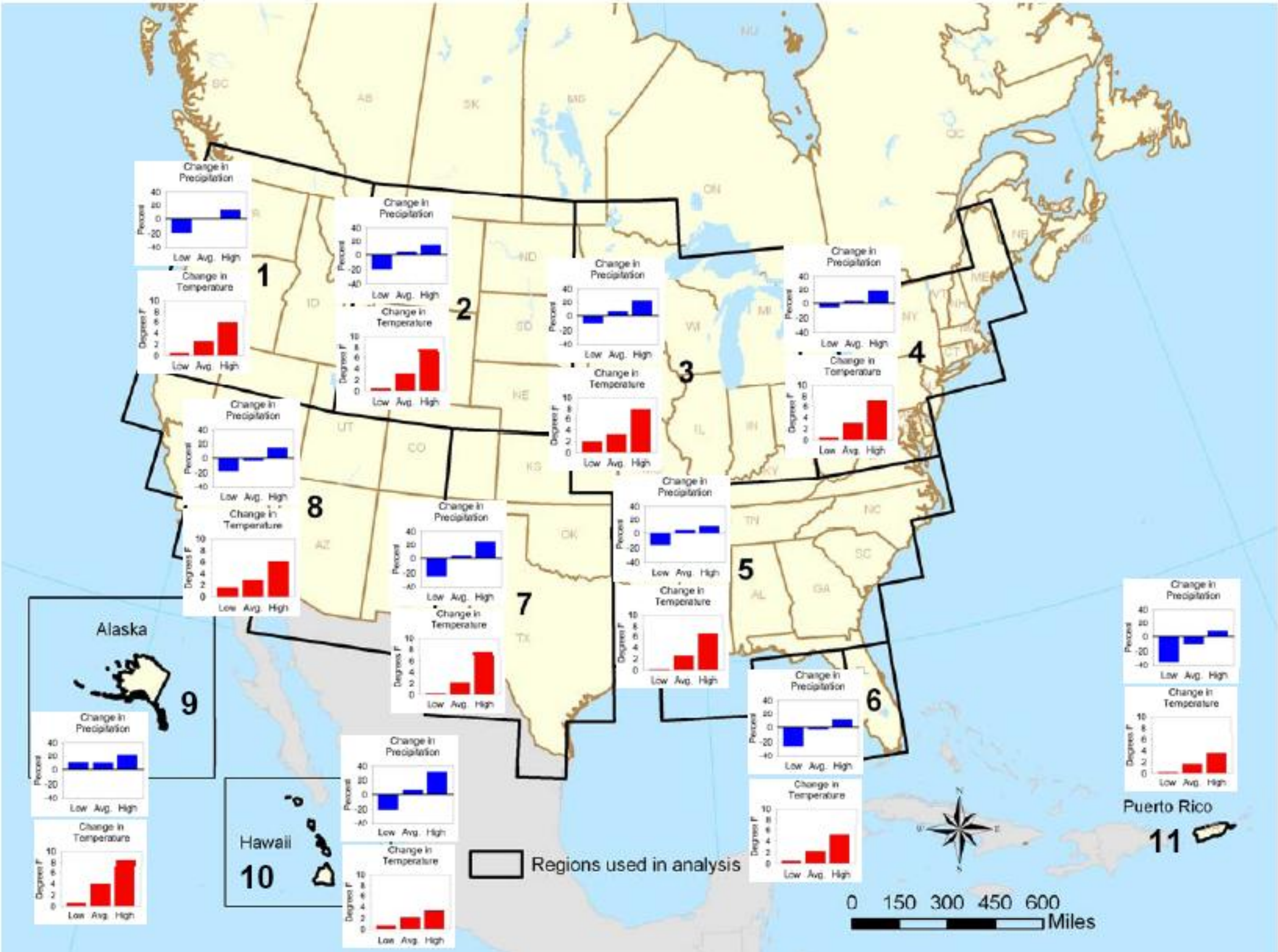
Estimated Increases in Temperature (^{o}C) in 2050 Relative to 1990 Using A1F1 Scenario, 3 ^{o}C Sensitivity



Projected Changes in Regional Annual Temperatures (ºF) from 2010 to 2050 (based on 10 GCMs)

