Appendix V: Greenhouse Gas and Climate Change

Greenhouse Gas Analysis and Climate Change Assessment

Greenhouse Gas Analysis and Climate Change Assessment

I-35 Capital Express Central Project
I-35 from US 290 East to US 290 West/SH 71

Travis County

CSJ Number(s): 0015-13-388
November 2022

Contents

List of Tables

List of Figures

List of Appendices

List of Acronyms

BAU	business as usual
cm	centimeters
CEQ	Council on Environmental Quality
CH_4	methane
CO_2	carbon dioxide
CO_2E	carbon dioxide equivalent
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
FHWA	Federal Highway Administration
GHGs	greenhouse gases
GWP	global warming potential
HOV	High-occupancy vehicle
ICE	Infrastructure Carbon Estimator
IPCC	Intergovernmental Panel on Climate Change
I-35	Interstate 35
MMT	million metric tons
MT	metric tons
N_2O	nitrous oxide
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
O&M	operations and maintenance
ppm	parts per million
ppt	parts per trillion
SF_6	sulfur hexafluoride
TxDOT	Texas Department of Transportation
USGCRP	U.S. Global Change Research Program
VMT	vehicle miles traveled

1. Introduction

Climate change is a current topic in public conversations. Climate change relates to transportation in two ways: first, transportation-related greenhouse gases (GHG) emissions may contribute to climate change, and second, the changing climate has the potential to affect the transportation system (White House 2021b). As a result, members of the public are frequently interested in understanding how the Texas Department of Transportation (TxDOT) is responding to the changing climate and how activities may contribute to climate change. TxDOT has prepared this report to assess project-level GHG emissions and climate change impacts for a proposed I-35 Capital Express-Central Project in the Austin District.

On January 27, 2021, the President signed Executive Order 14008 Tackling the Climate Crisis at Home and Abroad to establish a government-wide approach to the climate crisis by reducing greenhouse gas emissions and a policy to increase climate resilience (White House 2021). In January 2021, Executive Order 13990 Protecting Public Health and the Environment and Restoring Science to Tackle Climate Change (White House 2021a), directed White House Council on Environmental Quality (CEQ) to update its 2016 guidance and rescind its draft 2019 guidance. CEQ's updated guidance is pending.

This report includes: 1) an overview of GHGs and climate change, 2) a project-level GHG analysis, 3) a proposed project-level assessment of climate change, 4) resiliency risk assessment, 5) incomplete or unavailable information for specific climate change impacts, and 6) results and conclusions. A summary of key project-level or TxDOT program-level strategies for addressing the impacts of a changing climate is also disclosed. TxDOT's goal is to provide information regarding climate change and GHG emissions to the public and to provide information for consideration during the environmental analysis of the proposed project.

1.1. Project Description

The TxDOT Austin District is proposing improvements to Interstate 35 (I-35) from US Highway 290 East (US 290E) to State Highway 71 (SH 71)/Ben White Boulevard (CSJ: 0015-13-388), a distance of approximately 8 miles (Figure 1-1). The proposed improvements include the removal of the existing I-35 decks from Airport Boulevard to MLK Jr. Boulevard, lowering the roadway, and adding two high-occupancy vehicle (HOV) managed lanes in each direction. The project will also reconstruct east-west cross street bridges, add shared-use paths (SUP), bus rapid transit (BRT), and make additional safety and mobility improvements within the project limits. See the Draft Environmental Impact Statement – Chapter 2 for a complete description of the proposed project alternatives.

1.2. Principal Modeling Tools and Data Sources Used in the Analysis

Various climate, meteorological, and hydrological modeling tools and data sources were used in this project-level analysis of GHG emissions and climate change. Table 1-1 provides a summary. Additional details on the use of these tools and data sources are described in the relevant sections of this report.

Figure 1-1: Project General Location Map

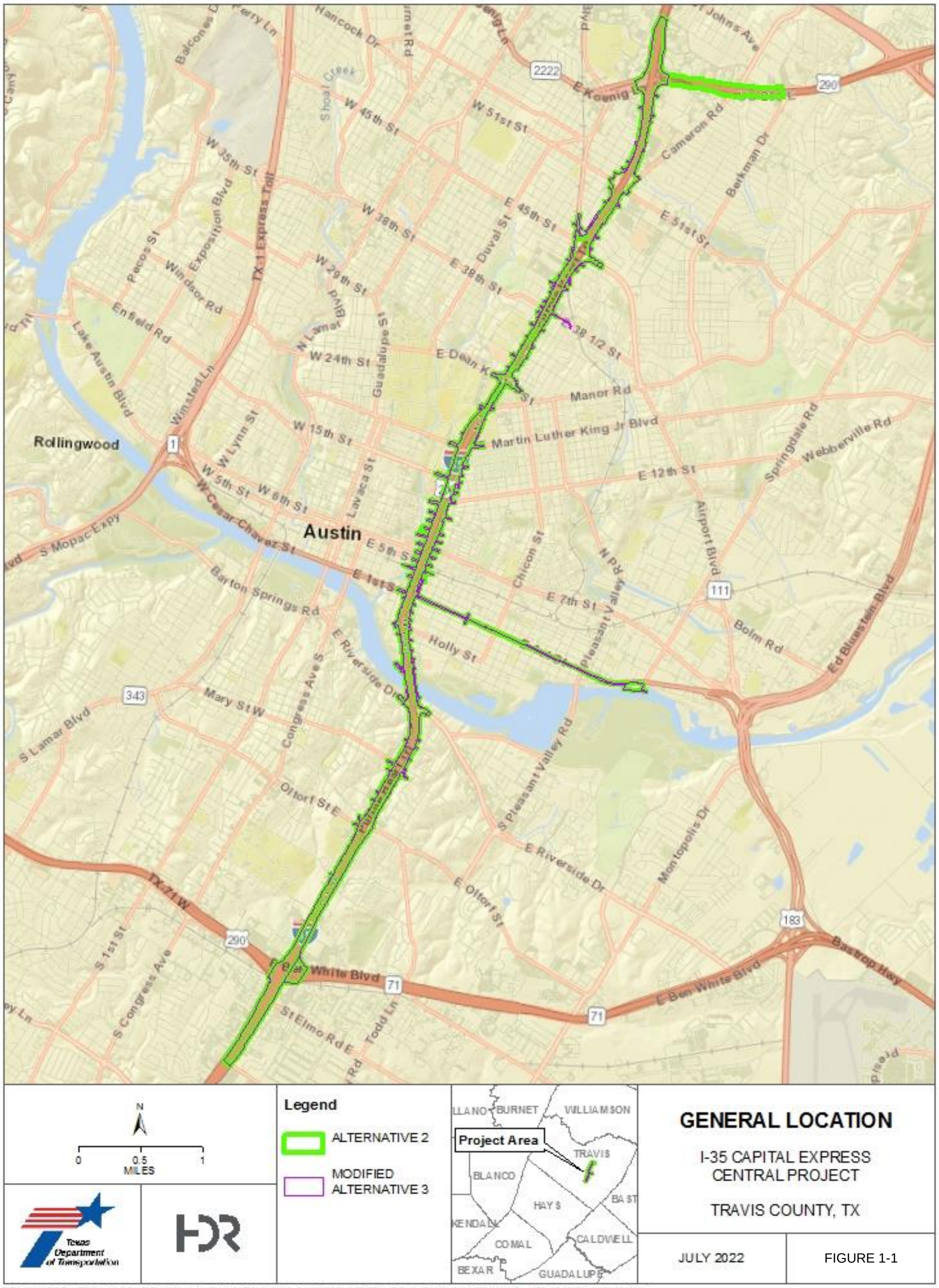


Table 1-1: Summary of Modeling Tools and Data Sources

Data	Use in Analysis	Source
Existing Precipitation and Temperature Data	Used for identifying trends for historical precipitation and minimum and maximum temperatures in Travis County.	U.S. Global Change Research Program 2014 and 2018 USGS National Climate Change Viewer 2022
Temperature Projections and Temperature Extremes	Used for analyzing predicted changes in temperature to assess the potential for impacts in Travis County.	U.S. Global Change Research Program 2014 and 2018 USGS National Climate Change Viewer 2022
Precipitation Projections and Precipitation Extremes	Used for analyzing predicted changes in precipitation to assess the potential for impacts in Travis County.	U.S. Global Change Research Program 2014 and 2018 USGS National Climate change Viewer 2022
Wildfire	Used for analyzing the predicted changes in areas burned to assess potential for impacts near the I-35 project site.	U.S. Department of Agriculture MC1 Dynamic Vegetation Model
Drought and Number of Dry Days	Used for analyzing the predicted number of dry days and the drought severity index in Travis County	U.S. Global Change Research Program 2014 and 2018 USGS National Climate Change Viewer 2022
Project Construction and Operation Information	Used in the Federal Highway Administration (FHWA) Infrastructure Carbon Estimator Model (version 2.1.3).	I-35 Capital Express Central Project Team 2022

2. Overview of GHG Emissions and Climate Change

2.1. Description of GHG Emissions

GHGs include both naturally occurring and anthropogenic gases, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro-chlorofluorocarbons, perfluorocarbons, and sulfur hexafluoride (SF_6). The accumulation of GHGs in the atmosphere influences the long-term range of average atmospheric temperatures (EPA 2022e). These gases trap the energy from the sun and help maintain the temperature of the Earth's surface, creating a process known as the greenhouse effect.

The effect each GHG has on global warming is a combination of the amount of their emissions and their global warming potential (GWP). GWP is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of CO_2. The larger the GWP, the more a given gas warms the earth compared to CO_2 over that time period. CH_4 and N_2O have substantially higher GWPs than CO_2. GHG emissions are typically presented in terms of metric tons of carbon dioxide equivalent (CO_2E), which are calculated as the product of the mass emitted of a given GHG and its specific GWP.

The most important GHG in human contributions is CO_2. While many gases have higher GWP than the naturally occurring GHGs, CO_2 is emitted in higher quantities and accounts for 80% of all GHGs emitted by the U.S. (EPA 2021a). GHGs can be attributed to the combustion of fossil fuels, such as the burning of coal and oil to generate electricity, power vehicles, or heat/cool buildings (IPCC 2021). CO_2 concentrations in the atmosphere have reached a high of 410 parts per million (ppm) in 2019 (IPCC 2021). Carbon dioxide cycles between the atmosphere, oceans and land biosphere. Its removal from the atmosphere involves a range of processes with different time scales. About 50% of a CO_2 increase will be removed from the atmosphere within 30 years, and a further 30% will be removed within a few centuries (IPCC 2018). The remaining 20% may stay in the atmosphere for thousands of years (IPCC 2018).

Concentrations of methane (CH_4), the second most prominent GHG, have also increased due to human activities such as rice production, the degradation of waste in landfills, cattle farming, and natural gas mining. In 2019, the atmospheric level of CH_4 was more than double the preindustrial level, up to 1,866 parts per billion (ppb) (IPCC 2021). CH_4 has a relatively short atmospheric lifespan of only 12 years, but it has a higher GWP potential than CO_2.

N_2O concentrations in the atmosphere rarely exceeded 280 ppb over the past 800,000 years. Levels have risen since the 1920s and reaching a new high of 332 ppb in 2019, primarily due to agricultural practices (IPCC 2021). N_2O has a 120-year atmospheric lifespan, meaning that, in addition to its relatively high GWP, its influence is long lasting, increasing its role in global warming.

SF_6 concentrations in the atmosphere have reached a high of 10 parts per trillion (ppt) in 2019 (IPCC 2021). SF_6, used in the electrical industry, and refrigerants, such as hydrofluorocarbons and perfluorinated compounds, are present in the atmosphere in relatively small concentrations but are very stable, with atmospheric lifetimes of 3,200 years, making them potent GHGs (EPA 2021b).

GHGs differ from other regulated air pollutants in that GHG emissions in the atmosphere do not directly cause adverse human health effects. Rather, the environmental effects of GHG emissions result from changes in global temperatures and climate, which in turn can have indirect effects on the environment, infrastructure, and human health. Appendices provides additional detail regarding the methodologies, data, and assumptions used for this GHG analysis and climate change assessment.

2.2. GHG Emission Inventories

In the U.S., fossil fuel combustion for electricity, heating, and transportation is the largest source of GHG emissions from human activities. The U.S. transportation sector is the largest source of GHG emissions (EPA 2022a). U.S. Environmental Protection Agency's (EPA) 1990-2019 GHG inventory indicates that U.S. GHG emissions were 6,558 million metric tons (MMT) CO_2E in 2019, down 1.7% from 2018 but up 1.8% from 1990 levels. Of these, 80% were CO_2, 10% were CH_4, and 7% were N_2O; the balance consisted of fluorinated gases. The transportation sector accounted for 27% of U.S. GHG emissions in 2020 (EPA 2022a).

Based on information released annually by the U.S. Energy Information Administration (EIA), Texas state-wide CO_2 emissions from fossil fuel consumption totaled 683.2 MMT CO_2E in 2019. The industrial sector was the top contributor to the reported statewide emissions, accounting for 34.6% of the total CO_2 emissions from fossil fuel use, followed by transportation (33.4%) and electric power generation (27.9%) (EIA 2022).

In a 2018 TxDOT study of statewide on-road GHG emissions, on-road and fuel-cycle CO_2E emissions in Texas were estimated to be 171 MMT per year in 2010. By 2040, emissions were estimated to be 168 MMT. Emissions were predicted to peak in 2017 at 176.6 MMT and reach a low in 2032 at 161.1 MMT. The peak emission reductions were predicted to be achieved by 2032 as later model-year vehicles increasingly enter the Texas fleet, and older vehicles are phased out. In this situation, the improvements in vehicle technology would reduce emissions more than future increases in vehicle miles traveled (VMT) would increase them. After 2012–2025 model-year vehicles have saturated the fleet, the CO_2E emissions would rise as VMT increases. Future changes to regulations, market penetration for new vehicles, fuel technology advances, electric vehicles, economics, and personal decisions regarding travel options could substantially affect future CO_2E emission estimates (TxDOT 2018).

2.3. Description of Climate Change for the U.S.

According to studies completed by U.S. Global Change Research Program (USGCRP), annual average temperatures have increased by 1.8°F across the contiguous United States since the beginning of the 20th century [1901] (USGCRP 2018). With climate change, heatwaves across the country are predicted to become more intense, while cold waves are predicted to become less intense. Climate change is also predicted to shift precipitation patterns. Precipitation in the U.S. has increased since 1900 while the number of extreme precipitation events has also increased (USGCRP 2017). USGCRP anticipates release of an updated national climate assessment in 2023.

2.4. Description of Climate Change

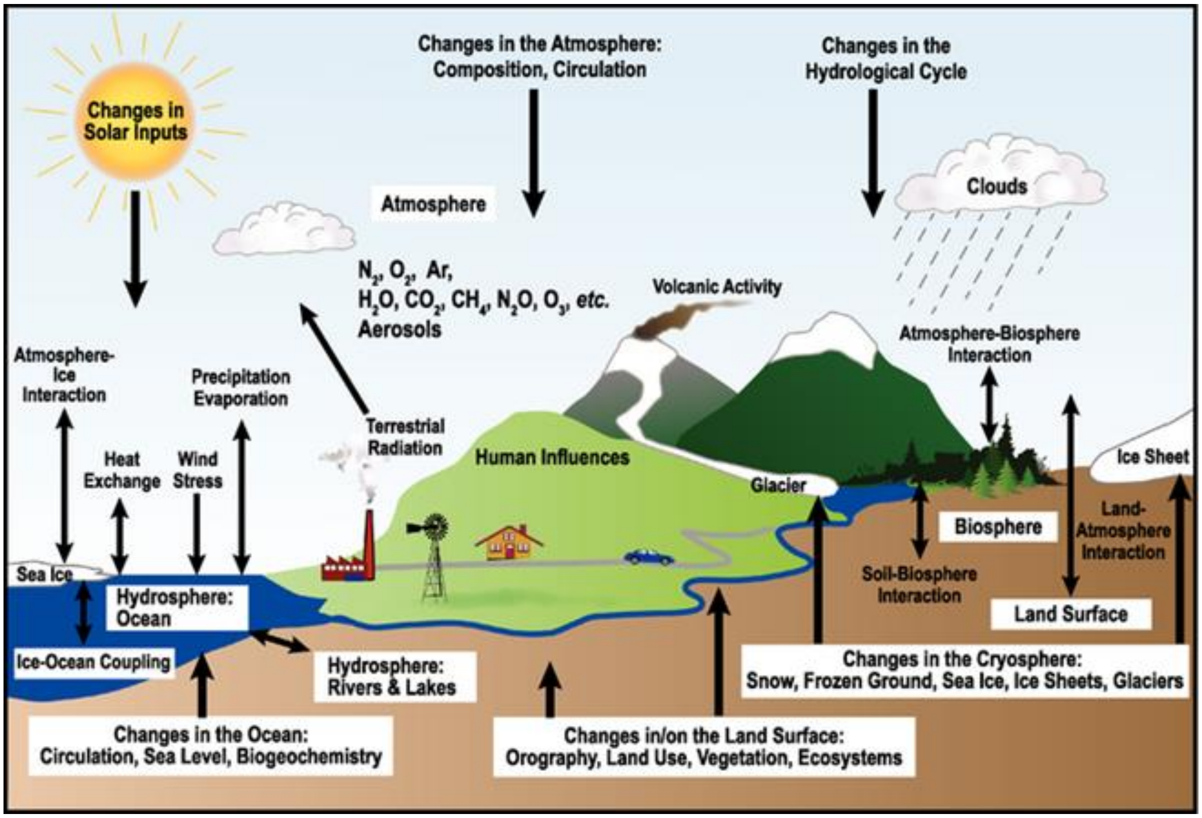
Climate change can be described by any substantial change in the climate over an extended period of time (EPA 2017). Although the Earth has gone through many natural changes in climate over time, concentrations of GHGs have increased by about 50% since the industrial revolution in the 1700s (USGCRP 2017; IPCC 2021). Changes in atmospheric GHG concentrations are resulting in rising global temperatures and global climate change, as indicated by observed changes in precipitation patterns, extreme weather events, drought, fire, flooding, and sea-level rise (IPCC 2021).

Figure 2-1 provides a diagram of the climate system. GHGs were named for their ability to trap heat (energy) like a greenhouse in the lower part of the atmosphere. Atmospheric GHGs, including water vapor, CO_2, CH_4, N_2O, and other gases, trap some of the outgoing net radiation from the Earth causing global temperatures to rise.

Increasing global temperatures can cause changes in precipitation patterns, sea level rise, and extreme weather events. (USGCRP 2018). For example, increased temperatures can increase melting of glaciers and snow in the artic causing the sea level to rise. Global sea level rises have increased by approximately 7 to 8 inches since 1900 and are predicted to increase 1 to 4 feet by the end of the century (Wuebbles et al. 2017). Predicted impacts of increased sea level rise include coastal flooding, decreased water quality, and inundation of deltas.

Globally, transportation contributes to 14% of the global GHG emissions (EPA 2022b). GHG emissions from (transportation) sector primarily involve fossil fuels burned for road, rail, air, and marine transportation. Almost all (95%) of the world's transportation energy comes from petroleum-based fuels, largely gasoline and diesel. (EPA 2022b).

Figure 2-1: Schematic View of the Components of the Climate System, Their Processes and Interactions



Source Treut et al. 2007

2.5. Description of Climate Change for Texas

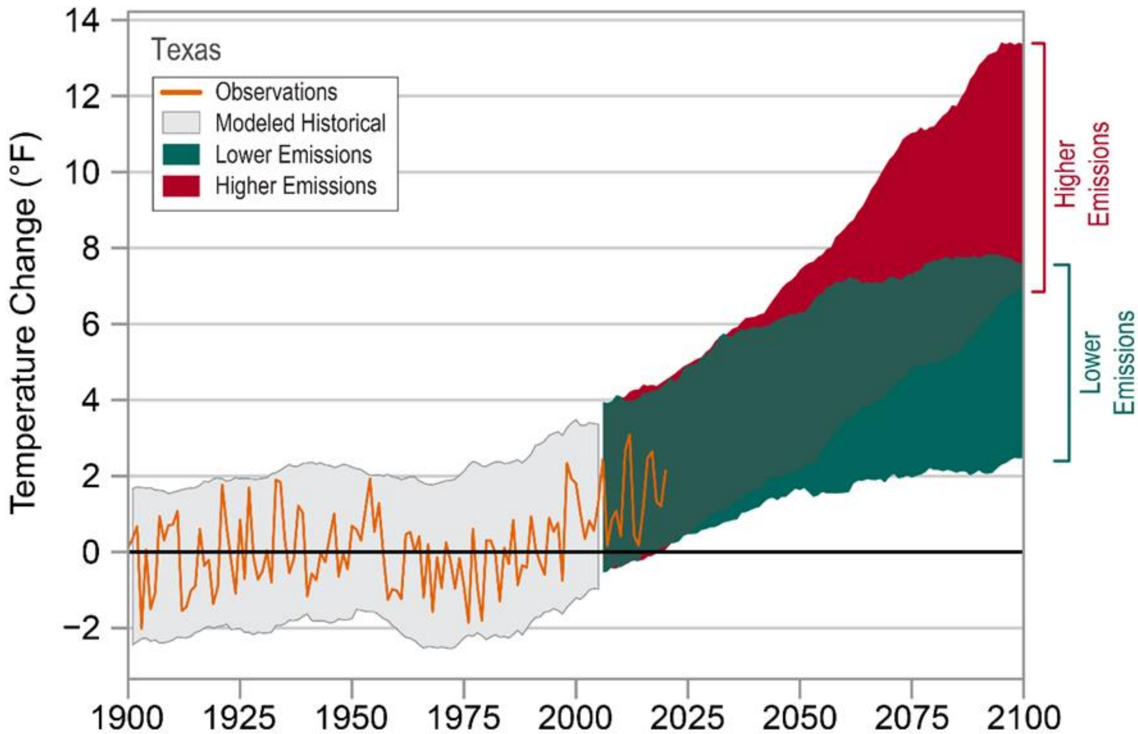
The climate of Texas is generally characterized by hot summers and mild to cool winters. In reference to climate change, temperatures in Texas have increased almost 1.5°F (0.83°C) since the beginning of the 20th century. In 2011, Texas experienced the warmest summer on record and had the highest recorded number of days that were greater than 100°F (NOAA 2022a).

Increases in temperatures can cause the state of Texas to experience longer and more frequent droughts. Higher temperatures can increase evapotranspiration rates and can result in greater water demand for the State. Increasing water demand can add additional stress on water supply sources and may decrease water supply reliability, particularly under drought conditions. In terms of precipitation, average changes in precipitation across the state remain uncertain. However, increases in extreme precipitation events such as tropical storms are likely to increase (NOAA 2022a). Between 1900 and 2020, Texas endured more than 85 tropical storms and hurricanes or about 3 storms every 4 years. Since 2000, Texas has been impacted by 19 named storms of which 8 were hurricanes (Runkle et al. 2022). Recent storms have more intensity and rainfall but is not currently known if this is a long-term trend (EPA 2016). For example, in 2017, Hurricane Harvey alone caused $125 billion in damages in Texas (Amadeo 2019).

Climate models are used to project how the climate will change in the future. These models produce climate change projections that are framed as potential futures or scientifically-based scenarios that reflect specific probabilities. The climate change projections used in this analysis were based on Representative Concentration Pathways (RCPs). RCPs are GHG concentration trajectories used for climate modeling and research and are based on assumptions relating to the level of GHG emissions now and into the future. The high and low CO_2E concentration RCP options were chosen for the TxDOT analysis. RCP8.5 (high emissions estimated to be approximately 1,370 parts per million [ppm] CO_2E in 2100) is a business as usual case with little to no additional worldwide GHG control measures. RCP4.5 (low emissions estimated to be approximately 650 ppm CO_2E in 2100) refers to a high level of GHG controls recommended to keep temperature rise below 2^o C in 2100.

Figure 2-2 depicts the observed and predicted changes for temperature in Texas. The observed data is from 1900 to 2020 while the predicted changes from 2006 to 2100 are based on simulations under RCP4.5 (lower emissions) and RCP8.5 (higher emissions) scenarios. From the observed data (orange line) the temperatures in Texas have increased approximately 1.5 °F since the beginning of the 20th century (Runkle et al. 2022).

Figure 2-2: Observed and Predicted Temperature Change



Source: Runkle et al. 2022

Due to the State's location on the Gulf of Mexico and climate of high dry summers, Texas has been considered one of the most vulnerable states to experience the impacts of climate change on the natural and built environments (Nielsen-Gammon, et al. 2020).

3. Project-Level GHG Analysis

3.1. GHG Emissions

Lifecycle GHG emissions associated with the proposed project construction and operation were quantified as a proxy to evaluate the potential contributions to global GHG emissions and to assess potential impacts to the environment. The lifecycle GHG emissions estimated for each of the proposed project alternatives include emissions associated with materials and fuel (upstream and transportation-related emissions), construction activities, infrastructure operations and maintenance (O&M), and vehicle travel. This section provides a summary of the GHG emission analysis approach and the results. Details of the GHG emission estimation, assumptions, and results are provided in Appendix A.

3.1.1.GHG Emission Calculation Methodology

GHG emissions for the proposed project alternatives were estimated using FHWA's Infrastructure Carbon Estimator (ICE), version 2.1.3 (FHWA 2020). The ICE 2.1.3 was developed by FHWA to estimate the lifecycle energy and GHG emissions from transportation infrastructure construction, maintenance, and operation. Five categories of GHG emissions from each proposed project alternative were modeled:

- Material: Includes the upstream emissions associated with materials extraction, production, chemical reaction, and raw material transportation.
- Transportation: Includes upstream emissions associated with the fuel used in transportation of materials to site.
- Construction: Includes the emissions from energy and fuel used in construction equipment.
- O&M: Includes the emissions from routine maintenance of the infrastructure, such as vegetation management, roadway repair and rehabilitation, and other routine maintenance.
- Usage: Includes emissions from vehicle operation on roadways, including vehicle travel delay during construction.

GHG emissions for the proposed project alternatives (i.e., the No Build Alternative, Alternative 2, and Modified Alternative 3) were modeled based on construction and operation, including the following infrastructure types:

- Bridges and Overpasses – new and reconstructed bridges and overpasses.
- Bus Rapid Transit
- Culverts
- Lighting
- Pathways
- Roadways
- Signage
- Vehicle Operations

ICE 2.1.3 inputs for each of the infrastructure types listed above were provided by I-35 Capital Express Central Project Team based on anticipated project construction activities, with adjustments to the model for the numbers and lengths of bridges and overpasses. The bridge and overpass module in ICE 2.1.3 applies to structures shorter than 1,000 feet, because longer bridges may be characterized by different material and energy intensities than those used to develop the prototypes in the ICE 2.1.3. Several of the bridges/overpasses under Alternative 2 and Modified Alternative 3 would have lengths greater than 1,000 feet. To capture the additional GHG emissions associated with the longer bridges/overpasses, the number of bridges/overpasses longer than 1,000 feet were adjusted based on the ratio of their bridge lengths to 1,000 feet. For example, a 2,000 feet long bridge was modeled as two bridges in the ICE 2.1.3. However, this approach does not account for the differences of materials and energy intensities between the ICE 2.1.3 prototypes and the longer bridges. The adjustment can be further refined in future study when additional bridge construction information becomes available. Construction information for each infrastructure type is provided in Appendix A.

Various construction and vehicle operation information used in the ICE 2.1.3 for each alternative are in VMT, as shown in Table 3-1.

Table 3-1: Project Construction and Vehicle Operation Information by Alternative

Model Inputs	No Build Alternative	Alternative 2	Modified Alternative 3
Bus Rapid Transit (lane miles)	0	40.3	36.7
Bicycle and Pedestrian Paths (miles)	0	17.7	19.3
Culverts (#)	0	14	14
Single-Span Bridge (#)	0	6	5
Two-Span Bridge (#)	0	13	11
Multi-Span Bridge (# over land)	0	42	61
Multi-Span Bridge (# over water)	0	1	1
Average Number of LED Lights per Roadway Mile (11500-1400 lumen 21000-28000 lumen 21000-28000 lumen w/ 8-ft arm)	0 0 0	48 53 42	48 53 42
Average Number of Signs per Roadway Mile (Small Medium Large)	0 0 0	1623 59 206	1469 53 186
2018 (Average Daily VMT)	1,700,100	-	-
2030 (Average Daily VMT)	2,011,900	2,034,600	2,035,600
2040 (Average Daily VMT)	2,259,500	2,288,700	2,292,300
2050 (Average Daily VMT)	2,507,000	2,542,700	2,551,000

NOTE: VMT in the table are for normal operations. VMT values as affected by proposed project construction are provided in Appendix A.

The time frame for annualization of GHG emissions is 20 years to be consistent with the proposed project operation between the 2030 opening year and 2050 design year. The modeled lifecycle GHG emissions are presented in units of MT CO_2E, which are calculated as the summed product of the mass of a given GHGs and their GWPs. The ICE 2.1.3 uses the 100-year GWP values from the IPCC Fourth Assessment Report (IPCC 2007), specifically:

- CO_2: 1
- CH_4: 25
- N_2O: 298

3.1.2. Project GHG Emissions Results

The estimated total lifecycle GHG emissions and the annualized GHG emissions by emission category for each proposed project alternative are summarized in **Table 3-2**. Project level emissions are measured in metric tons (MT) CO_2E verse the statewide emissions in MMT CO_2E (one million times one MT). For information and comparison purposes, the GHG emissions for vehicle operations under 2018 existing conditions were estimated. The 2018 GHG emissions were 373,344 MT CO_2E, estimated by multiplying the 2018 VMT on the existing roadways by the 2018 vehicle emission factors from ICE 2.1.3.

Table 3-2: Total Lifecycle and Annualized GHG Emissions by Emission Category by Alternative

Emission Category	No Build Alternative		Alternative 2		Modified Alternative 3	
	Total MT CO_2E	Annualized MT CO_2E/year	Total MT CO_2E	Annualized MT CO_2E/year	Total MT CO_2E	Annualized MT CO_2E/year
Materials	0	0	227,668	11,383	383,895	19,195
Transportation	0	0	10,135	507	13,576	679
Construction	0	0	76,456	3,823	108,066	5,403
O&M	18,606	930	56,358	2,818	54,008	2,700
Usage (VMT)	7,374,840	368,742	7,838,340	391,917	7,851,675	392,584
Total	7,393,446	369,672	8,208,956	410,448	8,411,220	420,561
NOTE: Annualized GHG emissions were calculated by dividing the total lifecycle GHG emissions by 20 years.						

The VMT estimated for both build alternatives are slightly higher than that for the No Build Alternative because the additional capacity increases the efficiency of the roadway and attracts rerouted trips from elsewhere in the transportation network. As shown in **Table 3-2**, vehicle operation emissions, i.e., emissions from vehicle travel on the roadways in the proposed project area, are the predominant source of GHG emissions estimated for each alternative. Vehicle operation emissions accounted for over 99 percent of total GHG emissions estimated for the No Build Alternative, 95 percent for Alternative 2, and 93 percent for Modified Alternative 3.

GHG emissions by the infrastructure type and by material types are summarized in **Table 3-3** and **Table 3-4**, respectively.

Table 3-3: Total Lifecycle and Annualized GHG Emissions by Infrastructure Type by Alternative

Infrastructure Type	No Build Alternative		Alternative 2		Modified Alternative 3	
	Total MT CO_2E	Annualized MT CO_2E/year	Total MT CO_2E	Annualized MT CO_2E/year	Total MT CO_2E	Annualized MT CO_2E/year
Bridges/Overpasses	0	0	201,914	10,096	399,984	19,999
Bus Rapid Transit	0	0	19,336	967	17,616	881
Culverts	0	0	12,731	637	12,731	637
Lighting	0	0	11,689	584	11,689	584
Pathways	0	0	870	43	948	47
Roadways	18,606	930	111,448	5,572	105,173	5,259
Signage	0	0	12,628	631	11,403	570
Vehicle Operations	7,374,840	368,742	7,838,340	391,917	7,851,675	392,584
Total	7,393,446	369,672	8,208,956	410,448	8,411,220	420,561

NOTE: Annualized GHG emissions were calculated by dividing the total lifecycle GHG emissions by 20 years.

Table 3-4: Total Lifecycle and Annualized GHG Emissions by Material Type by Alternative

Material Type	No Build Alternative		Alternative 2		Modified Alternative 3	
	Total MT CO_2E	Annualized MT CO_2E/year	Total MT CO_2E	Annualized MT CO_2E/year	Total MT CO_2E	Annualized MT CO_2E/year
Aggregate	0	0	8,751	438	11,814	591
Aluminum	0	0	1,469	73	1,327	66
Bitumen (Asphalt Binder)	0	0	8,333	417	7,811	391
Cement	0	0	141,556	7,078	253,766	12,688
Steel	0	0	67,429	3,371	108,937	5,447
Water	0	0	129	6	241	12
Transportation Fuel	0	0	10,135	507	13,576	679
Construction Fuel	0	0	76,456	3,823	108,066	5,403
O&M Electricity	0	0	10,886	544	10,886	544
O&M fuel (DGEs)	2,415	121	6,319	316	6,019	301
O&M Roadway Rehabilitation	16,191	810	39,154	1,958	37,103	1,855
Vehicle Fuel Usage (Operation VMT)	7,374,840	368,742	7,838,340	391,917	7,851,675	392,584
Total	7,393,446	369,672	8,208,956	410,448	8,411,220	420,561

NOTE: Annualized GHG emissions were calculated by dividing the total lifecycle GHG emissions by 20 years.

As shown previously, emissions from vehicle travel on the roadways in the proposed project area are the predominant source of GHG emissions estimated for each project alternative. For GHG emissions from constructing the proposed project infrastructure elements, top are bridges/overpasses, roadways, and vehicle operations as shown in **Table 3-3**. Top contributors of GHG emissions in terms of construction materials are cement, steel, and construction fuel use (**Table 3-4**).

Even though both build alternatives would have higher estimated GHG emissions than the No Build Alternative, Alternative 2 and Modified Alternative 3 have greater potential for mode shift (increase transit with BRTs and active transportation options with SUP), while there is no expanded mode shift with the No Build. Increased mode shift away from single occupant vehicles would reduce emissions more than the above estimates, but mode shift cannot be accurately quantified at this time. GHG emissions for all of the alternatives in future years would potential be lower due to future technology improvements (fleet electrification), and future vehicle emission standards. In addition, the major changes in mode shift, such as we saw during the pandemic, cannot at this time be accurately reflected in the future years traffic forecast, so if more individuals choose transit or work from home options, GHG emissions will be lower in the future years.

Construction emissions were estimated based on preliminary proposed project information and broad national assumptions provided by FHWA ICE 2.1.3. Details regarding construction materials and equipment are typically determined post- National Environmental Policy Act (NEPA) during the design or construction stage. Therefore, construction emissions may be slightly under or overestimated based on the information available.

Default vehicle speed information was used in the ICE 2.1.3 modeling due to the lack of project-specific speed information. Traffic congestion results in lower average travel speed and increased idle time, which increases vehicle fuel usage. Therefore, the emissions benefits associated with less traffic congestion and improved travel speeds under Alternative 2 and Modified Alternative 3, as compared to the No Build Alternative, may not be reflected in the GHG emission results.

3.1.3. Discussion

GHGs are different from other air pollutants evaluated in federal environmental reviews because their impacts are not localized or regional. GHG impacts are cumulative, global impacts. Each proposed project or emission source may make a relatively small contribution to global atmospheric GHG concentrations. In addition, from a quantitative perspective, fluctuations in global climate are the cumulative result of numerous and varied parameters. Therefore, it is not meaningful or useful to attempt to translate those relatively small GHG emission differences into climate outcomes (for example, temperature changes, drought/flooding severity). Currently, there is no scientific methodology for attributing specific climatological changes to emissions from a particular transportation project.

Neither the EPA nor the FHWA has issued explicit guidance or methods to conduct project-level GHG analysis. FHWA emphasizes concepts of resilience and sustainability in highway planning, project development, design, O&M (FHWA 2022). The CEQ historically recommends the use of GHG emissions rates as a proxy for potential climate change impacts because there is no scientifically supported method to quantitatively assess or assign the nominal emissions from typical NEPA projects to any specific global climate impact (CEQ 2016 - Pages 4 and 10 discuss using GHG emissions as a proxy for climate change).

Future changes to regulations, technological advances that alter the transportation system, vehicles, and/or fuels, combined with acts of nature (e.g., pandemics), societal changes, market forces, economics, and personal decisions could alter where and how people live, work, or travel, which will further affect global GHG emissions in ways that cannot be accurately accounted for at this time. Nonetheless, the GHG emission reduction measures described in **Section 3.2**, represent the current best available federal, state, and practical project-level measures that may help reduce GHG emissions on an incremental basis and could contribute to a long-term meaningful cumulative reduction when considered across the federal-aid highway program.

3.2. Strategies for GHG Emissions

Specific project build alternatives reduction strategies would include potential mode shift to transit and active transportation. Alternative 2 would incorporate approximately 40.25 miles of BRT and 17.69 miles of additional paths while Modified Alternative 3 includes 36.67 miles of BRT and 19.27 miles of additional paths. Austin Climate Equity Plan (COA 2021) calls for an equitable 50 percent mode shift from single-occupancy vehicles and the enhanced transit, biking, and walking. Both build alternatives have the greater mode shift potential than the No Build Alternative.

Implementation of the following federal, state, and regional GHG reduction strategies would broadly reduce transportation-related GHG emissions:

- Technological advances, including but not limited to those required by federal engine and fuel standards under the Clean Air Act, transportation laws, and the Energy Act.
- “Cash for Clunker” programs, such as those available through the Texas Emission Reduction Program implemented by the Texas Commission on Environmental Quality.
- Traffic System Management, which improves the operational characteristics of the transportation network (e.g., traffic light timing, pre-staged wrecker service to efficiently clear accidents, and/or traveler information systems).
- Travel demand management, such as demand reduction and systems efficiency optimization, reduce VMT and the associated GHG emissions (e.g., telework, transit, rideshare, high occupancy vehicle lanes, scooters, and bicycle and pedestrian facilities).

Most on-road tailpipe emission reductions to date have been achieved through federal vehicle engine and fuel standards and the associated technological advances in vehicle engines and fuels (FHWA 2013).

GHG mitigation measures are not specifically required under NEPA. However, the build alternatives would provide emissions benefits through BRT and SUPs, reduced traffic congestion, improved roadway operational efficiency, and more dependable and consistent routes for transit, emergency responders, motorists, and bicycle and pedestrian movements throughout the corridor. Vehicles in the proposed project area would be able to travel at faster speeds and use less travel time and fuel under the build alternatives. As a result, implementation of the proposed project has a potential to reduce transportation-related GHG emissions especially if there is a greater mode shift to transit and active transportation.

GHG emissions would be produced at different levels throughout the construction; their frequency and occurrence can be reduced through plans and specifications, construction equipment modernization, and better traffic management during the construction phase. Emission control measures such as limiting vehicle idling time and keeping construction equipment in good operational condition would have the benefit of reducing GHG emissions. These measures are part of TxDOT programmatic approaches to avoid and minimize environmental impacts. In addition, innovations such as longer pavement lives especially with the use of concrete throughout the corridor, improved traffic management plans, and changes in materials can further reduce project-level GHG emissions by allowing longer intervals between maintenance and rehabilitation events.

4. Project-Level Assessment of Climate Change

This section provides a project-level assessment of the potential for climate change to result in impacts on the proposed project. The assessment evaluates available information on the historic and projected climate variables that might affect the proposed project area of the I-35 Capital Express Central Project, Austin, and Travis County. In the Austin area, climate predictions indicate that the region will be warmer, drier, and subject to periodic extreme weather events (COA 2018). Table 4-1 provides an overview of the evaluated climate variables, their historical trends, and future projections. Appendix B provides additional detail regarding the historic and future climate variables. After the discussion of the climate variables in the proposed project area, the predicted risks of climate change impacts are described, as are programmatic and project-level enhanced climate resiliency strategies that help to reduce potential impacts from the predicted risks.

The USGCRP National Climate Assessment (NCA) 2014 and USGS National Climate Change Viewer (NCCV) were used for existing and future projections. TxDOT has not yet been able to obtain localized climate data for the NCA 2018 report. The NCA 2014 data provided here looks at the relative change in climate variables between current measurements and projected measurements. “Historical” data come from the 1971-2000 average for each variable, and these figures are compared to the 2041-2070 projected averages according to both the RCP4.5 and RCP8.5 scenarios. These figures are up-to-date through December 2016. NCCV predicts to the period of 2075-2099, from a base period of 1981-2010.

For transparency, several major sources of data limitations and uncertainty exist in climate projections and those are discussed in Section 5.

Table 4-1: Projected Climate Change Impacts

Climate Variable	Source	Indicator	Existing and Projected Changes
Temperature	NCA[1]	Existing	99.4°F (37.4°C) temperature from historical "7 hottest days" per year.
	NCA[1]	Projected	The range of additional hottest days per year is from 1.5 (RCP4.5) to 19.5 (RCP8.5).
	NCCV [2]	Existing	79.8°F (26.5°C) annual mean maximum temperature.
	NCCV [2]	Projected	4.4°F (2.5°C) [RCP4.5] to 8.4°F (4.7°C) [RCP8.5] change in annual mean maximum temperature.
Drought	NCA[1]	Existing	27.6 days for the number of consecutive dry days
	NCA[1]	Projected	1.5 days predicted increase in the number of consecutive dry days for RCP4.5 and RCP8.5.
	NCCV [2]	Existing	1.6 inches (4.2 cm) existing mean soil storage
	NCCV [2]	Projected	0.2 inches (0.6 cm) [RCP4.5] to 0.6 inches (1.4 cm) [RCP8.5], predicted change in annual mean soil storage.
	NCCV [2]	Existing	1.7 inches (4.2 cm) in monthly evaporative deficit.
	NCCV [2]	Projected	0.37 inches (0.94 cm) [RCP4.5] to 0.84 inches (2.13 cm) [RCP8.5] predicted increase in annual mean evaporative deficit per month
Wet	NCCV [2]	Projected	Less than 1 day decrease or increase (ranging from 0.27to 0.48 days) in the number of wet days per year between RCP4.5 and RCP8.5
Monthly Runoff	NCCV [2]	Existing	0.34 inches (0.76cm) per month in mean runoff.
	NCCV [2]	Projected	-0.01 inches (-0.03 cm) [RCP4.5] to -0.08 inches (0.20 cm) [RCP8.5] per month change (slightly less).

1: (USGCRP, 2014), projects climate data for the years 2041–2070. Texas county specific data was obtained from the GIS tables from this report.
2: (USGS, 2021) NCCV - The climate projections used were 2075–2099 compared to 1981–2010. Travis County specific data was used.

4.1. Climate change risk workshop

A climate change risk workshop was held on June 23, 2022, with participants from across environmental, engineering and design disciplines. Following the presentation of the climate change risk concept, the group discussed and described and how each factor may influence the major components of the I-35 Capital Express Central Project.

Following the workshop, the risk narratives were developed into a project-level climate change risk register and assessment for the project **Table 4-2**. A second meeting was held across environmental, engineering and design disciplines on July 19, 2022 before finalizing the risk register and assessment. Following **Table 4-2** are the definitions for risk rankings and an explanation for each of the risk factor consequences. The last column is the overall risk ranking.

Table 4-2: Climate Change Risk Register and Assessment by Climate Parameter

#	Climate Parameters	Risk/Hazard Description	Type of Risk	Project Component	Consequence/Impact	Programmatic and Enhanced Risk Controls	Consequence								Risk
							Life of Asset*	Likelihood	Financial	Infrastructure	Safety and Health	Business Interruption	Reputation	Environment	
1	Increased Temperature	Drier soils, expansion, and cracking of materials	Direct	Managed Lanes and Mainlanes (concrete pavement)	A drier climate can cause drier soils which can put additional pressure on roadways. The pressure can affect roadways' structural integrity, decreasing the asset life. In addition, high temperatures can cause the expansion and cracking of roadway materials and potential maintenance costs. Therefore, monitoring the roadway condition is important to ensure increased temperatures do not affect the infrastructure.	Travel lanes reflect current engineering standards. TxDOT's Pavement Management Information System and Texas Maintenance Assessment Program include monitoring, reporting, and implementing appropriate maintenance action plans if required. No further controls are needed.	30-50	1	1	1	1	0	1	0	L
				Frontage Roads and Cross Streets (asphalt pavement)			30-50	2	1	1	1	1	1	0	L
2				Bridges and Overpasses Structures	A drier climate can cause drier soils which can put additional pressure on the bridges and overpasses. The pressure can affect the bridges' structural integrity, decreasing the asset life. In addition, high temperatures can cause the expansion of decks and spans, potentially causing cracking of the bridge materials and potential maintenance costs. Therefore, monitoring the bridge and overpass condition is important to ensure increased temperatures do not affect the structures.	Bridge and overpass structures reflect current engineering standards. Construction will utilize concrete for shorter bridge spans and coated steel for longer bridge spans. Biennial monitoring of the performance of bridge and overpass structures along all lanes allows the implementation of appropriate maintenance action plans if required. No further controls are needed.	50-100	1	1	1	1	0	1	0	L
3				Pedestrian and Bicycle Shared Use Paths	A drier climate can cause drier soils which can put additional pressure on the SUPs. The pressure can affect the SUPs' structural integrity, decreasing the asset life. In addition, high temperatures can cause the expansion and cracking of SUPs. Therefore, monitoring the SUPs' condition is important to ensure increased temperatures do not affect the infrastructure.	Construction will utilize concrete for the SUPs, which is more resilient than asphalt pavement. Monitoring the performance of SUPs are conducted in conjunction with COA and facility users. Appropriate maintenance actions can be implemented if required.	15-20	1	1	1	1	0	1	0	L
4	High Temperature Extremes	Vehicle Durability	Indirect	Managed Lanes, Mainlanes, and Frontage Roads	Extreme heat can put car systems and engines at risk of damage. In addition, extreme heat can cause vehicles to break down and possibly alter the car's battery, tire pressure, or ability to start. Vehicle breakdowns can cause a safety risk to vehicle occupants and other vehicles on the road.	TxDOT's Highway Emergency Response Operator (HERO) patrol service program assists stranded motorists. Traffic management controls would be coordinated with local agencies, and public information signs would provide information to motorists for prolonged incidents. Incident response.	30-50	2	1	0	2	0	1	0	L
5				Bridges and Overpasses Structures	Extreme heat can put car systems and engines at risk of damage. In addition, extreme heat can cause vehicles to break down and possibly alter the car's battery, tire pressure, or ability to start. Vehicle breakdowns can cause a safety risk to vehicle occupants and other vehicles on the road.	TxDOT's HERO patrol service program assists stranded motorists. Traffic management controls would be coordinated with local agencies, and public information signs would provide information to motorists for prolonged incidents. Emergency management operations would also be utilized as needed.	50-100	2	1	0	2	0	1	0	L
6		Photochemical Smog, decreased visibility	Direct	Managed Lanes, Mainlanes, and Frontage Roads	Extreme heat can cause heat shimmer and photochemical smog, reducing visibility and affecting the safety of road users. Smog is a visible form of air pollution that can arise due to various emissions including those from car exhaust. Smog and heat shimmer reduce road visibility, resulting in potential road incidents.	Low due to existing EPA regulatory requirements. No further controls needed.	30-50	1	1	0	1	0	0	0	L

#	Climate Parameters	Risk/Hazard Description	Type of Risk	Project Component	Consequence/Impact	Programmatic and Enhanced Risk Controls	Life of Asset*	Likelihood	Consequence: Financial	Consequence: Infrastructure	Consequence: Safety and Health	Consequence: Business Interruption	Consequence: Reputation	Consequence: Environment	Risk
7	High Temperature Extremes	Photochemical Smog, decreased visibility	Direct	Bridges and Overpasses Structures	Extreme heat can cause heat shimmer and photochemical smog, reducing visibility and affecting the safety of road users. Smog is a visible form of air pollution that can arise due to various emissions including those from car exhaust. Smog and heat shimmer reduce road visibility, resulting in potential road incidents.	Low due to existing EPA regulatory requirements. No further controls needed.	50-100	1	1	0	1	0	0	0	L
8	High Temperature Extremes	Network power failure due to excess demands	Direct	Managed Lanes, Mainlanes, and Frontage Roads	Higher temperatures can cause local power networks to fail due to increased demand. As a result, temporary outages can cause traffic controls and signals to lose power, disrupting traffic and decreasing roadway safety. Temporary outrages can also cause temporary traffic closures, traffic diversion, and the use of manual traffic controls to facilitate vehicle movements.	Traffic management controls would be coordinated with local agencies. Emergency management operations would also be utilized as needed.	30-50	2	1	1	2	2	1	0	L
9	High Temperature Extremes	Network power failure due to excess demands	Direct	Bridges and Overpasses Structures	Higher temperatures can cause local power networks to fail due to increased demand. As a result, temporary outages can cause traffic controls and signals to lose power, disrupting traffic and decreasing roadway safety. Temporary outrages can also cause temporary traffic closures, traffic diversion, and the use of manual traffic controls to facilitate vehicle movements.	Traffic management controls would be coordinated with local agencies. Emergency management operations would also be utilized as needed.	50-100	2	1	1	2	2	1	0	L
10	High Temperature Extremes	Network power failure due to excess demands	Direct	Pedestrian and Bicycle Shared Use Paths	Higher temperatures can cause local power networks to fail due to increased demand. As a result, temporary outages can cause traffic controls and signals to lose power, disrupting traffic and decreasing roadway safety at intersections for pedestrians and bicyclists.	SUPs in the build alternatives are separate from the roadways wherever possible throughout the corridor to provide additional safety to facility users. At intersections or other points of conflict, traffic management controls would be coordinated with local agencies during a network power failure.	15-20	2	1	1	2	0	0	0	L
11	High Temperature Extremes	Health effects	Direct	Pedestrian and Bicycle Shared Use Paths	Extreme heat can affect users on the SUP, causing discomfort or health effects. Extreme heat can cause dehydration, heat exhaustion, and in severe cases, heat stroke.	Public information campaigns may be utilized with potential risks to users. TxDOT and COA are taking public input on various aesthetics proposed for the project. Aesthetics may include shade structures and vegetation along with the SUPs.	15-20	2	1	0	2	0	0	0	L
12	Low Temperature Extremes	Accumulation of winter precipitation	Direct	Managed Lanes, Mainlanes, and Frontage Roads	Low-temperature events can decrease roadway safety by reducing the pavement friction with a vehicle and can reduce the asset life.	Travel lanes reflect current engineering standards. Snow and Ice Control Operations will facilitate treatments of roadway surfaces and coordinate with local agencies. TxDOT's Pavement Management Information System and Texas Maintenance Assessment Program include monitoring, reporting, and implementing appropriate maintenance actions if required. No further controls are needed.	30-50	1	2	1	2	2	1	1	L

#	Climate Parameters	Risk/Hazard Description	Type of Risk	Project Component	Consequence/Impact	Programmatic and Enhanced Risk Controls	Consequence								Risk
							Life of Asset*	Likelihood	Financial	Infrastructure	Safety and Health	Business Interruption	Reputation	Environment	
13	Low Temperature Extremes	Accumulation of winter precipitation	Direct	Bridges and Overpasses Structures	Low-temperature events can decrease bridge and overpass safety by reducing the pavement friction with a vehicle and can reduce the asset life.	Bridge and overpass structures reflect current engineering standards. Construction will utilize concrete for shorter bridge spans and coated steel for longer bridge spans. Snow and Ice Control Operations will facilitate treatments of roadway surfaces and coordinate with local agencies. Biennial monitoring of the performance of bridge and overpass structures along all lanes allows the implementation of appropriate maintenance actions if required. No further controls are needed.	50-100	2	2	1	2	2	1	1	L
14				Pedestrian and Bicycle Shared Use Paths	Low-temperature events can decrease SUP safety by reducing the pavement friction with pedestrians or bicycles and can reduce the asset life.	Construction will utilize concrete for the SUPs, which is more resilient than asphalt pavement. Monitoring the performance of SUPs are conducted in conjunction with COA and facility users. Appropriate maintenance actions can be implemented if required.	15-20	1	1	2	2	0	1	1	L
15	Extreme Precipitation Events	Flooding	Direct	Managed Lanes, Mainlanes, and Frontage Roads	Flooding can exceed the roadway's drainage capacity, causing lanes to be shut down or road closures and the use of alternative routes. Decreased lanes or closures can increase traffic and increase the possibility of reduced roadway safety.	Traffic management controls and public information campaign could be utilized. The project will utilize updated NOAA Atlas 14 criteria for storm events. Travel lanes reflect current engineering standards, including using a 50-yr design event for depressed roadways. In addition, a pump station is proposed for the build alternatives for extreme storm events. Providing relief to the Boggy Creek watershed and not increasing flow into the Waller Creek waterway are proposed for the build alternatives. Have known detour routes and coordination with local agencies. Emergency management operations would also be utilized as needed.	30-50	1	2	2	2	2	2	2	M
16				Bridges and Overpasses Structures	Flooding can exceed the roadway's bridges, causing roadway closure and the use of alternative routes. In addition, bridge closure would increase traffic can increase reduce roadway safety.	Traffic management controls and public information campaigns could be utilized. The project will use updated NOAA Atlas 14 criteria for storm events. Bridges over waterways will be designed to allow the 50-yr design event volume to pass under the structure with an added freeboard height (safety factor). Overpasses and bridges are designed to reflect current engineering standards. Emergency management operations would also be utilized as needed, have known detour routes, and coordinate with local agencies.	50-100	1	1	1	1	1	1	1	L
17				Pedestrian and Bicycle Shared Use Paths	Flooding can exceed the drainage capacity of the SUP, causing the SUP to be shut down. Other facilities, sidewalks, roadways, and SUP should be used when this occurs.	Construction will utilize concrete for the SUPs, which is more resilient to flooding than asphalt pavement. Coordinate with local agencies and known detour routes would be used during occurrences of flooding.	15-20	2	1	2	2	0	1	2	M

#	Climate Parameters	Risk/Hazard Description	Type of Risk	Project Component	Consequence/Impact	Programmatic and Enhanced Risk Controls	Life of Asset*	Likelihood	Consequence: Financial	Consequence: Infrastructure	Consequence: Safety and Health	Consequence: Business Interruption	Consequence: Reputation	Consequence: Environment	Risk
18	Extreme Precipitation Events	Expansion and cracking of materials, water sheeting on project component surface	Direct	Managed Lanes, Mainlanes, and Frontage Roads	Extreme precipitation events can decrease roadway safety by reducing visibility and durability of the roadways. In addition, water sheeting on the roadways can cause expansion or cracking of the roadway structure, reducing the asset life.	Engineering standards include increasing cross slope at various intervals to manage sheet flow depth. In addition, the storm drainage system is designed to limit ponding and maintain operations. TxDOT's Pavement Management Information System and Texas Maintenance Assessment Program include monitoring, reporting, and implementing appropriate maintenance action plans if required. No further controls are needed.	30-50	2	1	1	1	0	0	0	L
19	Extreme Precipitation Events	Expansion and cracking of materials, water sheeting on project component surface	Direct	Bridges and Overpasses Structures	Extreme precipitation events can decrease roadway safety by reducing visibility and durability of the roadways. In addition, water sheeting on the roadways can cause expansion or cracking of the roadway structure, reducing the asset life.	Engineering standards include increasing cross slope at various intervals to manage sheet flow depth. In addition, the storm drainage system is designed to limit ponding and maintain operations. Biennial monitoring of the performance of bridge and overpass structures along all lanes allows the implementation of appropriate maintenance actions if required. No further controls are needed.	50-100	2	1	1	1	0	0	0	L
20	Extreme Precipitation Events	Expansion and cracking of materials, water sheeting on project component surface	Direct	Pedestrian and Bicycle Shared Use Paths	Decreased SUP safety, reduced durability. Extreme precipitation events can decrease SUP safety by reducing the durability of the SUP. Extreme precipitation events can cause the expansion or cracking of the SUP structure, reducing the asset life.	Construction will utilize concrete for the SUPs, which is more resilient than asphalt pavement. SUPs in the build alternatives are separate from the roadways wherever possible throughout the corridor to provide additional safety to facility users. Monitoring the performance of SUPs are conducted in conjunction with COA and facility users. Appropriate maintenance actions can be implemented if required.	15-20	2	1	2	1	0	0	1	L
21	Increased CO2	Durability of Structures	Direct	Managed Lanes, Mainlanes, and Frontage Roads	Increased CO2 can reduce the durability of concrete pavement, reducing asset life.	Travel lanes reflect current engineering standards. Construction will utilize concrete for the managed and mainlanes, which is more resilient than asphalt pavement. TxDOT's Pavement Management Information System and Texas Maintenance Assessment Program include monitoring, reporting, and implementing appropriate maintenance actions if required. No further controls are needed.	30-50	1	1	1	0	0	0	0	L
22	Increased CO2	Durability of Structures	Direct	Bridges and Overpasses Structures	Increased CO2 can reduce the durability of concrete bridge and overpass structures, reducing asset life.	Bridge and overpass structures reflect current engineering standards. Construction will utilize concrete for shorter bridge spans and coated steel for longer bridge spans. Biennial monitoring of the performance of bridge and overpass structures along all lanes allows the implementation of appropriate maintenance actions if required. No further controls are needed.	50-100	1	1	1	0	0	0	0	L
23	Increased CO2	Durability of Structures	Direct	Pedestrian and Bicycle Shared Use Paths	Increased CO2 can reduce the durability of concrete SUPs, reducing asset life.	Construction will utilize concrete for the SUPs, which is more resilient than asphalt pavement. Monitoring the performance of SUPs are conducted in conjunction with COA and facility users. Appropriate maintenance actions can be implemented if required.	15-20	1	1	1	0	0	0	0	L

#	Climate Parameters	Risk/Hazard Description	Type of Risk	Project Component	Consequence/Impact	Programmatic and Enhanced Risk Controls	Consequence: Life of Asset*	Likelihood	Financial	Infrastructure	Safety and Health	Business Interruption	Reputation	Environment	Risk
24	Wildfire	Fire and Heat Damage	Direct	Managed Lanes, Mainlanes, and Frontage Roads	Wildfires on or near roadways can decrease roadway safety if users cannot escape wildfires blazes, or proximity to wildfires can cause respiratory issues. Wildfires can also cause temporary traffic closures and diversion, reducing roadway safety.	Travel lanes reflect current engineering standards. Construction will utilize concrete for the managed and mainlanes of the roadway, which is more resilient to fire than asphalt pavement. Emergency management operations would be utilized as needed and coordinated with local agencies. Traffic management controls and public information signs would inform motorists of prolonged incidents and have detour routes. Wildfire risk is unlikely due to the urban built environment of the project area.	30-50	1	2	2	1	1	0	2	L
25				Bridges and Overpasses Structures	Wildfires on or near roadways can decrease roadway safety if users cannot escape wildfires blazes, or proximity to wildfires can cause respiratory issues. Wildfires can also cause temporary traffic closures and diversion, reducing roadway safety.	Bridges and overpasses reflect current engineering standards. Construction will utilize concrete for shorter bridge spans and coated steel for longer bridge spans, which is resilient to fire. Emergency management operations would be utilized as needed and coordinated with local agencies. Traffic management controls and public information signs would inform motorists of prolonged incidents and have detour routes. Wildfire risk is unlikely due to the urban built environment of the project area.	50-100	1	2	2	1	1	0	2	L
26				Pedestrian and Bicycle Shared Use Paths	Wildfire could decrease SUP safety and reduce the durability of the path. Wildfires along with the SUPs or in the area can cause respiratory issues for users. In addition, a wildfire in the project can cause extreme heat along with the SUP, reducing the asset life.	Construction will utilize concrete for the SUPs, which is more resilient to fire than asphalt pavement. Emergency management operations would also be utilized as needed and have known detour routes and coordination with local agencies. Monitoring the performance of SUPs are conducted in conjunction with COA and facility users. Appropriate maintenance actions can be implemented if required. Wildfire risk is unlikely due to the urban built environment of the project area.	15-20	1	1	2	1	0	0	2	L

* Life of Asset can be extended (50-100+) with future capital improvements projects which would require a new NEPA document(s)

Consequence Description	
Life of Asset	Estimate of how long the component will remain in a useable condition.
Likelihood	Probability of the climate parameter or hazard occurring.
Financial	Projected financial or economic costs to the component.
Infrastructure	Evaluation of the impact to the infrastructure of the component.
Safety and Health	Evaluation of the safety and health of the users of the component.
Business Interruption	Estimate of how businesses could be impacted/disrupted.
Reputation	Evaluation of the operator/constructor's reputation or reputation of the asset.
Environment	Estimate of the effect the climate parameter and hazard will have on the environment.

Consequence Value	Impact	Description
1	Low	Impacts do not directly or indirectly alter the infrastructure, SUP, or system function.
2	Moderate	Impacts cause localized direct or indirect impact to the infrastructure, SPU, or system function with little to no permanent damage.
3	High	Impacts cause large, direct or indirect impacts to the infrastructure, SUP, or system function and may include permanent or substantial damage.
4	Extreme	Impacts cause extensive, direct or indirect impacts to the infrastructure, SUP, or system function may include substantial damage.

4.2. Predicted Climate Change Impacts on the Proposed Project

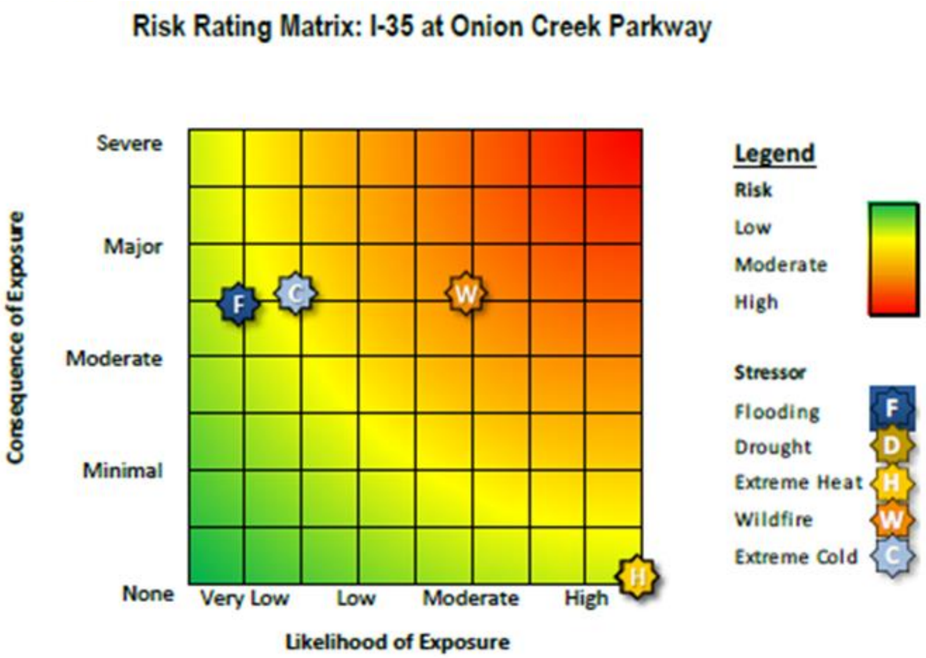
From the risk analysis, no high or extreme risks were identified for the proposed project. All risks are predicted to be low to medium with programmatic and enhanced risk controls strategies in place. The use of concrete for the roadways, bridges and SUP allows the components to be more resilient to potential changes and requires less maintenance therefore less impact to the facility users.

CAMPO Vulnerability and Risk Assessment – Onion Creek Parkway

In addition, a CAMPO study is consistent with the I-35 Capital Express Central Project Team analysis a change in climate is not projected to have major impacts on transportation infrastructure.

CAMPO utilized the U.S. DOT Vulnerability Assessment Scoring Tool (VAST) to facilitate vulnerability assessments for assets in the region (CAMPO, 2015a). The results of VAST is shown in the **Figure 3-1**.

Figure 3-1: Results from the VAST for CAMPO Vulnerability Study at Onion Creek Parkway



From the VAST risk assessment along the I-35 at Onion Creek Parkway, wildfire and icing are projected to have the greatest risk along the I-35. Drought, flooding, and extreme heat are expected to have minimal to no impact along the I-35. Although most stressors are not likely to cause significant impacts along the roadway, road closures due to effects from the climate variables may disrupt traffic.

Table 4-3: Summary Table Results from the VAST Vulnerability Study occurring at Onion Creek Parkway

Climate Variable	Impact
Flooding	Low
Drought	N/A
Extreme Heat	N/A
Wildfire	Moderate-High
Extreme Cold and Ice	Low-Moderate

CAMPO, 2015

4.3. Climate Resiliency Strategies

Flexibility is needed when developing strategies and programs to respond to a changing climate given the uncertainty and variability in the range of climate projections. Resiliency is the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. Based on the climate variables for a given project, adaptation and resiliency strategies may be considered during planning, project development, final design, construction, emergency response, asset management, traffic management, and/or operational and maintenance activities.

This section discusses TxDOT project and programmatic strategies to address resiliency to a changing climate for the proposed project area. In Austin and Travis County those changes are generally, warmer temperatures, greater drought conditions or greater number of dry days, and periodic extreme weather events.

Maintenance

Extreme heat, drought, or precipitation events may result in premature pavement failure. Pavement failure is addressed in the TxDOT Pavement Manual including both a routine monitoring system and a follow up investigation by the TxDOT Premature Distress Investigation Team. TxDOT improves and refines pavement designs to adapt to changing conditions. As needed, adjustments would be made to pavement binders and/or base design and materials.

Emergency Management and Response

Traffic Management: when roads are impassable due to flooding and wildfires. Traffic management is used for road closures and detours to maintain the safest movement possible through the transportation system before, during, and post event. The road closures and detours are relayed via notification systems.

TxDOT statewide inclement weather and road condition notification system: is available at DriveTexas™ or by phone at (800) 452-9292 and at: https://www.txdot.gov/driver/weather.html. Flash flooding is the leading cause of weather-related deaths in Texas. If you encounter a flooded road, "Turn Around, Don't Drown." More information on flooding is available at: https://www.txdot.gov/driver/weather/flash-floods.html. In addition, roadway signs and a variety of social media notifications provide the latest information on closures and detours.

Communication strategies: before, during, and after the event are critical to carrying out large response efforts. For example, the TxDOT DriveTexas.org website received more than 5,000,000 visits during and immediately after Hurricane Harvey. The site includes real-time updates made by TxDOT staff in the field and provided the most accurate information possible to emergency crews and the public regarding flooding, pavement damage, and road closures. Advanced planning includes having teams to ensure that TxDOT's emergency radio communications towers continue to function throughout emergencies.

Advance Preparation: Extreme weather may down traffic lights, cause flooding, damage roadway signs, or cause asphalt to buckle, but most extreme weather impacts lead to disruptions in travel rather than chronic damage to the pavement and other transportation structures. Advance preparation and practice along with pre-deploying crews and equipment remain critical for TxDOT to quickly respond to and then recover from extreme weather events.

Infrastructure Assessments are conducted after an event to determine needed clean up and repairs.

Design

The final project design process occurs after completion of the environmental process in accordance with applicable design requirements. New infrastructure is designed to current industry standards.

TxDOT Stormwater Management: helps reduce the frequency and extent of downstream flooding, soil erosion, sedimentation, and water pollution. Consistent with FHWA guidance, designs for stormwater management seek to mitigate the potential effects of runoff rates and stormwater volumes using the latest available information.

