

The Past, Present, and Future of Colorado's Climate

Russ S. Schumacher

Colorado State Climatologist

Director, Colorado Climate Center

Department of Atmospheric Science, Colorado State University

Along with: Zach Schwalbe, Becky Bolinger, Peter Goble, Nolan Doesken



CSU AES Research Center Conference
8 January 2019



ATMOSPHERIC SCIENCE
COLORADO STATE UNIVERSITY

Brief history of the CCC

- Until 1973, the federal government operated a “state climatologist” program – but in 1973 this was abolished
- Later that same year, Colorado established the Colorado Climate Center at CSU with support through the Colorado Agricultural Experiment Station



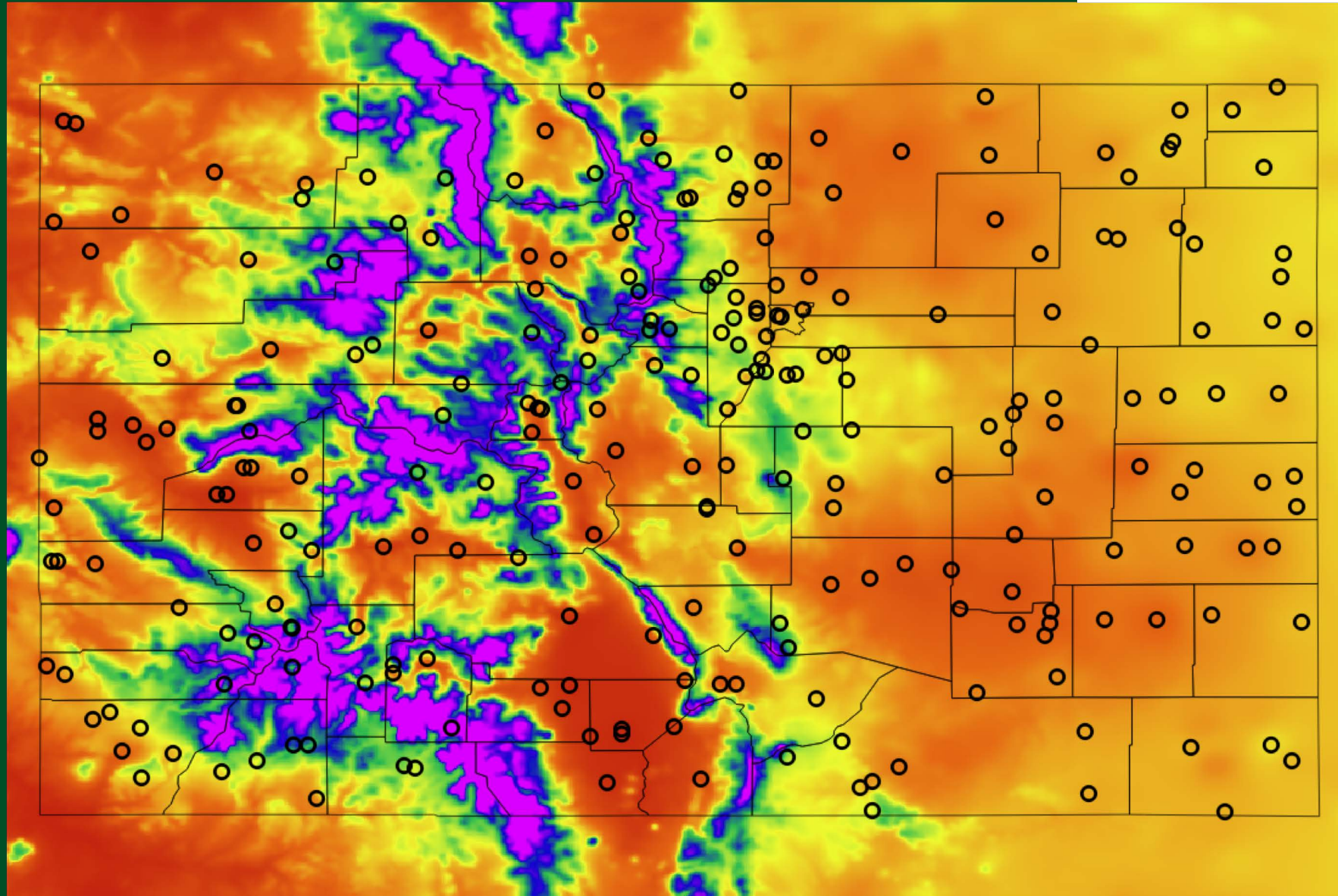
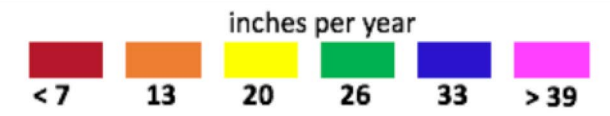
Our mission

The Colorado Climate Center at CSU provides valuable climate expertise to the residents of the state through its threefold program of:

- 1) ***Climate Monitoring*** (data acquisition, analysis, and archiving)
- 2) ***Climate Research***
- 3) ***Climate Services*** (providing data, analysis, climate expertise, education and outreach)



Annual average precipitation



Systematic weather data collection began in Colorado in the 1870s and 1880s

(FORM 4.)

WAR DEPARTMENT.

SIGNAL SERVICE, U. S. ARMY.

DIVISION OF TELEGRAMS AND REPORTS FOR THE BENEFIT OF COMMERCE.

METEOROLOGICAL RECORD for the *Week* ending *Nov. 25th 1871* at *Denver Col. Ter.*

Date of Observation.	Time of Observation.	Height of Barometer.	Height of attached Thermometers.	Reduced Barometer.	THERMOMETER (OPEN AIR.)		Direction of wind.	Velocity of wind in miles per hour.	Pressure of wind. Pounds per square foot.	Amount of cloud.	Direction in which upper clouds move.	Rain (or snow) commenced. (Time.)	Rain (or snow) ended. (Time.)	Amount of rain or melted snow.	Remarks.
					Dry Bulb.	Wet Bulb.									
<i>1871</i>															
<i>Sunday Nov. 19</i>	<i>5:43 a.m.</i>	<i>25.00</i>	<i>57 22</i>	<i>30.07</i>	<i>22 21</i>	<i>26</i>	<i>S</i>	<i>0</i>	<i>.02</i>	<i>4/4</i>					<i>Light Snow - Clear</i>
	<i>2:43 p.m.</i>	<i>25.09</i>	<i>63 36</i>	<i>24.97</i>	<i>36 30</i>	<i>46</i>	<i>S</i>	<i>2</i>	<i>.60</i>	<i>0</i>					<i>Clear</i>
	<i>5:43 a.m.</i>	<i>25.00</i>	<i>57 22</i>	<i>30.07</i>	<i>22 21</i>	<i>26</i>	<i>S</i>	<i>0</i>	<i>.60</i>	<i>0</i>					<i>Light Snow - Clear</i>
	<i>2:43 p.m.</i>	<i>25.09</i>	<i>63 36</i>	<i>24.97</i>	<i>36 30</i>	<i>46</i>	<i>S</i>	<i>2</i>	<i>.02</i>	<i>0</i>					<i>Clear</i>
<i>Monday Nov. 20</i>	<i>5:43 a.m.</i>	<i>25.12</i>	<i>58 14</i>	<i>30.20</i>	<i>14 12</i>	<i>64</i>	<i>S</i>	<i>11</i>	<i>.60</i>	<i>0</i>					<i>Clear</i>
	<i>2:43 p.m.</i>	<i>25.12</i>	<i>58 14</i>	<i>30.20</i>	<i>14 12</i>	<i>64</i>	<i>S</i>	<i>11</i>	<i>.60</i>	<i>0</i>					<i>Clear</i>
	<i>5:43 a.m.</i>	<i>24.99</i>	<i>50 21</i>	<i>30.07</i>	<i>31 19.5</i>	<i>78</i>	<i>S</i>	<i>13</i>	<i>.84</i>	<i>1/4</i>					<i>Stratus</i>
	<i>2:43 p.m.</i>	<i>24.88</i>	<i>56 43</i>	<i>29.67</i>	<i>43 34</i>	<i>28</i>	<i>NW</i>	<i>18</i>	<i>1.62</i>	<i>4/4</i>					<i>Stratus</i>
<i>Tuesday Nov. 21</i>	<i>5:43 p.m.</i>	<i>24.88</i>	<i>58 39</i>	<i>29.70</i>	<i>39 34</i>	<i>53</i>	<i>NW</i>	<i>2</i>	<i>.02</i>	<i>4/4</i>					<i>Stratus</i>
	<i>5:43 a.m.</i>	<i>24.70</i>	<i>55 31</i>	<i>29.59</i>	<i>34 29</i>	<i>79</i>	<i>S.W.</i>	<i>4</i>	<i>.08</i>	<i>4/4</i>					<i>Stratus</i>
	<i>2:43 p.m.</i>	<i>24.57</i>	<i>62 33</i>	<i>29.30</i>	<i>33 32</i>	<i>70</i>	<i>W</i>	<i>2</i>	<i>.02</i>	<i>4/4</i>					<i>"</i>
<i>Wednesday Nov. 22</i>	<i>5:43 p.m.</i>	<i>24.71</i>	<i>61 31</i>	<i>29.59</i>	<i>31 30</i>	<i>89</i>	<i>S</i>	<i>10</i>	<i>.50</i>	<i>4/4</i>				<i>.26</i>	<i>Light Snow</i>
	<i>5:43 a.m.</i>	<i>24.54</i>	<i>55 25</i>	<i>29.47</i>	<i>25 24</i>	<i>87</i>	<i>S</i>	<i>6</i>	<i>.18</i>	<i>4/4</i>					<i>Stratus</i>
	<i>2:43 p.m.</i>	<i>24.31</i>	<i>63 34</i>	<i>29.06</i>	<i>34 33</i>	<i>89</i>	<i>N.W.</i>	<i>5</i>	<i>.12</i>	<i>4/4</i>					<i>Light Snow</i>
<i>Thursday Nov. 23</i>	<i>5:43 p.m.</i>	<i>24.20</i>	<i>60 31</i>	<i>28.97</i>	<i>31 30</i>	<i>89</i>	<i>S</i>	<i>9</i>	<i>.40</i>	<i>3/4</i>					<i>"</i>
	<i>5:43 a.m.</i>	<i>24.36</i>	<i>56 32</i>	<i>29.17</i>	<i>32 32</i>	<i>100</i>	<i>S.W.</i>	<i>4</i>	<i>.08</i>	<i>4/4</i>					<i>Cloudy</i>
	<i>2:43 p.m.</i>	<i>24.37</i>	<i>70 42</i>	<i>29.04</i>	<i>42 37</i>	<i>38</i>	<i>"</i>	<i>2</i>	<i>.02</i>	<i>2/4</i>					<i>Pressure - Sun</i>
<i>Friday Nov. 24</i>	<i>5:43 p.m.</i>	<i>24.38</i>	<i>65 27</i>	<i>29.23</i>	<i>27 27</i>	<i>100</i>	<i>N.W.</i>	<i>2</i>	<i>.02</i>	<i>4/4</i>					<i>Fog</i>
	<i>5:43 a.m.</i>	<i>24.37</i>	<i>58 32</i>	<i>29.17</i>	<i>32 28</i>	<i>64</i>	<i>SW</i>	<i>7</i>	<i>.24</i>	<i>1/4</i>					<i>Stratus</i>
	<i>2:43 p.m.</i>	<i>24.42</i>	<i>70 49</i>	<i>29.03</i>	<i>49 39</i>	<i>31</i>	<i>S.E.</i>	<i>2</i>	<i>.02</i>	<i>2/4</i>					<i>Cirrus & Stratus</i>
<i>Saturday Nov. 25</i>	<i>5:43 p.m.</i>	<i>24.60</i>	<i>68 17</i>	<i>29.60</i>	<i>17 15.5</i>	<i>75</i>	<i>N.E.</i>	<i>18</i>	<i>1.62</i>	<i>3/4</i>					<i>Light scud fl</i>

2381

Denver November 19-25, 1871

Henry J. ...

Weather reports began on Pikes Peak in 1873



Credit: NOAA Photo Library

U. S. STATION & WEATHER BUREAU ON PIKES PEAK ALT 14147 FT - HIESTAND PHOTO

Reports were sent by telegraph every few hours

Stories abounded in the national media of the rigors of Colorado Climate

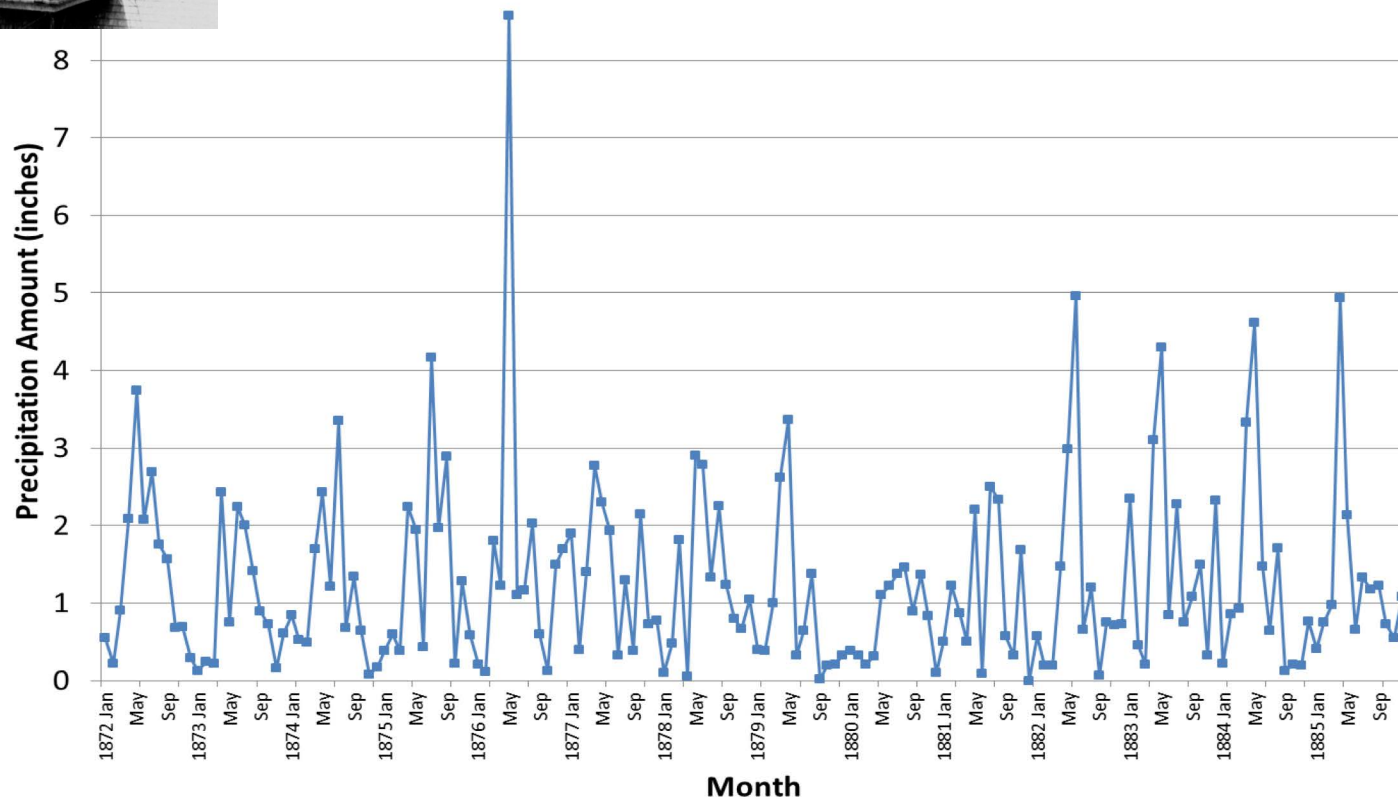
By 1885, the initial “climatology” of Colorado was taking shape



Photo Credit:
NOAA Photo
Library

The semiarid and highly variable nature of Colorado was identified quickly -- in many ways similar to today..

Denver Monthly Precipitation (1872 - 1885)



The goal back then was not to detect climate change – but to simply define and describe the climate of our region

But
"IT"
was
talked
about
even
then

Bulletin 245

June, 1918

The Agricultural Experiment Station

OF THE

Colorado Agricultural College

COLORADO CLIMATOLOGY

By ROBERT E. TRIMBLE

YEARS OF STUDY SHOWS CLIMATE NOT CHANGING

We often hear the statement made that the climate is changing, and the popular belief that such is the case can only be explained by the generally short and defective memories of people who through exposure to a few severe storms in the past, or inconvenience, or perhaps loss from a few of them, unintentionally exaggerate the severity and frequency of their occurrence. Although large fluctuations occur in different years with some indication of periodical terms, especially in Colorado, where the range of temperature is great, there seems to be no progressive change. These fluctuations are large and often in the same direction for several successive years.

In the meteorological data for the last one hundred years, the record of some places extending still further back, there

the mean temperature of any section of the country. Colorado being an arid state, the amount of precipitation is at all times a vital question. Liability to a marked deficiency in rainfall in any region is a matter of grave concern to those engaged in agriculture and other interests. We often hear it stated that the rainfall is changing, that the settling up of the country and the planting of trees and building of reservoirs, forming lakes and wet places throughout the country, is causing an increase in the amount of our precipitation, but long series of observations taken at different places over the world, do not bear out that claim.



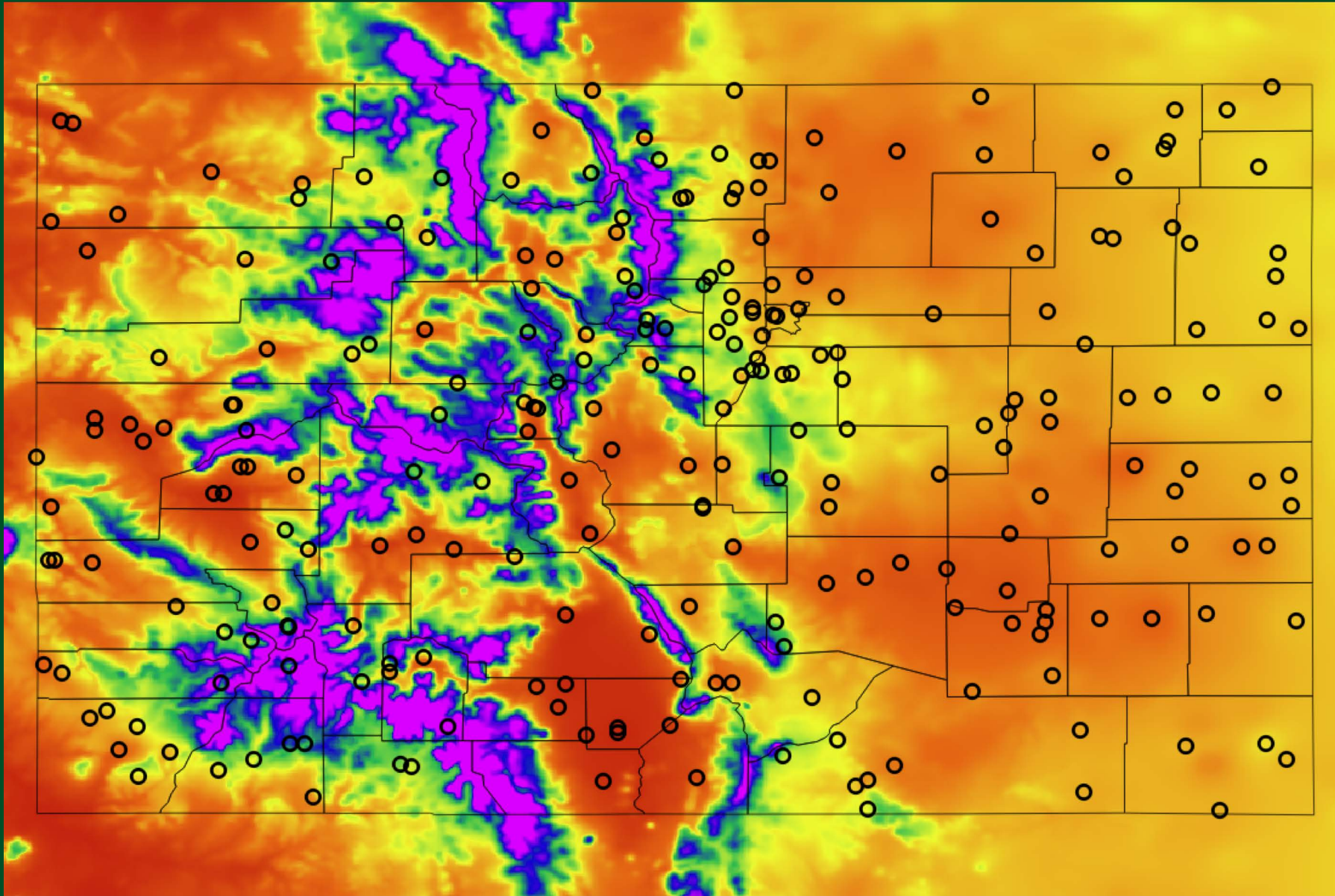
PUBLISHED BY THE EXPERIMENT STATION
FORT COLLINS, COLORADO
1918

So, what have we learned in the ~100 years of observations and research since this time?

Let's first look at where we get our data...



NWS Cooperative observer program – long-term measurements





The Historic Fort Collins Weather Station

National Weather Service Cooperative Station 05-3005

This is one of the longest operating weather stations in the western U.S. monitoring temperature, humidity, precipitation (rain, hail and snow), evaporation, winds, solar radiation, clouds, visibility, barometric pressure and soil temperatures. Weather observations for research, teaching and public information have been conducted on campus since the early 1870s. Continuous support for this historic weather station has been provided by the Colorado Agricultural Experiment Station since 1889. Early data collected here aided agricultural and irrigation research and development. Beginning in the 1930s, this station provided weather support for aviation and transportation safety. Uses continue to expand today. Data are publicly available for tracking climate trends, variations and extremes and their impacts here in northern Colorado.



Colorado State University

National Weather Service automated stations

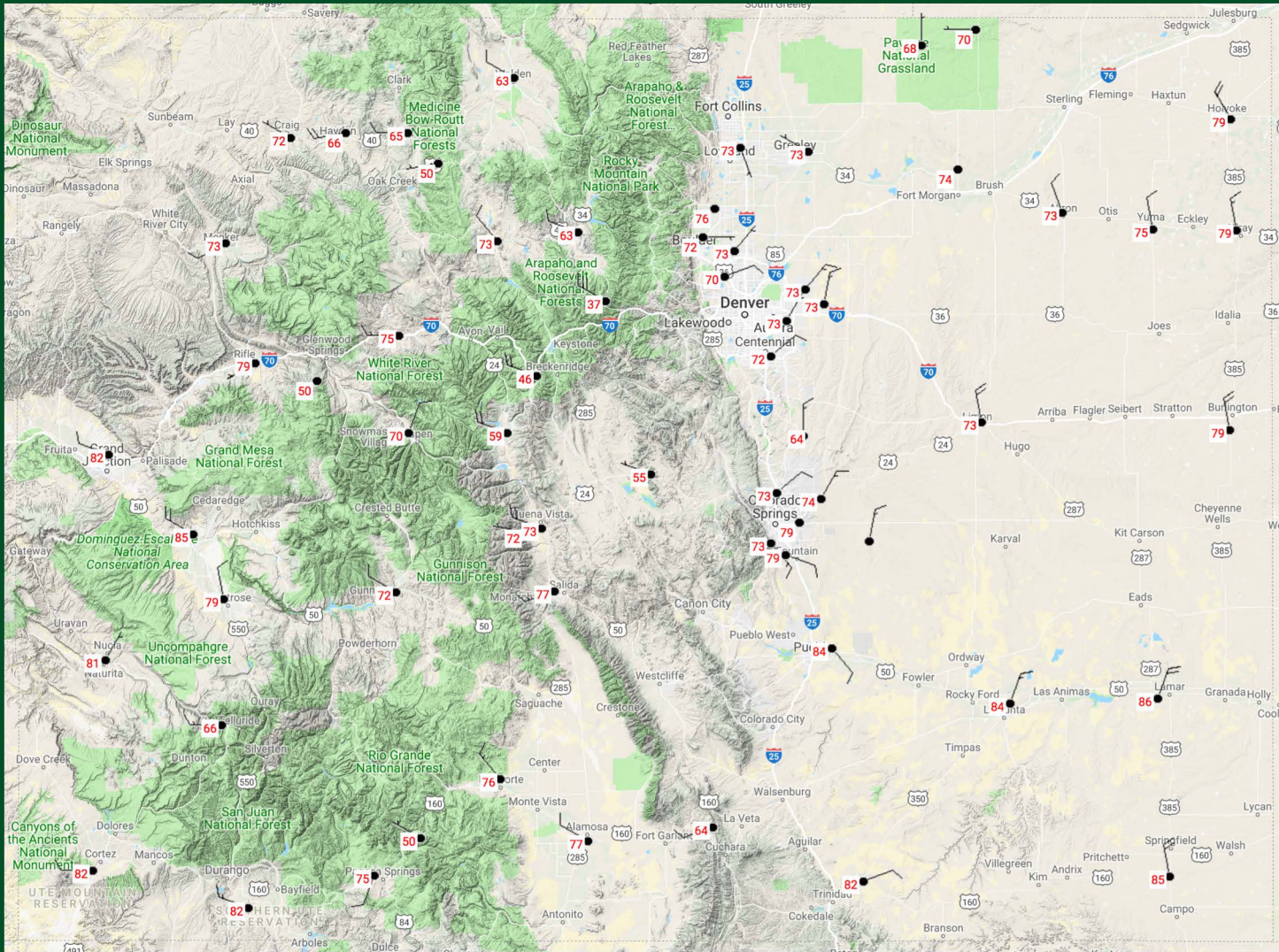


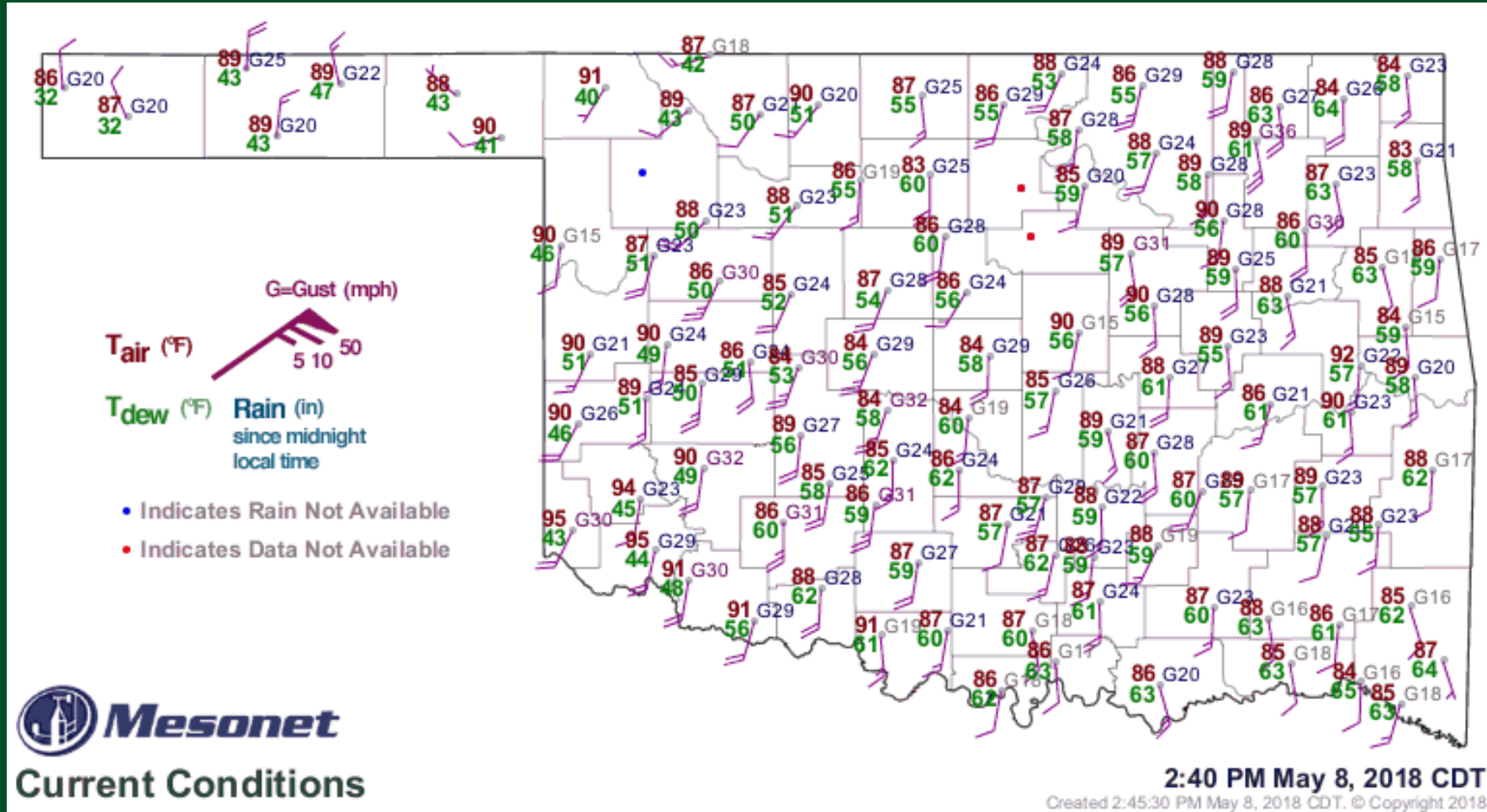
Photo of an ASOS station

Map showing NWS stations (from mesowest.utah.edu)



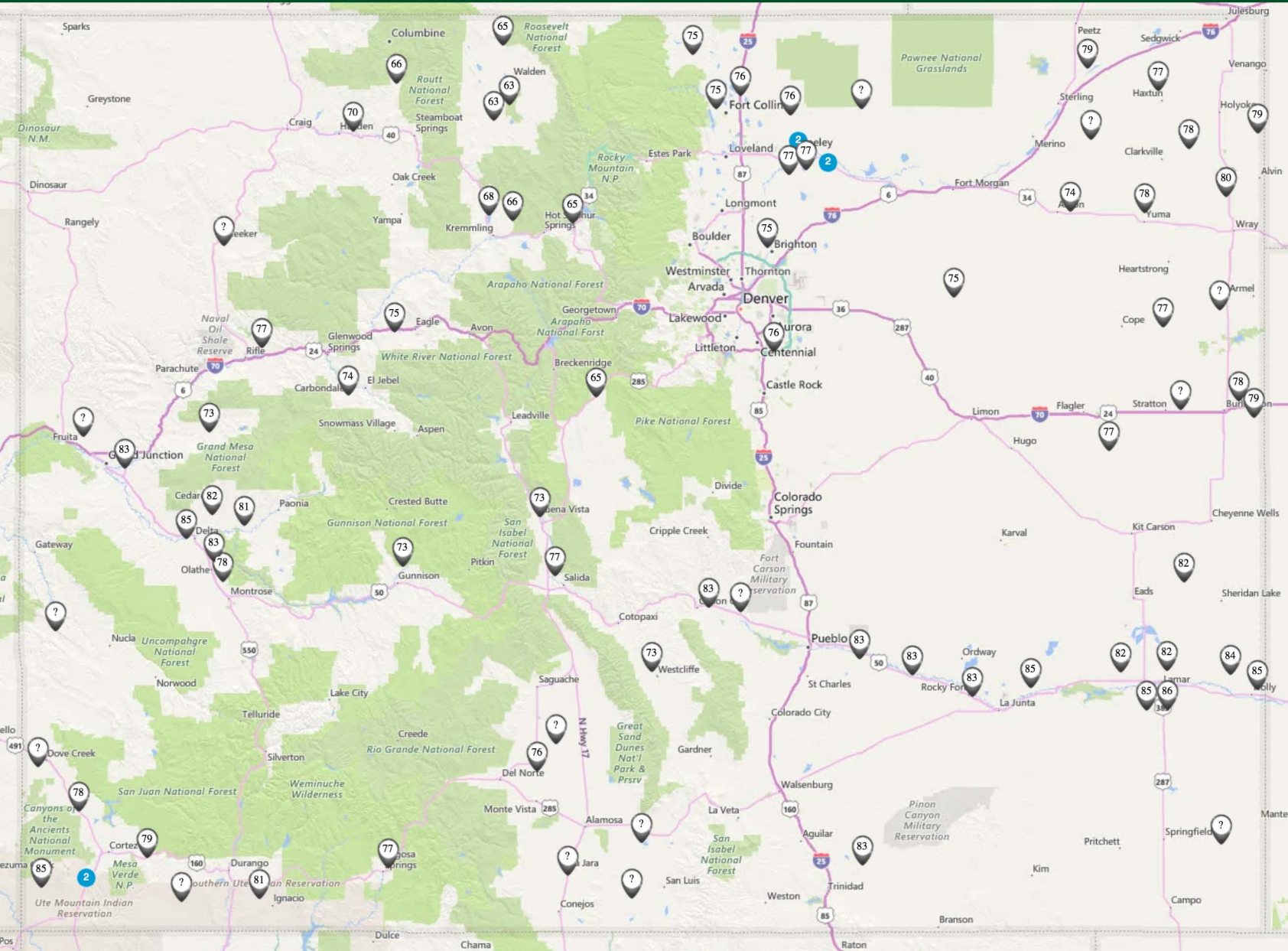
“Mesonets”