Regions	*Average Model Change*	*Low Model Projection*	*High Model Projection*
1. Northwest	3.7	0.5	5.9
2. Upper Great Plains	4.7	0.5	7.7
3. Upper Midwest	4.8	2.3	8.0
4. Northeast	4.2	0.5	7.2
5. Southeast	3.6	0.1	6.5
6. Florida	2.8	0.5	5.2
7. South Central	3.9	0.2	7.5
8. Southwest	3.8	1.5	6.1
9. Alaska	4.9	0.6	8.4
10 Hawaii	2.5	0.7	3.3
11. Puerto Rico	2.3	0.2	3.6

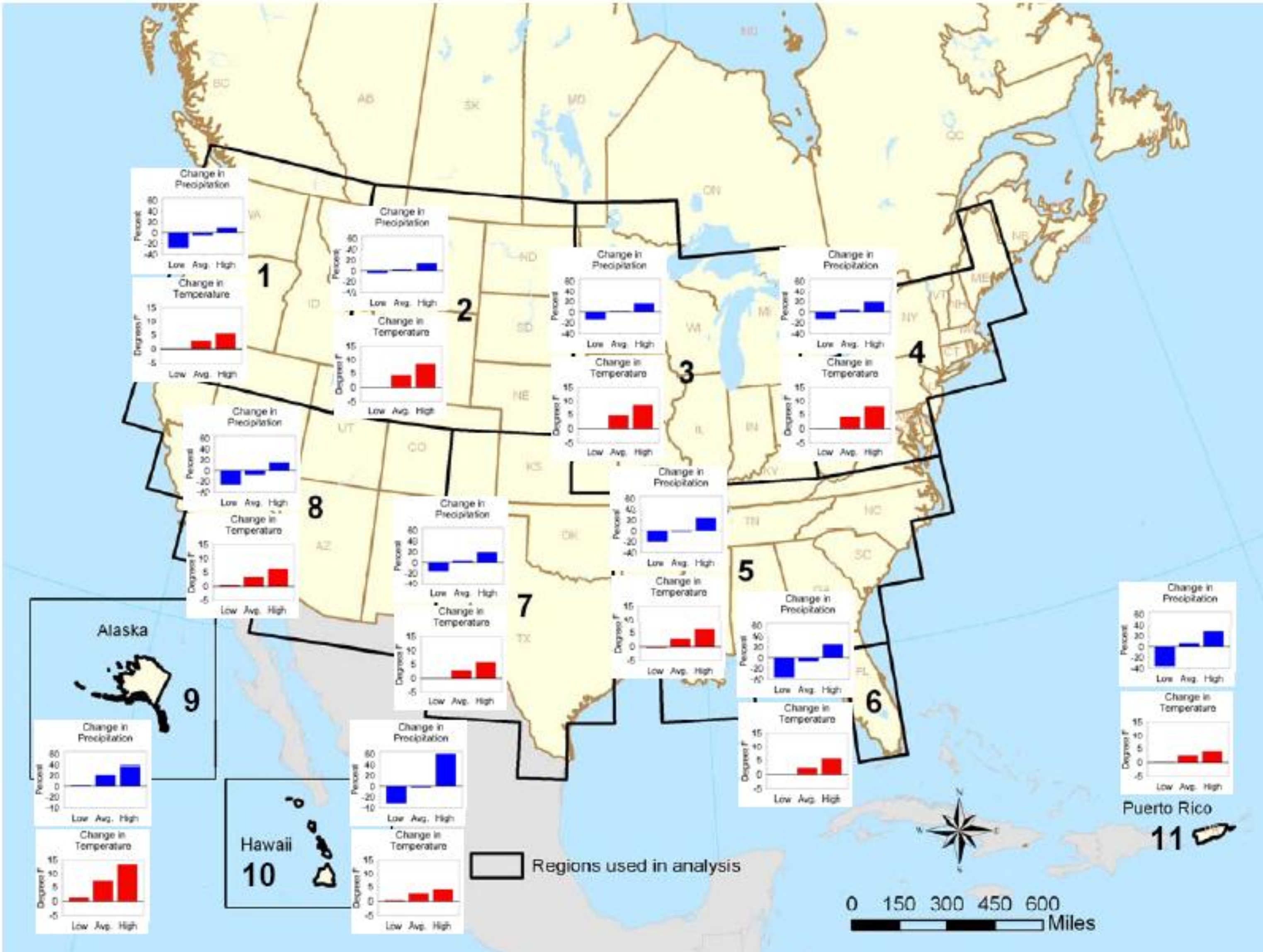
Projected Regional Changes in Annual Temperature and Precipitation in 2050



Projected Changes in Regional Winter Temperatures (°F) from 2010 to 2050 (based on 10 GCMs)

