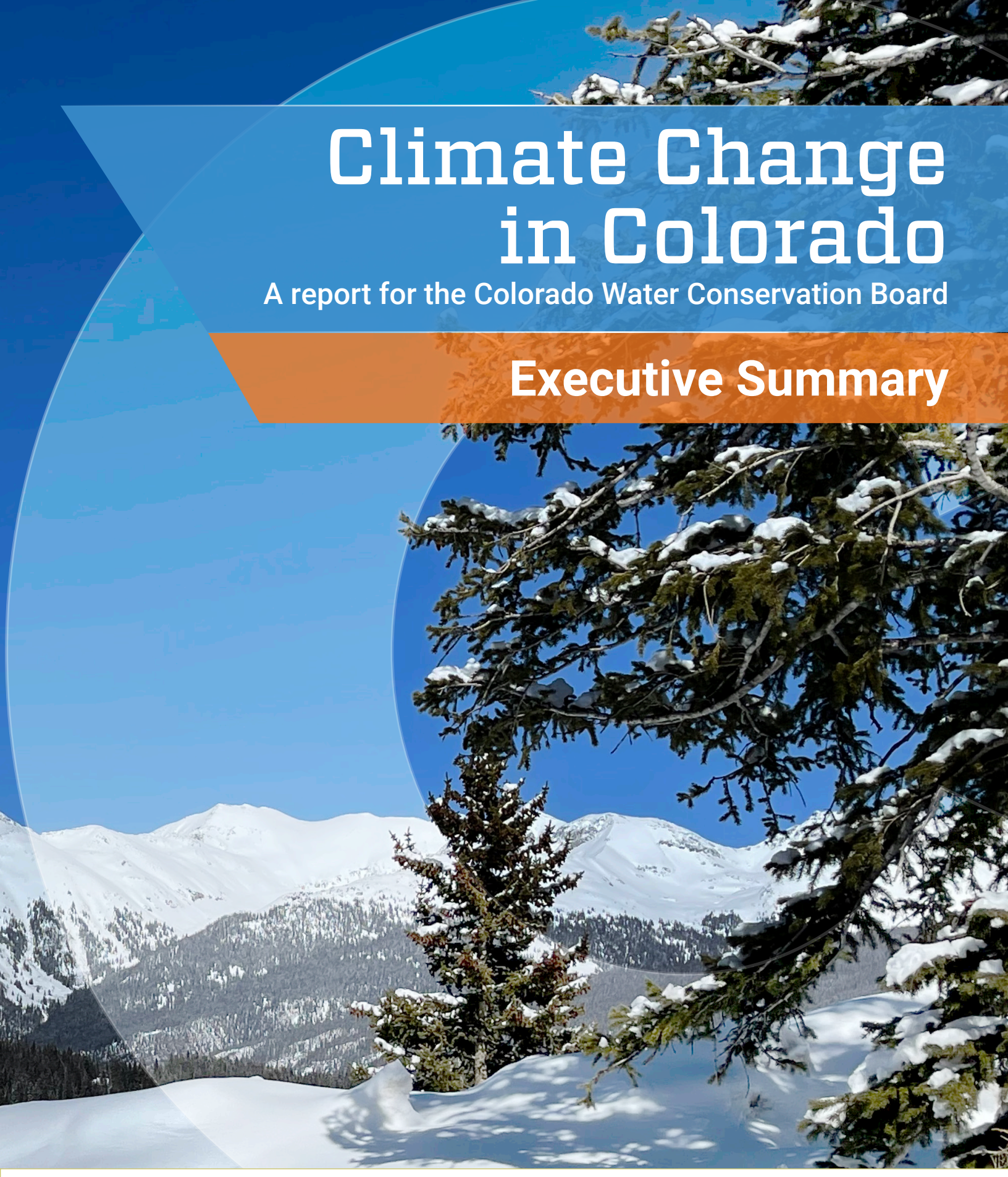
Climate Change in Colorado

A report for the Colorado Water Conservation Board

Executive Summary



COLORADO CLIMATE CENTER

ATMOSPHERIC SCIENCE
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Lukas Climate
Research and Consulting

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

DENVER WATER

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Third Edition | 2024 | Executive Summary

Authors

Becky Bolinger — Colorado Climate Center

Jeff Lukas — Lukas Climate Research and Consulting

Russ Schumacher — Colorado Climate Center

Peter Goble — Colorado Climate Center

Colorado Climate Center

Atmospheric Science, Colorado State University

Fort Collins, Colorado

Lukas Climate Research and Consulting

Lafayette, Colorado

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Colorado Water Conservation Board, Department of Natural Resources

Denver Water

About the report

climatechange.colostate.edu

This report is a synthesis of climate science relevant for management and planning for Colorado's water resources. This is an update of the 2014 report which focused on observed climate trends, climate modeling, and projections of temperature, precipitation, snowpack, and streamflow.