Oklahoma Mesonet
<http://www.mesonet.org/>



CoAgMET

- 85 stations
 - 44 stations with 5-minute data
 - interactive mapping through eRAMS
 - includes
 - time series charts
 - site photos
- coagmet.colostate.edu



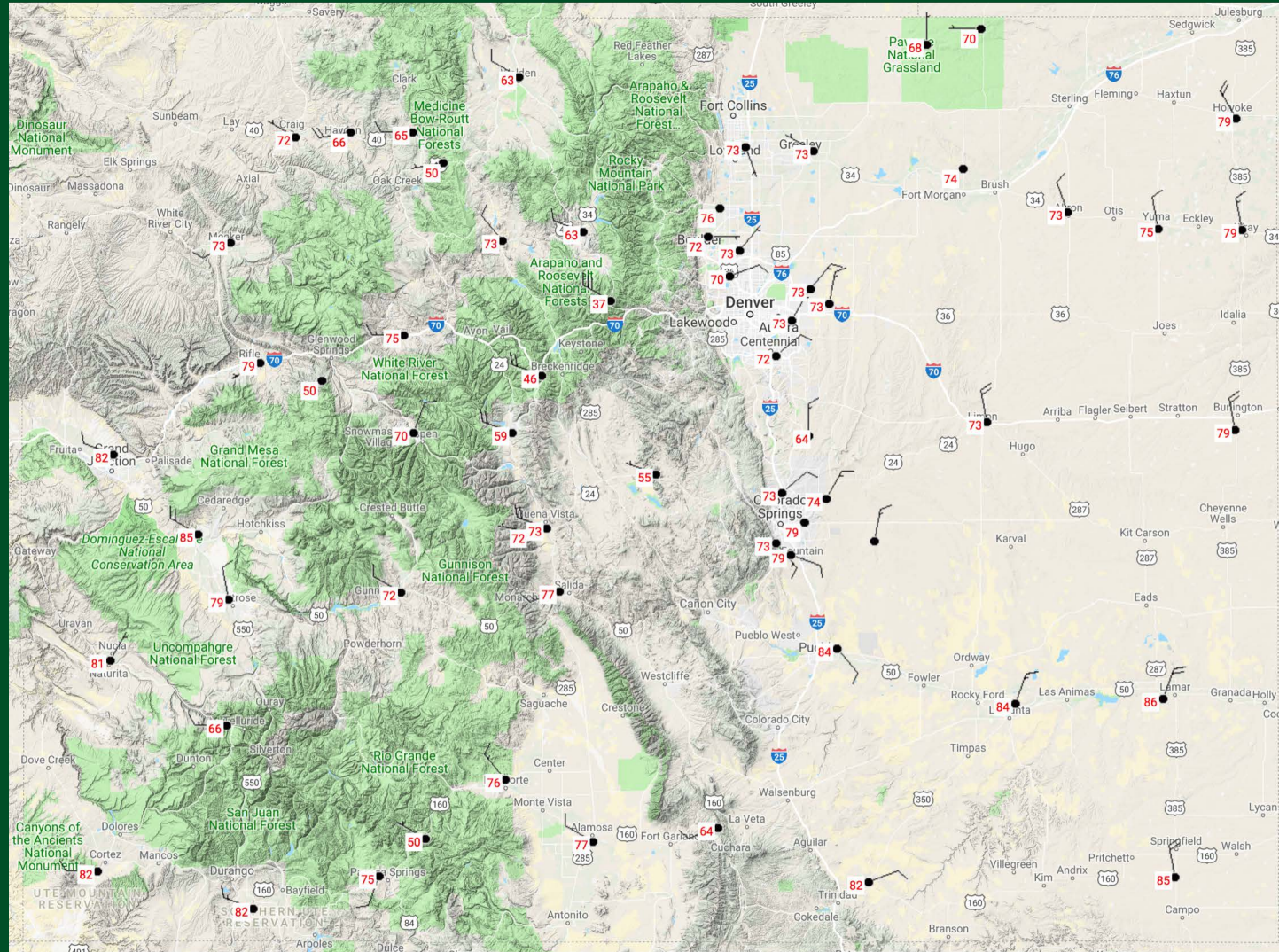
CoAgMET

- ❑ 85 stations
- ❑ 44 5-minute stations
- ❑ interactive mapping through eRAMS
- ❑ includes
 - ❑ time series charts
 - ❑ site photos

coagmet.colostate.edu



National Weather Service automated stations

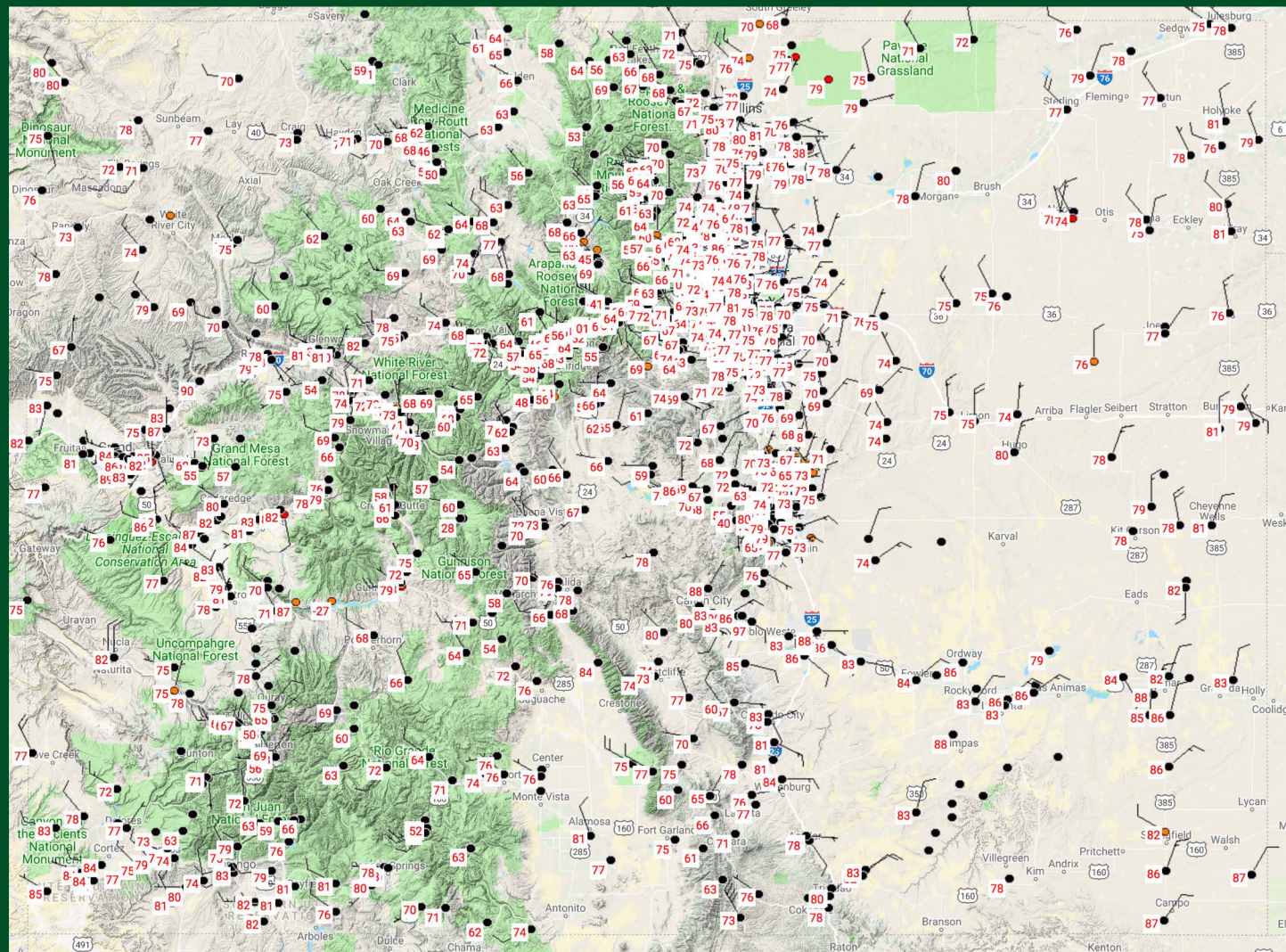


Map showing NWS stations (from mesowest.utah.edu)

COLORADO CLIMATE CENTER



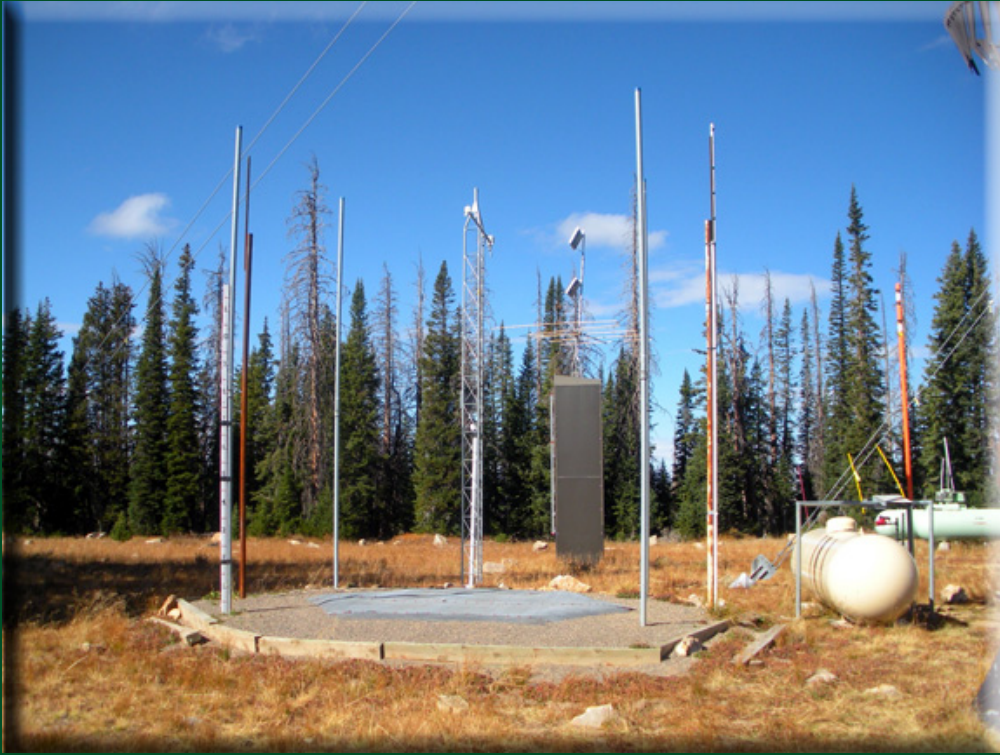
NWS stations + CoAgMET + other networks



(from mesowest.utah.edu)



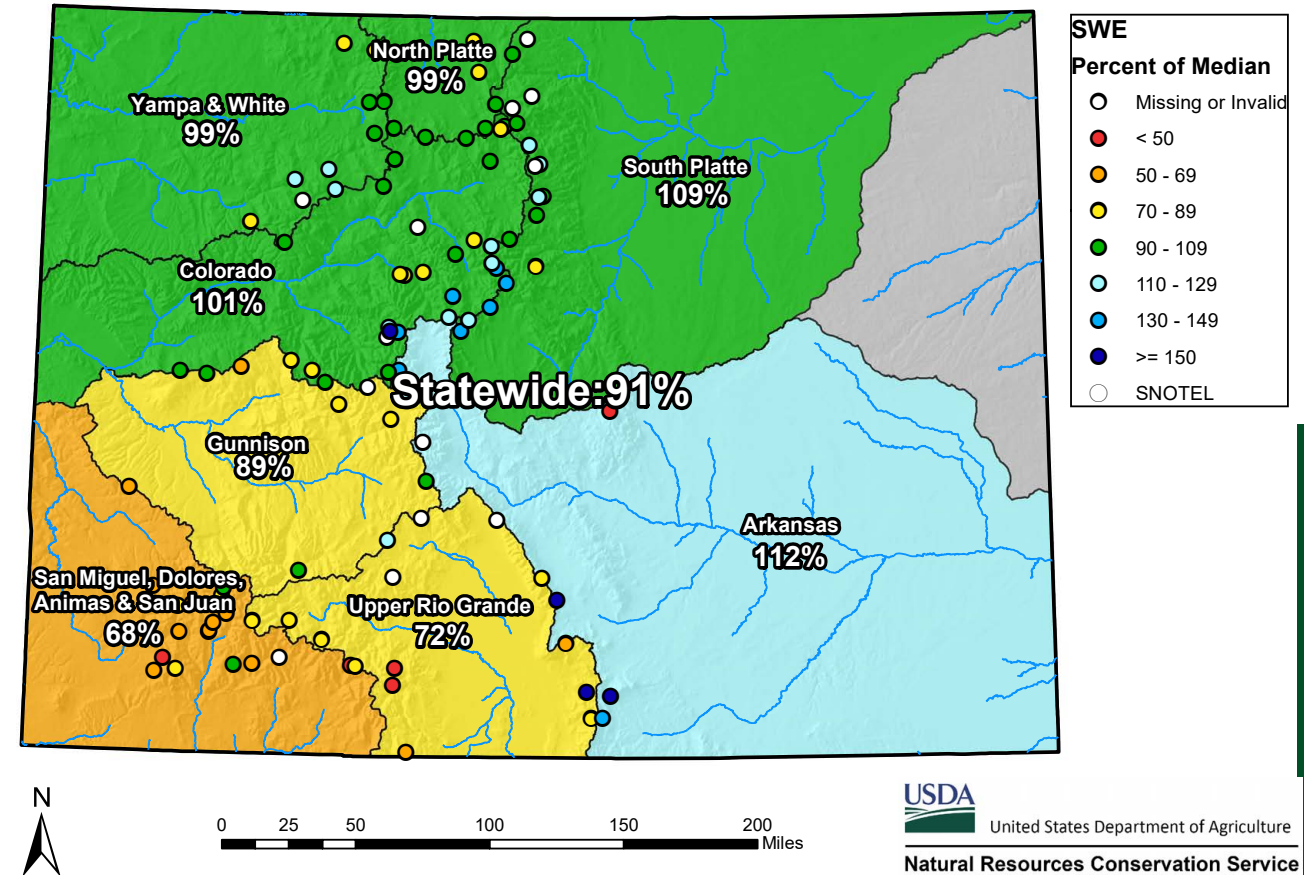
SNOTEL (Snow telemetry)



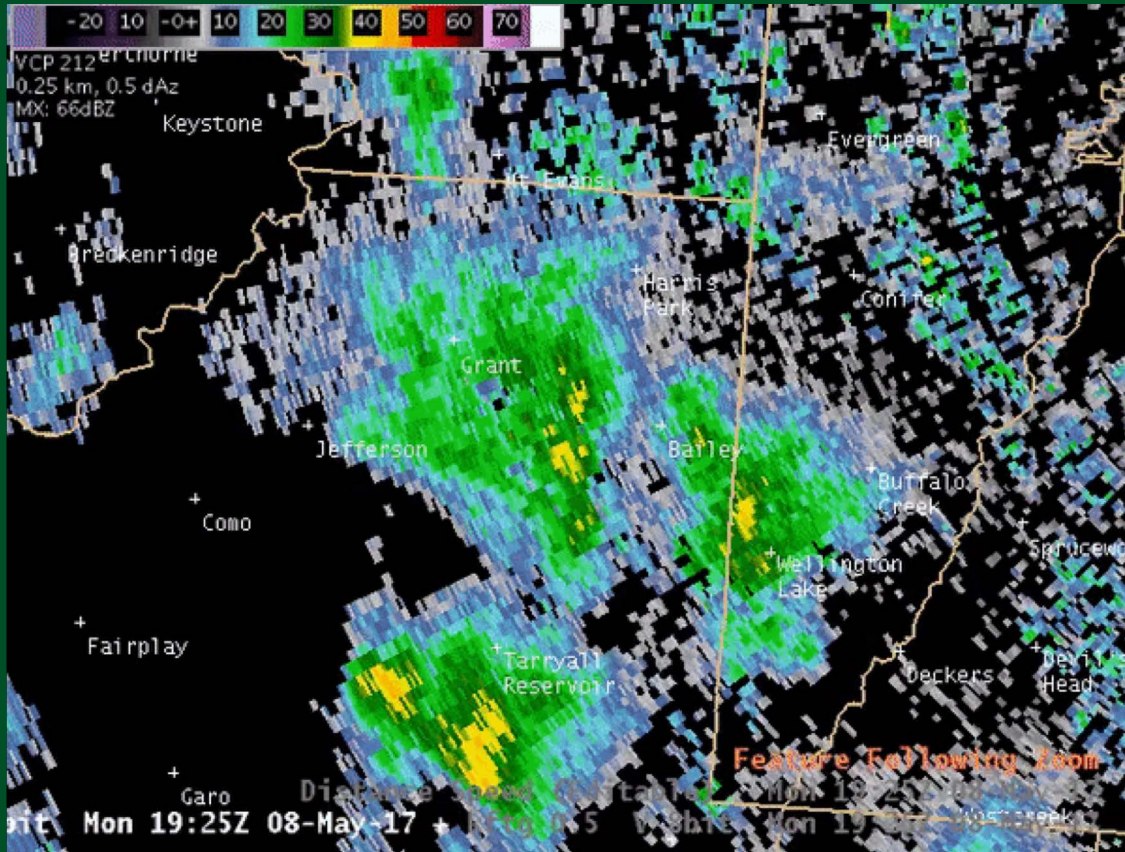
Tower SNOTEL site (10,500 ft, near Steamboat)
<https://www.wcc.nrcs.usda.gov/siteimages/825.jpg>

Colorado SNOTEL Snow Water Equivalent (SWE) Update Map with Site Data

Current as of Jan 06, 2019

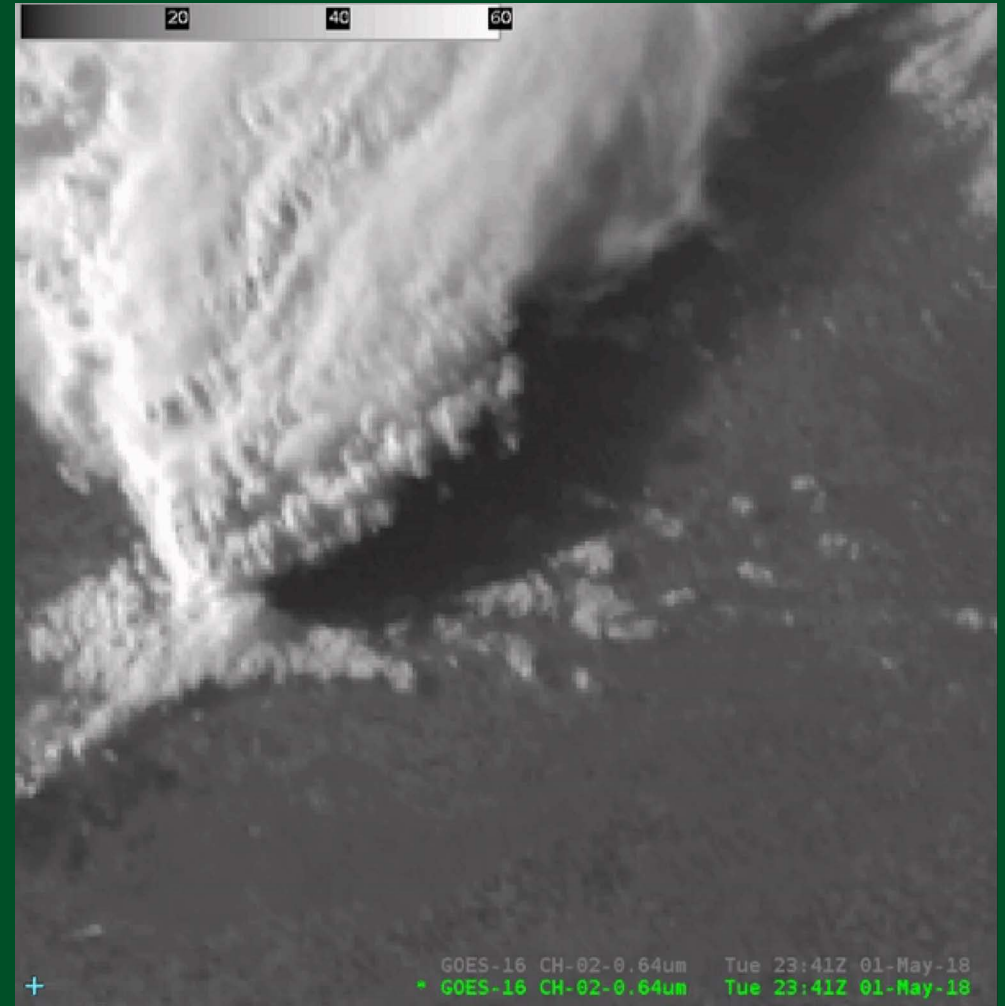


Remote sensing: radar and satellite



8 May 2017 hailstorm

<https://twitter.com/NWSBoulder/status/993937075920625665>

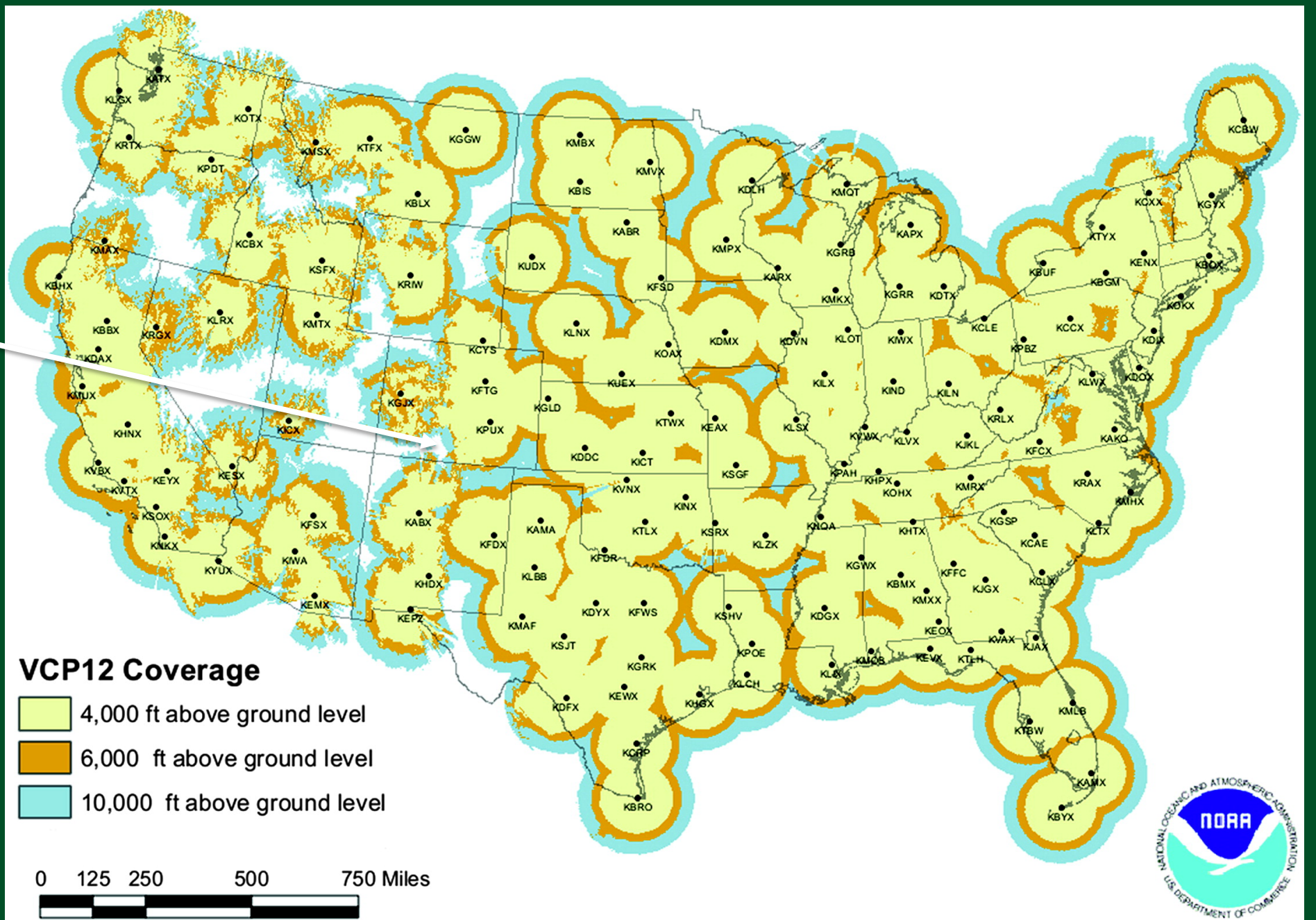


1 May 2018 storm in eastern Colorado

https://twitter.com/bill_line/status/991486848370466816



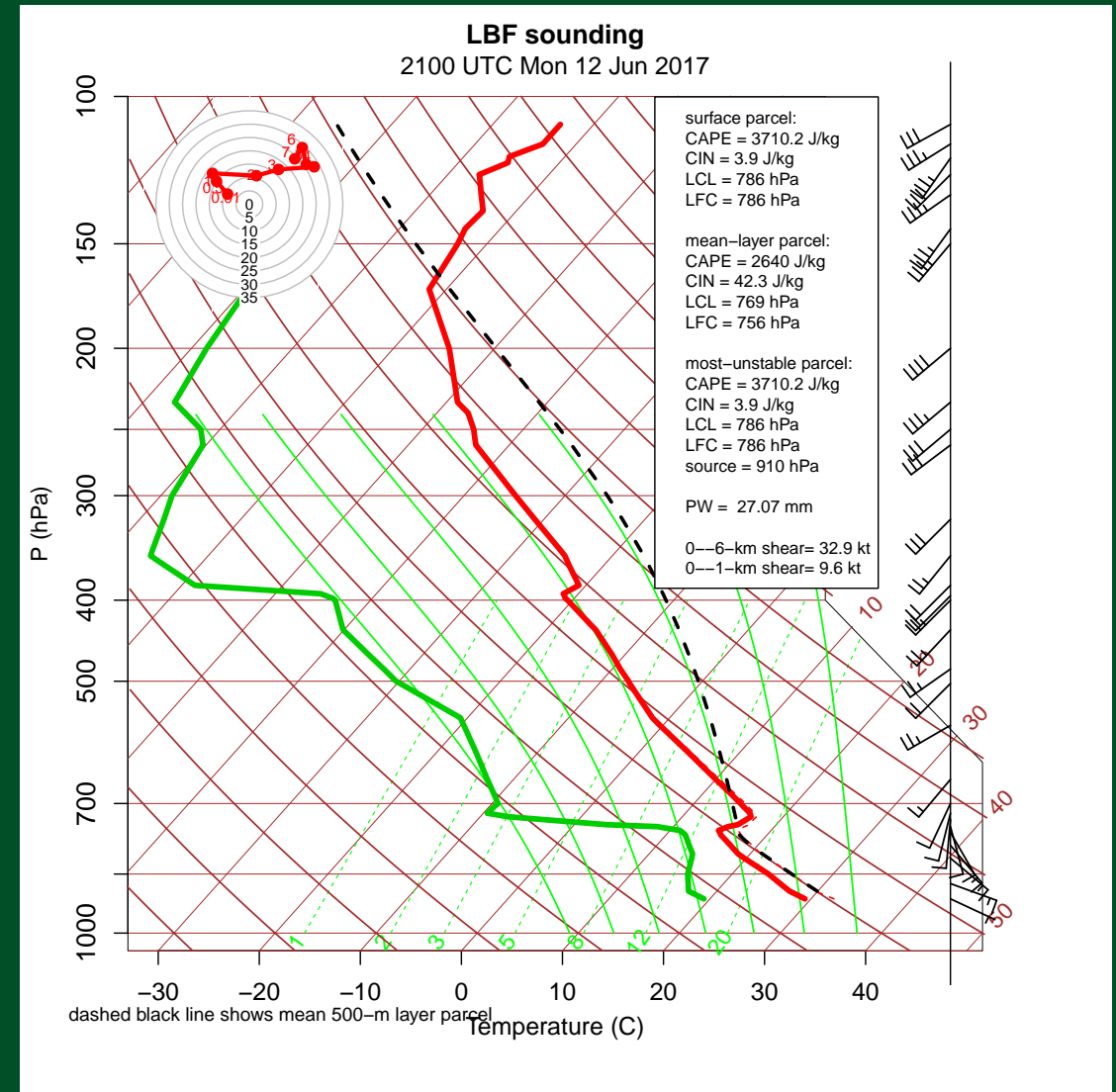
Mountains cause beam blockage for radars



Upper-air data



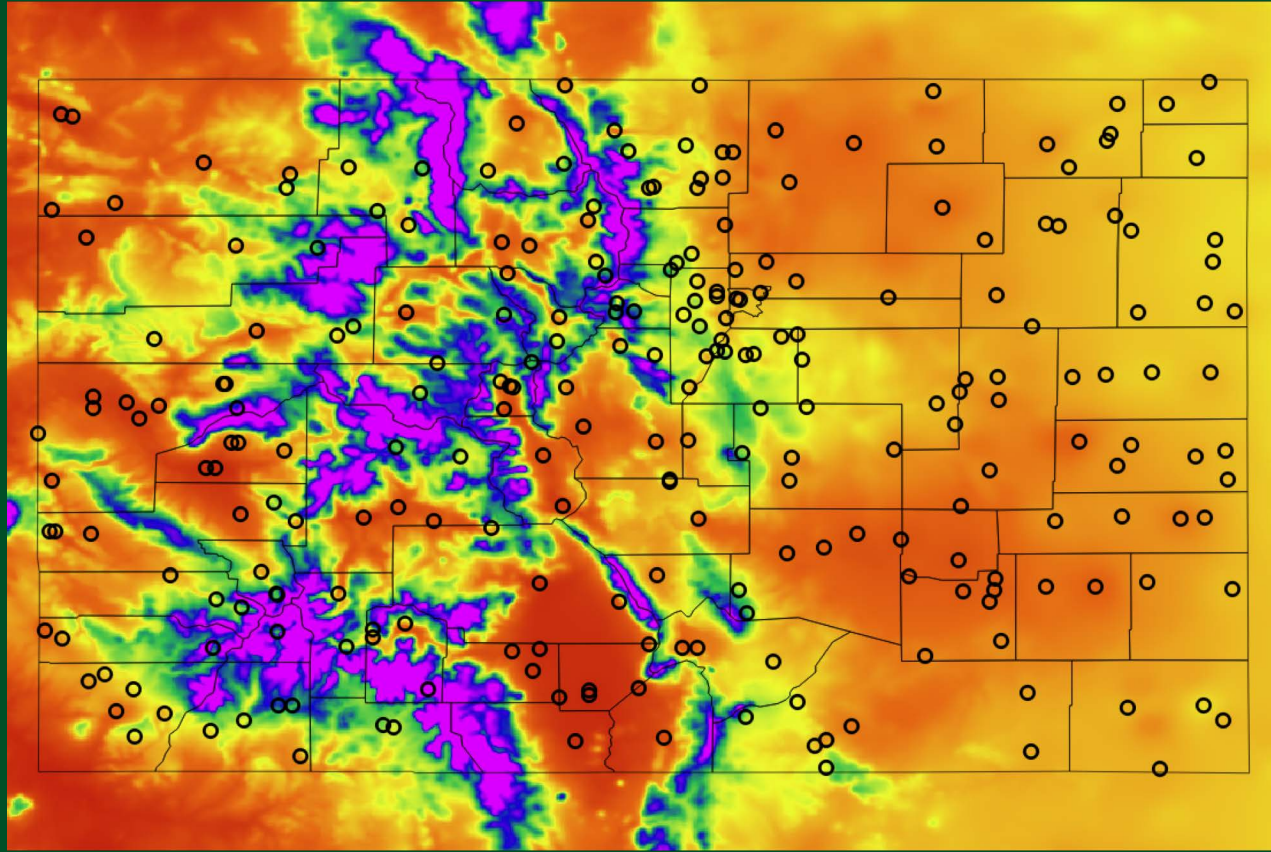
Weather balloon launch during the PECAN field campaign, June 2015