Regions	*Average Model Change*	*Low Model Projection*	*High Model Projection*
1. Northwest	2.9	0.0	5.5
2. Upper Great Plains	4.2	0.0	8.2
3. Upper Midwest	4.7	-0.1	8.2
4. Northeast	4.0	-0.2	7.7
5. Southeast	2.7	-0.5	6.2
6. Florida	2.1	0.1	5.4
7. South Central	2.7	0.0	5.7
8. Southwest	3.1	0.4	6.1
9. Alaska	7.0	1.0	13.2
10 Hawaii	2.5	0.5	4.0
11. Puerto Rico	2.5	0.2	3.9

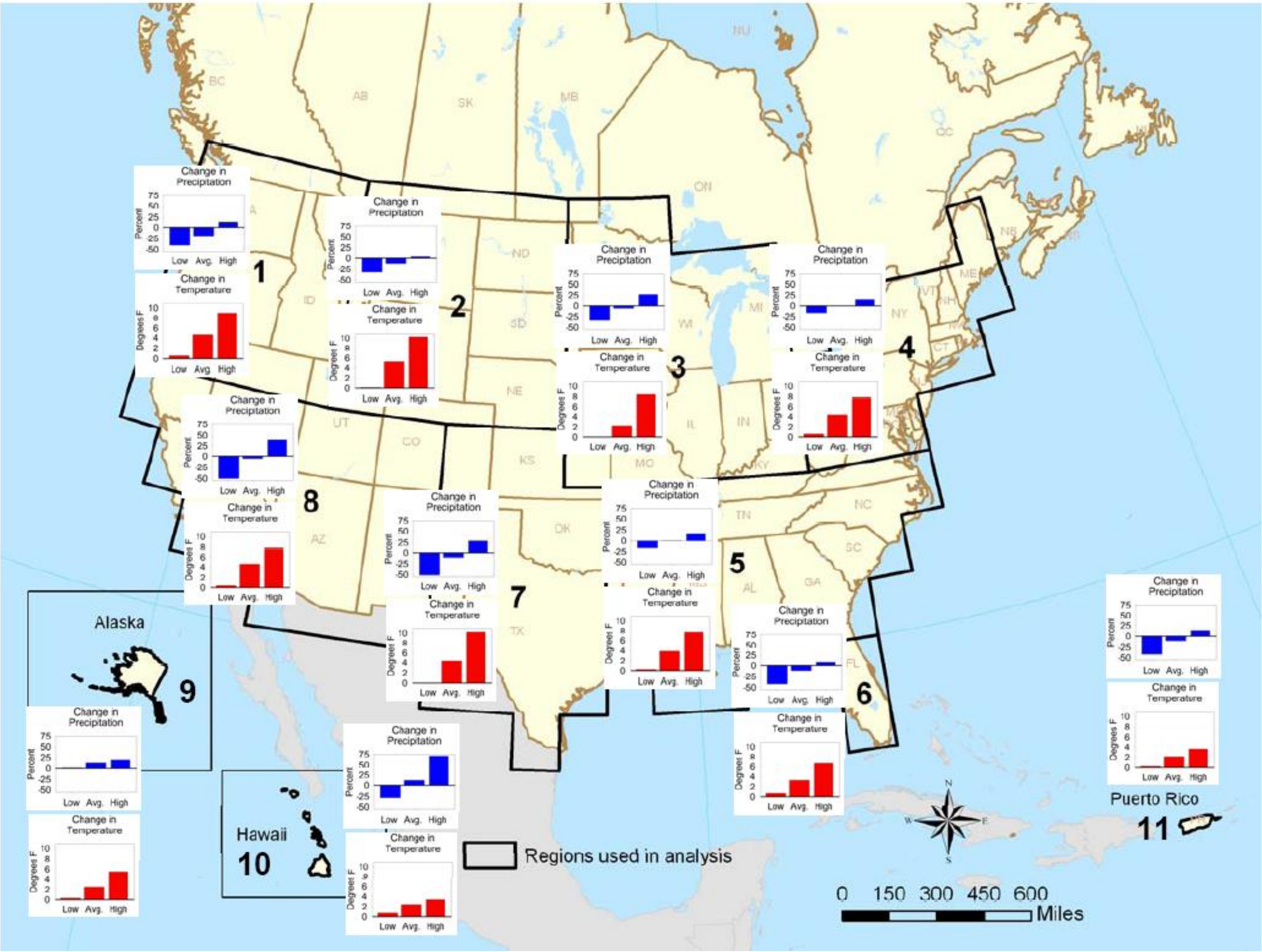
Projected Regional Changes in Winter Temperature and Precipitation in 2050