Hydraulics Transportation and Infrastructure: related designs typically consider 2-to 100-year event, the overtopping event, and/or the 500-year event (FHWA 2016). Design manuals used by TxDOT include the TxDOT 2019 Hydraulic Design Manual; FHWA 2016 Hydraulic Engineering Circular 17: Highways in the River Environment Floodplains, Extreme events, Risk, and Resilience; and FHWA 2013 Hydraulic Engineering Circular 22: Urban Drainage Design Manual. Additional design information is available on the TxDOT Design Division Hydrology/Hydraulics website. Additional design strategies that will be included:

Use of Best Available Data: TxDOT uses the National Oceanic and Atmospheric Administration (NOAA) National Water Model that simulates observed and forecasted streamflow over the U.S. In Texas. The National Water Model can be applied to forecast flow modeling at 27,000 bridges and 15,700 stream reaches and provide rapid flood inundation mapping. Improved modeling and forecasting help roadway crews prioritize responses to roadway sheeting, especially during extreme precipitation events as well as improve emergency responders' ability to navigate safely into a flooded area to provide help where it is needed the most.

Precipitation frequency estimates published in NOAA Atlas 14 and the best available data from Federal Emergency Management Agency allows TxDOT to evaluate changing storm frequency and flood event designations with their associated probabilities of occurrence. The updated information and best available data utilized by TxDOT to consider additional hazard and climate change considerations post-NEPA in the final designs for transportation projects.

- Aesthetics may include shade structures and vegetation design (TxDOT and COA engaging the public for aesthetic inputs)
- pump station is proposed for extreme storm events
- Plan transportation infrastructure to avoid potential climate-sensitive locations.

- Work in coordination with the city to improve resiliency and alleviate potential climate impacts on storm water and transportation infrastructure by providing relief to the Boggy Creek watershed, and no additional flow into the Waller Creek waterway
- Utilize transportation asset management and maintenance programs to ensure I-35 infrastructure elements are monitored, remain in good condition, and repair and reconstruction needs are planned as future investments.
- Evaluate the resiliency of I-35 detour routes to minimize distance traveled during potential road closure events.
- Large stormwater tunnel is proposed beginning at the Colorado River, downstream from Longhorn Dam

In summary, the flexibility and elasticity in TxDOT's transportation planning, design, emergency response, maintenance, asset management, and O&M of the transportation system are intended to consider any number of changing scenarios over time. TxDOT continues to monitor and update their programs and policies as necessary.

5. Uncertainties and Limitations of GHG and Climate Change Studies

While this analysis has endeavored to use the best available data, the outcomes are inevitably affected by limitations of that data and uncertainties that limit the accuracy of the tools used. This section describes key limitations to this analysis based on information extracted from Transportation Research Board studies for demographics and traffic and from the referenced climate change studies. Also discussed are overall limitations in emissions modeling and climate forecasting tools to address policy changes that might occur above and beyond current U.S. federal and state policy and regulations.

5.1. GHG Analysis Limitations

A level of uncertainty exists in the estimation of a transportation project's impact on GHG emissions. This uncertainty results from limitations in travel demand forecasting and emissions modeling tools. Travel demand modeling is used to forecast traffic operations and diversions related to transportation projects based on fuel use, traffic count data, local land use and plans, population and demographic forecasts and sources of traffic generation (e.g., employment centers). Emissions modeling reflects the existing standards and regulations but does not forecast for potential future changes to policy and regulations.

Uncertainty surrounds the travel choices, population and demographic futures, and other parameters that serve as the foundation for travel demand forecasting. The estimation of travel speeds remains an important step in the process, as emissions vary significantly by vehicle operation. Travel speeds are typically estimated using statistical relationships accounting for traffic volume, roadway capacity, and free-flow speeds. In addition, average, design, or posted speed is what is typically available for most projects, with only a few of the largest projects having detailed speed data for a reasonably accurate congested and free-flow speed analysis. These relationships may not fully represent the actual traffic conditions at specific locations in present or in future projections. ICE 2.1.3 tool utilizes lifecycle vehicle emission and energy factors were derived from EPA's MOtor Vehicle Emission Simulator (MOVES2014b) model along with the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model (DOE 2016). Although EPA's MOVES emission factor model provides the best available tool for conducting different types of transportation GHG analyses, there is some uncertainty when federal or state defaults are used due to the lack of project-specific data.

Application of these rates does not fully consider detailed location-specific vehicle operations including accelerations and decelerations, the variances by specific vehicle types by model year, and the variances by different road conditions and function. Changes in the future fuel supplies, fuel costs and fuel characteristics, and future regulations may dramatically change emissions in ways not accounted for by existing models and tools. More specifically, current EPA and FHWA guidance for regulatory decision analysis do not account for more recent market changes. An example of this would be the recent projections that new electric vehicle sales may exceed 50% by 2040. (Bloomberg L.P. 2021).

Technological advances may transform societies in ways that cannot be accurately predicted today, just as cell phones changed communication over the past 40 years and internal combustion engines changed horse, buggy, bike, and rail travel in the early 1900s. Other factors can also influence communities and transportation, a recent example of this is the COVID-19 pandemic and the corresponding change in travel patterns from remote work options and people moving to different regions for affordability/quality of life issues. It is not yet possible to accurately forecast how the pandemic might affect long-term transportation trends.

The ICE tool includes many factors and assumptions, which are summarized in Section 4 of the FHWA Infrastructure Carbon Estimator Version 2.1 Final Report and User's Guide (FHWA 2020). The tool incorporates estimates of the typical volumes of materials and amount of on-site construction activity associated with building various types of facilities, such as an urban freeway, an at-grade rail line, or an off-street bike path. The assumptions are based on data from a broad sample of activities. With a few exceptions related to mitigation strategies, the tool does not analyze the impacts of any project elements that would be specified post-NEPA during development of detailed design, engineering, and construction plans.

5.2. Climate Change Analysis Limitations

Climate change analysis and forecasting models are complex and incorporate many different assumptions. Many models use past patterns to estimate future scenarios. However, projections for the future are not always expected to follow the patterns of the past (IPCC 2021). Climate projections can be affected by the limitations in the data and uncertainties can limit the accuracy of the projections. General limitations for climate studies include natural variability and climate model uncertainty, human and scientific uncertainty, and uncertainties associated with the climate tools used. Each of these limited is further explained below.

5.2.1. Natural Variability and Climate Model Uncertainty

Natural variability refers to the changes in climate parameters caused by the natural environment without any changes caused by anthropogenic (human) influences. Natural variability can introduce uncertainties by affecting the initial conditions used as baseline in the climate change models. For example, projections for both temperature and precipitation variables may be subject to greater uncertainty because they can significantly vary from year to year and may undergo significant changes within any given decade. Scientific uncertainty refers to uncertainties in climate models associated with the parameters used and the state of science at the time the model was used. For example, the model structure and parameters may change over time, leading to uncertainties in future temperature and precipitation results or inconsistency with results from future modeling.

5.2.2. *Human and Scientific Uncertainty*

Human uncertainty refers to uncertainties in projections for human-caused GHG emissions. Human decision making is highly variable and can directly influence the quantity of GHG emissions emitted into the atmosphere. To address this uncertainty, two scenarios were used in this report: RCP4.5 and RCP8.5.

- RCP4.5 (low emissions scenario estimated to be approximately 650 ppm CO_2E in 2100) refers to a high level of GHG controls recommended to keep temperature rise below 2°C in 2100. This scenario assumes global carbon emissions peak and decline by the end of the century.
- RCP8.5 (high emissions scenario estimated to be approximately 1,370 ppm CO_2E in 2100) is a business-as-usual case with little to no additional worldwide GHG control measures. This scenario assumes that humans continue to have dependence on fossil fuels and increase carbon emissions through the scenario.

Some limitations of the RCP4.5 and RCP8.5 models are that the scenarios reflect the societal choices over the next century. Future RCP scenarios could change based on different economic, technologic, demographic, and policies in the future. Although GHG emissions from human sources can vary greatly, assuming both the lower and higher emissions scenarios can provide a reasonable range of results for climate change projections.

5.2.3. *Climate Change Explorer Tool Uncertainty*

The primary climate model used in this report is the NCCV. NCCV uses results that are generated by the Coupled Model Intercomparison Project Phase 5 (CMIP5). Some general uncertainties and limitations of global climate models include the following (Stouffer et. al. 2017):

- the models use different equations to represent the Earth's physical processes.
- poor quantification of radiative forcing in climate models.
- climate model simulations, when compared to observations, reveal a wide variety of errors on various time and space scale.
- On time scales of a decade or shorter, the influence of natural variability on the model climate tends to be larger than the response to changes in radiative forcing (Hawkins and Sutton 2009), especially at space scales smaller than hemispheric.
- the RCPs are generalized emissions scenarios and not year-by-year forecasts of emissions, and statistical downscaling method assumes that the future climate will behave similarly to the historical climate in terms of atmospheric and oceanic circulation patterns, which may not be true at every location.
- calculating a single average value for climate variables for each county inevitably also introduces error, in that the average cannot accurately represent every location in the county. The error for any location depends on differences in the environment such as elevation and proximity to lakes, a coast, or mountains.

Another source of uncertainty in the models is the lack of site-specific information. For example, the NCCV uses data near the project site in Travis County instead data from the specific project location in Austin.

6. Climate Change Plans, Reports, Funds, and Policies

6.1. NOAA Assessment- Texas State Climate Summary

These NOAA State Climate Summaries were originally produced in response to a growing demand for state-level information in the context of the Third National Climate Assessment (NCA) and subsequent sustained activities. Each summary consists of a description of the historical climate conditions in the state, as well as that of the climate conditions associated with future pathways of greenhouse gas emissions. (Runkle et al. 2022).

6.2. 2050 Statewide Transportation Report

The 2050 Statewide Transportation Report provides an evaluation of TxDOT transportation plan which develops a 24-year, long range plan containing transportation goals and targets. The primary statewide goals are to promote safety, preserve assets, optimize system performance, deliver the right projects, foster stewardship, and focus on the customer (TxDOT 2022).

6.3. Texas Flood Infrastructure Fund

The Texas Flood Infrastructure Fund provides loans and grants for flood control, flood mitigation, and drainage projects for Texas residents under Article III, Section 52 or Article XVI, Section 59 of the Texas Constitution. In 2019, Texas voters approved Proposition 8 which allowed for the Texas Flood Infrastructure Fund to also assist in the flood planning design activities, obtaining necessary regulatory approvals, and construction of flood projects (Texas Water Development Board 2020).

6.4. Texas Infrastructure Resiliency Fund

In 2019, Texas established the Texas Infrastructure Resiliency Fund which creates a fund for the purpose of financing flood mitigation and protection projects (Office of the Comptroller – Texas 2022). The fund consists of four separate accounts: (1) the federal matching account, (2) the floodplain management account, (3) the floodplain implementation account, and (4) the Hurricane Harvey Account. The federal matching account provides funding to at-risk communities to implement flood protection projects that can be eligible for partial federal funding. The floodplain management account consists of $3 million insurance maintenance taxes that can be used for flood planning, protection, mitigation, or adaptation projects (Office of the Comptroller – Texas 2022). The floodplain implementation account provides financing for projects in the state flood plan, while the Hurricane Harvey Account provides money to the Department of Emergency Management to help with Hurricane Harvey Projects.

6.5. TxDOT Statewide On-Road Greenhouse Gas Emissions Analysis and Climate Change Assessment Technical Report

This report provides an analysis of: 1) available data regarding statewide greenhouse gas (GHG) emissions and on-road and fuel cycle GHG emissions, 1 2) projected climate change for the state of Texas and 3) TxDOT's current strategies and plans for addressing the changing climate. TxDOT's goal is to provide reasonably available information regarding climate change to the public and to provide information for consideration during the environmental analysis of a project.

6.6. TxDOT Statewide Resilience Plan

TxDOT is developing the Statewide Resilience Plan. The plan will be focused on the vulnerability of transportation infrastructure to possible disruptions (e.g climate, cyber, etc.) and incorporate adaptation and resilience solutions.

6.7. FHWA Carbon Reduction Program

TxDOT is evaluating what is needed for the Infrastructure Investment and Jobs Act (IIJR) Carbon Reduction Program, which provides funds for projects designed to reduce transportation emissions, defined as CO_2 emissions from on-road highway sources.

6.8. National Electric Vehicle Infrastructure Program

TxDOT has developed a draft Texas Electric Vehicle Infrastructure Plan to distribute electric vehicle (EV) charging station equitably throughout Texas. The Statewide EV plan for Texas is a multi-year plan to enable current and future drivers of electric vehicles to confidently travel across the state for work, recreation, and exploration. Plan includes distribution of funds to local MPOs which would support the Austin Climate Equity Plan for electric vehicles.

6.9. Local Climate Assessments and Policy

6.9.1. Central Texas Extreme Weather and Climate Vulnerability Assessment of Regional Transportation Infrastructure

The *Central Texas Extreme Weather and Climate Vulnerability Assessment* (CAMPO 2015a) provides recommendations for the Central Texas region for climate risks such as flooding and drought. Some of the key findings of the assessment are to incorporate extreme weather conditions into the 2040 Long Range Transportation Plan (CAMPO 2015b), expand the vulnerability assessment to cities and roads, and to implement adaptation options such as elevating flood prone areas and increasing drainage capacities (Cambridge Systematics 2015).

6.9.2. Travis County Environmental Quality Program

The Travis County Environmental Quality Program goals are to maintain and enhance water quality, reduce water pollution, eliminate industrial waste, and conserve water resources. The mission of program is to address environmental pollution that can enter and affect Travis County's water resources and air quality (Travis County 2022)

6.9.3. Austin/Travis County Community Wildfire Protection Plan

The Austin/Travis County Community Wildfire Protection Program helps regions collaborate to reduce the quantity of vegetation that could provide fire risks in communities. The goal of the program is to develop a multijurisdictional collaborative process that can provide for the safety of residents, protect homes, and protect ecosystems (Bowman Consulting 2014). The program develops a regional strategy to increase wildfire preparedness in the future. Examples of current strategies are to restore natural landscapes, create fire adapted communities, and implement risk management responses to wildfires (Travis County 2020).

6.9.4. Land Water and Transportation Plan

In 2014, Travis County adopted the Land Water and Transportation Plan which provides a framework for protecting Travis County's land and water resources (Travis County 2020). The overall objective of the plan is to regulate construction and development on floodplains, mitigate the impacts of wildfires and floods, and protect the county's natural resources (Travis County 2014).

6.9.5. Resolution No. 20140828-157- Austin's New Energy Plan

Adopted by the City of Austin in 2014, the purpose of the New Energy Plan is to establish zero CO_2 emissions from city-controlled generation resources by 2030 (City of Austin 2014). The resolution also aims to increase the number of renewable generation resources such as through the advancement of solar technologies.

6.9.6. Resolution No. 20140410-024- Austin's Community Climate Plan

Adopted by the City of Austin in 2015, the Community Climate Plan establishes the goal of net-zero GHG emissions by 2050. The Community Climate Plan Steering Group and Technical Advisory Groups will create strategic plans for each major GHG emission sector (City of Austin 2015).

6.9.7. Resolution No. 20190808-078- Climate Emergency

Adopted by the City of Austin in 2019, the climate emergency resolution establishes regional collaboration with the city council to address overarching climate change goals. The plan provides clarity on leadership responsibilities and identifies budget items that can have a significant contribution to GHG emissions (City of Austin 2019).

7. Conclusions

The GHG modeled emissions, compared to the No Build, are estimated to be approximately 10.5 percent to 12.9 percent higher due mostly to build alternatives emissions for materials, transportation of the materials, and construction. Modified Alternative 3 emissions are 2.4 percent more than Alternative 2 due mainly to additional bridge structures required for Modified Alternative 3. Both build alternatives have more significant potential for mode shift that may further reduce GHG emissions than the No Build Alternative. Alternative 2 provides 40.3 miles of BRT and 17.7 miles of additional SUPs, while Modified Alternative 3 provides 36.7 miles of BRT and 19.3 miles of additional SUPs.

Future on-road GHG emissions may be affected by changes that may alter the transportation system and associated emissions, such as: 1) the results of federal policy including tailpipe and fuel controls, 2) market forces that may alter vehicle technology and purchase (such as electric vehicle manufacturing and sales), 3) individual choice decisions regarding commute options including mode shift, 4) reductions that can be achieved through traffic system management operation and/or demand management, and 5) technological advancements, and 6) societal changes.

TxDOT has implemented programmatic strategies to reduce GHG emissions including: 1) travel demand management projects and funding to reduce VMT, such as bicycle and pedestrian facilities, 2) traffic system management projects and funding to improve the operation of the transportation system, 3) participation in the national alternative fuels corridor program, 4) clean construction activities, 5) clean fleet activities, 6) CMAQ funding, 7) transit funding, 8) two statewide campaigns to reduce tailpipe emissions, 9) projects and operational improvements to reduce and manage congestion, and 10) electric vehicle charging plan and funding.

TxDOT also has strategies and funding to address a changing climate in accordance with TxDOT and FHWA design, maintenance, emergency response, and operational policies and guidance. The flexibility and elasticity in TxDOT transportation planning, design, emergency response, maintenance, asset management, and operation and maintenance of the transportation system are intended to consider any number of changing climate scenarios over time.

8. References

Alder, J. R. and S. W. Hostetler, 2013. USGS National Climate Change Viewer. US Geological Survey https://doi.org/10.5066/F7W9575T

Amadeo, K. 2019. Hurricane Harvey Facts, Damage and Costs. What Made Harvey So Devastating. January 20, 2019. https://www.lamar.edu/_files/documents/resilience-recovery/grant/recovery-and-resiliency/hurric2.pdf.

Bachelet, D., J. M. Lenihan, C. Daly, et al. 2001. MC1: a dynamic vegetation model for estimating the distribution of vegetation and associated carbon, nutrients, and water – technical documentation. Version 1.0. General Technical Report. PNW-GTR-508. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Bloomberg L.P. 2021. At Least Two-Thirds of Global Car Sales Will Be Electric by 2040. August 8. https://www.bloomberg.com/news/articles/2021-08-09/at-least-two-thirds-of-global-car-sales-will-be-electric-by-2040.

Bowman Consulting. 2014. Austin-Travis County Community Wildfire Protection Plan. October 17. https://www.austintexas.gov/sites/default/files/files/Section_Cover_Page_and_Table_of_Contents.pdf.

Cambridge Systematics. 2015. Central Texas Extreme Weather and Climate Vulnerability Assessment of Regional Transportation Infrastructure. January. https://www.austintexas.gov/sites/default/files/files/CAMPO_Extreme_Weather_Vulnerability_Assessment_FINAL.pdf.

Capital Area Metropolitan Planning Organization (CAMPO). 2015a. Central Texas Extreme Weather and Climate Change Vulnerability Assessment of Regional Transportation Infrastructure. January. https://www.austintexas.gov/sites/default/files/files/CAMPO_Extreme_Weather_Vulnerability_Assessment_FINAL.pdf.

CAMPO 2015b. CAMPO 2040 Regional Transportation Plan. September. https://47kzwj6dn1447gy9z7do16an-wpengine.netdna-ssl.com/wp-content/uploads/2018/03/CAMPO2040PlanFinal.pdf.

Council on Environmental Quality (CEQ). 2016. Rescinded Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews. August. https://ceq.doe.gov/docs/ceq-regulations-and-guidance/nepa_final_ghg_guidance.pdf.

CEQ. 2022. 40 CFR Parts 1502, 1507, and 1508 National Environmental Policy Act. Implementing Regulations Revisions. April 19. https://www.govinfo.gov/content/pkg/FR-2022-04-20/pdf/2022-08288.pdf.

City of Austin (COA). 2014. Resolution No. 20140828-157. *Austin's New Energy Plan*. https://www.austintexas.gov/edims/document.cfm?id=216608.

COA. 2015. Resolution No. 20140410-024. Austin Community Climate Plan. https://www.austintexas.gov/sites/default/files/files/Sustainability/FINAL_-_OOS_AustinClimatePlan_061015.pdf.

COA. 2016. Hazard Mitigation Plan Update. March. https://www.austintexas.gov/sites/default/files/files/hsem/Draft_City_of_Austin_HMAP_Update.4.4.16_-_PUBLIC_COPY.pdf.

COA. 2018. Climate Resilience Action Plan for City Assets and Operations. April. https://www.austintexas.gov/sites/default/files/files/Sustainability/Climate_Resilience_Action_Plan.compressed.pdf.

COA. 2019. Resolution No. 20190808-078. Climate Emergency. August. Accessed February 25, 2022. https://www.austintexas.gov/edims/document.cfm?id=325549.

U.S. Department of Energy (DOE). 2015. Office of NEPA Policy and Compliance. CEQ Issues Revised Draft NEPA Guidance on GHG Emissions and Climate Change. March 3. https://www.energy.gov/nepa/articles/ceq-issues-revised-draft-nepa-guidance-ghg-emissions-and-climate-change.

DOE. 2016. Office of Energy Efficiency & Renewable Energy. GREET: The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model. May 16. https://www.energy.gov/eere/bioenergy/articles/greet-greenhouse-gases-regulated-emissions-and-energy-use-transportation#:~:text=BIOPROSE%20BLOG-,The%20Greenhouse%20Gases%2C%20Regulated%20Emissions%2C%20and%20Energy%20Use%20in%20Transportation,%2C%20products%2C%20and%20energy%20systems.

U.S. Energy Information Administration (EIA). 2022 Energy-Related CO2 Emission Data Tables. Texas Carbon Dioxide Emissions from Fossil Fuel Consumption (1970-2019). Released April. https://www.eia.gov/environment/emissions/state/excel/states/texas.xlsx.

U.S. Environmental Protection Agency (EPA). 2016. What Climate Change Means for Texas. August. https://www.epa.gov/sites/default/files/2016-09/documents/climate-change-tx.pdf.

EPA. 2017. Climate Change: Basic Information. January. https://19january2017snapshot.epa.gov/climatechange/climate-change-basic-information_.html.

EPA. 2020. EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks. For the 2020 report, it was Annex 3.2, Table A-121 "Total U.S. GHG Emissions from Transportation and Mobile Sources".

EPA. 2021a. Climate Change Indicators: Atmospheric Concentrations of Greenhouse Gases. July. https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases#:~:text=Over%20the%20past%20800%2C000%20years,is%20primarily%20due%20to%20agriculture.

EPA 2021b. Sulfur Hexafluoride (SF6) Basics. September. https://www.epa.gov/eps-partnership/sulfur-hexafluoride-sf6-basics.

EPA. 2022a. Sources of Greenhouse Gas Emissions. April. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

EPA. 2022b. Global Greenhouse Gas Emissions Data. February. https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data.

EPA. 2022c. MOVES and Other Mobile Source Emissions Models. June. https://www.epa.gov/moves.

Federal Highway Administration (FHWA). 2013. A Performance-Based Approach to Addressing Greenhouse Gas Emissions. December. https://ssti.us/wp-content/uploads/sites/1303/2014/04/FHWA-ghg_planning.pdf.

FHWA. 2016. Hydraulic Engineering Circular No. 17, 2nd Edition. June. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif16018.pdf.

FHWA. 2020. Infrastructure Carbon Estimator version 2.1 Final Report and User's Guide. Updated September 24, 2020. http://www.dot.state.mn.us/sustainability/ghg-analysis.html.

FHWA. 2022. Office of Planning, Environment, & Realty, Sustainable Transportation. https://www.fhwa.dot.gov/environment/sustainability/.

Geos Institute. 2016. Hot Enough Yet? The Future of Extreme Weather in Austin, Texas. April. https://climatewise.org/wp-content/uploads/projects/austin-report-2016-08.pdf.

Hyser, Raymond. 2021. Texas Hurricanes: Past, Present, and Future. IHS Climate in Context series. January. https://notevenpast.org/texas-hurricanes-past-present-and-future/.

Intergovernmental Panel on Climate Change (IPCC). 2007. Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate [Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007] Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter2-1.pdf.

IPCC. 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. https://www.ipcc.ch/report/ar5/wg1/.

IPCC. 2014: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_frontmatter.pdf.

IPCC. 2018: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press. https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_version_stand_alone_LR.pdf

IPCC. 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani,S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32, doi:10.1017/9781009157896.001.

National Environmental Modeling and Analysis Center (NEMAC). 2022. Climate Explorer Tool. Accessed June 14, 2022. https://crt-climate-explorer.nemac.org/faq/

Nielsen-Gammon, John; Escobedo, Jacob; Ott, Catherine; Dedrick, Jeramy; Van Fleet, Ali 2020. Assessment of Historic and Future Trends of Extreme Weather in Texas, 1900-2036. Texas A&M University. Office of the Texas State Climatologist. August. https://climatexas.tamu.edu/files/ClimateReport-1900to2036-2021Update#:~:text=The%20number%20of%20100%2Ddegree,to%20the%201950%2D1999%20average.

National Oceanic and Atmospheric Administration (NOAA). 2016. National Water Model. August. https://water.noaa.gov/documents/wrn-national-water-model.pdf.

NOAA. 2021. Geophysical Fluid Dynamics Laboratory. Global Warming and Hurricanes. April. https://www.gfdl.noaa.gov/global-warming-and-hurricanes/

NOAA. 2022a. National Centers for Environmental Information. Storms Events Database. https://www.ncdc.noaa.gov/stormevents/listevents.jsp?eventType=%28C%29+Tornado&beginDate_mm=01&beginDate_dd=01&beginDate_yyyy=1950&endDate_mm=01&endDate_dd=31&endDate_yyyy=2022&county=TRAVIS%3A453&hailfilter=0.00&tornfilter=0&windfilter=000&sort=DT&submitbutton=Search&statefips=48%2CTEXAS.

NOAA. 2022b. National Integrated Drought Information System (NIDIS). March. https://www.drought.gov/states/texas/county/travis.

NOAA. 2022C. NOAA Atlas 14 Point Precipitation Frequency Estimates. https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html.

Office of the Comptroller – Texas. 2022. Texas Infrastructure Resiliency Fund. Comptroller Texas. https://fmcpa.cpa.state.tx.us/fiscalmoa/fund.jsp?num=0175.

Ray, A. 2015. Georgetown Climate Center a Leading Resource for State and Federal Policy. China and US Case Studies: Preparing for Climate Change, Austin TX: Preparing for Water Scarcity and Drought. August. https://www.georgetownclimate.org/files/report/GCC-Austin_Drought-August2015_1.pdf.

Runkle, J., K.E. Kunkel, J. Nielson-Gammon, R. Frankson, S.M. Champion, B.C. Stewart, L. Romolo, and W. Sweet, 2022: Texas State Climate Summary 2022. NOAA Technical Report NESDIS 150-TX. NOAA/NESDIS, Silver Spring, MD, 5 pp. https://statesummaries.ncics.org/chapter/tx/.

Stouffer R.J., V. Eyring, G. A. Meehl, S. Bony, C. Senior, B. Stevens, and K. E. Taylor. 2017: CMIP5 Scientific Gaps and Recommendations for CMIP6. American Meteorological Society, 11 pp. https://journals.ametsoc.org/view/journals/bams/98/1/bams-d-15-00013.1.xml.

Taylor, K.E., R.J. Stouffer, and G.A. Meehl, 2012: An overview of CMIP5 and the experiment design. Bulletin of the American Meteorological Society, 93 (4), 485–498. doi:10.1175/BAMS-D-11-00094.1

Texas A&M Forest Service. 2022. Texas Wildfire Risk Explorer. https://wrap.texaswildfirerisk.com/Map/Public/#whats-your-risk.

Texas Department of Transportation (TxDOT) 2018. Technical Report. Statewide On-Road Greenhouse Gas Emissions Analysis and Climate Change Assessment. October. https://ftp.txdot.gov/pub/txdot/get-involved/sat/loop-1604-from-sh16-i-35/091020-greenhouse-gas-report.pdf.

TxDOT. 2022. 2050 Statewide Transportation Report. January. https://ftp.txdot.gov/pub/txdot/tpp/2050/statewide-transportation-report.pdf.

Texas Water Development Board. 2020. 2020 Flood Intended Use Plan. September. https://www.twdb.texas.gov/financial/programs/fif/doc/2020_Flood_Intended_Use_Plan.pdf?d=75136.5.

Travis County. 2014. Land, Water & Transportation Plan. Travis County TX. December. https://www.traviscountytx.gov/images/tnr/Docs/lwtp-Executive_Summary.pdf.

Travis County. 2020. Travis County Climate Action Plan. https://www.traviscountytx.gov/images/tnr/Docs/conserve/climate-action-plan.pdf.

Travis County. 2022. About the Environmental Quality Program. Travis County TX. https://www.traviscountytx.gov/tnr/environmental-quality/about.

Transportation Research Board (TRB). 2022. National Cooperative Highway Research Program's Web-Only Document 308: Methods for State DOTs to Reduce Greenhouse Gas Emissions from the Transportation Sector. March 8. https://www.trb.org/Main/Blurbs/182696.aspx.

Treut, L.; Somerville, H. R.; Cubasch, U.; Ding, Y.; Mauritzen, C.; Mokssit, A.; Peterson T.; Prather, M. Historical Overview of Climate Change. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller Eds. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007; pp. 104-105.

U.S. Climate Resilience Toolkit. 2022. Climate Explorer Version 3.1 for Austin, Travis County. https://crt-climate-explorer.nemac.org/cards_home/?city=Austin%2C+TX&county=Travis%2BCounty&area-id=48453&fips=48453&zoom=7&lat=30.267153&lon=-97.7430608\.

U.S. Global Change Research Program (USGCRP). 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.

USGCRP. 2017. Climate science special report: Fourth National Climate Assessment, Volume I. Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, eds. https://science2017.globalchange.gov. doi:10.7930/J0J964J6.

USGCRP. 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018. https://nca2018.globalchange.gov/.

United States Geological Survey (USGS). 2021. U.S. Geological Survey - National Climate Change Viewer Summary of Travis County, Texas. May https://www.usgs.gov/tools/national-climate-change-viewer-nccv.

USGS. 2021. National Climate Change Viewer (NCCV). June. https://www.usgs.gov/tools/national-climate-change-viewer-nccv.

White House. 2021a. Executive Order 13990 Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis. January. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-protecting-public-health-and-environment-and-restoring-science-to-tackle-climate-crisis/.

White House. 2021b. Executive Order 14008 Tackling the Climate Crisis at Home and Abroad. January. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/.

Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, B. DeAngelo, S. Doherty, K. Hayhoe, R. Horton, J.P. Kossin, P.C. Taylor, A.M. Waple, and C.P. Weaver. 2017: Executive summary. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 12-34, doi: 10.7930/J0DJ5CTG. https://www.globalchange.gov/browse/reports/executive-summary-climate-science-special-report-fourth-national-climate-assessment.

Appendix A: Supplemental Greenhouse Gas Analysis Information

Introduction

Consideration of greenhouse gases (GHGs) and climate change in NEPA analysis presents a unique challenge. After recognizing that Federal agencies needed assistance in determining the appropriate level of analysis for greenhouse gases and climate change in the NEPA context, the Council on Environmental Quality (CEQ) issued draft guidance in 2010, updated the draft guidance in 2014 and then issued final guidance titled, Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews in August of 2016 (CEQ 2016 Guidance). The stated goal of the guidance was to provide consistency for federal agencies' consideration of climate change impacts in NEPA documents. In March 2017, the Trump Administration rescinded the August 2016 Guidance through an Executive Order, Promoting Energy Independence, and Economic Growth (E.O. 13783). CEQ then proposed for public comment, but never finalized, "Draft National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions" (2019 Draft Guidance, 84 FR 30097).

Upon taking office on January 20, 2021, President Biden rescinded President Trump's Executive Order (EO)13783 and issued his "Executive Order on Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis" (EO 13990). EO 13990 calls for all federal agencies to review climate-related regulations and actions taken in the past 4 years, and tasks the CEQ with updating its August 2016 final guidance (81 FR 51866). Pursuant to EO 13990, CEQ rescinded the draft GHG-related NEPA guidance issued in 2019 and is currently reviewing the 2016 final guidance for revision and update (CEQ 2021). In the interim, CEQ instructs agencies to consider all available tools and resources in assessing GHG emissions and climate change effects, including the 2016 GHG Guidance.

With the current lack of a clear standard or revised CEQ guidance, NEPA decision-maker is challenged to determine what constitutes a hard look at the climate change implications of a project decision. The 2016 CEQ guidance recognized that inherent in NEPA and the CEQ regulations is a rule of reason which ensures that agencies are afforded the discretion, based on their expertise and experience, to determine whether and to what extent to prepare an analysis based on the availability of information, the usefulness of that information to the decision-making process and the public, and the extent of the anticipated environmental consequences.

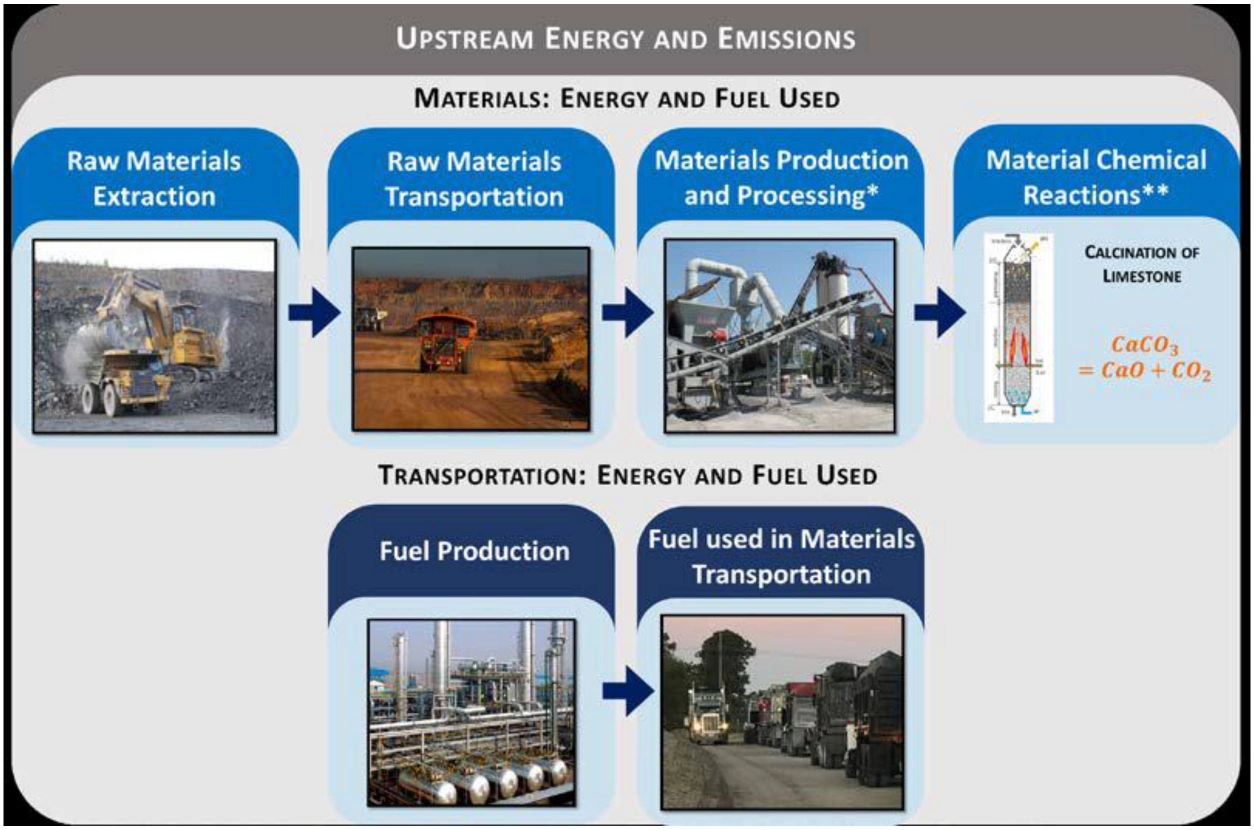
A.1 Greenhouse Gas Analysis Methodology

As part of the evaluation undertaken for this proposed project, a quantitative assessment was completed to compare the GHG emissions of the No-Build and build alternatives. This GHG emission analyses considered both the direct and indirect GHG emissions associated with the project as a proxy for climate change impacts.

A.1.1 GHG Analysis Using FHWA ICE 2.1.3.

GHG emissions from the project were estimated using FHWA Infrastructure Carbon Estimator (ICE), Version 2.1.3. The ICE tool was developed by FHWA to estimate the lifecycle energy and GHG emission from construction, operation, and maintenance of transportation facilities. It estimates emissions from construction equipment and upstream emissions from materials, as well as vehicle emissions from using the facilities. The tool requires limited basic project data inputs and is designed to inform planning and pre-engineering analysis.

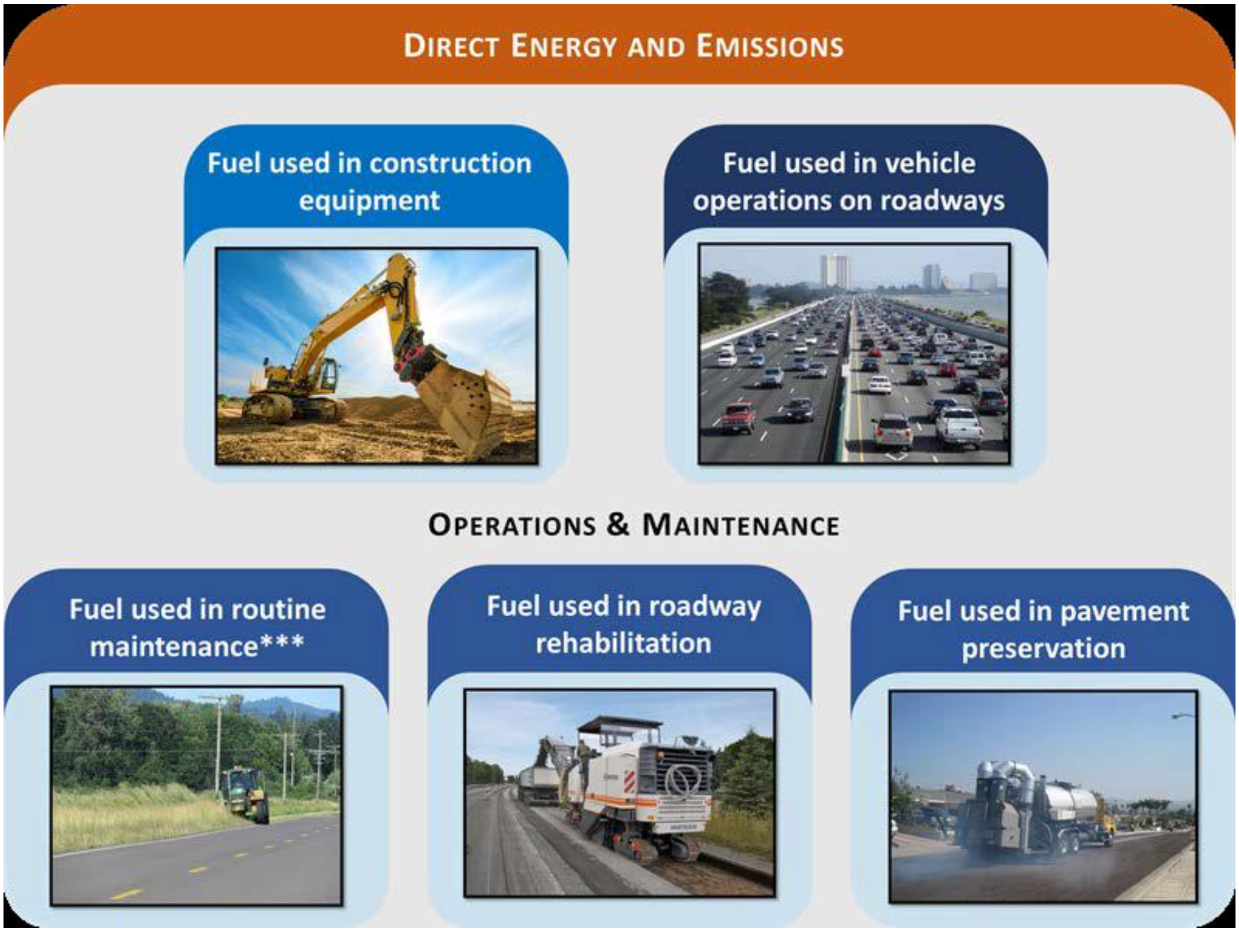
The FHWA ICE 2.1.3 considers the following direct and upstream emissions to estimate construction, operation, and maintenance related emissions.



* e.g., crushing of aggregate,

** e.g., CO_2 emitted from calcination of limestone

*** activities include sweeping, striping, bridge deck repair, litter pickup, and maintenance of appurtenances



The GHG emissions analysis of the project included both direct emissions (tailpipe emissions from vehicles and equipment) and indirect emissions (fuel cycle emissions and upstream construction material emissions) from the project. ICE 2.1.3 breaks GHG emissions into five categories in the emission modeling:

- Material: Includes the upstream emissions associated with project materials extraction, production, chemical reaction, and raw material transportation.
- Transportation: Includes upstream emissions associated with fuel used in transportation of materials to site.
- Construction: Includes the emissions from energy and fuel used in construction equipment
- Operation and Maintenance (O&M): Includes the emissions from routine maintenance such as snow removal and vegetation management, roadway repair and rehabilitation, and other routine maintenance.
- Usage: Includes emissions from vehicle operation on roadways, including delay during construction.

GHG emissions from the project were modeled based on the construction and operation information of the proposed project facilities, including:

Bridges and Overpasses: new and reconstructed bridges and overpasses.

- Bus Rapid Transit (BRT)

- Culverts
- Lighting
- Pathways
- Roadways
- Signage

ICE 2.1.3 inputs of each the facility type were provided by I-35 Capital Express Central Team based on anticipated project construction activities. ICE 2.1.3 input information for each facility type under each alternative are in **Appendices A.3, A-4, and A-5.**

Vehicle operation emissions in future years were modeled based on the vehicle miles traveled (VMT), as shown in **Table A.1-1**. There are no significant differences in VMT between the No Build and Build Alternatives. VMTs of Alternatives 2 and Modified 3 are similar in the future analysis years, with Modified Alternative 3 has slightly higher (approximately 0.3%) than Alternative 2. VMT of Alternatives 2 and Modified 3 are approximately 1.4% to 1.7% higher than No Build in 2050, respectfully.

Table A.1-1 Project VMT Information

Scenarios	No Build	Alternative 2	Modified Alternative 3
2018	1,700,100	0	0
2030	2,011,900	2,034,600	2,035,600
2040	2,259,500	2,288,700	2,292,300
2050	2,507,000	2,542,700	2,551,000

NOTE: VMT in the table are during normal operation. VMT affected by project construction are in Appendix A1.

The time frame of the GHG analysis for the project is 20 years to be consistent with the project operation between the 2030 opening year and 2050 design year. The modeled GHG emissions are presented in the unit of MT CO_2E, which are calculated as the product of the mass emitted of a given GHG and its specific GWP. The ICE 2.1.3 uses the 100-year GWP values from Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4, IPCC 2007), as shown the following:

- CO_2: 1
- CH_4: 25
- N_2O: 298

A.1.2 GHG Analysis for Long-Span Bridges and Depressed Lane Structures

The ICE 2.1.3 was used to estimate the construction emissions of roadways, bridges/overpasses, and other infrastructures of the project. However, emissions from portions of the project, such as bridges/overpasses with spans greater than 1,000 feet and the depressed lanes structures, may not be properly estimated by ICE 2.1.3.

The bridge and overpass module in ICE 2.1.3 applies to structures shorter than 1000 feet because longer bridges may be characterized by different material and energy intensities than those used to develop the prototypes in the ICE 2.1.3 (ICF, 2020). Several of the bridges of the project build alternatives would have lengths greater than 1000 feet. The number of bridges were adjusted for those greater than 1000 feet, based on the ratio of their bridge length to 1,000 feet. For example, a 2,000 feet bridge were modeled as 2 bridges in the ICE 2.1.3 to count for the additional GHG emissions due to the extra lengths. However, this approach does not take into account the differences of materials and energy intensities from the ICE 2.1.3 prototypes and can be further refined in the future when additional bridge construction information becomes available. The length of bridges over 1,000 feet by alternative are in **Table A.1-2**.

Table A.1-2 Bridges Over 1,000 feet by Alternative

Bridges over 1,000 Feet	No Build (feet)	Alternative 2 (feet)	Modified Alternative 3 (feet)
New Bridges			
I-35 NB Managed Lanes Direct Connector	-	3,580	3,580
I-35 SB Managed Lanes Direct Connector	-	3,580	3,580
NB Frontage Rd. MLK - 32nd St	-	2,998	-
NB Frontage Rd. Holly Street - 32nd St	-	-	12,804
SB Frontage Rd. 15th. St - 38th 1/2 St.	-	6,289	6,289
NB 7th St. - Dean Keeton Bypass over Mainlanes at MLK Blvd	-	-	1,294
SB Mainlane Entrance Ramp East Riverside - Woodland Ave.	-	1,111	1,111
Deck Park North Clyde Littlefield to MLK B	-	1,020	-
Deck Park North MLK to 15th St.	-	-	1,365
Reconstructed Bridges			
NB Mainlanes over Lady Bird Lake	-	1,163	1,163
SB Mainlanes over Lady Bird Lake	-	1,163	1,163
NB Frontage Roads over Lady Bird Lake	-	1,475	1,475
SB Frontage Roads over Lady Bird Lake	-	1,163	1,163

ICE 2.1.3 does not provide specific instructions or differentiate at-grade and depressed roadways in the input. No adjustment was made to the construction of depressed lanes.

A.2 Lifecycle GHG Emission Results

Results of the lifecycle total GHG emissions and the annualized GHG emissions from the project by each of the five emission categories are summarized in **Tables A.2-1** through **A.2-3**. For information and comparison purposes, the existing condition's GHG emissions from vehicle operation were also estimated. The 2018 GHG emissions were 373,344 MT CO_2E, estimated by multiplying the vehicle miles traveled (VMT) in 2018 in the project area by the vehicle emission factors from ICE 2.1.3 for 2018.

Table A.2-1: Lifecycle GHG Emissions by Emission Category by Alternative

Emission Category	No Build Alternative		Alternative 2		Modified Alternative 3	
	Total MT CO_2E	Annualized MT CO_2E/year	Total MT CO_2E	Annualized MT CO_2E/year	Total MT CO_2E	Annualized MT CO_2E/year
Materials	0	0	227,668	11,383	383,895	19,195
Transportation	0	0	10,135	507	13,576	679
Construction	0	0	76,456	3,823	108,066	5,403
O&M	18,606	930	56,358	2,818	54,008	2,700
Usage (VMT)	7,374,840	368,742	7,838,340	391,917	7,851,675	392,584
Total	7,393,446	369,672	8,208,956	410,448	8,411,220	420,561

NOTE: Annualized GHG emissions were calculated by dividing the total lifecycle GHG emissions by 20 years.

Table A.2-2: Lifecycle GHG Emissions by Infrastructure Type by Alternative

Infrastructure Type	No Build Alternative		Alternative 2		Alternative 3 Modified	
	Total MT CO_2E	Annualized MT CO_2E/year	Total MT CO_2E	Annualized MT CO_2E/year	Total MT CO_2E	Annualized MT CO_2E/year
Bridges/Overpasses	0	0	201,914	10,096	399,984	19,999
Bus Rapid Transit	0	0	19,336	967	17,616	881
Culverts	0	0	12,731	637	12,731	637
Lighting	0	0	11,689	584	11,689	584
Pathways	0	0	870	43	948	47
Roadways	18,606	930	111,448	5,572	105,173	5,259
Signage	0	0	12,628	631	11,403	570
Vehicle Operations	7,374,840	368,742	7,838,340	391,917	7,851,675	392,584
Total	7,393,446	369,672	8,208,956	410,448	8,411,220	420,561

NOTE: Annualized GHG emissions were calculated by dividing the total lifecycle GHG emissions by 20 years.

Table A.2-3: Lifecycle GHG Emissions by Material Type by Alternative

Material Type	No Build Alternative		Alternative 2		Alternative 3 Modified	
	Total MT CO_2E	Annualized MT CO_2E/year	Total MT CO_2E	Annualized MT CO_2E/year	Total MT CO_2E	Annualized MT CO_2E/year
Aggregate	0	0	8,751	438	11,814	591
Aluminum	0	0	1,469	73	1,327	66
Bitumen (Asphalt Binder)	0	0	8,333	417	7,811	391
Cement	0	0	141,556	7,078	253,766	12,688
Steel	0	0	67,429	3,371	108,937	5,447
Water	0	0	129	6	241	12
Transportation Fuel	0	0	10,135	507	13,576	679
Construction Fuel	0	0	76,456	3,823	108,066	5,403
O&M Electricity	0	0	10,886	544	10,886	544
O&M fuel (DGEs)	2,415	121	6,319	316	6,019	301
O&M Roadway Rehabilitation	16,191	810	39,154	1,958	37,103	1,855
Vehicle Fuel Usage (Operation VMT)	7,374,840	368,742	7,838,340	391,917	7,851,675	392,584
Total	7,393,446	369,672	8,208,956	410,448	8,411,220	420,561

NOTE: Annualized GHG emissions were calculated by dividing the total lifecycle GHG emissions by 20 years.

A.3 ICE 2.1.3 Inputs and Outputs: ICE Model - No Build

Introduction to the Infrastructure Carbon Estimator (ICE), version 2.1

Note: This tool is designed to allow users to create screening-level estimates of energy and GHG emissions using limited data inputs. It asks for limited data to estimate lifecycle energy use emissions from a single or group of projects. The tool is not appropriate to inform engineering analysis and pavement selection. Other tools should be consulted for those purposes. More details about suggested uses for the tool are provided in the accompanying ICE User's Guide .

Project Inputs Page

Summary Results Page

Infrastructure Carbon Estimator (ICE) 2.1.3. Final Tool. Released 03/24/2021.

OVERVIEW

The Infrastructure Carbon Estimator (ICE) estimates the lifecycle energy and greenhouse gas (GHG) emissions from the construction and maintenance of transportation facilities. The ICE tool was created to solve the problem of "planning level" estimation of embodied carbon emissions in transportation infrastructure. Without the need for any engineering studies, ICE helps answer this question: How much carbon will be embodied in the building, modification, maintenance, and/or use of this transportation project (or group of projects)?

ICE evaluates energy use and greenhouse gas emissions at the project- or planning-level. The tool uses the term "project" to generally refer to a single project type, with access to some additional details and project customization. "Planning" is designed to accept inputs from long-range transportation plans or other plans that consist of a suite of projects but limited customization.

The tool estimates emissions for the following types of facilities and projects:

1. Bridges and Overpasses
2. Bus Rapid Transit (BRT)
3. Culverts
4. Light Rail
5. Lighting
6. Heavy Rail
7. Parking
8. Pathways
9. Roadways
10. Signage
11. Vehicle Operations
12. Standalone Maintenance Projects on Existing Roadways
13. Custom Pavement Projects with Data Imported from External Tools

(Please note Types 12 and 13 address specific and limited applications. These are discussed in the individal tabs and the User's Guide.)

For each type of facility, the tool calculates both mitigated results that take into account the effect of various energy/GHG reduction strategies and unmitigated results.

USING THE TOOL

Details on use of ICE is available in the User's Guide.

Color Scheme

ICE uses the following color scheme to describe the function of each cell:

Description Cells
Computed Value Cells
Cell value is not relevant (Cell is NA)
Data Entry Cells
Action Cell
Command button - on
Command button - off
Command button - disabled

The tool provides users the ability to display results in 508 compliant format, which among other features, will add data labels to all results charts. The color scheme when 508 compliant is activated deviates slightly from when the format is turned off.

Analysis Mode

The tool can be used in either *Planning* or *Project* mode. This is set at the top of the *Project Inputs* page

Planning mode reveals all facility types on one page. Using the buttons at the top of the screen allows you to add or remove facilities from your analysis. Individual facility details can be viewed via the links below the input table or by navigating the separate tabs for each infrastructure type. Clicking the hyperlinks above and below each infrastructure type's inputs in the *Project Inputs* page navigates to the various sections in each *analysis page* for that infrastructure type. The relevant *analysis page(* s), *Mitigation Strategies* page, and the *Summary Results* page will be shown when an infrastructure type is selected. Buttons on the *analysis pages* carry the user to specify mitigation measures and back to the *analysis pages.*

The *Project mode* operates similarly. In the *Project* mode, the user has the option to view all inputs or have ICE walk the user through each step. In walkthrough mode, green action cells direct the user through each step. Only a single infrastructure type can be modeled in *Project mode* .

Tabs and Navigation

The tool can be navigated in multiple ways. Users will start by describing their project on the *Project Inputs* page. This includes the infrastructure type(s), analysis lifetime, location, and analysis mode. Hyperlinks carry users through the various tabs. Three comment boxes allow the user to input descriptive text that will be carried through to the output pages. This could include analysis date, analyst, project descriptions, or other information the analyst may want to include in their report.

First, select your level of analysis (Project or Planning) and input the requested information for your project on the *Project Inputs* page. Input the US state for your analysis, the project analysis lifetime (in years), and whether the impacts of a custom electricity emission program, such as a Renewable Portfolio Standard (RPS), are to be included. Answering "yes" on the latter will open the *Annual Electricity Emissions* tab for populating.

If using the Planning level of analysis, "turn on" all infrastructure types to be analyzed on the *Project Inputs* page. If using the *Project* level of analysis, then select the single infrastructure type to analyze.

Hyperlinks from the *Project Inputs* page will take you to the *analysis page* for your project type(s). (The project analysis pages are titled according to the infrastructure type.) Here some additional inputs for your project may be requested. At the top of each analysis page is a hyperlink that carries you to the *Mitigation Strategies* page.

Each *analysis page* includes the following sections:

- Specifications – Fixed and input values describing the project
- Baseline Energy Use and GHG Emissions – Total energy use and GHG emissions over the project's lifetime
- Mitigated Results – Annualized energy use and GHG emissions for the project without (baseline) and with (both business as usual and control scenario) mitigations applied.
- Results - Charts – Summary charts and tables of the mitigated and unmitigated energy use and emissions by emission category, material, and individualized mitigation effects. Results can be viewed as annualized or cumulative GHG emissions or energy.

On the *Mitigation Strategies* page, you have the option to input certain strategies that reduce energy and GHG emissions for your project. Only relevant strategies are shown. Hyperlinks at the top return you to the *analysis page* for your project type.

ICE Model - No Build

Below the project specifications in each *analysis page*, the calculated, annualized baseline, business-as-usual (BAU), and mitigated levels of energy or GHG emissions for your project type(s) are displayed. This shows results by the five emission categories and by material for both mitigated and unmitigated cases. It also shows emission or energy reductions by mitigation measure.

The *Summary Results* page displays a summary of results for all infrastructure types analyzed. If the analysis is at the *Project* level, this display is nearly identical to that on the *analysis page.* For *Planning* level, buttons appear allowing the user to turn on or off the different project types included in the combined results. The "Show" dropdown menu selects the results displayed: Annualized Greenhouse Gas Emissions, Annualized Energy Use, Cumulative Greenhouse Gas Emissions, and Cumulative Energy Use. An additional chart in the *Summary Results* page, not available in the individual *analysis pages* , displays values by infrastructure type.

If the use phase of automobiles is to be considered in your project, you must include the *Vehicle Operations* project type. Resulting energy and emissions from project use will be added to the summary charts on the *Summary Results* page.

At any time, the user can view overall results in the *Summary Results* page or enter a custom mitigation approach for energy and GHG emissions on the *Mitigation Strategies* page. The user can switch directly between various pages indicated in Excel tabs at any time. The *Print Results* tab collects outputs and formats them for standard printing, either to an electronic or paper copy for archiving the outputs of your simulation. This can be used to compare multiple simulations, such as for a Build vs. No-Build analysis.

Units and Time Periods

ICE requests the analysis timeframe (in years) from the user. It produces lifecycle (to end-of-life) estimates of energy use and/or GHG emissions. Both values can be reported on an annualized or total lifespan basis. The standard reporting unit for energy is "mmBTU", or millions of British Thermal Units. The standard reporting unit for greenhouse gas emissions is "MT CO2e", or metric tons of CO2-equivalent gases. 1 metric tons = 1,000 kg. CO2 equivalency is defined by a global-warming potential basis.

EMISSIONS SOURCES ESTIMATED

Construction and maintenance activities covered by the tool are broken into five categories:

Materials

Upstream Energy and Emissions associated with project materials:

1. Energy and fuel used in raw material extraction
2. Energy and fuel used in material production*
3. Chemical reactions in material production**
4. Energy and fuel used in raw material transportation

Transportation

Upstream Energy and Emissions associated with:

1. Fuel used in transportation of materials to site

Construction

1. Energy and fuel used in construction equipment

Operations and Maintenance (O&M)

Routine Maintenance, including:

1. Fuel used in snow removal equipment
2. Fuel used in vegetation management equipment
3. Fuel used in other routine maintenance***
4. Energy and emissions from roadway repair and rehabilitation
5. Net energy and emissions from pavement preservation activities (optional)

Usage

Energy and Emissions associated with:

1. Vehicle operations on roadways, including delay during construction

*e.g. crushing of aggregate, asphalt batch plants
**e.g CO2 emitted from calcination of limestone
***activities include sweeping, stripping, bridge deck repair, litter pickup, and maintenance of appurtenances

ICE does not include energy or emissions associated with land use change from the project.

Project Inputs

Display result in 508 compliant format:	No
Hide Instructions	No

INSTRUCTIONS

1. Populate location (state) and lifetime (years) for your analysis.
2. Select operating mode (*Project* or *Planning*) for your analysis. (The tool can analyze different individual projects (*Project* mode) or a suite of projects in a comprehensive plan (*Planning* mode).
3. Select the infrastructure type(s) to analyze. Input all requested data using information from the project or plan you want to analyze. Then navigate to the relevant *analysis page(s)* for your project or the individual project(s) in your plan and complete the analysis for each infrastructure type by entering information in all cells that are shaded yellow. Blue and gray cells display fixed values and results; do not change the information in these cells.
4. Apply any selected mitigation measures on the *Mitigation Strategies* tab.
5. Review outputs on the *Summary Results* tab.
6. For further instructions, refer to the accompanying User Guide for detailed descriptions of factors and assumptions used in this tool.

Clear All User Data

Infrastructure location (state)	TX
The lifetime of your plan or project (years)	20
Use custom electric emission profile (RPS)?	No

Tool Use	Planning

Bridges & Overpasses | Culverts | Lighting | Parking | Roadways | Vehicle Operations | Roadway Rehabilitation

BRT | Light Rail | Heavy Rail | Pathways | Signage | Custom Pavement

	Title: No build	Title:	Title:
Enter comments and comment titles. These will be displayed on the Summary Results worksheet.			

Planning Summary of Inputs - See Individual Tabs for Details

Roadways

Roadway System	
Total existing centerline miles	9.95
Total newly constructed centerline miles	0

Roadway Projects

Facility type	Roadway System	Roadway Construction				
	Existing Roadway (lane miles)	New Roadway (lane miles)	Construct Additional Lane (lane miles)	Realignment (lane miles)	Lane Widening (lane miles)	Shoulder Improvement (centerline miles)
Rural Interstates						
Rural Principal Arterials						
Rural Minor Arterials						
Rural Collectors						
Urban Interstates / Expressways	68.17					
Urban Principal Arterials	6.21					
Urban Minor Arterials / Collectors	44.87					

Include roadway rehabilitation activities (reconstruct and resurface)	Yes
% roadway construction on rocky / mountainous terrain	

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

Vehicle Ops

Vehicle Operating Emissions

	Year		Avg Daily VMT on project	Average Daily (Congested) Speed (mph) (or NA)
	Default	Custom		
Project Opening Year	2022	2030	2011900	NA
Project Interim Year	2027	2040	2259500	NA
Project Design/Horizon Year	2050	2050	2507000	NA

Construction Delay, Additional Emissions

	Year		Avg Daily VMT impacted by project	Average Daily (Congested) Speed (mph) (or NA)
	Default	Custom		
Construction start year	2022			
Pre-construction (baseline) year	2021			
Project Opening Year	2030			

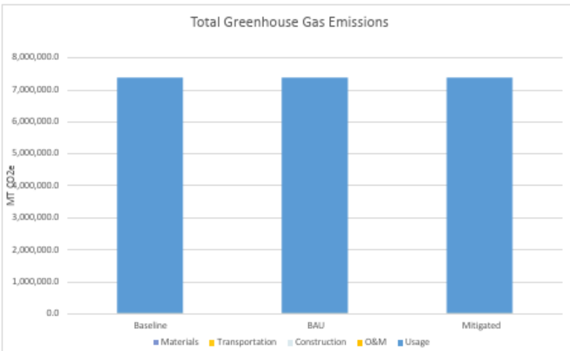
ICE Model - No Build

Summary Results

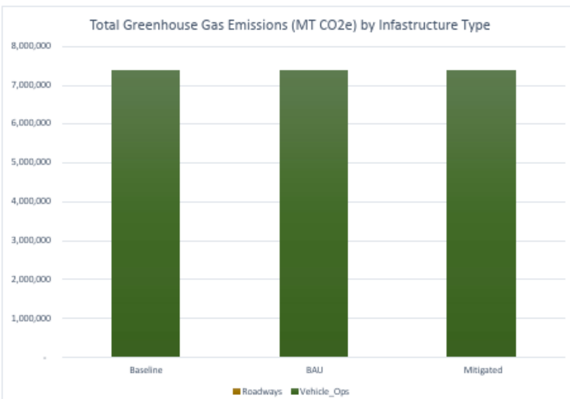
Bridges & Overpasses | Culverts | Lighting | Parking | Roadways | Vehicle Operations
BRT | Light Rail | Heavy Rail | Pathways | Signage | Custom Pavement

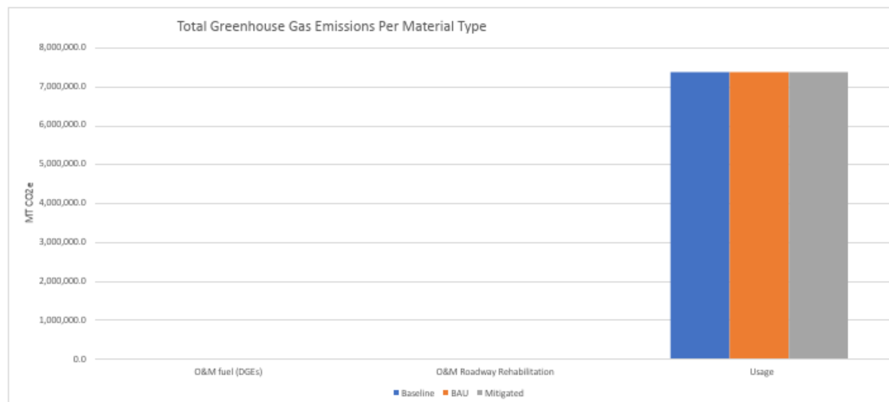
Show	Total Greenhouse Gas Emissions	Units	MT CO2e

Summary Results - Charts



Baseline refers to values without any mitigations applied.
Business-as-Usual (BAU) deployment refers to any "default" mitigations that are deployed through standard agency practices.
Planned deployment reflects the level of mitigations planned for the analyzed case.





Summary Results - Tables

	Total Greenhouse Gas Emissions		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Materials	-	-	-
Transportation	-	-	-
Construction	-	-	-
O&M	18,606	18,606	18,606
Usage	7,374,840	7,374,840	7,374,840
Total	**7,393,446**	**7,393,446**	**7,393,446**

	Total Greenhouse Gas Emissions Per Material Type		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
O&M fuel (DGEs)	2,415	2,415	2,415
O&M Roadway Rehabilitation	16,191	16,191	16,191
Usage	7,374,840	7,374,840	7,374,840
Total	**7,393,446**	**7,393,446**	**7,393,446**

	Total Greenhouse Gas Emissions Reductions Relative to BAU				
	MT CO2e Materials	MT CO2e Transportation	MT CO2e Construction	MT CO2e O&M	MT CO2e TOTAL
Total	-	-	-	-	-

	Total Greenhouse Gas Emissions (MT CO2e) by Infastructure Typ		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Roadways	18,606	18,606	18,606
Vehicle_Ops	7,374,840	7,374,840	7,374,840
Total	**7,393,446**	**7,393,446**	**7,393,446**

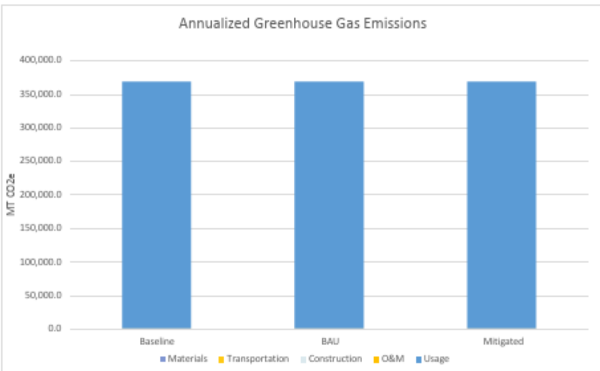
ICE Model - No Build

Summary Results

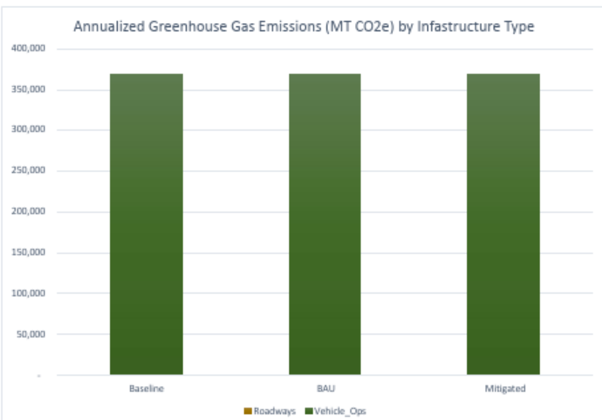
Bridges & Overpasses	Culverts	Lighting	Parking	Roadways	Vehicle Operations
BRT	Light Rail	Heavy Rail	Pathways	Signage	Custom Pavement

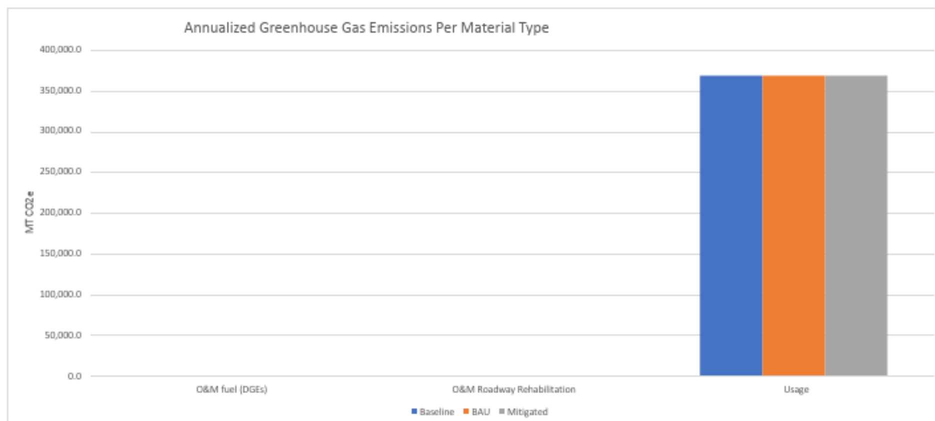
Show	Annualized Greenhouse Gas Emissions	Units	MT CO2e

Summary Results - Charts



Baseline refers to values without any mitigations applied.
Business-as-Usual (BAU) deployment refers to any "default" mitigations that are deployed through standard agency practices.
Planned deployment reflects the level of mitigations planned for the analyzed case.