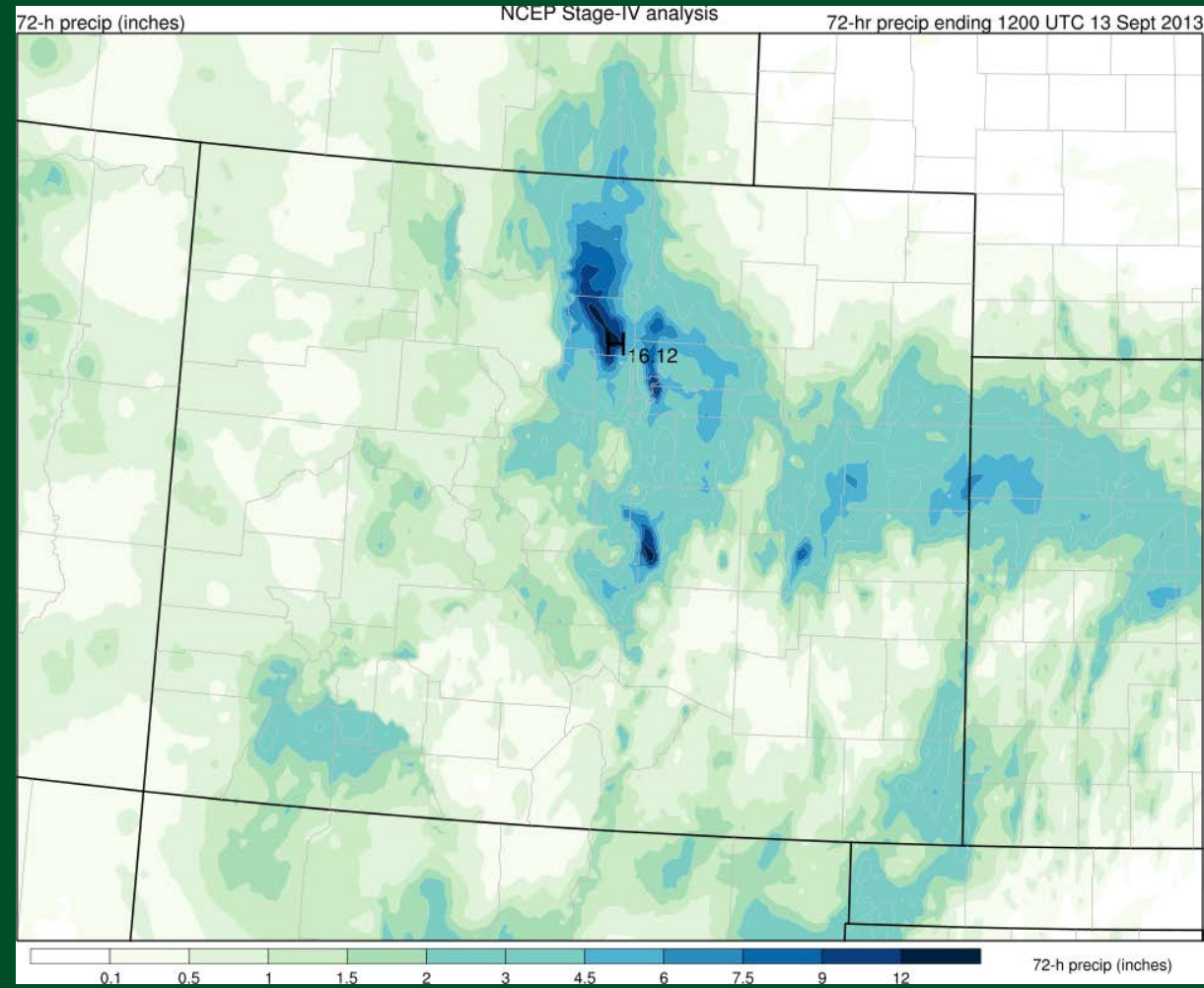
Skew T log p thermodynamic diagram



Putting them all together...



PRISM technique, prism.oregonstate.edu



NOAA multi-sensor precipitation analysis (radars + gauges)
(3 days ending 13 Sept 2013)

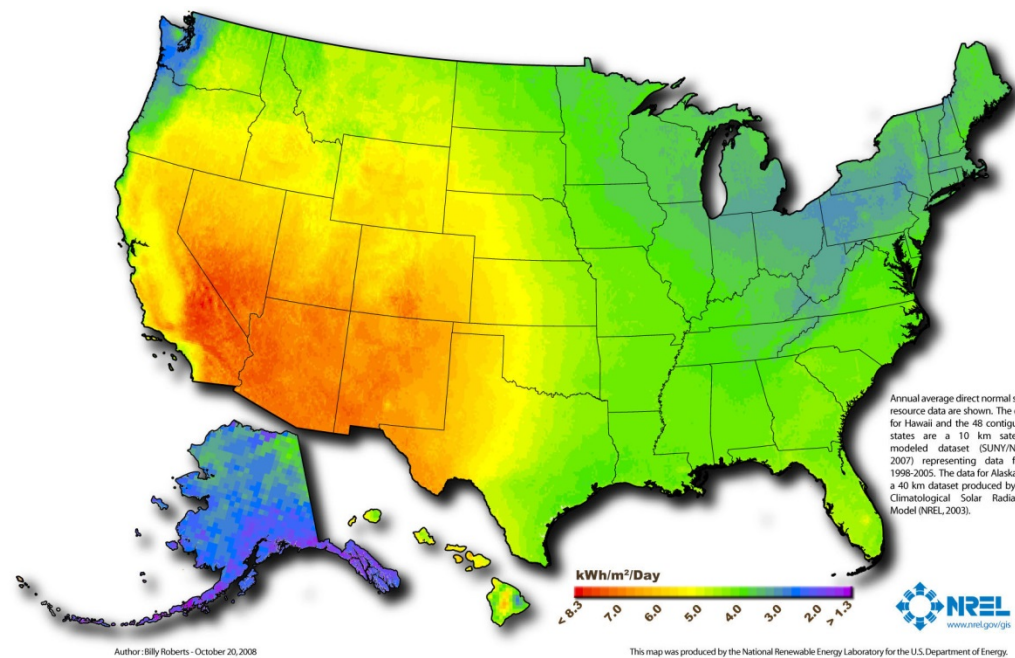
What Makes Our Colorado Climate

- High elevation (highest state by far)
- Mid-Latitude location (lively seasonal changes)
- Interior Continental Location far from moisture sources
- Complex Mountain topography
- Solar energy and seasonal cycles drive our climate

**What have we learned
from 130 years of
continuous climate
monitoring?**

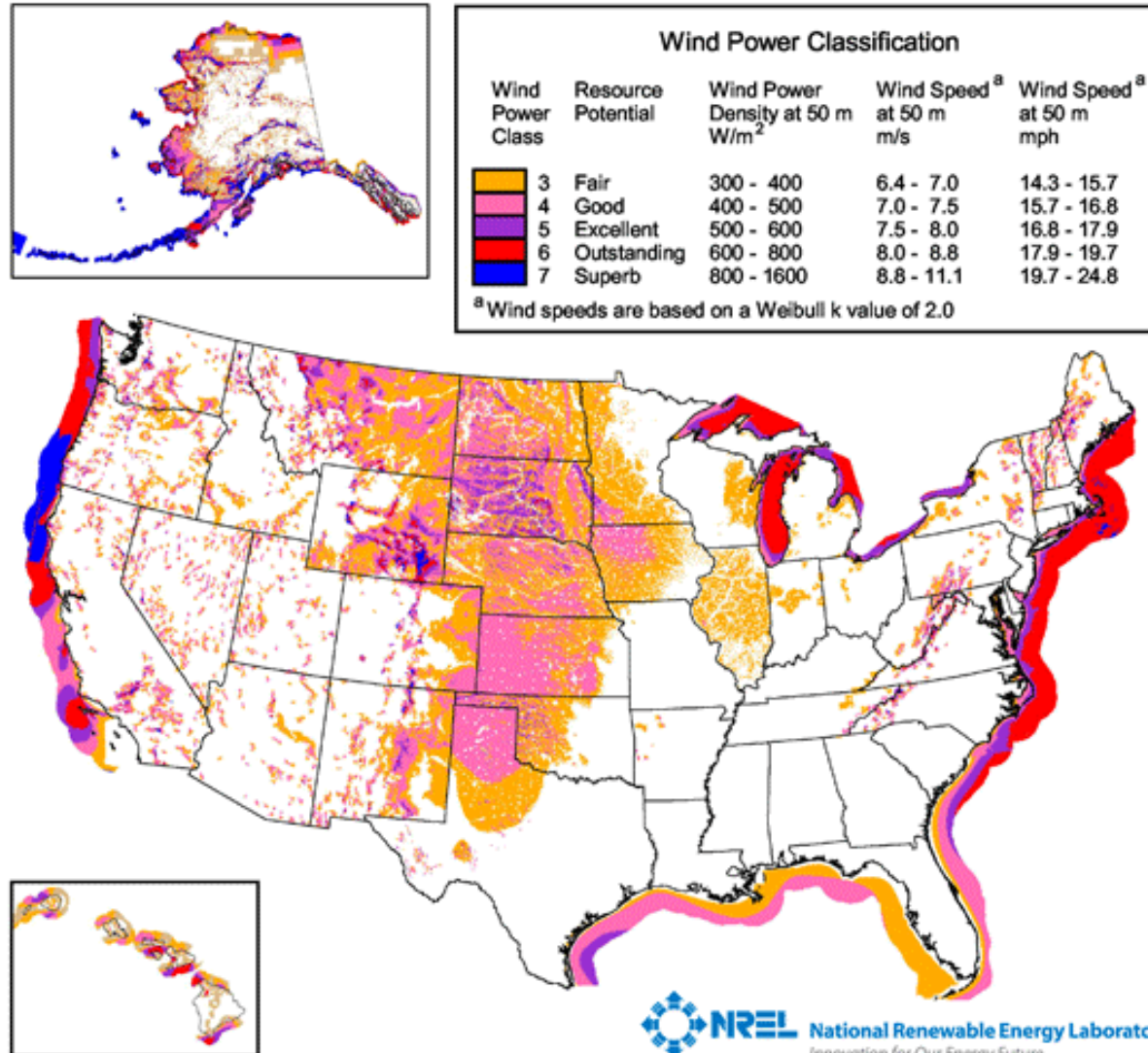


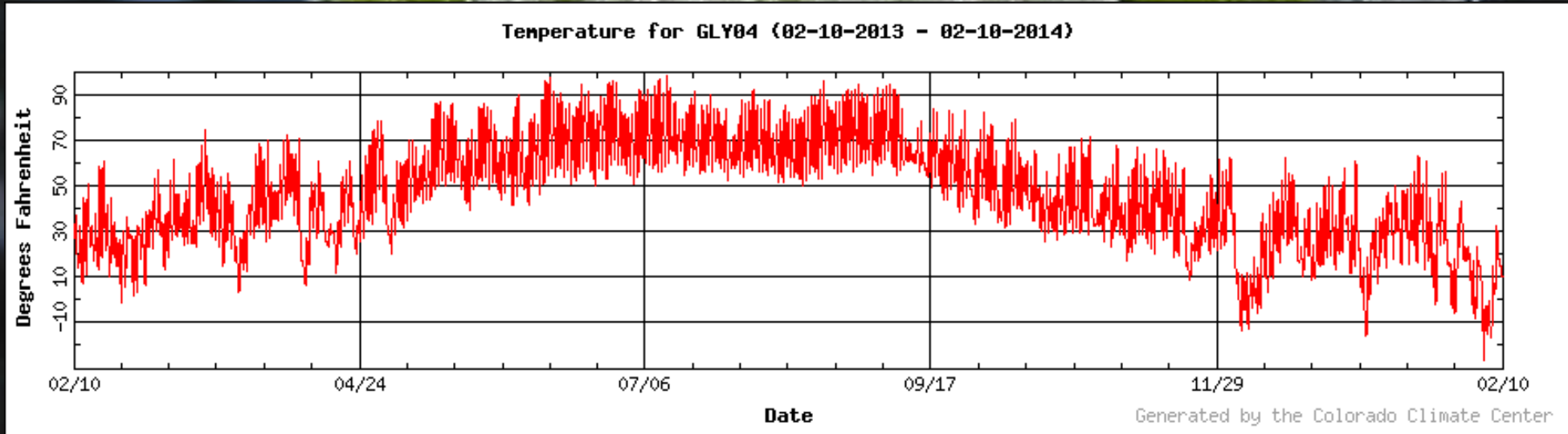
**Colorado is a sunny place.
People like sunshine!
So does vegetation – to a point.**



National Renewable Energy Laboratory: www.nrel.gov

The winds blow, but not as persistently as some places

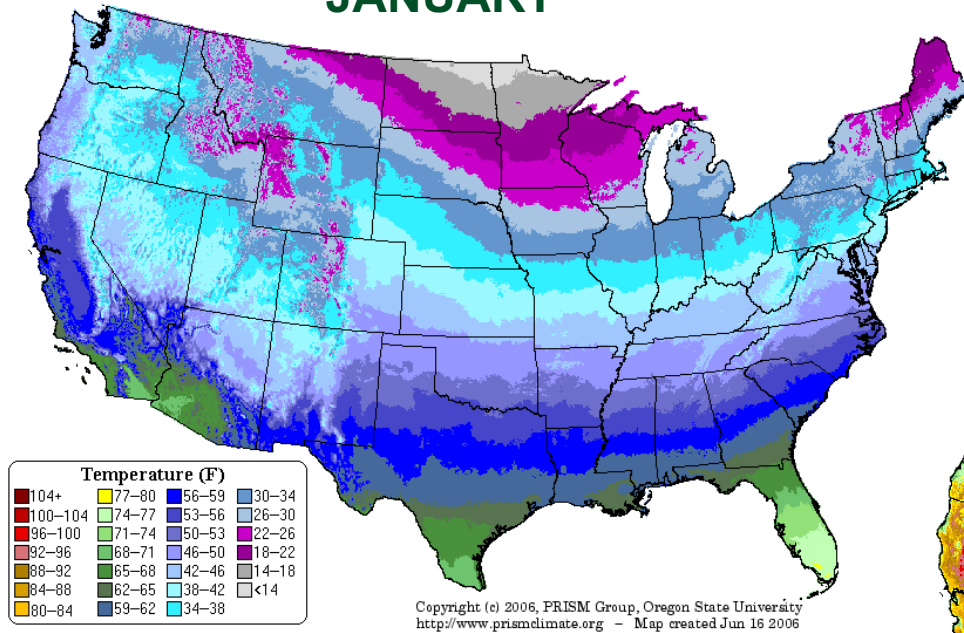




We always experience large seasonal and diurnal temperature variations

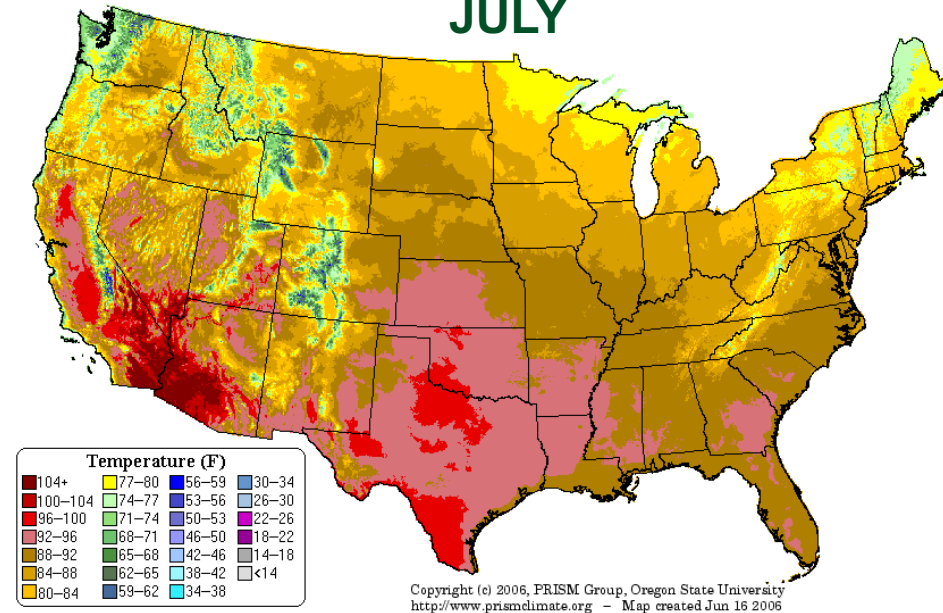
Complex temperature variations due to elevation and topography

Maximum Temperature: January Climatology (1971–2000)
JANUARY



Usually colder in the mountains!

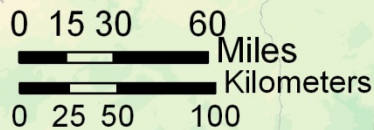
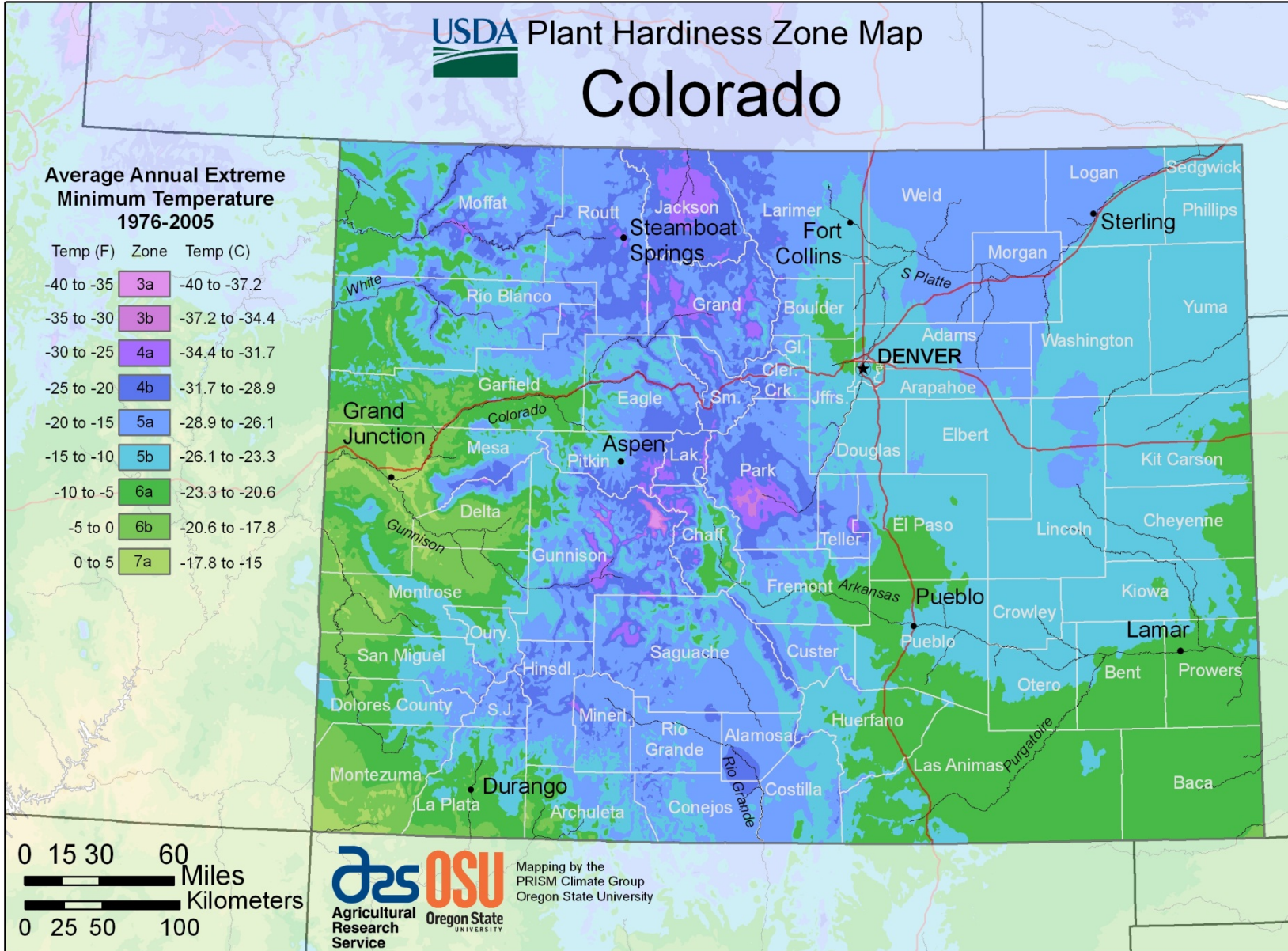
Maximum Temperature: July Climatology (1971–2000)
JULY



USDA Plant Hardiness Zone Map
Colorado

Average Annual Extreme Minimum Temperature 1976-2005

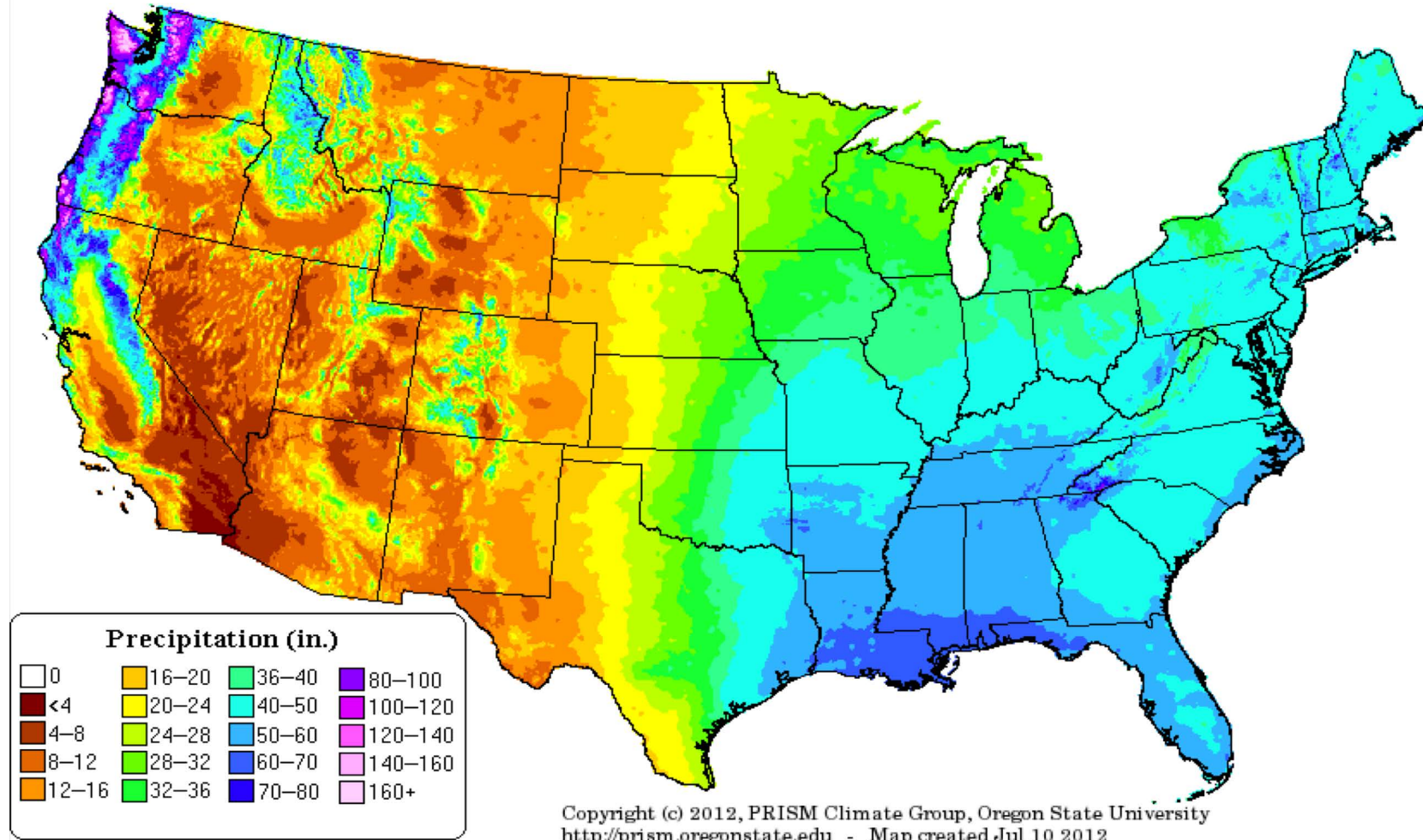
Temp (F)	Zone	Temp (C)
-40 to -35	3a	-40 to -37.2
-35 to -30	3b	-37.2 to -34.4
-30 to -25	4a	-34.4 to -31.7
-25 to -20	4b	-31.7 to -28.9
-20 to -15	5a	-28.9 to -26.1
-15 to -10	5b	-26.1 to -23.3
-10 to -5	6a	-23.3 to -20.6
-5 to 0	6b	-20.6 to -17.8
0 to 5	7a	-17.8 to -15



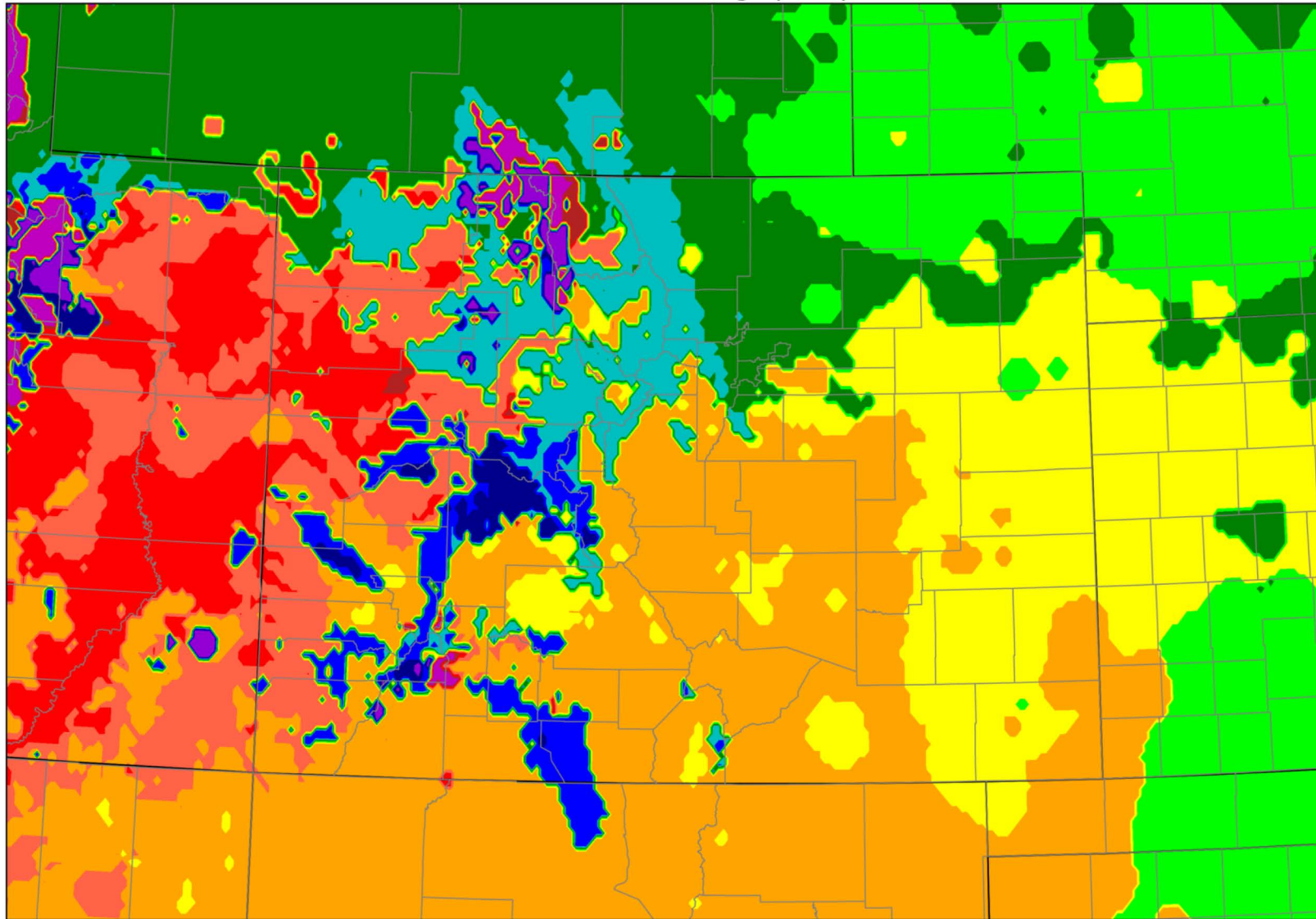
OSU Mapping by the PRISM Climate Group
 Oregon State University
Agricultural Research Service **Oregon State University**

We get rain and snow – but often not enough

Precipitation: Annual Climatology (1981-2010)



month of maximum average precipitation



Seasonal precipitation in Colorado varies greatly from place to place

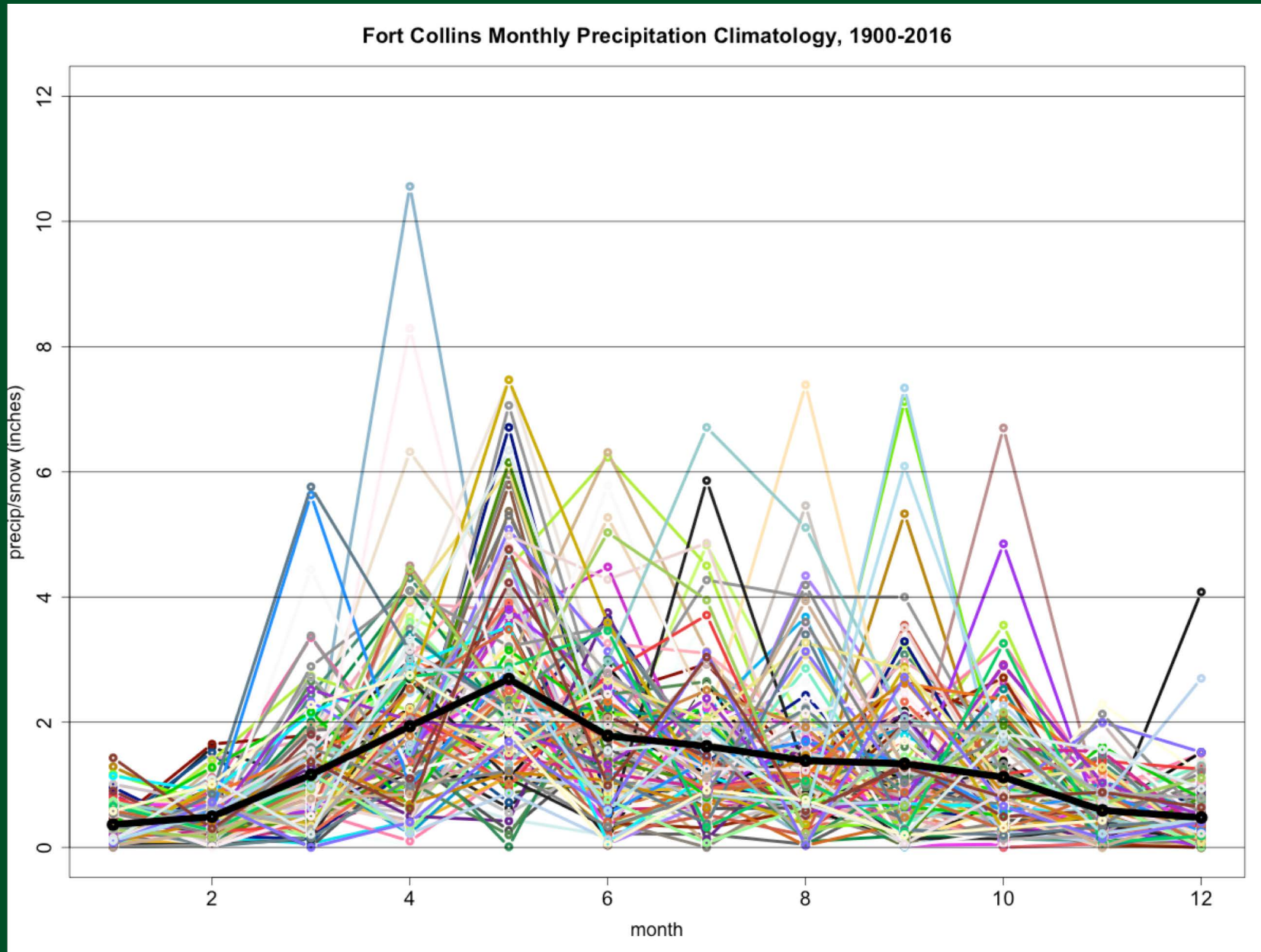
Month of maximum average precip
Data: PRISM Climate Group,
prism.oregonstate.edu