More of this report is devoted to extreme climate-driven events – including heat waves, droughts, wildfires, and floods – than the previous reports. Overall societal impacts of climate change will not only be determined by changes in the average climate, but by changes in these climate-driven extreme events.

The report was created by researchers at Colorado State University in the Department of Atmospheric Science within the Walter Scott, Jr. College of Engineering, and by Lukas Climate Research and Consulting. CSU Research Scientist and Assistant State Climatologist Becky Bolinger is the lead author. This project is funded by and in collaboration with the Colorado Water Conservation Board and Denver Water.

Topics

Chapter 2 | Changes in Colorado's Climate

KEY MESSAGES

Temperature

- Statewide annual average temperatures warmed by 2.3°F from 1980 to 2022.
- Only one year in the 21st century has been cooler than the 1971-2000 average. 2012 remains the state's warmest year in the 128-year record, at 48.3°F (3.2°F warmer than the 1971-2000 average).
- The greatest amount of warming in recent decades has occurred in the fall, with statewide temperatures increasing by 3.1°F from 1980-2022.
- Southwestern and South-central Colorado have experienced the largest magnitude of warming.
- The observed warming trend in Colorado is strongly linked to the overall human influence on climate and recent global warming. The observed warming over the last 20 years is comparable to what was projected by earlier climate models run in the 2000s.
- Further and significant warming is expected in all parts of Colorado, in all seasons, over the next several decades.
- By 2050 (the 2035-2064 period average), Colorado statewide annual temperatures are projected to warm by +2.5°F to +5.5°F compared to a 1971-2000 baseline, and +1.0°F to +4.0°F compared to today, under a medium-low emissions scenario (RCP4.5).
- By 2070 (the 2055-2084 period average), Colorado statewide annual temperatures are projected to warm by +3.0°F to +6.5°F compared to the late 20th century, and +1.5°F to +5.0°F compared to today, under RCP4.5.
- By 2050, the average year is likely to be as warm as the very warmest years on record through 2022. By 2070, the average year is likely to be warmer than the very warmest years through 2022.
- Summer and fall are projected to warm slightly more than winter and spring.

Climate variable/event	Recent trend	Projected future change	Confidence in change
Average Temperature	**Warmer**	**Warmer**	**Very High** ●
Annual Precipitation	**Lower**	Uncertain	Low ◔

Table 2.1 Summary of the observed and projected changes in annual average temperature and annual precipitation for Colorado, as detailed in the following sections. "Confidence in change" reflects the judgment of the authors, based on both the assessments in higher-level climate reports (NCA, IPCC) as well as relevant literature and model output for Colorado.

Precipitation

- Colorado has observed persistent dry conditions in the 21st century. According to water year precipitation accumulations, October 1 – September 30, four of the five driest years have occurred since 2000.
- Drying trends have been observed over the majority of the state during the spring, summer, and fall seasons.
- Northwest Colorado summer precipitation has decreased 20% since the 1951-2000 period.
- Southwest Colorado spring precipitation has decreased 22% since the 1951-2000 period.
- The direction of future change in annual statewide precipitation for Colorado is much less clear than for temperature. The climate model projections for 2050 range from -7% to +7% compared to the late 20th century average, under a medium-low (RCP4.5) emissions scenario.
- The model projections for precipitation change by 2070 are very similar to those for 2050.
- Most climate models project an increase in winter (Dec-Feb) statewide precipitation; the model consensus is weaker for the other seasons. The models do suggest enhanced potential for large decreases (-10% to –25%) in summer precipitation.

Chapter 3 Changes in Colorado's Water

KEY MESSAGES

Climate variable/event	Recent trend	Projected future change	Confidence in change
Spring Snowpack	**Lower**	Lower	Medium
Runoff timing	**Earlier**	**Earlier**	**High**
Annual Streamflow	**Lower**	Lower	Medium
Summer soil moisture	**Lower**	**Lower**	**High**
Evaporative demand	**Higher**	**Higher**	**Very High**

Table 3.1 Summary of the observed and projected changes in hydrology and water resources for Colorado, as detailed in the following sections. "Confidence in change" reflects the judgment of the authors, based on both the assessments in higher-level climate reports (NCA, IPCC), as well as relevant literature and model output for Colorado. In general, there is higher confidence in the changes in variables that are driven mainly by warming and less by the more uncertain change in annual precipitation.