Summary Results - Tables

	Annualized Greenhouse Gas Emissions		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Materials	-	-	-
Transportation	-	-	-
Construction	-	-	-
O&M	930	930	930
Usage	368,742	368,742	368,742
Total	**369,672**	**369,672**	**369,672**

	Annualized Greenhouse Gas Emissions Per Material Type		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
O&M fuel (DGEs)	121	121	121
O&M Roadway Rehabilitation	810	810	810
Usage	368,742	368,742	368,742
Total	**369,672**	**369,672**	**369,672**

	Annualized Greenhouse Gas Emissions Reductions Relative to BAU				
	MT CO2e Materials	MT CO2e Transportation	MT CO2e Construction	MT CO2e O&M	MT CO2e TOTAL
Total	-	-	-	-	-

	ualized Greenhouse Gas Emissions (MT CO2e) by Infastructure T		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Roadways	930	930	930
Vehicle_Ops	368,742	368,742	368,742
Total	**369,672**	**369,672**	**369,672**

ICE Model - No Build

Mitigation Strategies

Return To S

Instructions: Follow the steps below to calculate the impact of energy and GHG mitigation strategies:

The user will enter both the business as usual (BAU) deployment (i.e., the extent to which the strategy is deployed through standard agency practices) in Column F and the planned deployment (i.e., the extent to which the strategy will be deployed in the project that you are examining) in Column G. (Baseline refers to values without any mitigations.) For Pavement Preservation strategies, enter both the schedule change and application frequency.

Column H displays the increase in deployment from implementation of the strategy. Some reduction strategies (e.g., Switch from diesel to Soy bean-based BD20 and biodiesel/hybrid maintenance vehicles and equipment) may be incompatible. The user should take care that inputs do not describe a total deployment greater than 100% for overlapping strategies. The tool will warn if "excess" energy savings from mitigation are predicted or incompatible strategies are selected.

For a more refined mitigation analysis, please refer to FHWA's upcoming Pavement LCA Tool.

						BAU Reductions		Planned Reductions	
Strategy	BAU deployment	Planned deployment	Deployment increase	Energy reduction factor	GHG reduction factor	Energy reductions	GHG reductions	Energy reductions	GHG reductions
Alternative fuels and vehicle hybridization									
Switch from diesel to Soy bean-based BD20			0.0%	-5%	12%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to Soy bean-based RDII 100			0.0%	-20%	66%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to Forest Residue-based RDII 100			0.0%	-61%	71%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to E-Diesel, Corn			0.0%	-3%	0%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to PHEV: Diesel and Electricity (U.S. Mix)			0.0%	41%	44%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to CNG, NA NG			0.0%	-6%	11%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to LNG, NA NG			0.0%	-11%	7%	0.0%	0.0%	0.0%	0.0%
Hybrid maintenance vehicles and equipment			0.0%	11%	11%	0.0%	0.0%	0.0%	0.0%
Combined hybridization/B20 in maintenance vehicles and equipment			0.0%	1%	27%	0.0%	0.0%	0.0%	0.0%
Hybrid construction vehicles and equipment			0.0%	11%	11%	0.0%	0.0%	0.0%	0.0%
Combined hybridization/B20 in construction vehicles and equipment			0.0%	1%	27%	0.0%	0.0%	0.0%	0.0%
Vegetation management									
Alternative vegetation management strategies (hardscaping, alternative mowing, integrated roadway/vegetation management)			N/A	25%	25%	0.0%	0.0%	0.0%	0.0%
Snow fencing and removal strategies									
Alternative snow removal strategies (snow fencing, wing plows)			N/A	0%	0%	0.0%	0.0%	0.0%	0.0%
In-place roadway recycling									
Cold In-place recycling			0.0%	33%	37%	0.0%	0.0%	0.0%	0.0%
Full depth reclamation			0.0%	68%	68%	0.0%	0.0%	0.0%	0.0%
Warm-mix asphalt									
Warm-mix asphalt			0.0%	37%	37%	0.0%	0.0%	0.0%	0.0%
Recycled and reclaimed materials									
Use recycled asphalt pavement as a substitute for virgin asphalt aggregate			0.0%	12%	12%	0.0%	0.0%	0.0%	0.0%
Use recycled asphalt pavement as a substitute for virgin asphalt bitumen			0.0%	84%	84%	0.0%	0.0%	0.0%	0.0%
Use industrial byproducts as substitutes for Portland cement			0.0%	59%	59%	0.0%	0.0%	0.0%	0.0%
Use recycled concrete aggregate as a substitute for base stone			0.0%	58%	58%	0.0%	0.0%	0.0%	0.0%
Pavement preservation									
Pavement preservation extends roadway life by (years)			N/A	N/A	N/A	N/A	N/A	N/A	N/A
Pavement preservation frequency (every N years, for entire roadway system)			N/A	N/A	N/A	N/A	N/A	N/A	N/A

Roadways

Roadway example.
Source:
https://commons.wikimedia.org/wiki/File:Veterans_Memorial_Parkway,_London,_Ontario.jpg

ICE accounts for the full roadway lifespan, including construction, rehabilitation, routine maintenance, and preventive maintenance. ICE handles these activities in different ways. Separate inputs are required for construction, rehabilitation, and effects of preventative maintenance. Specifically:

- New construction – The user enters lane miles of construction (or centerline miles of shoulder improvement) projects. Separately, the user indicates what fraction of roadway construction is in difficult terrain.
- Roadway rehabilitation – The user enters expected lane miles for reconstruction and resurfacing projects the length of the analysis period. Separately, the user enters a rehabilitation schedule. (Defaults are provided and used if no values are entered.) As a general rule of thumb, new roadways require resurfacing after 15 years and reconstruction after 30 years. Note that roadway rehabilitation applies to both existing and new roadways. This can lead to unexpectedly high operations and maintenance energy consumption and GHG emissions.
- Preventive maintenance – Preventive maintenance is pavement preservation techniques, such as crack sealing, patching, chip seals, and micro-surfacing, that prolong the life of the pavement. In ICE2.0, the user has the option to specify an extension of the roadway rehabilitation schedule due to implementation of a (generic) preventive maintenance program. Application of preventative maintenance is accessible on the *Mitigation Strategies* tab. Note that the energy and emissions "cost" of a preventative maintenance program is based on an average of several potential strategies from different studies. More specific values may be obtainable from FHWA's Pavement LCA tool (when it becomes available).

Emissions and energy associated with routine maintenance (sweeping, striping, bridge deck repair, litter pickup, and maintenance of appurtenances) and roadway rehabilitation is automatically estimated per lane mile of both new and existing roadways associated with your project. To estimate associated use-phase emissions, visit the Vehicle Operations tab.

Note that roadway projects do not include sidewalks. If your project or plan includes constructing sidewalks, they should be entered separately in the Rail, Bus, Bicycle, and Pedestrian Facilities section of the tool.

Note that ICE2.0 does not calculate energy or GHG emissions savings from pavement smoothness effects related to any resurfacing and reconstruction projects.

ICE also does not intrinsically allow customized pavement configurations. Most analyses should use this *Roadway* tab and ICE's internal pavement configuration. The *Custom Pavement* analysis relies on external data rather than ICE's calculations to estimate lifecycle values for different configurations. Please see the *Custom Pavement* tab for more information. Users should not enter both *Roadway* and *Custom Pavement* values for the same project.

Example: The user enters new construction of 10 lane miles of new freeway, with an analysis period of 40 years. Assuming that all construction takes place in year 1, the user enters 10 lane miles of freeway resurfacing (assumed to take place in year 15) and 10 lane miles of freeway reconstruction (assumed to take place in year 30). The tool automatically includes routine maintenance of the 10 newly constructed lane miles. The user has the option of specifying a generic preventive maintenance program, which will increase the longevity of the pavement surface and therefore reduce the amount of energy and emissions associated with resurfacing and rehabilitation.

Specification

Select Mitigation Strategies

Roadway System	Existing	New	Total
Total centerline miles	10	0	10
Total lane miles	115	0	115

Roadway Projects

		Facility type						
		Rural Interstates	Rural Principal Arterials	Rural Minor Arterials	Rural Collectors	Urban Interstates / Expressways	Urban Principal Arterials	Urban Minor Arterials / Collectors
Roadway Lane Width (feet) (before construction)	Default	12	11	11	11	12	11	11
Roadway System	Existing Roadways (ICE equivalent lane miles)	0.0	0.0	0.0	0.0	68.2	5.7	41.1

Include roadway rehabilitation activities (reconstruct and resurface)	Yes
% roadway construction on rocky / mountainous terrain	0%

ICE Model - No Build

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions	Construction	Construction Energy use (mmBTU)	Construction GHG emissions (MT CO2e)	O&M Roadway Rehabilitation	O&M Roadway Rehabilitation Energy use (mmBTU)	O&M Roadway Rehabilitation GHG emissions (MT CO2e)
Aggregate		0	0		20,364	1,139
Bitumen (Asphalt Binder)		0	0		37,733	2,919
Cement		0	0		22,781	4,246
Steel		0	0		16,049	1,260
Water		0	0		9	1
Total		0	0		96,935	9,565

Materials Transportation	Construction	Construction Energy use (mmBTU)	Construction GHG emissions (MT CO2e)	O&M Roadway Rehabilitation	O&M Roadway Rehabilitation Energy use (mmBTU)	O&M Roadway Rehabilitation GHG emissions (MT CO2e)
Transportation fuel (DGEs)		0	0		11,215	1,098
Total		0	0		11,215	1,098

Construction Process	Construction	Construction Energy use (mmBTU)	Construction GHG emissions (MT CO2e)	O&M Roadway Rehabilitation	O&M Roadway Rehabilitation Energy use (mmBTU)	O&M Roadway Rehabilitation GHG emissions (MT CO2e)
Electricity (kWh)		0	0		0	0
Construction fuel (DGEs)		0	0		56,431	5,527
Total		0	0		56,431	5,527

Operations and Maintenance		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Maintenance fuel (DGEs)		24,652.4	2,414.7
Roadway Rehabilitation (O&M)		164,581.3	16,191.1
Water		-	-
Total		189,233.7	18,605.8

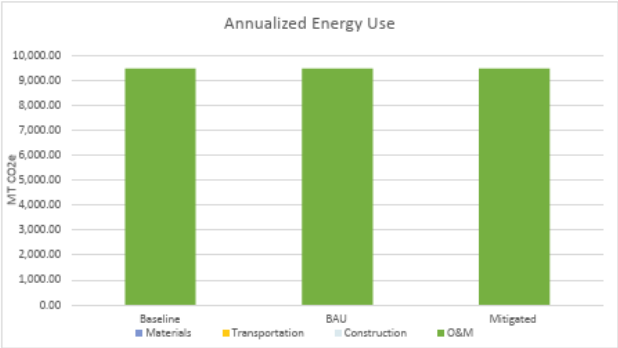
Mitigated Results

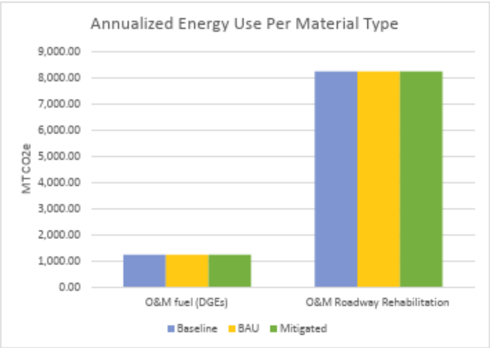
20 year Annualized Results	Construction: Annualized Energy Use – Baseline Energy use (mmBTU)	BAU Energy use (mmBTU)	Mitigated Energy use (mmBTU)	Construction: Annualized Greenhouse Gas Emissions – Baseline GHG emissions (MT CO2e)	BAU GHG emissions (MT CO2e)	Mitigated GHG emissions (MT CO2e)
Aggregate	-	-	-	-	-	-
Bitumen (Asphalt Binder)	-	-	-	-	-	-
Cement	-	-	-	-	-	-
Steel	-	-	-	-	-	-
Water	-	-	-	-	-	-
Transportation Fuel	-	-	-	-	-	-
Construction Fuel	-	-	-	-	-	-
O&M fuel (DGEs)	1,233	1,233	1,233	121	121	121
O&M Roadway Rehabilitation	8,229	8,229	8,229	810	810	810
Materials subtotal	-	-	-	-	-	-
Transportation subtotal	-	-	-	-	-	-
Construction subtotal	-	-	-	-	-	-
Operations & Maintenance subtotal	9,462	9,462	9,462	930	930	930
Total	9,462	9,462	9,462	930	930	930

20 year Annualized Results	O&M Roadway Rehabilitation: Annualized Energy Use – Baseline Energy use (mmBTU)	BAU Energy use (mmBTU)	Mitigated Energy use (mmBTU)	O&M Roadway Rehabilitation: Annualized Greenhouse Gas Emissions – Baseline GHG emissions (MT CO2e)	BAU GHG emissions (MT CO2e)	Mitigated GHG emissions (MT CO2e)
Aggregate	1,018	1,018	1,018	57	57	57
Bitumen (Asphalt Binder)	1,887	1,887	1,887	146	146	146
Cement	1,139	1,139	1,139	212	212	212
Steel	802	802	802	63	63	63
Water	0	0	0	0	0	0
Transportation Fuel	561	561	561	55	55	55
Construction Fuel	2,822	2,822	2,822	276	276	276
O&M fuel (DGEs)	-	-	-	-	-	-
O&M Roadway Rehabilitation	8,229	8,229	8,229	810	810	810

Results - Charts

Show	Annualized Energy Use	Units	MT CO2e





	Annualized Energy Use		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Materials	-	-	-
Transportation	-	-	-
Construction	-	-	-
O&M	9,462	9,462	9,462
Total	9,462	9,462	9,462

	Annualized Energy Use Per Material Type		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
O&M fuel (DGEs)	1,233	1,233	1,233
O&M Roadway Rehabilitation	8,229	8,229	8,229
Total	9,462	9,462	9,462

	Annualized Energy Use Reductions Relative to BAU				
	MT CO2e	MT CO2e	MT CO2e	MT CO2e	MT CO2e
	Materials	Transportation	Construction	O&M	TOTAL
Total	-	-	-	-	-

Vehicle Operations and Construction Delay Emissions

Example of Vehicle Operations
Source: https://www.greencarreports.com/news/1093560_1-2-billion-vehicles-on-worlds-roads-now-2-billion-by-2035-report

ICE estimates vehicle operations impacts of infrastructure projects from two distinct effects:

•Vehicle operating emissions – The user enters the years, average daily traffic (AADVMT), and average speed for the opening, design, and horizon years on the project. ICE computes the cumulative operating emissions over on the project's lifetime.
•Construction delay emissions – The user enters the years, average daily traffic (AADVMT), and average speed for the year construction starts, project opening year, and the baseline year for comparison (typically the year before construction starts). ICE computes the additional energy and GHG emissions due to vehicle delay during construction.

Note that mitigations are not applicable for vehicle operating emissions. Also, the calcualtions reflect a standard automobile fleet. They should not be used to estimate bus emissions on BRT or train emissions from Light- or Heavy-Rail. Also, results are integrated over the project lifetime. (I.e., "baseline" doesn't just mean baseline year.)

Estimates of emissions and additional energy use from construction delay and vehicle operating emissions are meant to provide a rough sense of the scale of emissions relative to the construction processes themselves, and are not meant to replace estimates derived from traffic modeling software. Planned construction projects that will result in significant lane closures on high volume roads should be evaluated using traffic modeling software.

Specification

Vehicle Operations Emissions

	Year	Avg Daily VMT on project	Speed
Project Opening Year	2030	2011900	NA
Project Interim Year	2040	2259500	NA
Project Design/Horizon Year	2050	2507000	NA

Construction Delay, Additional Emissions

	Year	Avg Daily VMT impacted by project	Speed
Construction start year	2022	0	0.0
Pre-construction (baseline) year	2021	0	0.0
Project Opening Year	2030		

Baseline Energy Use and GHG Emissions

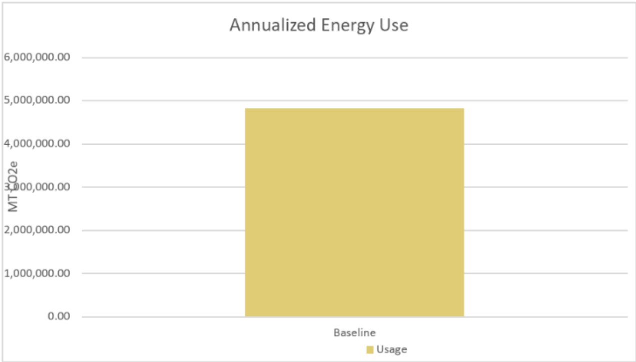
Usage Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Vehicle Operating Emissions		96,121,594	7,374,840
Construction Delay		0	0
Total		96,121,594	7,374,840

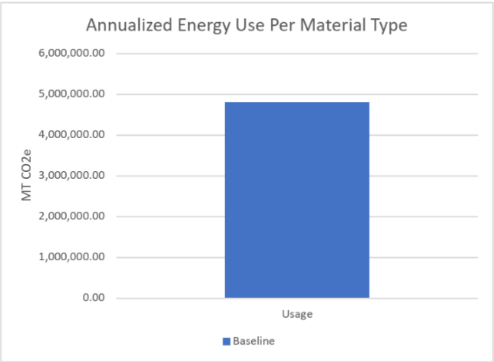
Mitigated Results

	Annualized Energy Use	Annualized Greenhouse Gas Emissions
	Baseline	Baseline
20 year Annualized Results	Energy use (mmBTU)	GHG emissions (MT CO2e)
Usage Emissions	4,806,080	368,742
Materials subtotal	-	-
Transportation subtotal	-	-
Construction subtotal	-	-
Usage subtotal	4,806,080	368,742
Total	4,806,080	368,742

Results - Charts

Show	Annualized Energy Use	Units	MT CO2e





No mitigations are available for Vehicle Ops.

	Annualized Energy Use MT CO2e Baseline
Usage	4,806,080
Total	**4,806,080**

	Annualized Energy Use Per Material Type MT CO2e Baseline
Usage	4,806,080
Total	**4,806,080**

A.4 ICE 2.1.3 Inputs and Outputs: ICE Model – Alternative 2

Introduction to the Infrastructure Carbon Estimator (ICE), version 2.1

***Note:** This tool is designed to allow users to create screening-level estimates of energy and GHG emissions using limited data inputs. It asks for limited data to estimate lifecycle energy use emissions from a single or group of projects. The tool is not appropriate to inform engineering analysis and pavement selection. Other tools should be consulted for those purposes. More details about suggested uses for the tool are provided in the accompanying ICE User's Guide .*

Project Inputs Page

Summary Results Page

Infrastructure Carbon Estimator (ICE) 2.1.3. Final Tool. Released 03/24/2021.

OVERVIEW

The Infrastructure Carbon Estimator (ICE) estimates the lifecycle energy and greenhouse gas (GHG) emissions from the construction and maintenance of transportation facilities. The ICE tool was created to solve the problem of "planning level" estimation of embodied carbon emissions in transportation infrastructure. Without the need for any engineering studies, ICE helps answer this question: How much carbon will be embodied in the building, modification, maintenance, and/or use of this transportation project (or group of projects)?

ICE evaluates energy use and greenhouse gas emissions at the project- or planning-level. The tool uses the term "project" to generally refer to a single project type, with access to some additional details and project customization. "Planning" is designed to accept inputs from long-range transportation plans or other plans that consist of a suite of projects but limited customization.

The tool estimates emissions for the following types of facilities and projects:

1. Bridges and Overpasses
2. Bus Rapid Transit (BRT)
3. Culverts
4. Light Rail
5. Lighting
6. Heavy Rail
7. Parking
8. Pathways
9. Roadways
10. Signage
11. Vehicle Operations
12. Standalone Maintenance Projects on Existing Roadways

13. Custom Pavement Projects with Data Imported from External Tools

(Please note Types 12 and 13 address specific and limited applications. These are discussed in the individual tabs and the User's Guide.)

For each type of facility, the tool calculates both mitigated results that take into account the effect of various energy/GHG reduction strategies and unmitigated results.

USING THE TOOL

Details on use of ICE is available in the User's Guide.

Color Scheme

ICE uses the following color scheme to describe the function of each cell:

Description Cells
Computed Value Cells
Cell value is not relevant (Cell is NA)
Data Entry Cells
Action Cell
Command button - on
Command button - off
Command button - disabled

The tool provides users the ability to display results in 508 compliant format, which among other features, will add data labels to all results charts. The color scheme when 508 compliant is activated deviates slightly from when the format is turned off.

Analysis Mode

The tool can be used in either *Planning* or *Project* mode. This is set at the top of the *Project Inputs* page.

Planning mode reveals all facility types on one page. Using the buttons at the top of the screen allows you to add or remove facilities from your analysis. Individual facility details can be viewed via the links below the input table or by navigating the separate tabs for each infrastructure type. Clicking the hyperlinks above and below each infrastructure type's inputs in the *Project Inputs* page navigates to the various sections in each *analysis page* for that infrastructure type. The relevant *analysis page(* s), *Mitigation Strategies* page, and the *Summary Results* page will be shown when an infrastructure type is selected. Buttons on the *analysis pages* carry the user to specify mitigation measures and back to the *analysis pages.*

The *Project mode* operates similarly. In the *Project* mode, the user has the option to view all inputs or have ICE walk the user through each step. In walkthrough mode, green action cells direct the user through each step. Only a single infrastructure type can be modeled in *Project mode* .

Tabs and Navigation

The tool can be navigated in multiple ways. Users will start by describing their project on the *Project Inputs* page. This includes the infrastructure type(s), analysis lifetime, location, and analysis mode. Hyperlinks carry users through the various tabs. Three comment boxes allow the user to input descriptive text that will be carried through to the output pages. This could include analysis date, analyst, project descriptions, or other information the analyst may want to include in their report.

First, select your level of analysis (Project or Planning) and input the requested information for your project on the *Project Inputs* page. Input the US state for your analysis, the project analysis lifetime (in years), and whether the impacts of a custom electricity emission program, such as a Renewable Portfolio Standard (RPS), are to be included. Answering "yes" on the latter will open the *Annual Electricity Emissions* tab for populating.

If using the Planning level of analysis, "turn on" all infrastructure types to be analyzed on the *Project Inputs* page. If using the *Project* level of analysis, then select the single infrastructure type to analyze.

Hyperlinks from the *Project Inputs* page will take you to the *analysis page* for your project type(s). (The project analysis pages are titled according to the infrastructure type.) Here some additional inputs for your project may be requested. At the top of each analysis page is a hyperlink that carries you to the *Mitigation Strategies* page.

Each *analysis page* includes the following sections:

- Specifications – Fixed and input values describing the project
- Baseline Energy Use and GHG Emissions – Total energy use and GHG emissions over the project's lifetime
- Mitigated Results – Annualized energy use and GHG emissions for the project without (baseline) and with (both business as usual and control scenario) mitigations applied.
- Results - Charts – Summary charts and tables of the mitigated and unmitigated energy use and emissions by emission category, material, and individualized mitigation effects. Results can be viewed as annualized or cumulative GHG emissions or energy.

On the *Mitigation Strategies* page, you have the option to input certain strategies that reduce energy and GHG emissions for your project. Only relevant strategies are shown. Hyperlinks at the top return you to the *analysis page* for your project type.

Below the project specifications in each *analysis page,* the calculated, annualized baseline, business-as-usual (BAU), and mitigated levels of energy or GHG emissions for your project type(s) are displayed. This shows results by the five emission categories and by material for both mitigated and unmitigated cases. It also shows emission or energy reductions by mitigation measure.

The *Summary Results* page displays a summary of results for all infrastructure types analyzed. If the analysis is at the *Project* level, this display is nearly identical to that on the *analysis page.* For *Planning* level, buttons appear allowing the user to turn on or off the different project types included in the combined results. The "Show" dropdown menu selects the results displayed: Annualized Greenhouse Gas Emissions, Annualized Energy Use, Cumulative Greenhouse Gas Emissions, and Cumulative Energy Use. An additional chart in the *Summary Results* page, not available in the individual *analysis pages*, displays values by infrastructure type.

If the use phase of automobiles is to be considered in your project, you must include the *Vehicle Operations* project type. Resulting energy and emissions from project use will be added to the summary charts on the *Summary Results* page.

At any time, the user can view overall results in the *Summary Results* page or enter a custom mitigation approach for energy and GHG emissions on the *Mitigation Strategies* page. The user can switch directly between various pages indicated in Excel tabs at any time. The *Print Results* tab collects outputs and formats them for standard printing, either to an electronic or paper copy for archiving the outputs of your simulation. This can be used to compare multiple simulations, such as for a Build vs. No-Build analysis.

Units and Time Periods

ICE requests the analysis timeframe (in years) from the user. It produces lifecycle (to end-of-life) estimates of energy use and/or GHG emissions. Both values can be reported on an annualized or total lifespan basis. The standard reporting unit for energy is "mmBTU", or millions of British Thermal Units. The standard reporting unit for greenhouse gas emissions is "MT CO2e", or metric tons of CO2-equivalent gases. 1 metric tons = 1,000 kg. CO2 equivalency is defined by a global-warming potential basis.

EMISSIONS SOURCES ESTIMATED

Construction and maintenance activities covered by the tool are broken into five categories:

Materials

Upstream Energy and Emissions associated with project materials:

1. Energy and fuel used in raw material extraction
2. Energy and fuel used in material production*
3. Chemical reactions in material production**
4. Energy and fuel used in raw material transportation

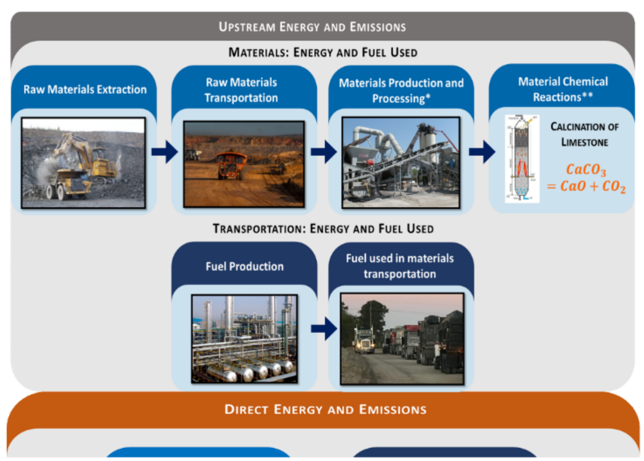
Transportation

Upstream Energy and Emissions associated with:

1. Fuel used in transportation of materials to site

Construction

1. Energy and fuel used in construction equipment



Operations and Maintenance (O&M)
Routine Maintenance, including:
1. Fuel used in snow removal equipment
2. Fuel used in vegetation management equipment
3. Fuel used in other routine maintenance***
4. Energy and emissions from roadway repair and rehabilitation
5. Net energy and emissions from pavement preservation activities (optional)

Usage
Energy and Emissions associated with:
1. Vehicle operations on roadways, including delay during construction

*e.g. crushing of aggregate, asphalt batch plants
**e.g CO_2 emitted from calcination of limestone
***activities include sweeping, stripping, bridge deck repair, litter pickup, and maintenance of appurtenances

ICE does not include energy or emissions associated with land use change from the project.

ADDITIONAL INFORMATION
Refer to the accompanying User's Guide for further instructions, detailed descriptions of factors, and assumptions regarding this tool.

Project Inputs

Display result in 508 compliant format:	No

Hide Instructions	Yes
Infrastructure location (state)	TX
The lifetime of your plan or project (years)	20
Use custom electric emission profile (RPS)?	No

Tool Use	Planning

Bridges & Overpasses | Culverts | Lighting | Parking | Roadways | Vehicle Operations | Roadway Rehabilitation

BRT | Light Rail | Heavy Rail | Pathways | Signage | Custom Pavement

	Title: ALTERNATIVE 2	Title:	Title:
Enter comments and comment titles. These will be displayed on the Summary Results worksheet.			

Planning Summary of Inputs - See Individual Tabs for Details

Bridges & Overpasses

Bridge/Overpass Structure	Construct New Bridge/Overpass: Number of bridges & overpasses	Average number of spans per structure	Average number of lanes per structure	Total number of lane-spans	Reconstruct Bridge/Overpass: Number of bridges & overpasses	Average number of spans per structure	Average number of lanes reconstructed per structure	Total number of lane-spans	Add Lane to Bridge/Overpass: Number of bridges & overpasses	Average number of spans per structure	Average number of lanes per structure added	Total number of lane-spans
Single-Span	6	1	21.2	127.2	0	1	0	0	0	1		0
Two-Span	13	2	7.2	187.2	3	2	8.7	52.2	0	2		0
Multi-Span (over land)	42	8.8	4.4	1626.24	8	4.3	10.3	354.32	0			0
Multi-Span (over water)	1	13	1	13	5	8.5	6.5	276.25	0			0

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

Bus Rapid Transit

Bus Rapid Transit

Total existing lane miles of bus rapid transit	0

Bus rapid transit construction

New lane or right-of-way - lane miles	40.25
Converted or upgraded lane/facility - lane miles	0
New BRT Stations	0

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

Culverts

	Number of culverts	Average culvert length (ft)
Default Culvert	14	3211.27

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

Lighting

Number of roadway miles	9

Lighting Structures Support Structure Type	Lumen Range	Ave. number of HPS lights per roadway mile	Ave. number of LED lights per roadway mile
Vertical	4000-5000		
Vertical	7000-8800		
Vertical	8500-11500		
Vertical	11500-14000		48
Vertical	21000-28000		53
Vertical and Vertical with 8' Arm	4000-5000		
Vertical and Vertical with 8' Arm	7000-8800		
Vertical and Vertical with 8' Arm	8500-11500		
Vertical and Vertical with 8' Arm	11500-14000		
Vertical and Vertical with 8' Arm	21000-28000		42
High Mast	28800 - 42000		
High Mast	46500-52800		
High Mast	52500-58300		

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

Pathways

Bicycle and Pedestrian Facilities Project Type	New Construction	Resurfacing
Off-Street Bicycle or Pedestrian Path - miles	17.68	
On-Street Bicycle Lane - lane miles		
On-Street Sidewalk - miles		N/A

[Specification](#)
[Baseline Energy Use and GHG Emissions](#)
[Mitigated Results](#)
[Results - Charts](#)

Roadways

Roadway System	
Total existing centerline miles	10.85
Total newly constructed centerline miles	7.73

Roadway Projects

Facility type	Roadway System	Roadway Construction				
	Existing Roadway (lane miles)	New Roadway (lane miles)	Construct Additional Lane (lane miles)	Realignment (lane miles)	Lane Widening (lane miles)	Shoulder Improvement (centerline miles)
Rural Interstates						
Rural Principal Arterials						
Rural Minor Arterials						
Rural Collectors						
Urban Interstates / Expressways	72.96	105.65	5.55			
Urban Principal Arterials	6.21	7.06				
Urban Minor Arterials / Collectors	45.73	40.22				

Include roadway rehabilitation activities (reconstruct and resurface)	Yes
% roadway construction on rocky / mountainous terrain	0%

[Specification](#)
[Baseline Energy Use and GHG Emissions](#)
[Mitigated Results](#)
[Results - Charts](#)

Signage

Number of roadway miles	9

Signage Structures	Avg. number of signs per roadway mile
Small (3'x3') - 14 Gauge Steel Post (MDOT SIGN-150-D)	1623
Medium (6'x6') - 14 Gauge Steel Posts (MDOT SIGN-150-D)	59
Large (10'x14') - 8 Gauge Cantilever Arm (MDOT SIGN-300-A)	206

[Specification](#)
[Baseline Energy Use and GHG Emissions](#)
[Mitigated Results](#)
[Results - Charts](#)

Vehicle_Ops

	Vehicle Operating Emissions			
	Year		Avg Daily VMT on project	Average Daily (Congested) Speed (mph) (or NA)
	Default	Custom		
Project Opening Year	2022	2030	2034600	NA
Project Interim Year	2027	2040	2288700	NA
Project Design/Horizon Year	2050	2050	2542700	NA

	Construction Delay, Additional Emissions			
	Year		Avg Daily VMT impacted by project	Average Daily (Congested) Speed (mph) (or NA)
	Default	Custom		
Construction start year	2022	2024	1856000	NA
Pre-construction (baseline) year	2021	2021	1778100	60
Project Opening Year	2030	2030		

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

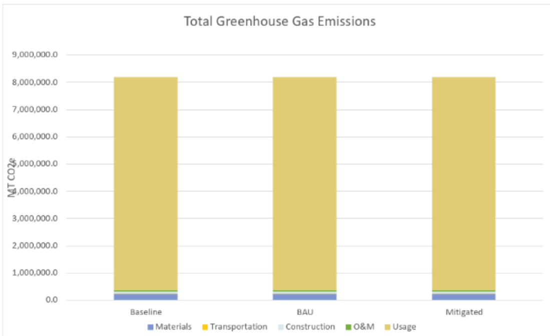
ICE Model - Alternative 2

Summary Results

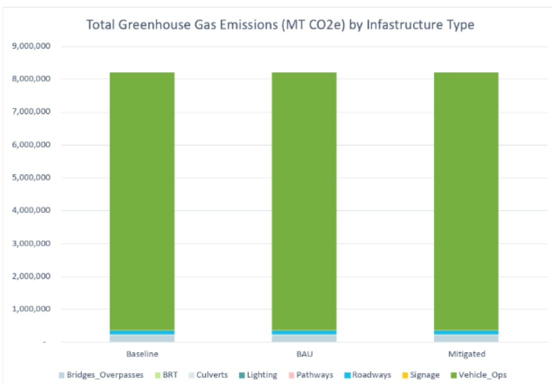
Bridges & Overpasses	Culverts	Lighting	Parking	Roadways	Vehicle Operations
BRT	Light Rail	Heavy Rail	Pathways	Signage	Custom Pavement

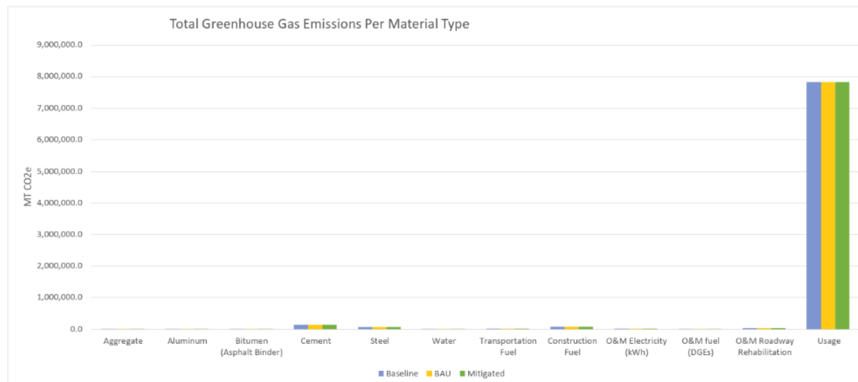
Show	Total Greenhouse Gas Emissions	Units	MT CO2e

Summary Results - Charts



Baseline refers to values without any mitigations applied.
Business-as-Usual (BAU) deployment refers to any "default" mitigations that are deployed through standard agency practices.
Planned deployment reflects the level of mitigations planned for the





ICE Model - Alternative 2

Summary Results - Tables

	Total Greenhouse Gas Emissions		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Materials	227,668	227,668	227,668
Transportation	10,135	10,135	10,135
Construction	76,456	76,456	76,456
O&M	56,358	56,358	56,358
Usage	7,838,340	7,838,340	7,838,340
Total	**8,208,956**	**8,208,956**	**8,208,956**

	Total Greenhouse Gas Emissions Per Material Type		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Aggregate	8,751	8,751	8,751
Aluminum	1,469	1,469	1,469
Bitumen (Asphalt Binder)	8,333	8,333	8,333
Cement	141,556	141,556	141,556
Steel	67,429	67,429	67,429
Water	129	129	129
Transportation Fuel	10,135	10,135	10,135
Construction Fuel	76,456	76,456	76,456
O&M Electricity (kWh)	10,886	10,886	10,886
O&M fuel (DGEs)	6,319	6,319	6,319
O&M Roadway Rehabilitation	39,154	39,154	39,154
Usage	7,838,340	7,838,340	7,838,340
Total	**8,208,956**	**8,208,956**	**8,208,956**

	Total Greenhouse Gas Emissions Reductions Relative to BAU				
	MT CO2e	MT CO2e	MT CO2e	MT CO2e	MT CO2e
	Materials	Transportation	Construction	O&M	TOTAL
Total	-	-	-	-	-

	Total Greenhouse Gas Emissions (MT CO2e) by Infastructure Type		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Bridges_Overpasses	201,914	201,914	201,914
BRT	19,336	19,336	19,336
Culverts	12,731	12,731	12,731
Lighting	11,689	11,689	11,689
Pathways	870	870	870
Roadways	111,448	111,448	111,448
Signage	12,628	12,628	12,628
Vehicle_Ops	7,838,340	7,838,340	7,838,340
Total	**8,208,956**	**8,208,956**	**8,208,956**

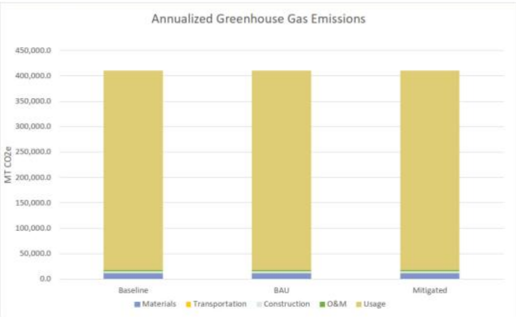
ICE Model - Alternative 2

Summary Results

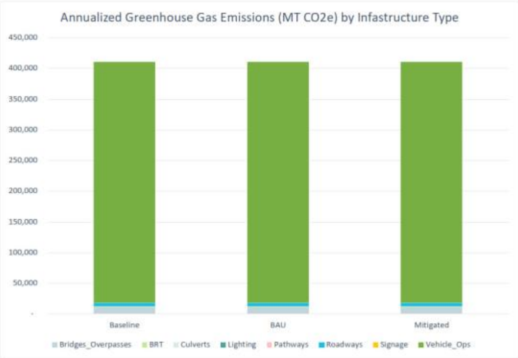
Bridges & Overpasses	Culverts	Lighting	Parking	Roadways	Vehicle Operations
BRT	Light Rail	Heavy Rail	Pathways	Signage	Custom Pavement

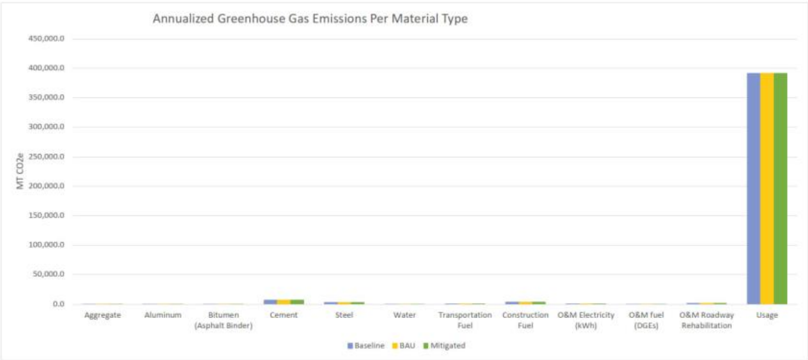
Show	Annualized Greenhouse Gas Emissions	Units	MT CO2e

Summary Results - Charts



Baseline refers to values without any mitigations applied.
Business-as-Usual (BAU) deployment refers to any "default" mitigations that are deployed through standard agency practices.
Planned deployment reflects the level of mitigations planned for the





ICE Model - Alternative 2

Summary Results - Tables

	Annualized Greenhouse Gas Emissions		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Materials	11,383	11,383	11,383
Transportation	507	507	507
Construction	3,823	3,823	3,823
O&M	2,818	2,818	2,818
Usage	391,917	391,917	391,917
Total	**410,448**	**410,448**	**410,448**

	Annualized Greenhouse Gas Emissions Per Material Type		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Aggregate	438	438	438
Aluminum	73	73	73
Bitumen (Asphalt Binder)	417	417	417
Cement	7,078	7,078	7,078
Steel	3,371	3,371	3,371
Water	6	6	6
Transportation Fuel	507	507	507
Construction Fuel	3,823	3,823	3,823
O&M Electricity (kWh)	544	544	544
O&M fuel (DGEs)	316	316	316
O&M Roadway Rehabilitation	1,958	1,958	1,958
Usage	391,917	391,917	391,917
Total	**410,448**	**410,448**	**410,448**

	Annualized Greenhouse Gas Emissions Reductions Relative to BAU				
	MT CO2e	MT CO2e	MT CO2e	MT CO2e	MT CO2e
	Materials	Transportation	Construction	O&M	TOTAL
Total	-	-	-	-	-

	ualized Greenhouse Gas Emissions (MT CO2e) by Infastructure T		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Bridges_Overpasses	10,096	10,096	10,096
BRT	967	967	967
Culverts	637	637	637
Lighting	584	584	584
Pathways	43	43	43
Roadways	5,572	5,572	5,572
Signage	631	631	631
Vehicle_Ops	391,917	391,917	391,917
Total	**410,448**	**410,448**	**410,448**

Mitigation Strategies

Return To Summary Results

Instructions: Follow the steps below to calculate the impact of energy and GHG mitigation strategies:

The user will enter both the business as usual (BAU) deployment (i.e., the extent to which the strategy is deployed through standard agency practices) in Column F and the planned deployment (i.e., the extent to which the strategy will be deployed in the project that you are examining) in Column G. (Baseline refers to values without any mitigations.) For Pavement Preservation strategies, enter both the schedule change and application frequency.

Column H displays the increase in deployment from implementation of the strategy. Some reduction strategies (e.g., Switch from diesel to Soy bean-based BD20 and biodiesel/hybrid maintenance vehicles and equipment) may be incompatible. The user should take care that inputs do not describe a total deployment greater than 100% for overlapping strategies. The tool will warn if "excess" energy savings from mitigation are predicted or incompatible strategies are selected.

For a more refined mitigation analysis, please refer to FHWA's upcoming Pavement LCA Tool.

						BAU Reductions		Planned Reductions	
Strategy	BAU deployment	Planned deployment	Deployment increase	Energy reduction factor	GHG reduction factor	Energy reductions	GHG reductions	Energy reductions	GHG reductions
Alternative fuels and vehicle hybridization									
Switch from diesel to Soy bean-based BD20			0.0%	-5%	12%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to Soy bean-based RDII 100			0.0%	-20%	66%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to Forest Residue-based RDII 100			0.0%	-61%	71%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to E-Diesel, Corn			0.0%	-3%	0%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to PHEV: Diesel and Electricity (U.S. Mix)			0.0%	41%	44%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to CNG, NA NG			0.0%	-6%	11%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to LNG, NA NG			0.0%	-11%	7%	0.0%	0.0%	0.0%	0.0%
Hybrid maintenance vehicles and equipment			0.0%	11%	11%	0.0%	0.0%	0.0%	0.0%
Combined hybridization/B20 in maintenance vehicles and equipment			0.0%	1%	27%	0.0%	0.0%	0.0%	0.0%
Hybrid construction vehicles and equipment			0.0%	11%	11%	0.0%	0.0%	0.0%	0.0%
Combined hybridization/B20 in construction vehicles and equipment			0.0%	1%	27%	0.0%	0.0%	0.0%	0.0%
Vegetation management									
Alternative vegetation management strategies (hardscaping, alternative mowing, integrated roadway/vegetation management)			N/A	25%	25%	0.0%	0.0%	0.0%	0.0%
Snow fencing and removal strategies									
Alternative snow removal strategies (snow fencing, wing plows)			N/A	0%	0%	0.0%	0.0%	0.0%	0.0%
In-place roadway recycling									
Cold In-place recycling			0.0%	33%	37%	0.0%	0.0%	0.0%	0.0%
Full depth reclamation			0.0%	68%	68%	0.0%	0.0%	0.0%	0.0%
Warm-mix asphalt									
Warm-mix asphalt			0.0%	37%	37%	0.0%	0.0%	0.0%	0.0%
Recycled and reclaimed materials									
Use recycled asphalt pavement as a substitute for virgin asphalt aggregate			0.0%	12%	12%	0.0%	0.0%	0.0%	0.0%
Use recycled asphalt pavement as a substitute for virgin asphalt bitumen			0.0%	84%	84%	0.0%	0.0%	0.0%	0.0%
Use industrial byproducts as substitutes for Portland cement			0.0%	59%	59%	0.0%	0.0%	0.0%	0.0%
Use recycled concrete aggregate as a substitute for base stone			0.0%	58%	58%	0.0%	0.0%	0.0%	0.0%
Pavement preservation									
Pavement preservation extends roadway life by (years)			N/A	N/A	N/A	N/A	N/A	N/A	N/A
Pavement preservation frequency (every N years, for entire roadway system)			N/A	N/A	N/A	N/A	N/A	N/A	N/A

Bridges & Overpasses

Example of a concrete bridge
(not representative of all possible project types).

Source: https://en.wikipedia.org/wiki/Low-water_crossing#/media/File:Roanoke_River_low_water_crossing.jpg

ICE estimates the energy and GHG emissions associated with the construction, reconstruction, or lane addition for single span, two-span, and multi-span bridges and overpasses. Bridges and overpasses are treated as being functionally equivalent in ICE.

The *Bridges and Overpasses* module in ICE applies to the construction of the bridge structure rather than the pavement surface. Bridge paving activities should be entered as part of the Roadway construction activities.

Approximately half of short bridges in the U.S. (less than 1000 feet long) are single-span or double-span. If information about number of spans is not available, it is reasonable to assume a mix of single-span and two-span bridges. Note that the number of spans is an important factor in energy use and GHG emissions.

Please note that very large bridges that carry traffic very high or span very deep spaces are unique and likely require additional materials and construction processes that cannot be approximated by ICE.

Specification

Select Mitigation Strategies

	Construct New Bridge				Reconstruct Bridge				Add Lane to Bridge			
Bridge and Overpass Structures	Number of bridges	Avg number of spans per bridge	Avg number of lanes per bridge	Total number of lane-spans	Number of bridges	Avg number of spans per bridge	Avg number of lanes per bridge	Total number of lane-spans	Number of bridges	Avg number of spans per bridge	Avg number of new lanes per bridge	Total number of lane-spans
Single-Span	6	1	21	**127**	-	1	-	**-**	-	1	-	**-**
Two-Span	13	2	7	**187**	3	2	9	**52**	-	2	-	**-**
Multi-Span (over land)	42	9	4	**1,626**	8	4	10	**354**	-	-	-	**-**
Multi-Span (over water)	1	13	1	**13**	5	9	7	**276**	-	-	-	**-**

Baseline Energy Use and GHG Emissions

Material Requirements (metric tons)		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		67,854	3,699
Cement		619,367	115,437
Steel		546,657	41,742
Water		910	122
Total		1,234,787	161,001

Materials Transportation		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		39,376	3,857
Total		39,376	3,857

Construction Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Construction fuel (DGEs)		378,323	37,057
Total		378,323	37,057

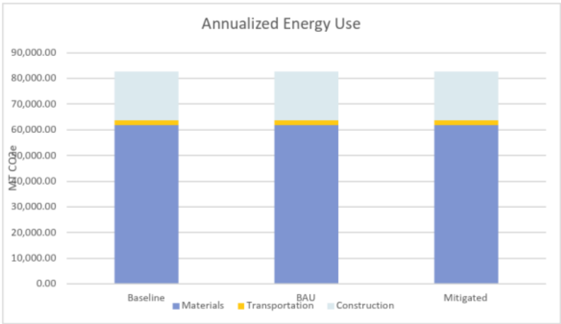
ICE Model - Alternative 2

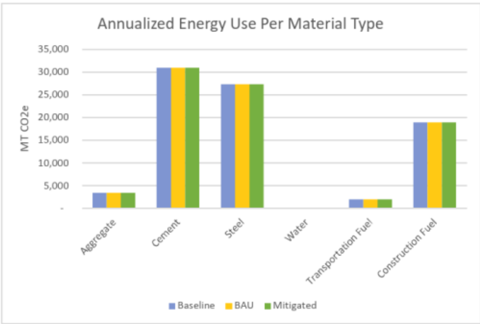
Mitigated Results

20 year Annualized Results	Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	3,393	3,393	3,393	185	185	185
Cement	30,968	30,968	30,968	5,772	5,772	5,772
Steel	27,333	27,333	27,333	2,087	2,087	2,087
Water	46	46	46	6	6	6
Transportation Fuel	1,969	1,969	1,969	193	193	193
Construction Fuel	18,916	18,916	18,916	1,853	1,853	1,853
Materials subtotal	61,739	61,739	61,739	8,050	8,050	8,050
Transportation subtotal	1,969	1,969	1,969	193	193	193
Construction subtotal	18,916	18,916	18,916	1,853	1,853	1,853
Total	82,624	82,624	82,624	10,096	10,096	10,096

Results - Charts

Show	Annualized Energy Use	Units	MT CO2e





	Annualized Energy Use		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Materials	61,739	61,739	61,739
Transportation	1,969	1,969	1,969
Construction	18,916	18,916	18,916
Total	**82,624**	**82,624**	**82,624**

	Annualized Energy Use Per Material Type		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Aggregate	3,393	3,393	3,393
Cement	30,968	30,968	30,968
Steel	27,333	27,333	27,333
Water	46	46	46
Transportation Fuel	1,969	1,969	1,969
Construction Fuel	18,916	18,916	18,916
Total	**82,624**	**82,624**	**82,624**

	Annualized Energy Use Reductions Relative to BAU				
	MT CO2e Materials	MT CO2e Transportation	MT CO2e Construction	MT CO2e O&M	MT CO2e TOTAL
Total	-	-	-	-	-

Bus Rapid Transit

Example of dedicated bus lane for bus rapid transit.

Source: World Resources Institute

ICE considers construction or conversion of bus rapid transit (BRT) facilities. This is characterized in terms of roadway lanes dedicated to bus transit and not shared with general traffic.

Note that use phase vehicle emissions are currently incompatible with this infrastructure type.

Specification

Select Mitigation Strategies

Construction	Bus rapid transit
New lane or right-of-way - lane miles	40
Converted or upgraded lane/facility - lane miles	-
New BRT Stations	-

Maintenance	New	Existing
BRT (lane miles)	40	-

Factors - Alt mode maintenance	Fuel use (DGEs)
BRT (per lane mile)	79

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		15,891	841
Bitumen (Asphalt Binder)		13,783	1,066
Cement		25,133	4,684
Steel		16,671	1,300
Water		10	1
Total		71,487	7,894

Materials Transportation		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		9,981	978
Total		9,981	978

Construction Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Construction fuel (DGEs)		102,679	10,057
Total		102,679	10,057

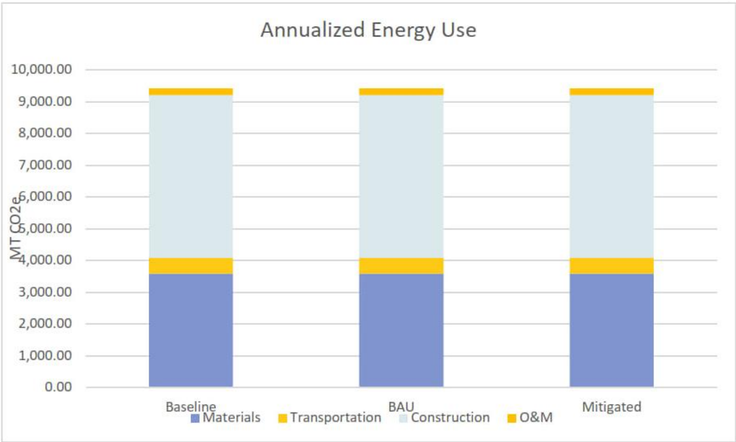
Operations and Maintenance		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Mainenance fuel (DGEs)		4,161	408
Water		-	-
Total		4,161	408

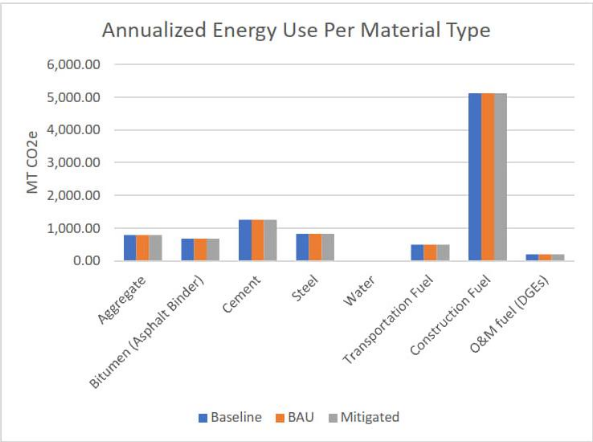
Mitigated Results

20 year Annualized Results	Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	795	795	795	42	42	42
Bitumen (Asphalt Binder)	689	689	689	53	53	53
Cement	1,257	1,257	1,257	234	234	234
Steel	834	834	834	65	65	65
Water	0	0	0	0	0	0
Transportation Fuel	499	499	499	49	49	49
Construction Fuel	5,134	5,134	5,134	503	503	503
O&M fuel (DGEs)	208	208	208	20	20	20
Materials subtotal	3,574	3,574	3,574	395	395	395
Transportation subtotal	499	499	499	49	49	49
Construction subtotal	5,134	5,134	5,134	503	503	503
Operations & Maintenance subtotal	208	208	208	20	20	20
Total	9,415	9,415	9,415	967	967	967

Results - Charts

Show	Annualized Energy Use	Units	MT CO2e





	Annualized Energy Use		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Materials	3,574	3,574	3,574
Transportation	499	499	499
Construction	5,134	5,134	5,134
O&M	208	208	208
Total	**9,415**	**9,415**	**9,415**

	Annualized Energy Use Per Material Type		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Aggregate	795	795	795
Bitumen (Asphalt Binder)	689	689	689
Cement	1,257	1,257	1,257
Steel	834	834	834
Water	0	0	0
Transportation Fuel	499	499	499
Construction Fuel	5,134	5,134	5,134
O&M fuel (DGEs)	208	208	208
Total	**9,415**	**9,415**	**9,415**

	Annualized Energy Use Reductions Relative to BAU				
	MT CO2e Materials	MT CO2e Transportation	MT CO2e Construction	MT CO2e O&M	MT CO2e TOTAL
Total	-	-	-	-	-

Culverts

Examples of double box (top) and pipe culverts (bottom)

Sources: https://www.civilgeo.com/knowledge-base/hec-ras-culvert-shapes-dimensions/
researchgate.net/publication/254958586_Freshwater_Fish_Habitat_Rehabilitation_in_the_Mackay_Whitsunday_Region

ICE characterizes single box culverts, double box culverts, and pipe culverts of various sizes and lengths.

Box culverts are typically constructed with reinforced concrete with thickness and size dependent on application. Box culvert designs are based on a maximum fill height of 10 feet. Pipe culverts are smaller drainage structures with common diameters ranging from one to four feet depending on application. Pipe culvert prototypes include corrugated steel pipe and reinforced concrete headwalls on both ends.

In ICE, culvert size follows a small/medium/large classification. Approximate pipe diameter/cell size is shown to illustrate these sizes. *Project* mode allows for customization of pipe diameter, length, width, etc. by selecting the "custom" culvert size.

Specification

Select Mitigation Strategies

	Number of culverts	Avg culvert length (ft)
Medium (e.g., 8'x8' cell or 24" pipe)	14	3,211

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		2,152	114
Cement		34,138	6,363
Steel		74,103	5,077
Water		13	2
Total		110,405	11,556

Materials Transportation		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		8,863	868
Total		8,863	868

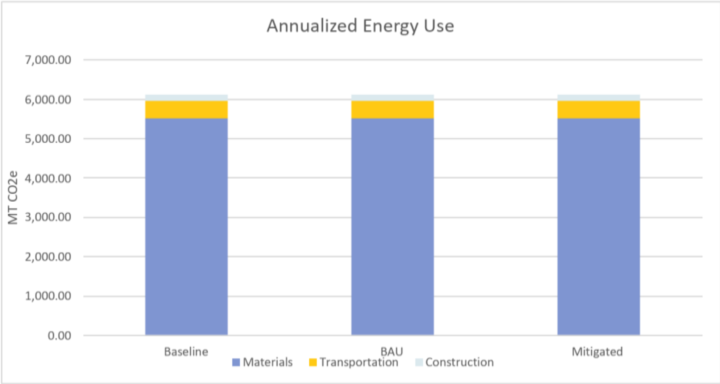
Construction Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Construction fuel (DGEs)		3,134	307
Total		3,134	307

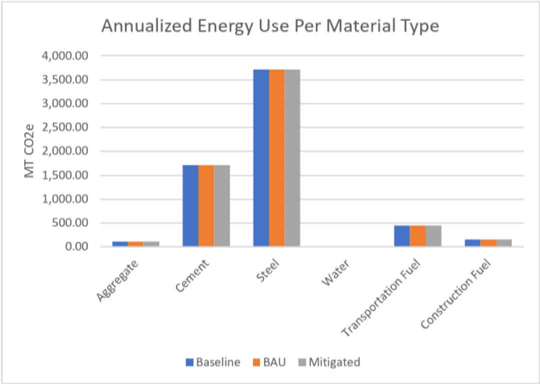
Mitigated Results

20 year Annualized Results	Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	108	108	108	6	6	6
Cement	1,707	1,707	1,707	318	318	318
Steel	3,705	3,705	3,705	254	254	254
Water	1	1	1	0	0	0
Transportation Fuel	443	443	443	43	43	43
Construction Fuel	157	157	157	15	15	15
Materials subtotal	5,520	5,520	5,520	578	578	578
Transportation subtotal	443	443	443	43	43	43
Construction subtotal	157	157	157	15	15	15
Total	6,120	6,120	6,120	637	637	637

Results - Charts

Show	Annualized Energy Use	Units	MT CO2e





	Annualized Energy Use		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Materials	5,520	5,520	5,520
Transportation	443	443	443
Construction	157	157	157
Total	**6,120**	**6,120**	**6,120**

	Annualized Energy Use Per Material Type		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Aggregate	108	108	108
Cement	1,707	1,707	1,707
Steel	3,705	3,705	3,705
Water	1	1	1
Transportation Fuel	443	443	443
Construction Fuel	157	157	157
Total	**6,120**	**6,120**	**6,120**

	Annualized Energy Use Reductions Relative to BAU				
	MT CO2e	MT CO2e	MT CO2e	MT CO2e	MT CO2e
	Materials	Transportation	Construction	O&M	TOTAL
Total	-	-	-	-	-

Lighting

Example of vertical with arm lighting.
Source: http://www.sanengineeringllc.com/Projects/Structural-Engineering-NMDOT.php

ICE estimates the energy and GHG emissions associated with lighting use projects. Annual energy consumption will be paired with energy emission factors for individual states to determine GHG emissions.

Roadway lighting projects can be a significant contributor to the annual energy use and GHG emissions of many transportation agencies. ICE estimates the energy and GHG emissions associated with lighting projects. ICE evaluates the impacts of two of the most common lighting technologies: High Pressure Sodium (HPS) & Light Emitting Diode (LED). It includes lifecycle impacts associated with common support structures: High Mast, Vertical, and Vertical with arm.

Note that ICE only includes roadway lighting energy and GHG emissions from the use phase and lighting support structures, as manufacturing energy and emissions for HPS and LED luminaries and replacement parts is currently poorly characterized.

Specification

Select Mitigation Strategies

Lighting Structures		Avg number of HPS lights per roadway mile	Avg number of LED lights per roadway mile
Support Structure Type	Lumen Range		
Vertical	4000-5000	-	-
Vertical	7000-8800	-	-
Vertical	8500-11500	-	-
Vertical	11500-14000	-	48.0
Vertical	21000-28000	-	53.0
Vertical and Vertical with 8' Arm	4000-5000	-	-
Vertical and Vertical with 8' Arm	7000-8800	-	-
Vertical and Vertical with 8' Arm	8500-11500	-	-
Vertical and Vertical with 8' Arm	11500-14000	-	-
Vertical and Vertical with 8' Arm	21000-28000	-	42.0
High Mast	28800 - 42000	-	-
High Mast	46500-52800	-	-
High Mast	52500-58300	-	-

Number of roadway miles	9

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		53	3
Aluminum			
Cement		839	156
Steel		7,414	638
Water		0	0
Total		8,307	797

Materials Transportation		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		66	6
Total		66	6

Construction Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Construction fuel (DGEs)		-	-
Total		-	-

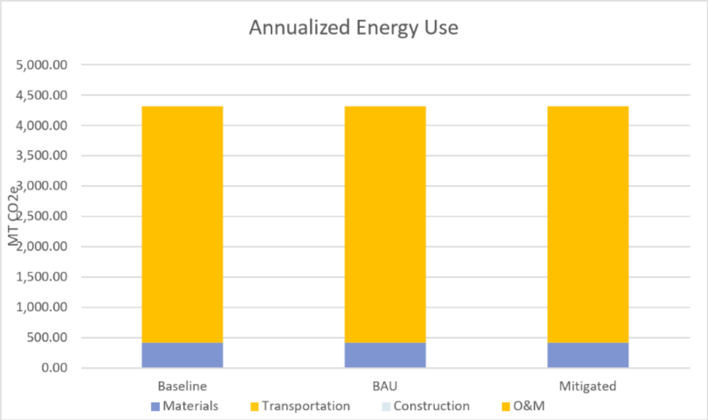
Operations and Maintenance		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		77,987	10,886
Maintenance fuel (DGEs)		-	-
Water		-	-
Total		77,987	10,886

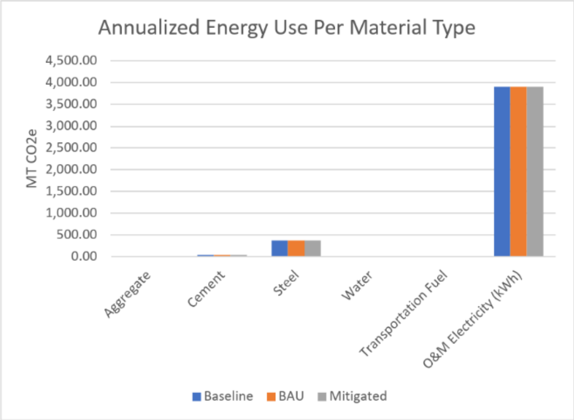
Mitigated Results

20 year Annualized Results	Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	3	3	3	0	0	0
Aluminum	-	-	-	-	-	-
Cement	42	42	42	8	8	8
Steel	371	371	371	32	32	32
Water	0	0	0	0	0	0
Transportation Fuel	3	3	3	0	0	0
Construction Fuel	-	-	-	-	-	-
O&M Electricity (kWh)	3,899	3,899	3,899	544	544	544
Materials subtotal	415	415	415	40	40	40
Transportation subtotal	3	3	3	0	0	0
Construction subtotal	-	-	-	-	-	-
Operations & Maintenance subtotal	3,899	3,899	3,899	544	544	544
Total	4,318	4,318	4,318	584	584	584

Results - Charts

Show	Annualized Energy Use	Units	MT CO2e





	Annualized Energy Use		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Materials	415	415	415
Transportation	3	3	3
Construction	-	-	-
O&M	3,899	3,899	3,899
Total	**4,318**	**4,318**	**4,318**

	Annualized Energy Use Per Material Type		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Aggregate	3	3	3
Cement	42	42	42
Steel	371	371	371
Water	0	0	0
Transportation Fuel	3	3	3
O&M Electricity (kWh)	3,899	3,899	3,899
Total	**4,318**	**4,318**	**4,318**

	Annualized Energy Use Reductions Relative to BAU				
	MT CO2e Materials	MT CO2e Transportation	MT CO2e Construction	MT CO2e O&M	MT CO2e TOTAL
Total	-	-	-	-	-

Bicycle and Pedestrian Pathways

Example separated bike (top) and pedestrian pathway (bottom).
Source: https://altaplanning.com/separated-bike-lanes/ ; https://www.fhwa.dot.gov/publications/research/safety/pedbike/05085/pptchapt9.cfm

ICE characterizes the new construction, resurfacing, and restriping of off-street bicycle or pedestrian paths, on-street bicycle lanes, and on-street pedestrian sidewalks.

On-street bicycle lanes applies where new roadway service is constructed for a bicycle lane. Roadway resurfacing of existing surfaces to create a bicycle lane should be included under 'Resurfacing'. Bicycle lanes created by restriping existing roadway space should be entered under 'Restriping'. However, restriping will not affect the energy and GHG estimates of the tool, since energy expended in restriping is negligible compared to energy expended in resurfacing or new construction.

Pedestrian facilities include the construction and resurfacing of new off-street paths and the construction of new on-street sidewalk miles. Note that sidewalk construction must be entered in this table, as roadway projects are assumed to include no sidewalks. For example, plans that include sidewalks on all newly constructed roads should multiply centerline miles of roadway by two to calculate construction of new on-street sidewalk miles. Only new construction of sidewalks is included in the tool because property owners are typically responsible for maintenance and repair of sidewalks.