Figure: Russ Schumacher/Colorado Climate Center
Data: PRISM climate group (prism.oregonstate.edu)

Year-to-Year Variations in Precipitation are Huge

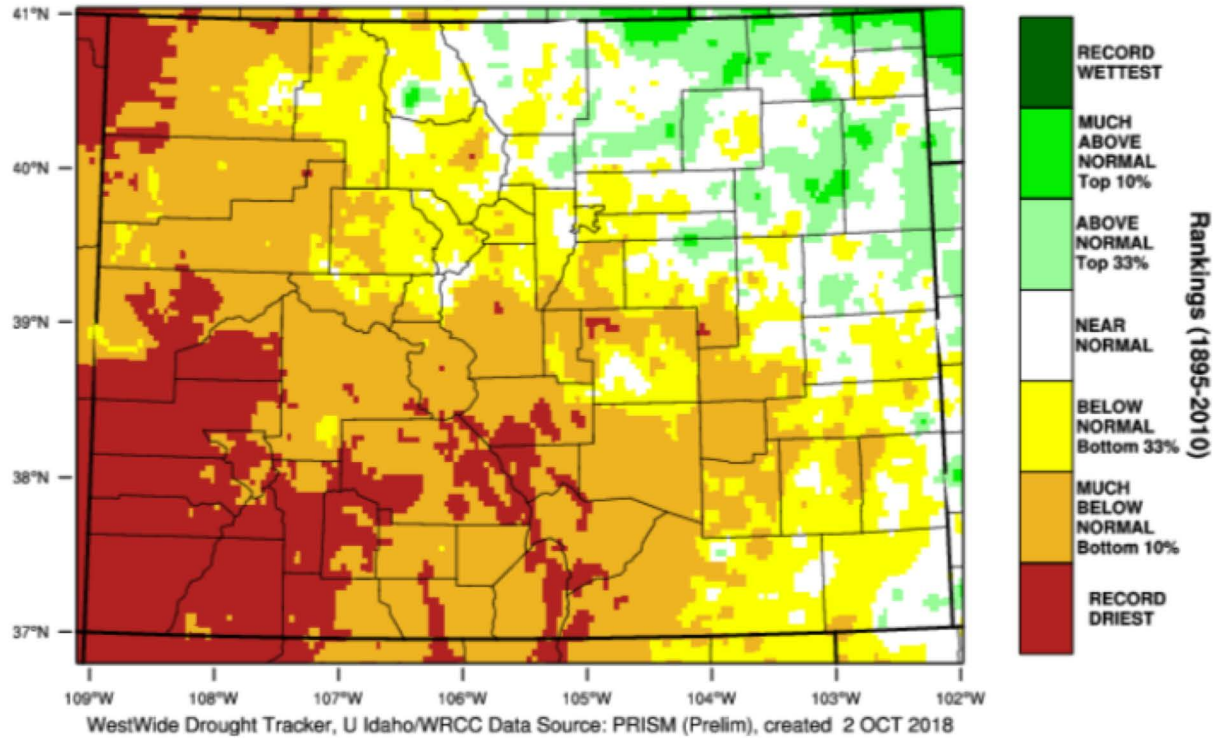


No two years are ever the same

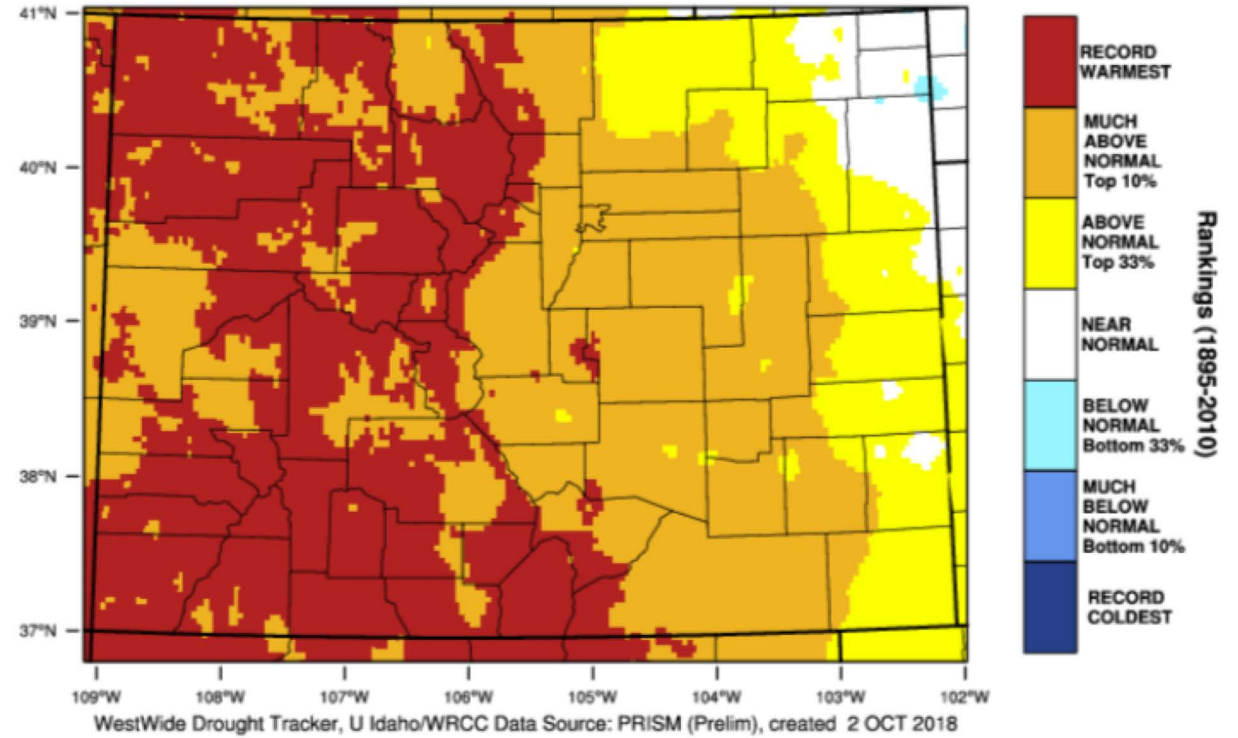


Water Year 2018: One to forget!

Colorado - Precipitation
October-September 2018 Percentile



Colorado - Mean Temperature
October-September 2018 Percentile



2nd driest water year on record for Colorado

3rd warmest water year on record for Colorado

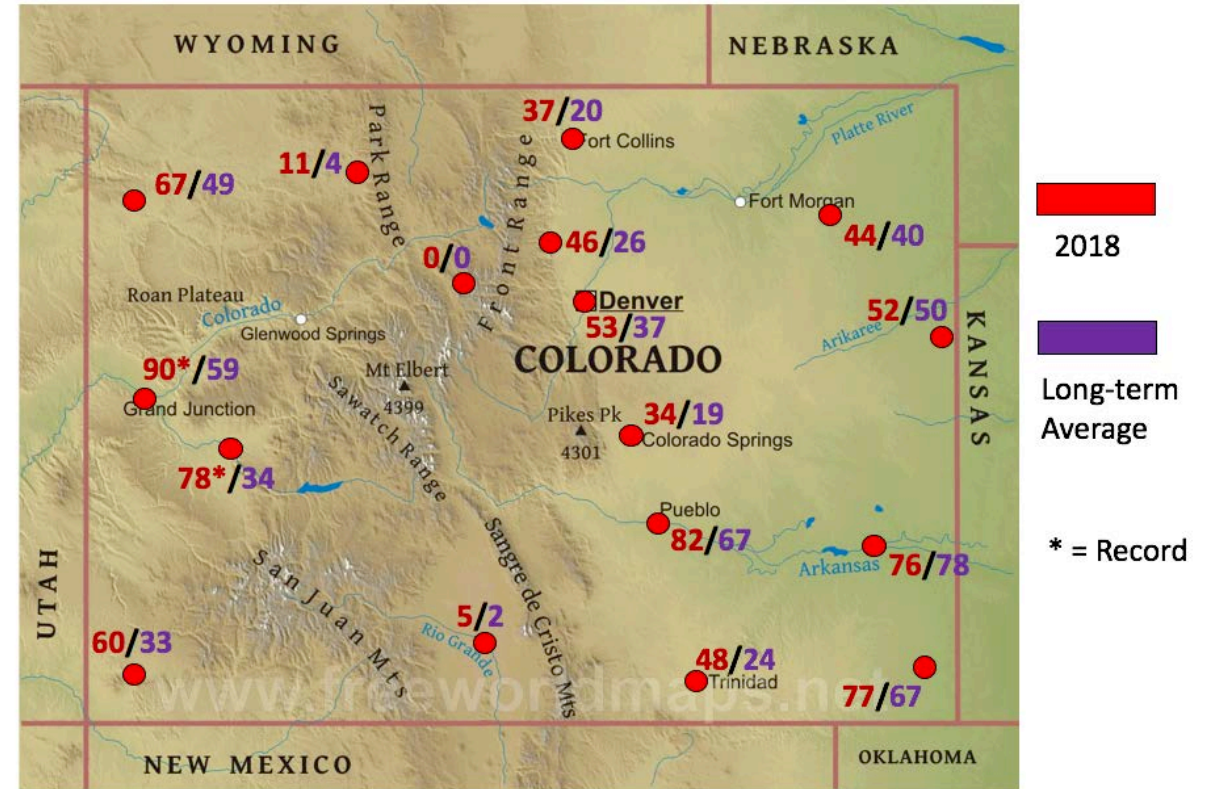


Water Year 2018: One to forget!

	90° days	Rank	Normal	Record	Record Year
Denver	53	7th of 70	37	67	2012
Fort Collins	37	10th of 121	20	57	2012
Boulder	46	10th of 104	26	60	1952
Colorado Springs	34	T4th of 70	19	49	2012
Pueblo	82	T7th of 65	67	90	2000
Burlington	52	40th of 85	50	88	1954
Lamar	76	T66th of 114	78	129	1934
Walsh	77	9th of 51	67	95	2011
Alamosa	5	T10th of 71	2	20	2003
Cortez	60	2nd of 78	33	69	2002
Grand Junction	90	T1st of 119	59	90	2018
Montrose	78	1st of 113	34	78	2018
Steamboat Springs	11	T13th of 98	4	29	2002
Lake Dillon	0	NA	0	0	NA
Rangely	67	T5th of 58	49	71	1955
Akron	44	T30th of 79	40	73	2012
Trinidad	48	T7th of 97	24	62	2002

Data gathered by Peter Goble (Colorado Climate Center)

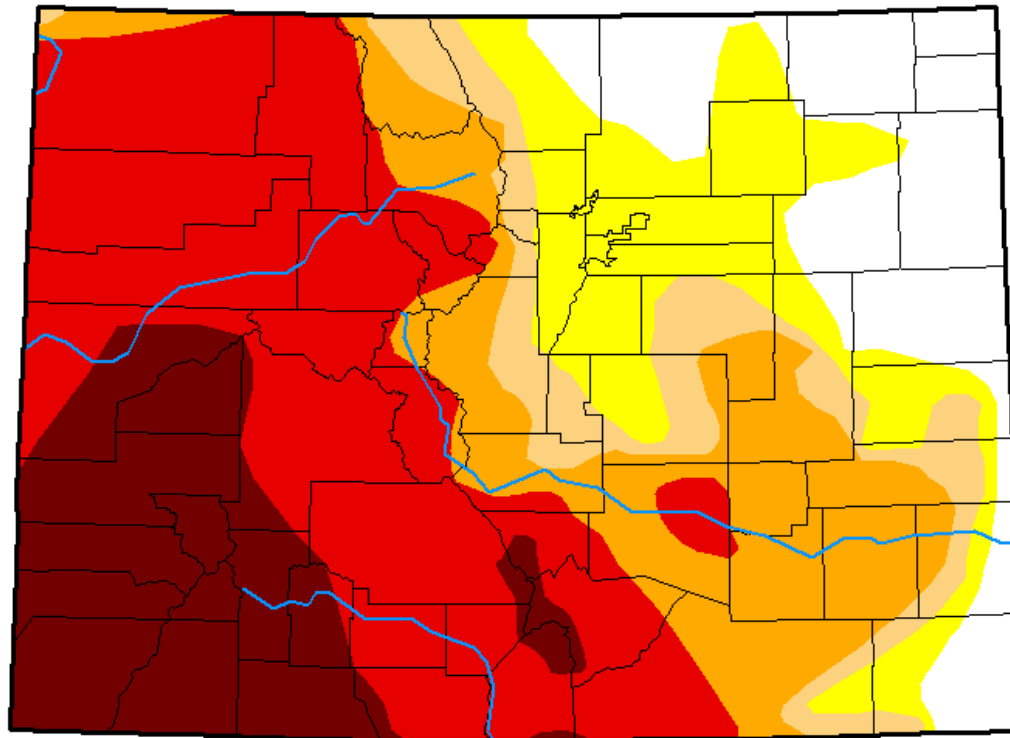
Number of 90 Degree Days








Water Year 2018: One to forget!

U.S. Drought Monitor Colorado

October 2, 2018
(Released Thursday, Oct. 4, 2018)
Valid 8 a.m. EDT



Intensity:

-  D0 Abnormally Dry
-  D1 Moderate Drought
-  D2 Severe Drought
-  D3 Extreme Drought
-  D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:

David Miskus
NOAA/NWS/NCEP/CPC



<http://droughtmonitor.unl.edu/>



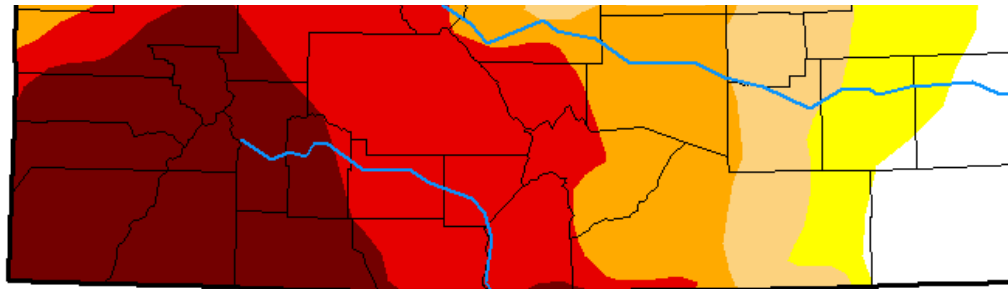
Water Year 2019: Off to a better start, but still reasons for concern

U.S. Drought Monitor Colorado

January 1, 2019
(Released Thursday, Jan. 3, 2019)
Valid 7 a.m. EST

Statistics Comparison

Week	None	D0-D4	D1-D4	D2-D4	D3-D4	D4	DSCI
2019-01-01	17.94	82.06	66.26	54.91	27.11	11.22	242
2018-10-02	14.19	85.81	72.30	64.41	48.47	16.21	287
Change	-3.75	3.75	6.04	9.50	21.36	4.99	45



The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:

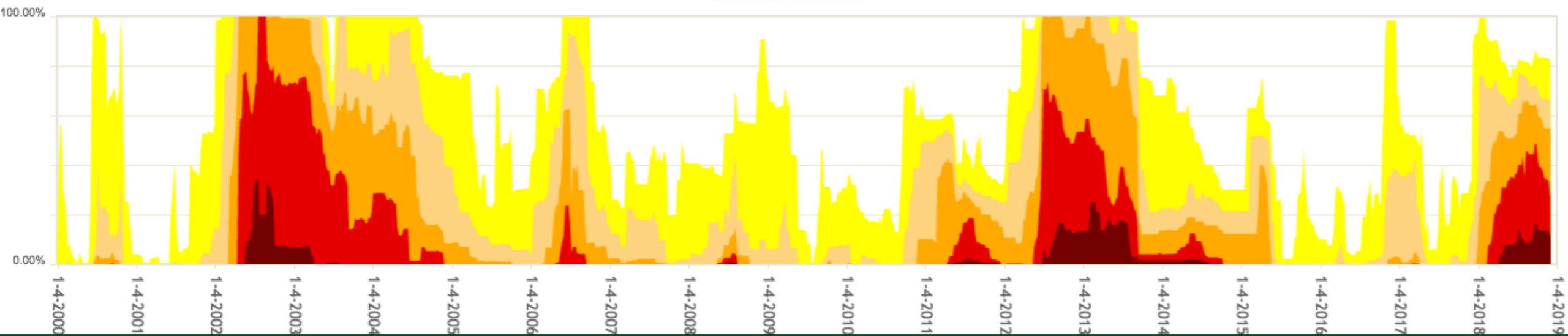
David Miskus
NOAA/NWS/NCEP/CPC



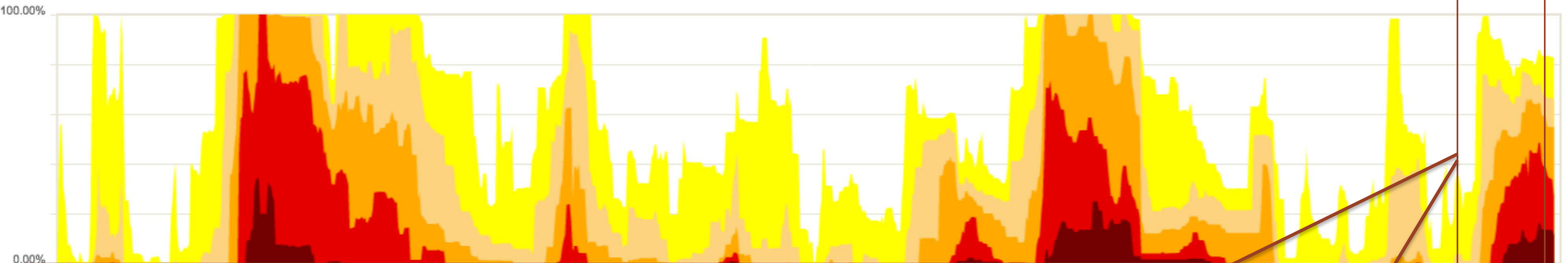
<http://droughtmonitor.unl.edu/>



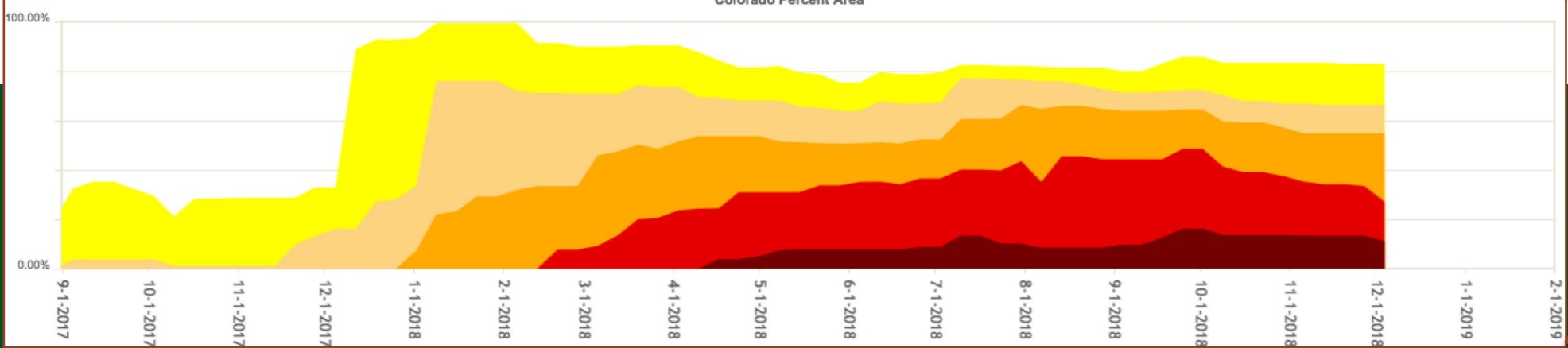
Colorado Percent Area



Colorado Percent Area



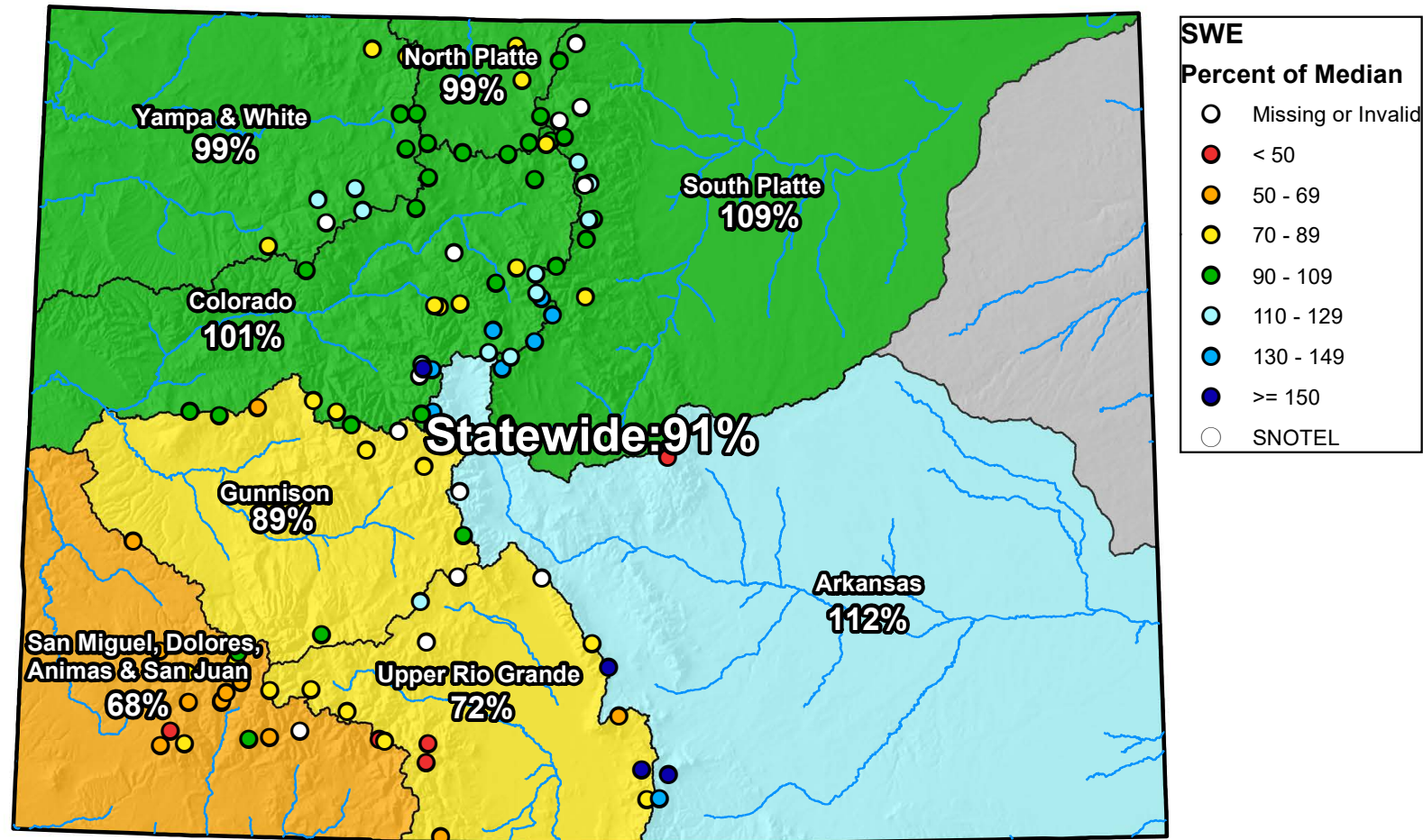
Colorado Percent Area



Water Year 2019: Off to a better start, but still reasons for concern

Colorado SNOTEL Snow Water Equivalent (SWE) Update Map with Site Data

Current as of Jan 06, 2019



0 25 50 100 150 200 Miles



United States Department of Agriculture

Natural Resources Conservation Service



About the stations

Anemometer and wind vane: Wind speed, direction and gusts

2 m

Above all else facing South

Pyranometer: Solar radiation

Temperature/Humidity sensor in radiation shield

2 m

Tipping bucket rain gage

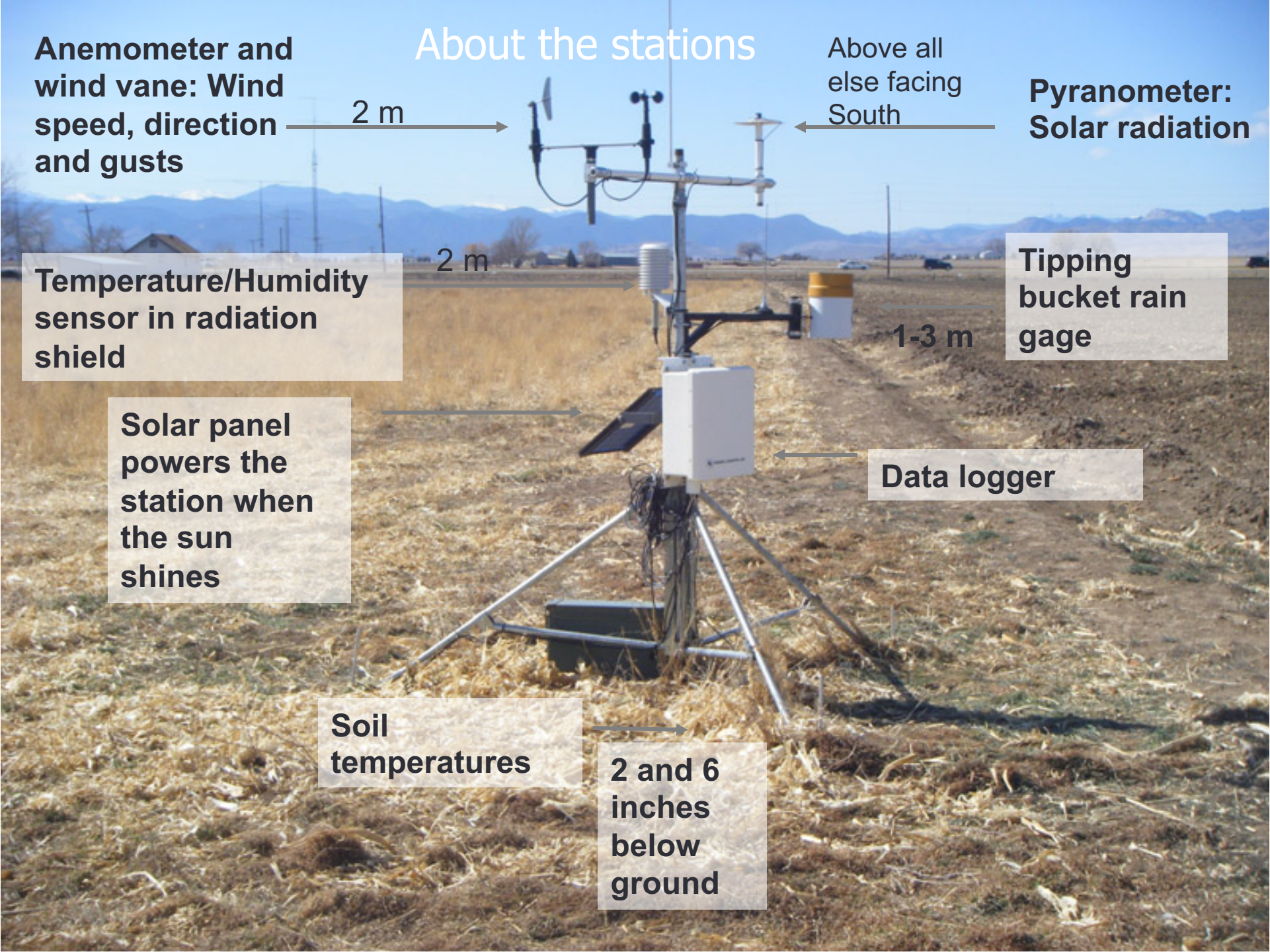
1-3 m

Solar panel powers the station when the sun shines

Data logger

Soil temperatures

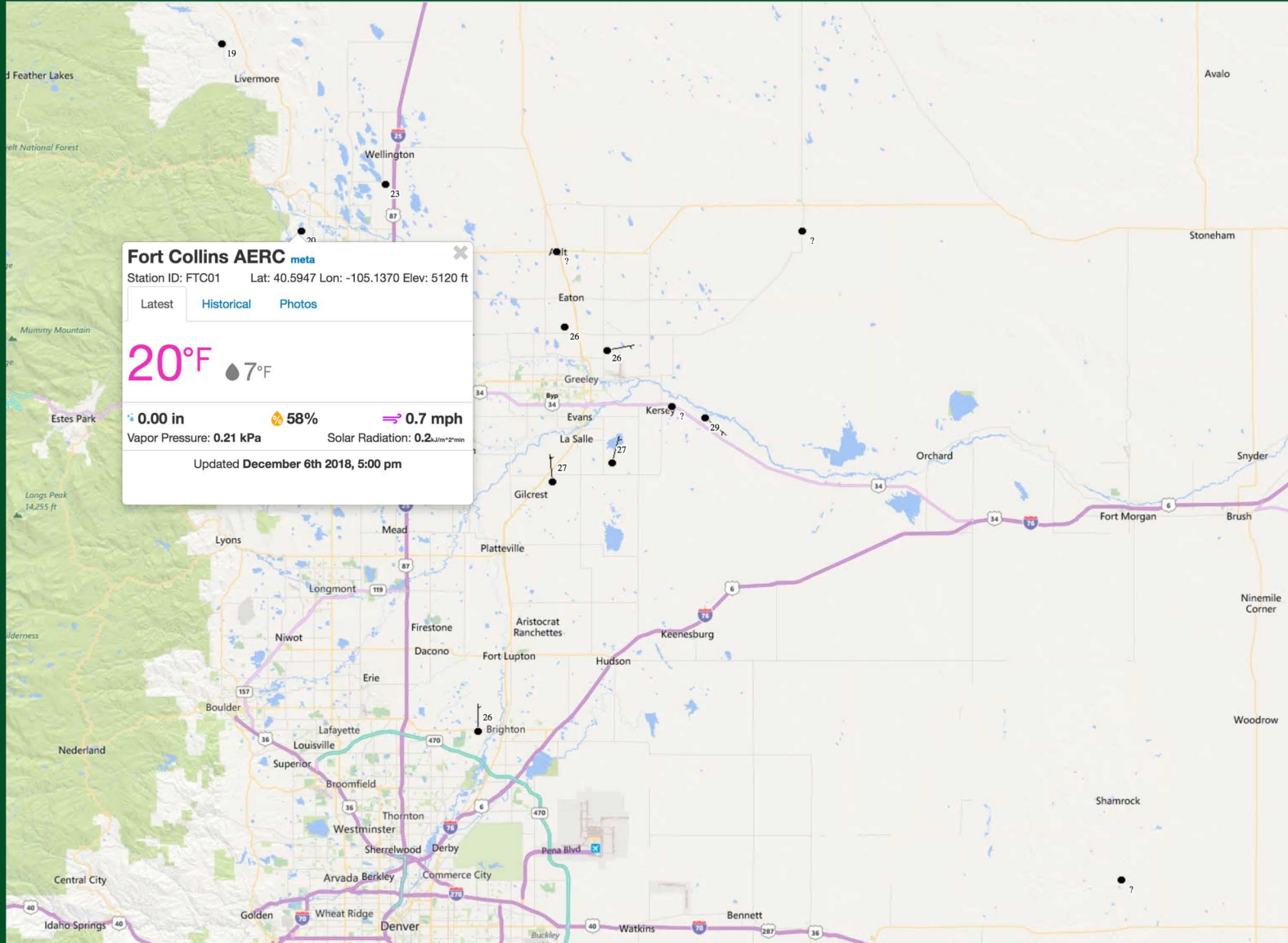
2 and 6 inches below ground



CoAgMET

- ☐ 85 stations
- ☐ 44 5-minute stations
- ☐ interactive mapping through eRAMS
- ☐ includes
 - ☐ time series charts
 - ☐ site photos