Snowpack

- April 1 SWE (snow water equivalent) during the 21st century has been 3% to 23% lower than the 1951-2000 average across Colorado's major river basins.
- Future warming will lead to further reductions in Colorado's spring snowpack. Most climate model projections of April 1 SWE in the state's major river basins show reductions of -5% to -30% for 2050 compared to 1971-2000; the individual projections that show increasing snowpack assume large increases in fall-winter-spring precipitation.
- The seasonal peak of the snowpack is projected to shift earlier by a few days to several weeks by 2050, depending on the amount of warming and the precipitation change. This warming-driven shift could be accelerated by increases in dust-on-snow events.

Streamflow

- Since 2000, annual streamflow in all of Colorado major river basins has been 3% to 19% lower than the 1951-2000 average.
- Modeling studies have attributed up to half of the observed decrease in streamflow since 1980 in Colorado river basins to warming temperatures.
- Future warming will act to reduce annual streamflows. Most climate model projections of annual streamflows in the state's major river basins for 2050 show reductions of 5% to 30% compared to 1971-2000.
- Higher future streamflow would require large overall increases in precipitation to offset the effects of warming, an outcome that appears unlikely.
- Summer and fall streamflows are projected to decline significantly by 2050 as the seasonal runoff peak shifts earlier, by 1-4 weeks, due to warming.

Soil moisture

- Modeled soil moisture based on meteorological observations suggests overall declines in high-elevation soil moisture from 1980-2022.
- Future warming will lead to declines in summer (June-August) soil moisture throughout the state. Spring (March-May) soil moisture will likely increase at higher elevations as snowmelt shifts earlier.
- Rapid depletion of soil moisture under warm conditions exacerbates warming. When summer sunshine hits a landscape with dry soil a greater fraction of solar energy directly heats the surface, leading to even warmer conditions.

Evapotranspiration

- The evaporative demand ("thirst") of the atmosphere—as measured by potential evapotranspiration (PET) and Reference ET—has increased across Colorado since 1980, mainly due to the warming trend. Statewide, growing-season PET increased by 5% from 1980-2022.
- Additional future warming will drive greater evaporative demand; all climate model projections show statewide annual PET increasing by 8-17% by 2050, compared to 1971-2000.

Chapter 4 | Climate Extremes and Hazards

KEY MESSAGES

Climate variable/event	Recent trend	Projected future change	Confidence in change
Heat waves	**More frequent/intense**	**More frequent/intense**	**Very High**
Cold waves	**Fewer**	**Fewer**	Medium
Droughts	**More frequent/intense**	**More frequent/intense**	**High**
Wildfires	**More and larger**	**More and larger**	**High**
Extreme precipitation	**More intense**	**More frequent/intense**	Medium
Flooding	Mixed	**Higher**	Medium
Windstorms	Uncertain	Uncertain	Low
Severe thunderstorms	Uncertain	More frequent	Low
Hail	Uncertain	More large hail	Low
Tornadoes	Uncertain	Uncertain	Low
Winter storms	Uncertain	Larger storms	Low
Dust on snow events	**Greater dust levels**	**Greater dust levels**	Medium

Table 4.1: Summary of the observed and projected changes in climate extremes and hazards for Colorado, as detailed in the following sections.

Heat waves and cold waves

- Hot days and heat waves have become more common, and the number cold nights and cold waves has decreased across Colorado in recent decades, but the changes have not been equal. There have been significant increases in extreme heat across most of the state, whereas the decrease in extreme cold has been more modest.
- Projected future changes are similarly asymmetric: Heat waves are projected to increase in frequency by as much as ten-fold by the middle of the 21st century, whereas the frequency of cold waves is projected to decrease by less than half.

Drought

- Warming temperatures have increased the severity of 21st century droughts in Colorado.
- Regardless of changes in precipitation, it is likely that warmer temperatures will contribute to more frequent and severe droughts. Warmer temperatures will also decrease the benefit of wetter years.
- Intense droughts have occurred multiple times in the 21st century, including in 2002, 2012, 2018, and 2020.