Specification

Select Mitigation Strategies

Bicycle and Pedestrian Facilities	New Construction	Resurfacing
Off-Street Bicycle or Pedestrian Path - miles	18	-
On-Street Bicycle Lane - lane miles	-	-
On-Street Sidewalk - miles	-	N/A

New lane or right-of-way - lane miles	18
Converted or upgraded lane/facility - lane miles	-
New sidewalk - sidewalk miles	-

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		2,066	111
Bitumen (Asphalt Binder)		2,408	186
Cement		-	-
Steel		45	4
Water		-	-
Total		4,520	301

Materials Transportation		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		1,186	116
Total		1,186	116

Construction Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Construction fuel (DGEs)		2,794	274
Total		2,794	274

Operations and Maintenance		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Maintenance fuel (DGEs)		1,828	179
Water		-	-
Total		1,828	179

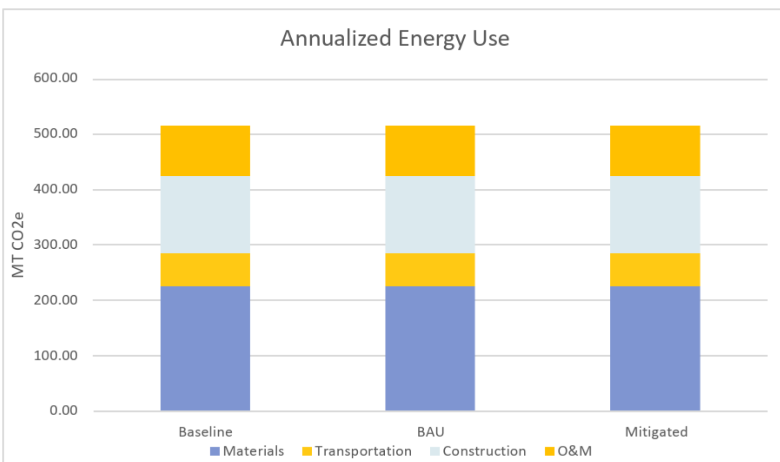
ICE Model - Alternative 2

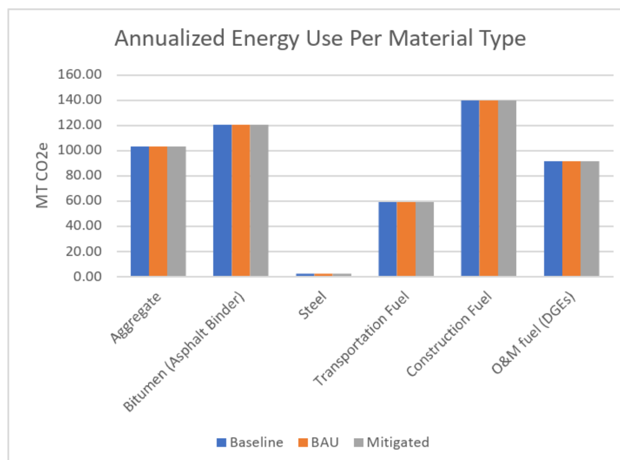
Mitigated Results

20 year Annualized Results	Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	103	103	103	6	6	6
Bitumen (Asphalt Binder)	120	120	120	9	9	9
Cement	-	-	-	-	-	-
Steel	2	2	2	0	0	0
Water	-	-	-	-	-	-
Transportation Fuel	59	59	59	6	6	6
Construction Fuel	140	140	140	14	14	14
O&M fuel (DGEs)	91	91	91	9	9	9
Materials subtotal	226	226	226	15	15	15
Transportation subtotal	59	59	59	6	6	6
Construction subtotal	140	140	140	14	14	14
Operations & Maintenance subtotal	91	91	91	9	9	9
Total	516	516	516	43	43	43

Results - Charts

Show	Annualized Energy Use	Units	MT CO2e





	Annualized Energy Use		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Materials	226	226	226
Transportation	59	59	59
Construction	140	140	140
O&M	91	91	91
Total	**516**	**516**	**516**

	Annualized Energy Use Per Material Type		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Aggregate	103	103	103
Bitumen (Asphalt Binder)	120	120	120
Steel	2	2	2
Transportation Fuel	59	59	59
Construction Fuel	140	140	140
O&M fuel (DGEs)	91	91	91
Total	**516**	**516**	**516**

	Annualized Energy Use Reductions Relative to BAU				
	MT CO2e	MT CO2e	MT CO2e	MT CO2e	MT CO2e
	Materials	Transportation	Construction	O&M	TOTAL
Total	-	-	-	-	-

Roadways

Roadway example.
Source:
https://commons.wikimedia.org/wiki/File:Veterans_Memorial_Parkway,_London,_Ontario.jpg

ICE accounts for the full roadway lifespan, including construction, rehabilitation, routine maintenance, and preventive maintenance. ICE handles these activities in different ways. Separate inputs are required for construction, rehabilitation, and effects of preventative maintenance. Specifically:

•New construction – The user enters lane miles of construction (or centerline miles of shoulder improvement) projects. Separately, the user indicates what fraction of roadway construction is in difficult terrain.

•Roadway rehabilitation – The user enters expected lane miles for reconstruction and resurfacing projects the length of the analysis period. Separately, the user enters a rehabilitation schedule. (Defaults are provided and used if no values are entered.) As a general rule of thumb, new roadways require resurfacing after 15 years and reconstruction after 30 years. Note that roadway rehabilitation applies to both existing and new roadways. This can lead to unexpectedly high operations and maintenance energy consumption and GHG emissions.

•Preventive maintenance – Preventive maintenance is pavement preservation techniques, such as crack sealing, patching, chip seals, and micro-surfacing, that prolong the life of the pavement. In ICE2.0, the user has the option to specify an extension of the roadway rehabilitiation schedule due to implementation of a (generic) preventive maintenance program. Application of preventative maintenance is accessible on the *Mitigation Strategies* tab. Note that the energy and emissions "cost" of a preventative maintenance program is based on an average of several potential strategies from different studies. More specific values may be obtainable from FHWA's Pavement LCA tool (when it becomes available).

Emissions and energy associated with routine maintenance (sweeping, striping, bridge deck repair, litter pickup, and maintenance of appurtenances) and roadway rehabilitation is automatically estimated per lane mile of both new and existing roadways associated with your project. To estimate associated use-phase emissions, visit the Vehicle Operations tab.

Note that roadway projects do not include sidewalks. If your project or plan includes constructing sidewalks, they should be entered separately in the Rail, Bus, Bicycle, and Pedestrian Facilities section of the tool.

Note that ICE2.0 does not calculate energy or GHG emissions savings from pavement smoothness effects related to any resurfacing and reconstruction projects.

ICE also does not intrinsically allow customized pavement configurations. Most analyses should use this *Roadway* tab and ICE's internal pavement configuration. The *Custom Pavement* analysis relies on external data rather than ICE's calculations to estimate lifecycle values for different configurations. Please see the *Custom Pavement* tab for more information. Users should not enter both *Roadway* and *Custom Pavement* values for the same project.

Example: The user enters new construction of 10 lane miles of new freeway, with an analysis period of 40 years. Assuming that all construction takes place in year 1, the user enters 10 lane miles of freeway resurfacing (assumed to take place in year 15) and 10 lane miles of freeway reconstruction (assumed to take place in year 30). The tool automatically includes routine maintenance of the 10 newly constructed lane miles. The user has the option of specifying a generic preventive maintenance program, which will increase the longevity of the pavement surface and therefore reduce the amount of energy and emissions associated with resurfacing and rehabilitation.

Specification

Select Mitigation Strategies

Roadway System	Existing	New	Total
Total centerline miles	11	8	19
Total lane miles	121	155	275

Roadway Projects

		Facility type						
		Rural Interstates	Rural Principal Arterials	Rural Minor Arterials	Rural Collectors	Urban Interstates / Expressways	Urban Principal Arterials	Urban Minor Arterials / Collectors
Roadway Lane Width (feet) (before construction)	Default	12	11	11	11	12	11	11
Roadway System	Existing Roadways (ICE equivalent lane miles)	0.0	0.0	0.0	0.0	73.0	5.7	41.9
Roadway Construction	New Roadway (ICE equivalent lane miles)	0.0	0.0	0.0	0.0	105.7	6.5	36.9
Roadway Construction	Construct Additional Lane (equivalent lane miles)	0.0	0.0	0.0	0.0	5.6	0.0	0.0

Include roadway rehabilitation activities (reconstruct and resurface)	Yes
% roadway construction on rocky / mountainous terrain	0%

ICE Model - Alternative 2

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions	Construction			O&M Roadway Rehabilitation		
		Energy use (mmBTU)	GHG emissions (MT CO2e)		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		73,525	3,971		49,789	2,782
Bitumen (Asphalt Binder)		91,517	7,081		91,730	7,097
Cement		76,414	14,242		54,665	10,188
Steel		100,124	8,240		38,070	2,985
Water		29	4		21	3
Total		341,609	33,538		234,275	23,056

Materials Transportation	Construction			O&M Roadway Rehabilitation		
		Energy use (mmBTU)	GHG emissions (MT CO2e)		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		43,527	4,263		27,433	2,687
Total		43,527	4,263		27,433	2,687

Construction Process	Construction			O&M Roadway Rehabilitation		
		Energy use (mmBTU)	GHG emissions (MT CO2e)		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		0	0		0	0
Construction fuel (DGEs)		293,628	28,761		136,917	13,411
Total		293,628	28,761		136,917	13,411

Operations and Maintenance		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Maintenance fuel (DGEs)		58,519.2	5,731.9
Roadway Rehabilitation (O&M)		398,625.1	39,154.0
Water		-	-
Total		457,144.2	44,885.9

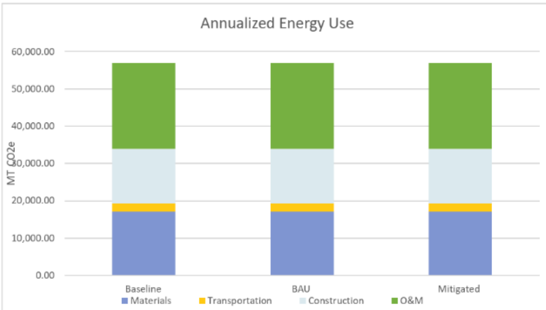
Mitigated Results

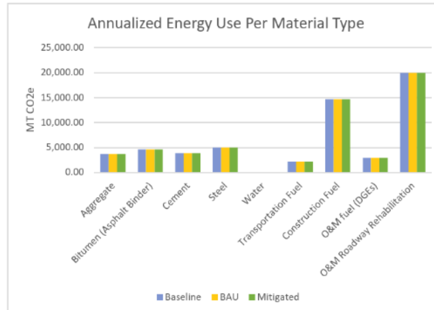
20 year Annualized Results	Construction						O&M Roadway Rehabilitation					
	Annualized Energy Use			Annualized Greenhouse Gas Emissions			Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	3,676	3,676	3,676	199	199	199	2,489	2,489	2,489	139	139	139
Bitumen (Asphalt Binder)	4,576	4,576	4,576	354	354	354	4,587	4,587	4,587	355	355	355
Cement	3,821	3,821	3,821	712	712	712	2,733	2,733	2,733	509	509	509
Steel	5,006	5,006	5,006	412	412	412	1,903	1,903	1,903	149	149	149
Water	1	1	1	0	0	0	1	1	1	0	0	0
Transportation Fuel	2,176	2,176	2,176	213	213	213	1,372	1,372	1,372	134	134	134
Construction Fuel	14,681	14,681	14,681	1,438	1,438	1,438	6,846	6,846	6,846	671	671	671
O&M fuel (DGEs)	2,926	2,926	2,926	287	287	287	-	-	-	-	-	-
O&M Roadway Rehabilitation	19,931	19,931	19,931	1,958	1,958	1,958	19,931	19,931	19,931	1,958	1,958	1,958
Materials subtotal	17,080	17,080	17,080	1,677	1,677	1,677						
Transportation subtotal	2,176	2,176	2,176	213	213	213						
Construction subtotal	14,681	14,681	14,681	1,438	1,438	1,438						
Operations & Maintenance subtotal	22,857	22,857	22,857	2,244	2,244	2,244						
Total	56,795	56,795	56,795	5,572	5,572	5,572						

ICE Model - Alternative 2

Results - Charts

Show	Annualized Energy Use	Units	MT CO2e





	Annualized Energy Use		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Materials	17,080	17,080	17,080
Transportation	2,176	2,176	2,176
Construction	14,681	14,681	14,681
O&M	22,857	22,857	22,857
Total	**56,795**	**56,795**	**56,795**

	Annualized Energy Use Per Material Type		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Aggregate	3,676.3	3,676.3	3,676.3
Bitumen (Asphalt Binder)	4,576	4,576	4,576
Cement	3,821	3,821	3,821
Steel	5,006	5,006	5,006
Water	1	1	1
Transportation Fuel	2,176	2,176	2,176
Construction Fuel	14,681	14,681	14,681
O&M fuel (DGEs)	2,926	2,926	2,926
O&M Roadway Rehabilitation	19,931	19,931	19,931
Total	**56,795**	**56,795**	**56,795**

	Annualized Energy Use Reductions Relative to BAU				
	MT CO2e	MT CO2e	MT CO2e	MT CO2e	MT CO2e
	Materials	Transportation	Construction	O&M	TOTAL
Total	-	-	-	-	-

Signage

ICE divides the signage category is divided into small, medium, and large structures representing the three most common types of roadway signs. Small and medium sized signs are typically regulatory and warning signs supported by a single post. Large signs include overhead guidance highway signs, typically supported by two posts or hung overhead on large steel cantilever arms. Signage infrastructure is a combination of aluminum sheet metal, and directly embedded or concrete encased supports.

The user enters the average number of each type of sign per roadway mile and the total project roadway miles.

Example large, medium, and small signs.
Source: dot.state.mn.us/trafficeng/publ/tem/2009/Chapter-06.pdf; https://www.defensivedriving.org/dmv-handbook/29-unusual-road-signs/; https://www.waaytv.com/content/news/School-bus-warning-signs-installed-on-Highway-43-463727923.html

Specification

Select Mitigation Strategies

Signage Structures	Avg. number of signs per roadway mile
Small (3'x3') - 14 Gauge Steel Post (MDOT SIGN-150-D)	1,623.0
Medium (6'x6') - 14 Gauge Steel Posts (MDOT SIGN-150-D)	59.0
Large (10'x14') - 8 Gauge Cantilever Arm (MDOT SIGN-300-A)	206.0

Number of roadway miles	9

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		228	12
Aluminum		22,127	1,469
Cement		3,612	673
Steel		120,506	10,427
Water		1	0
Total		146,473	12,582

Materials Transportation		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		469	46
Total		469	46

Construction Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		0	0
Construction fuel (DGEs)		0	0
Total		0	0

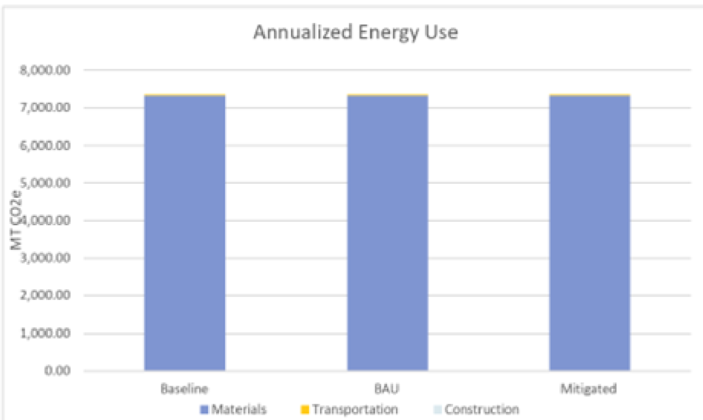
Operations and Maintenance		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		0	0
Maintenance fuel (DGEs)		0	0
Water		0	0
Total		0	0

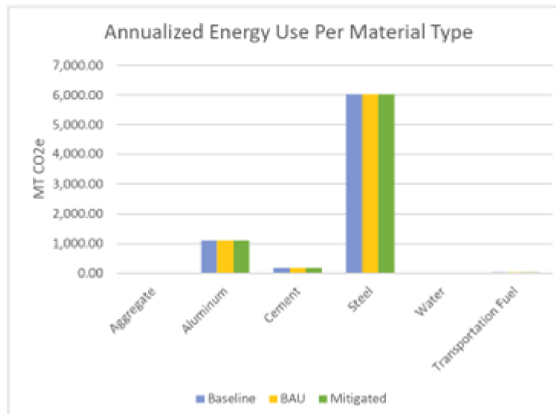
Mitigated Results

20 year Annualized Results	Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	11	11	11	1	1	1
Aluminum	1,106	1,106	1,106	73	73	73
Cement	181	181	181	34	34	34
Steel	6,025	6,025	6,025	521	521	521
Water	0	0	0	0	0	0
Transportation Fuel	23	23	23	2	2	2
Construction Fuel	-	-	-	-	-	-
Materials subtotal	7,324	7,324	7,324	629	629	629
Transportation subtotal	23	23	23	2	2	2
Construction subtotal	-	-	-	-	-	-
Total	7,347	7,347	7,347	631	631	631

Results - Charts

Show	Annualized Energy Use	Units	MT CO2e





ICE Model - Alternative 2

	Annualized Energy Use		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Materials	7,324	7,324	7,324
Transportation	23	23	23
Construction	-	-	-
Total	**7,347**	**7,347**	**7,347**

	Annualized Energy Use Per Material Type		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Aggregate	11	11	11
Aluminum	1,106	1,106	1,106
Cement	181	181	181
Steel	6,025	6,025	6,025
Water	0	0	0
Transportation Fuel	23	23	23
Total	**7,347**	**7,347**	**7,347**

	Annualized Energy Use Reductions Relative to BAU				
	MT CO2e	MT CO2e	MT CO2e	MT CO2e	MT CO2e
	Materials	Transportation	Construction	O&M	TOTAL
Total	-	-	-	-	-

Vehicle Operations and Construction Delay Emissions

Example of Vehicle Operations
Source: https://www.greencarreports.com/news/1093560_1-2-billion-vehicles-on-worlds-roads-now-2-billion-by-2035-report

ICE estimates vehicle operations impacts of infrastructure projects from two distinct effects:

•Vehicle operating emissions – The user enters the years, average daily traffic (AADVMT), and average speed for the opening, design, and horizon years on the project. ICE computes the cumulative operating emissions over on the project's lifetime.
•Construction delay emissions – The user enters the years, average daily traffic (AADVMT), and average speed for the year construction starts, project opening year, and the baseline year for comparison (typically the year before construction starts). ICE computes the additional energy and GHG emissions due to vehicle delay during construction.

Note that mitigations are not applicable for vehicle operating emissions. Also, the calcualtions reflect a standard automobile fleet. They should not be used to estimate bus emissions on BRT or train emissions from Light- or Heavy-Rail. Also, results are integrated over the project lifetime. (I.e., "baseline" doesn't just mean baseline year.)

Estimates of emissions and additional energy use from construction delay and vehicle operating emissions are meant to provide a rough sense of the scale of emissions relative to the construction processes themselves, and are not meant to replace estimates derived from traffic modeling software. Planned construction projects that will result in significant lane closures on high volume roads should be evaluated using traffic modeling software.

Specification

Vehicle Operations Emissions

	Year	Avg Daily VMT on project	Speed
Project Opening Year	2030	2034600	NA
Project Interim Year	2040	2288700	NA
Project Design/Horizon Year	2050	2542700	NA

Construction Delay, Additional Emissions

	Year	Avg Daily VMT impacted by project	Speed
Construction start year	2024	1856000	NA
Pre-construction (baseline) year	2021	1778100	60.0
Project Opening Year	2030		

Baseline Energy Use and GHG Emissions

Usage Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Vehicle Operating Emissions		97,361,392	7,469,984
Construction Delay		4,827,695	368,356
Total		102,189,087	7,838,340

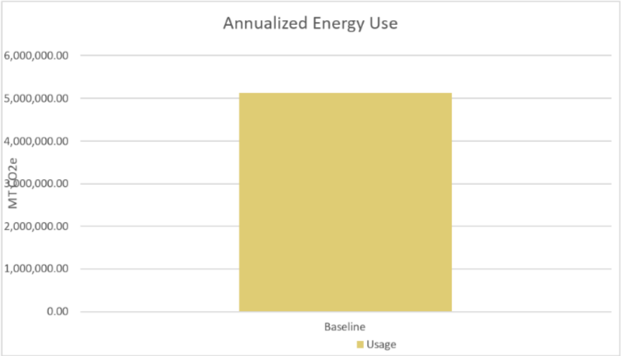
Mitigated Results

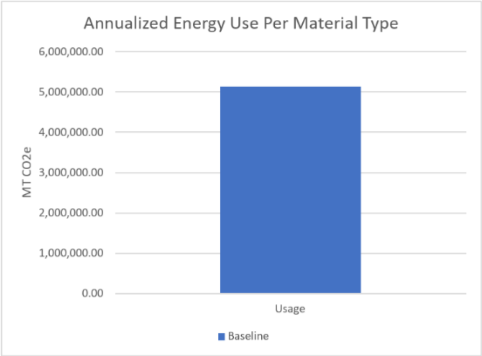
	Annualized Energy Use	Annualized Greenhouse Gas Emissions
	Baseline	Baseline
20 year Annualized Results	Energy use (mmBTU)	GHG emissions (MT CO2e)
Usage Emissions	5,109,454	391,917
Materials subtotal	-	-
Transportation subtotal	-	-
Construction subtotal	-	-
Usage subtotal	5,109,454	391,917
Total	5,109,454	391,917

Results - Charts

Show	Annualized Energy Use	Units	MT CO2e

No mitigations are available for Vehicle Ops.





	Annualized Energy Use
	MT CO2e
	Baseline
Usage	5,109,454
Total	**5,109,454**

	Annualized Energy Use Per Material Type
	MT CO2e
	Baseline
Usage	5,109,454
Total	**5,109,454**

A.5 ICE 2.1.3 Inputs and Outputs: ICE Model – Modified Alternative 3

Introduction to the Infrastructure Carbon Estimator (ICE), version 2.1

Note: This tool is designed to allow users to create screening-level estimates of energy and GHG emissions using limited data inputs. It asks for limited data to estimate lifecycle energy use emissions from a single or group of projects. The tool is not appropriate to inform engineering analysis and pavement selection. Other tools should be consulted for those purposes. More details about suggested uses for the tool are provided in the accompanying ICE User's Guide .

Project Inputs Page

Summary Results Page

Infrastructure Carbon Estimator (ICE) 2.1.3. Final Tool. Released 03/24/2021.

OVERVIEW

The Infrastructure Carbon Estimator (ICE) estimates the lifecycle energy and greenhouse gas (GHG) emissions from the construction and maintenance of transportation facilities. The ICE tool was created to solve the problem of "planning level" estimation of embodied carbon emissions in transportation infrastructure. Without the need for any engineering studies, ICE helps answer this question: How much carbon will be embodied in the building, modification, maintenance, and/or use of this transportation project (or group of projects)?

ICE evaluates energy use and greenhouse gas emissions at the project- or planning-level. The tool uses the term "project" to generally refer to a single project type, with access to some additional details and project customization. "Planning" is designed to accept inputs from long-range transportation plans or other plans that consist of a suite of projects but limited customization.

The tool estimates emissions for the following types of facilities and projects:

1. Bridges and Overpasses
2. Bus Rapid Transit (BRT)
3. Culverts
4. Light Rail
5. Lighting
6. Heavy Rail
7. Parking
8. Pathways
9. Roadways
10. Signage
11. Vehicle Operations
12. Standalone Maintenance Projects on Existing Roadways
13. Custom Pavement Projects with Data Imported from External Tools

(Please note Types 12 and 13 address specific and limited applications. These are discussed in the individual tabs and the User's Guide.)

For each type of facility, the tool calculates both mitigated results that take into account the effect of various energy/GHG reduction strategies and unmitigated results.

USING THE TOOL

Details on use of ICE is available in the User's Guide.

Color Scheme

ICE uses the following color scheme to describe the function of each cell:

Description Cells
Computed Value Cells
Cell value is not relevant (Cell is NA)
Data Entry Cells
Action Cell
Command button - on
Command button - off
Command button - disabled

The tool provides users the ability to display results in 508 compliant format, which among other features, will add data labels to all results charts. The color scheme when 508 compliant is activated deviates slightly from when the format is turned off.

Analysis Mode

The tool can be used in either *Planning* or *Project* mode. This is set at the top of the *Project Inputs* page.

Planning mode reveals all facility types on one page. Using the buttons at the top of the screen allows you to add or remove facilities from your analysis. Individual facility details can be viewed via the links below the input table or by navigating the separate tabs for each infrastructure type. Clicking the hyperlinks above and below each infrastructure type's inputs in the *Project Inputs* page navigates to the various sections in each *analysis page* for that infrastructure type. The relevant *analysis page(* s), *Mitigation Strategies* page, and the *Summary Results* page will be shown when an infrastructure type is selected. Buttons on the *analysis pages* carry the user to specify mitigation measures and back to the *analysis pages.*

The *Project mode* operates similarly. In the *Project* mode, the user has the option to view all inputs or have ICE walk the user through each step. In walkthrough mode, green action cells direct the user through each step. Only a single infrastructure type can be modeled in *Project mode* .

Tabs and Navigation

The tool can be navigated in multiple ways. Users will start by describing their project on the *Project Inputs* page. This includes the infrastructure type(s), analysis lifetime, location, and analysis mode. Hyperlinks carry users through the various tabs. Three comment boxes allow the user to input descriptive text that will be carried through to the output pages. This could include analysis date, analyst, project descriptions, or other information the analyst may want to include in their report.

First, select your level of analysis (Project or Planning) and input the requested information for your project on the *Project Inputs* page. Input the US state for your analysis, the project analysis lifetime (in years), and whether the impacts of a custom electricity emission program, such as a Renewable Portfolio Standard (RPS), are to be included. Answering "yes" on the latter will open the *Annual Electricity Emissions* tab for populating.

If using the Planning level of analysis, "turn on" all infrastructure types to be analyzed on the *Project Inputs* page. If using the *Project* level of analysis, then select the single infrastructure type to analyze.

Hyperlinks from the *Project Inputs* page will take you to the *analysis page* for your project type(s). (The project analysis pages are titled according to the infrastructure type.) Here some additional inputs for your project may be requested. At the top of each analysis page is a hyperlink that carries you to the *Mitigation Strategies* page.

Each *analysis page* includes the following sections:

- <u>Specifications</u> – Fixed and input values describing the project
- <u>Baseline Energy Use and GHG Emissions</u> – Total energy use and GHG emissions over the project's lifetime
- <u>Mitigated Results</u> – Annualized energy use and GHG emissions for the project without (baseline) and with (both business as usual and control scenario) mitigations applied.
- <u>Results - Charts</u> – Summary charts and tables of the mitigated and unmitigated energy use and emissions by emission category, material, and individualized mitigation effects. Results can be viewed as annualized or cumulative GHG emissions or energy.

On the *Mitigation Strategies* page, you have the option to input certain strategies that reduce energy and GHG emissions for your project. Only relevant strategies are shown. Hyperlinks at the top return you to the *analysis page* for your project type.

Below the project specifications in each *analysis page,* the calculated, annualized baseline, business-as-usual (BAU), and mitigated levels of energy or GHG emissions for your project type(s) are displayed. This shows results by the five emission categories and by material for both mitigated and unmitigated cases. It also shows emission or energy reductions by mitigation measure.

The *Summary Results* page displays a summary of results for all infrastructure types analyzed. If the analysis is at the *Project* level, this display is nearly identical to that on the *analysis page.* For *Planning* level, buttons appear allowing the user to turn on or off the different project types included in the combined results. The "Show" dropdown menu selects the results displayed: Annualized Greenhouse Gas Emissions, Annualized Energy Use, Cumulative Greenhouse Gas Emissions, and Cumulative Energy Use. An additional chart in the *Summary Results* page, not available in the individual *analysis pages* , displays values by infrastructure type.

If the use phase of automobiles is to be considered in your project, you must include the *Vehicle Operations* project type. Resulting energy and emissions from project use will be added to the summary charts on the *Summary Results* page.

At any time, the user can view overall results in the *Summary Results* page or enter a custom mitigation approach for energy and GHG emissions on the *Mitigation Strategies* page. The user can switch directly between various pages indicated in Excel tabs at any time. The *Print Results* tab collects outputs and formats them for standard printing, either to an electronic or paper copy for archiving the outputs of your simulation. This can be used to compare multiple simulations, such as for a Build vs. No-Build analysis.

Units and Time Periods

ICE requests the analysis timeframe (in years) from the user. It produces lifecycle (to end-of-life) estimates of energy use and/or GHG emissions. Both values can be reported on an annualized or total lifespan basis. The standard reporting unit for energy is "mmBTU", or millions of British Thermal Units. The standard reporting unit for greenhouse gas emissions is "MT CO2e", or metric tons of CO2-equivalent gases. 1 metric tons = 1,000 kg. CO2 equivalency is defined by a global-warming potential basis.

EMISSIONS SOURCES ESTIMATED

Construction and maintenance activities covered by the tool are broken into five categories:

Materials

Upstream Energy and Emissions associated with project materials:

1. Energy and fuel used in raw material extraction
2. Energy and fuel used in material production*
3. Chemical reactions in material production**
4. Energy and fuel used in raw material transportation

Transportation

Upstream Energy and Emissions associated with:

1. Fuel used in transportation of materials to site

Construction

1. Energy and fuel used in construction equipment

Operations and Maintenance (O&M)

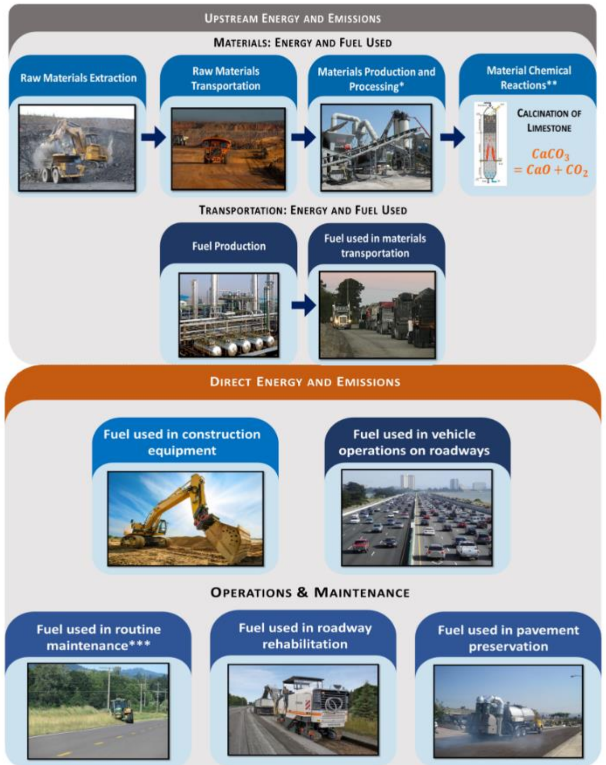
Routine Maintenance, including:

1. Fuel used in snow removal equipment
2. Fuel used in vegetation management equipment
3. Fuel used in other routine maintenance***
4. Energy and emissions from roadway repair and rehabilitation
5. Net energy and emissions from pavement preservation activities (optional)

Usage

Energy and Emissions associated with:

1. Vehicle operations on roadways, including delay during construction



*e.g. crushing of aggregate, asphalt batch plants
**e.g CO2 emitted from calcination of limestone
***activities include sweeping, stripping, bridge deck repair, litter pickup, and maintenance of appurtenances

ICE does not include energy or emissions associated with land use change from the project.

ADDITIONAL INFORMATION

Refer to the accompanying User's Guide for further instructions, detailed descriptions of factors, and assumptions regarding this tool.

Project Inputs

Display result in 508 compliant format:	No
Tool Use	Planning

Hide Instructions	Yes
Infrastructure location (state)	TX
The lifetime of your plan or project (years)	20
Use custom electric emission profile (RPS)?	No

Bridges & Overpasses | Culverts | Lighting | Parking | Roadways | Vehicle Operations | Roadway Rehabilitation

BRT | Light Rail | Heavy Rail | Pathways | Signage | Custom Pavement

Enter comments and comment titles. These will be displayed on the Summary Results worksheet.	Title: ALTERNATIVE 3	Title:	Title:

Planning Summary of Inputs - See Individual Tabs for Details

Bridges & Overpasses

Bridge/Overpass Structure	Construct New Bridge/Overpass				Reconstruct Bridge/Overpass				Add Lane to Bridge/Overpass			
	Number of bridges & overpasses	Average number of spans per structure	Average number of lanes per structure	Total number of lane-spans	Number of bridges & overpasses	Average number of spans per structure	Average number of lanes recon-structed per structure	Total number of lane-spans	Number of bridges & overpasses	Average number of spans per structure	Average number of lanes per structure added	Total number of lane-spans
Single-Span	5	1	25.2	**126**	0	1	0	**0**	0	1		**0**
Two-Span	11	2	10.5	**231**	2	2	5	**20**	0	2		**0**
Multi-Span (over land)	61	10.1	6.6	**4066.26**	8	4.3	10.5	**361.2**	0			**0**
Multi-Span (over water)	1	13	1	**13**	6	8.5	6.5	**331.5**	0			**0**

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

Bus Rapid Transit

Bus Rapid Transit	
Total existing lane miles of bus rapid transit	0

Bus rapid transit construction	
New lane or right-of-way - lane miles	36.67
Converted or upgraded lane/facility - lane miles	0
New BRT Stations	0

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

Culverts

	Number of culverts	Average culvert length (ft)
Default Culvert	14	3211.271324

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

Lighting

Number of roadway miles	9

Lighting Structures Support Structure Type	Lumen Range	Ave. number of HPS lights per roadway mile	Ave. number of LED lights per roadway mile
Vertical	4000-5000		
Vertical	7000-8800		
Vertical	8500-11500		
Vertical	11500-14000		48
Vertical	21000-28000		53
Vertical and Vertical with 8' Arm	4000-5000		
Vertical and Vertical with 8' Arm	7000-8800		
Vertical and Vertical with 8' Arm	8500-11500		
Vertical and Vertical with 8' Arm	11500-14000		
Vertical and Vertical with 8' Arm	21000-28000		42
High Mast	28800 - 42000		
High Mast	46500-52800		
High Mast	52500-58300		

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

Pathways

Bicycle and Pedestrian Facilities Project Type	New Construction	Resurfacing
Off-Street Bicycle or Pedestrian Path - miles	19.27	
On-Street Bicycle Lane - lane miles		
On-Street Sidewalk - miles		N/A

Roadways

Roadway System	
Total existing centerline miles	9.95
Total newly constructed centerline miles	6.83

Roadway Projects						
Facility type	Roadway System	Roadway Construction				
	Existing Roadway (lane miles)	New Roadway (lane miles)	Construct Additional Lane (lane miles)	Realignment (lane miles)	Lane Widening (lane miles)	Shoulder Improvement (centerline miles)
Rural Interstates						
Rural Principal Arterials						
Rural Minor Arterials						
Rural Collectors						
Urban Interstates / Expressways	68.17	91.64	5.55			
Urban Principal Arterials	6.21	7.32				
Urban Minor Arterials / Collectors	44.87	47.12				

Include roadway rehabilitation activities (reconstruct and resurface)	Yes
% roadway construction on rocky / mountainous terrain	0%

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

Signage

Number of roadway miles	9

Signage Structures	Avg. number of signs per roadway mile
Small (3'x3') - 14 Gauge Steel Post (MDOT SIGN-150-D)	1469
Medium (6'x6') - 14 Gauge Steel Posts (MDOT SIGN-150-D)	53
Large (10'x14') - 8 Gauge Cantilever Arm (MDOT SIGN-300-A)	186

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

Vehicle_Ops

Vehicle Operating Emissions				
	Year		Avg Daily VMT on project	Average Daily (Congested) Speed (mph) (or NA)
	Default	Custom		
Project Opening Year	2022	2030	2035600	NA
Project Interim Year	2027	2040	2292300	NA
Project Design/Horizon Year	2050	2050	2551000	NA

Construction Delay, Additional Emissions				
	Year		Avg Daily VMT impacted by project	Average Daily (Congested) Speed (mph) (or NA)
	Default	Custom		
Construction start year	2022	2024	1856000	NA
Pre-construction (baseline) year	2021	2021	1780000	60
Project Opening Year	2030	2030		

Specification
Baseline Energy Use and GHG Emissions
Mitigated Results
Results - Charts

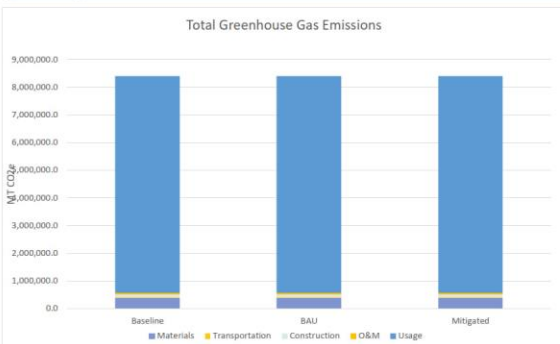
ICE Model - Alternative 3 Modified

Summary Results

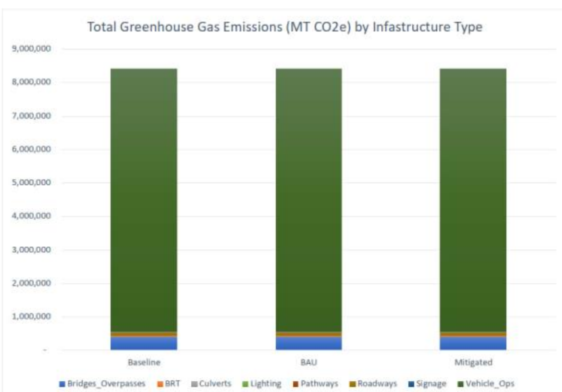
Bridges & Overpasses	Culverts	Lighting	Parking	Roadways	Vehicle Operations
BRT	Light Rail	Heavy Rail	Pathways	Signage	Custom Pavement

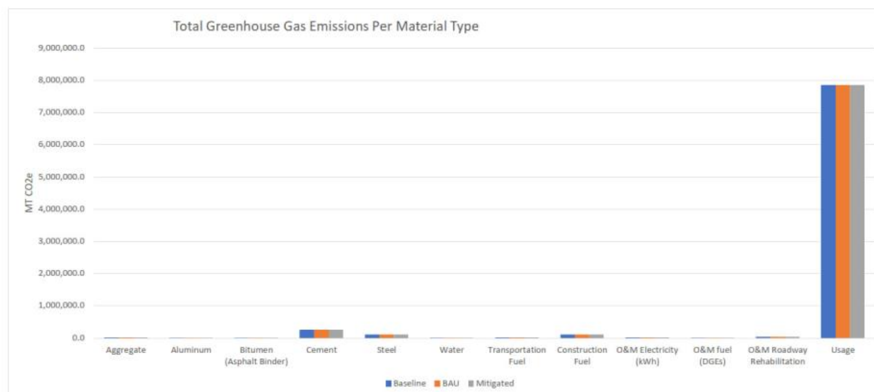
Show	Total Greenhouse Gas Emissions	Units	MT CO2e

Summary Results - Charts



Baseline refers to values without any mitigations applied.
Business-as-Usual (BAU) deployment refers to any "default" mitigations that are deployed through standard agency practices.
Planned deployment reflects the level of mitigations planned for the





ICE Model - Alternative 3 Modified

Summary Results - Tables

Total Greenhouse Gas Emissions	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Materials	383,895	383,895	383,895
Transportation	13,576	13,576	13,576
Construction	108,066	108,066	108,066
O&M	54,008	54,008	54,008
Usage	7,851,675	7,851,675	7,851,675
Total	**8,411,220**	**8,411,220**	**8,411,220**

Total Greenhouse Gas Emissions Per Material Type	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Aggregate	11,814	11,814	11,814
Aluminum	1,327	1,327	1,327
Bitumen (Asphalt Binder)	7,811	7,811	7,811
Cement	253,766	253,766	253,766
Steel	108,937	108,937	108,937
Water	241	241	241
Transportation Fuel	13,576	13,576	13,576
Construction Fuel	108,066	108,066	108,066
O&M Electricity (kWh)	10,886	10,886	10,886
O&M fuel (DGEs)	6,019	6,019	6,019
O&M Roadway Rehabilitation	37,103	37,103	37,103
Usage	7,851,675	7,851,675	7,851,675
Total	**8,411,220**	**8,411,220**	**8,411,220**

Total Greenhouse Gas Emissions Reductions Relative to BAU	MT CO2e Materials	MT CO2e Transportation	MT CO2e Construction	MT CO2e O&M	MT CO2e TOTAL
Total	-	-	-	-	-

Total Greenhouse Gas Emissions (MT CO2e) by Infastructure Type	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Bridges_Overpasses	399,984	399,984	399,984
BRT	17,616	17,616	17,616
Culverts	12,731	12,731	12,731
Lighting	11,689	11,689	11,689
Pathways	948	948	948
Roadways	105,173	105,173	105,173
Signage	11,403	11,403	11,403
Vehicle_Ops	7,851,675	7,851,675	7,851,675
Total	**8,411,220**	**8,411,220**	**8,411,220**

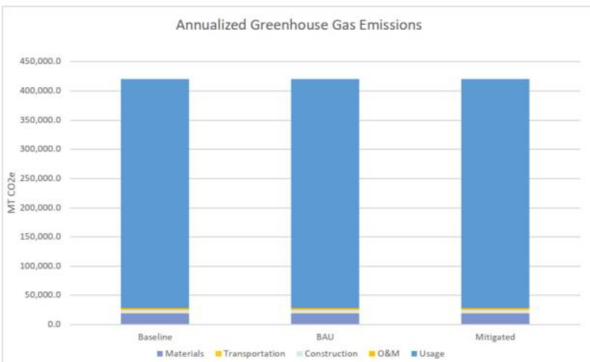
ICE Model - Alternative 3 Modified

Summary Results

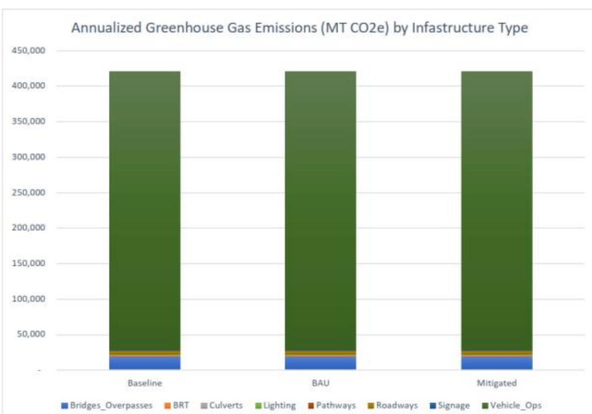
Bridges & Overpasses	Culverts	Lighting	Parking	Roadways	Vehicle Operations
BRT	Light Rail	Heavy Rail	Pathways	Signage	Custom Pavement

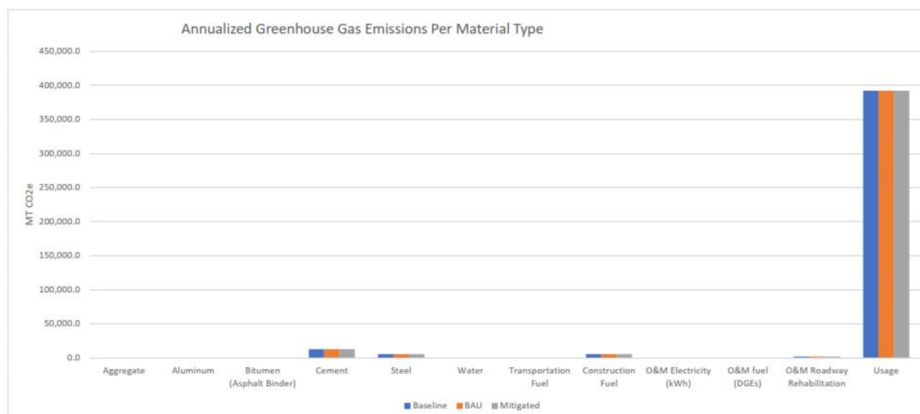
Show	Annualized Greenhouse Gas Emissions	Units	MT CO2e

Summary Results - Charts



Baseline refers to values without any mitigations applied.
Business-as-Usual (BAU) deployment refers to any "default" mitigations that are deployed through standard agency practices.
Planned deployment reflects the level of mitigations planned for the analyzed case.





ICE Model - Alternative 3 Modified

Summary Results - Tables

	Annualized Greenhouse Gas Emissions		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Materials	19,195	19,195	19,195
Transportation	679	679	679
Construction	5,403	5,403	5,403
O&M	2,700	2,700	2,700
Usage	392,584	392,584	392,584
Total	**420,561**	**420,561**	**420,561**

	Annualized Greenhouse Gas Emissions Per Material Type		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Aggregate	591	591	591
Aluminum	66	66	66
Bitumen (Asphalt Binder)	391	391	391
Cement	12,688	12,688	12,688
Steel	5,447	5,447	5,447
Water	12	12	12
Transportation Fuel	679	679	679
Construction Fuel	5,403	5,403	5,403
O&M Electricity (kWh)	544	544	544
O&M fuel (DGEs)	301	301	301
O&M Roadway Rehabilitation	1,855	1,855	1,855
Usage	392,584	392,584	392,584
Total	**420,561**	**420,561**	**420,561**

	Annualized Greenhouse Gas Emissions Reductions Relative to BAU				
	MT CO2e Materials	MT CO2e Transportation	MT CO2e Construction	MT CO2e O&M	MT CO2e TOTAL
Total	-	-	-	-	-

	ualized Greenhouse Gas Emissions (MT CO2e) by Infastructure T		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Bridges_Overpasses	19,999	19,999	19,999
BRT	881	881	881
Culverts	637	637	637
Lighting	584	584	584
Pathways	47	47	47
Roadways	5,259	5,259	5,259
Signage	570	570	570
Vehicle_Ops	392,584	392,584	392,584
Total	**420,561**	**420,561**	**420,561**

Mitigation Strategies

Return T

Instructions: Follow the steps below to calculate the impact of energy and GHG mitigation strategies:

The user will enter both the business as usual (BAU) deployment (i.e., the extent to which the strategy is deployed through standard agency practices) in Column F and the planned deployment (i.e., the extent to which the strategy will be deployed in the project that you are examining) in Column G. (Baseline refers to values without any mitigations.) For Pavement Preservation strategies, enter both the schedule change and application frequency.

Column H displays the increase in deployment from implementation of the strategy. Some reduction strategies (e.g., Switch from diesel to Soy bean-based BD20 and biodiesel/hybrid maintenance vehicles and equipment) may be incompatible. The user should take care that inputs do not describe a total deployment greater than 100% for overlapping strategies. The tool will warn if "excess" energy savings from mitigation are predicted or incompatible strategies are selected.

For a more refined mitigation analysis, please refer to FHWA's upcoming Pavement LCA Tool.

						BAU Reductions		Planned Reductions	
Strategy	BAU deployment	Planned deployment	Deployment increase	Energy reduction factor	GHG reduction factor	Energy reductions	GHG reductions	Energy reductions	GHG reductions
Alternative fuels and vehicle hybridization									
Switch from diesel to Soy bean-based BD20			0.0%	-5%	12%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to Soy bean-based RDII 100			0.0%	-20%	66%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to Forest Residue-based RDII 100			0.0%	-61%	71%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to E-Diesel, Corn			0.0%	-3%	0%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to PHEV: Diesel and Electricity (U.S. Mix)			0.0%	41%	44%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to CNG, NA NG			0.0%	-6%	11%	0.0%	0.0%	0.0%	0.0%
Switch from diesel to LNG, NA NG			0.0%	-11%	7%	0.0%	0.0%	0.0%	0.0%
Hybrid maintenance vehicles and equipment			0.0%	11%	11%	0.0%	0.0%	0.0%	0.0%
Combined hybridization/B20 in maintenance vehicles and equipment			0.0%	1%	27%	0.0%	0.0%	0.0%	0.0%
Hybrid construction vehicles and equipment			0.0%	11%	11%	0.0%	0.0%	0.0%	0.0%
Combined hybridization/B20 in construction vehicles and equipment			0.0%	1%	27%	0.0%	0.0%	0.0%	0.0%
Vegetation management									
Alternative vegetation management strategies (hardscaping, alternative mowing, integrated roadway/vegetation management)			N/A	25%	25%	0.0%	0.0%	0.0%	0.0%
Snow fencing and removal strategies									
Alternative snow removal strategies (snow fencing, wing plows)			N/A	0%	0%	0.0%	0.0%	0.0%	0.0%
In-place roadway recycling									
Cold In-place recycling			0.0%	33%	37%	0.0%	0.0%	0.0%	0.0%
Full depth reclamation			0.0%	68%	68%	0.0%	0.0%	0.0%	0.0%
Warm-mix asphalt									
Warm-mix asphalt			0.0%	37%	37%	0.0%	0.0%	0.0%	0.0%
Recycled and reclaimed materials									
Use recycled asphalt pavement as a substitute for virgin asphalt aggregate			0.0%	12%	12%	0.0%	0.0%	0.0%	0.0%
Use recycled asphalt pavement as a substitute for virgin asphalt bitumen			0.0%	84%	84%	0.0%	0.0%	0.0%	0.0%
Use industrial byproducts as substitutes for Portland cement			0.0%	59%	59%	0.0%	0.0%	0.0%	0.0%
Use recycled concrete aggregate as a substitute for base stone			0.0%	58%	58%	0.0%	0.0%	0.0%	0.0%
Pavement preservation									
Pavement preservation extends roadway life by (years)			N/A	N/A	N/A	N/A	N/A	N/A	N/A
Pavement preservation frequency (every N years, for entire roadway system)			N/A	N/A	N/A	N/A	N/A	N/A	N/A

Bridges & Overpasses

Example of a concrete bridge
(not representative of all possible project types).

Source: https://en.wikipedia.org/wiki/Low-water_crossing#/media/File:Roanoke_River_low_water_crossing.jpg

ICE estimates the energy and GHG emissions associated with the construction, reconstruction, or lane addition for single span, two-span, and multi-span bridges and overpasses. Bridges and overpasses are treated as being functionally equivalent in ICE.

The *Bridges and Overpasses* module in ICE applies to the construction of the bridge structure rather than the pavement surface. Bridge paving activities should be entered as part of the Roadway construction activities.

Approximately half of short bridges in the U.S. (less than 1000 feet long) are single-span or double-span. If information about number of spans is not available, it is reasonable to assume a mix of single-span and two-span bridges. Note that the number of spans is an important factor in energy use and GHG emissions.

Please note that very large bridges that carry traffic very high or span very deep spaces are unique and likely require additional materials and construction processes that cannot be approximated by ICE.

Specification

Select Mitigation Strategies

	Construct New Bridge				Reconstruct Bridge				Add Lane to Bridge			
Bridge and Overpass Structures	Number of bridges	Avg number of spans per bridge	Avg number of lanes per bridge	Total number of lane-spans	Number of bridges	Avg number of spans per bridge	Avg number of lanes per bridge	Total number of lane-spans	Number of bridges	Avg number of spans per bridge	Avg number of new lanes per bridge	Total number of lane-spans
Single-Span	5	1	25	**126**	-	1	-	-	-	1	-	-
Two-Span	11	2	11	**231**	2	2	5	**20**	-	2	-	-
Multi-Span (over land)	61	10	7	**4,066**	8	4	11	**361**	-	-	-	-
Multi-Span (over water)	1	13	1	**13**	6	9	7	**332**	-	-	-	-

Baseline Energy Use and GHG Emissions

Material Requirements (metric tons)		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		130,001	7,087
Cement		1,228,836	229,030
Steel		1,111,311	84,976
Water		1,744	234
Total		2,471,891	321,327

Materials Transportation		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		78,210	7,661
Total		78,210	7,661

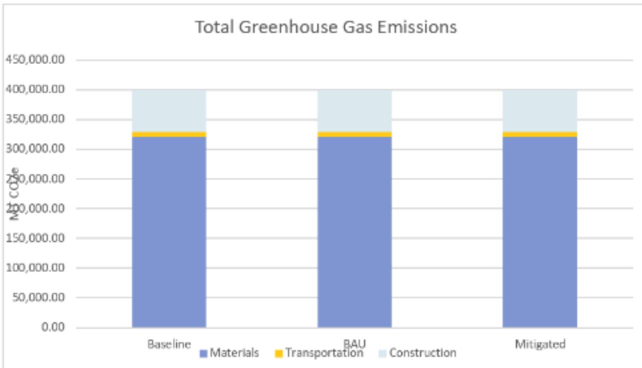
Construction Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Construction fuel (DGEs)		724,826	70,997
Total		724,826	70,997

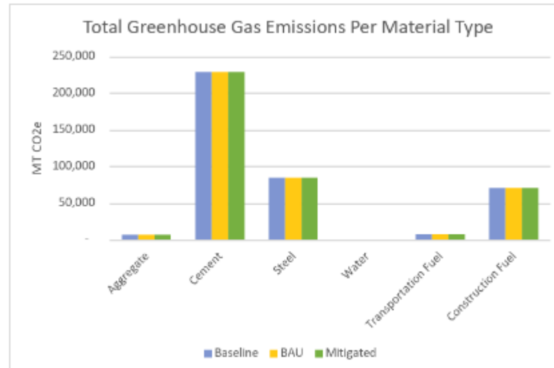
Mitigated Results

20 year Annualized Results	Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	6,500	6,500	6,500	354	354	354
Cement	61,442	61,442	61,442	11,452	11,452	11,452
Steel	55,566	55,566	55,566	4,249	4,249	4,249
Water	87	87	87	12	12	12
Transportation Fuel	3,910	3,910	3,910	383	383	383
Construction Fuel	36,241	36,241	36,241	3,550	3,550	3,550
Materials subtotal	123,595	123,595	123,595	16,066	16,066	16,066
Transportation subtotal	3,910	3,910	3,910	383	383	383
Construction subtotal	36,241	36,241	36,241	3,550	3,550	3,550
Total	163,746	163,746	163,746	19,999	19,999	19,999

Results - Charts

Show	Total Greenhouse Gas Emissions	Units	MT CO2e





	Total Greenhouse Gas Emissions		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Materials	321,327	321,327	321,327
Transportation	7,661	7,661	7,661
Construction	70,997	70,997	70,997
Total	**399,984**	**399,984**	**399,984**

	Total Greenhouse Gas Emissions Per Material Type		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Aggregate	7,087	7,087	7,087
Cement	229,030	229,030	229,030
Steel	84,976	84,976	84,976
Water	234	234	234
Transportation Fuel	7,661	7,661	7,661
Construction Fuel	70,997	70,997	70,997
Total	**399,984**	**399,984**	**399,984**

	Total Greenhouse Gas Emissions Reductions Relative to BAU				
	MT CO2e	MT CO2e	MT CO2e	MT CO2e	MT CO2e
	Materials	Transportation	Construction	O&M	TOTAL
Total	-	-	-	-	-

ICE Model - Alternative 3 Modified

Bus Rapid Transit

Example of dedicated bus lane for bus rapid transit.
Source: World Resources Institute

ICE considers construction or conversion of bus rapid transit (BRT) facilities. This is characterized in terms of roadway lanes dedicated to bus transit and not shared with general traffic.

Note that use phase vehicle emissions are currently incompatible with this infrastructure type.

Specification

Select Mitigation Strategies

Construction	Bus rapid transit
New lane or right-of-way - lane miles	37
Converted or upgraded lane/facility - lane miles	-
New BRT Stations	-

Maintenance	New	Existing
BRT (lane miles)	37	-

Factors - Alt mode maintenance	Fuel use (DGEs)
BRT (per lane mile)	79

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		14,477	767
Bitumen (Asphalt Binder)		12,557	972
Cement		22,897	4,268
Steel		15,188	1,185
Water		9	1
Total		65,129	7,192

Materials Transportation		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		9,093	891
Total		9,093	891

Construction Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Construction fuel (DGEs)		93,546	9,163
Total		93,546	9,163

Operations and Maintenance		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Mainenance fuel (DGEs)		3,791	371
Water		-	-
Total		3,791	371

ICE Model - Alternative 3 Modified

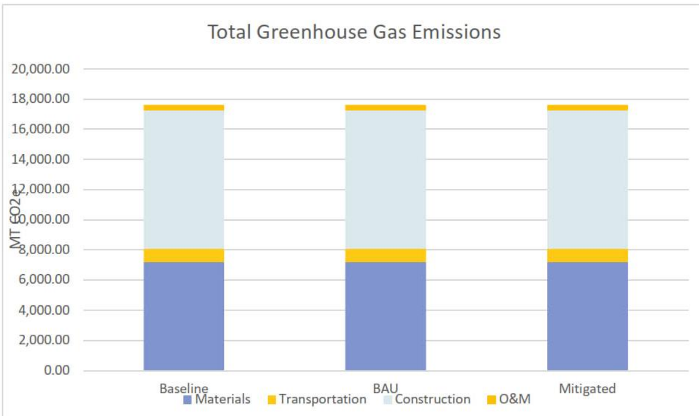
Mitigated Results

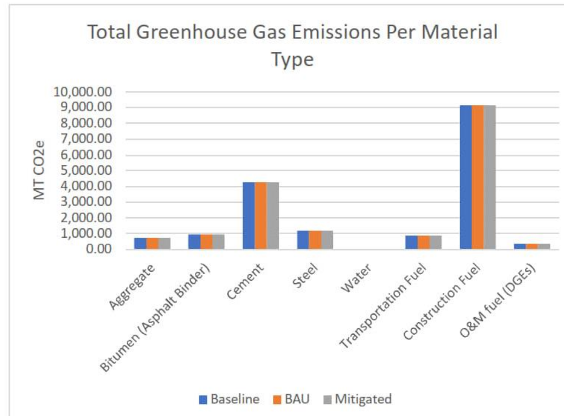
	Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
20 year Annualized Results	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	724	724	724	38	38	38
Bitumen (Asphalt Binder)	628	628	628	49	49	49
Cement	1,145	1,145	1,145	213	213	213
Steel	759	759	759	59	59	59
Water	0	0	0	0	0	0
Transportation Fuel	455	455	455	45	45	45
Construction Fuel	4,677	4,677	4,677	458	458	458
O&M fuel (DGEs)	190	190	190	19	19	19
Materials subtotal	3,256	3,256	3,256	360	360	360
Transportation subtotal	455	455	455	45	45	45
Construction subtotal	4,677	4,677	4,677	458	458	458
Operations & Maintenance subtotal	190	190	190	19	19	19
Total	8,578	8,578	8,578	881	881	881

ICE Model - Alternative 3 Modified

Results - Charts

Show	Total Greenhouse Gas Emissions	Units	MT CO2e





	Total Greenhouse Gas Emissions		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Materials	7,192	7,192	7,192
Transportation	891	891	891
Construction	9,163	9,163	9,163
O&M	371	371	371
Total	**17,616**	**17,616**	**17,616**

	Total Greenhouse Gas Emissions Per Material Type		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Aggregate	767	767	767
Bitumen (Asphalt Binder)	972	972	972
Cement	4,268	4,268	4,268
Steel	1,185	1,185	1,185
Water	1	1	1
Transportation Fuel	891	891	891
Construction Fuel	9,163	9,163	9,163
O&M fuel (DGEs)	371	371	371
Total	**17,616**	**17,616**	**17,616**

	Total Greenhouse Gas Emissions Reductions Relative to BAU				
	MT CO2e	MT CO2e	MT CO2e	MT CO2e	MT CO2e
	Materials	Transportation	Construction	O&M	TOTAL
Total	-	-	-	-	-

Culverts

Examples of double box (top) and pipe culverts (bottom)

Sources: https://www.civilgeo.com/knowledge-base/hec-ras-culvert-shapes-dimensions/
researchgate.net/publication/254958586_Freshwater_Fish_Habitat_Rehabilitation_in_the_Mackay_Whitsunday_Region

ICE characterizes single box culverts, double box culverts, and pipe culverts of various sizes and lengths.

Box culverts are typically constructed with reinforced concrete with thickness and size dependent on application. Box culvert designs are based on a maximum fill height of 10 feet. Pipe culverts are smaller drainage structures with common diameters ranging from one to four feet depending on application. Pipe culvert prototypes include corrugated steel pipe and reinforced concrete headwalls on both ends.

In ICE, culvert size follows a small/medium/large classification. Approximate pipe diameter/cell size is shown to illustrate these sizes. *Project* mode allows for customization of pipe diameter, length, width, etc. by selecting the "custom" culvert size.

Specification

Select Mitigation Strategies

	Number of culverts	Avg culvert length (ft)
Medium (e.g., 8'x8' cell or 24" pipe)	14	3,211

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		2,152	114
Cement		34,138	6,363
Steel		74,103	5,077
Water		13	2
Total		110,405	11,556

Materials Transportation		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		8,863	868
Total		8,863	868

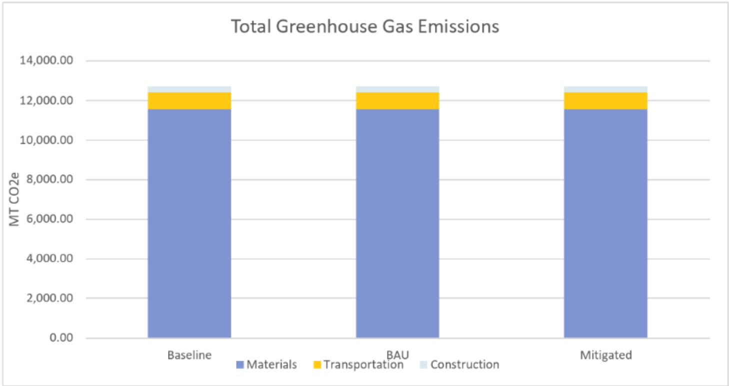
Construction Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Construction fuel (DGEs)		3,134	307
Total		3,134	307

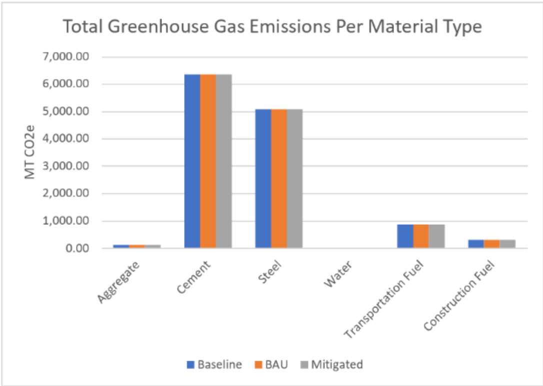
Mitigated Results

20 year Annualized Results	Annualized Energy Use – Baseline: Energy use (mmBTU)	Annualized Energy Use – BAU: Energy use (mmBTU)	Annualized Energy Use – Mitigated: Energy use (mmBTU)	Annualized Greenhouse Gas Emissions – Baseline: GHG emissions (MT CO2e)	Annualized Greenhouse Gas Emissions – BAU: GHG emissions (MT CO2e)	Annualized Greenhouse Gas Emissions – Mitigated: GHG emissions (MT CO2e)
Aggregate	108	108	108	6	6	6
Cement	1,707	1,707	1,707	318	318	318
Steel	3,705	3,705	3,705	254	254	254
Water	1	1	1	0	0	0
Transportation Fuel	443	443	443	43	43	43
Construction Fuel	157	157	157	15	15	15
Materials subtotal	5,520	5,520	5,520	578	578	578
Transportation subtotal	443	443	443	43	43	43
Construction subtotal	157	157	157	15	15	15
Total	6,120	6,120	6,120	637	637	637

Results - Charts

Show	Total Greenhouse Gas Emissions	Units	MT CO2e





	Total Greenhouse Gas Emissions		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Materials	11,556	11,556	11,556
Transportation	868	868	868
Construction	307	307	307
Total	**12,731**	**12,731**	**12,731**

	Total Greenhouse Gas Emissions Per Material Type		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Aggregate	114	114	114
Cement	6,363	6,363	6,363
Steel	5,077	5,077	5,077
Water	2	2	2
Transportation Fuel	868	868	868
Construction Fuel	307	307	307
Total	**12,731**	**12,731**	**12,731**

	Total Greenhouse Gas Emissions Reductions Relative to BAU				
	MT CO2e Materials	MT CO2e Transportation	MT CO2e Construction	MT CO2e O&M	MT CO2e TOTAL
Total	-	-	-	-	-

Lighting

Example of vertical with arm lighting.
Source: http://www.sanengineeringllc.com/Projects/Structural-Engineering-NMDOT.php

ICE estimates the energy and GHG emissions associated with lighting use projects. Annual energy consumption will be paired with energy emission factors for individual states to determine GHG emissions.

Roadway lighting projects can be a significant contributor to the annual energy use and GHG emissions of many transportation agencies. ICE estimates the energy and GHG emissions associated with lighting projects. ICE evaluates the impacts of two of the most common lighting technologies: High Pressure Sodium (HPS) & Light Emitting Diode (LED). It includes lifecycle impacts associated with common support structures: High Mast, Vertical, and Vertical with arm.

Note that ICE only includes roadway lighting energy and GHG emissions from the use phase and lighting support structures, as manufacturing energy and emissions for HPS and LED luminaries and replacement parts is currently poorly characterized.

Specification

Select Mitigation Strategies

Lighting Structures		Avg number of HPS lights per roadway mile	Avg number of LED lights per roadway mile
Support Structure Type	Lumen Range		
Vertical	4000-5000	-	-
Vertical	7000-8800	-	-
Vertical	8500-11500	-	-
Vertical	11500-14000	-	48.0
Vertical	21000-28000	-	53.0
Vertical and Vertical with 8' Arm	4000-5000	-	-
Vertical and Vertical with 8' Arm	7000-8800	-	-
Vertical and Vertical with 8' Arm	8500-11500	-	-
Vertical and Vertical with 8' Arm	11500-14000	-	-
Vertical and Vertical with 8' Arm	21000-28000	-	42.0
High Mast	28800 - 42000	-	-
High Mast	46500-52800	-	-
High Mast	52500-58300	-	-

Number of roadway miles	9

ICE Model - Alternative 3 Modified

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		53	3
Aluminum			
Cement		839	156
Steel		7,414	638
Water		0	0
Total		8,307	797

Materials Transportation		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		66	6
Total		66	6

Construction Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Construction fuel (DGEs)		-	-
Total		-	-

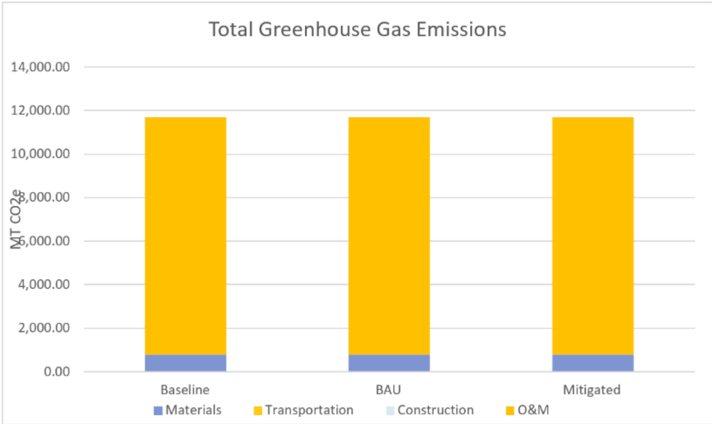
Operations and Maintenance		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		77,987	10,886
Maintenance fuel (DGEs)		-	-
Water		-	-
Total		77,987	10,886

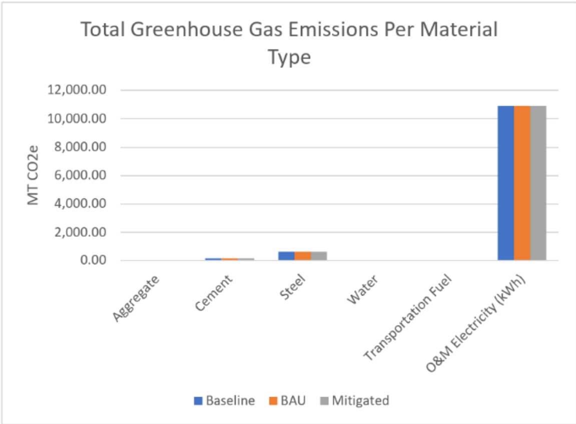
Mitigated Results

	Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
20 year Annualized Results	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	3	3	3	0	0	0
Aluminum	-	-	-	-	-	-
Cement	42	42	42	8	8	8
Steel	371	371	371	32	32	32
Water	0	0	0	0	0	0
Transportation Fuel	3	3	3	0	0	0
Construction Fuel	-	-	-	-	-	-
O&M Electricity (kWh)	3,899	3,899	3,899	544	544	544
Materials subtotal	415	415	415	40	40	40
Transportation subtotal	3	3	3	0	0	0
Construction subtotal	-	-	-	-	-	-
Operations & Maintenance subtotal	3,899	3,899	3,899	544	544	544
Total	4,318	4,318	4,318	584	584	584

Results - Charts

Show	Total Greenhouse Gas Emissions	Units	MT CO2e





	Total Greenhouse Gas Emissions		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Materials	797	797	797
Transportation	6	6	6
Construction	-	-	-
O&M	10,886	10,886	10,886
Total	**11,689**	**11,689**	**11,689**

	Total Greenhouse Gas Emissions Per Material Type		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Aggregate	3	3	3
Cement	156	156	156
Steel	638	638	638
Water	0	0	0
Transportation Fuel	6	6	6
O&M Electricity (kWh)	10,886	10,886	10,886
Total	**11,689**	**11,689**	**11,689**

ICE Model - Alternative 3 Modified

	Total Greenhouse Gas Emissions Reductions Relative to BAU				
	MT CO2e	MT CO2e	MT CO2e	MT CO2e	MT CO2e
	Materials	Transportation	Construction	O&M	TOTAL
Total	-	-	-	-	-

Bicycle and Pedestrian Pathways

Example separated bike (top) and pedestrian pathway (bottom).