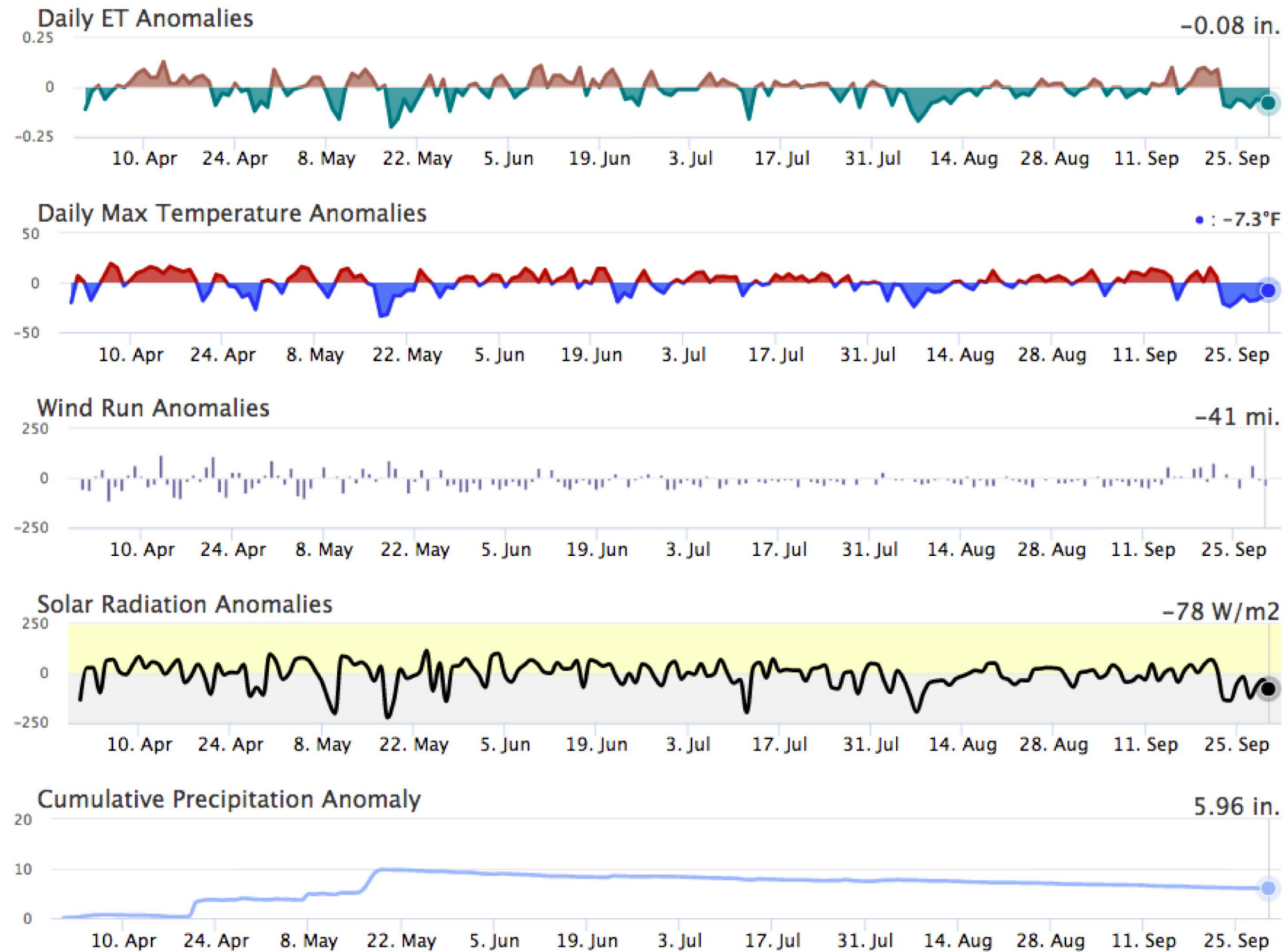
coagmet.colostate.edu



Fort Collins AERC meta
 Station ID: FTC01 Lat: 40.5947 Lon: -105.1370 Elev: 5120 ft
 Latest Historical Photos
20°F 7°F
 0.00 in 58% 0.7 mph
 Vapor Pressure: 0.21 kPa Solar Radiation: 0.2 kWh/m²/min
 Updated December 6th 2018, 5:00 pm

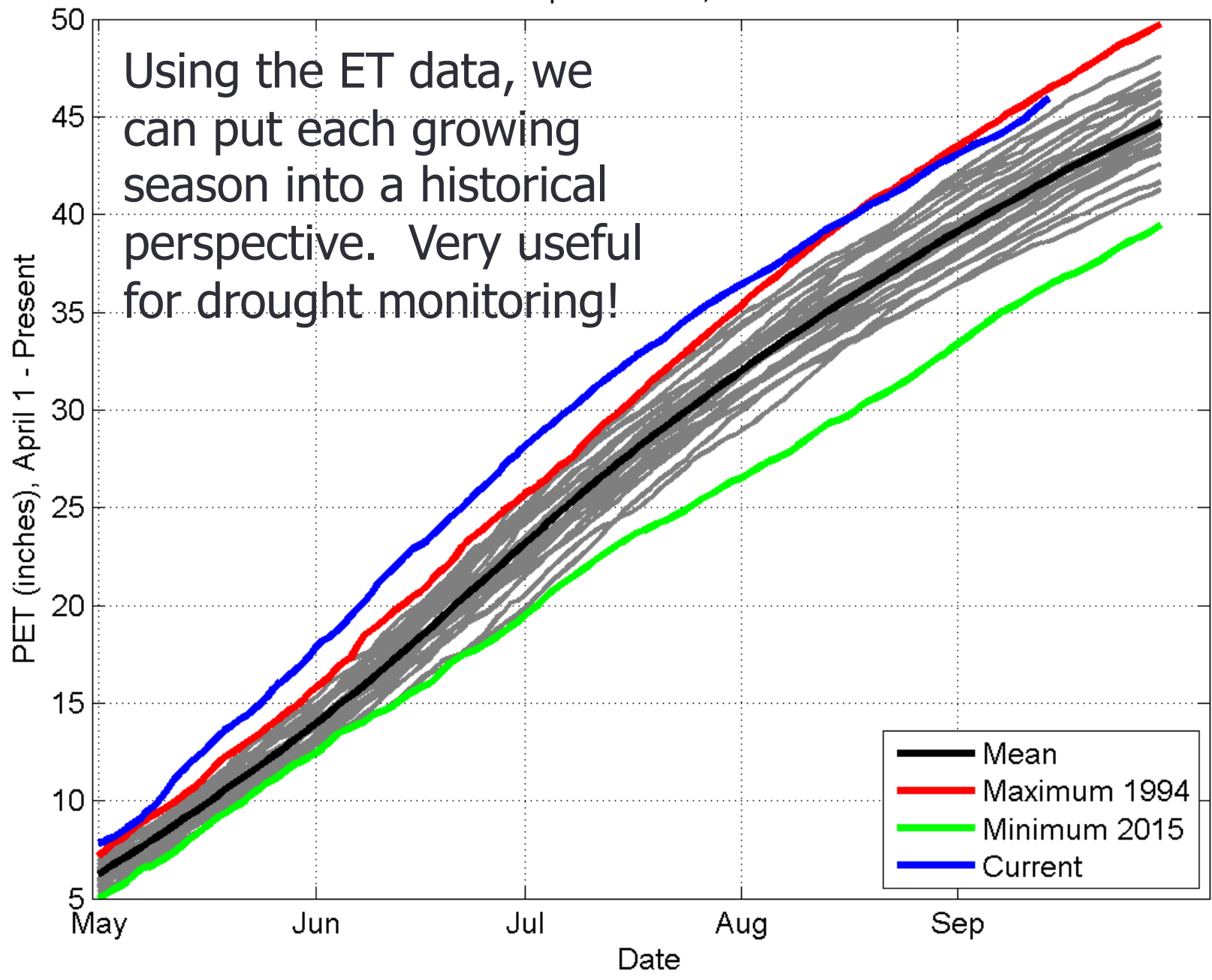
Displaying Hourly Mean Temperature (f)
 Thursday, December 6th 2018, 17:00 MST

Growing season summaries at long-term stations: Lucerne (2017)



http://climate.colostate.edu/2017ET/et_summary_lcn_ano_m.html

Olathe Growing Season Evaporative Demand
September 14, 2018



The Greenhouse Effect

Some of the infrared radiation passes through the atmosphere but most is absorbed and re-emitted in all directions by greenhouse gas molecules and clouds. The effect of this is to warm the Earth's surface and the lower atmosphere.

Solar radiation powers the climate system.



Some solar radiation is reflected by the Earth and the atmosphere.



ATMOSPHERE

EARTH

About half the solar radiation is absorbed by the Earth's surface and warms it.

Infrared radiation is emitted from the Earth's surface.



(illustration to follow courtesy of Scott Denning, CSU ATS)



Fall Night in Colorado

radiation
emitted
by soil

5 PM surface temperature = 15°C = 60°F



390 W m^{-2}

4 inches
= 10 cm



Fall Night in Colorado

radiation
emitted
by soil

6 AM surface temperature = -60°C = -78°F



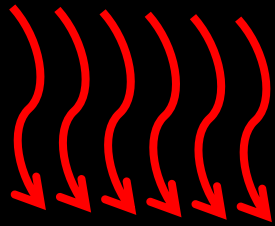
390 W m^{-2}

4 inches
= 10 cm



Fall Night in Colorado

radiation
emitted
by air



340 W m^{-2}

radiation
emitted
by soil



6 AM surface temperature = $5^\circ \text{ C} = 40^\circ \text{ F}$

390 W m^{-2}

4 inches
= 10 cm

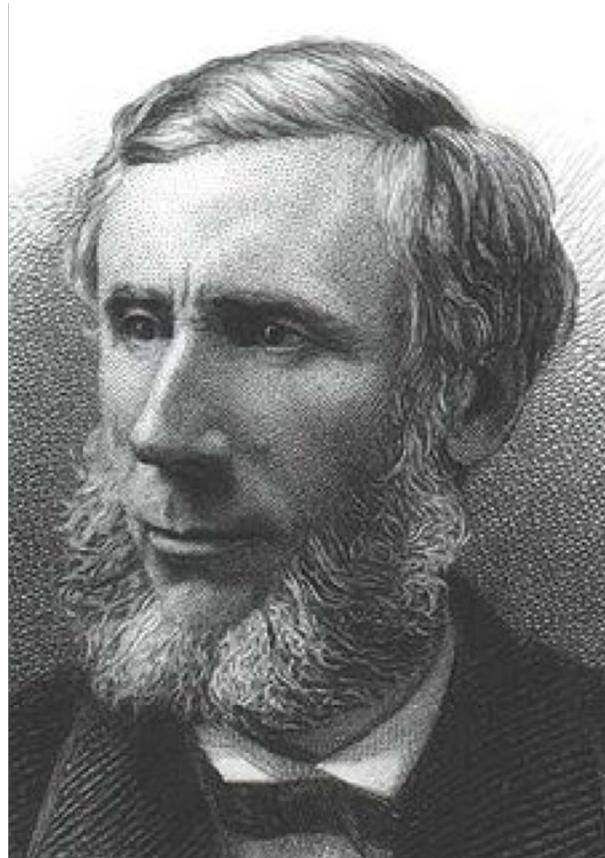




**The strongest
evidence for the
Greenhouse Effect**

**is that we can
survive night!**

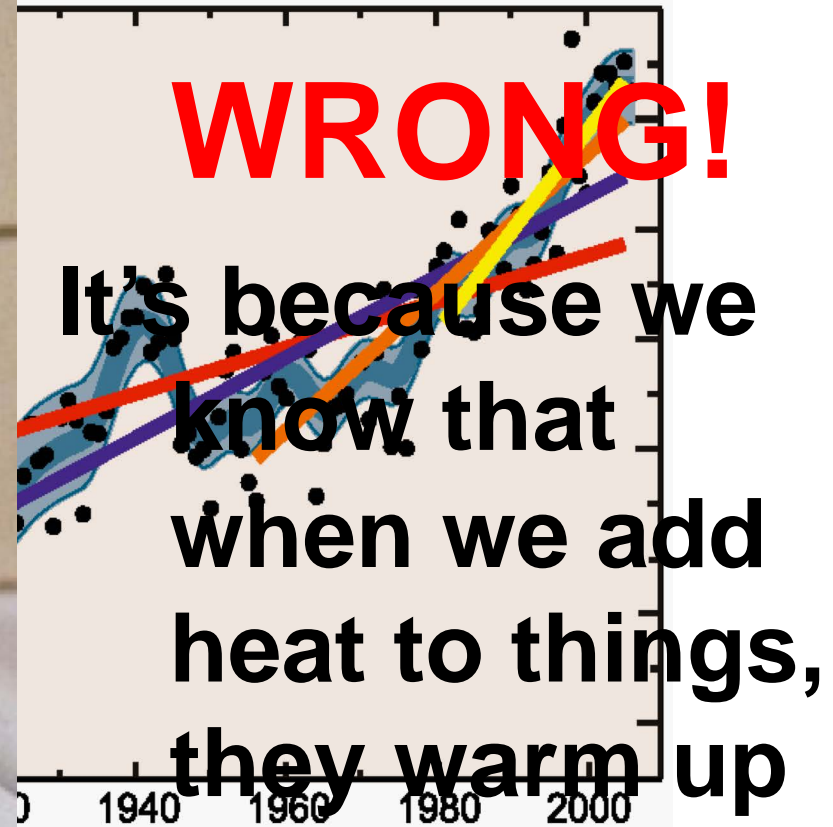
What effects do gases like CO₂ have?



John Tyndall, January 1863

- Doubling CO₂ would add **4 watts to every square meter** of the surface of the Earth, **24/7**
- Doing that would make the surface **warmer**
- This was known before light bulbs were invented!

“Scientists expect a warmer future because it’s been warming up recently”



My background is in weather modeling and forecasting: how are weather & climate models different?

- They use the same basic physics: equations describing the motion of air
- They also use similar equations to represent processes like clouds, rain, etc.
- But there are some key aspects that are really important to one type of modeling and not so much to the other...

Mass conservation:

$$\frac{\partial}{\partial t} \left(\frac{\partial p}{\partial s} \right) + \nabla_s \cdot \left(\mathbf{v} \frac{\partial p}{\partial s} \right) + \frac{\partial}{\partial s} \left(\dot{s} \frac{\partial p}{\partial s} \right) = 0 \quad (1)$$

Thermal energy conservation:

$$\frac{\partial}{\partial t} \left(\theta \frac{\partial p}{\partial s} \right) + \nabla_s \cdot \left(\mathbf{v} \frac{\partial p}{\partial s} \theta \right) + \frac{\partial}{\partial s} \left(\dot{s} \frac{\partial p}{\partial s} \theta \right) = \dot{\theta} \frac{\partial p}{\partial s} \quad (2)$$

Momentum conservation:

$$\begin{aligned} \frac{\partial \mathbf{v}}{\partial t} + (\zeta + f) \mathbf{k} \times \mathbf{v} + \left(\dot{s} \frac{\partial p}{\partial s} \right) \frac{\partial \mathbf{v}}{\partial p} \\ + \nabla_s \cdot \left(M + \frac{\mathbf{v}^2}{2} \right) - \Pi \nabla_s \theta = \mathbf{F} \end{aligned} \quad (3)$$

Hydrostatic Equation:

$$\frac{\partial M}{\partial \theta} = \Pi. \quad (4)$$



Initial conditions are critical for weather forecasts!

One example of a
chaotic system Lorenz
explains is a ski run with
moguls – he suggested
Cat's Meow at Loveland



<http://www.karlkelman.com/ski-pictures/loveland/lovebyrun/chairone/cats-meow/middle-cats-meow-loveland-basin-2009-04-27.jpg>



Develop a model for a ski or board pushed from the top of the slope from the top of the slope at a specified velocity

From Lorenz, *The Essence of Chaos*

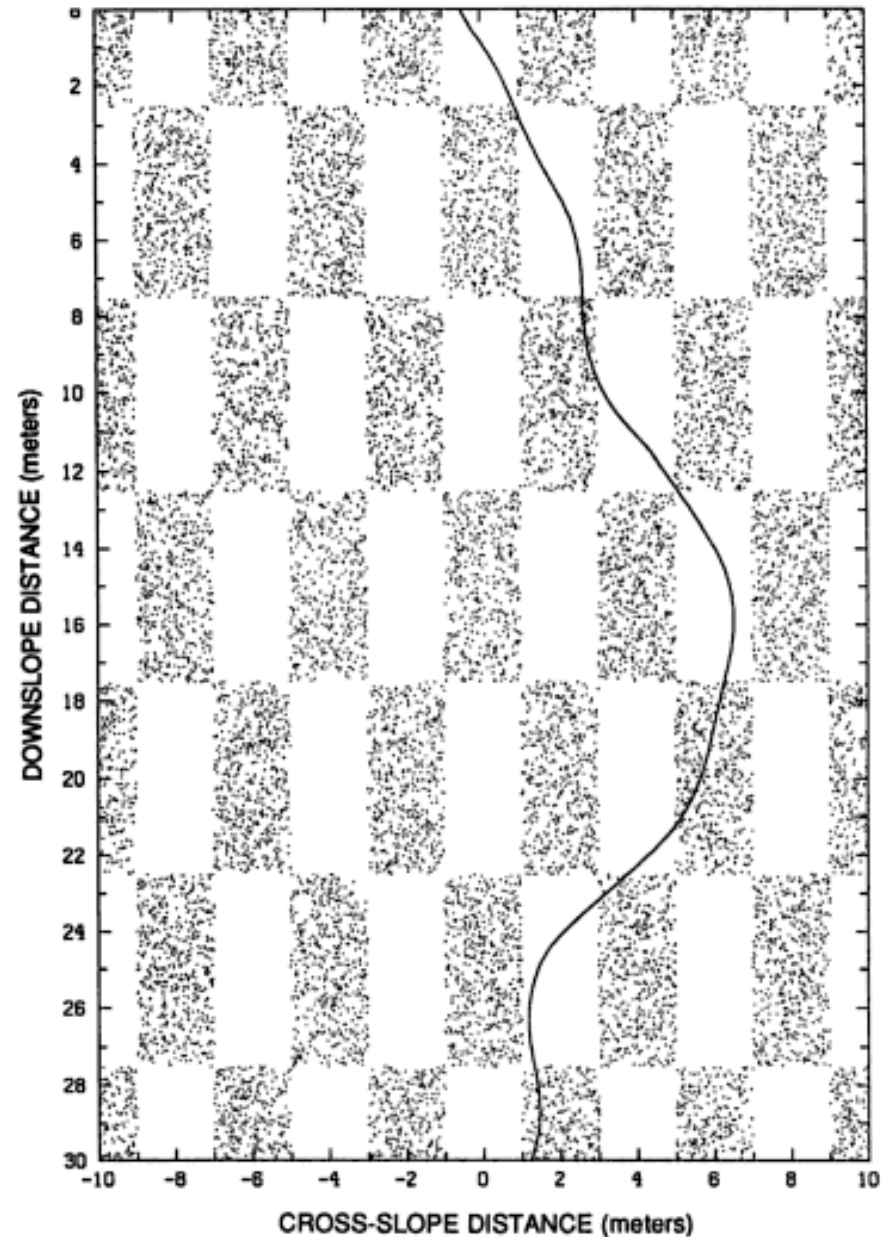
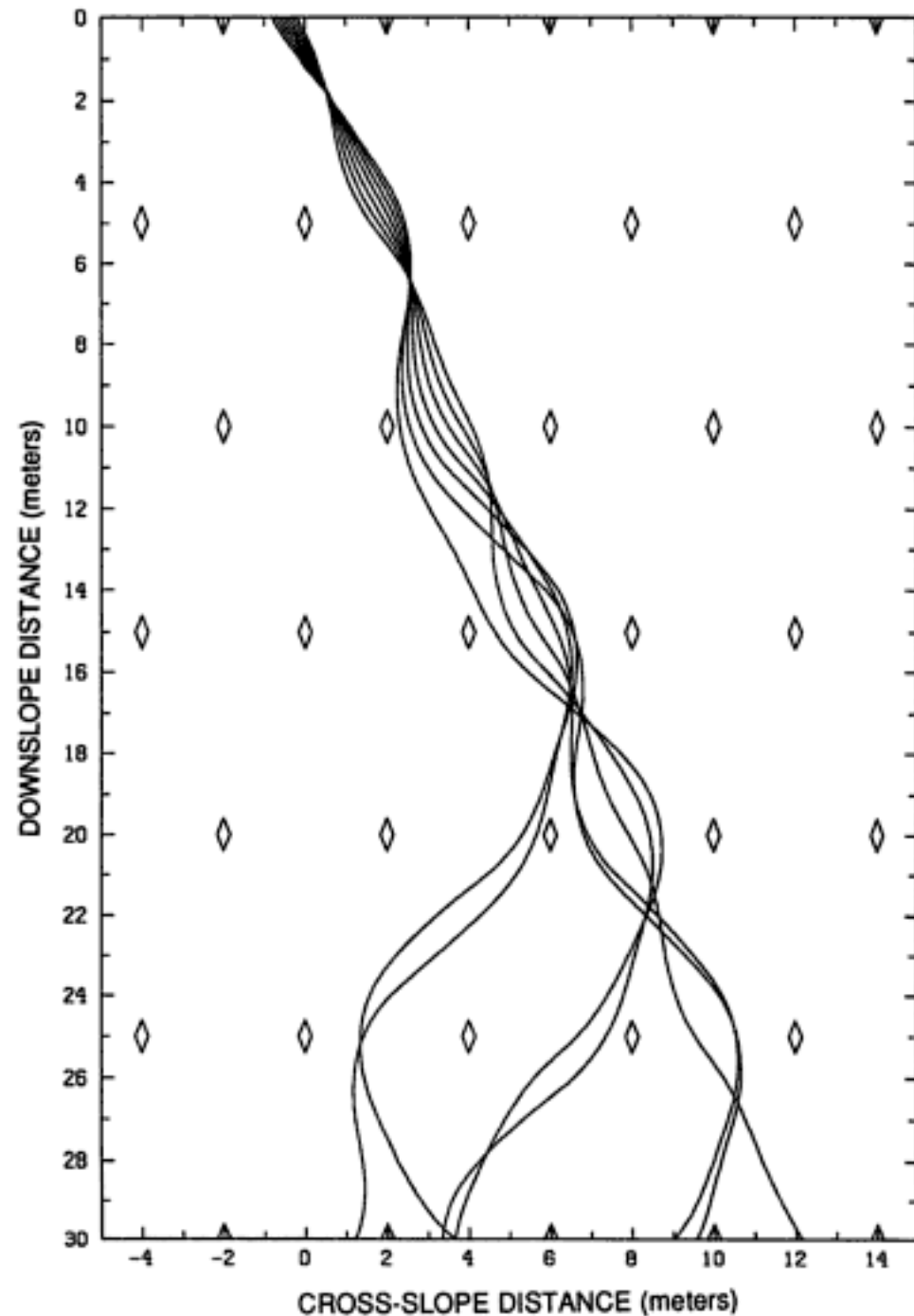


Figure 6. A top view of a section of the model ski slope, with the path of a single board sliding down it. The shaded rectangular areas of the slope project above a simple inclined plane, while the unshaded areas project below.

Space the boards 10 cm apart and push down the slope at identical velocity

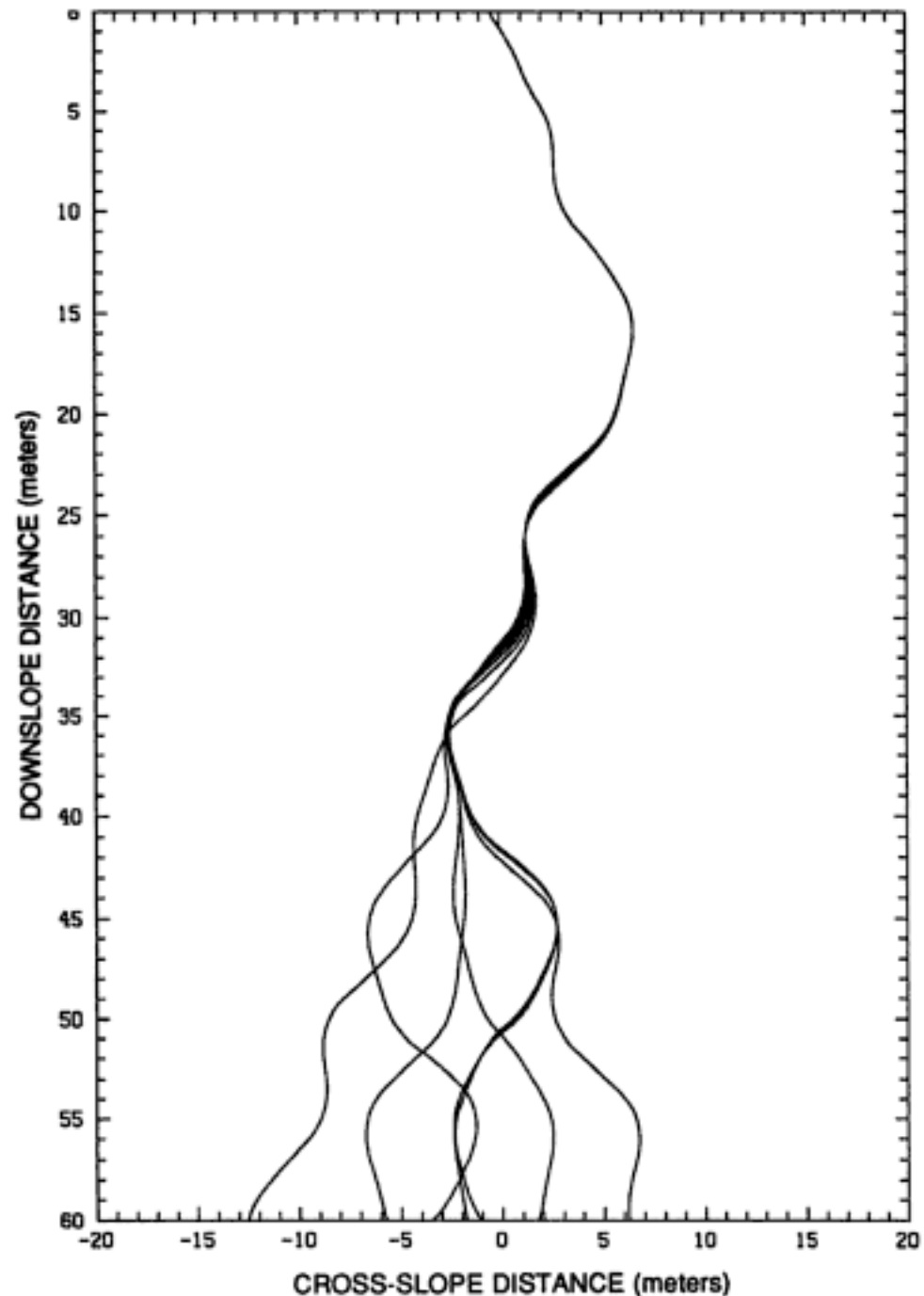
From Lorenz, *The Essence of Chaos*



Now space them 1 millimeter apart

It takes more time/distance, but the boards eventually diverge even in this situation

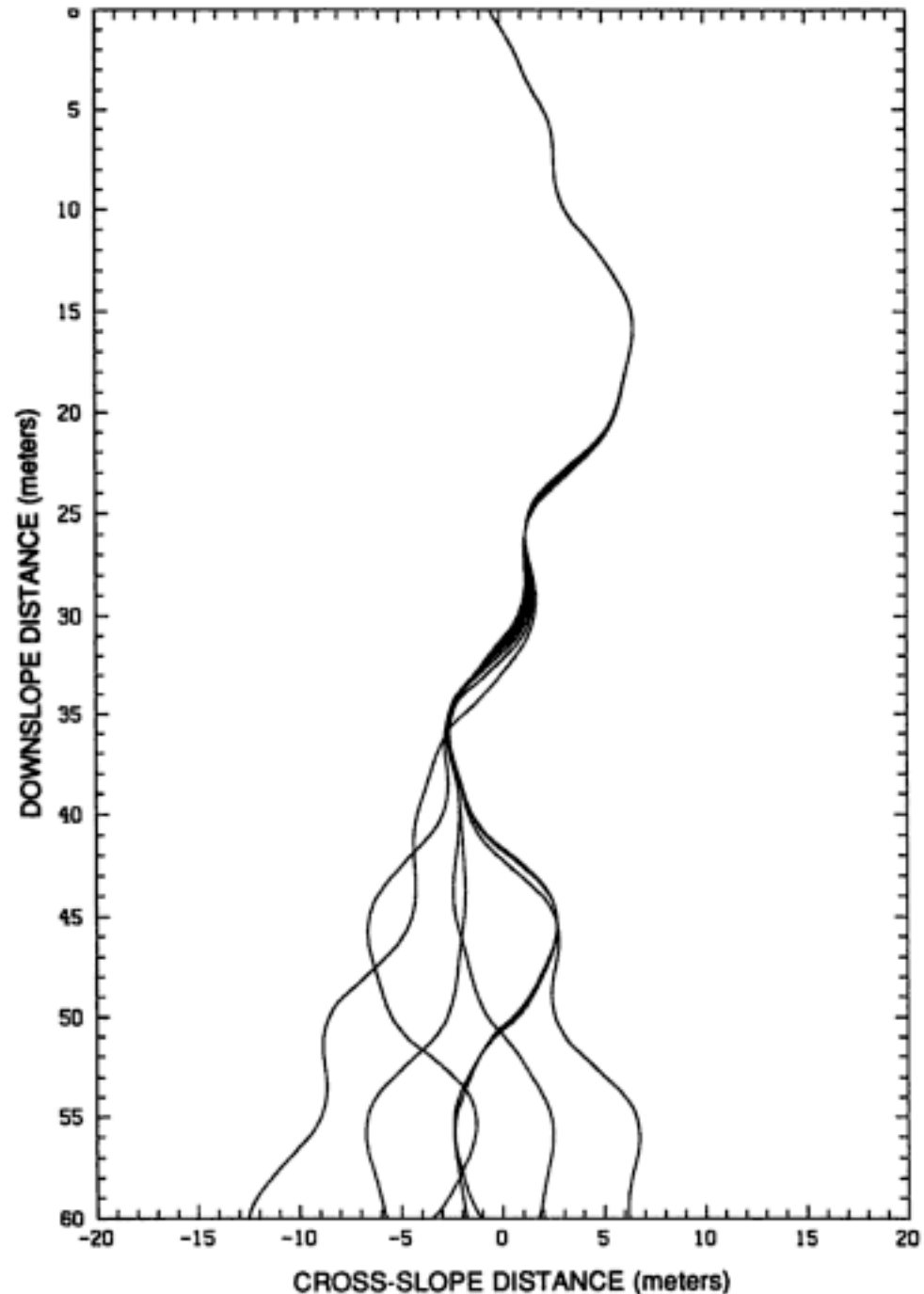
From Lorenz, *The Essence of Chaos*



But they all ended up at the bottom of the hill!