Wildfire

- Since 2000, Colorado has experienced a large increase in the number of large wildfires and in the annual area burned by all wildfires; on average, fires have burned at higher elevations and with higher intensity than in the late 20th century. While several factors have contributed to these trends, rising temperatures are a major driver.
- Future warming is expected to lead to further increases in the occurrence of large wildfires and in annual area burned by all fires, especially in forest ecosystems, according to multiple studies. A greater percentage of fires will occur in the fall, winter, and spring than at present.

KEY MESSAGES CONTINUED:

Heavy and extreme rainfall, Floods, Thunderstorm hazards, Non-convective windstorms, Winter storms, Dust-on-snow

Heavy and extreme rainfall

- There are some indications of recent increasing trends in heavy and extreme rainfall in Colorado, but these are not consistent across all indicators and time periods, unlike in other regions of the U.S.
- Atmospheric moisture has generally increased over Colorado, but not by as much as one would predict from the warming atmosphere alone.
- Future warming, by increasing the moisture-holding capacity of the atmosphere, will make heavy and extreme rainfall more likely unless counterbalanced by declining trends in other storm "ingredients". Climate-model projections for Colorado show overall increases in the magnitudes of heavy and extreme rainfall events.

Floods

- Gaged streamflow records show no widespread, consistent trends in the magnitude of flood events in Colorado of different frequencies (e.g., 1-year, 20-year, 50-year, 100-year).
- The expectation that heavy and extreme rainfall events will increase in Colorado implies increases in future flood risk as well, but there are many factors influencing how rainfall is translated into runoff. Increased exposure to flooding through floodplain development may be more important than climate-driven changes in risk.

Thunderstorm hazards

- Because of the relatively short data record for thunderstorm hazards and the influences of changing observation systems, the sign and magnitude of any long-term changes is unclear.
- Some studies have suggested increases in the average size of hail in a warmer climate, with smaller hail becoming less frequent but larger hail more frequent. Overall, however, there remain large uncertainties regarding future changes, as data limitations and the infrequent and localized nature of these storms makes them challenging to study in the context of a changing climate.

Climate Extremes and Hazards

Chapter 4

KEY MESSAGES

Non-convective windstorms

- Colorado is prone to intense winds in the mountains and from downslope windstorms along the Front Range. These windstorms can cause considerable damage, and can exacerbate wildfires, such as in the 2021 Marshall Fire. Long-term changes in extreme winds have not been extensively studied, and potential future changes are highly uncertain.

Winter storms

- Despite warming temperatures in the winter, there are no detectable trends in winter severity across the Colorado Front Range and Eastern Plains. There are also minimal trends in large snowfall events.
- Several notable and high impact winter storm events have occurred over eastern Colorado in the last decade, including extreme cold, high winds, strong cold fronts, and large accumulations of snow.
- Future trends in winter storms remain highly uncertain, but the risk of high-impact winter events is likely to remain.

Dust-on-snow

- Dust-on-snow events have emerged as a concern since 2000 due to better understanding of its hydrologic effects, as well as an overall increase in the occurrence of dust-on-snow. Dust-on-snow causes earlier melt and runoff and may reduce annual runoff.
- It is likely that in a future warmer climate, drier conditions in the dust-source regions will allow for greater dust emission and thus deposition on snowpacks. Dust-on-snow and warming will both drive earlier snowmelt and runoff.

About the Colorado Climate Center

The Colorado Climate Center is located at Colorado State University within the Department of Atmospheric Science. With the support of the Agricultural Experiment Station, it is the Center's privilege and duty to provide services and expertise related to Colorado's complex climate.

As a recognized State Climate Office, the Center strives to collect and observe data with the purpose of monitoring the climate, placing individual events into historical perspective, disseminating climate information to the user community, and providing climate expertise as part of the decision-making process.

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The Colorado Water Conservation Board and Colorado Climate Center hope this report can be used to support climate adaptation and water planning efforts across Colorado. The report describes recent trends in Colorado's climate and hydrology and interprets the model-based projections of future climate and hydrology. This information can be used by local, state, and federal partners to inform planning efforts across Colorado.

The Colorado Water Conservation Board is committed to continued work across all types of communities, including those which are disproportionately impacted by environmental injustice and climate impacts. This also includes a commitment to ongoing meaningful consultation with tribal nations on water and climate change issues. Integrating Indigenous knowledge and multiple perspectives into state water planning can enhance and advance climate adaptation efforts.

This commitment to collaboration is also embodied in the Colorado Water Plan which acknowledges the need for not just state action but local action, tribal coordination, and cross-sector leadership. By working together Colorado can realize a more sustainable and resilient future.