Source: https://altaplanning.com/separated-bike-lanes/ ; https://www.fhwa.dot.gov/publications/research/safety/pedbike/05085/pptchapt9.cfm

ICE characterizes the new construction, resurfacing, and restriping of off-street bicycle or pedestrian paths, on-street bicycle lanes, and on-street pedestrian sidewalks.

On-street bicycle lanes applies where new roadway service is constructed for a bicycle lane. Roadway resurfacing of existing surfaces to create a bicycle lane should be included under 'Resurfacing'. Bicycle lanes created by restriping existing roadway space should be entered under 'Restriping'. However, restriping will not affect the energy and GHG estimates of the tool, since energy expended in restriping is negligible compared to energy expended in resurfacing or new construction.

Pedestrian facilities include the construction and resurfacing of new off-street paths and the construction of new on-street sidewalk miles. Note that sidewalk construction must be entered in this table, as roadway projects are assumed to include no sidewalks. For example, plans that include sidewalks on all newly constructed roads should multiply centerline miles of roadway by two to calculate construction of new on-street sidewalk miles. Only new construction of sidewalks is included in the tool because property owners are typically responsible for maintenance and repair of sidewalks.

Specification

Select Mitigation Strategies

Bicycle and Pedestrian Facilities	New Construction	Resurfacing
Off-Street Bicycle or Pedestrian Path - miles	19	-
On-Street Bicycle Lane - lane miles	-	-
On-Street Sidewalk - miles	-	N/A

New lane or right-of-way - lane miles	19
Converted or upgraded lane/facility - lane miles	-
New sidewalk - sidewalk miles	-

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		2,252	121
Bitumen (Asphalt Binder)		2,625	203
Cement		-	-
Steel		50	4
Water		-	-
Total		4,926	328

Materials Transportation		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		1,293	127
Total		1,293	127

Construction Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Construction fuel (DGEs)		3,045	298
Total		3,045	298

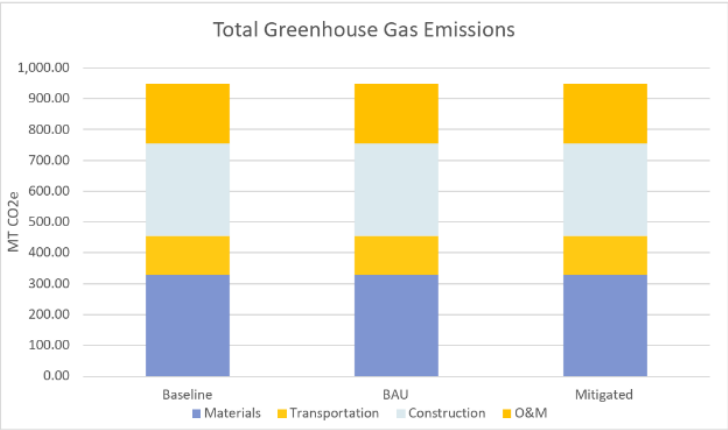
Operations and Maintenance		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		-	-
Maintenance fuel (DGEs)		1,992	195
Water		-	-
Total		1,992	195

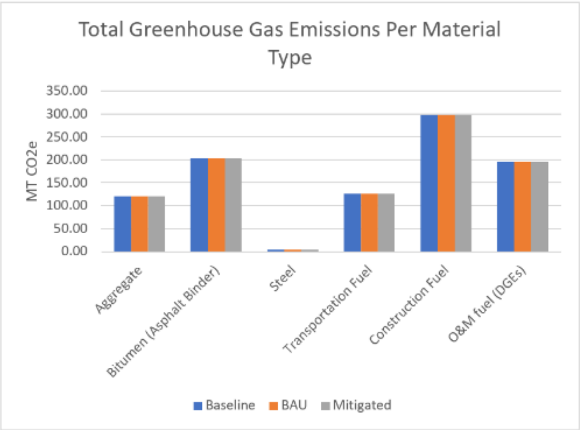
Mitigated Results

	Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
20 year Annualized Results	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	113	113	113	6	6	6
Bitumen (Asphalt Binder)	131	131	131	10	10	10
Cement	-	-	-	-	-	-
Steel	2	2	2	0	0	0
Water	-	-	-	-	-	-
Transportation Fuel	65	65	65	6	6	6
Construction Fuel	152	152	152	15	15	15
O&M fuel (DGEs)	100	100	100	10	10	10
Materials subtotal	246	246	246	16	16	16
Transportation subtotal	65	65	65	6	6	6
Construction subtotal	152	152	152	15	15	15
Operations & Maintenance subtotal	100	100	100	10	10	10
Total	563	563	563	47	47	47

Results - Charts

Show	Total Greenhouse Gas Emissions	Units	MT CO2e





	Total Greenhouse Gas Emissions		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Materials	328	328	328
Transportation	127	127	127
Construction	298	298	298
O&M	195	195	195
Total	**948**	**948**	**948**

	Total Greenhouse Gas Emissions Per Material Type		
	MT CO2e	MT CO2e	MT CO2e
	Baseline	BAU	Mitigated
Aggregate	121	121	121
Bitumen (Asphalt Binder)	203	203	203
Steel	4	4	4
Transportation Fuel	127	127	127
Construction Fuel	298	298	298
O&M fuel (DGEs)	195	195	195
Total	**948**	**948**	**948**

	Total Greenhouse Gas Emissions Reductions Relative to BAU				
	MT CO2e	MT CO2e	MT CO2e	MT CO2e	MT CO2e
	Materials	Transportation	Construction	O&M	TOTAL
Total	-	-	-	-	-

Roadways

Roadway example.
Source: https://commons.wikimedia.org/wiki/File:Veterans_Memorial_Parkway,_London,_Ontario.jpg

ICE accounts for the full roadway lifespan, including construction, rehabilitation, routine maintenance, and preventive maintenance. ICE handles these activities in different ways. Separate inputs are required for construction, rehabilitation, and effects of preventative maintenance. Specifically:

•New construction – The user enters lane miles of construction (or centerline miles of shoulder improvement) projects. Separately, the user indicates what fraction of roadway construction is in difficult terrain.

•Roadway rehabilitation – The user enters expected lane miles for reconstruction and resurfacing projects the length of the analysis period. Separately, the user enters a rehabilitation schedule. (Defaults are provided and used if no values are entered.) As a general rule of thumb, new roadways require resurfacing after 15 years and reconstruction after 30 years. Note that roadway rehabilitation applies to both existing and new roadways. This can lead to unexpectedly high operations and maintenance energy consumption and GHG emissions.

•Preventive maintenance – Preventive maintenance is pavement preservation techniques, such as crack sealing, patching, chip seals, and micro-surfacing, that prolong the life of the pavement. In ICE2.0, the user has the option to specify an extension of the roadway rehabilitiation schedule due to implementation of a (generic) preventive maintenance program. Application of preventative maintenance is accessible on the *Mitigation Strategies* tab. Note that the energy and emissions "cost" of a preventative maintenance program is based on an average of several potential strategies from different studies. More specific values may be obtainable from FHWA's Pavement LCA tool (when it becomes available).

Emissions and energy associated with routine maintenance (sweeping, striping, bridge deck repair, litter pickup, and maintenance of appurtenances) and roadway rehabilitation is automatically estimated per lane mile of both new and existing roadways associated with your project. To estimate associated use-phase emissions, visit the Vehicle Operations tab.

Note that roadway projects do not include sidewalks. If your project or plan includes constructing sidewalks, they should be entered separately in the Rail, Bus, Bicycle, and Pedestrian Facilities section of the tool.

Note that ICE2.0 does not calculate energy or GHG emissions savings from pavement smoothness effects related to any resurfacing and reconstruction projects.

ICE also does not intrinsically allow customized pavement configurations. Most analyses should use this *Roadway* tab and ICE's internal pavement configuration. The *Custom Pavement* analysis relies on external data rather than ICE's calculations to estimate lifecycle values for different configurations. Please see the *Custom Pavement* tab for more information. Users should not enter both *Roadway* and *Custom Pavement* values for the same project.

Example: The user enters new construction of 10 lane miles of new freeway, with an analysis period of 40 years. Assuming that all construction takes place in year 1, the user enters 10 lane miles of freeway resurfacing (assumed to take place in year 15) and 10 lane miles of freeway reconstruction (assumed to take place in year 30). The tool automatically includes routine maintenance of the 10 newly constructed lane miles. The user has the option of specifying a generic preventive maintenance program, which will increase the longevity of the pavement surface and therefore reduce the amount of energy and emissions associated with resurfacing and rehabilitation.

Specification

Select Mitigation Strategies

Roadway System	Existing	New	Total
Total centerline miles	10	7	17
Total lane miles	115	147	262

Roadway Projects

			Facility type						
			Rural Interstates	Rural Principal Arterials	Rural Minor Arterials	Rural Collectors	Urban Interstates / Expressways	Urban Principal Arterials	Urban Minor Arterials / Collectors
Roadway Lane Width (feet) (before construction)		Default	12	11	11	11	12	11	11
Roadway System	Existing Roadways (ICE equivalent lane miles)		0.0	0.0	0.0	0.0	68.2	5.7	41.1
Roadway Construction	New Roadway (ICE equivalent lane miles)		0.0	0.0	0.0	0.0	91.6	6.7	43.2
Roadway Construction	Construct Additional Lane (equivalent lane miles)		0.0	0.0	0.0	0.0	5.6	0.0	0.0

Include roadway rehabilitation activities (reconstruct and resurface)	Yes
% roadway construction on rocky / mountainous terrain	0%

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions	Construction: Energy use (mmBTU)	Construction: GHG emissions (MT CO2e)	O&M Roadway Rehabilitation: Energy use (mmBTU)	O&M Roadway Rehabilitation: GHG emissions (MT CO2e)
Aggregate	68,699	3,712	46,923	2,623
Bitumen (Asphalt Binder)	85,778	6,637	86,693	6,707
Cement	71,581	13,341	52,009	9,693
Steel	92,892	7,641	36,425	2,858
Water	27	4	20	3
Total	318,977	31,334	222,070	21,884

Materials Transportation	Construction: Energy use (mmBTU)	Construction: GHG emissions (MT CO2e)	O&M Roadway Rehabilitation: Energy use (mmBTU)	O&M Roadway Rehabilitation: GHG emissions (MT CO2e)
Transportation fuel (DGEs)	40,654	3,982	25,848	2,532
Total	40,654	3,982	25,848	2,532

Construction Process	Construction: Energy use (mmBTU)	Construction: GHG emissions (MT CO2e)	O&M Roadway Rehabilitation: Energy use (mmBTU)	O&M Roadway Rehabilitation: GHG emissions (MT CO2e)
Electricity (kWh)	0	0	0	0
Construction fuel (DGEs)	278,727	27,301	129,527	12,687
Total	278,727	27,301	129,527	12,687

Operations and Maintenance	Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)	-	-
Maintenance fuel (DGEs)	55,667.6	5,452.6
Roadway Rehabilitation (O&M)	377,445.5	37,103.5
Water	-	-
Total	433,113.1	42,556.1

Mitigated Results

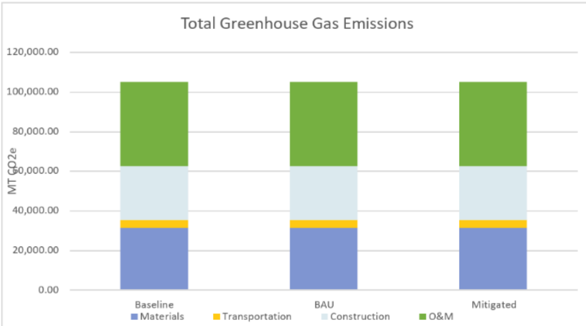
	Construction					
	Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
20 year Annualized Results	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	3,435	3,435	3,435	186	186	186
Bitumen (Asphalt Binder)	4,289	4,289	4,289	332	332	332
Cement	3,579	3,579	3,579	667	667	667
Steel	4,645	4,645	4,645	382	382	382
Water	1	1	1	0	0	0
Transportation Fuel	2,033	2,033	2,033	199	199	199
Construction Fuel	13,936	13,936	13,936	1,365	1,365	1,365
O&M fuel (DGEs)	2,783	2,783	2,783	273	273	273
O&M Roadway Rehabilitation	18,872	18,872	18,872	1,855	1,855	1,855
Materials subtotal	15,949	15,949	15,949	1,567	1,567	1,567
Transportation subtotal	2,033	2,033	2,033	199	199	199
Construction subtotal	13,936	13,936	13,936	1,365	1,365	1,365
Operations & Maintenance subtotal	21,656	21,656	21,656	2,128	2,128	2,128
Total	53,574	53,574	53,574	5,259	5,259	5,259

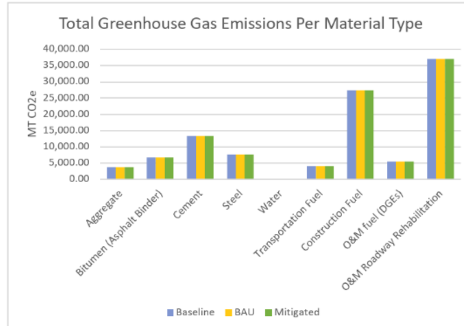
	O&M Roadway Rehabilitation					
	Annualized Energy Use			Annualized Greenhouse Gas Emissions		
	Baseline	BAU	Mitigated	Baseline	BAU	Mitigated
20 year Annualized Results	Energy use (mmBTU)	Energy use (mmBTU)	Energy use (mmBTU)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)	GHG emissions (MT CO2e)
Aggregate	2,346	2,346	2,346	131	131	131
Bitumen (Asphalt Binder)	4,335	4,335	4,335	335	335	335
Cement	2,600	2,600	2,600	485	485	485
Steel	1,821	1,821	1,821	143	143	143
Water	1	1	1	0	0	0
Transportation Fuel	1,292	1,292	1,292	127	127	127
Construction Fuel	6,476	6,476	6,476	634	634	634
O&M fuel (DGEs)	-	-	-	-	-	-
O&M Roadway Rehabilitation	18,872	18,872	18,872	1,855	1,855	1,855

ICE Model - Alternative 3 Modified

Results - Charts

Show	Total Greenhouse Gas Emissions	Units	MT CO2e





	Total Greenhouse Gas Emissions		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Materials	31,334	31,334	31,334
Transportation	3,982	3,982	3,982
Construction	27,301	27,301	27,301
O&M	42,556	42,556	42,556
Total	**105,173**	**105,173**	**105,173**

	Total Greenhouse Gas Emissions Per Material Type		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Aggregate	3,711.6	3,711.6	3,711.6
Bitumen (Asphalt Binder)	6,637	6,637	6,637
Cement	13,341	13,341	13,341
Steel	7,641	7,641	7,641
Water	4	4	4
Transportation Fuel	3,982	3,982	3,982
Construction Fuel	27,301	27,301	27,301
O&M fuel (DGEs)	5,453	5,453	5,453
O&M Roadway Rehabilitation	37,103	37,103	37,103
Total	**105,173**	**105,173**	**105,173**

	Total Greenhouse Gas Emissions Reductions Relative to BAU				
	MT CO2e Materials	MT CO2e Transportation	MT CO2e Construction	MT CO2e O&M	MT CO2e TOTAL
Total	-	-	-	-	-

Signage

Example large, medium, and small signs.

Source: dot.state.mn.us/trafficeng/publ/tem/2009/Chapter-06.pdf; https://www.defensivedriving.org/dmv-handbook/29-unusual-road-signs/; https://www.waaytv.com/content/news/School-bus-warning-signs-installed-on-Highway-43-463727923.html

ICE divides the signage category is divided into small, medium, and large structures representing the three most common types of roadway signs. Small and medium sized signs are typically regulatory and warning signs supported by a single post. Large signs include overhead guidance highway signs, typically supported by two posts or hung overhead on large steel cantilever arms. Signage infrastructure is a combination of aluminum sheet metal, and directly embedded or concrete encased supports.

The user enters the average number of each type of sign per roadway mile and the total project roadway miles.

Specification

Select Mitigation Strategies

Signage Structures	Avg. number of signs per roadway mile
Small (3'x3') - 14 Gauge Steel Post (MDOT SIGN-150-D)	1,469.0
Medium (6'x6') - 14 Gauge Steel Posts (MDOT SIGN-150-D)	53.0
Large (10'x14') - 8 Gauge Cantilever Arm (MDOT SIGN-300-A)	186.0

Number of roadway miles	9

Baseline Energy Use and GHG Emissions

Material Energy Use and Emissions		Energy use (mmBTU)	GHG emissions (MT CO2e)
Aggregate		206	11
Aluminum		19,985	1,327
Cement		3,261	608
Steel		108,818	9,416
Water		1	0
Total		132,270	11,361

Materials Transportation		Energy use (mmBTU)	GHG emissions (MT CO2e)
Transportation fuel (DGEs)		423	41
Total		423	41

Construction Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		0	0
Construction fuel (DGEs)		0	0
Total		0	0

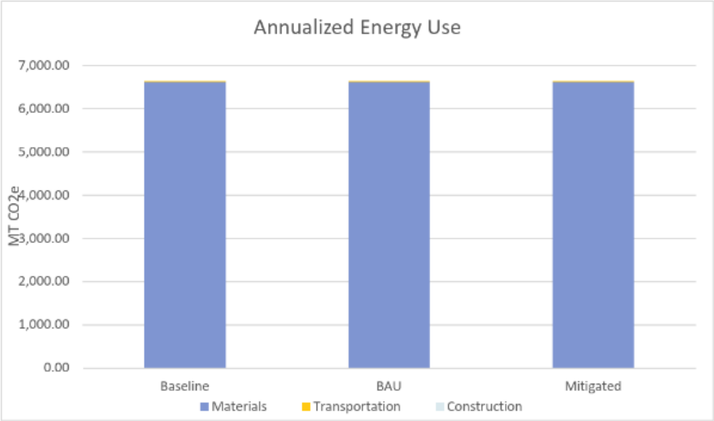
Operations and Maintenance		Energy use (mmBTU)	GHG emissions (MT CO2e)
Electricity (kWh)		0	0
Maintenance fuel (DGEs)		0	0
Water		0	0
Total		0	0

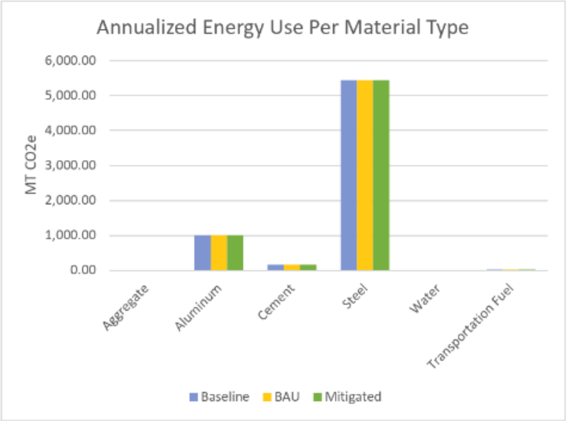
Mitigated Results

20 year Annualized Results	Annualized Energy Use – Baseline Energy use (mmBTU)	Annualized Energy Use – BAU Energy use (mmBTU)	Annualized Energy Use – Mitigated Energy use (mmBTU)	Annualized Greenhouse Gas Emissions – Baseline GHG emissions (MT CO2e)	Annualized Greenhouse Gas Emissions – BAU GHG emissions (MT CO2e)	Annualized Greenhouse Gas Emissions – Mitigated GHG emissions (MT CO2e)
Aggregate	10	10	10	1	1	1
Aluminum	999	999	999	66	66	66
Cement	163	163	163	30	30	30
Steel	5,441	5,441	5,441	471	471	471
Water	0	0	0	0	0	0
Transportation Fuel	21	21	21	2	2	2
Construction Fuel	-	-	-	-	-	-
Materials subtotal	6,614	6,614	6,614	568	568	568
Transportation subtotal	21	21	21	2	2	2
Construction subtotal	-	-	-	-	-	-
Total	6,635	6,635	6,635	570	570	570

Results - Charts

Show	Annualized Energy Use	Units	MT CO2e





	Annualized Energy Use		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Materials	6,614	6,614	6,614
Transportation	21	21	21
Construction	-	-	-
Total	**6,635**	**6,635**	**6,635**

	Annualized Energy Use Per Material Type		
	MT CO2e Baseline	MT CO2e BAU	MT CO2e Mitigated
Aggregate	10	10	10
Aluminum	999	999	999
Cement	163	163	163
Steel	5,441	5,441	5,441
Water	0	0	0
Transportation Fuel	21	21	21
Total	**6,635**	**6,635**	**6,635**

	Annualized Energy Use Reductions Relative to BAU				
	MT CO2e Materials	MT CO2e Transportation	MT CO2e Construction	MT CO2e O&M	MT CO2e TOTAL
Total	-	-	-	-	-

Vehicle Operations and Construction Delay Emissions

Example of Vehicle Operations
Source: https://www.greencarreports.com/news/1093560_1-2-billion-vehicles-on-worlds-roads-now-2-billion-by-2035-report

ICE estimates vehicle operations impacts of infrastructure projects from two distinct effects:

•Vehicle operating emissions – The user enters the years, average daily traffic (AADVMT), and average speed for the opening, design, and horizon years on the project. ICE computes the cumulative operating emissions over on the project's lifetime.
•Construction delay emissions – The user enters the years, average daily traffic (AADVMT), and average speed for the year construction starts, project opening year, and the baseline year for comparison (typically the year before construction starts). ICE computes the additional energy and GHG emissions due to vehicle delay during construction.

Note that mitigations are not applicable for vehicle operating emissions. Also, the calcualtions reflect a standard automobile fleet. They should not be used to estimate bus emissions on BRT or train emissions from Light- or Heavy-Rail. Also, results are integrated over the project lifetime. (I.e., "baseline" doesn't just mean baseline year.)

Estimates of emissions and additional energy use from construction delay and vehicle operating emissions are meant to provide a rough sense of the scale of emissions relative to the construction processes themselves, and are not meant to replace estimates derived from traffic modeling software. Planned construction projects that will result in significant lane closures on high volume roads should be evaluated using traffic modeling software.

Specification

Vehicle Operations Emissions

	Year	Avg Daily VMT on project	Speed
Project Opening Year	2030	2035600	NA
Project Interim Year	2040	2292300	NA
Project Design/Horizon Year	2050	2551000	NA

Construction Delay, Additional Emissions

	Year	Avg Daily VMT Impacted by project	Speed
Construction start year	2024	1856000	NA
Pre-construction (baseline) year	2021	1780000	60.0
Project Opening Year	2030		

Baseline Energy Use and GHG Emissions

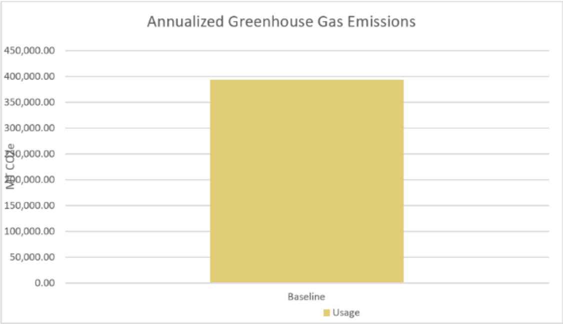
Usage Process		Energy use (mmBTU)	GHG emissions (MT CO2e)
Vehicle Operating Emissions		97,534,952	7,483,319
Construction Delay		4,827,695	368,356
Total		102,362,647	7,851,675

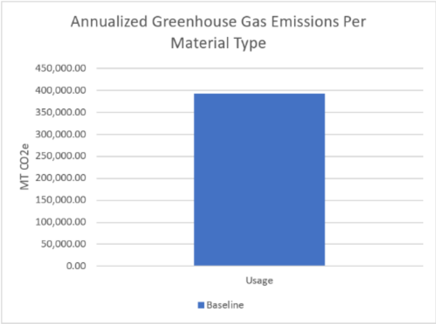
Mitigated Results

	Annualized Energy Use	Annualized Greenhouse Gas Emissions
	Baseline	Baseline
20 year Annualized Results	Energy use (mmBTU)	GHG emissions (MT CO2e)
Usage Emissions	5,118,132	392,584
Materials subtotal	-	-
Transportation subtotal	-	-
Construction subtotal	-	-
Usage subtotal	5,118,132	392,584
Total	5,118,132	392,584

Results - Charts

Show	Annualized Greenhouse Gas Emissions	Units	MT CO2e





No mitigations are available for Vehicle Ops.

	Annualized Greenhouse Gas Emissions MT CO2e Baseline
Usage	392,584
Total	**392,584**

	Annualized Greenhouse Gas Emissions Per MT CO2e Baseline
Usage	392,584
Total	**392,584**

Appendix B: Supplemental Climate Change Analysis Information

Climate Model Projections

Appendices B, B-1, and B-2 provide additional detailed information for Section 4: Project Level Assessment of Climate Change in the Technical Report.

B.1 Data and Overview

Travis County is projected to become warmer and drier with increasing periods of drought and subject to periodic extreme weather events. Freezing temperatures are expected to be reduced, but storms such as Winterstorm Uri could periodically impact Travis County even with an overall warming trend.

Future Travis County climate projections were obtained from the USGCRP National Climate Assessment 2014 county-level GIS tables, from the Dynamic General Vegetation Model (MC1) model taken from Geos Institute, the Texas Forest Service, and the USGS National Climate Change Viewer (NCCV). The NCCV data are based on 20 downscaled climate model simulations from the Coupled Model Intercomparison Project Phase 5 (CMIP5).

Please refer to NCA2014 and the NCCV for further details on the data used and their assumptions. TxDOT received copies of the Texas GIS tables that were part of the background information for the USGCRP 2014 National Climate Assessment TxDOT has not yet obtained similar GIS tables for the 2018 National Climate Assessment. The NCA 2014 data provided looks at the relative change in climate variables between current measurements and projected measurements. “Historical” data come from the 1971-2000 average for each variable, and these figures are compared to the 2041-2070 projected averages according to both the B1 (lower emissions) and A2 (higher emissions) scenarios. These figures are up-to-date through December 2016. NCCV predicts to the period of 2075-2099, from a base period of 1981-2010.

The climate models in the CMIP5 use a set of emission scenarios (called Representative Concentration Pathways [RCPs]) to reflect potential trajectories of greenhouse gas emissions over the century. Four scenario pathways are (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) used in the CMIP5. NCCV and NCA2014 both use RCP4.5 and RCP8.5. As discussed in Section 5.2.2, Climate Change Analysis Limitations in the Capital Express Central Greenhouse Gas and Climate Change Technical Report, RCP4.5 corresponds to the lower emissions scenario (about 650 ppm CO_2E) in which humans reduce and stabilize global emissions. Hence, temperatures do not increase by more than 2^{o} C. In comparison, RCP8.5 refers to an emission scenario (about 1370 ppm CO_2E) where humans continue to increase emissions through the end of the 21^{st} century or a business as usual case with no additional future year GHG reduction measures.

The NCA2014 evaluates the relative change in climate variables between historic 1971-2000 average compared to 2041-2070 projected averages. The NCCV includes the historical (1950-2005) and future (2006-2099) climate and water balance projections based on 20 downscaled climate model simulations from the CMIP5 for the RCP4.5 and RCP8.5 emissions scenarios.

The NCCV allows users to visualize projected changes in climate (maximum and minimum air temperature, precipitation, vapor pressure deficit) and the water balance (snow water equivalent, runoff, soil water storage, and evaporative deficit) for any state, county, and USGS Hydrologic Units (HUC4 and HUC8) using a variety of graphics and tools.

- The NCCV provides monthly time series and averages for the historical period (1981-2010) and four future time periods (2025-2049, 2050-2074, and 2075-2099).

- The NCCV provides useful tools for characterizing climate change, including maps, climograph (plots of monthly averages), histograms that show the distribution or spread of the model simulations, time series plots, and tables that summarize projected changes. The application also provides comprehensive summary reports in PDF format and CSV files for each geographic area's climate and water balance variables.
- In addition to monthly and annual averages, the application now displays seasonal averages (Winter: December, January, February; Spring: March, April, May; Summer: June, July, August; Fall: September, October, and November).

The NCCV data report for Travis County is in **Appendix B-1**, while information on how to read and interpret the data along with key data assumptions are in the NCCV documentation report that is in **Appendix B-2**.

B.2 Projected Climate Changes

B.2.1 Extreme Weather

Austin has recently experienced significant flooding, wind storms, extreme precipitation, droughts, fires, and a major winter storm. While extreme weather is predicted to increase, the location, frequency, and severity remain uncertain. The most recent NCA report indicated: "The role of climate change in altering the frequency of the types of severe weather most typically associated with the Southern Great Plains, such as severe local storms, hailstorms, and tornadoes, remains difficult to quantify." (Cite: (USGCRP [Reidmiller, 2018), chapter 23 Southern Great Plains, page 989).

B.2.2 Temperature

In Texas, temperatures have risen almost 1.5°F (0.8°C) since the beginning of the 20th century (Runkle 2022).

Predictions

NCCV temperature data for Travis County is in Section 1 to Section 3 of C-1 Appendix: Travis County NCCV Data. The overall annual mean model temperature, annual mean model maximum temperature, and mean yearly model minimum temperature are projected to increase by the mid to late century. For example, for the 2074-2099 projected period, the annual mean model maximum temperature is projected to increase by 4.43°F (2.5°C) to 8.44°F (4.7°C) degrees for RCP4.5 to RCP8.5 respectively, compared to the 1980-2010 base year period of 79.77°F mean model data (26.54°C).

The NCA2014 data projects 1.51 to 19.48 more days for the additional number of hottest days (above 100°F) per year for RCP4.5 to RCP8.5, respectively. While TxDOT does not yet have updated NCA2018 data for Travis County, NCA2018 indicates an additional 30-60 days per year above 100°F by late in the 21st century for the State of Texas, from a base average between 1976-2005 (USGCRP [Reidmiller], 2018).

Extreme heat events are projected to be between 2-5 times more likely by the mid-century. For all three climate scenarios, the number of days per year with maximum temperatures of 95°F (35°C), 100°F (38°C), and 110°F (43°C) are projected to increase into the end of the century (GEOS, 2015). In terms of precipitation, the number of dry days is expected to increase over time, while the number of days with more than two inches of precipitation is expected to increase in variability over time.

B.2.3 Precipitation - Predictions

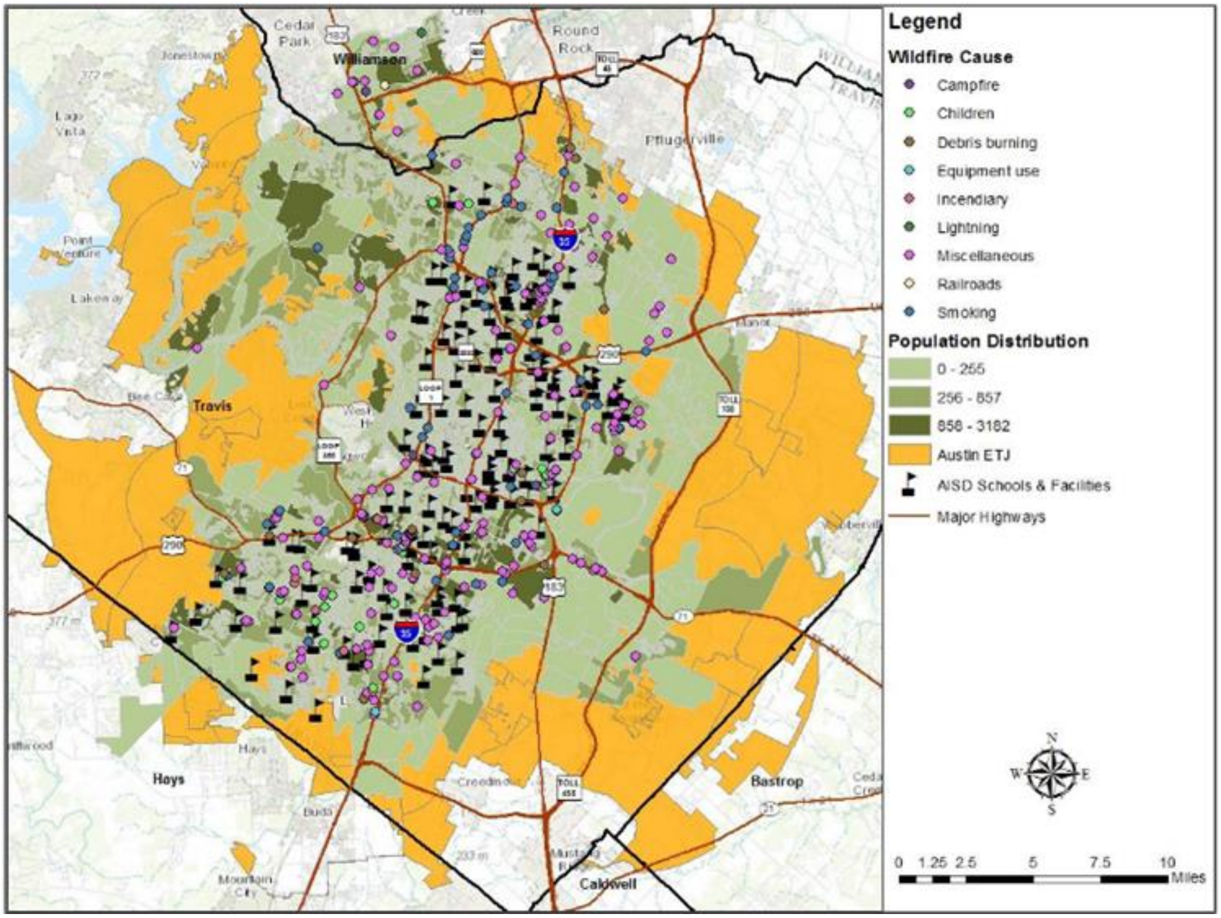
NCCV Precipitation data for Travis County is in Section 3 to Section 4 of C-1 Appendix: Travis County NCCV Data, which predicts a slight downward trend in inches per month through 2075-2099, 0.01 to 0.22 inches/per month less than base years of 1981-2010. Predicted changes in annual precipitation for Travis County are relatively constant, with less than a 1-day increase or decrease in the number of wet days per year. However, extreme events are predicted to increase, but no distinguishable patterns can be identified.

B.2.4 Wildfires

2005 to 2015

The Texas Forest Service began collecting wildfire data in 1985; however, they did not start reporting events until 2005. Although historical information was unavailable, the City of Austin experienced 305 wildfire incidents between 2005 and 2015. The most significant number of wildfires occurred in 2006, totaling 108 wildfire events (City of Austin 2016). From the wildfires occurring between 2005-2015, the historical loss estimates due to wildfires was $1.2 million, with about 475 acres burned. Figure B-1 shows the location of historic wildfire events in Austin from 2005-2015.

Figure B-1: Location and Historic Wildfire events occurring in Austin, Texas from 2005-2015

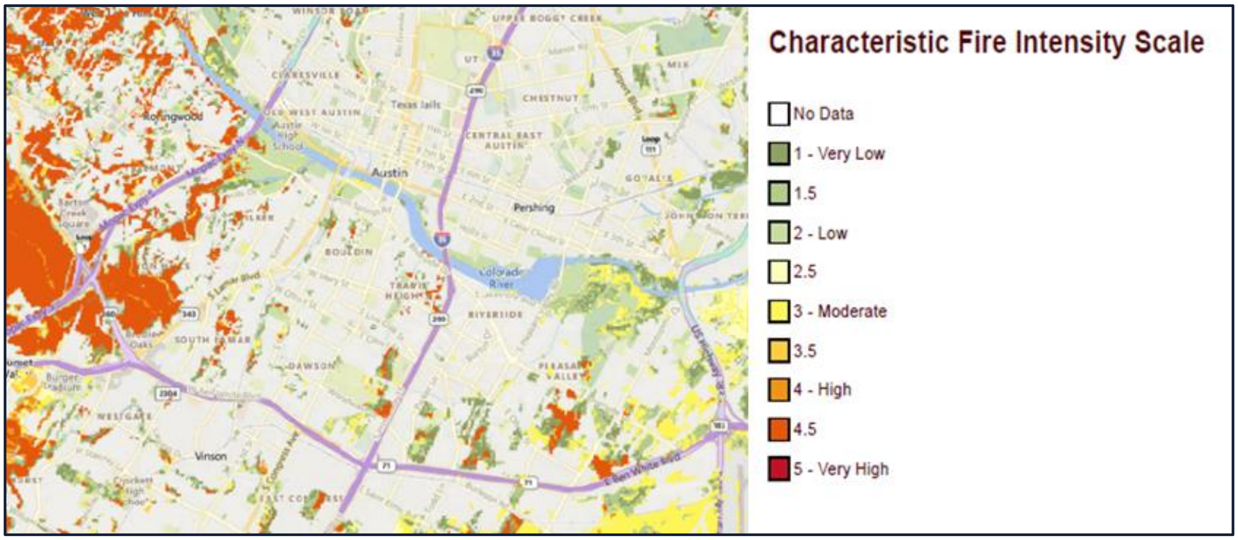


Source: Location and Historic Wildfire Events for Austin and AISD (City of Austin 2016)

Future Predictions

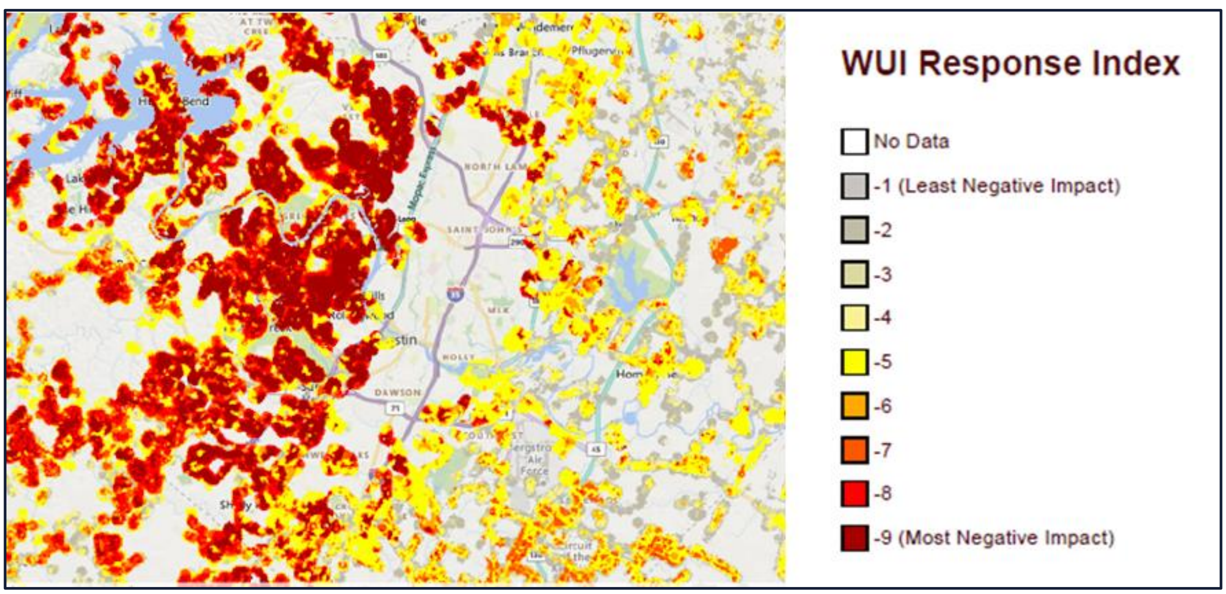
Under the high emissions scenario, the predicted range of overall area burned in wildfires in Central Texas is expected to experience a 2% decrease or a 23% increase between 2035 and 2045. Between 2075 and 2086, the range of the overall area burned in a wildfire is expected to be between a 36% decrease or a 16% increase. Late-century wildfire projections are quite variable, with possible increases and decreases depending on the global climate model used. As displayed in **Figure B-2** and **Figure B-3** from the Texas A&M Forest Service (2022), the predicted wildfire threat is low along I-35.

Figure B-2: Characteristic Fire Intensity Scale Along I-35



Source: Texas A&M Forest Service 2022

Figure B-3: WUI – Wildland Urban Interface Response Index Along I-35 Source: Texas A&M Forest Service 2022



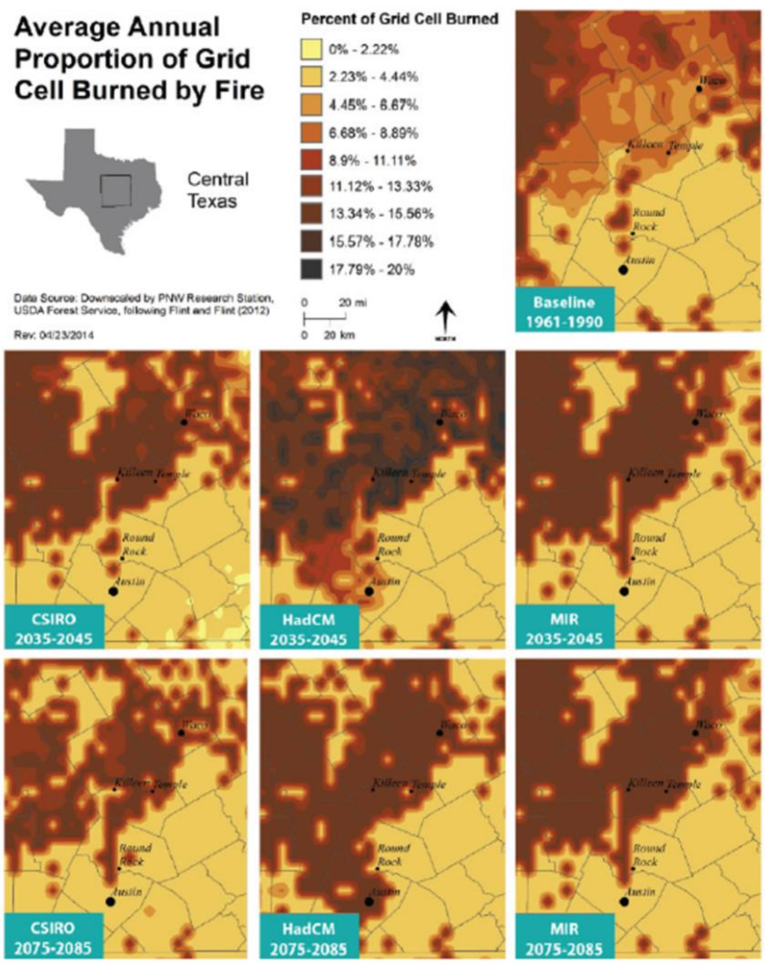
Source: Texas A&M Forest Service 2022

Using climate projections from the Dynamic General Vegetation Model (MC1) model (**Figure B-4**) taken from Geos Institute, wildfire projections for Central Texas project an increase by the mid-century; however, late century projections are variable.

However, due to the urban built environment of the project area, wildfires are an extremely low probability. Wildfires threaten infrastructure and reduce visibility. The response to the Bastrop County Complex fire in 2011 was one of the larger recent wildfires in Texas and is an example of how TxDOT responds to fires. It resulted in minor damage to guardrails and no damage to on-road system pavement; however, roads were temporarily closed due to fire hazards and visibility.

Figure B-4 The average percent of area that is affected by wildfires each year based on MC1 model results based on three utilizing the higher emissions scenario.

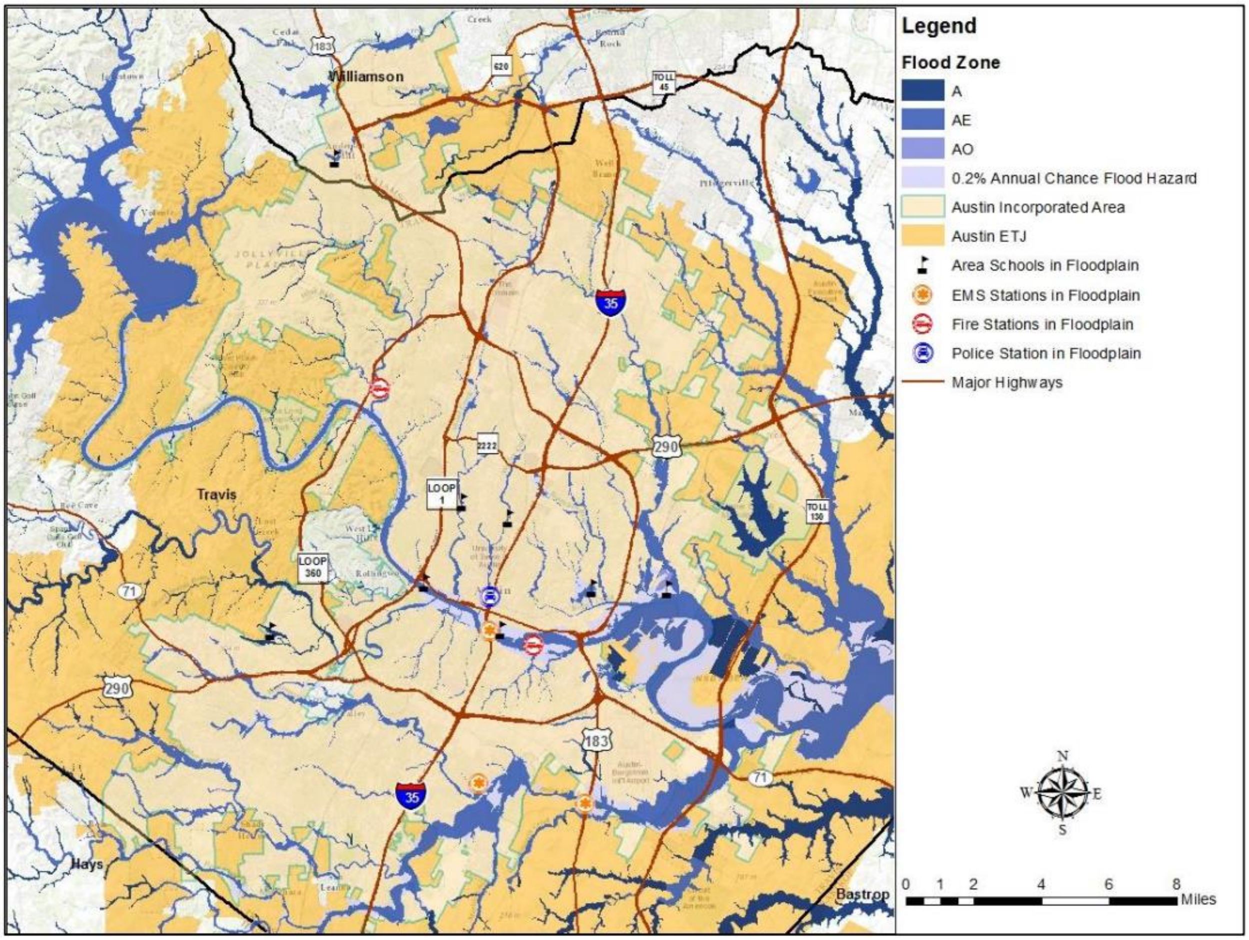
Figure 9 The average percent of the area affected by wildfire each year, based on output from the MC1 vegetation model, three GCMs (HadCM, MIR, CSIRO), and a higher emissions scenario (A2). The historic period (top) is compared to mid-century (middle row) and late-century (bottom row). The models indicate uncertainty in whether wildfire will increase or decrease.



B.2.5 Flooding

Figure B-5 depicts the current and predicted flood zones in the City of Austin based on the digital flood insurance maps from the Federal Emergency Management Agency.

Figure B-5: Estimated Flood zones in the City of Austin



Source: City of Austin Local Hazard Mitigation Plan Update (City of Austin 2016).

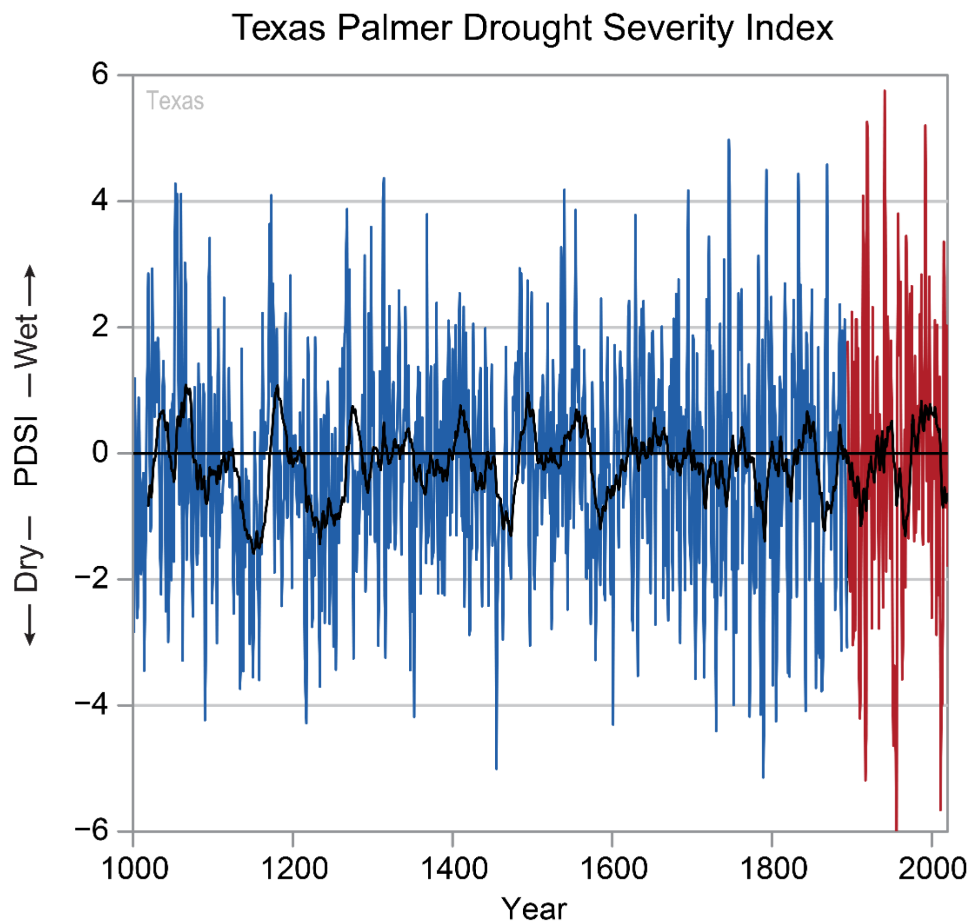
Zones A, AE, and AO flood zones are defined as an area with a 1% annual chance of flooding and a 26% chance of flooding over a 30-year period, also characterized as being within a 100-year floodplain. The 0.2% Annual Chance of Flood Hazard areas are within the 500-year floodplain.

B.2.6 Drought

Drier conditions and the potential for droughts are projected to increase by the 2075-2099. NCCV drought-related data is in Sections 8 and 9 of Appendix C-1. One of the NCCV indicators for soil dryness is the monthly evaporative deficit. From 1981-2010, the monthly evaporative deficit was 1.65 inches. By 2075-2099, the deficit is expected to increase, indicating drier soils by 0.37 inches to 0.84 inches for RCP4.5 to RCP8.5, respectively. In addition, NCA14 shows the existing average number of consecutive dry days is 27.6, projected to increase by 1.5 days for RCP4.5 and RCP8.5.

Historically, droughts have occurred in Texas in the 1910s, 1950s, and 2010s. In **Figure B-6**, values for 1895 to 2020 (red) are based on measured temperature and precipitation. Values before 1895 (blue) are estimated from indirect measures, such as tree rings. The variances between the two segments may not be consistent because of these data and methodological differences. The fluctuating black line is a running 20-year average. Periods of drought are common in Texas, and the most severe droughts since 1895 were those in 1917, 1956, and 2011. Before 1895, droughts of the severity experienced in 1917, 1956, and 2011 occurred occasionally (Runkle et al. 2022).

Figure B-6: Time Series of the Palmer Drought Severity Index for Texas from the Year 1000 to 2020

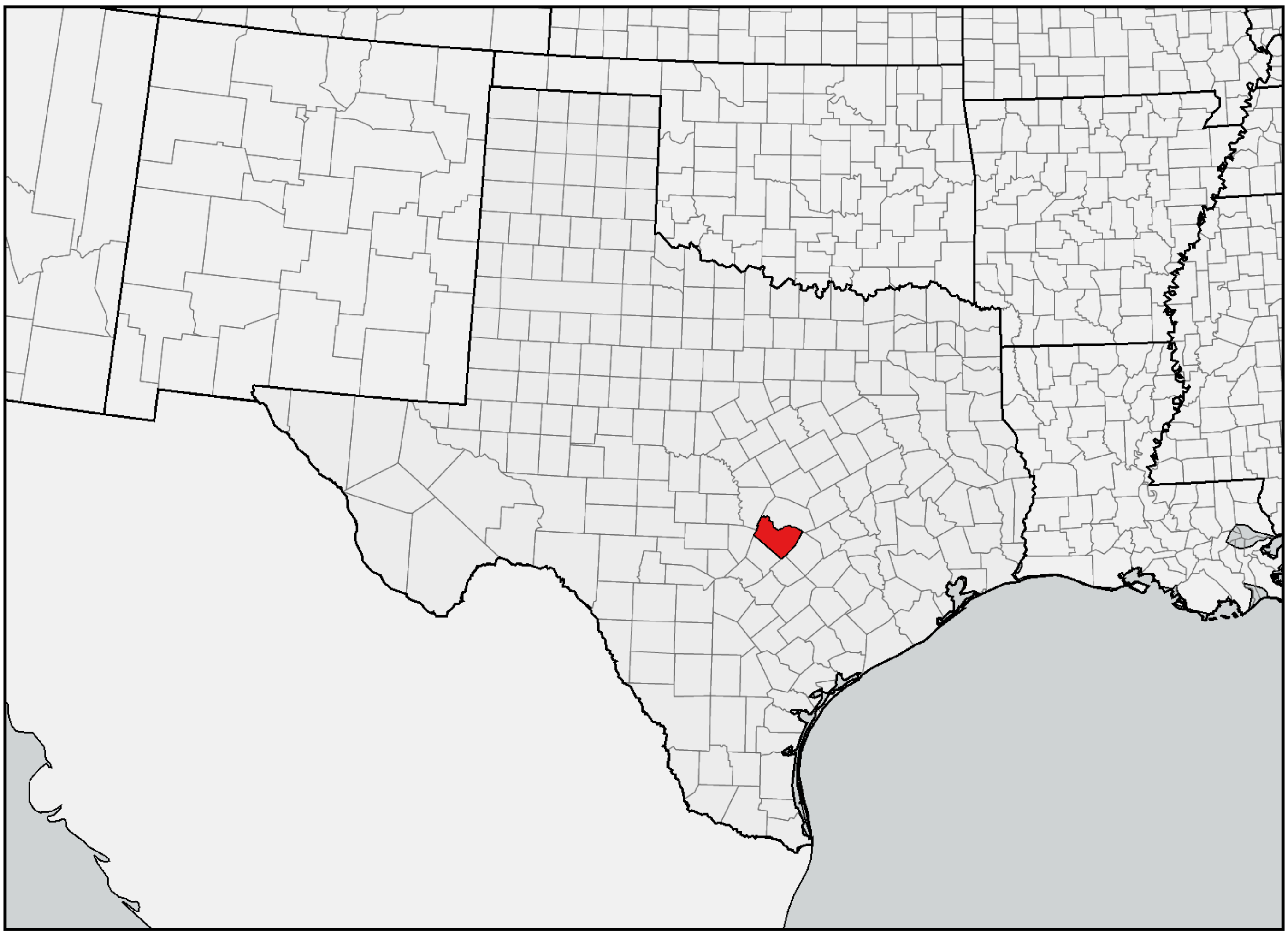


Data: nClimDiv and NADAv2 (Runkle et al. 2022).

Appendix B-1: Travis County USGS National Climate Change Viewer Report

U.S. Geological Survey - National Climate Change Viewer

Summary of Travis County, Texas



May 5, 2021

1 Mean temperature

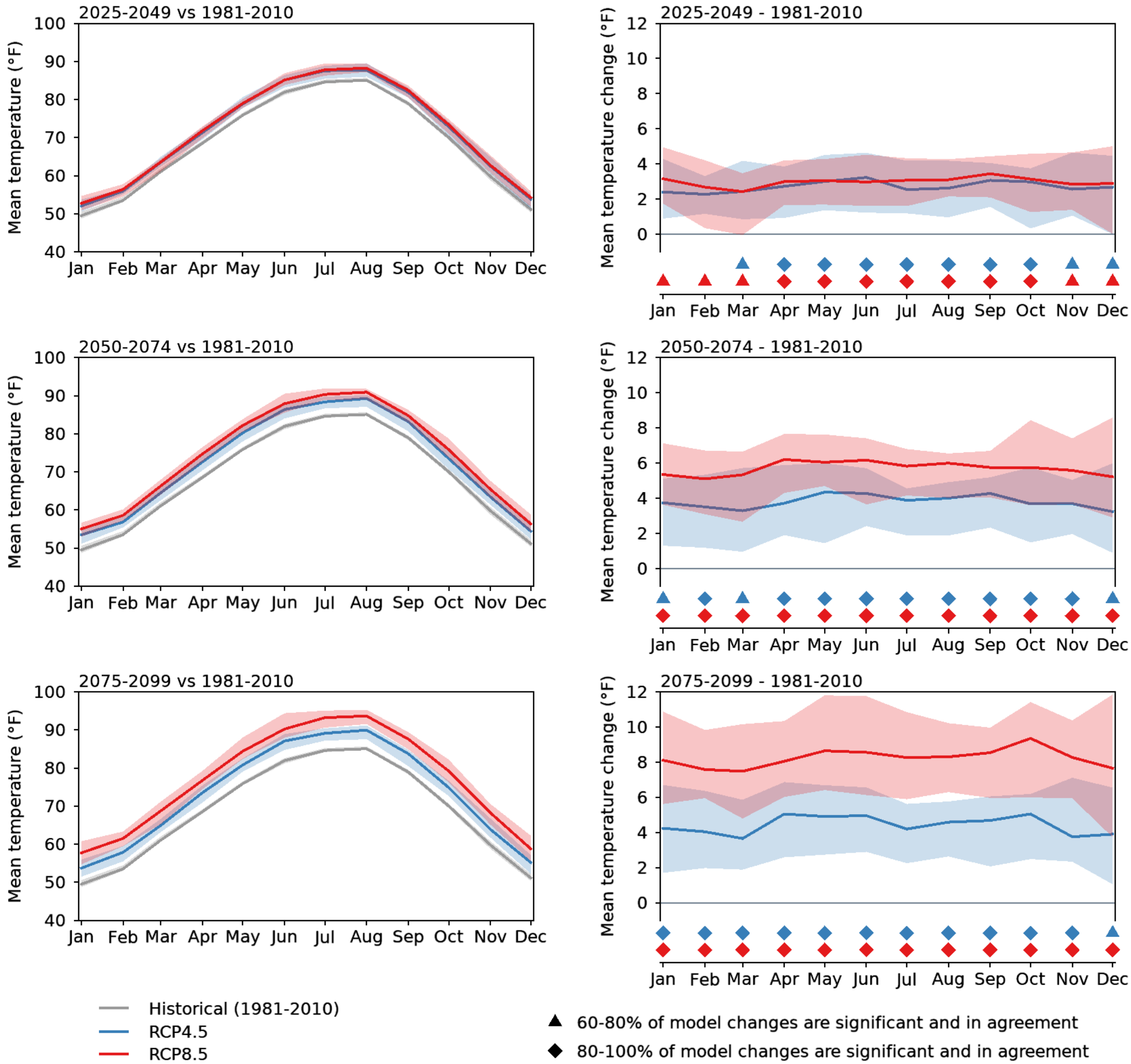


Figure 1: Monthly averages of mean temperature for the three future time periods for the RCP4.5 and RCP8.5 simulations. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes. Raw values relative to the historical simulation (1981-2010) are shown in the left column and future minus historical changes are shown in the right column. Triangle and diamond symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A Mann-Whitney rank test is used to establish significance ($\rho < 0.05$).

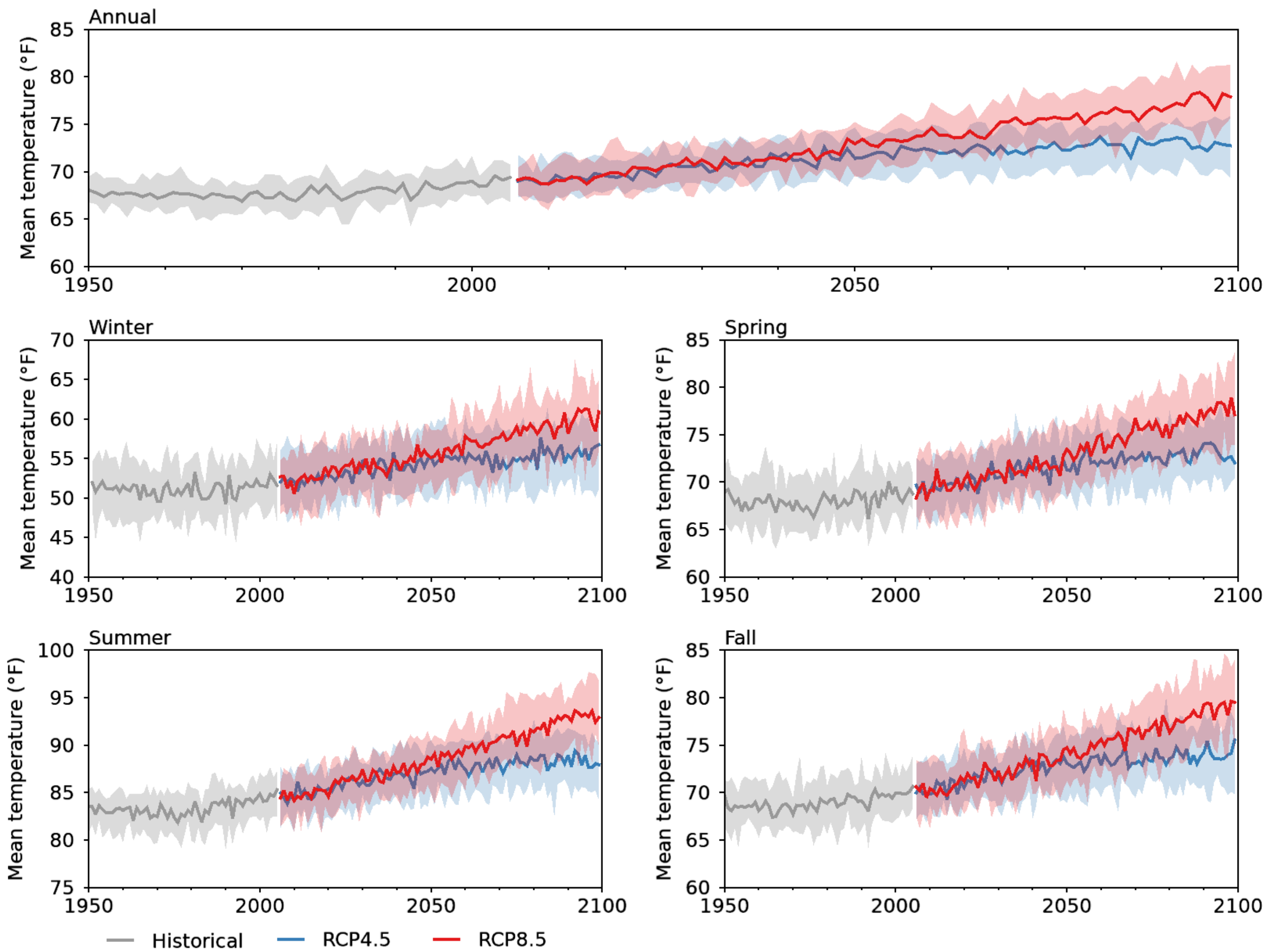


Figure 2: Annual and seasonal time series of mean temperature for historical (gray), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes.

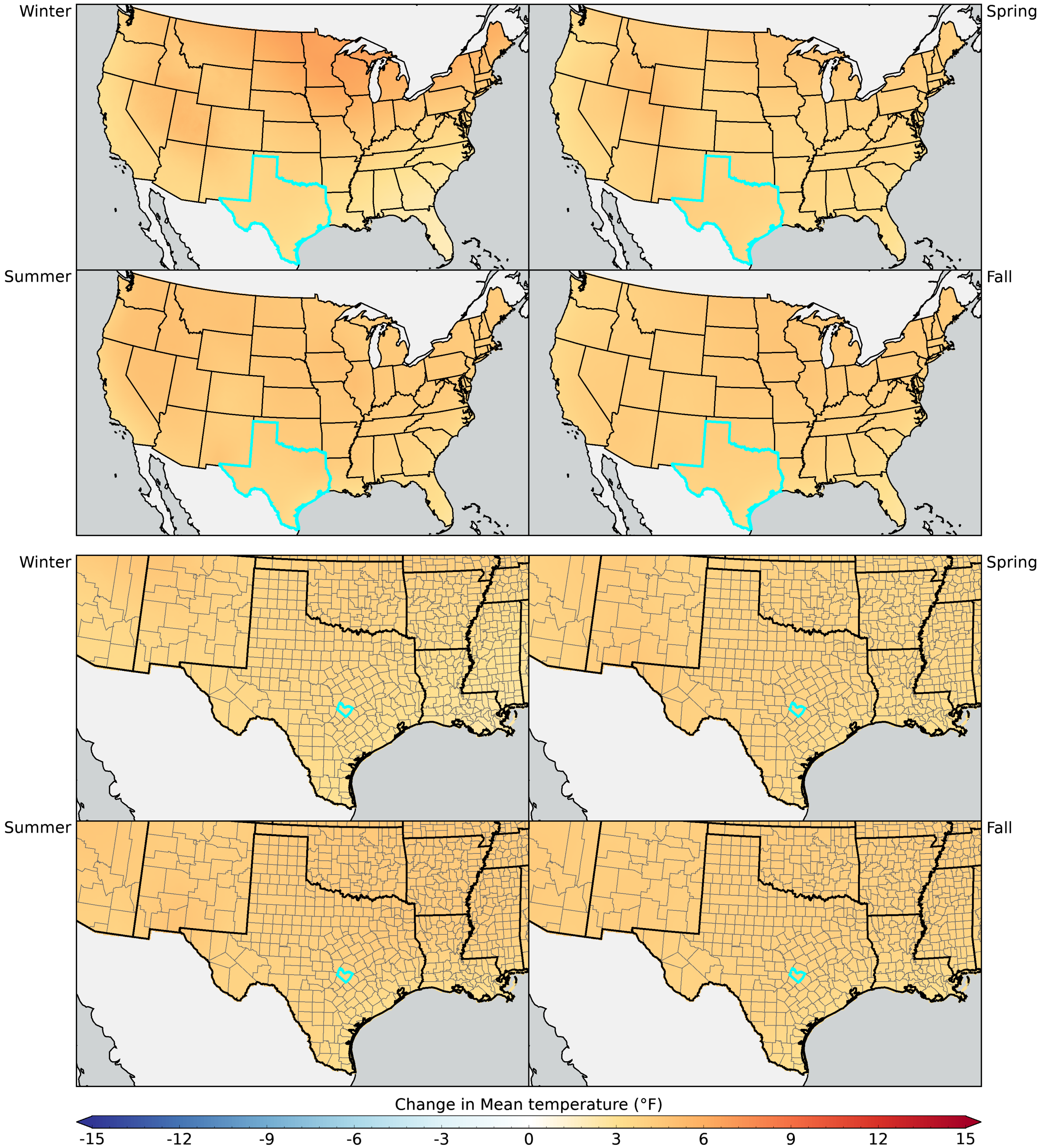


Figure 3: Seasonal maps of mean temperature for RCP4.5 2050-2074 minus 1981-2010 for the ensemble mean model.