Projected Changes in Regional Summer Temperatures (°F) from 2010 to 2050 (based on 10 GCMs)

Regions	*Average Model Change*	*Low Model Projection*	*High Model Projection*
1. Northwest	4.6	0.5	9.0
2. Upper Great Plains	5.3	0.1	10.2
3. Upper Midwest	2.3	0.0	8.5
4. Northeast	4.3	0.6	7.7
5. Southeast	3.9	0.2	7.7
6. Florida	3.3	0.7	6.6
7. South Central	4.3	0.0	10.2
8. Southwest	4.6	0.4	7.7
9. Alaska	2.5	0.3	5.5
10 Hawaii	2.4	0.7	3.4
11. Puerto Rico	2.2	0.2	3.6

Projected Regional Changes in Summer Temperature and Precipitation in 2050



Extreme Events

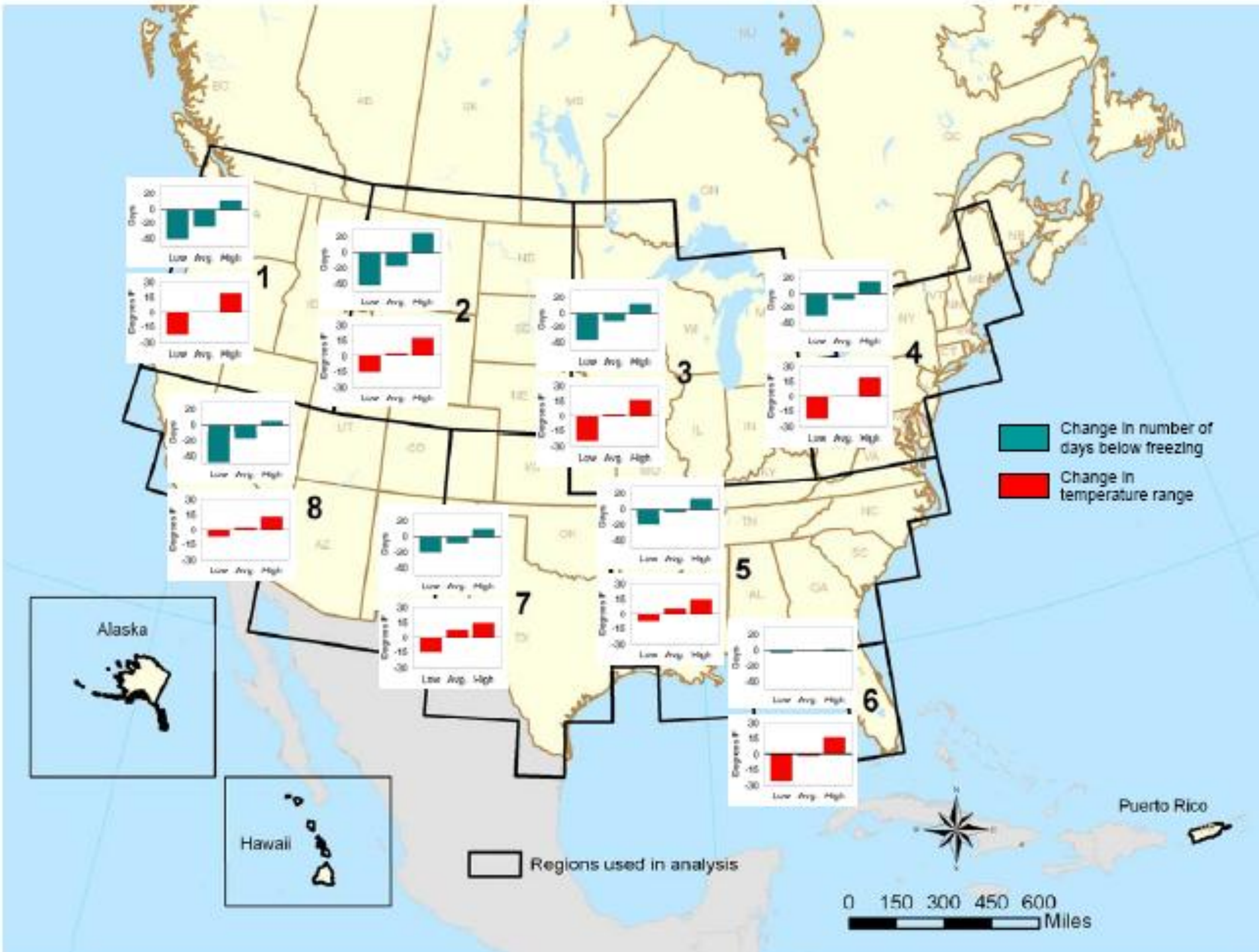
1. Intra-annual extreme temperature range (ETR), defined as the difference between the highest temperature of the year and the lowest