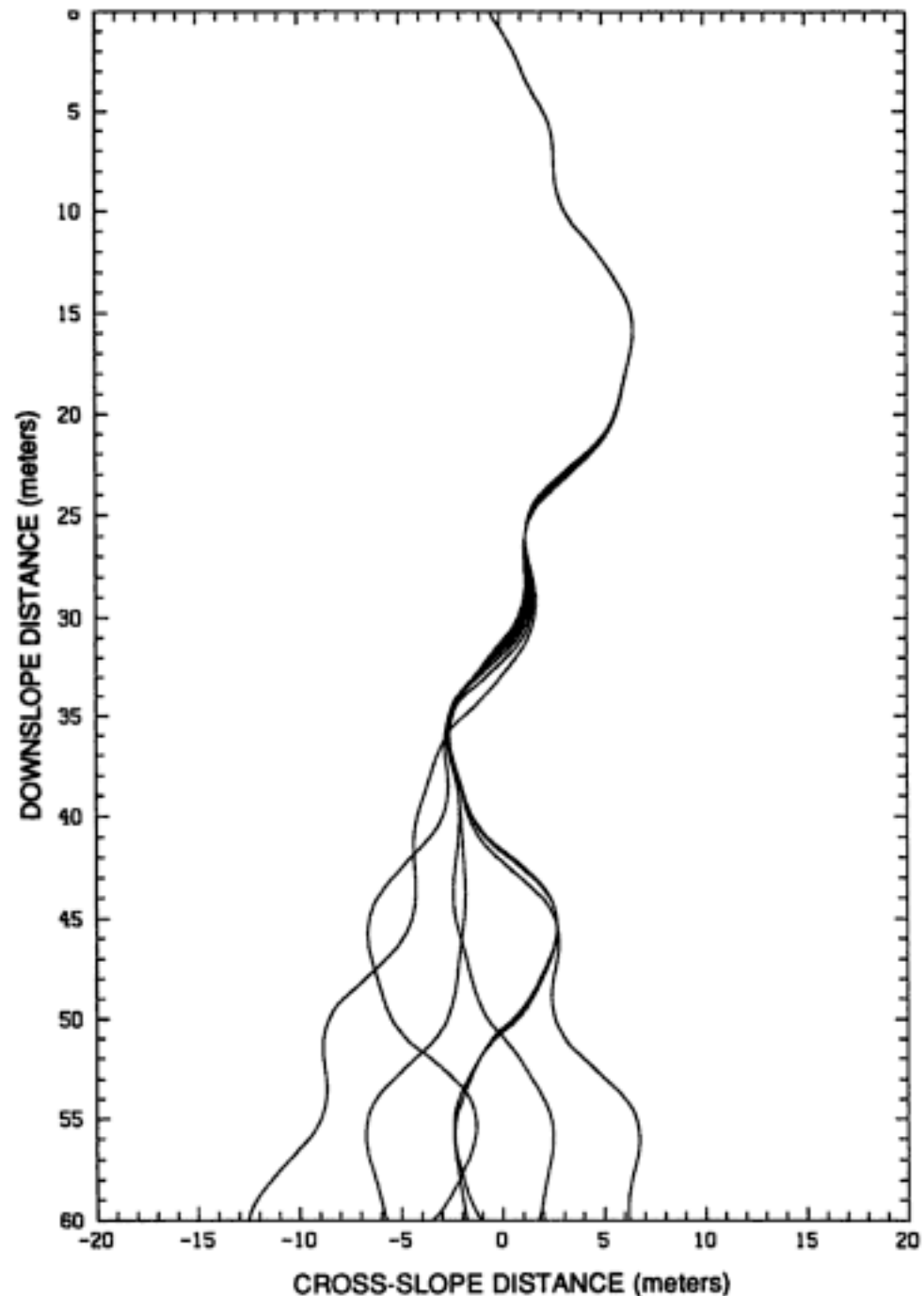
And if you pushed lots and lots of boards, you'd get a pretty good idea of where they tend to finish – this is akin to climate modeling, where you don't care about the weather on a given day, but about the **statistics** of the weather over long time periods

From Lorenz, *The Essence of Chaos*



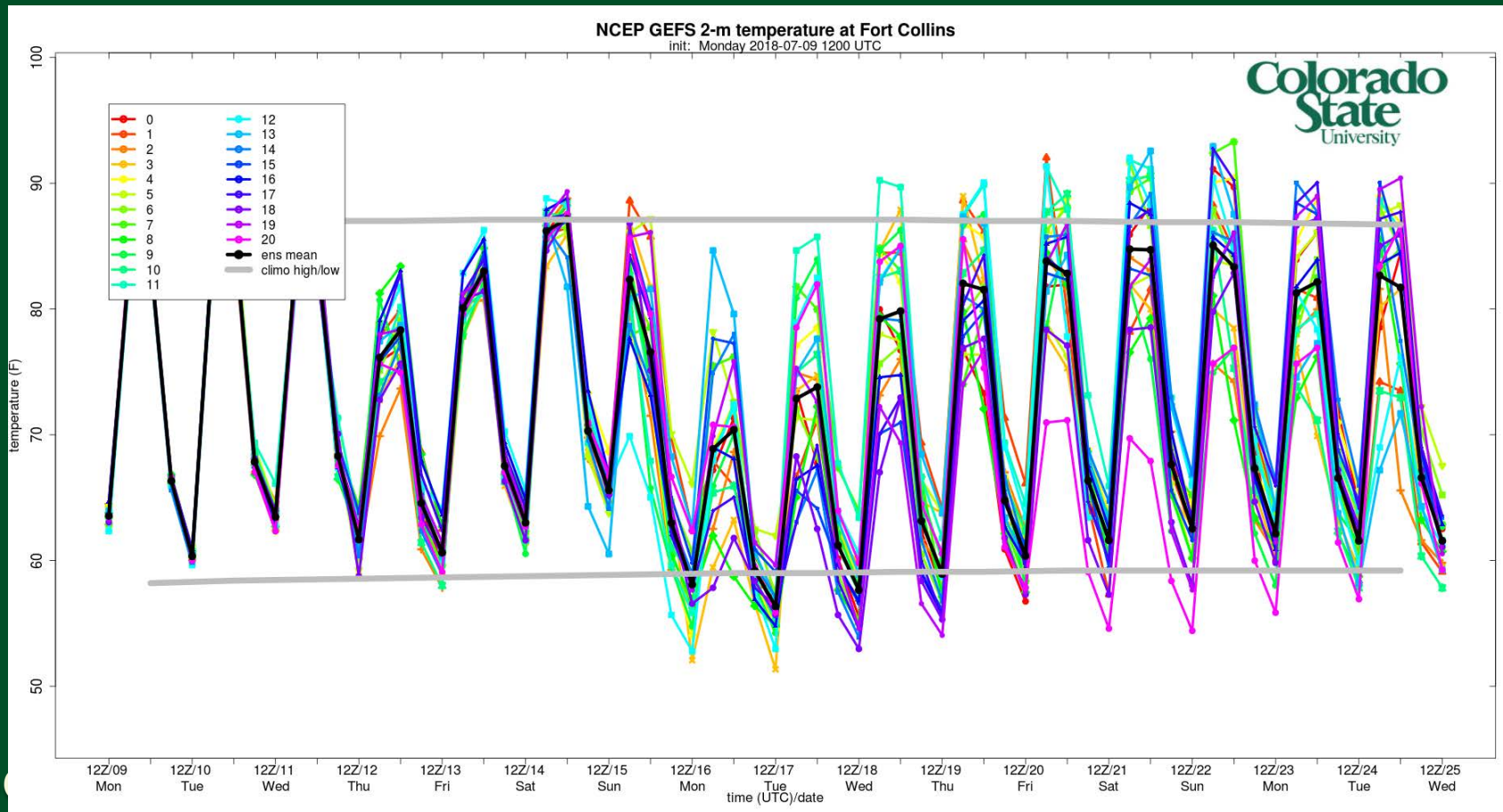
And if you changed the steepness of the hill, or removed some of the moguls, you'd expect some rather different outcomes...

From Lorenz, *The Essence of Chaos*



Ensembles of models

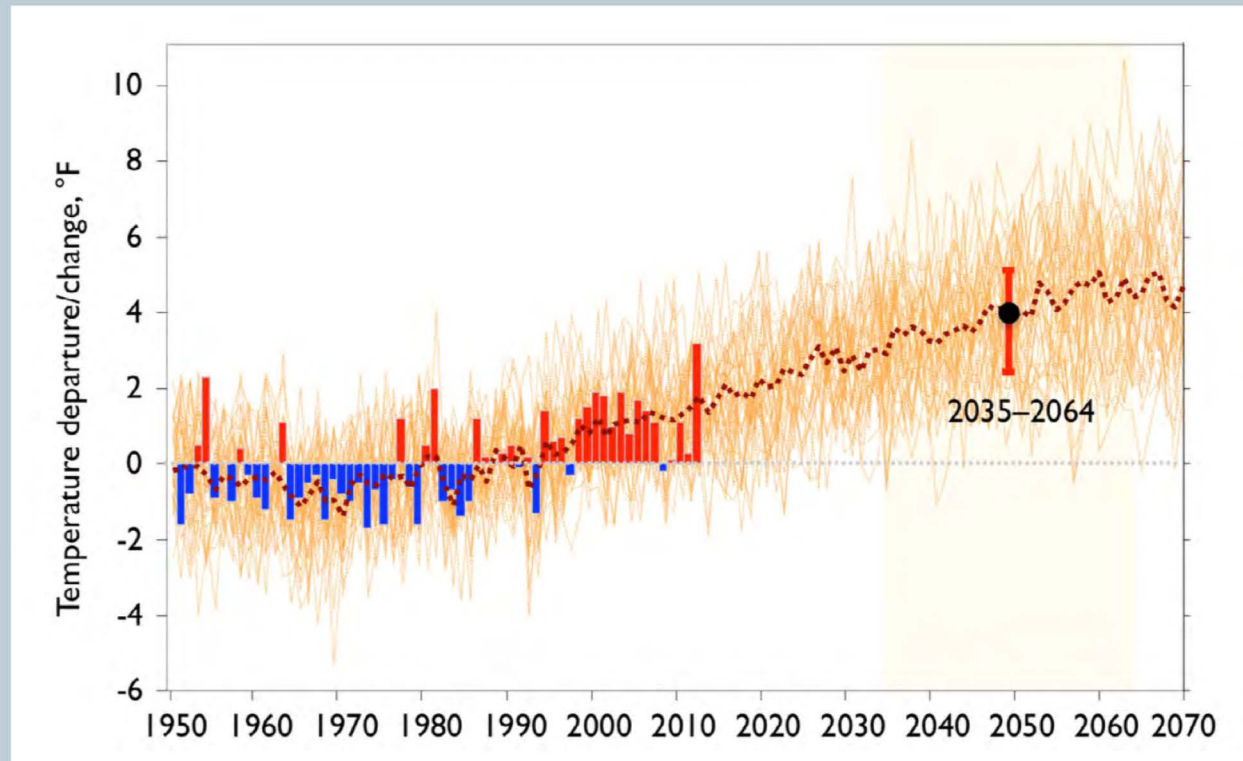
- In both weather and climate modeling, we want to use ‘ensembles’ – multiple models with some small changes to the initial conditions, or the parameters in the model – in principle this gives a good representation of the range of possible outcomes, best and worst case scenarios, etc.



Ensembles of models

- In both weather and climate modeling, we want to use ‘ensembles’ – multiple models with some small changes to the initial conditions, or the parameters in the model – in principle this gives a good representation of the range of possible outcomes, best and worst case scenarios, etc.

FIGURE 5-2. Projected Colorado annual temperature under RCP 4.5 compared to observations



Climate Change in Colorado

*A Synthesis to Support Water Resources
Management and Adaptation*

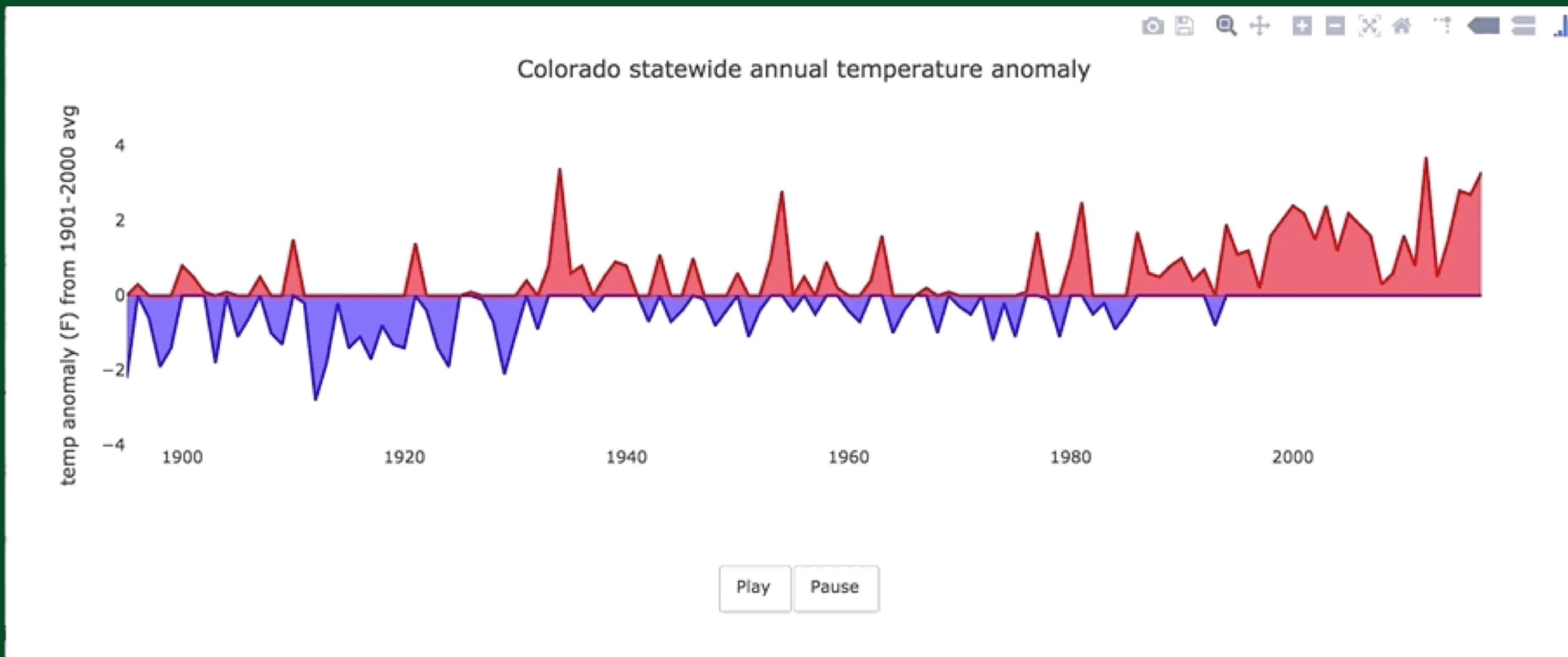


A Report for the Colorado Water Conservation Board

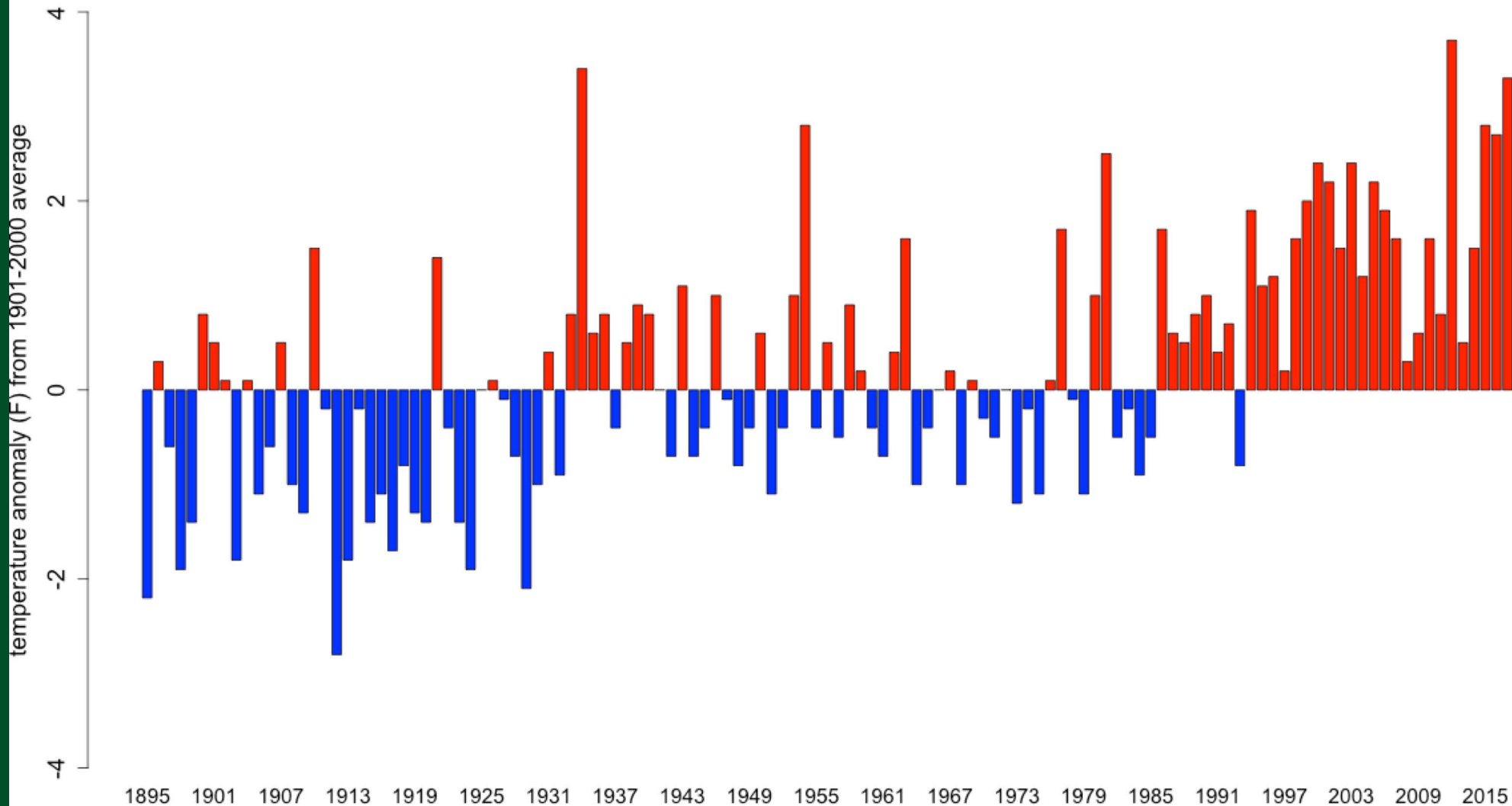
Recommended reading –
some of the following is
based on this report

<http://wwa.colorado.edu/climate/co2014report/>

Statewide temperatures, 1895-2017



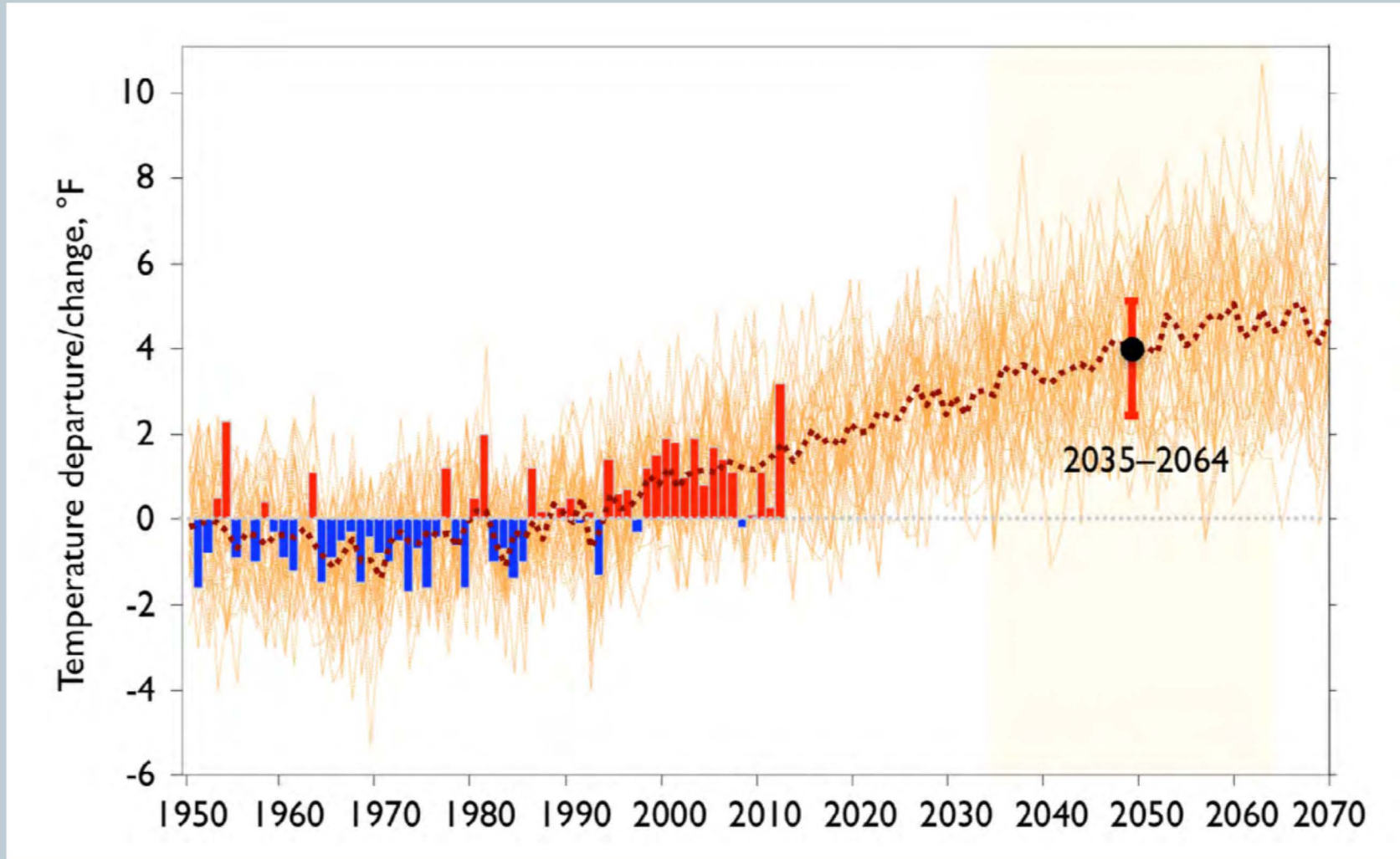
Colorado statewide annual temperature anomaly



Updated through 2017



FIGURE 5-2. Projected Colorado annual temperature under RCP 4.5 compared to observations

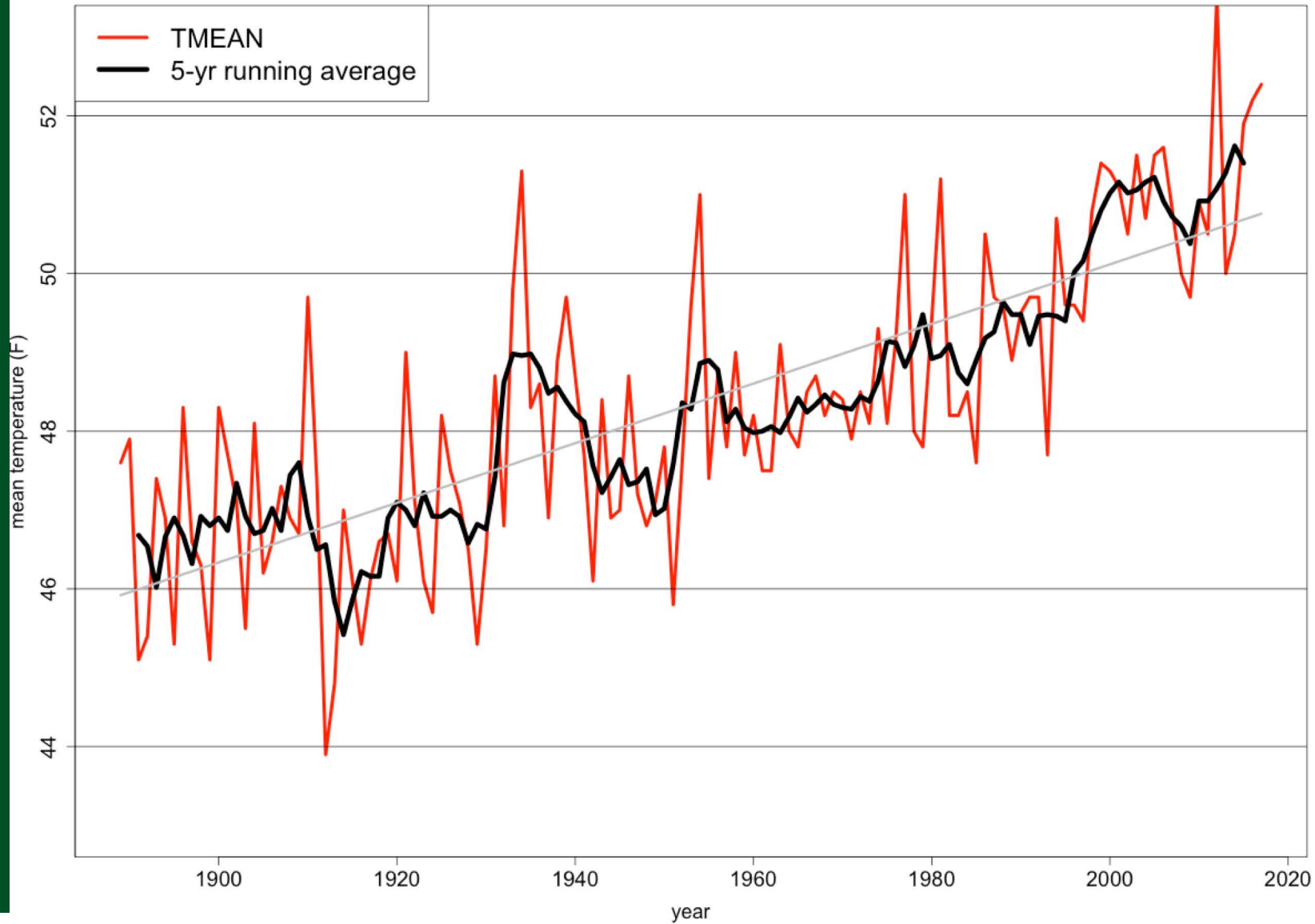


Average temperature increase of 2.5-5°F, for middle-of-the-road emissions scenario

From Lukas et al. (2014), *Climate Change in Colorado*



Fort Collins Annual Mean Temperature, 1889-2017



Mean: 48.3 °F

Std Dev: 1.9 °F

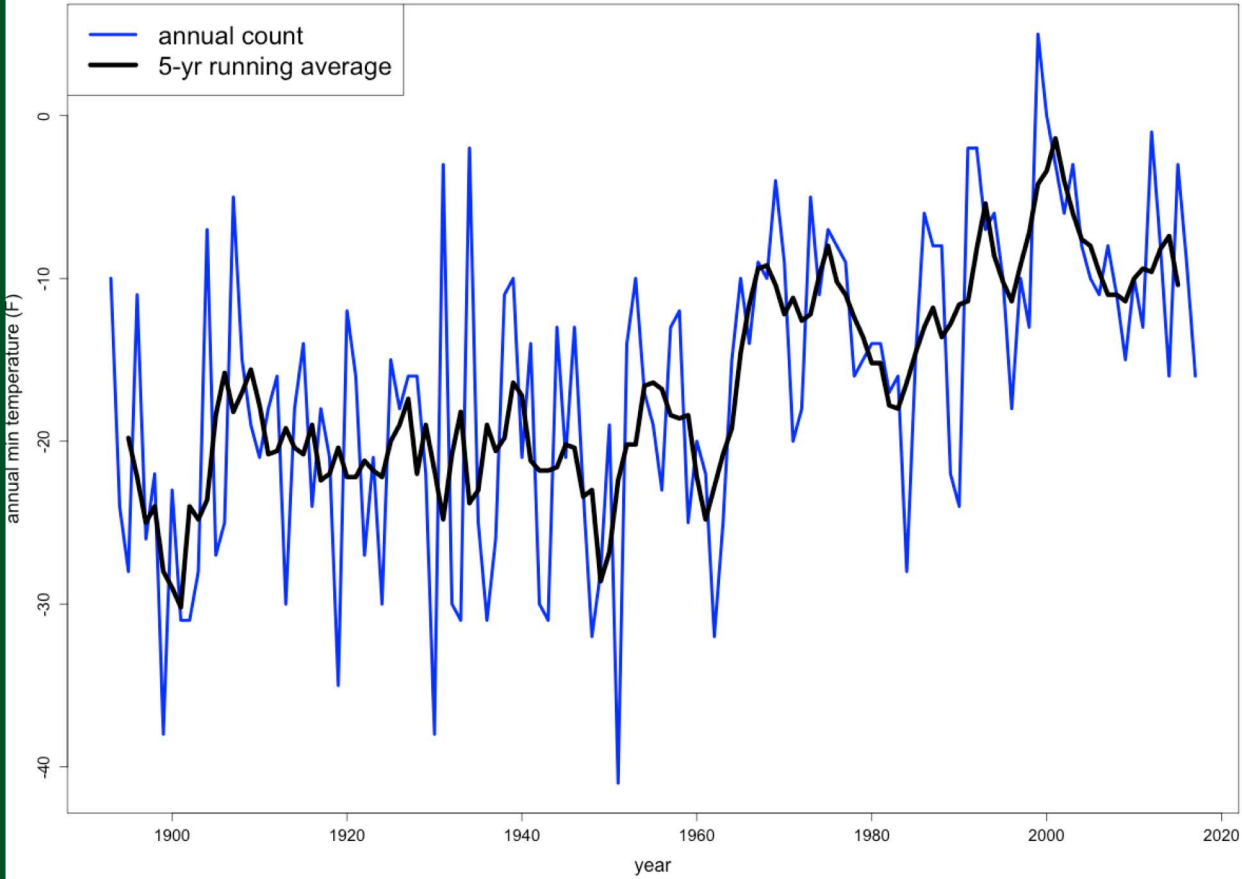
Warmest Year: 53.5° F (2012) 2017 was 2nd warmest at 52.4° F

2018: 51.2, 11th warmest

Coollest Year: 43.9° F (1912)