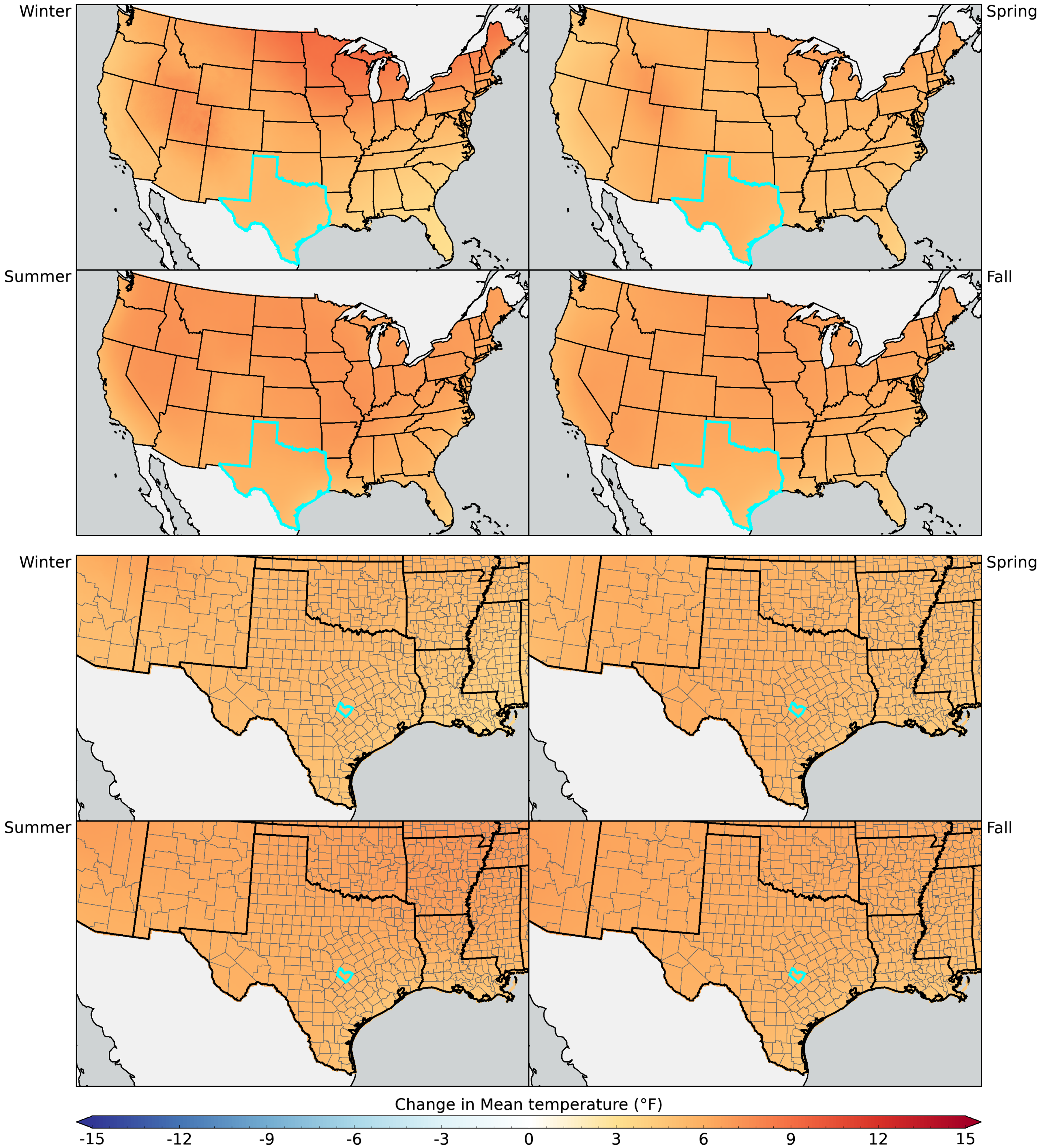


Figure 4: Seasonal maps of mean temperature for RCP8.5 2050-2074 minus 1981-2010 for the ensemble mean model.

2 Maximum temperature

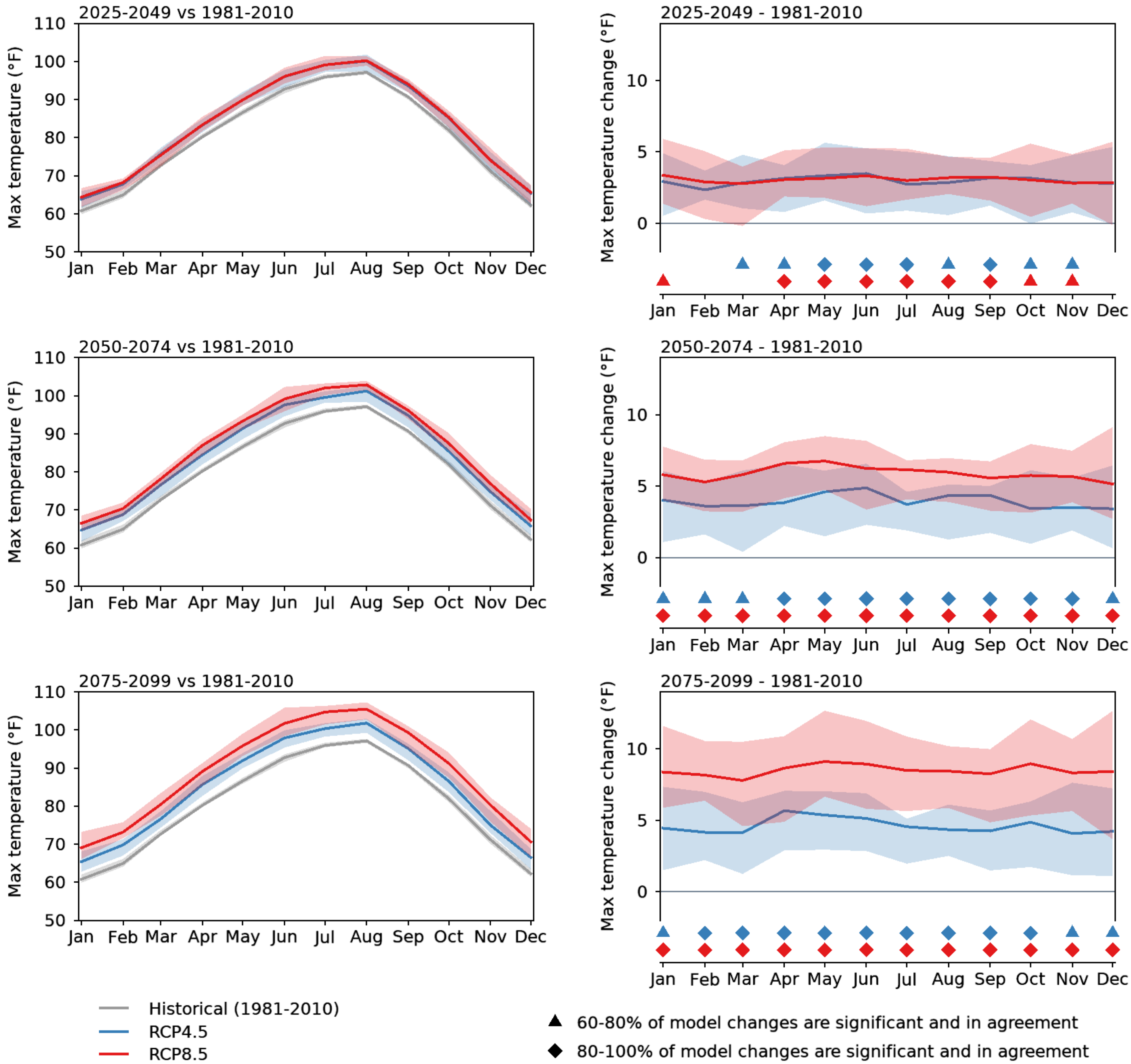


Figure 5: Monthly averages of maximum temperature for the three future time periods for the RCP4.5 and RCP8.5 simulations. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes. Raw values relative to the historical simulation (1981-2010) are shown in the left column and future minus historical changes are shown in the right column. Triangle and diamond symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A Mann-Whitney rank test is used to establish significance ($\rho < 0.05$).

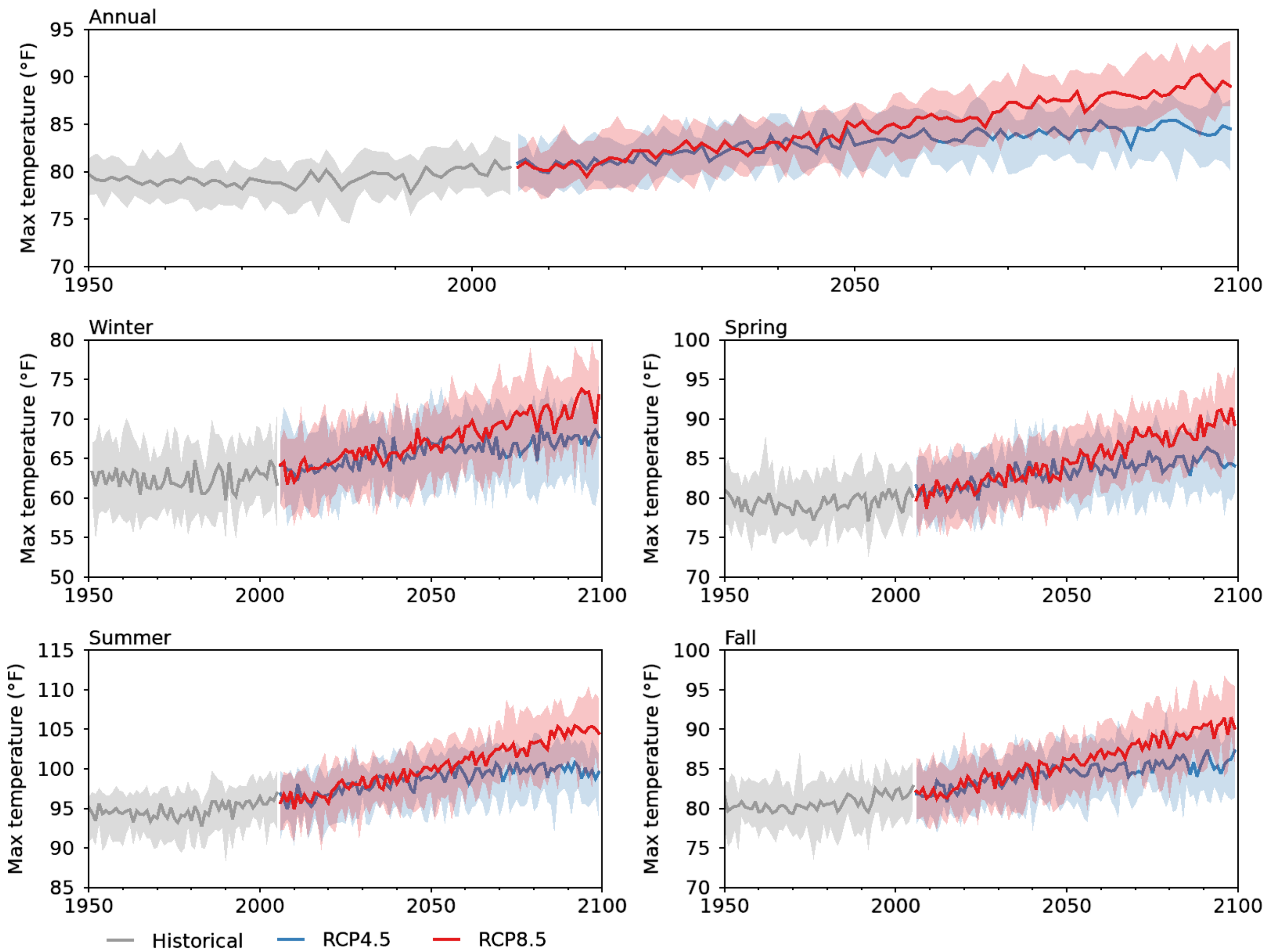


Figure 6: Annual and seasonal time series of maximum temperature for historical (gray), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes.

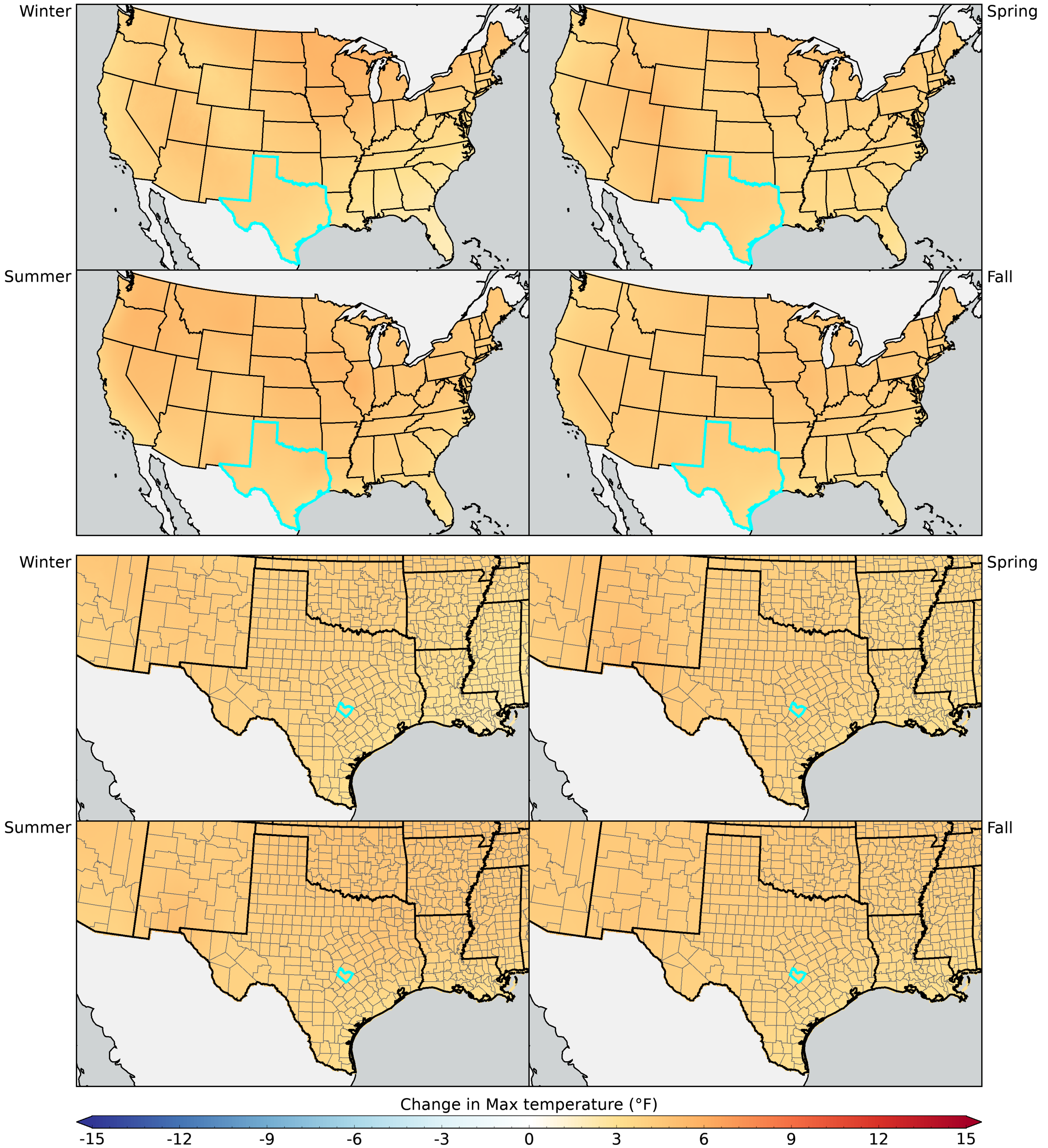


Figure 7: Seasonal maps of maximum temperature for RCP4.5 2050-2074 minus 1981-2010 for the ensemble mean model.

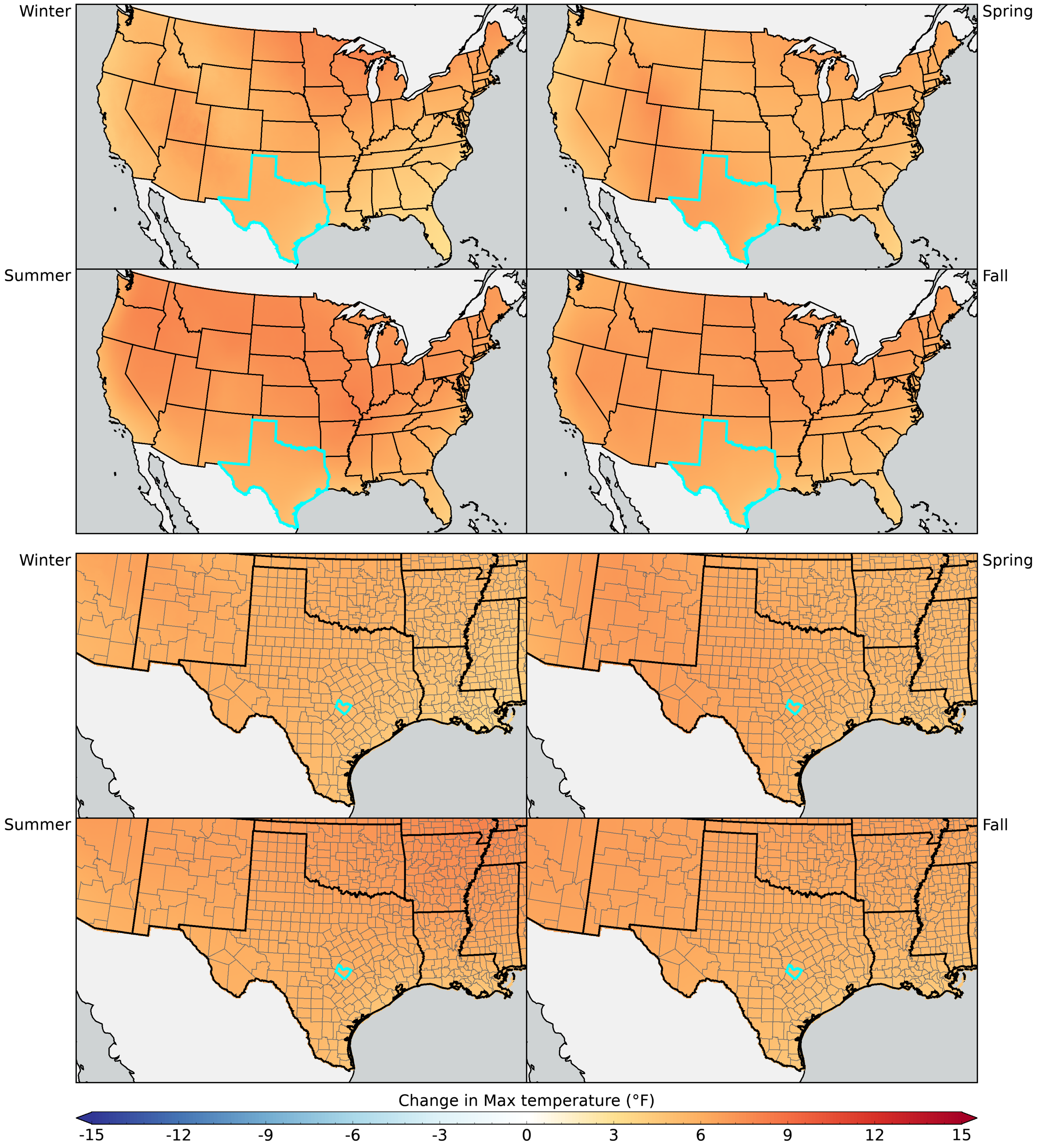


Figure 8: Seasonal maps of maximum temperature for RCP8.5 2050-2074 minus 1981-2010 for the ensemble mean model.

3 Minimum temperature

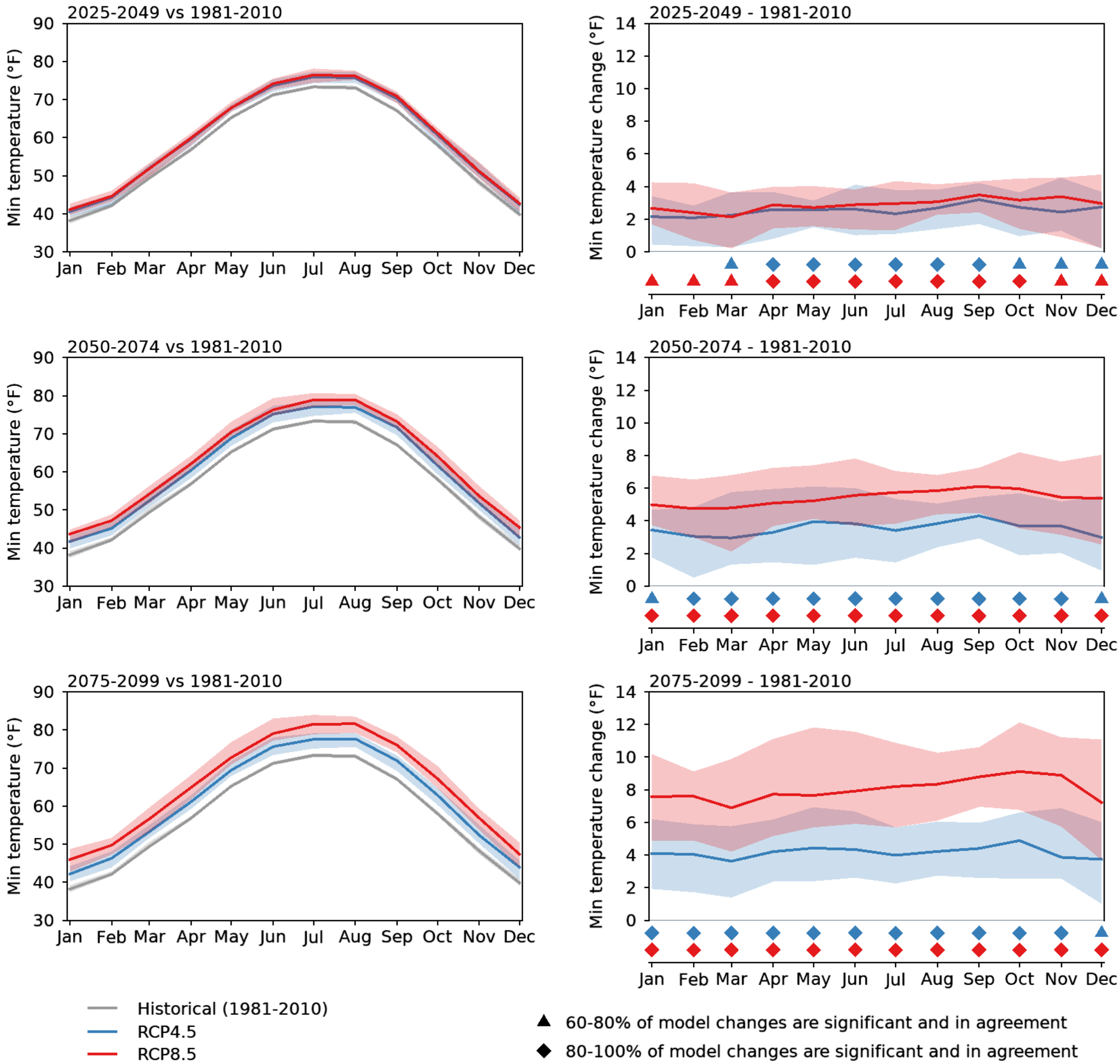


Figure 9: Monthly averages of minimum temperature for the three future time periods for the RCP4.5 and RCP8.5 simulations. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes. Raw values relative to the historical simulation (1981-2010) are shown in the left column and future minus historical changes are shown in the right column. Triangle and diamond symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A Mann-Whitney rank test is used to establish significance ($\rho < 0.05$).

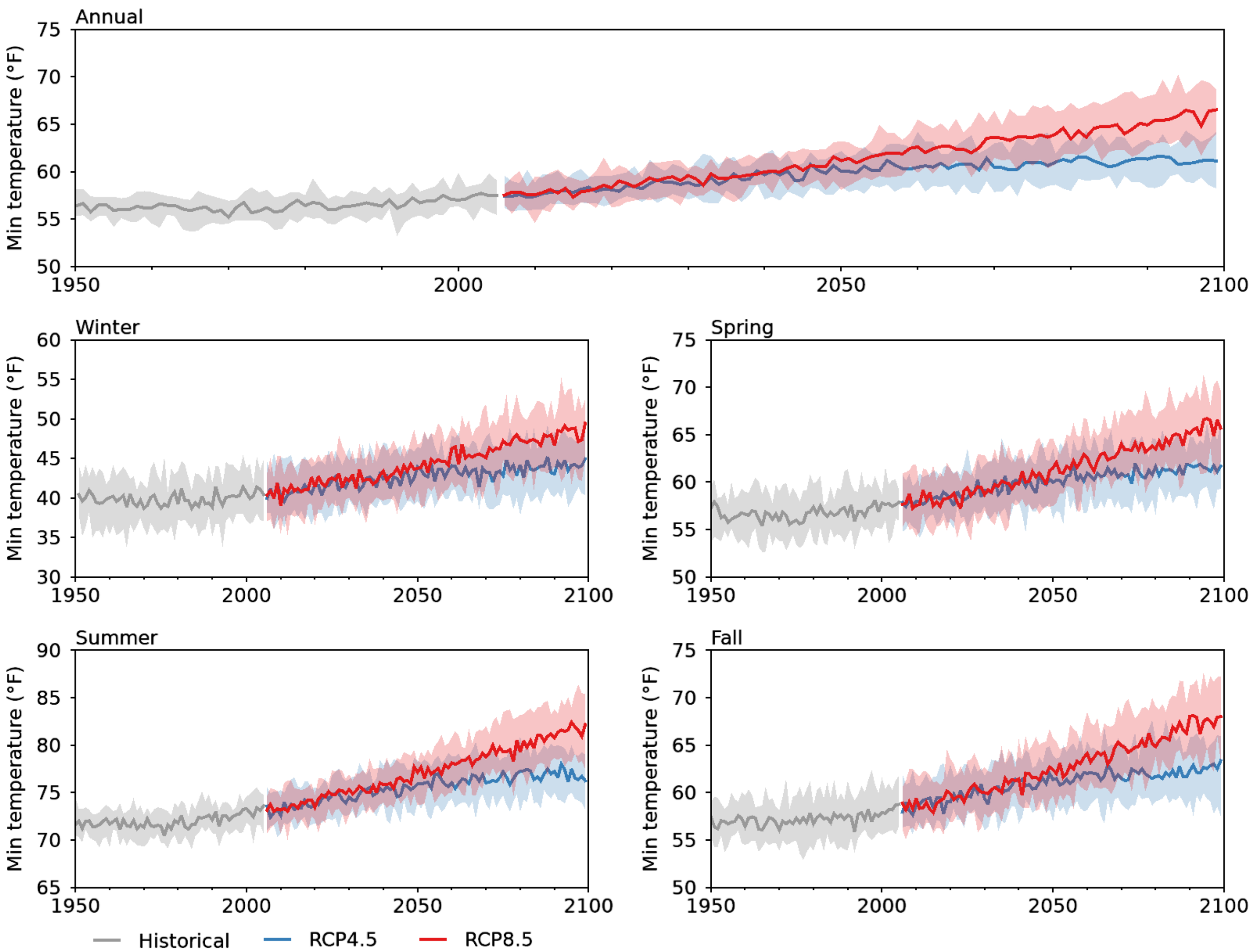


Figure 10: Annual and seasonal time series of minimum temperature for historical (gray), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes.

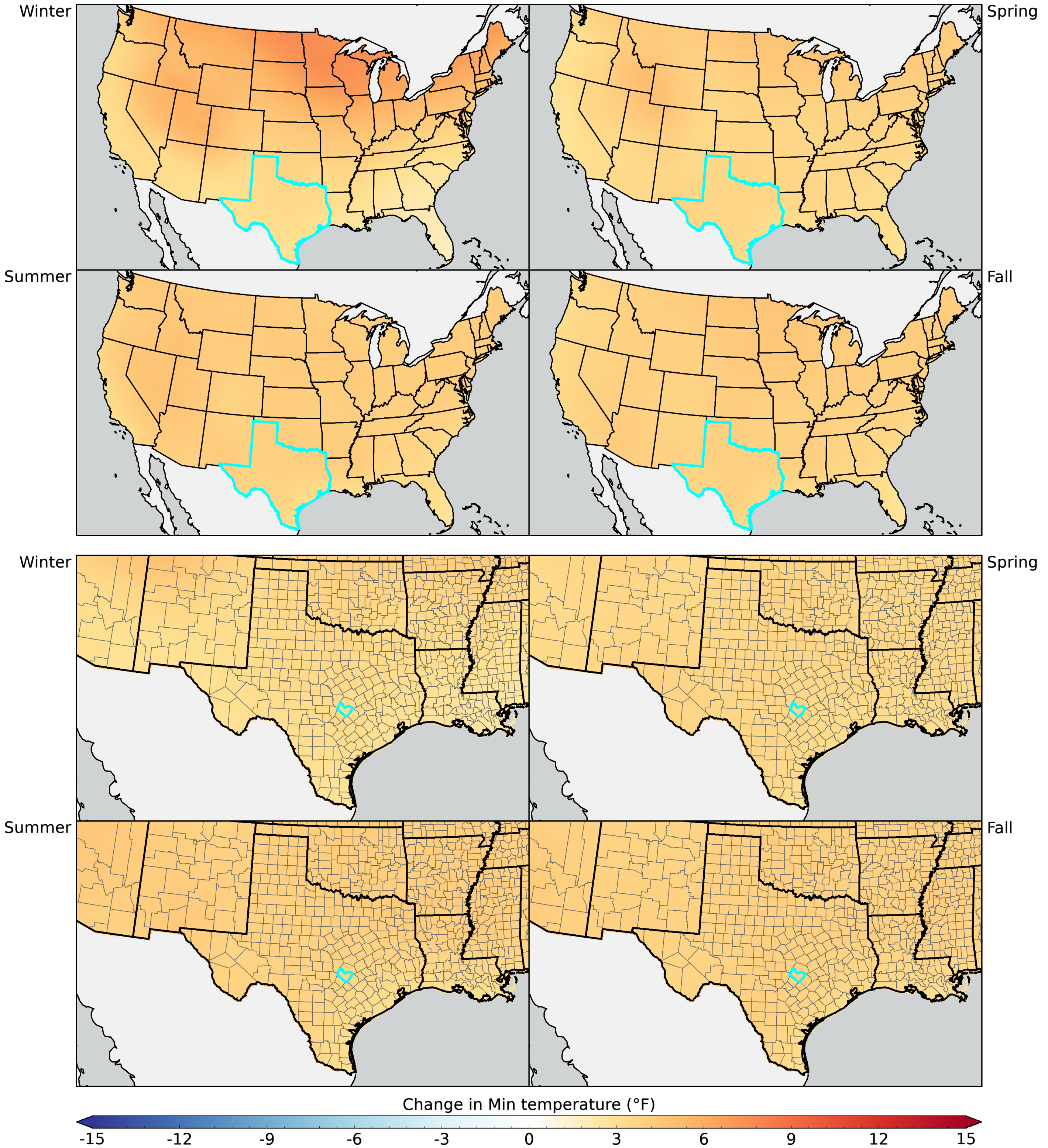


Figure 11: Seasonal maps of minimum temperature for RCP4.5 2050-2074 minus 1981-2010 for the ensemble mean model.

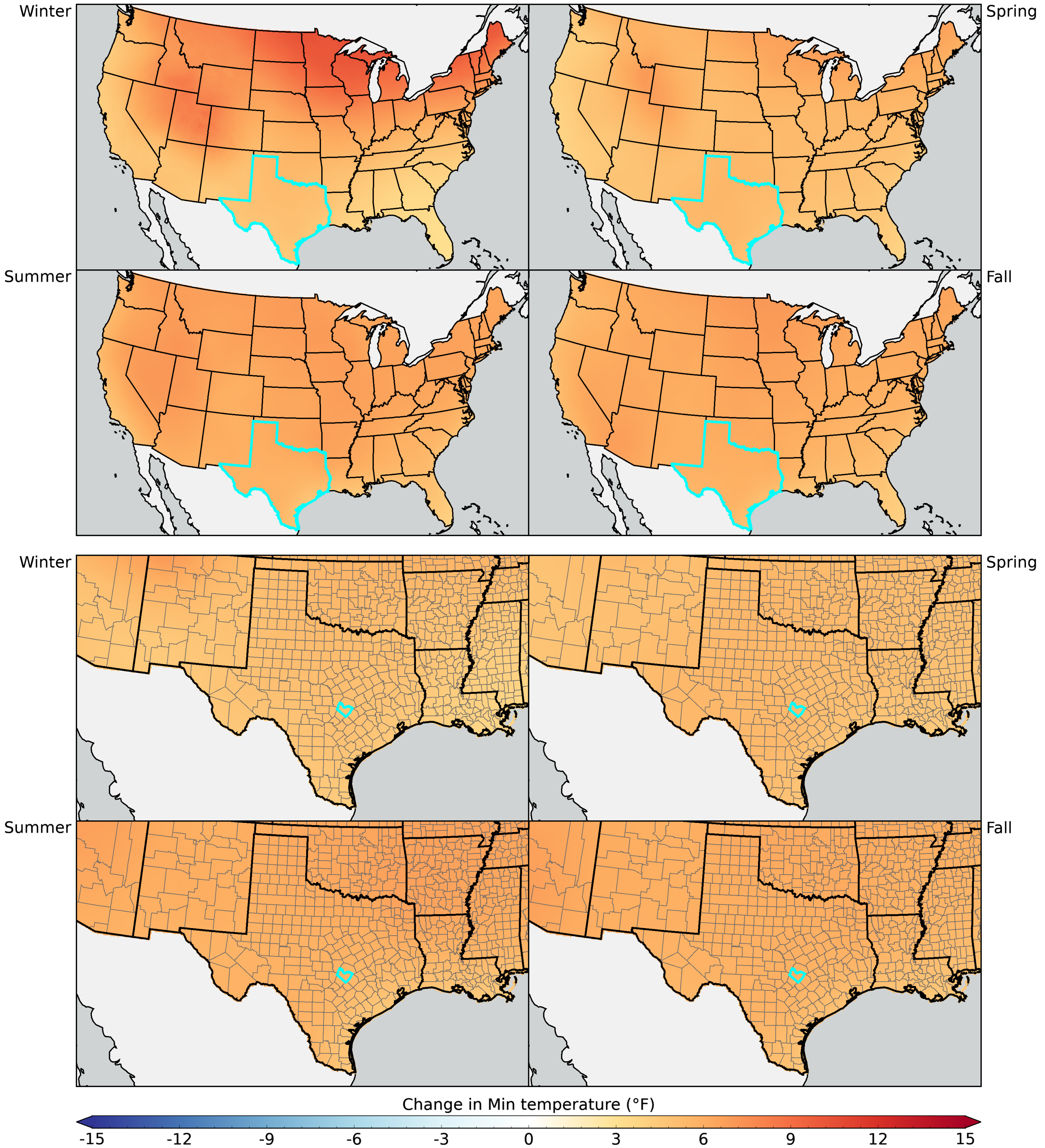


Figure 12: Seasonal maps of minimum temperature for RCP8.5 2050-2074 minus 1981-2010 for the ensemble mean model.

4 Precipitation

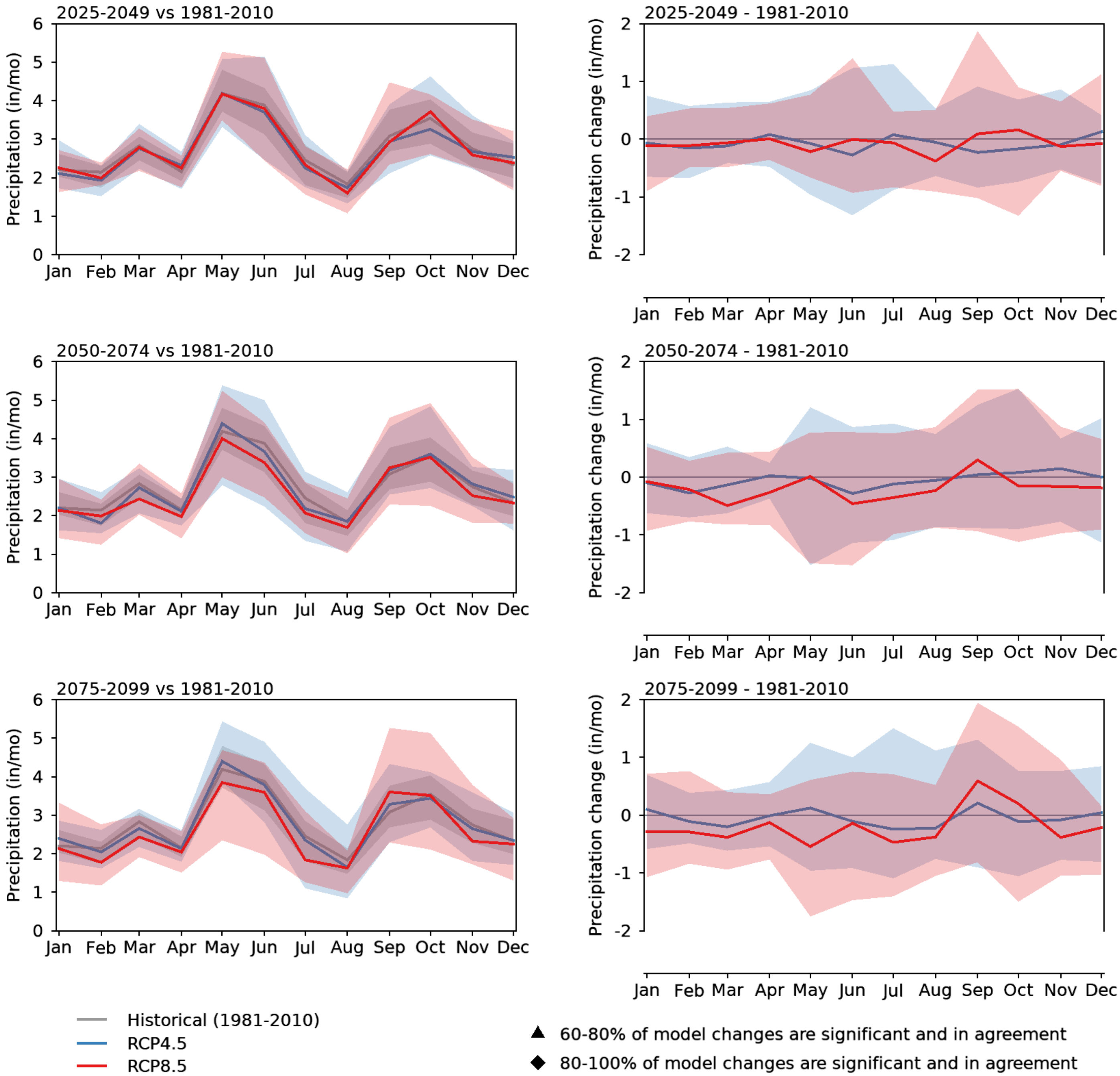


Figure 13: Monthly averages of precipitation for the three future time periods for the RCP4.5 and RCP8.5 simulations. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes. Raw values relative to the historical simulation (1981-2010) are shown in the left column and future minus historical changes are shown in the right column. Triangle and diamond symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A Mann-Whitney rank test is used to establish significance ($\rho < 0.05$).

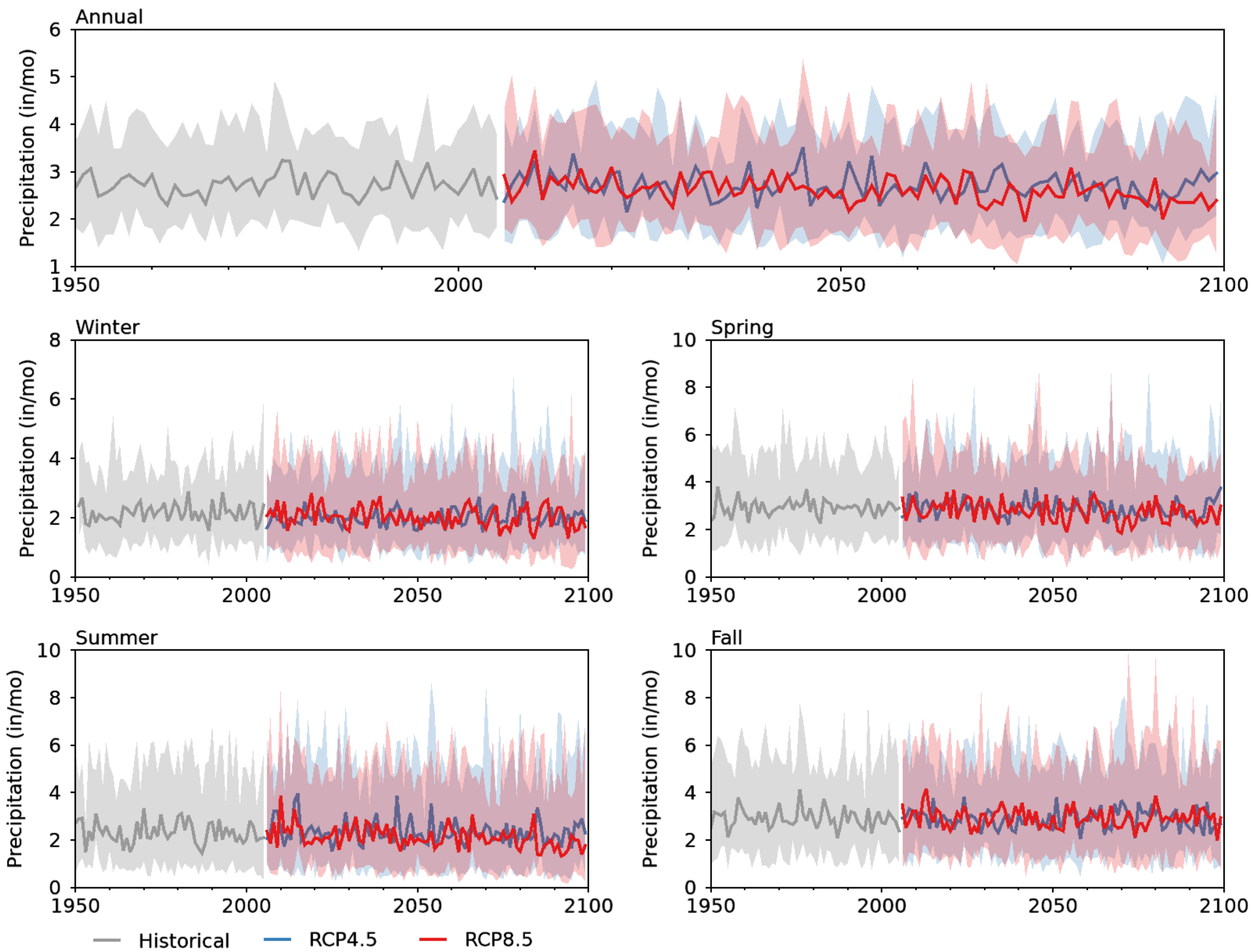


Figure 14: Annual and seasonal time series of precipitation for historical (gray), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes.

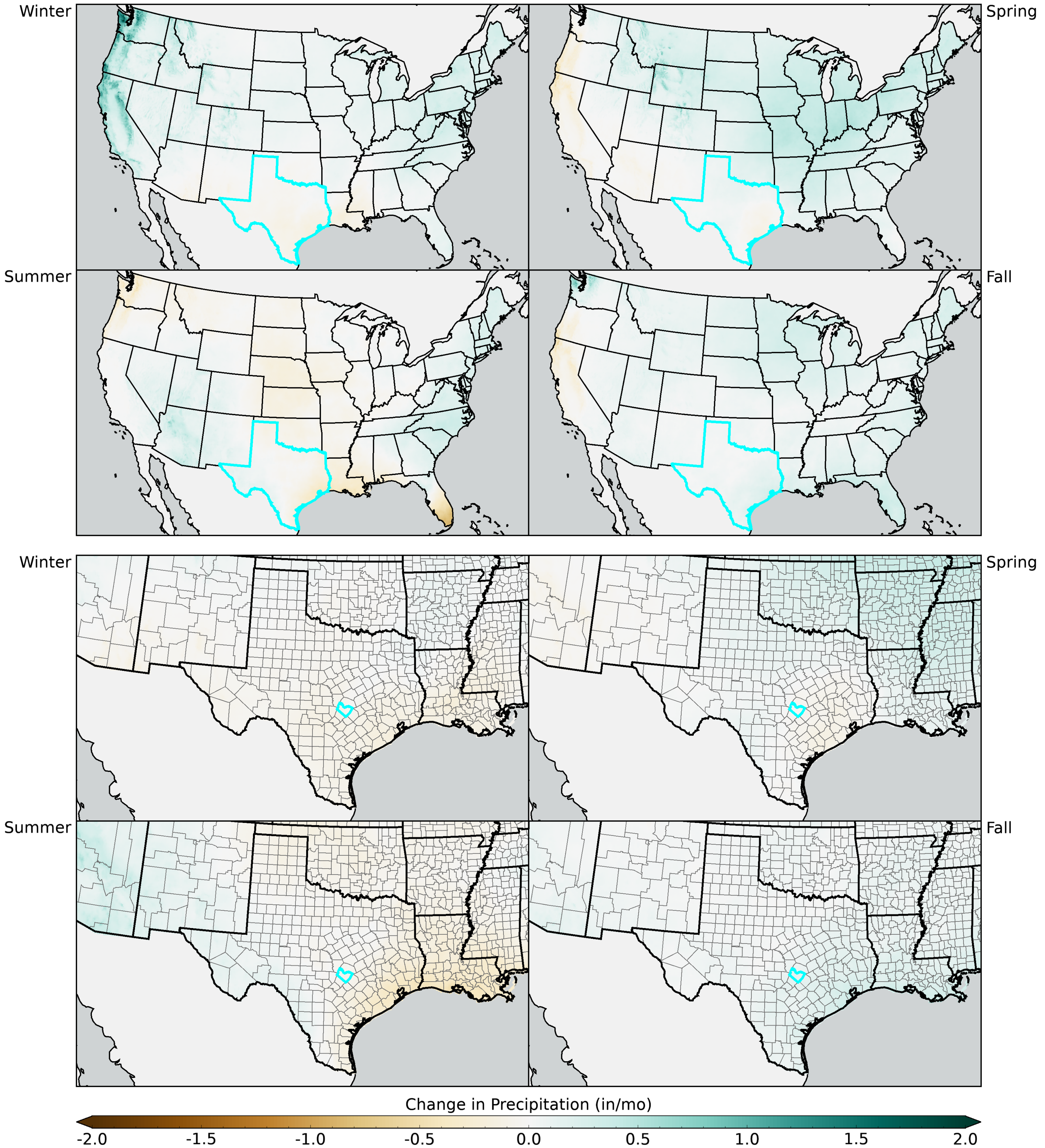


Figure 15: Seasonal maps of precipitation for RCP4.5 2050-2074 minus 1981-2010 for the ensemble mean model.

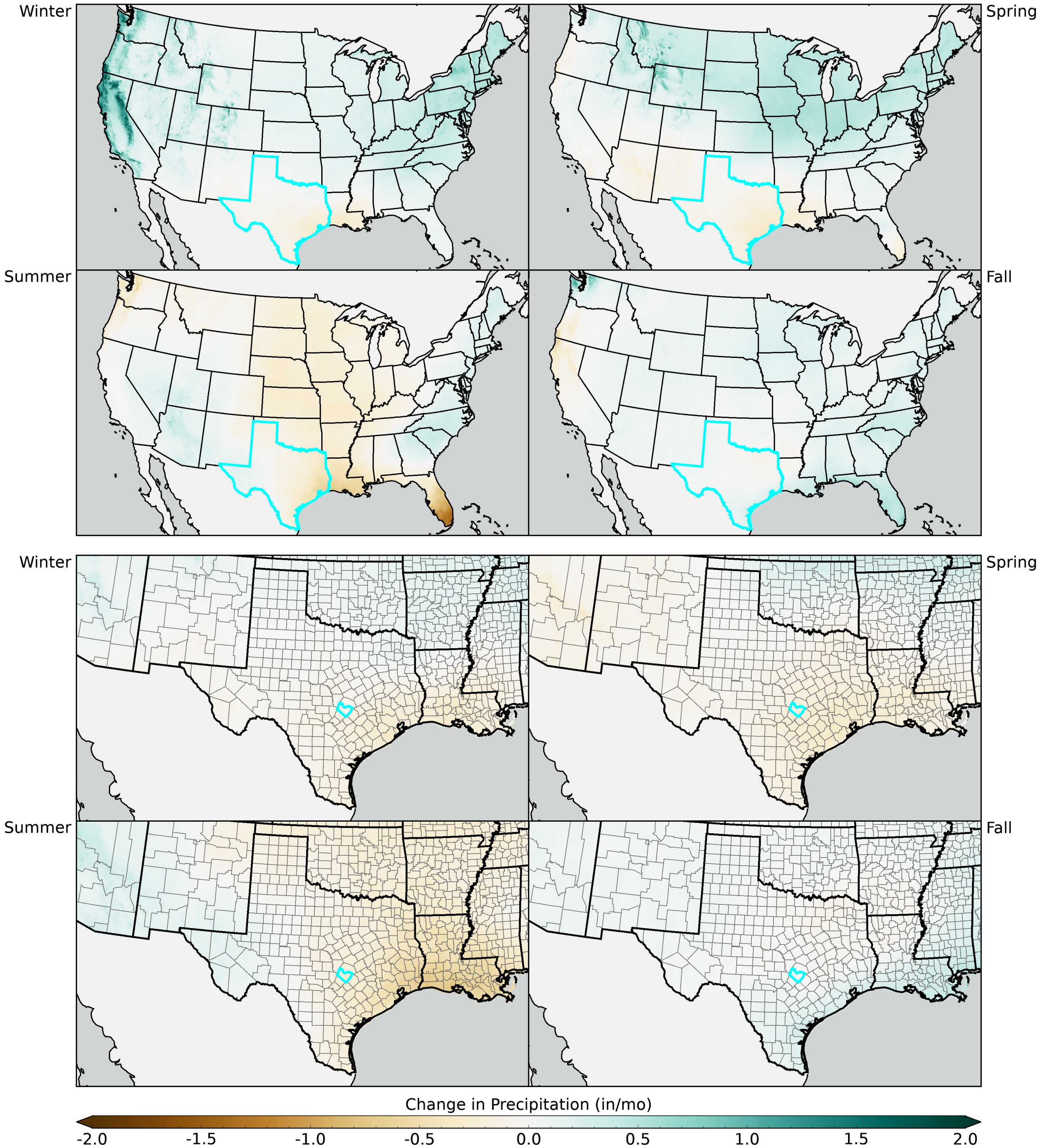


Figure 16: Seasonal maps of precipitation for RCP8.5 2050-2074 minus 1981-2010 for the ensemble mean model.

5 Vapor pressure deficit

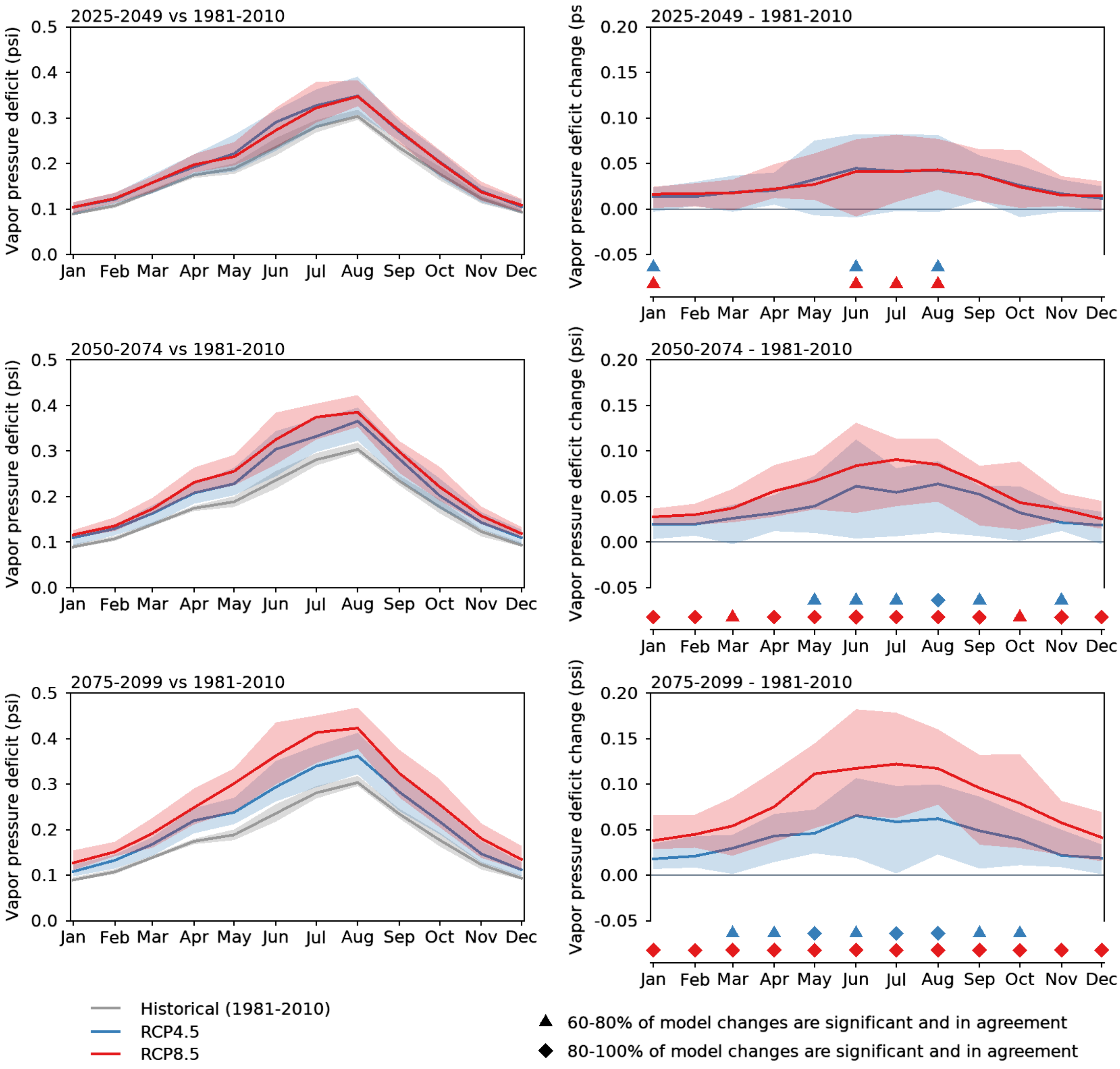


Figure 17: Monthly averages of vapor pressure deficit for the three future time periods for the RCP4.5 and RCP8.5 simulations. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes. Raw values relative to the historical simulation (1981-2010) are shown in the left column and future minus historical changes are shown in the right column. Triangle and diamond symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A Mann-Whitney rank test is used to establish significance ($\rho < 0.05$).

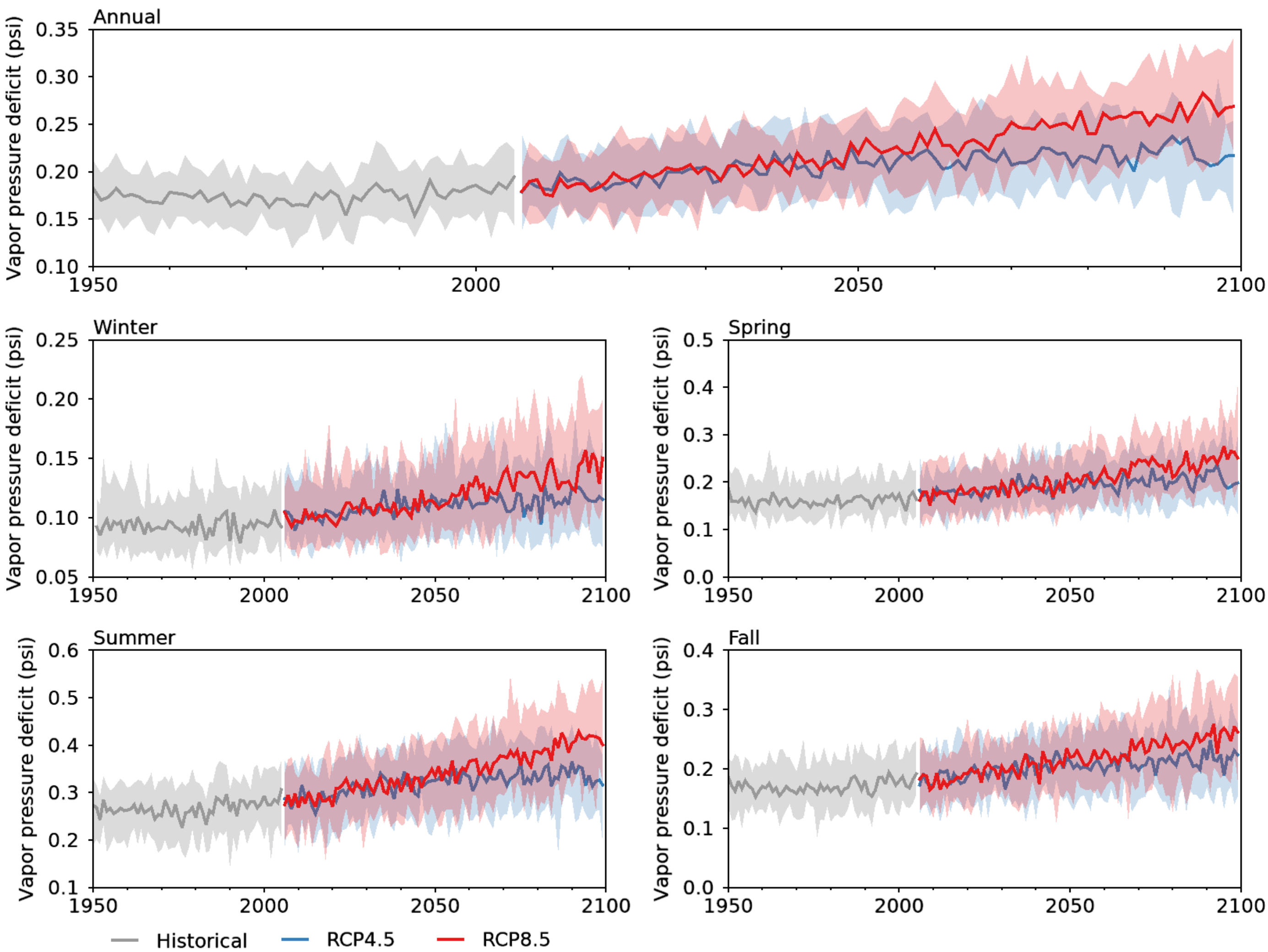


Figure 18: Annual and seasonal time series of vapor pressure deficit for historical (gray), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes.

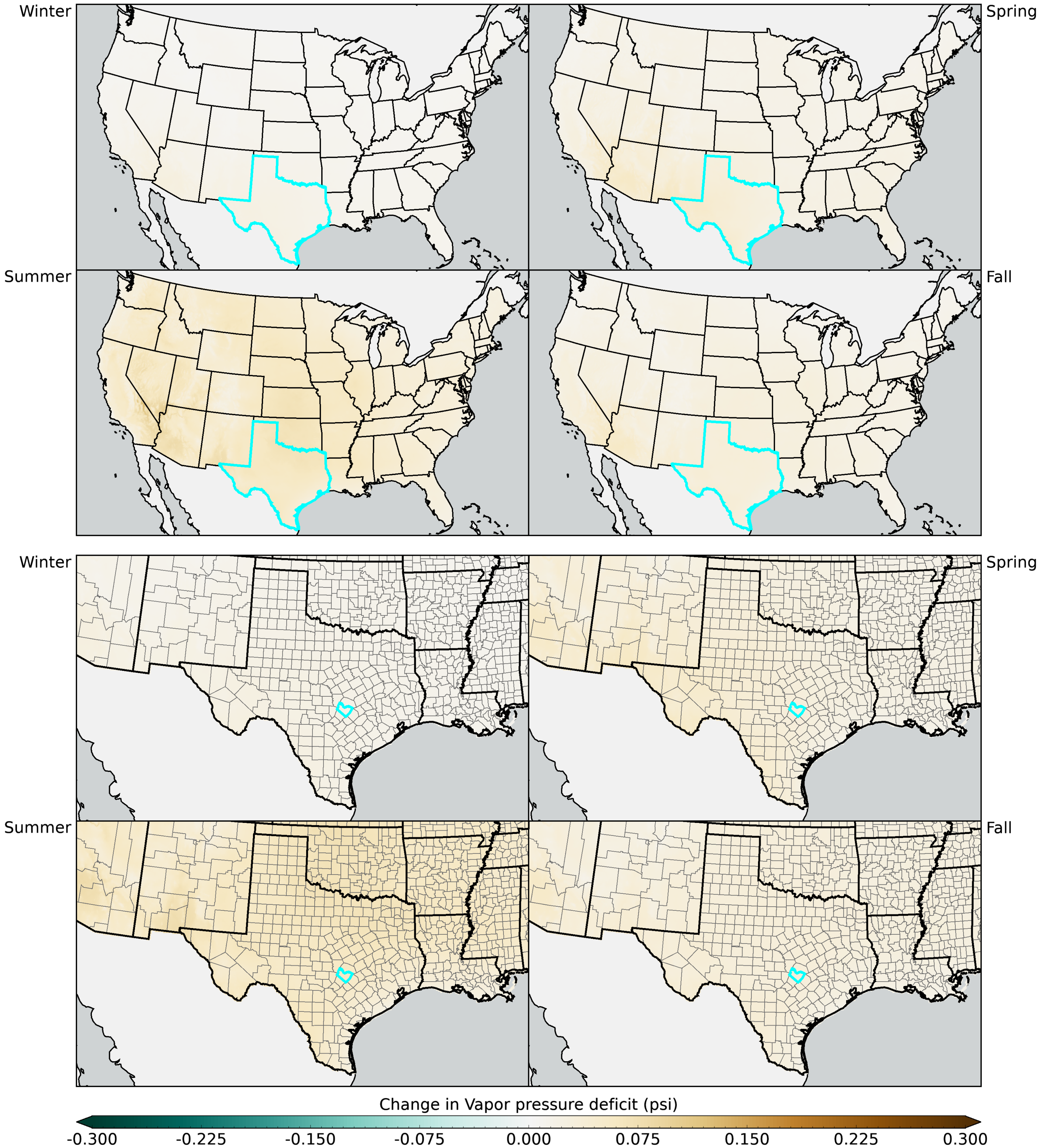


Figure 19: Seasonal maps of vapor pressure deficit for RCP4.5 2050-2074 minus 1981-2010 for the ensemble mean model.

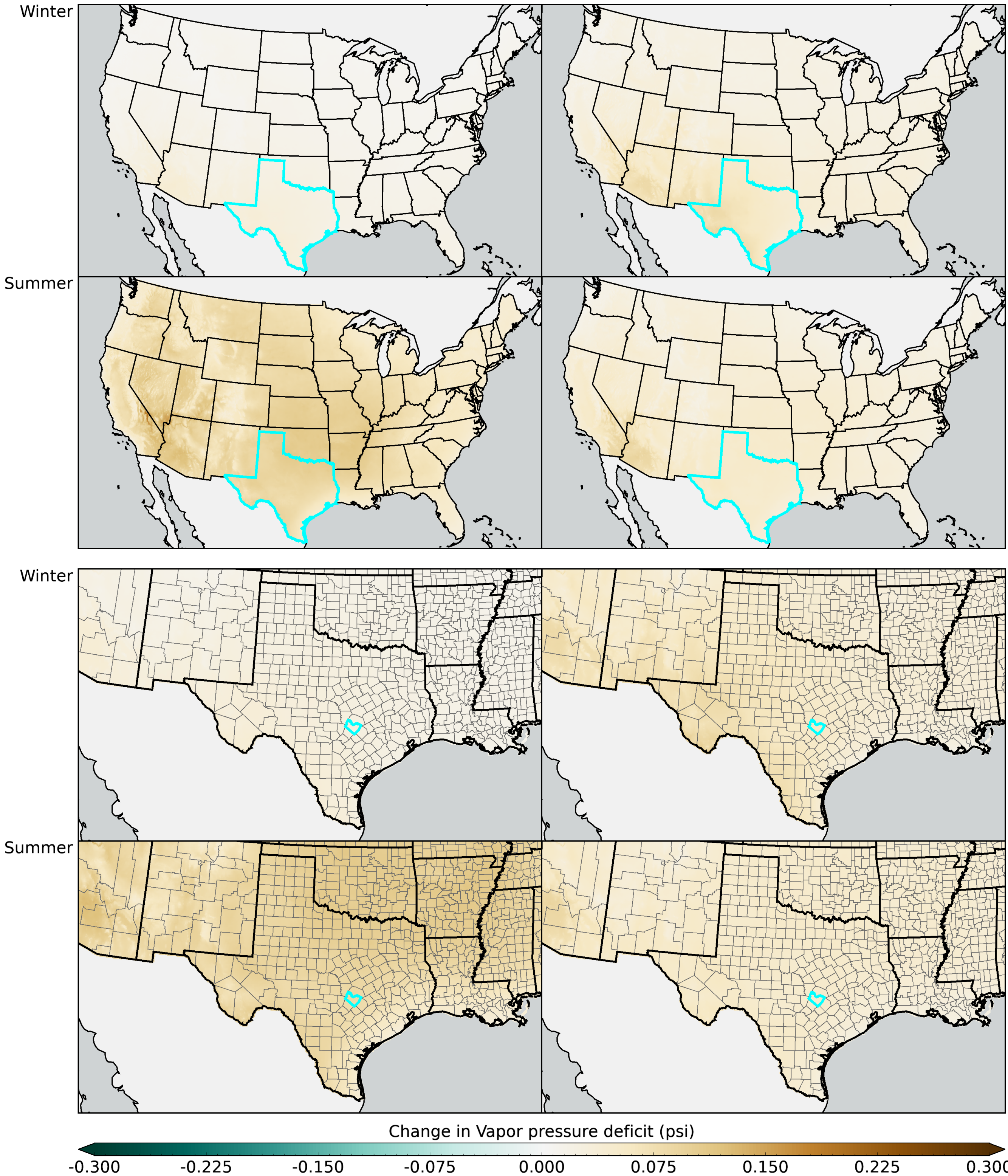


Figure 20: Seasonal maps of vapor pressure deficit for RCP8.5 2050-2074 minus 1981-2010 for the ensemble mean model.