2. Total number of frost days (FD), defined as the annual total number of days with absolute minimum temperature below 32°F (0°C)

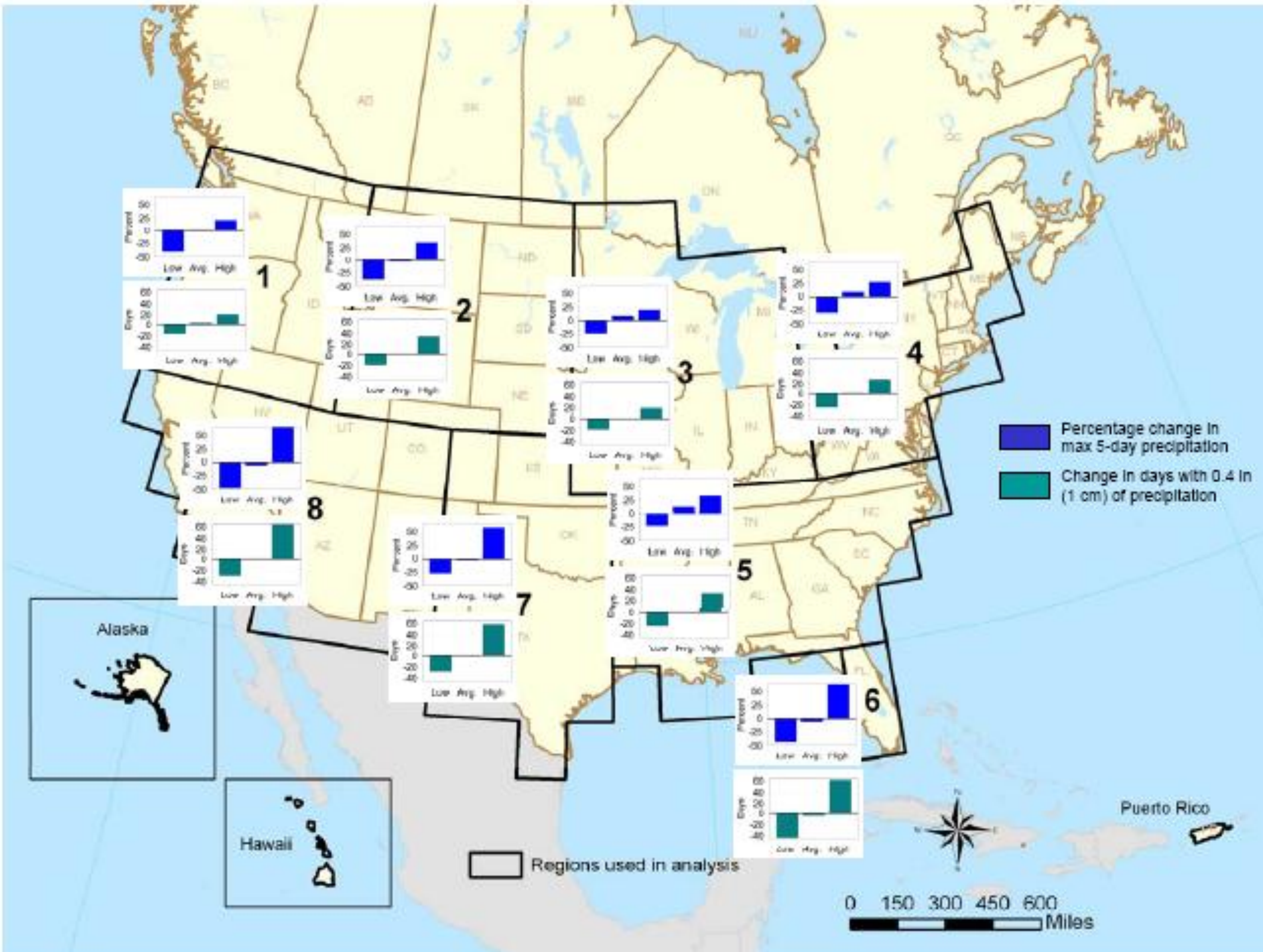
3. Number of days with precipitation greater than 10 mm (0.4 inches; R10)