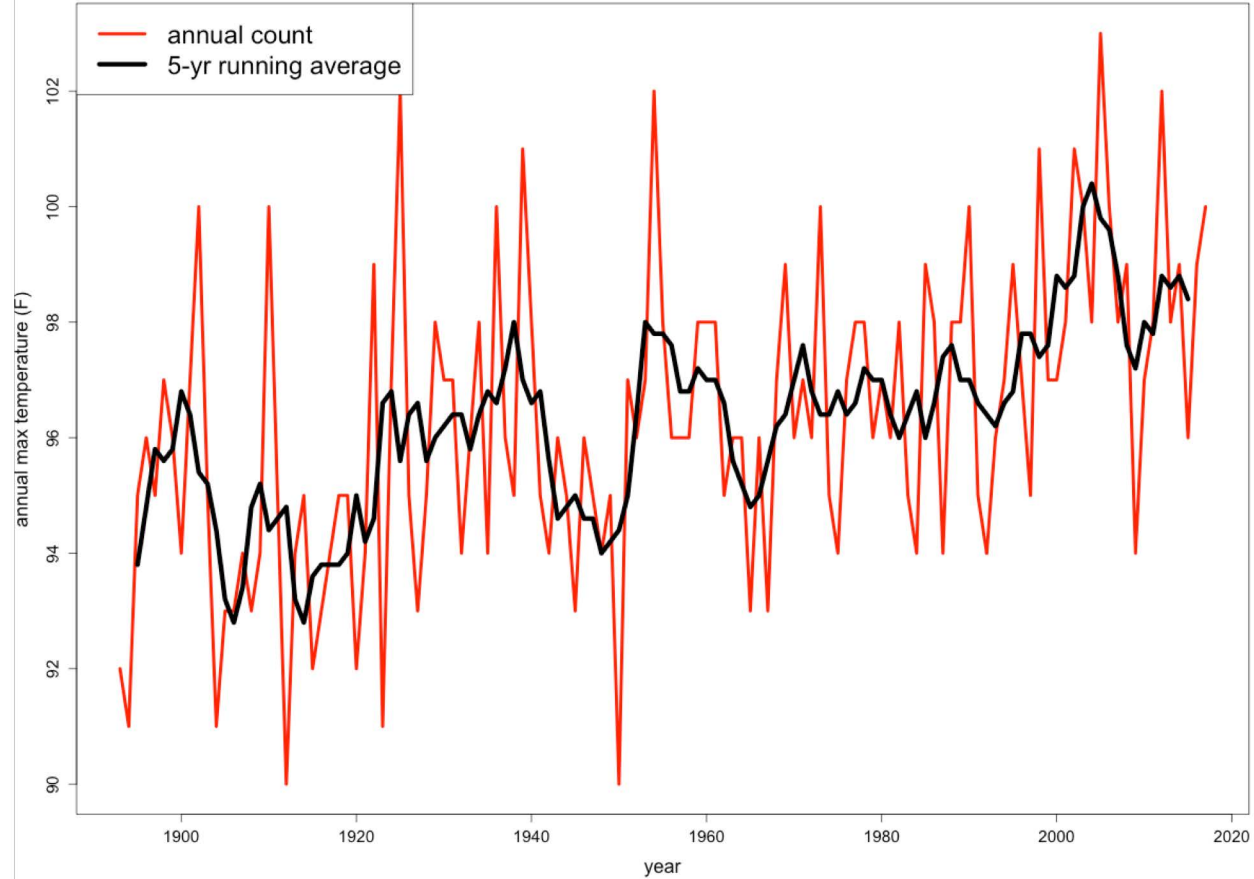
Lowest temperature of each year

coldest temp (F) each year at Fort Collins, 1893-2017



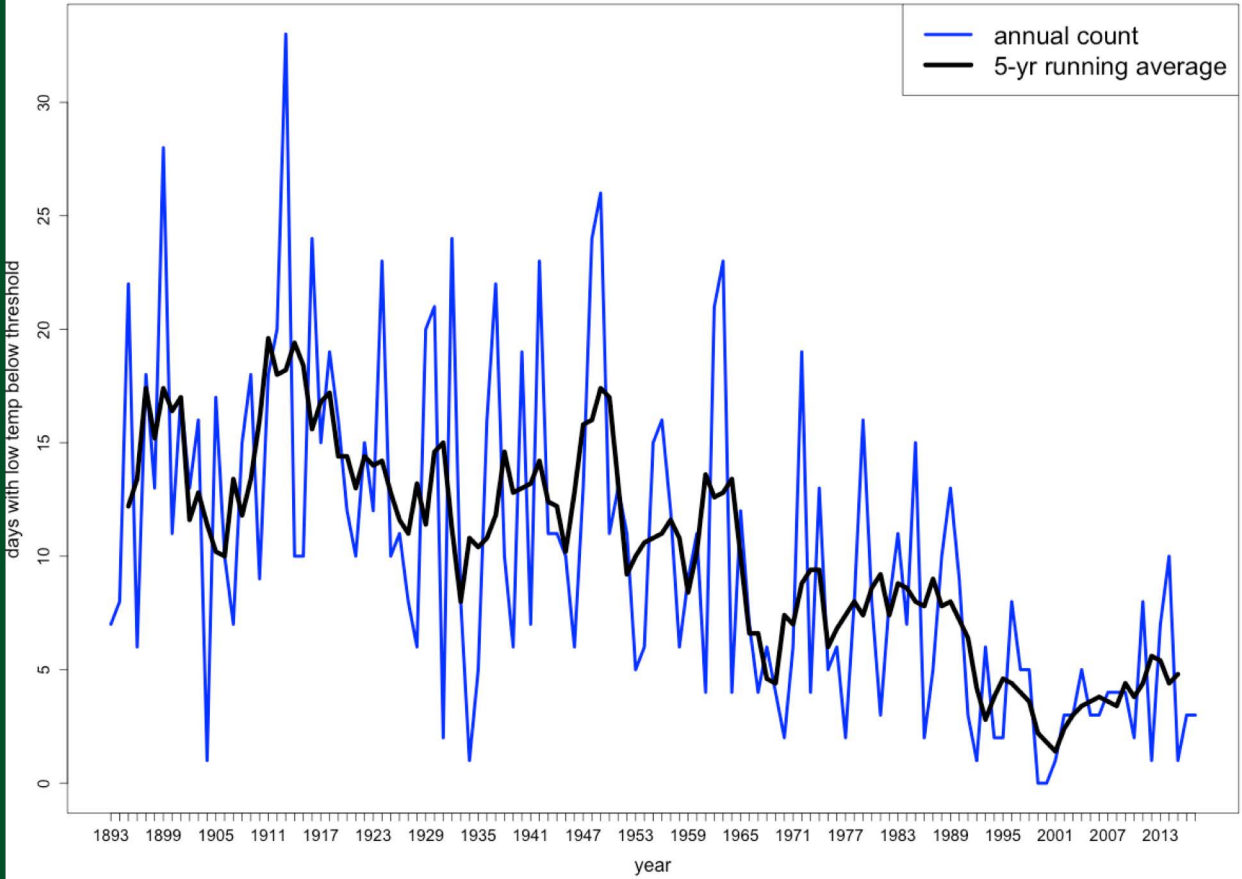
Highest temperature of each year

warmest temp (F) each year at Fort Collins, 1893-2017



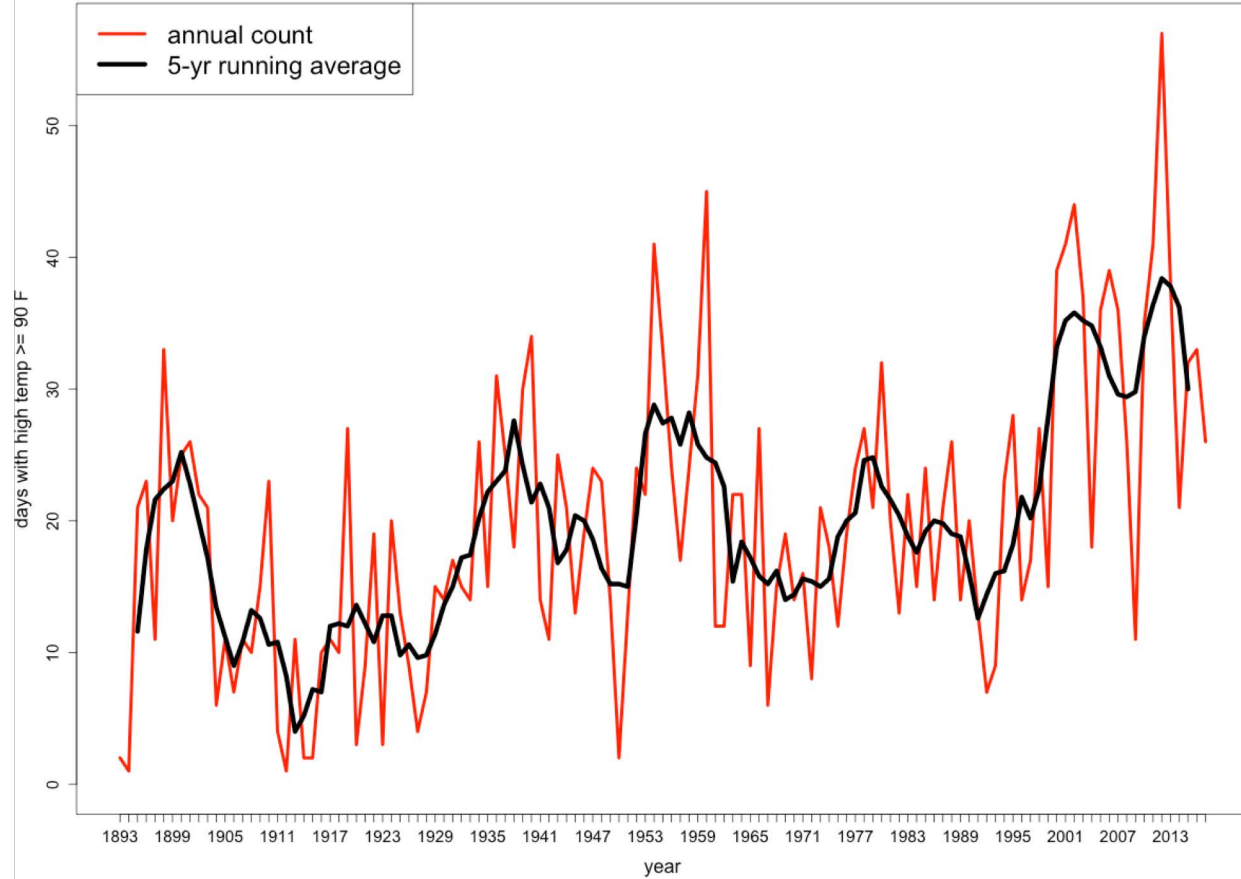
Number of below-zero nights

number of daily min temps < 0 F at Fort Collins

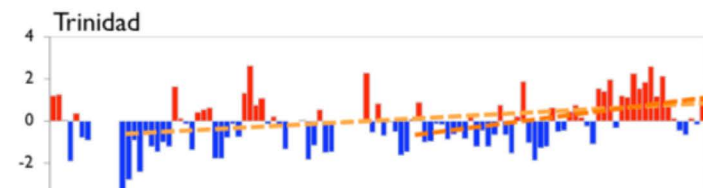
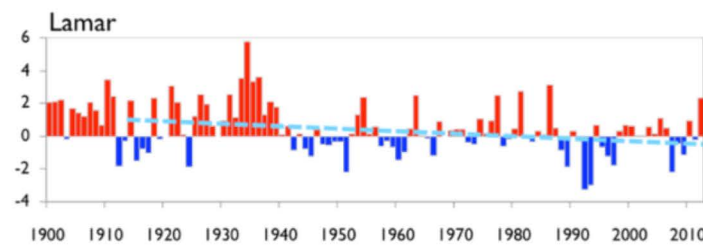
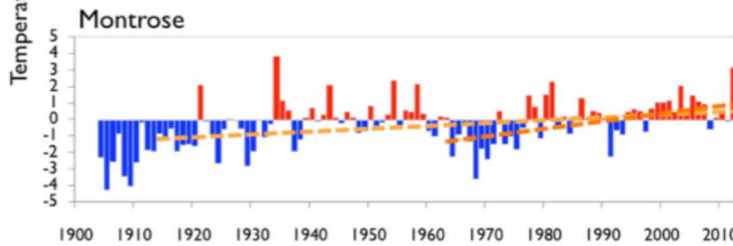
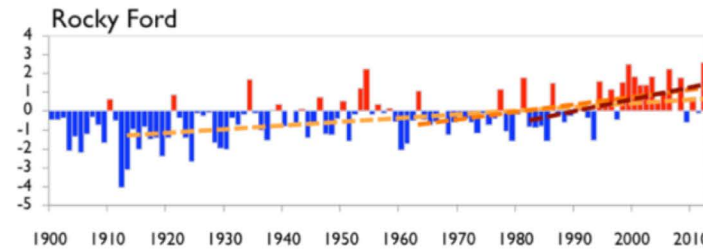
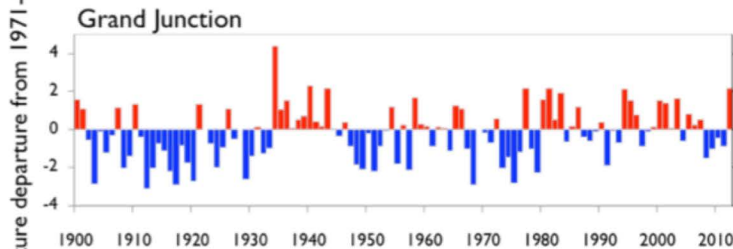
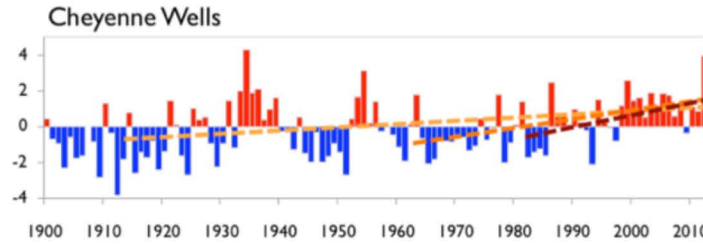
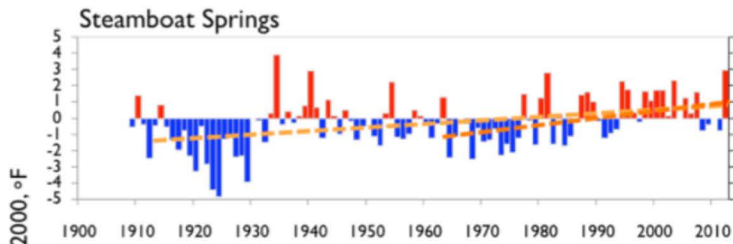
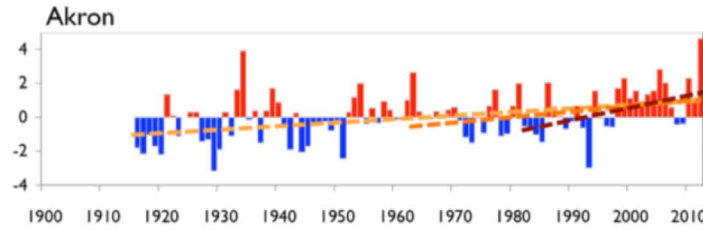
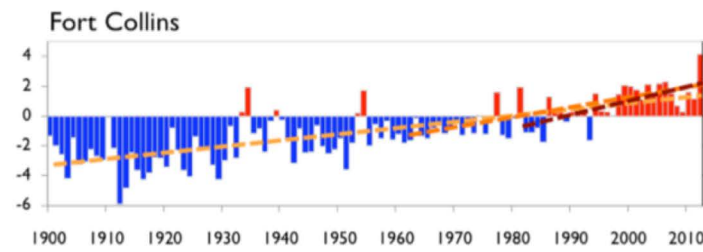
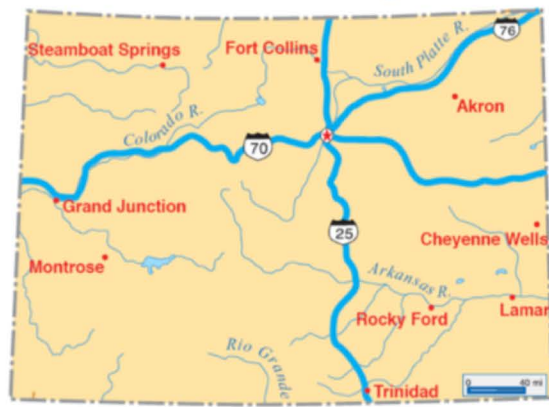


Number of 90-degree days

number of daily max temps >= 90 F at Fort Collins

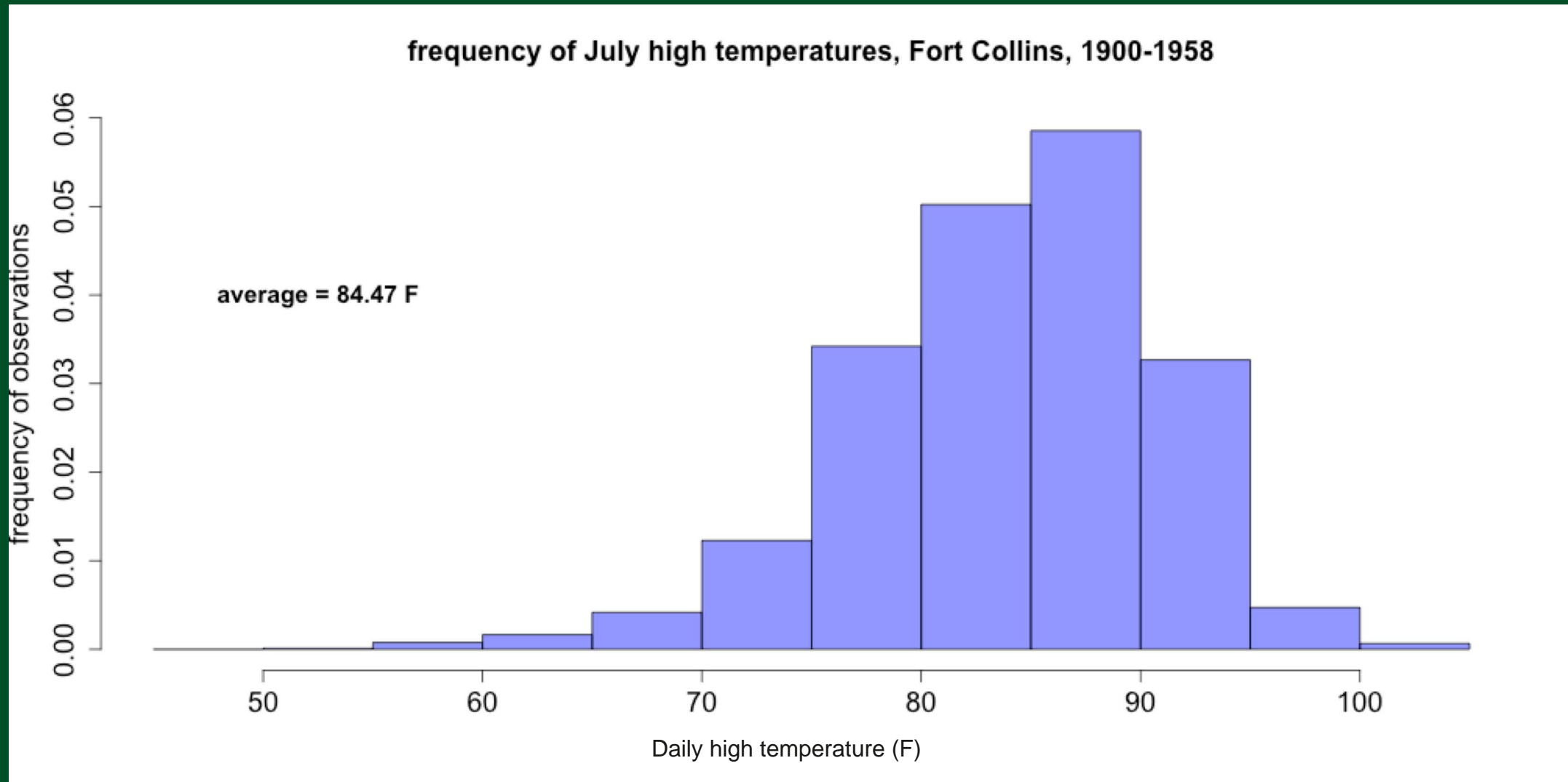


Trends around the state: temperature

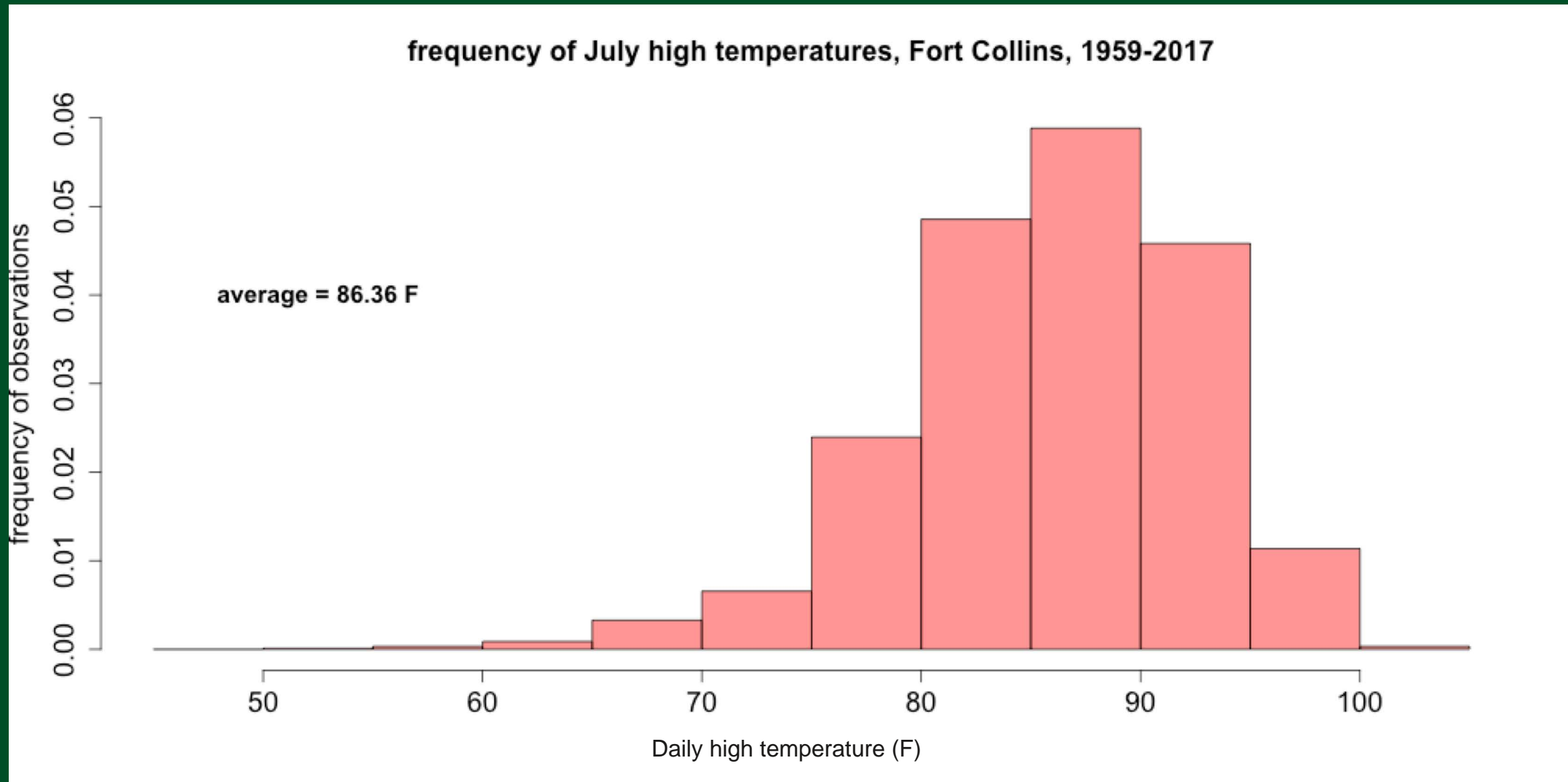


From "Climate Change in Colorado"
report, 2014:
<http://wwa.colorado.edu/climate/co2014report/>

What does a 2-degree change in average temperature look like?



What does a 2-degree change in average temperature look like?



What does a 2-degree change in average temperature look like?

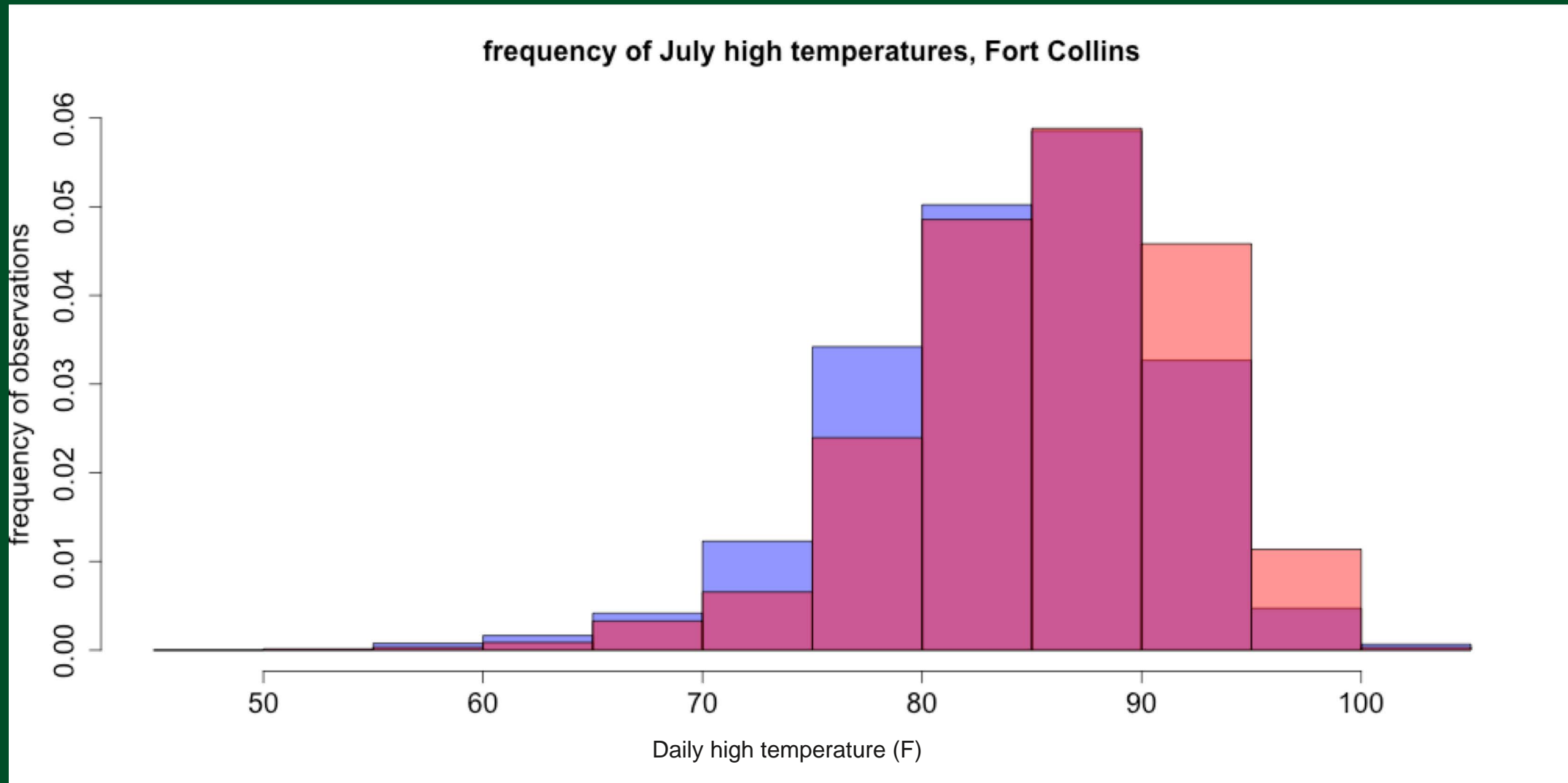
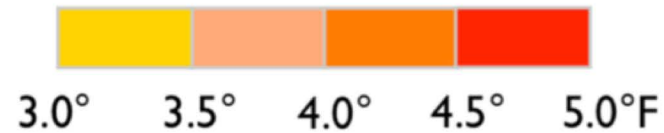
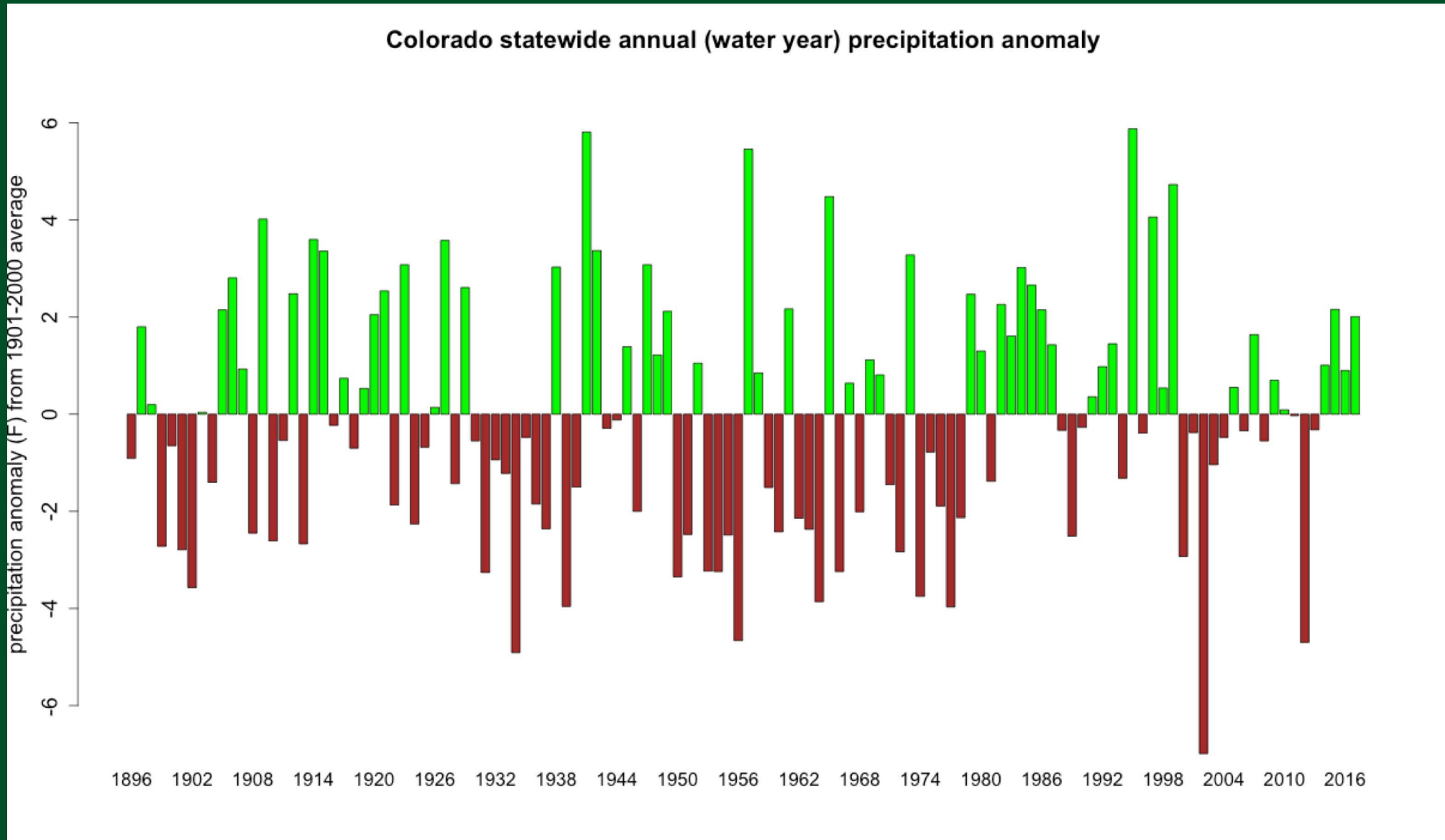


TABLE 5-1. Projected monthly temperature change for eight subregions under RCP 4.5 for 2035–2064

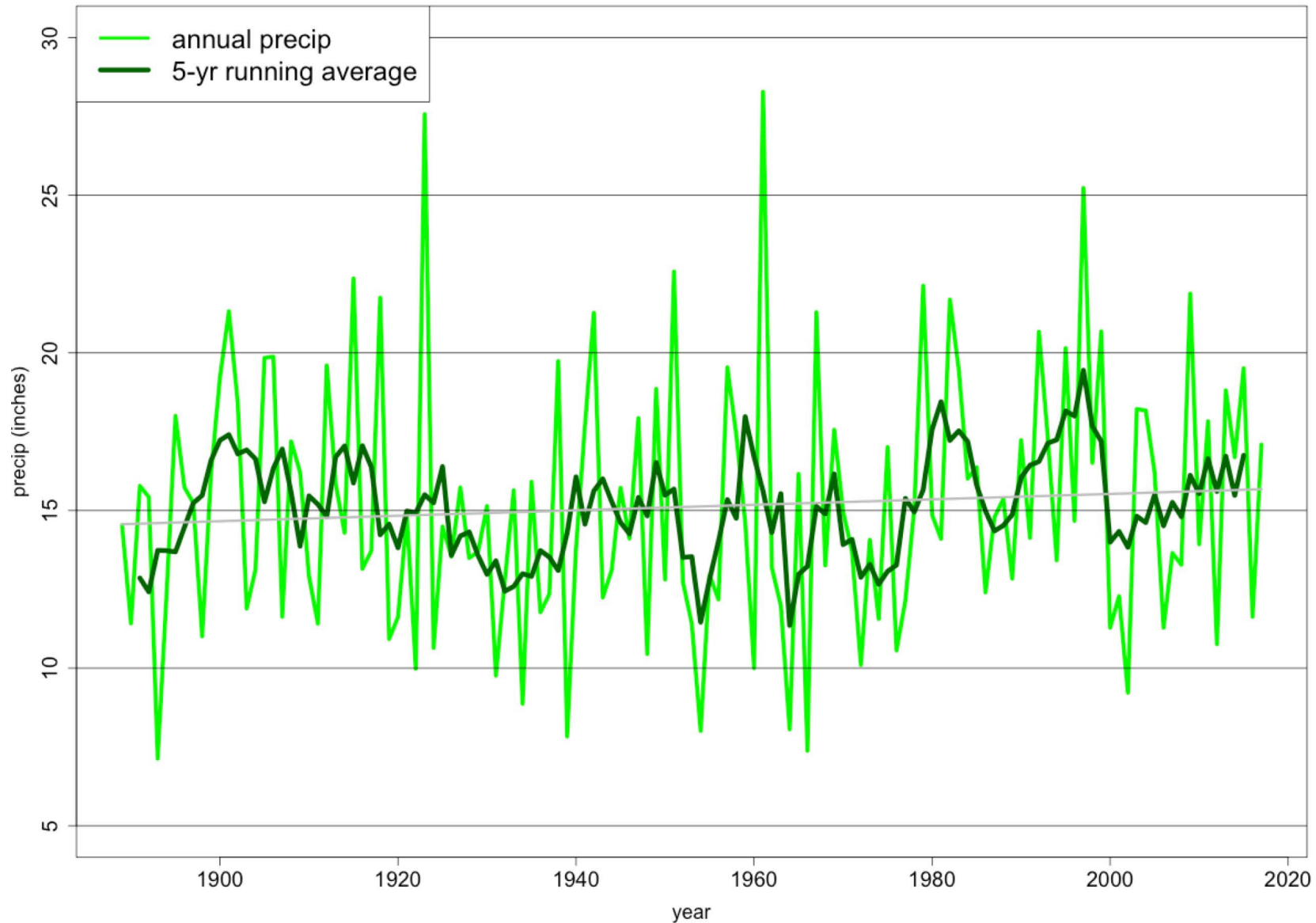
Subregion	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
Northeastern Plains	3.5°	4.0°	4.0°	4.0°	3.5°	3.5°	4.5°	4.5°	4.5°	3.5°	3.5°	3.5°	3.5°
Denver Metro	4.0°	4.0°	4.0°	4.0°	4.0°	3.5°	4.0°	4.5°	4.5°	4.0°	3.5°	3.5°	4.0°
Arkansas Valley	4.0°	4.0°	4.0°	4.0°	4.0°	4.0°	4.0°	4.0°	4.5°	4.0°	3.5°	3.5°	3.5°
San Luis Valley	4.0°	4.0°	4.0°	3.5°	4.0°	4.0°	4.0°	4.0°	4.5°	4.0°	3.5°	4.0°	3.5°
Central Mountains	3.5°	4.0°	4.0°	3.5°	4.0°	4.0°	4.0°	4.0°	4.5°	4.0°	3.5°	3.5°	4.0°
Yampa Valley	4.0°	4.0°	3.5°	3.5°	4.0°	4.0°	4.0°	4.5°	4.5°	4.0°	3.5°	3.5°	4.0°
Grand Valley	4.0°	3.5°	3.5°	3.5°	4.5°	4.0°	4.0°	4.5°	4.5°	4.0°	3.5°	4.0°	4.0°
Western San Juans	4.0°	4.0°	3.5°	3.5°	4.5°	4.0°	4.0°	4.5°	4.5°	4.0°	3.5°	3.5°	4.0°



Precipitation is a lot more complicated...