6 Snow Water Equivalent

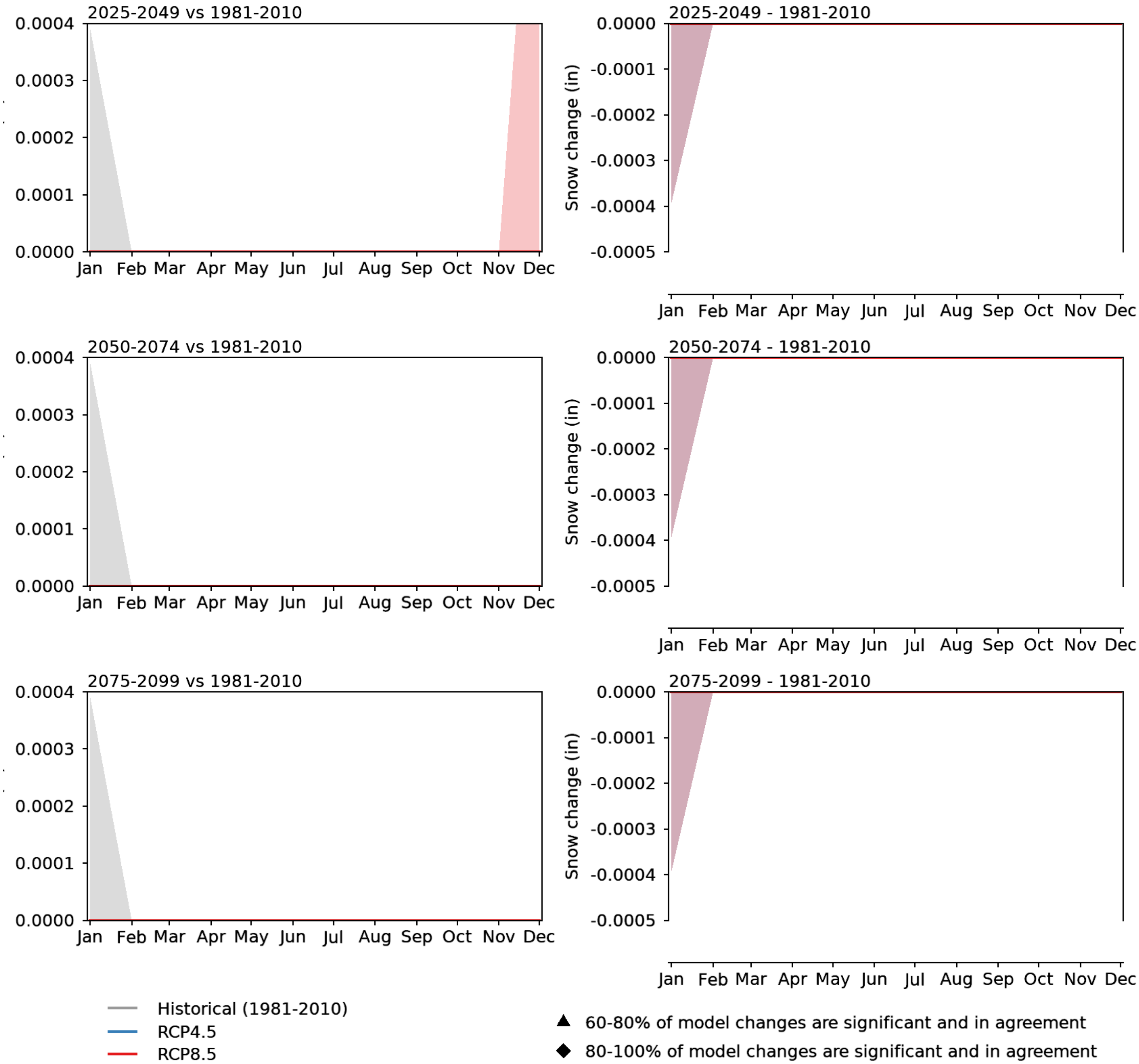


Figure 21: Monthly averages of snow water equivalent for the three future time periods for the RCP4.5 and RCP8.5 simulations. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes. Raw values relative to the historical simulation (1981-2010) are shown in the left column and future minus historical changes are shown in the right column. Triangle and diamond symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A Mann-Whitney rank test is used to establish significance ($\rho < 0.05$).

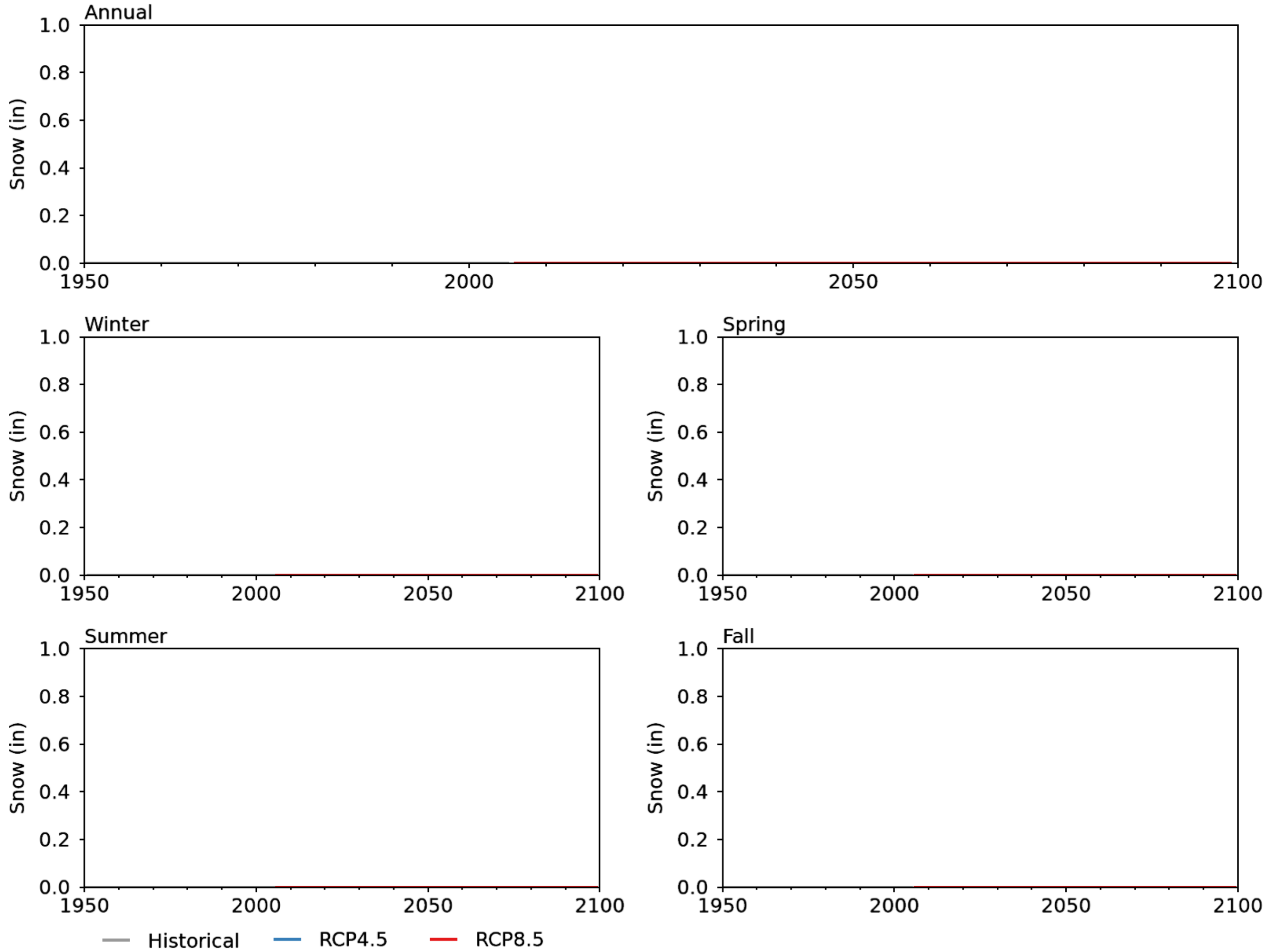


Figure 22: Annual and seasonal time series of snow water equivalent for historical (gray), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes.

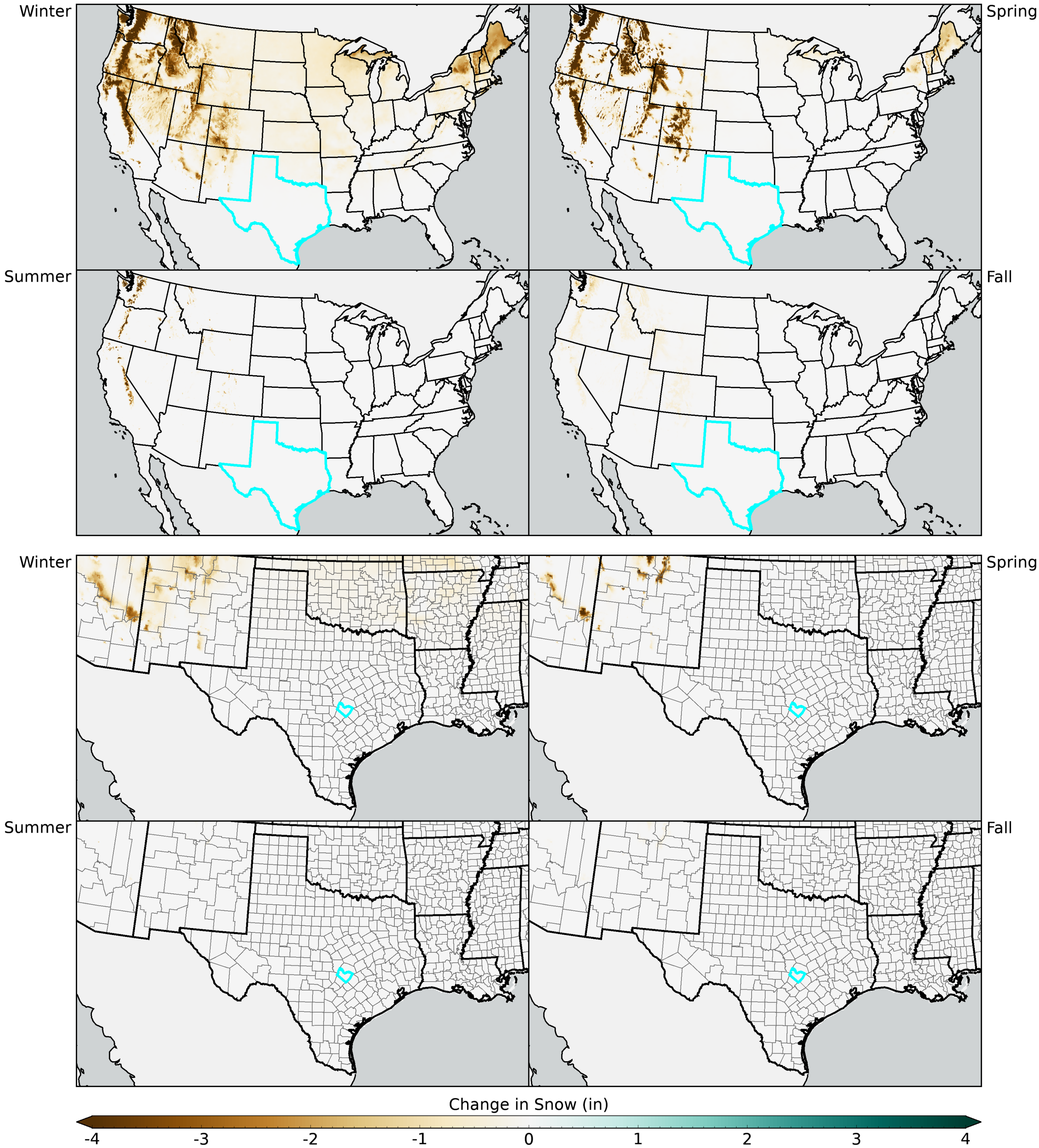


Figure 23: Seasonal maps of snow water equivalent for RCP4.5 2050-2074 minus 1981-2010 for the ensemble mean model.

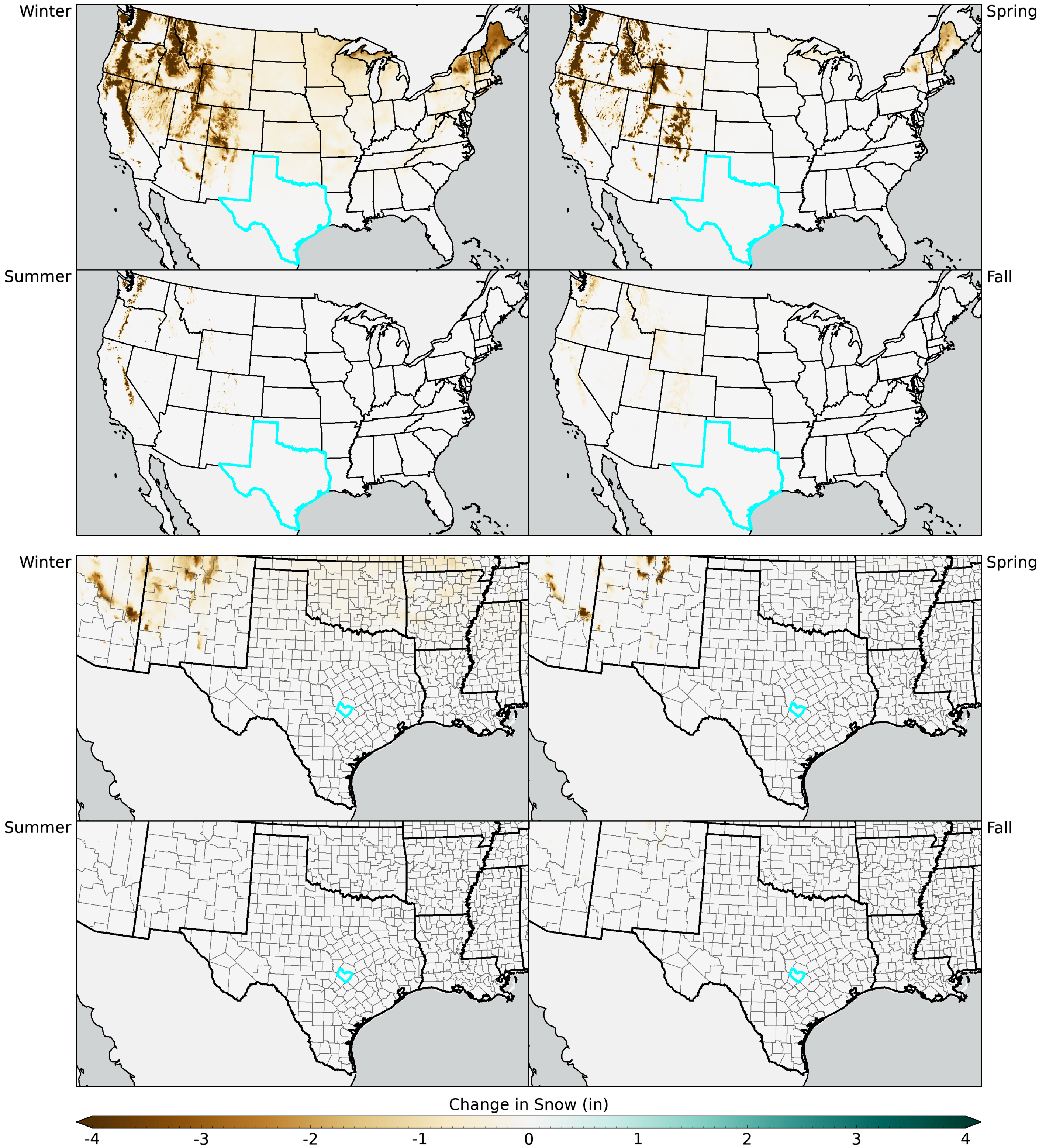


Figure 24: Seasonal maps of snow water equivalent for RCP8.5 2050-2074 minus 1981-2010 for the ensemble mean model.

7 Runoff

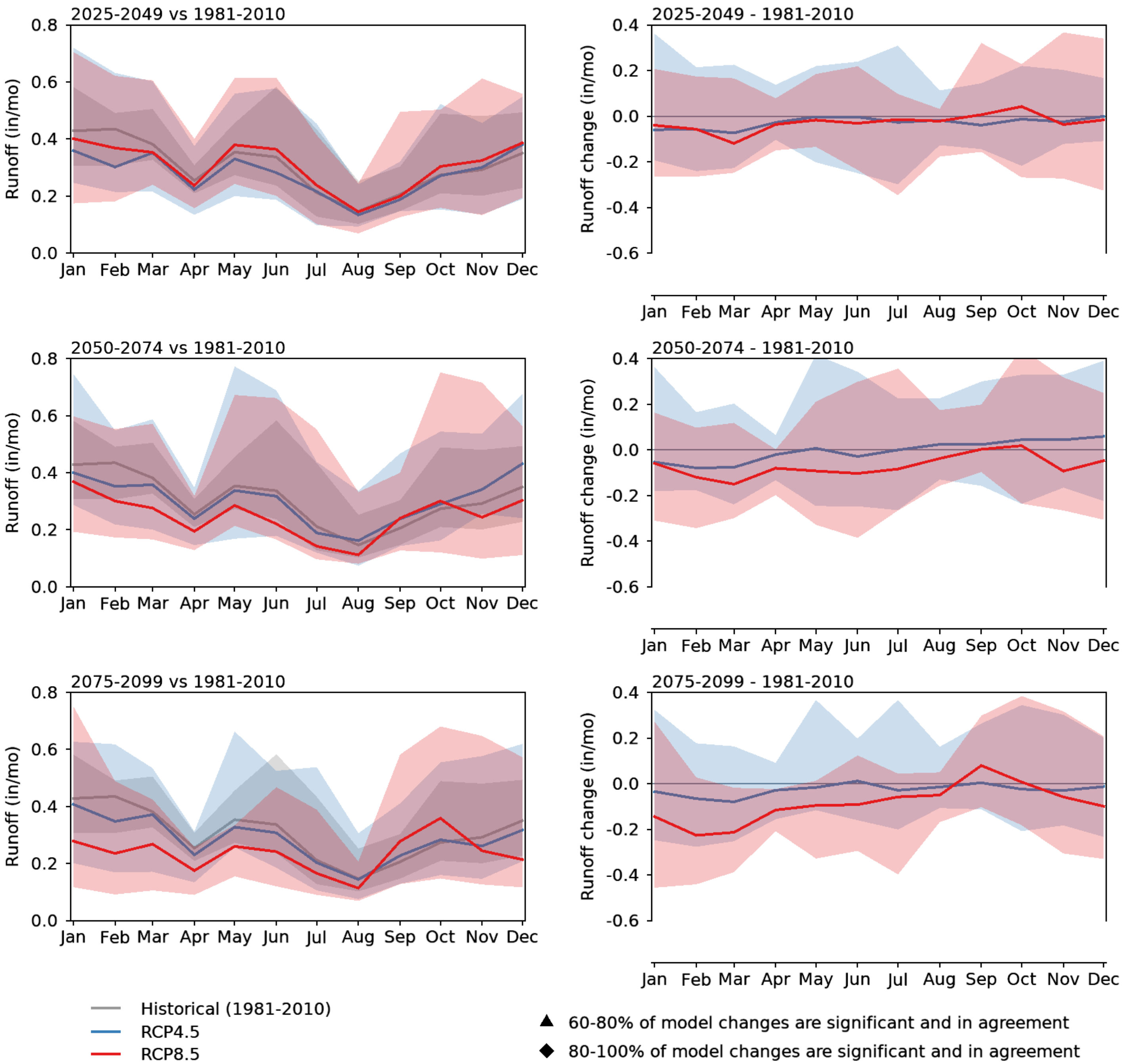


Figure 25: Monthly averages of runoff for the three future time periods for the RCP4.5 and RCP8.5 simulations. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes. Raw values relative to the historical simulation (1981-2010) are shown in the left column and future minus historical changes are shown in the right column. Triangle and diamond symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A Mann-Whitney rank test is used to establish significance ($\rho < 0.05$).

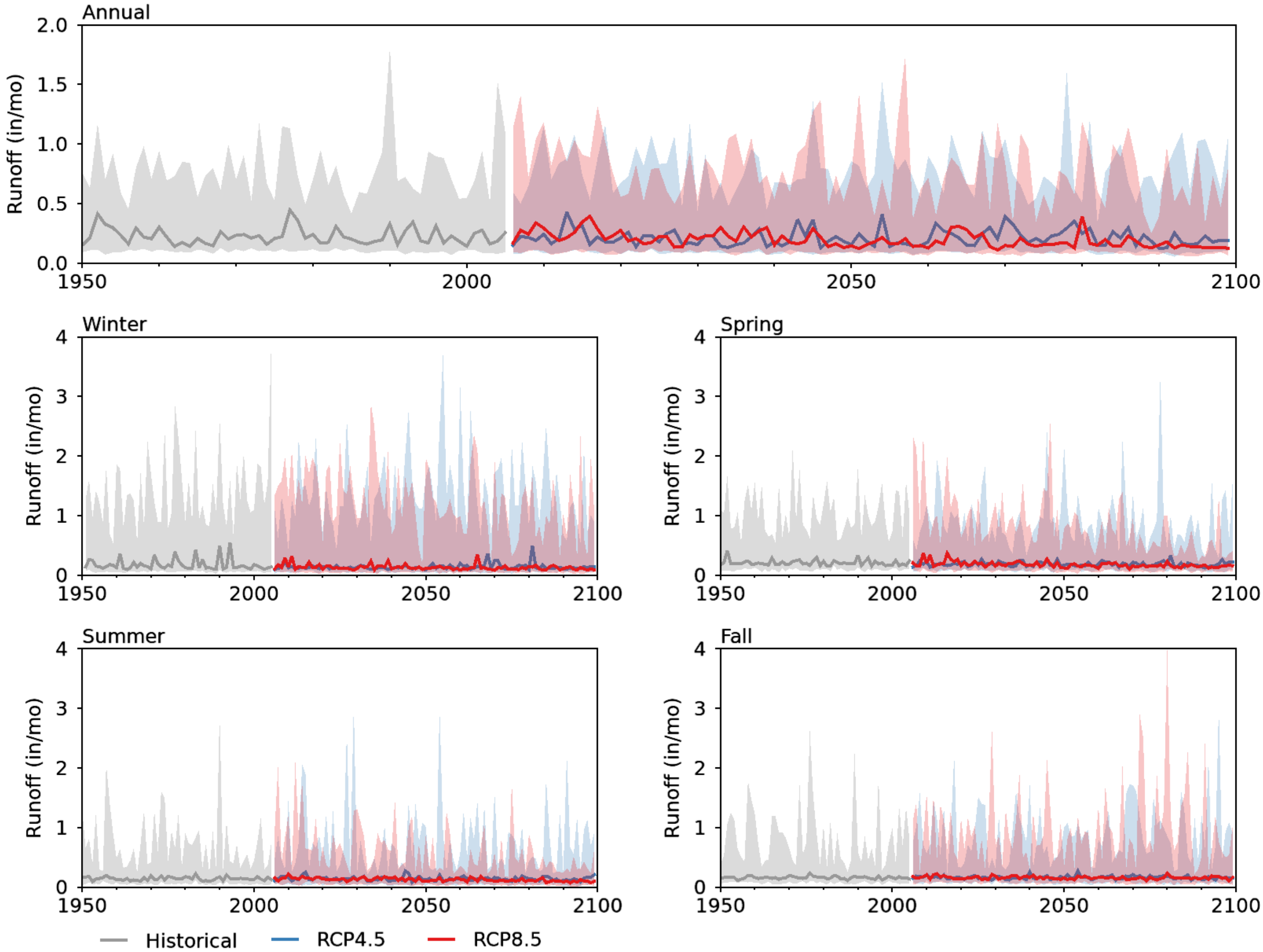


Figure 26: Annual and seasonal time series of runoff for historical (gray), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes.

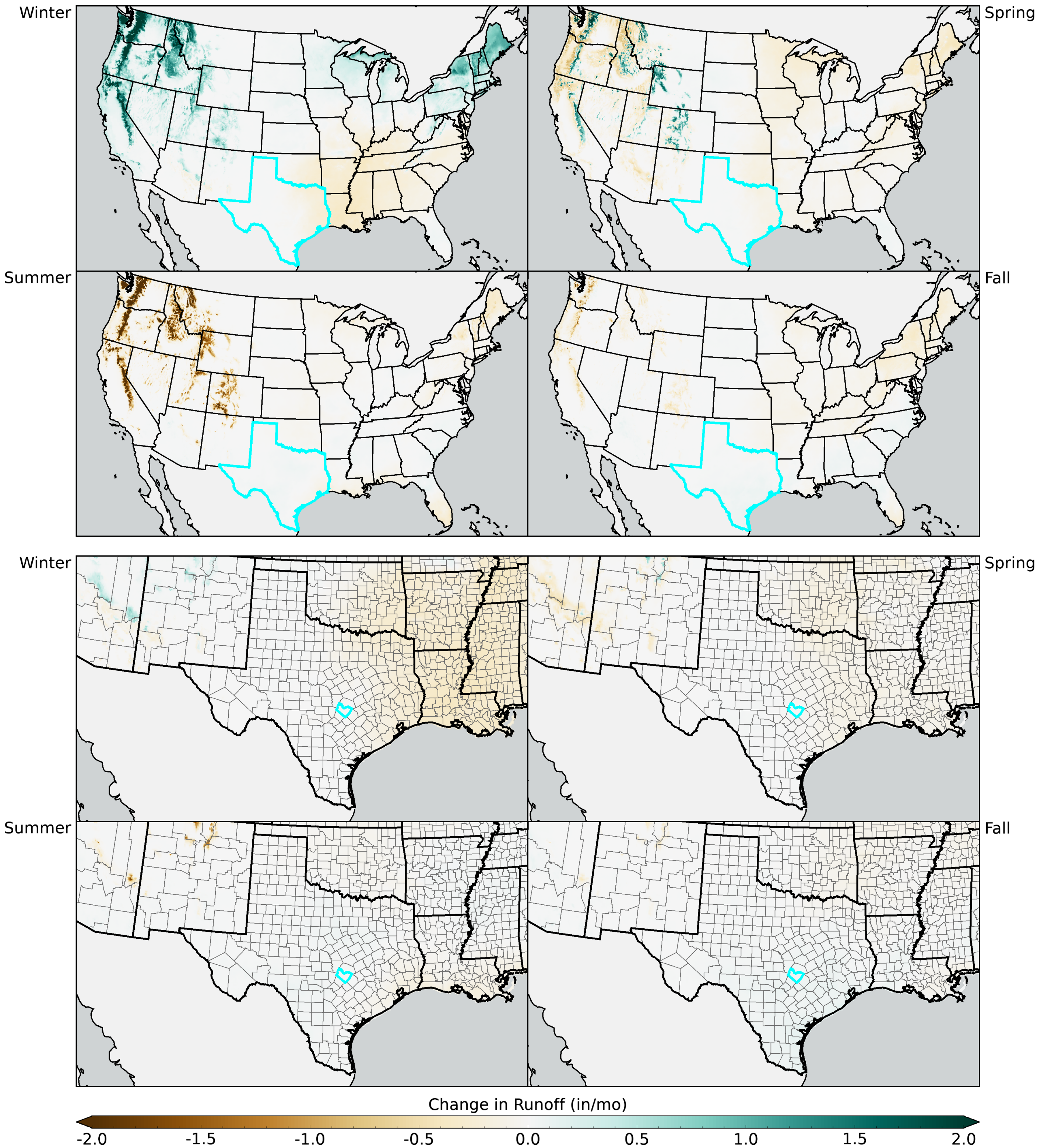


Figure 27: Seasonal maps of runoff for RCP4.5 2050-2074 minus 1981-2010 for the ensemble mean model.

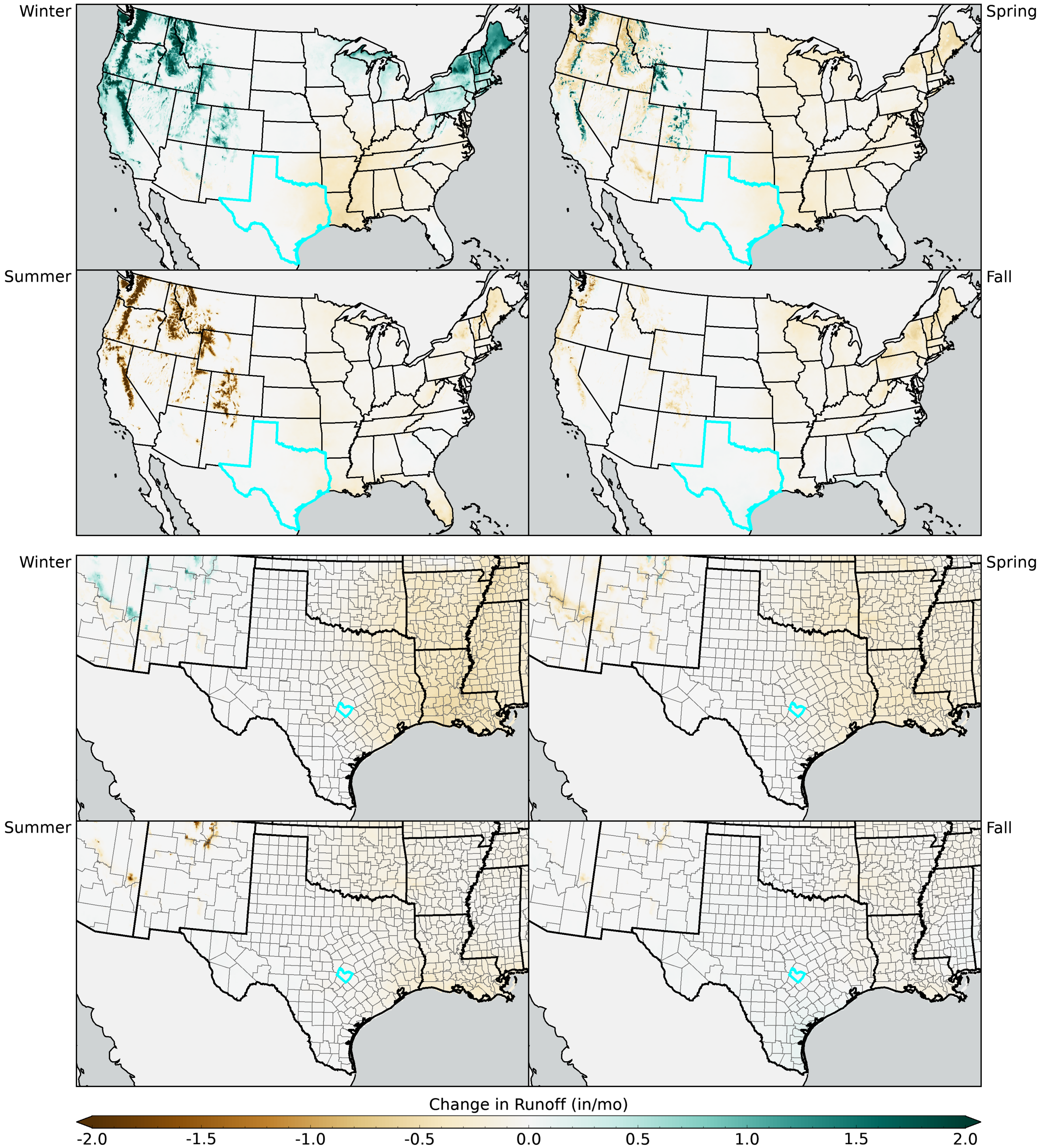


Figure 28: Seasonal maps of runoff for RCP8.5 2050-2074 minus 1981-2010 for the ensemble mean model.

8 Soil Water Storage

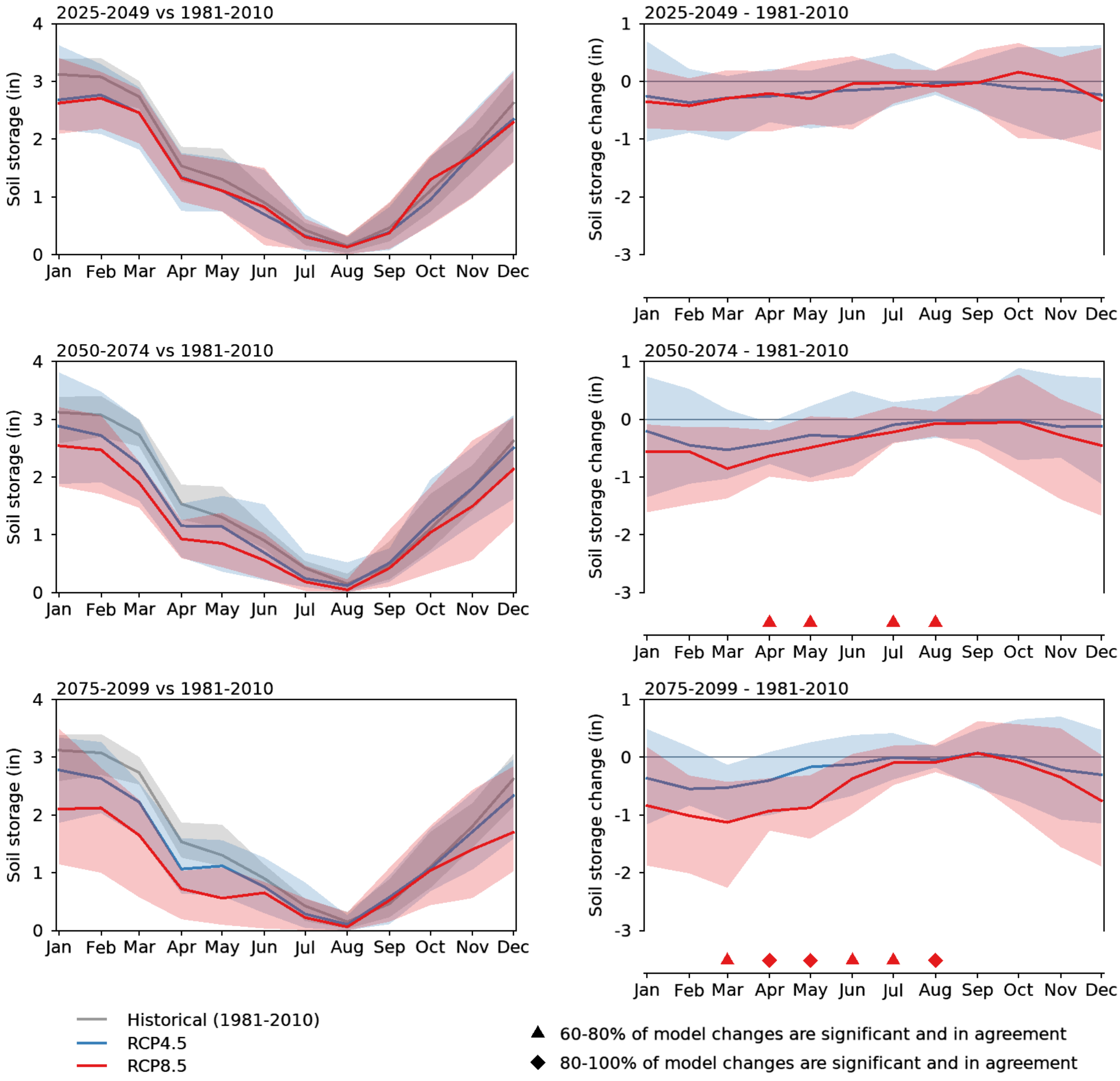


Figure 29: Monthly averages of soil water storage for the three future time periods for the RCP4.5 and RCP8.5 simulations. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes. Raw values relative to the historical simulation (1981-2010) are shown in the left column and future minus historical changes are shown in the right column. Triangle and diamond symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A Mann-Whitney rank test is used to establish significance ($\rho < 0.05$).

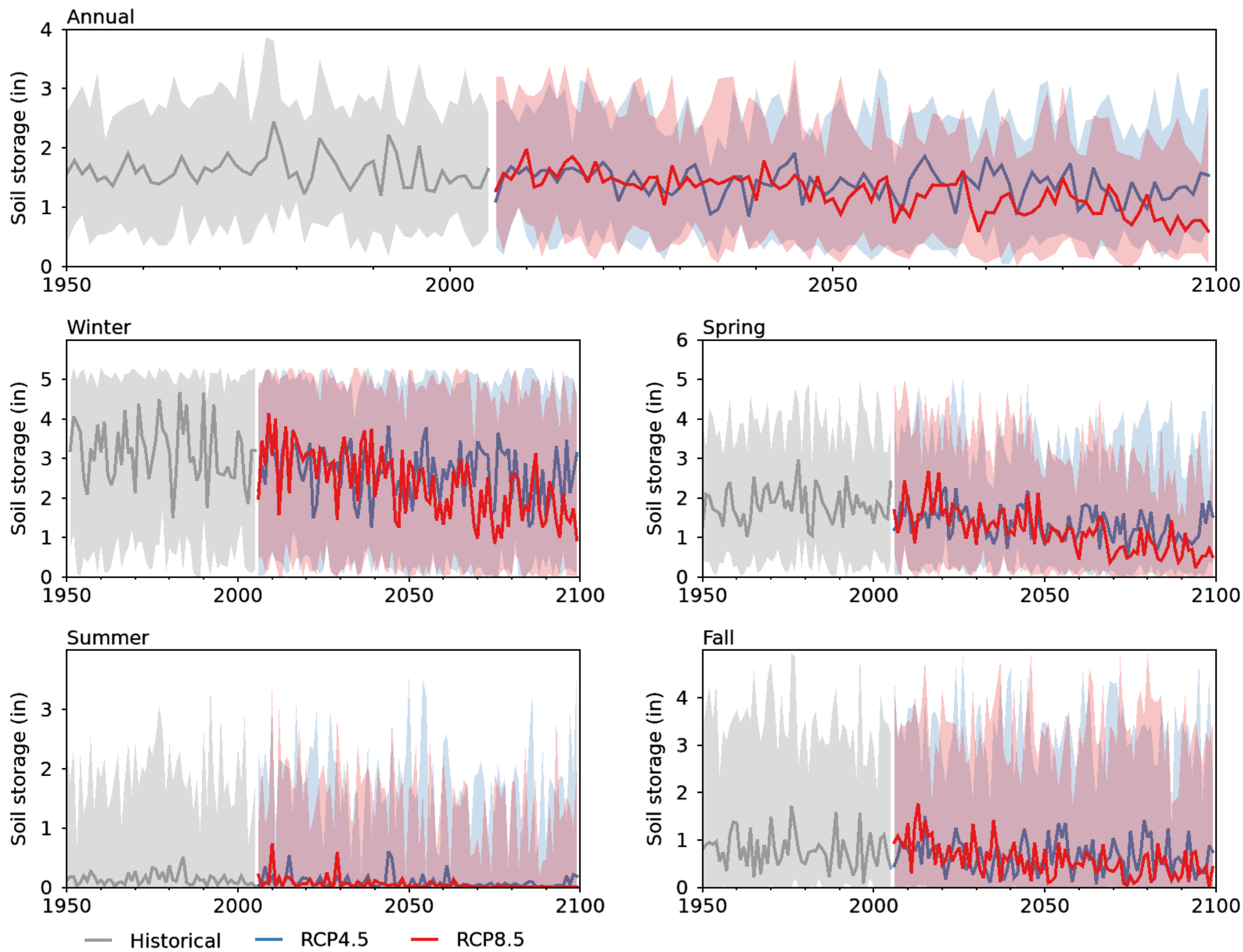


Figure 30: Annual and seasonal time series of soil water storage for historical (gray), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes.

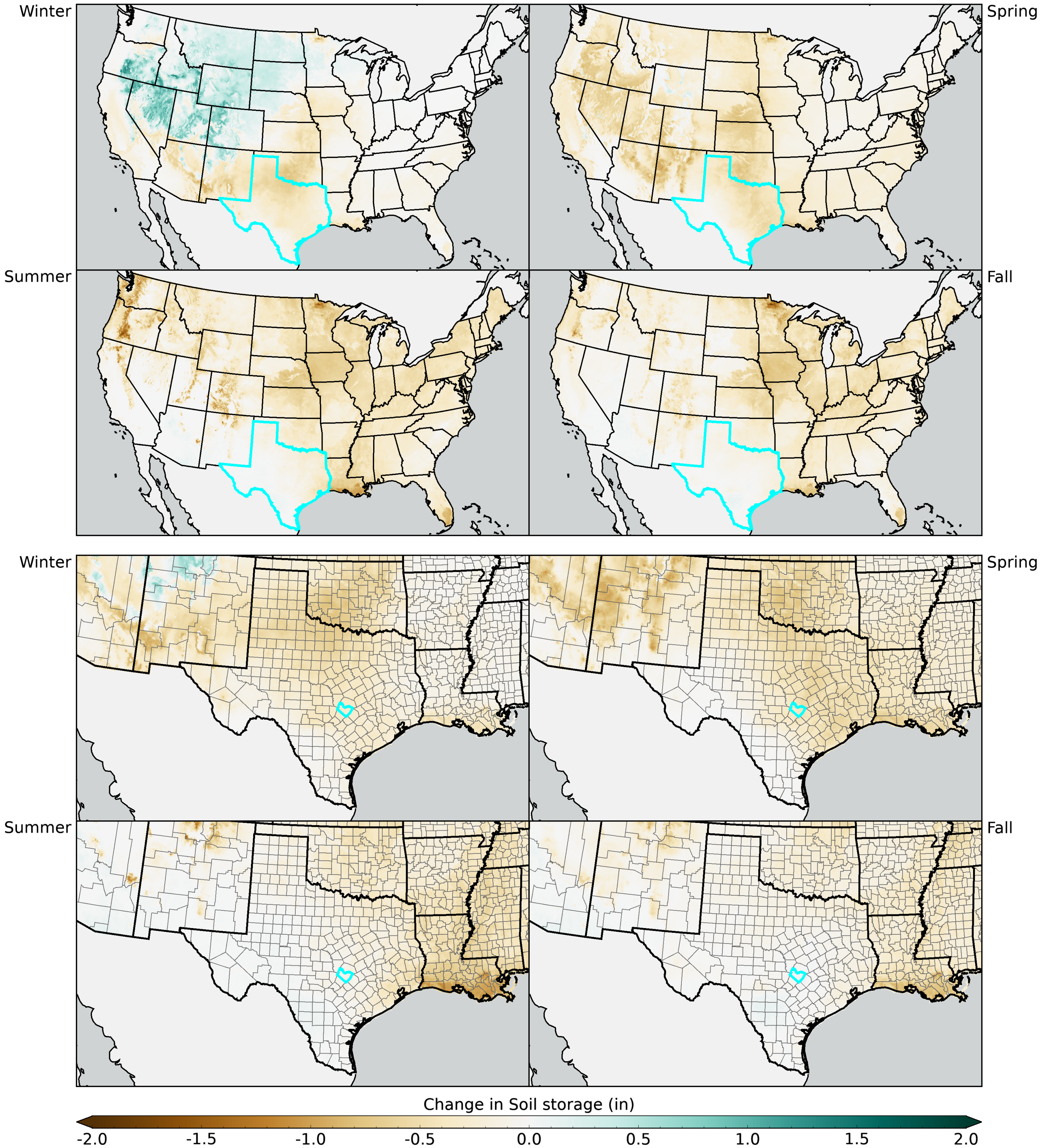


Figure 31: Seasonal maps of soil water storage for RCP4.5 2050-2074 minus 1981-2010 for the ensemble mean model.

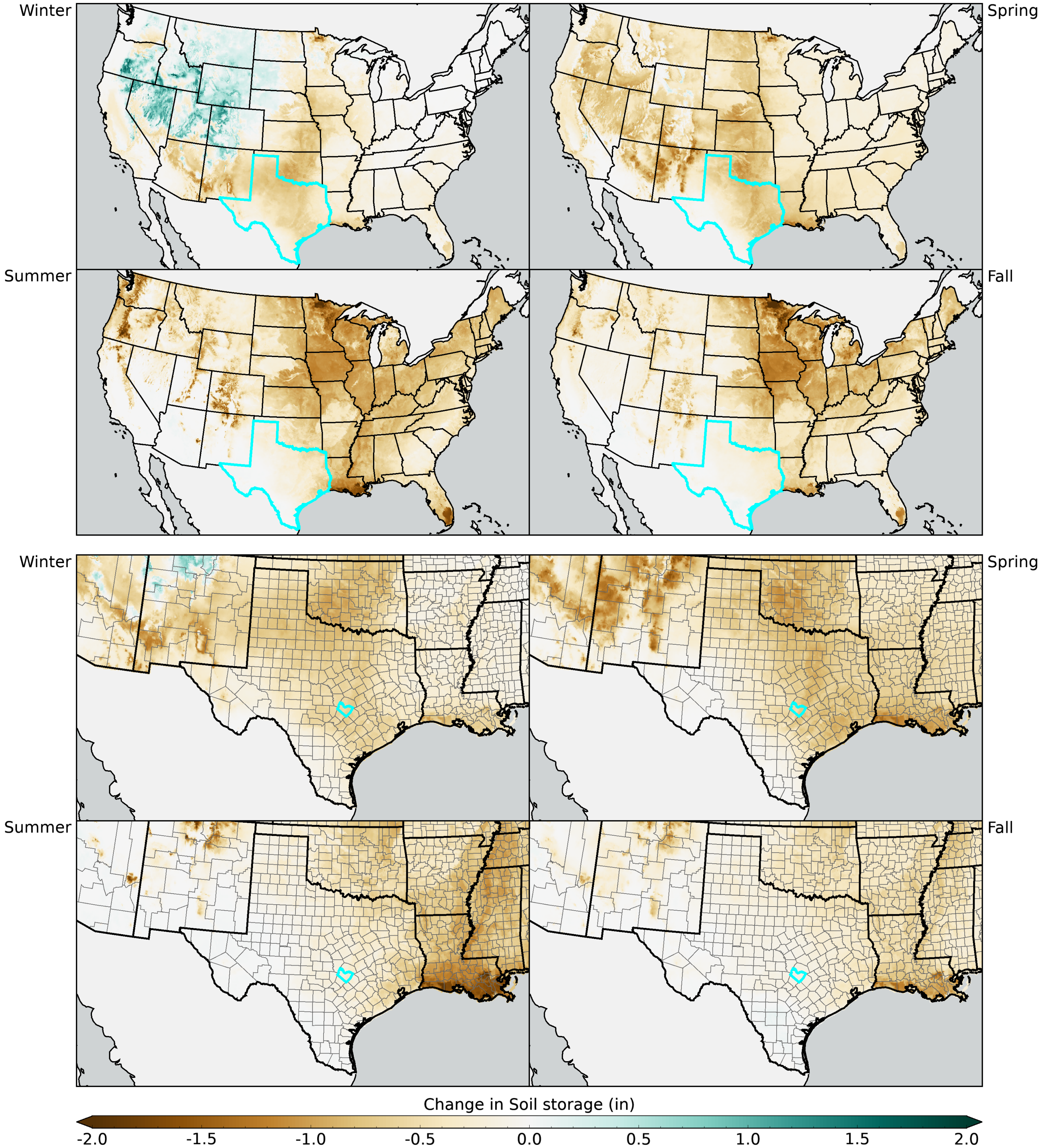


Figure 32: Seasonal maps of soil water storage for RCP8.5 2050-2074 minus 1981-2010 for the ensemble mean model.

9 Evaporative Deficit

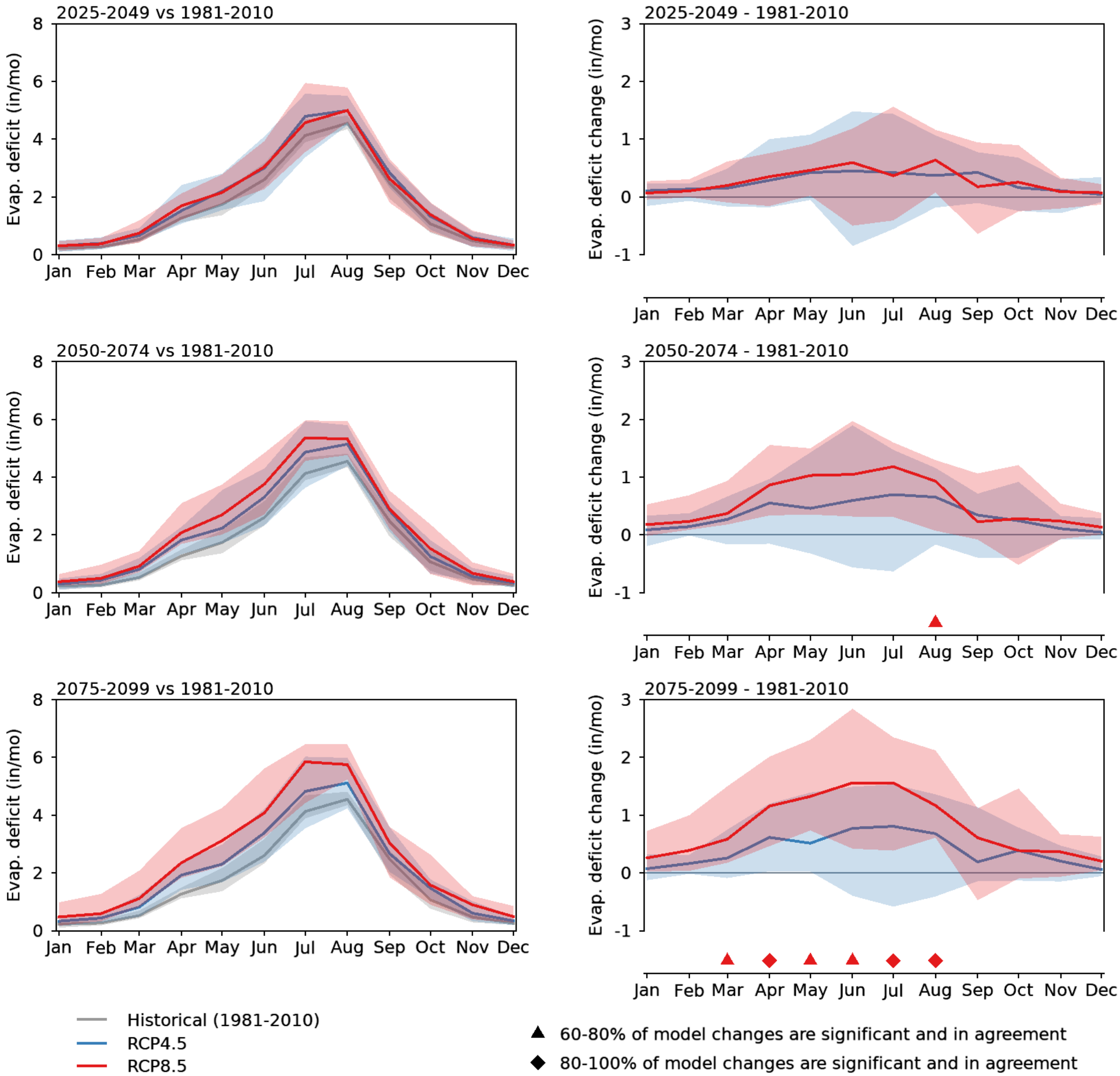


Figure 33: Monthly averages of evaporative deficit for the three future time periods for the RCP4.5 and RCP8.5 simulations. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes. Raw values relative to the historical simulation (1981-2010) are shown in the left column and future minus historical changes are shown in the right column. Triangle and diamond symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A Mann-Whitney rank test is used to establish significance ($\rho < 0.05$).

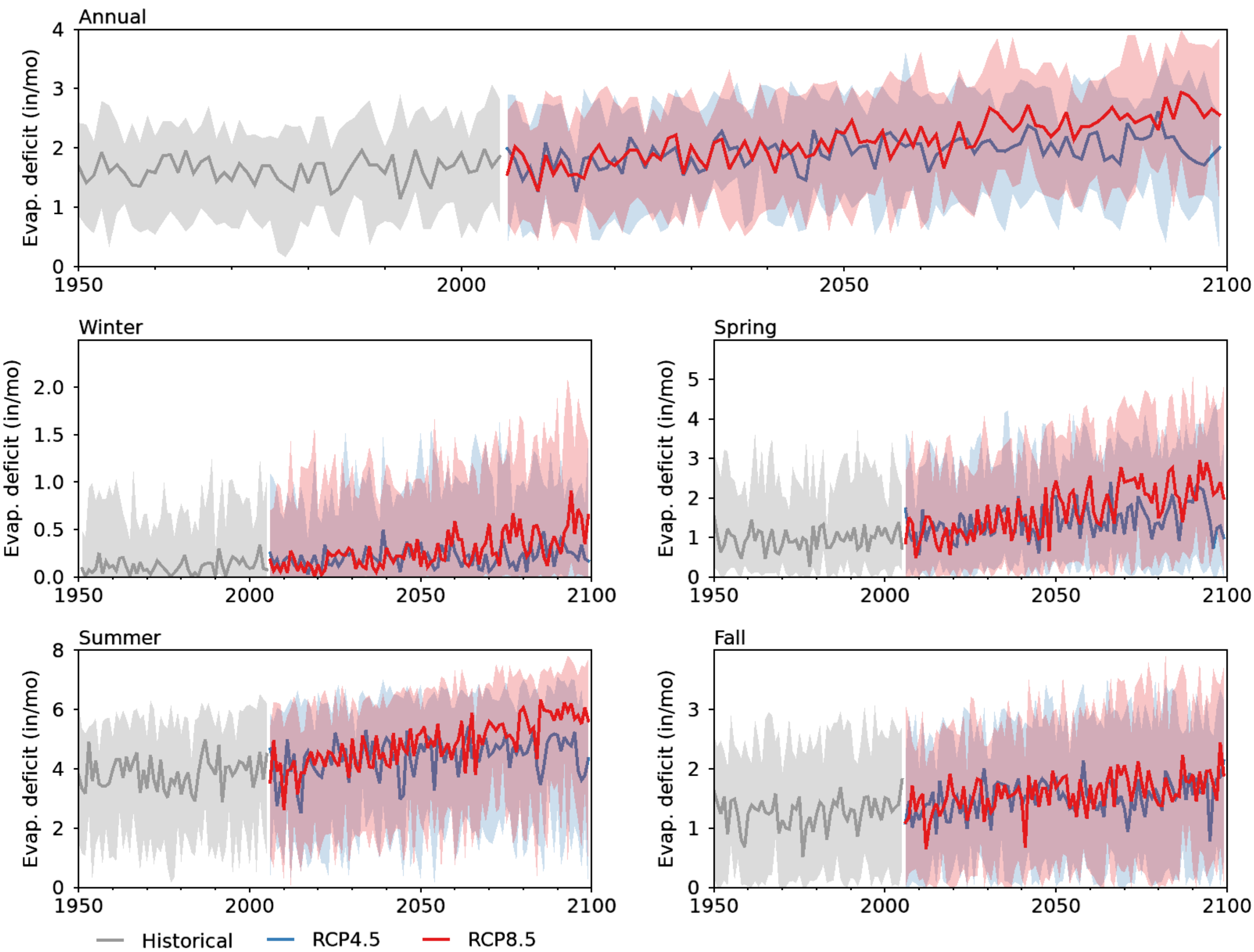


Figure 34: Annual and seasonal time series of evaporative deficit for historical (gray), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The median of 20 CMIP5 models is indicated by the solid lines and the ensemble 10th to 90th percentile range is indicated by the respective shaded envelopes.

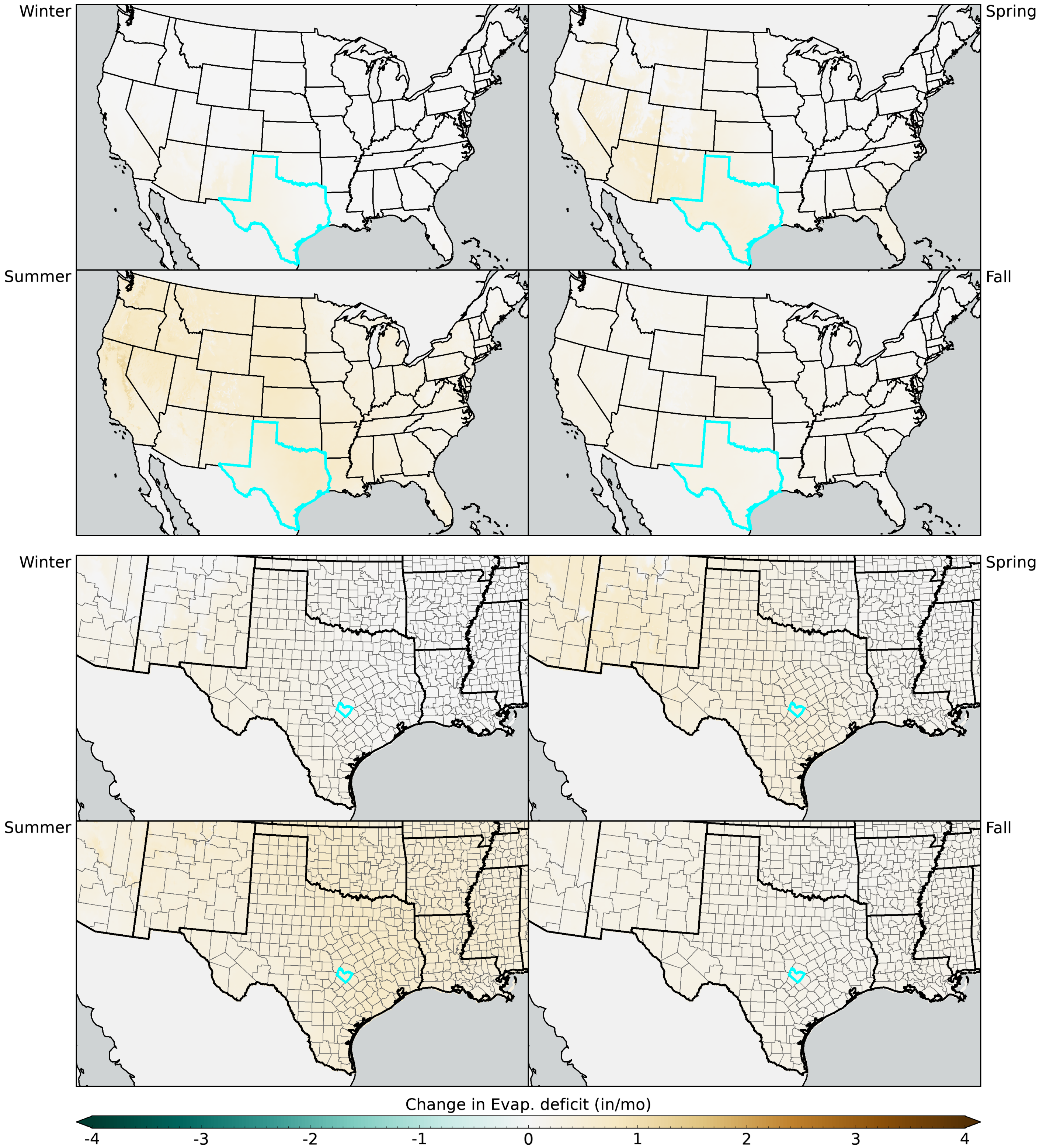


Figure 35: Seasonal maps of evaporative deficit for RCP4.5 2050-2074 minus 1981-2010 for the ensemble mean model.

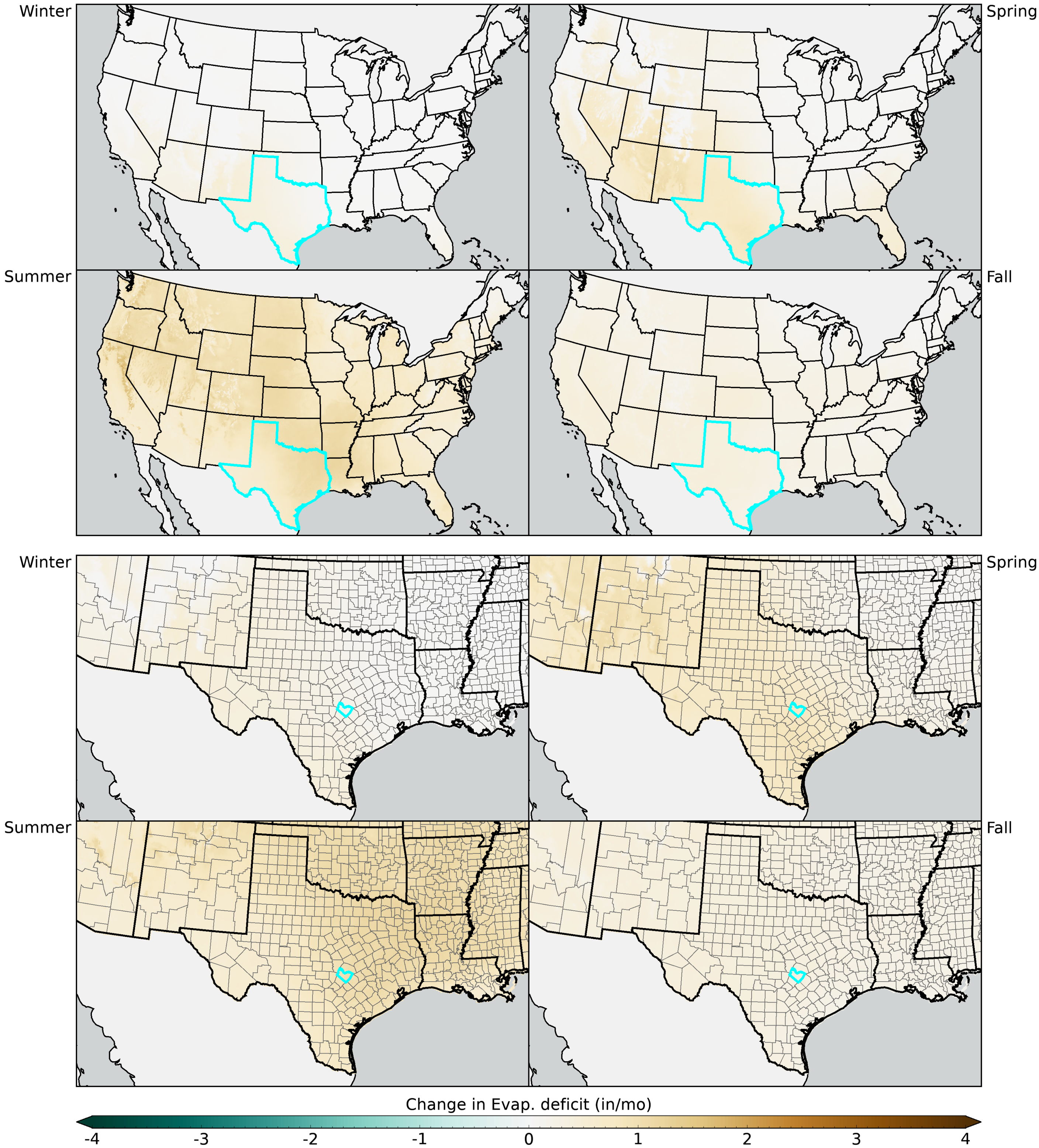


Figure 36: Seasonal maps of evaporative deficit for RCP8.5 2050-2074 minus 1981-2010 for the ensemble mean model.

10 Data

The temperature, precipitation, and vapor pressure deficit summaries are created by spatially averaging the MACAv2-METDATA data set (Abatzoglou and Brown, 2012). The water-balance variables snow water equivalent, runoff, soil water storage and evaporative deficit are simulated by using the MACAv2-METDATA temperature and precipitation as input to a simple model (McCabe and Wolock, 2007). The water-balance model accounts for the partitioning of water through the various components of the hydrologic system, but does not account for groundwater, diversions or regulation by impoundments.

11 Models

MeanModel	bcc-csm1-1-m	bcc-csm1-1	BNU-ESM	CanESM2
CCSM4	CNRM-CM5	CSIRO-Mk3-6-0	GFDL-ESM2G	GFDL-ESM2M
HadGEM2-CC365	HadGEM2-ES365	inmcm4	IPSL-CM5A-LR	IPSL-CM5A-MR
IPSL-CM5B-LR	MIROC5	MIROC-ESM	MIROC-ESM-CHEM	MRI-CGCM3

12 Citation Information

Abatzoglou, J.T., 2011. Development of gridded surface meteorological data for ecological applications and modelling. International Journal of Climatology, doi: 10.1002/joc.3413.

Abatzoglou, J.T., and Brown T.J., 2012. A comparison of statistical downscaling methods suited for wildfire applications. International Journal of Climatology, doi: 10.1002/joc.2312.

Alder, J. R. and S. W. Hostetler, 2013. USGS National Climate Change Viewer. US Geological Survey https://doi.org/10.5066/F7W9575T.

Hostetler, S.W. and Alder, J.R., 2016. Implementation and evaluation of a monthly water balance model over the U.S. on an 800 m grid. Water Resources Research, 52, doi:10.1002/2016WR018665.

13 Disclaimer

These freely available, derived data sets were produced by J. Alder and S. Hostetler, US Geological Survey (Alder, J. R. and S. W. Hostetler, 2013. USGS National Climate Change Viewer. US Geological Survey https://doi.org/10.5066/F7W9575T). Climate forcings in the MACAv2-METDATA were drawn from a statistical downscaling of global climate model (GCM) data from the Coupled Model Intercomparison Project 5 (CMIP5, Taylor et al. 2010) utilizing a modification of the Multivariate Adaptive Constructed Analogs (MACA, Abatzoglou and Brown, 2012) method with the METDATA(Abatzoglou, 2011) observational dataset as training data. No warranty expressed or implied is made by the USGS regarding the display or utility of the derived data on any other system, or for general or scientific purposes, nor shall the act of distribution constitute any such warranty. The USGS shall not be held liable for improper or incorrect use of the data described and/or contained herein.