4. Maximum 5-day precipitation total (R5D).

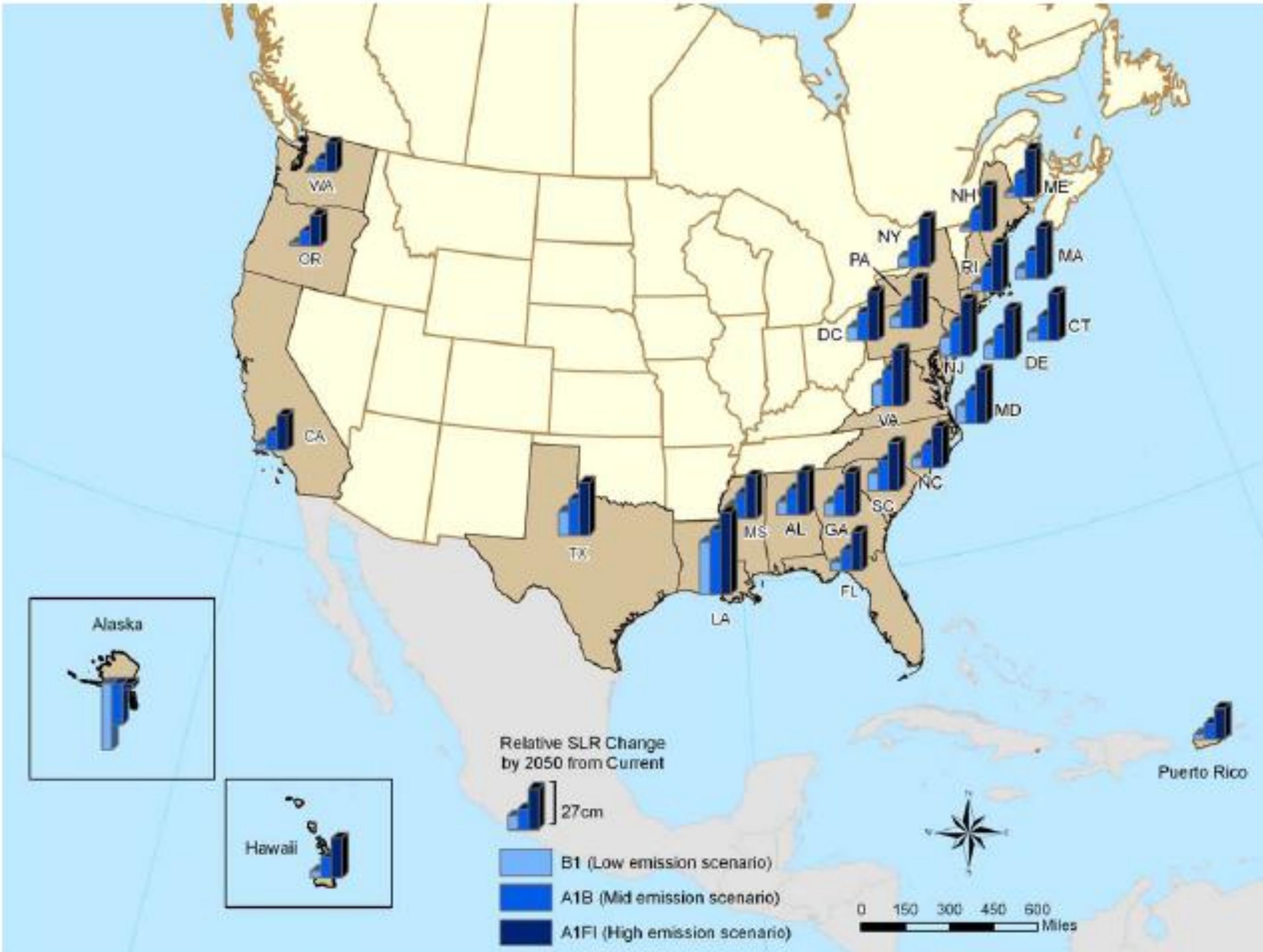
Projected Changes in Extreme Temperature Events in 2050 for Eight Regions



Projected Changes in Extreme Precipitation Events in 2050 for Eight Regions



Coastal State Projections of Sea Level Rise by 2050 Relative to 2010



Adaptation Planning Framework