Appendix B-2: USGS National Climate Change Viewer Documentation Report

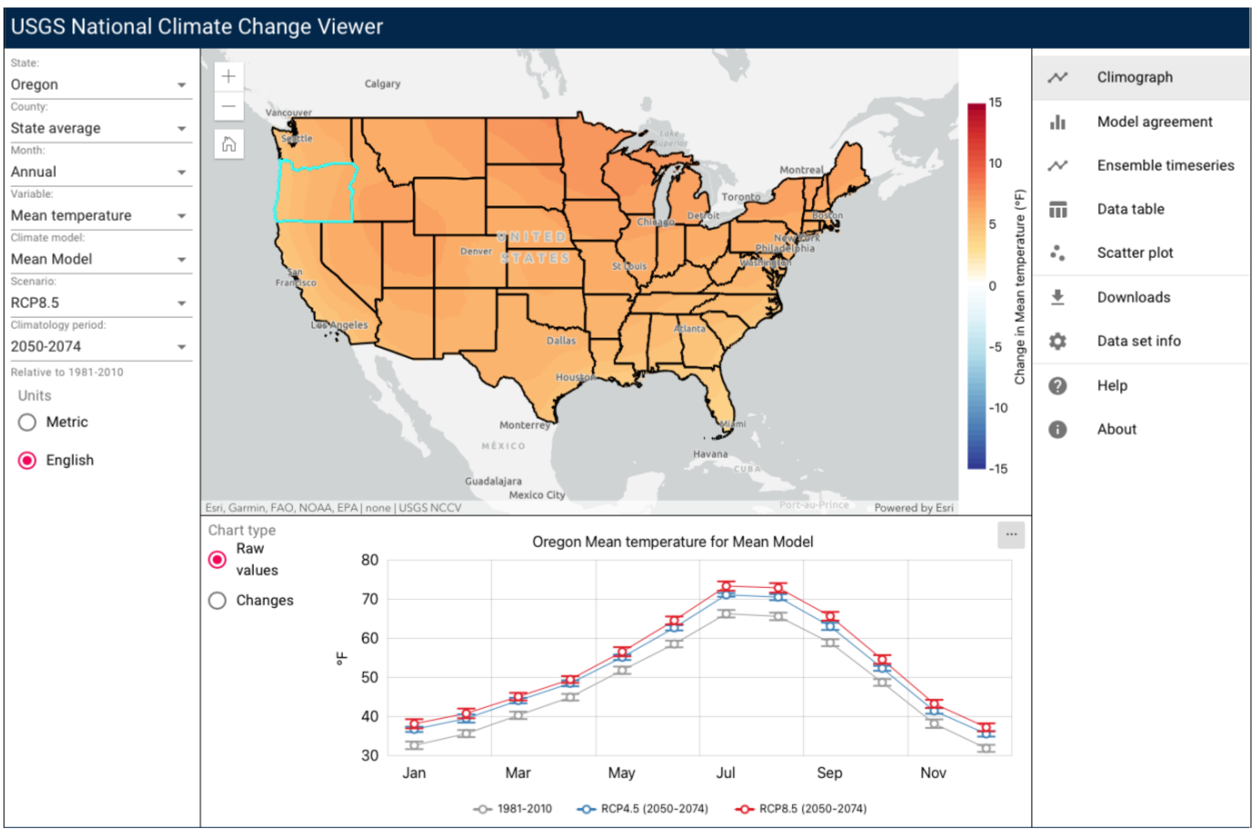
National Climate Change Viewer Documentation

By Jay R. Alder[1], and Steve W. Hostetler[2]

---

[1]Geology, Minerals, Energy, and Geophysics Science Center, USGS, Corvallis, OR.

[2]Northern Rocky Mountain Science Center, USGS, Corvallis, OR.



Outline

Introduction

Worldwide climate modeling centers participating in the 5th Climate Model Intercomparison Program (CMIP5) provided climate information for the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). The output from the CMIP5 models is typically provided on grids of ~1 to 3 degrees in latitude and longitude (roughly 80 to 230 km at 45° latitude). To derive higher resolution data for regional climate change assessments, the Multivariate Adaptive Constructed Analogs (MACA) method was applied to statistically downscaled maximum and minimum air temperature and precipitation from 20 of the CMIP5 models to produce the MACAv2-METDATA data set on a 4 km grid (**Figure 1**) over the continental United States (Abatzoglou J.T. and Brown T.J., *International Journal of Climatology*, 2012, doi:10.1002/joc.2312). The data set was bias corrected using the METDATA observational data set (Abatzoglou J. T., *International Journal of Climatology*, 2011, doi:10.1002/joc.3413).

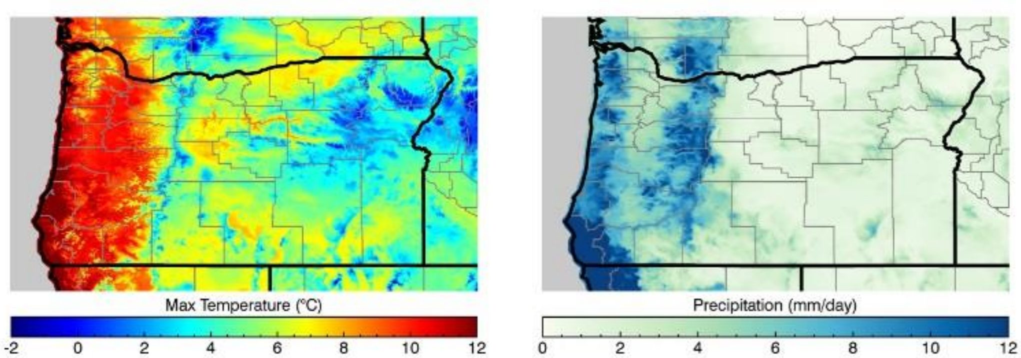


Figure 1.

The MACAv2-METDATA data set includes 20 climate models for historical and 21st century simulations for two Representative Concentration Pathways (RCP) greenhouse gas (GHG) emission scenarios developed for AR5. (Further details regarding the science behind developing and applying the RCPs are given by Moss et al., *Nature*, Volume 463, 2010, doi:10.1038/nature08823). The USGS National Climate Change Viewer (NCCV) includes the historical and future climate projections from 20 of the downscaled models for two of the RCP emission scenarios, RCP4.5 and RCP8.5. RCP4.5 is one of the possible emissions scenarios in which atmospheric GHG concentrations are stabilized so as not to exceed a radiative equivalent of 4.5 Wm^{-2} after 2100, about 650 ppm CO_2 equivalent. RCP8.5 is the most aggressive emissions scenario in which GHGs continue to rise unchecked through the end of the century leading to an equivalent radiative forcing of 8.5 Wm^{-2}, about 1370 ppm CO_2 equivalent. For perspective, the current atmospheric CO_2 level is about 416 ppm. Additionally, we have used the climate data (temperature and precipitation) to simulate changes in the contiguous United States (CONUS) water balance over the historical and future time periods (Hostetler, S.W. and Alder, J.R., Water Resources Research, 52, 2016, doi:10.1002/2016WR018665).

The NCCV allows the user to visualize projected changes in climate (mean, minimum, and maximum air temperature and precipitation) and the simulated water balance (snow water equivalent, runoff, soil water storage, and evaporative deficit) for a state or county and for USGS Hydrologic Units (HUC) HUC4 and HUC8. USGS HUCs are hierarchical units of watershed area. For example, the California-Northern Klamath-Costal HUC4, spans an area of 4.3×10^4 km^2 whereas the Upper Klamath Lake, Oregon. HUC8 subbasin within that HUC4 spans an area of 1.8×10^3 km^2. To create a manageable number of permutations in the viewer, we averaged the climate and water balance data into four climatology periods: 1981-2010, 2025-2049, 2050-2074, and 2075-2099. The 1981-2010 range represents the current climate normal period; although, the MACAv2-METDATA data set is bias corrected over the 1979-2012 period (see details here). The viewer provides many useful tools for exploring climate change such as maps, climographs (plots of monthly averages), histograms that show the distribution or spread of the model simulations, monthly time series spanning 1950-2099, the ability to view individual model spread by combinations of variables (e.g., temperature and snow water equivalent), and tables that summarize projections for each variable. The application also provides access to summary reports of climate and water balance variables in PDF format and CSV files of monthly time series. Users can also download the chart data used within the application as compressed JSON files. The gridded MACAv2-METDATA data are available in NetCDF format from the MACA web site (https://climate.northwestknowledge.net/MACA/index.php), and the water balance data are available from USGS ScienceBase (https://doi.org/10.5066/P9B2O22V).

Overview of the USGS National Climate Change Viewer

Interpreting output from many climate models in time and space is challenging. To aid in addressing that challenge, we have designed a viewer that strikes a balance between visualizing and summarizing climate information and the complexity of navigating the site. The features of the viewer are readily discovered and learned by experimenting and interacting; however, for reference we provide the following tutorial to explain most of the details of the viewer.

Controls, map navigation, and charts

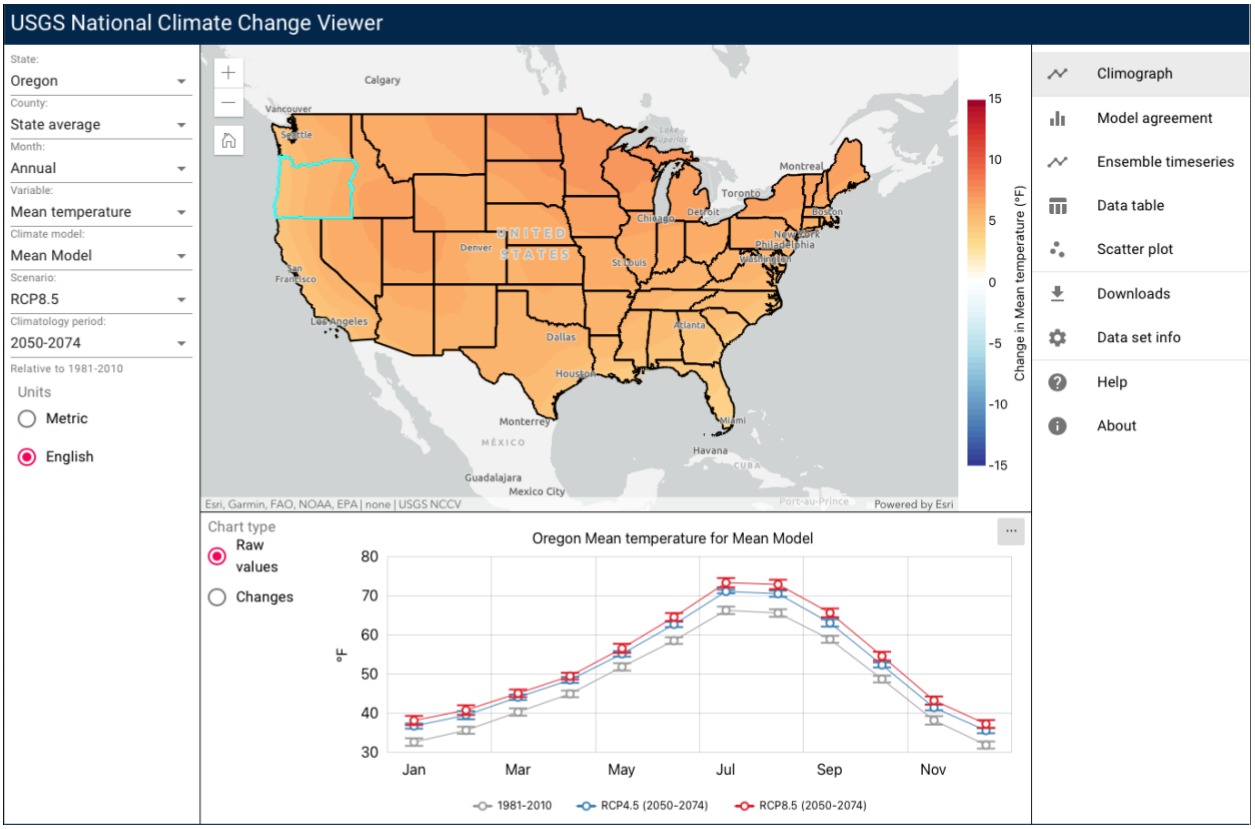


Figure 2

The main window of the NCCV (**Figure 2**) displays maps of future change (the difference between the historical period and the selected period) in a selected climate or water-balance variable and related selectable charts and tables. The maps provide the spatial variability of change across the contiguous United States, states, and counties. The dropdowns on the left-hand side of the application indicate the current selection of place, month or season, variable, climate model, emission scenario, and climatology period, which determine what is displayed in the maps and accompanying charts and tables. The application supports English or metric units throughout. Changing any of the settings updates all components of the viewer. The right-hand menu lists a series of charts in the application for visualizing climate projections for the selected place. We detail each of these charts and views in individual sections below.

The county, state, or watershed of interested can be selected either by the dropdown menus in the left control panel or by clicking on the map, which highlights the area of interest in cyan color. The map can be panned and zoomed using the mouse, scroll wheel, + and – buttons in top left of map (**Figure 3**) or by using the keyboard (up, down, left, right keys to pan and + and – keys to zoom). The map needs to be selected for keyboard navigation (often the tab key or shift+tab keys are used to navigate web pages without the use of a mouse). The home icon in top left of map returns the map to view full CONUS.

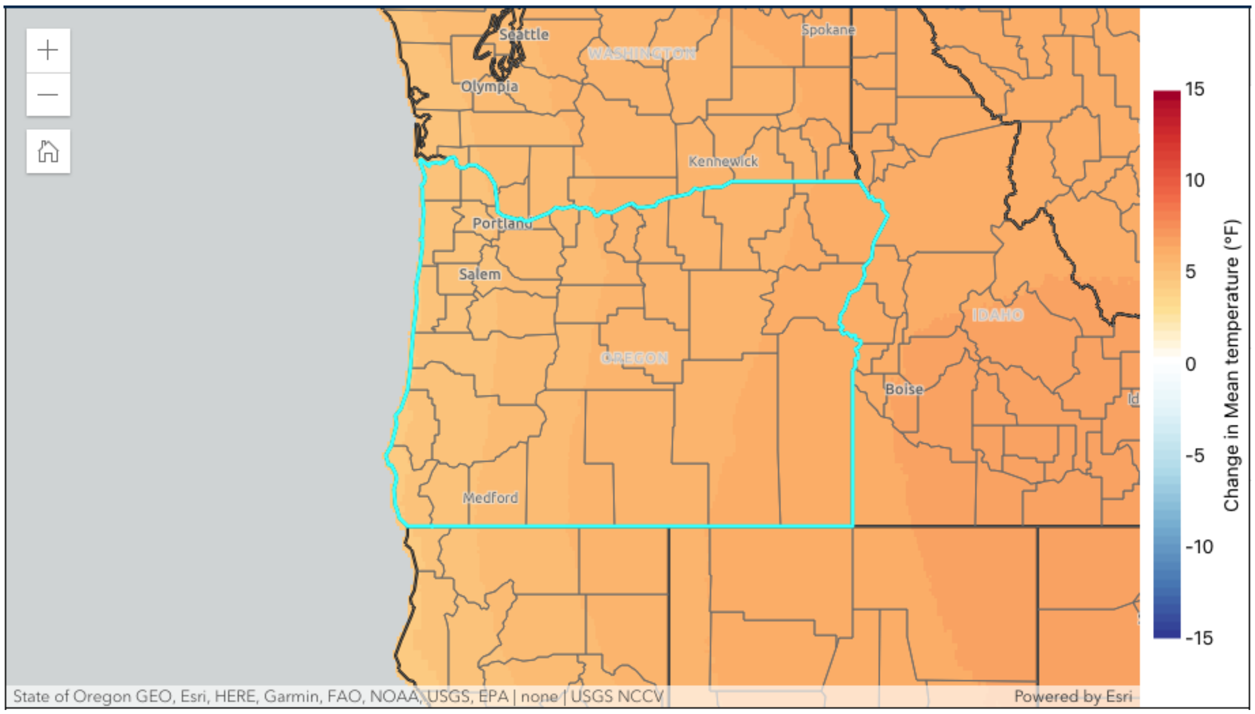


Figure 3

Climate projections can be viewed for each of the twelve months, seasonal averages (i.e., Winter: December, January, February; Spring: March, April, May; Summer: June, July, August; Fall: September, October, November), and annual average. The Climograph chart will only display the twelve calendar months. The application currently displays nine variables: mean temperature (the average of min and max temperature), maximum temperature, minimum temperature, precipitation, vapor pressure deficit, surface runoff, snow water equivalent (SWE), soil storage, and the evaporative deficit, which is the difference between potential evapotranspiration and actual evapotranspiration and is a measure of aridity. Individual climate models or the average of all the models (Mean Model) can be selected in the dropdown box. The scenario and climatology period menus (Figure 2) allows the user to select either the RCP4.5 or the RCP8.5 scenario and one of three time periods of interest: 2025-2049, 2050-2074, or 2075-2099. Changes are all relative to the 1981-2010 historical period. The maps always display anomalies (future minus historical differences), but the Climograph and Ensemble time series charts can display either raw values or anomalies.

Climograph

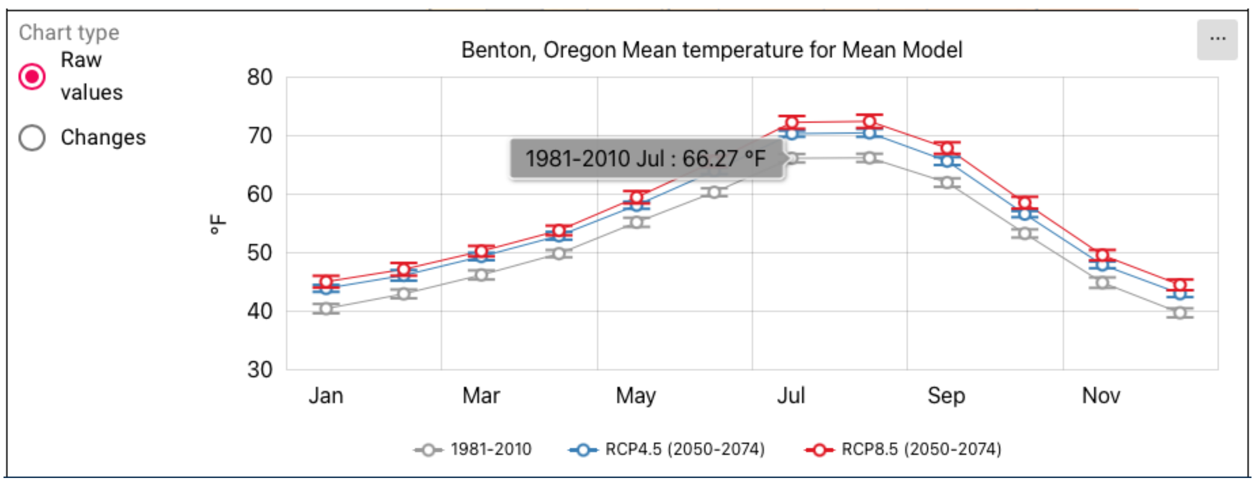


Figure 4

The Climograph chart displays the seasonal cycle for the selected location and climate variable comparing the historical period (1981-2010) to a future period for the RCP4.5 and RCP8.5 scenarios (**Figure 4**). The error bars represent ± 1 standard deviation within the climatology period (ie 2050-2074), a measure of temporal variability. The mouse can be used to hover over the month circle symbols to display the numeric values. Clicking the circle symbols changes the selected scenario, month, and updates the map display. Individual series can be shown or hidden by clicking on the legend.

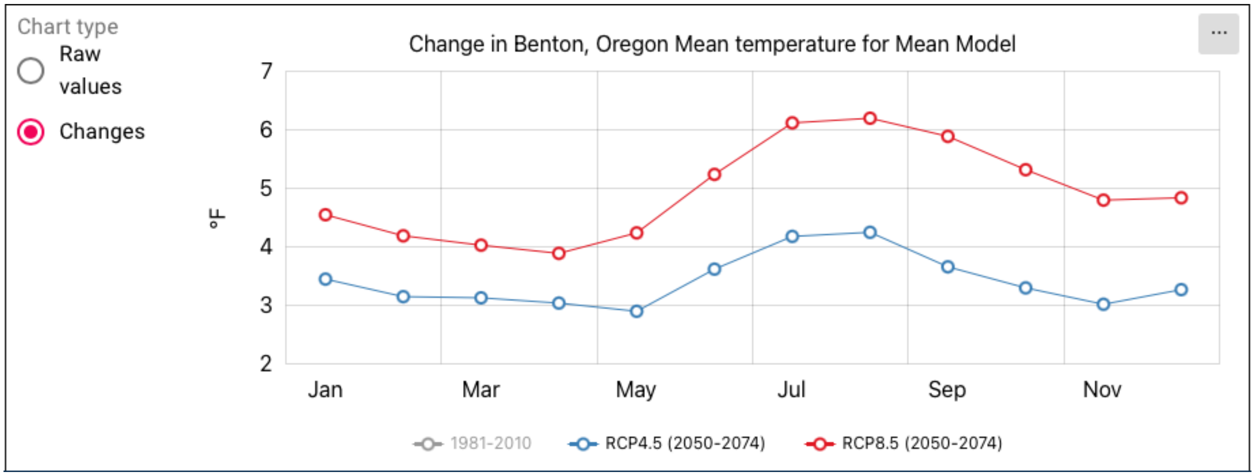


Figure 5

The chart can also display changes in the seasonal cycle which highlights the magnitude of monthly change projected at this location (**Figure 5**).

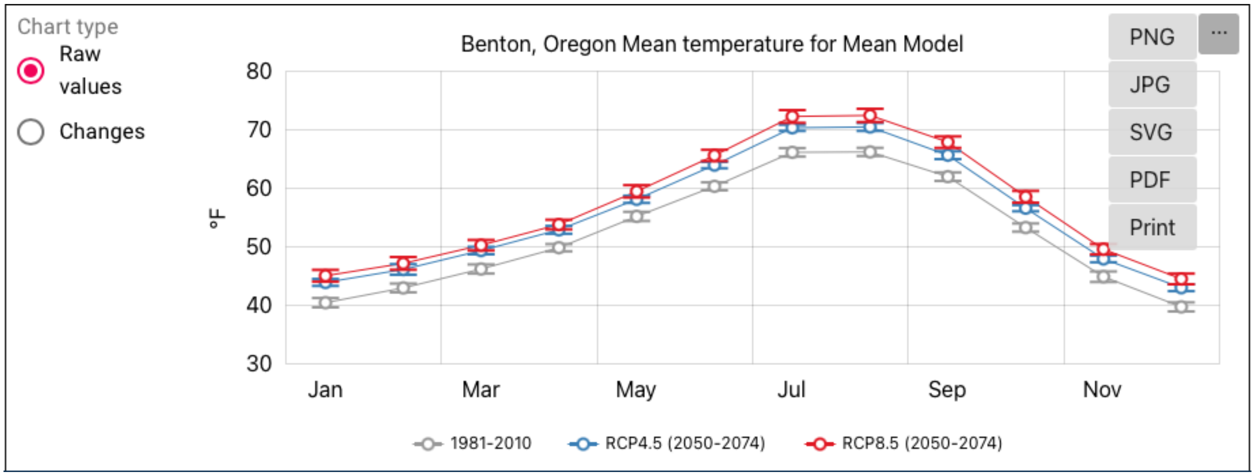


Figure 6

All charts within the application can be exported for download in various image formats by clicking the […] menu in the top right of each graphic (**Figure 6**).

Model agreement

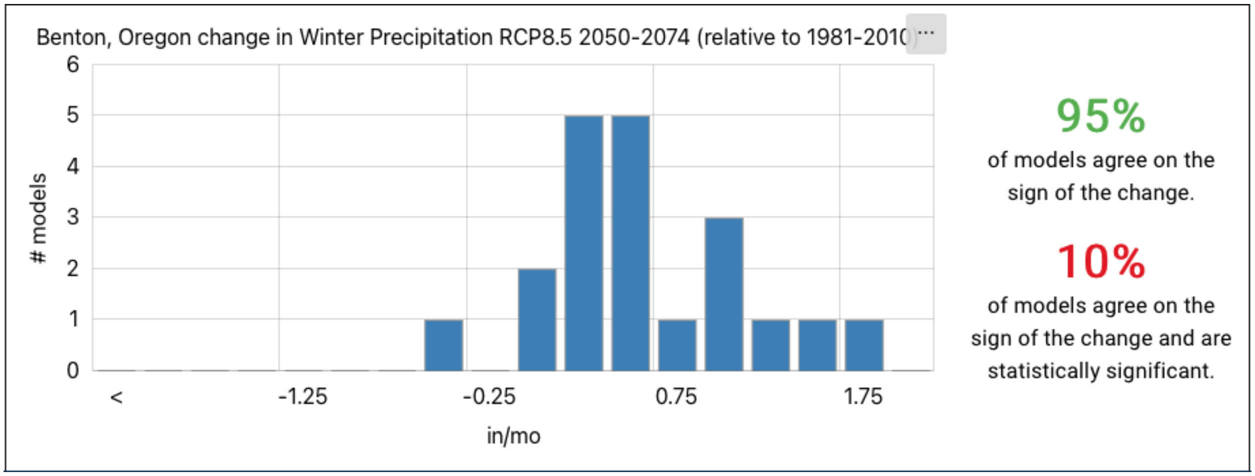


Figure 7

The Model agreement chart displays a histogram of the future changes simulated by each climate model (**Figure 7**). This graphic is a useful way to quickly determine if the climate models are simulating changes of similar sign and magnitude and gives a summary of the model spread. In the example above, 19 out of 20 climate models simulate increased winter precipitation in Benton County, Oregon in 2050-2074 under the RCP8.5 scenario. However, there is lack of agreement on the magnitude of the increase, with most models simulating a modest 0.25 – 0.75 in/mo increase. Hovering the mouse over the histogram columns displays the individual models in each bin. Clicking on the histogram column will cycle through the models within each bin.

To the right of the histogram chart are two additional metrics for model agreement and statistical significance of the simulated changes. The top number indicates the percent of the 20-models that share the same sign as the ensemble median. The text is color coded into three categories: low (red, <60% agreement), medium (orange: 60 ≤ 80% agreement), high (green > 80% agreement). The lower number indicates the percent of the models that share the both sign as the ensemble median and are statistically significant based on a Mann-Whitney rank test ($p < 0.05$). In the example above (**Figure 7**), a majority (95%, 19/20 models) of the models simulate an increased winter precipitation in Benton County, Oregon, but only 10% (2/20 models) of the model changes are positive and statistically significant. This can be corroborated in the Data table view.

Ensemble timeseries

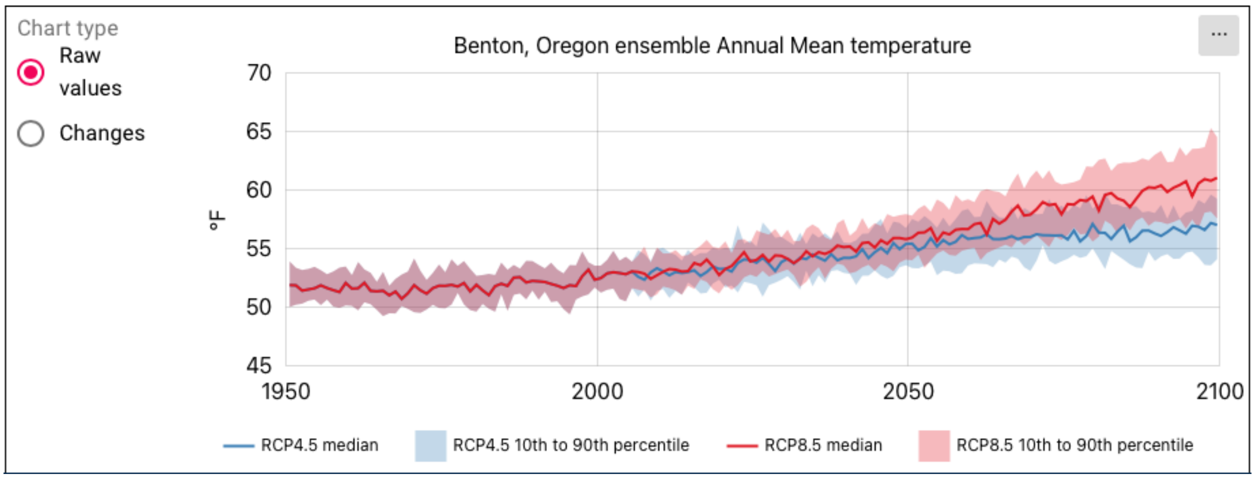


Figure 8

The Ensemble timeseries chart displays the year-by-year climate projections for the ensemble median and 10th to 90th percentile range from 1950-2099 (**Figure 8**). The percentile range omits the highest and lowest models, but plots 80% of the ensemble (ie 16/20 models). Unlike the previous charts, the model selection in left control panel does not apply here, as the ensemble is displayed rather than an individual model. The map will still reflect the currently selected climate model. Like the Climograph chart, the timeseries can be viewed as either raw values or change (relative to the 1981-2010 base period) (**Figure 9**). The mouse can be used to hover over the timeseries to display detailed information for an individual year. The chart cannot be clicked on to update the map selection.

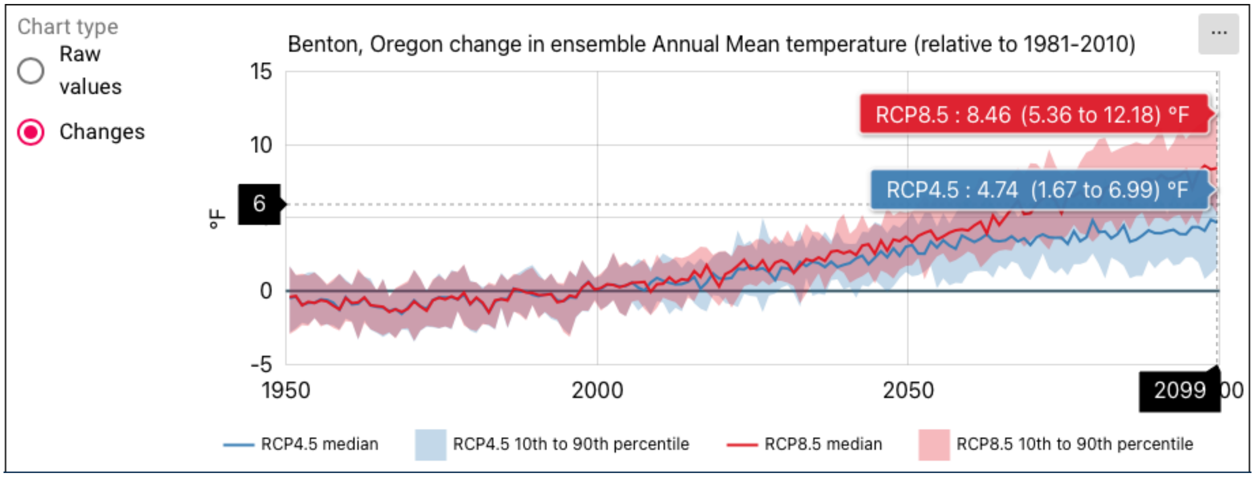
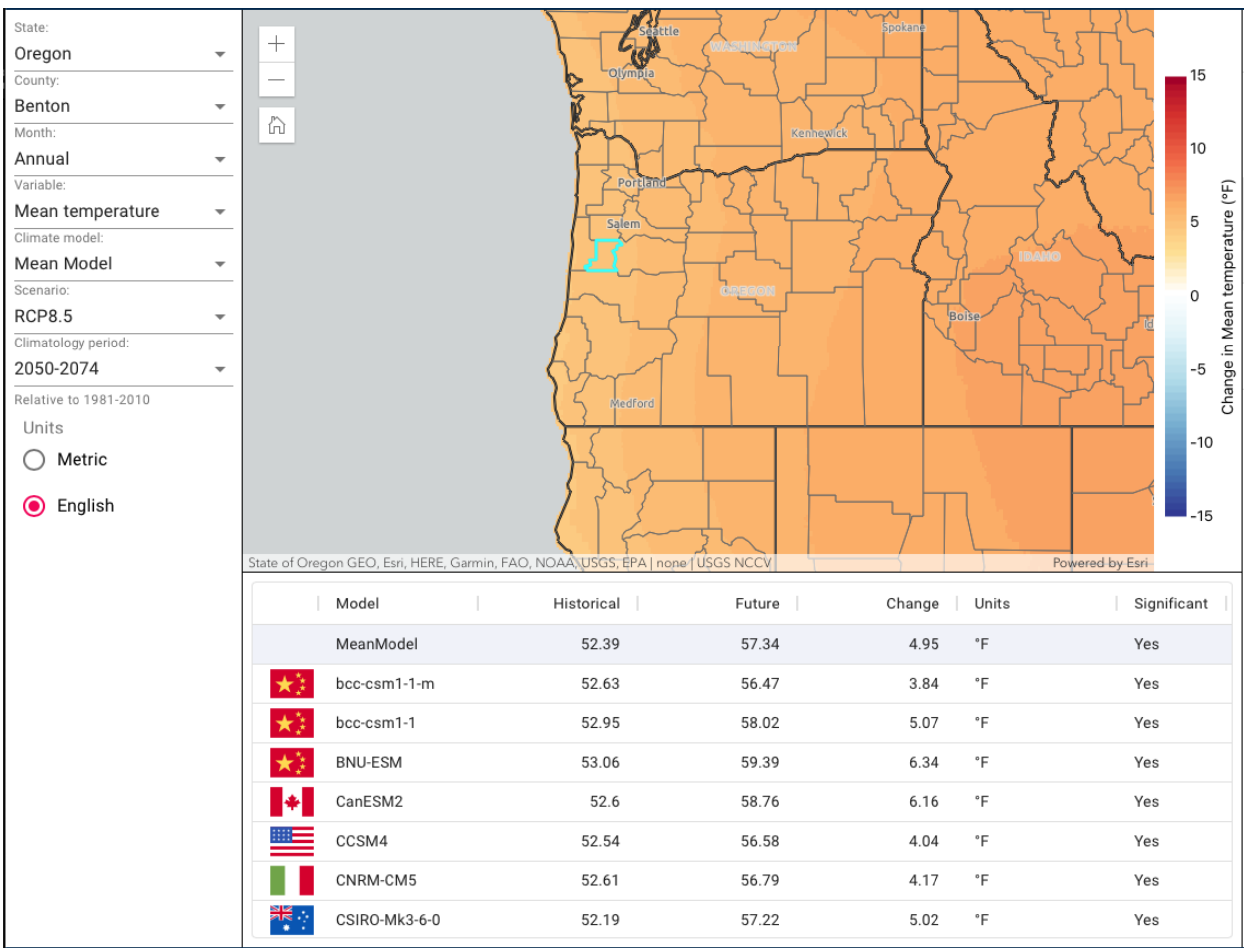


Figure 9

Data table



	Model	Historical	Future	Change	Units	Significant
	MeanModel	52.39	57.34	4.95	°F	Yes
	bcc-csm1-1-m	52.63	56.47	3.84	°F	Yes
	bcc-csm1-1	52.95	58.02	5.07	°F	Yes
	BNU-ESM	53.06	59.39	6.34	°F	Yes
	CanESM2	52.6	58.76	6.16	°F	Yes
	CCSM4	52.54	56.58	4.04	°F	Yes
	CNRM-CM5	52.61	56.79	4.17	°F	Yes
	CSIRO-Mk3-6-0	52.19	57.22	5.02	°F	Yes

Figure 10

The Data table displays the full tabular information for the current selection of location, variable, scenario and climatology period for all 20 climate models. The columns can be sorted by value and the rows can be clicked on to select an individual climate model. Used in combination, these features can be useful to sort the climate models by the magnitude of the future change and click on individual rows to visualize how the spatial patterns of change vary among high or low sorted models.

Scatter plot

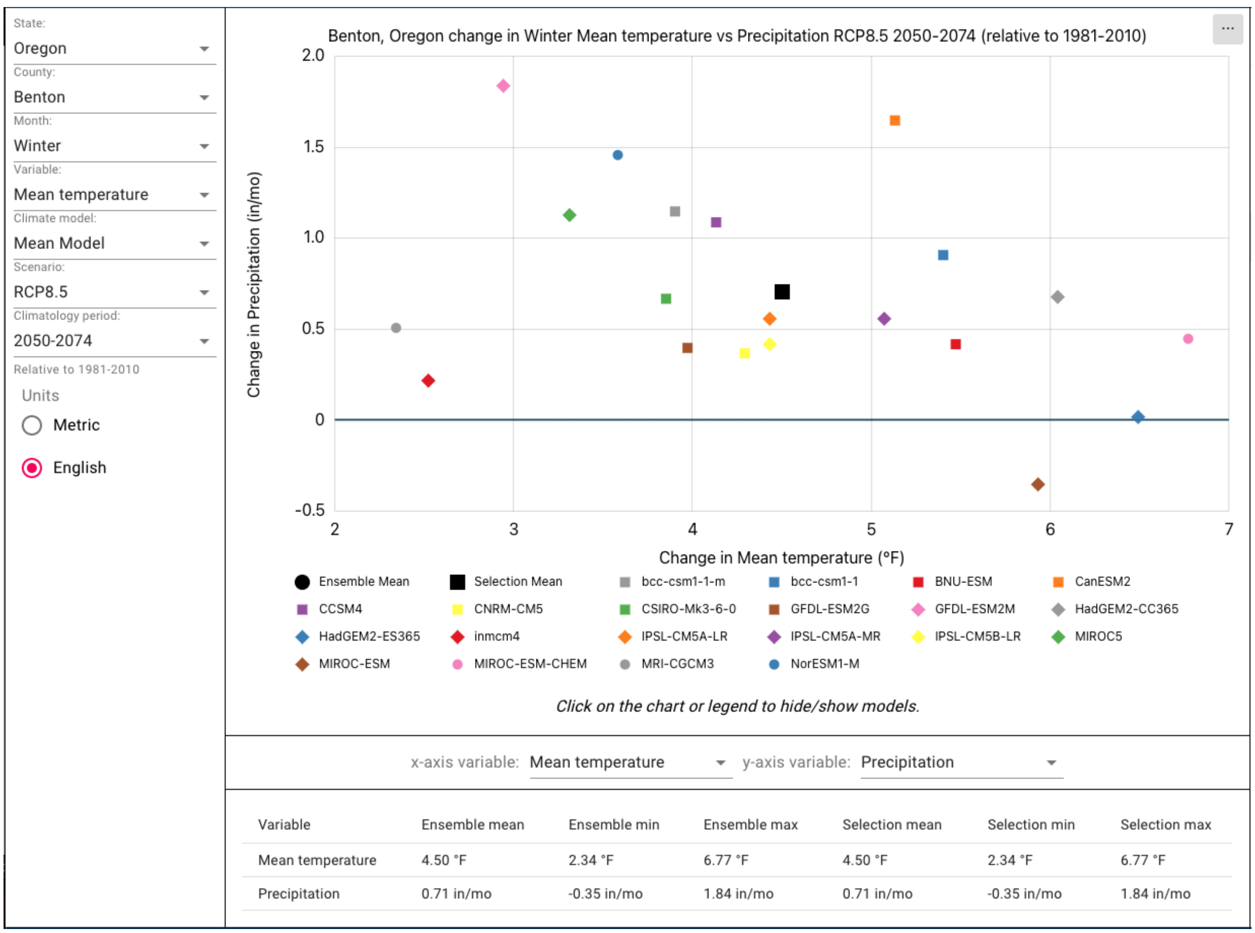


Figure 11

The Scatter plot graph allows users to explore multivariate response of climate change for a given location (**Figure 11**). The graph plots the future minus historical changes for two selected climate or water balance variables for a given month, scenario, and climatology period. This chart is useful to users interested in climate model selection for additional analysis, where it might be impractical to use the full model ensemble. Individual climate models can be turned on and off by clicking on the symbol in the chart or on the legend. Below the chart the table displays the full ensemble mean and range in addition to the current selection mean and range when a group of models have been excluded. In the example of **Figure 12**, 14 out of 20 models have been disabled. As indicated by the close agreement of the 6-model selection mean (black square) and the full 20-model ensemble mean (black circle) the change in temperature and precipitation means and ranges in the subset of 6 models is preserved, indicating that these models are representative of the full ensemble for this location and selected variables. The Scatter plot can also be useful to test the response of removing models that may be outliers relative to the larger ensemble.

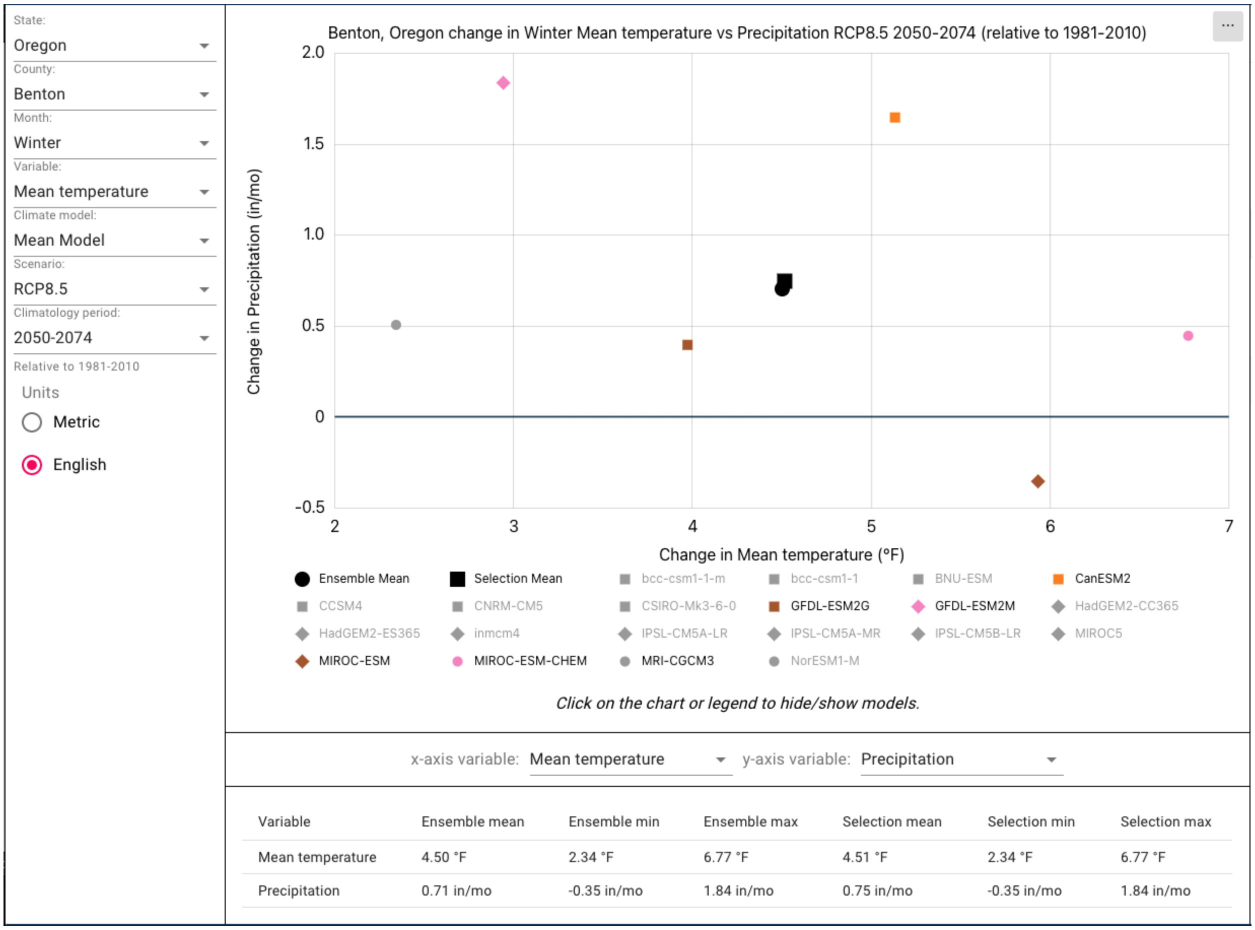


Figure 12

Download data

Chart data, monthly time series and summary PDF reports for each county, state, and watershed can be downloaded in either English or metric units (**Figure 13**). The PDF reports (**Figure 14**) provide a comprehensive summary of the climate projections for a given location through a suite of graphics similar to those found in the viewer. Graphics are provided for all the variables used in the application. The PDF reports summarize the model ensemble rather than an individual model.

The downloadable comma separated variable (CSV) files contain the 1950-2099 monthly timeseries of all variables for both RCP4.5 and RCP8.5 (**Figure 15**). Time series files for each model are available for additional analysis outside the application. Metadata is included to describe the file contents and the monthly values for the two scenarios are registered in time by the model year and month. Note that the data are the raw averages and not the differences between the scenarios and the historical period. The data files used to create the charts within the application can also be downloaded as compressed JSON files. While not in the Download data view, any chart displayed in the application can be downloaded by clicking the […] menu in the top right of each graphic (see **Figure 6**).

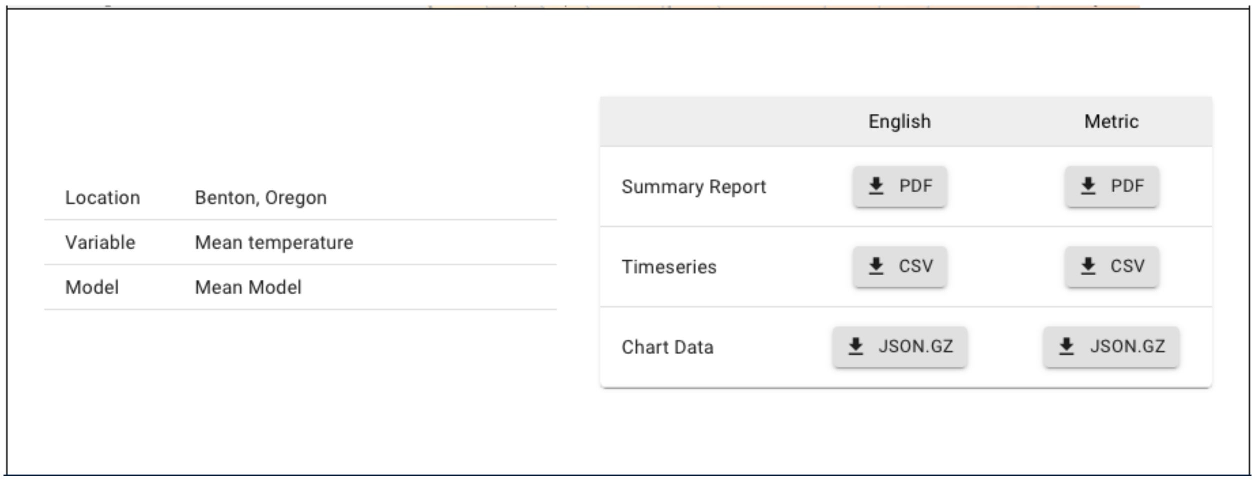


Figure 13

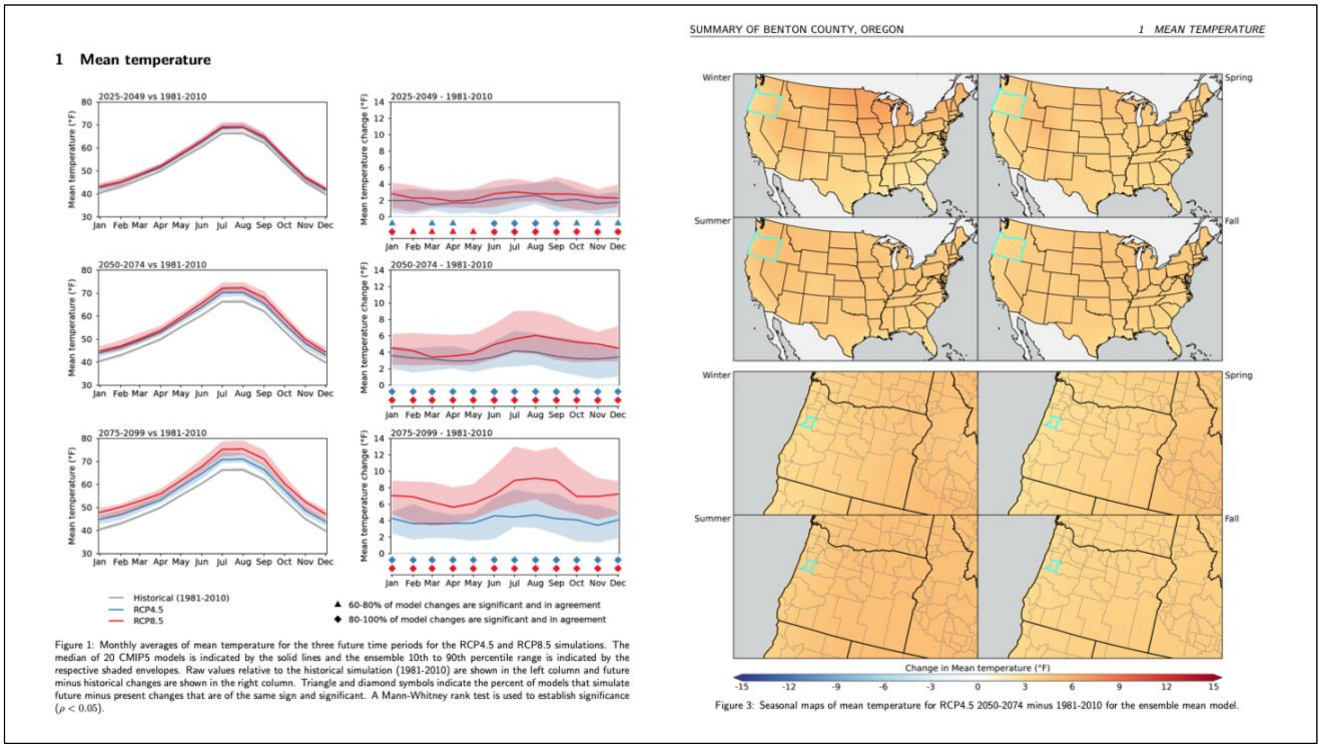


Figure 14

These freely available, derived data sets were produced by J. Alder and S. Hostetler,
US Geological Survey (Alder, J. R. and S. W. Hostetler, 2013. USGS National Climate Change Viewer.
US Geological Survey https://doi.org/10.5066/F7W9575T). Climate forcings in the MACAv2-METDATA were
drawn from a statistical downscaling of global climate model (GCM) data from the Coupled Model
Intercomparison Project 5 (CMIP5, Taylor et al. 2010) utilizing a modification of the Multivariate
Adaptive Constructed Analogs (MACA, Abatzoglou and Brown, 2012) method with the METDATA(Abatzoglou, 2011)
observational dataset as training data. No warranty expressed or implied is made by the
USGS regarding the display or utility of the derived data on any other system, or for
general or scientific purposes, nor shall the act of distribution constitute any such
warranty. The USGS shall not be held liable for improper or incorrect use of the data
described and/or contained herein.

Data revised on : Wed Apr 28 10:25:03 2021

County : Benton, Oregon
Model : MeanModel (r1i1p1)

Years from 1950-2005 are from the Historical experiment and the years from 2006-2099 are from
either the RCP4.5 or RCP8.5 experiments

Date	RCP4.5 Mear	RCP4.5 Max	RCP4.5 Min t	RCP4.5 Preci	RCP4.5 Vapo	RCP4.5 Runo	RCP4.5 Snow	RCP4.5 Soil s	RCP4.5 Evap.	RCP8.5 Mear	RCP8.5 Max	RCP8.5 Min t	RCP8.5 Preci	RCP8.5 Vapo	RCP8.5 Runo	RCP8.5 Snow	RCP8.5 Soil s	RCP8.5 Evap.
1/15/1950	40.039	46.202	33.876	8.518	0.021	7.015	1.46	6.415	0	40.039	46.202	33.876	8.518	0.021	7.015	1.46	6.415	0
2/15/1950	42.547	50.116	34.979	8.169	0.032	7.346	1.283	6.415	0	42.547	50.116	34.979	8.169	0.032	7.346	1.283	6.415	0
3/15/1950	45.01	53.758	36.261	6.723	0.042	6.591	0.648	6.415	0	45.01	53.758	36.261	6.723	0.042	6.591	0.648	6.415	0
4/15/1950	49.801	60.166	39.437	4.498	0.062	4.616	0.264	6.159	0	49.801	60.166	39.437	4.498	0.062	4.616	0.264	6.159	0
5/15/1950	54.511	65.59	43.432	3.038	0.083	2.638	0.061	5.303	0.059	54.511	65.59	43.432	3.038	0.083	2.638	0.061	5.303	0.059
6/15/1950	60.099	72.082	48.116	1.722	0.11	1.361	0.001	3.203	0.426	60.099	72.082	48.116	1.722	0.11	1.361	0.001	3.203	0.426
7/15/1950	66.167	80.38	51.955	0.469	0.163	0.661	0	1.038	2.241	66.167	80.38	51.955	0.469	0.163	0.661	0	1.038	2.241
8/15/1950	65.692	80.075	51.309	0.751	0.155	0.356	0	0.482	2.949	65.692	80.075	51.309	0.751	0.155	0.356	0	0.482	2.949
9/15/1950	61.766	75.253	48.278	1.206	0.136	0.221	0	0.518	1.809	61.766	75.253	48.278	1.206	0.136	0.221	0	0.518	1.809
10/15/50	52.81	62.882	42.739	4.317	0.063	0.455	0	2.886	0.234	52.81	62.882	42.739	4.317	0.063	0.455	0	2.886	0.234
11/15/50	44.468	51.256	37.681	9.269	0.026	3.152	0.014	5.823	0.007	44.468	51.256	37.681	9.269	0.026	3.152	0.014	5.823	0.007
12/15/50	39.921	45.638	34.204	11.373	0.019	6.369	1.002	6.411	0	39.921	45.638	34.204	11.373	0.019	6.369	1.002	6.411	0
1/15/1951	40.47	46.8	34.14	9.588	0.022	7.682	1.254	6.414	0	40.47	46.8	34.14	9.588	0.022	7.682	1.254	6.414	0
2/15/1951	42.97	50.235	35.704	7.915	0.031	7.571	0.95	6.415	0	42.97	50.235	35.704	7.915	0.031	7.571	0.95	6.415	0
3/15/1951	45.996	55.043	36.949	6.524	0.044	6.542	0.418	6.388	0	45.996	55.043	36.949	6.524	0.044	6.542	0.418	6.388	0
4/15/1951	48.833	58.807	38.859	4.79	0.058	4.722	0.183	6.127	0.001	48.833	58.807	38.859	4.79	0.058	4.722	0.183	6.127	0.001
5/15/1951	55.097	66.487	43.708	2.772	0.089	2.609	0.044	5.052	0.097	55.097	66.487	43.708	2.772	0.089	2.609	0.044	5.052	0.097
6/15/1951	59.848	71.646	48.049	1.641	0.108	1.345	0	3.072	0.602	59.848	71.646	48.049	1.641	0.108	1.345	0	3.072	0.602
7/15/1951	65.786	80.097	51.475	0.46	0.165	0.654	0	1.019	2.319	65.786	80.097	51.475	0.46	0.165	0.654	0	1.019	2.319
8/15/1951	66.169	80.579	51.758	0.453	0.161	0.338	0	0.423	3.241	66.169	80.579	51.758	0.453	0.161	0.338	0	0.423	3.241
9/15/1951	61.065	74.441	47.691	1.724	0.128	0.246	0	0.564	1.369	61.065	74.441	47.691	1.724	0.128	0.246	0	0.564	1.369

Figure 15

Water Balance Variables

In addition to information about temperature and precipitation, related projections of future change in the terrestrial hydrological cycle are of interest. We applied a simple water-balance model driven by the 4-km MACAv2-METDATA temperature and precipitation from all the included CMIP5 models to simulate changes in the monthly water balance through the 21st century.

Overview and limitations of the Water-Balance model

The water-balance model (WBM) was developed by USGS scientists G. McCabe and D. Wolock (*J. Am. Water Resour. Assoc*., 35, 1999, doi:10.1111/j.1752-1688.1999.tb04231.x). It has been applied to investigate the surface water-balance under climate change over the US and globally (McCabe and Wolock, *Climatic. Change*, 2010, doi:10.1007/s10584-009-9675-2; Pederson et al., *Geophysical Research Letters*, 2013, doi:10.1002/grl.50424, 2013). A detailed evaluation of the water-balance model using our specific configuration is also available (Hostetler, S.W. and Alder, J.R., Water Resources Research, 52, 2016, doi:10.1002/2016WR018665).

From inputs of temperature, precipitation, and potential solar radiation, the WBM accounts for the partitioning of water through the various components of the hydrological system (**Figure 16**). Air temperature determines the portion of precipitation that falls as rain and snow, the accumulation and melting of the snowpack, and evapotranspiration (PET and AET). Rain and melting snow are partitioned into direct surface runoff (DRO), soil moisture (ST), and surplus runoff that occurs when soil moisture capacity is at 100% (RO). Potential evapotranspiration is determined from temperature and potential solar radiation by the Oudin method (Oudin et al. 2005).

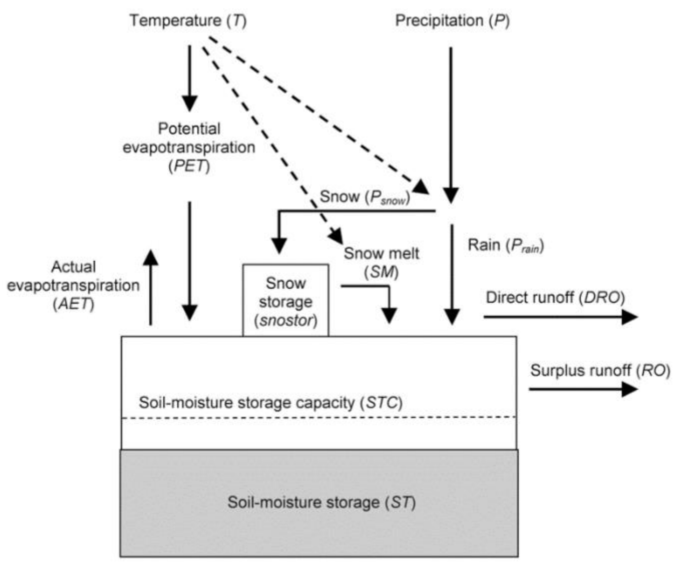


Figure 16 From McCabe and Markstrom, 2007, US Geological Survey Open-File Report 2007-1088.

We include four water balance variables in the viewer (**Figure 16**):

- Snow water equivalent (SWE), the liquid water stored in the snowpack,
- Soil water storage, the water stored in soil column,
- Evaporative deficit, the difference between potential evapotranspiration (PET), which is the amount of evapotranspiration that would occur if unlimited water were available, and actual evapotranspiration (AET) which is what occurs but can be water limited, and
- Runoff, the sum of direct runoff (DRO) that occurs from precipitation and snow melt and surplus runoff (RO) which occurs when soil moisture is at 100% capacity

The values for all variables are given in units of average depth (e.g., inches or millimeters) over the area of the selected state, county or HUC.

The simplicity of the WBM facilitates the computational performance needed to run 40 implementations of the model for 150 years over the 4 km MACAv2-METDATA grid cells. An additional strength of the WBM is that it provides a common method for simulating change in the water balance, as driven by temperature and precipitation from the CMIP5 models, thereby producing outputs that are directly comparable across all models (**Figure 17**).

There are tradeoffs, however, in using the simple WBM instead of more complex, calibrated watershed models that use more meteorological inputs (e.g., solar radiation, wind speed) and are adjusted to account for groundwater and water management. These limitations should be kept in mind when viewing the water balance components:

- the model is run on a monthly time step, so it does not capture day-to-day variability nor extreme events such as intense precipitation and floods;
- while physically based, the model simplifies more complex energy balance detail that determines evapotranspiration and snow dynamics;
- the model simulates the runoff of a grid cell but does not route runoff among grid cells or into stream networks or groundwater;
- the parameters used in the model are independent of land use and vegetation;
- surface elevation is implicit through the MACAv2-METDATA temperature and precipitation data, but the model does not account for detail of slope or aspect below the resolution of the 4-km by 4-km (2.5-mile by 2.5-mile) grid cells; and
- there are no man-made diversions or reservoirs.

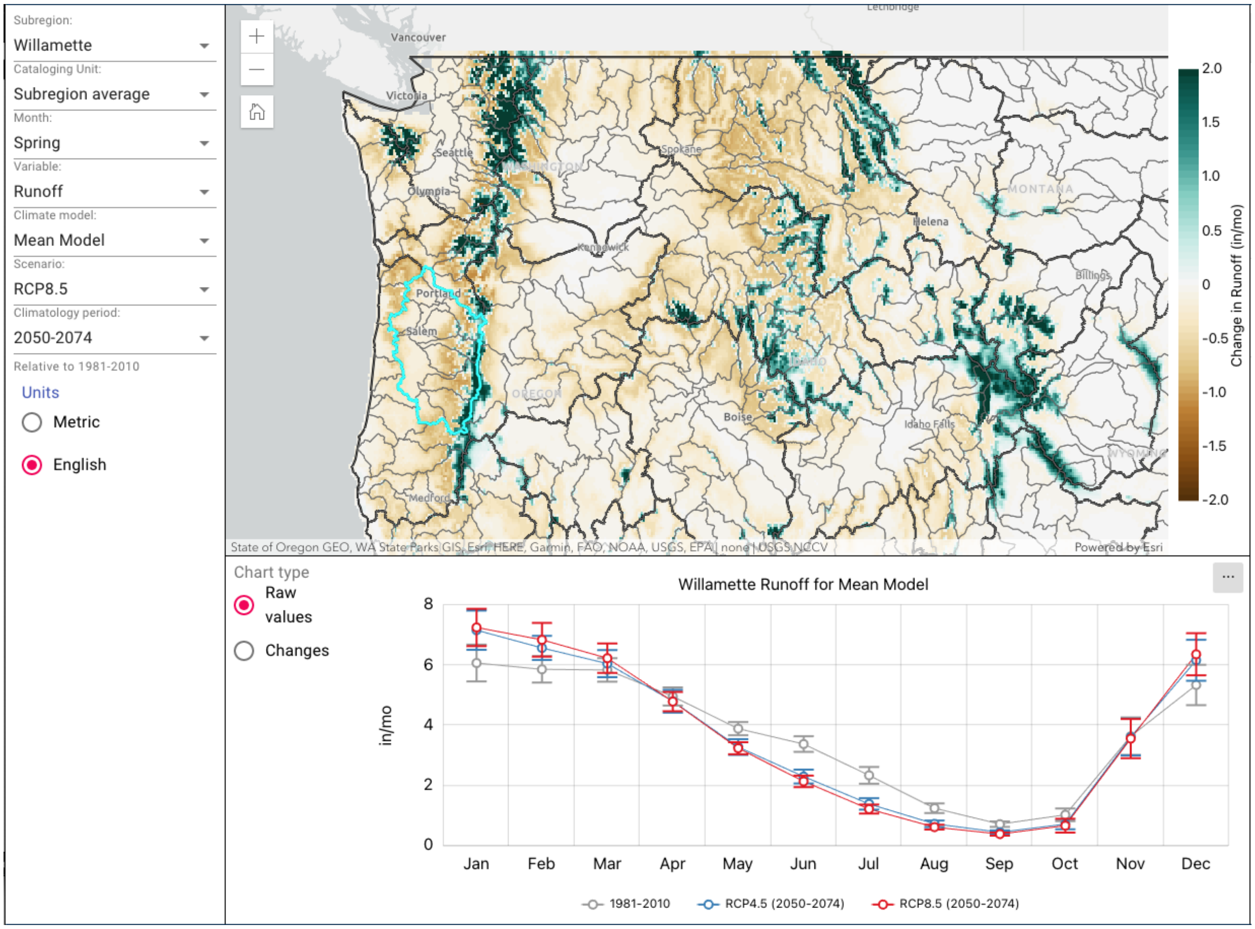

Subregion:
Willamette
Cataloging Unit:
Subregion average
Month:
Spring
Variable:
Runoff
Climate model:
Mean Model
Scenario:
RCP8.5
Climatology period:
2050-2074
Relative to 1981-2010
Units
Metric
English
Change in Runoff (in/mo)
State of Oregon GEO, WA State Parks GIS, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA | none | USGS NCCV
Powered by Esri
Chart type
Raw values
Changes
Willamette Runoff for Mean Model
in/mo
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1981-2010
RCP4.5 (2050-2074)
RCP8.5 (2050-2074)

Figure 17

Appendix

Methods

The MACAv2-METDATA data set statistically downscales general circulation models with varying grid resolutions to 1/24-degree (~4 km). The 4 km gridded temperature and precipitation data facilitated water-balance modeling over the US, and the consistent grid spacing and fine resolution of the data sets simplified averaging the data over states, counties and watersheds. Here is an example for creating county averages. Application to the watersheds is identical.

Step 1 A GIS shapefile for all the counties in the United States is used to assign each 4 km grid cell a county ID for all the cells falling within the county's boundary. The example below shows counties within Oregon. Grid cells on the boundaries are spatially weighted by the fraction of the grid cell area within the county boundary (not shown).

Step 2 Changes or anomalies in temperature, precipitation and the components of the water-balance are calculated for the three 25-year averaging periods 2025–2049, 2050–2074 and 2075–2099 relative to the base period of 1981-2010. The 4 km anomalies are displayed as map in the application.

Step 3 The county ID mask created in Step 1 is used to calculate area weighted spatial averages of the anomalies for every county for each month between 1950–2099. The county averages are used in the application climographs, histograms, timeseries and data tables.

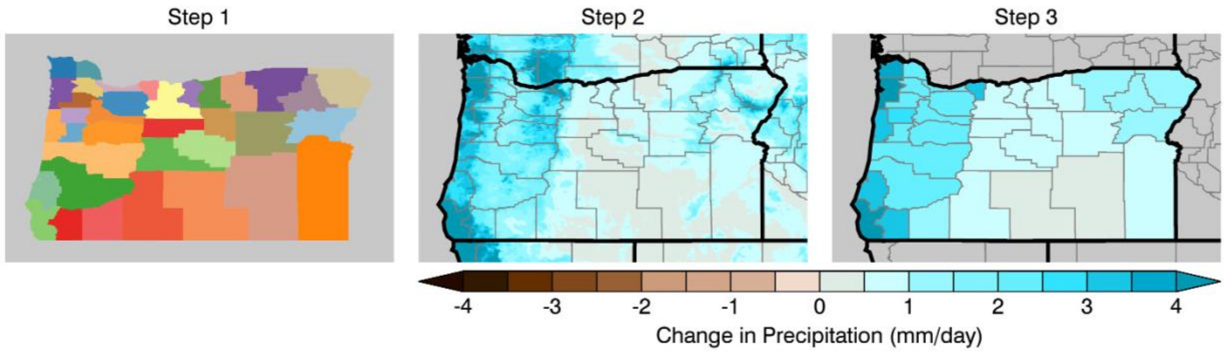


Figure 18

Models

bcc-csm1-1	bcc-csm1-1-m	BNU-ESM	CanESM2	CCSM4
CNRM-CM5	CSIRO-Mk3-6-0	GFDL-ESM2G	GFDL-ESM2M	HadGEM2-CC365
HadGEM2-ES365	inmcm4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR
MIROC5	MIROC-ESM	MIROC-ESM-CHEM	MRI-CGCM3	NorESM1-M

Citation Information

Abatzoglou, J.T., 2011. Development of gridded surface meteorological data for ecological applications and modelling. International Journal of Climatology, doi: 10.1002/joc.3413.

Abatzoglou, J.T., and Brown T.J., 2012. A comparison of statistical downscaling methods suited for wildfire applications. International Journal of Climatology, doi: 10.1002/joc.2312.

Alder, J. R. and S. W. Hostetler, 2013. USGS National Climate Change Viewer. US Geological Survey https://doi.org/10.5066/F7W9575T.

Hostetler, S.W. and Alder, J.R., 2016. Implementation and evaluation of a monthly water balance model over the U.S. on an 800 m grid. Water Resources Research, 52, doi:10.1002/2016WR018665.

Disclaimer

These freely available, derived data sets were produced by J. Alder and S. Hostetler, US Geological Survey (Alder, J. R. and S. W. Hostetler, 2013. USGS National Climate Change Viewer. US Geological Survey https://doi.org/10.5066/F7W9575T). Climate forcings in the MACAv2-METDATA were drawn from a statistical downscaling of global climate model

(GCM) data from the Coupled Model Intercomparison Project 5 (CMIP5, Taylor et al. 2010) utilizing a modification of the Multivariate Adaptive Constructed Analogs (MACA, Abatzoglou and Brown, 2012) method with the METDATA (Abatzoglou, 2011) observational dataset as training data. No warranty expressed or implied is made by the USGS regarding the display or utility of the derived data on any other system, or for general or scientific purposes, nor shall the act of distribution constitute any such warranty. The USGS shall not be held liable for improper or incorrect use of the data described and/or contained herein.