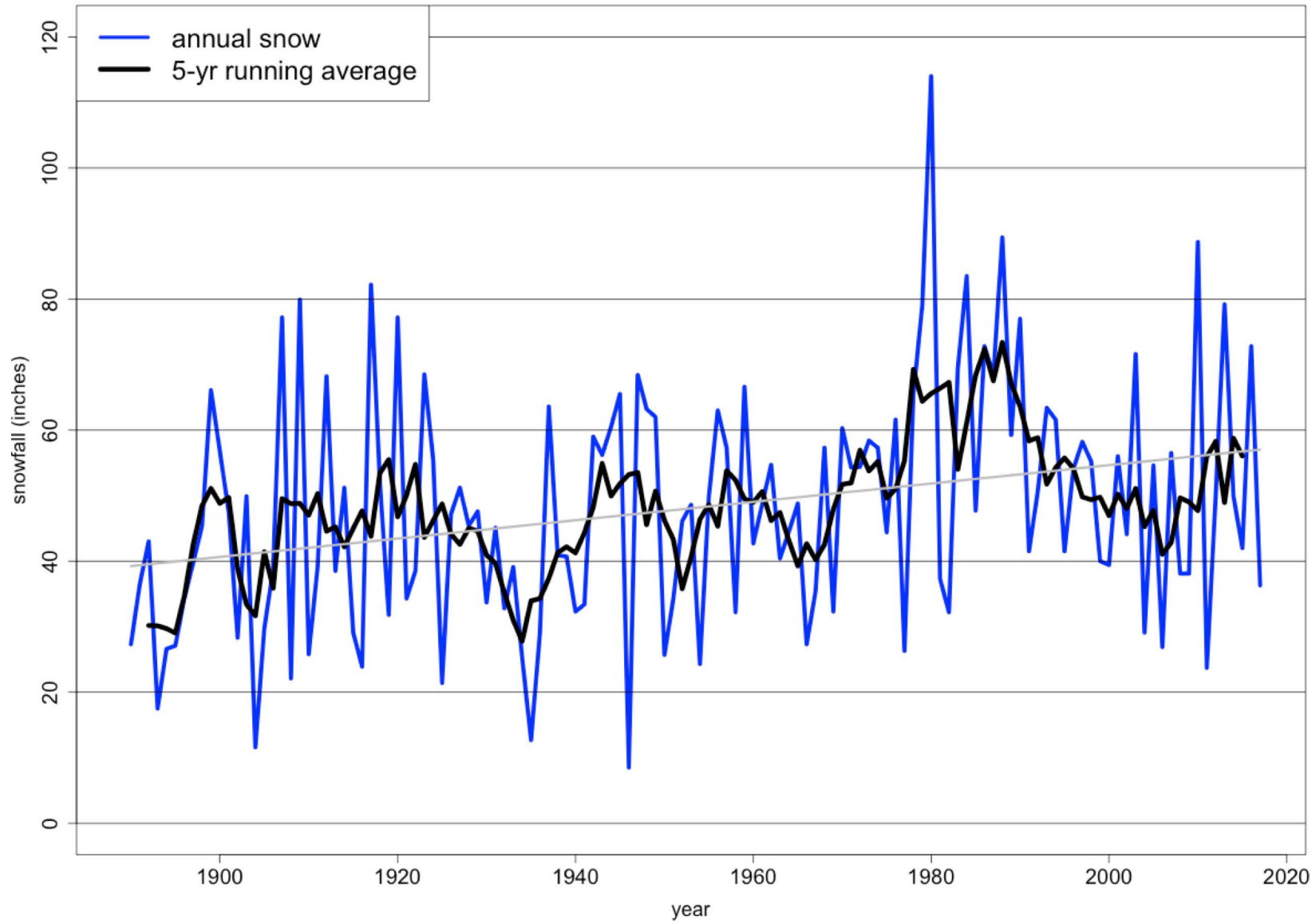
Fort Collins Annual Precipitation, 1889-2017



Mean: 15.1"
Std Dev: 4.0"
Wettest Year: 28.28" (1961)
Driest Year: 7.13" (1893)

Note: these averages are over the entire record, rather than the 30-year window used for official normals

Fort Collins Seasonal Snowfall, 1889-2017



Mean: 48.1"

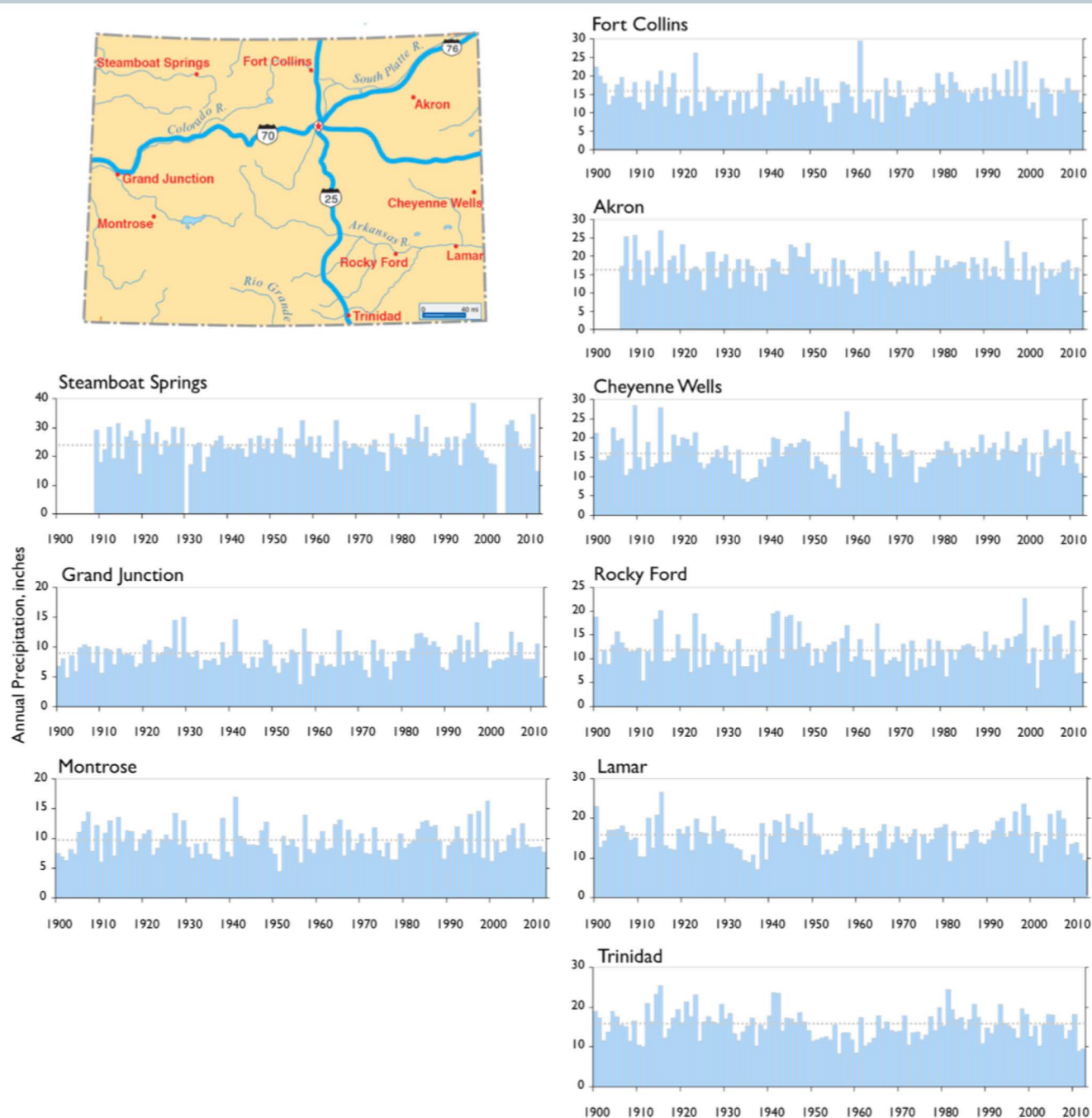
Std Dev: 18.3"

Record High: 114.0" (1979-80)

Record Low: 8.5" (1945-46)

FIGURE 2-6. Annual precipitation at nine long-term observing stations, 1900–2012

Trends around the state: precipitation

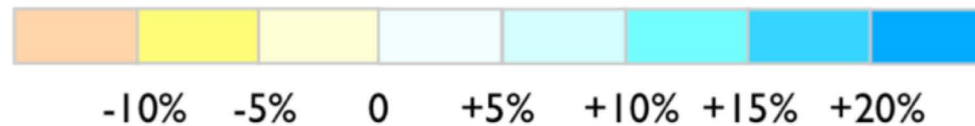


From “Climate Change in Colorado”
report, 2014:
[http://wwa.colorado.edu/climate/co
2014report/](http://wwa.colorado.edu/climate/co2014report/)

Precipitation is a lot more complicated...

TABLE 5-2. Projected monthly precipitation change for eight subregions under RCP 4.5 for 2035–2064

Subregion	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
Northeastern Plains	+15%	+15%	+15%	+5%	+5%	+5%	+10%	+10%	+10%	+10%	+15%	+15%	+10%
Denver Metro	+15%	+15%	+15%	+5%	+5%	+10%	+10%	+10%	+5%	+10%	+5%	+15%	+10%
Arkansas Valley	+15%	+15%	+10%	+5%	+5%	+10%	+10%	+10%	+10%	+10%	+10%	+15%	+10%
San Luis Valley	+5%	+15%	+15%	+5%	+10%	+10%	+10%	+10%	+10%	+5%	+15%	+5%	+5%
Central Mountains	+15%	+5%	+15%	+5%	+10%	+5%	+5%	+5%	+5%	+10%	+5%	+5%	+5%
Yampa Valley	+15%	+5%	+15%	+5%	+10%	+10%	+5%	+5%	+10%	+5%	+5%	+5%	+5%
Grand Valley	+5%	+5%	+5%	+5%	-5%	+10%	+5%	+5%	+5%	+5%	+10%	+5%	+5%
Western San Juans	+5%	+5%	+5%	+10%	-5%	+10%	+5%	+5%	+10%	+10%	+10%	+10%	+10%



From Lukas et al. (2014), *Climate Change in Colorado*



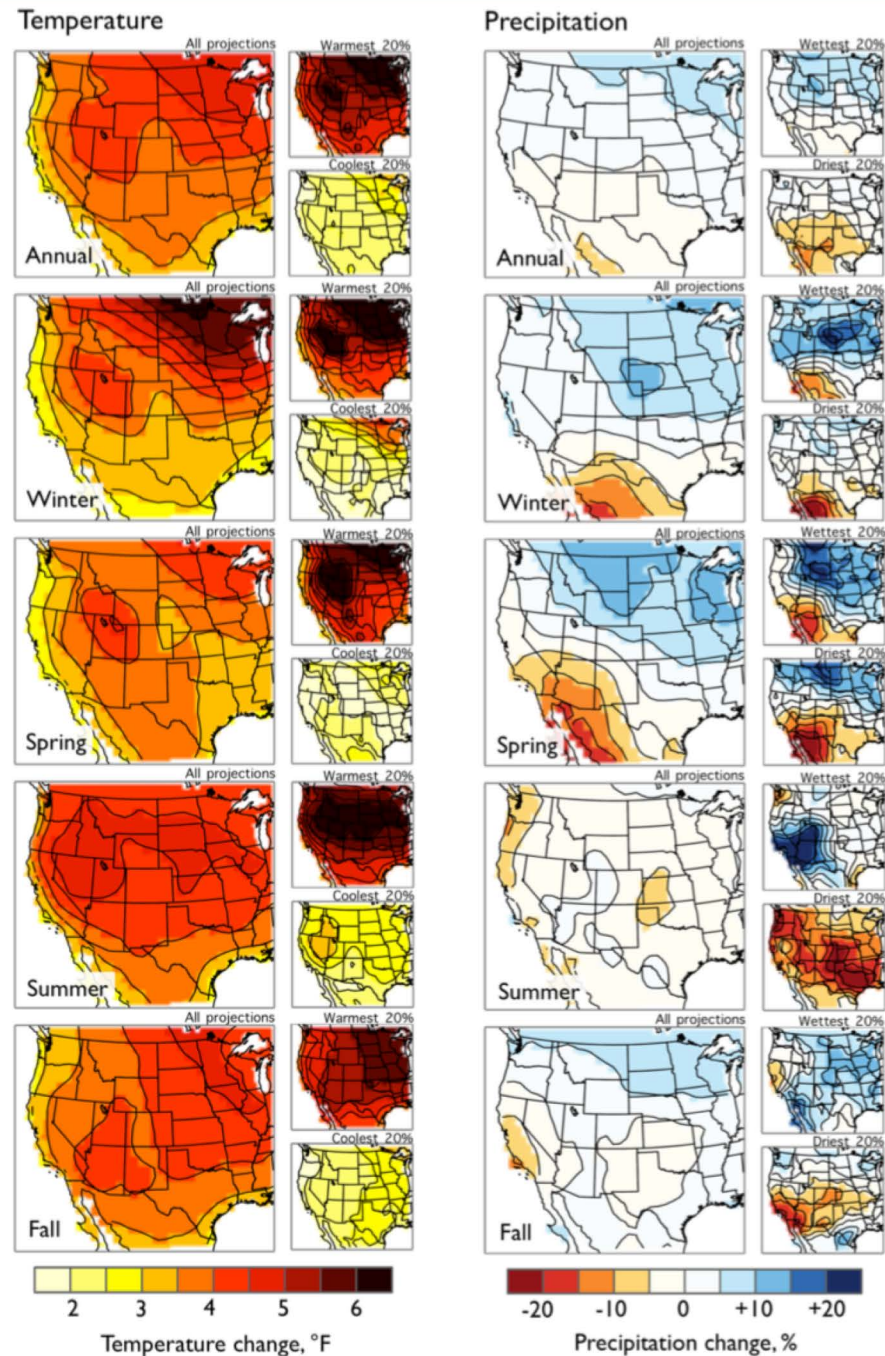
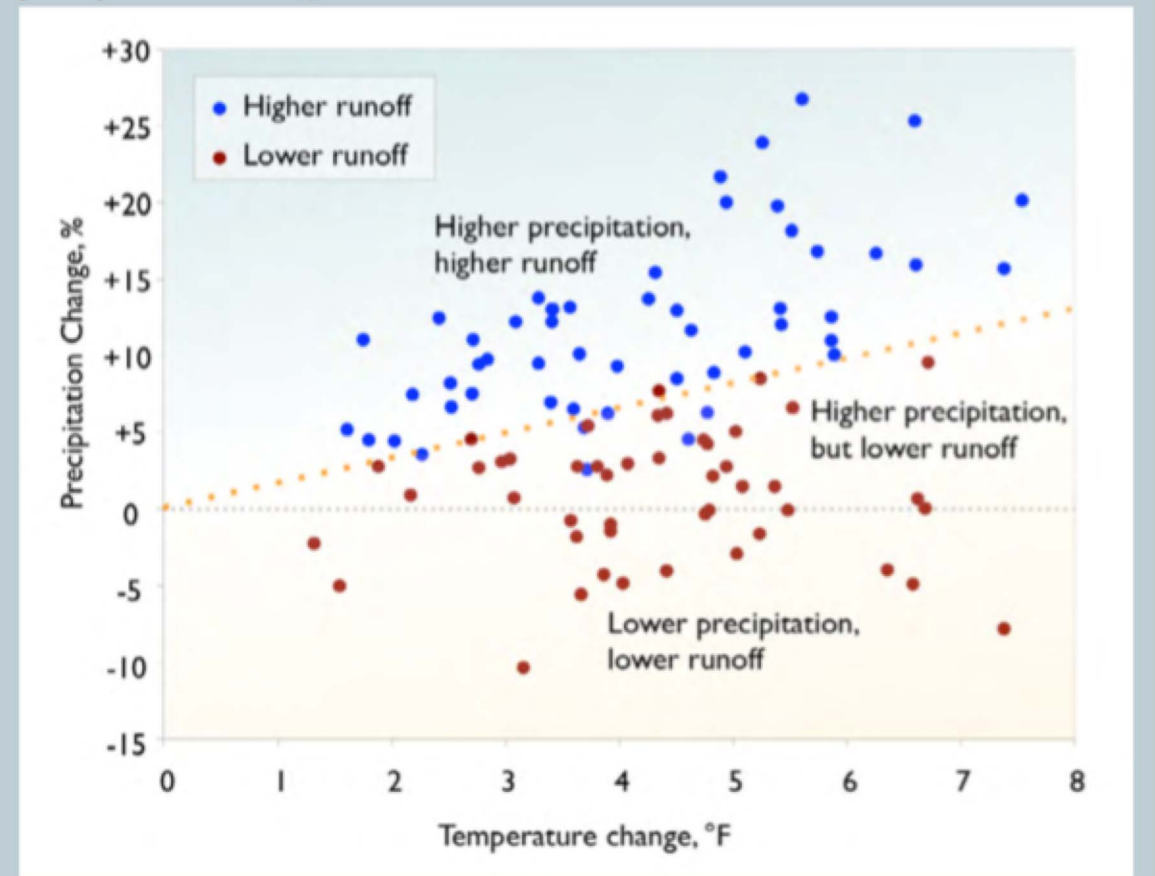


FIGURE 5-14. Direction of projected annual runoff change for the Colorado River as a function of projected temperature change and precipitation change

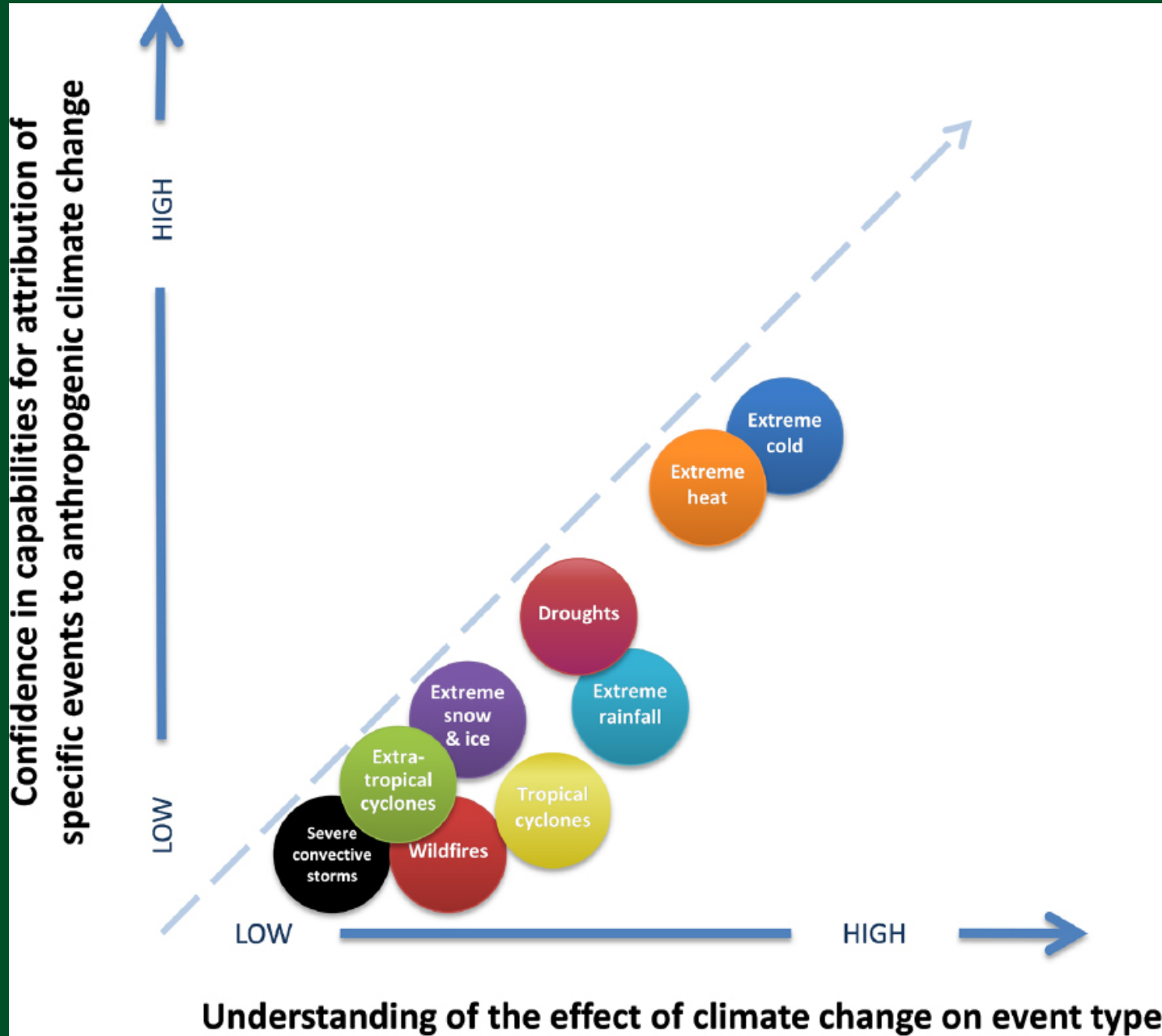


From Lukas et al. (2014), *Climate Change in Colorado*

Climate change is water change

- Remember that even if precipitation doesn't change (or increases slightly), higher temperatures...
- Cause more evaporation & evapotranspiration
 - Puts stress on plants requiring irrigation; can reduce reservoir levels
 - We have always had & will always have droughts in CO, but this could make them worse
- Can lead to earlier/faster spring snowmelt
 - Changes the expected time of water availability in rivers





What can be said about extreme events?

From National Academies Report, 2016, "Attribution of Extreme Weather Events in the context of Climate Change"

<https://www.nap.edu/catalog/21852/attribution-of-extreme-weather-events-in-the-context-of-climate-change>

Summary (1)

- We've seen warming in Colorado across all seasons, with the largest trend since about 1980
- No long-term trends have been detected for statewide precipitation
- Peak snowpack (SWE) does not show a long-term trend, but the timing of the peak has shifted earlier, owing to both higher temperatures and dust-on-snow
- Long-term warming is expected to continue (with high confidence); future changes in precipitation are much less certain
- For most types of extreme/hazardous weather, it remains challenging to establish a climate-change fingerprint, aside from decreased occurrence of very cold air
 - Some, like wildland fire, likely have been influenced by climate change, but challenging to separate from other influences



Summary (2)

- By 2050, the climate of Colorado will still be recognizable as the climate of Colorado:
 - Plenty of snow in the mountains most winters
 - Summers with warm days and (relatively) cool nights
 - Highly variable precipitation from year to year
 - Regular problems with droughts, floods, fires, water availability, and severe weather
- But:
 - The snowpack is likely to melt earlier in the spring
 - More frequent occurrence of warm weather, less frequent extreme cold
 - When droughts happen, they may be worse (mainly owing to increased evaporation) – increasing threats to water supply
 - Not clear what changes there will be to other hazards like extreme rainfall, severe weather, etc.



**And finally, the all-important question:
“Do you have a rain gauge?” (and a
snowboard!)**



A large, rounded mound of snow dominates the frame. The acronym 'COCORAHHS' is written in the snow in a simple, hand-drawn style. The letters are dark, likely from a marker or a stick. The background shows some dry grass and bare branches, suggesting a winter setting.

COCORAHHS

If you are interested in weather and the variations in precipitation, please join the Community Collaborative Rain, Hail and Snow Network

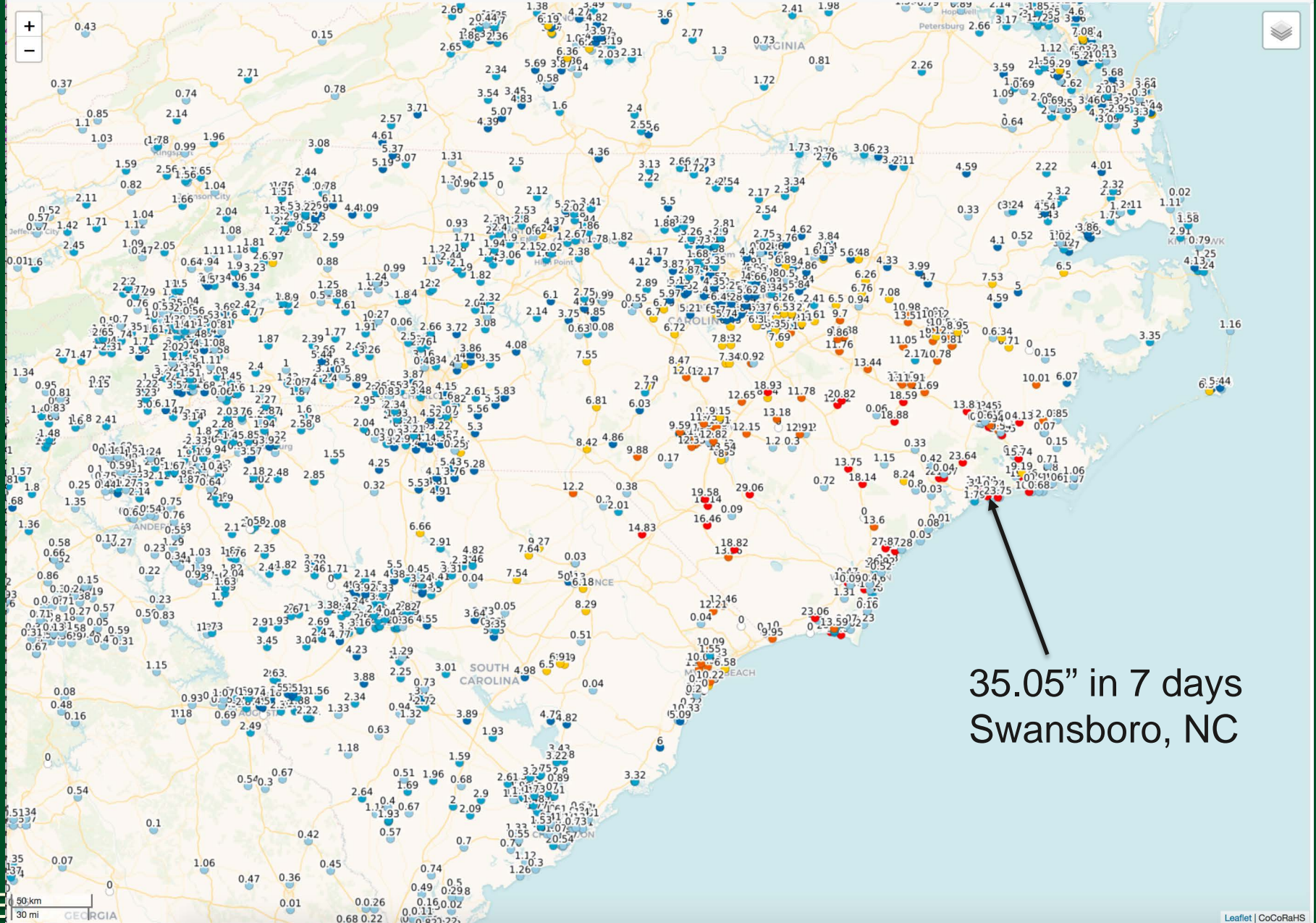
<http://www.cocorahhs.org>

or see me today

CoCoRaHS data in Hurricane Florence, September 2018

CoCoRaHS Mapping System
Accumulated Precipitation from 2018-09-09 to 2018-09-16 values in inches

● NA ○ Zero ○ Trace ○ 0.01 - 1.35 ● 1.36 - 3.54 ● 3.55 - 6.17 ● 6.18 - 9.42 ● 9.43 - 13.66 ● 13.67 - 35.05



35.05" in 7 days
Swansboro, NC

CoCoRaHS data in Hurricane Florence, September 2018

CoCoRaHS Mapping System
Accumulated Precipitation from 2018-09-09 to 2018-09-16 values in inches
● NA ○ Zero ○ Trace ● 0.01 - 1.35 ● 1.36 - 3.54 ● 3.55 - 6.17 ● 6.18 - 9.42 ● 9.43 - 13.66 ● 13.67 - 35.05

The Weather Channel
Show me the weather in... city, zip, or place FIND ME
85° Washington, DC 3

Next Article
Typhoon Mangkhut Slams Philippines, C

NEWS

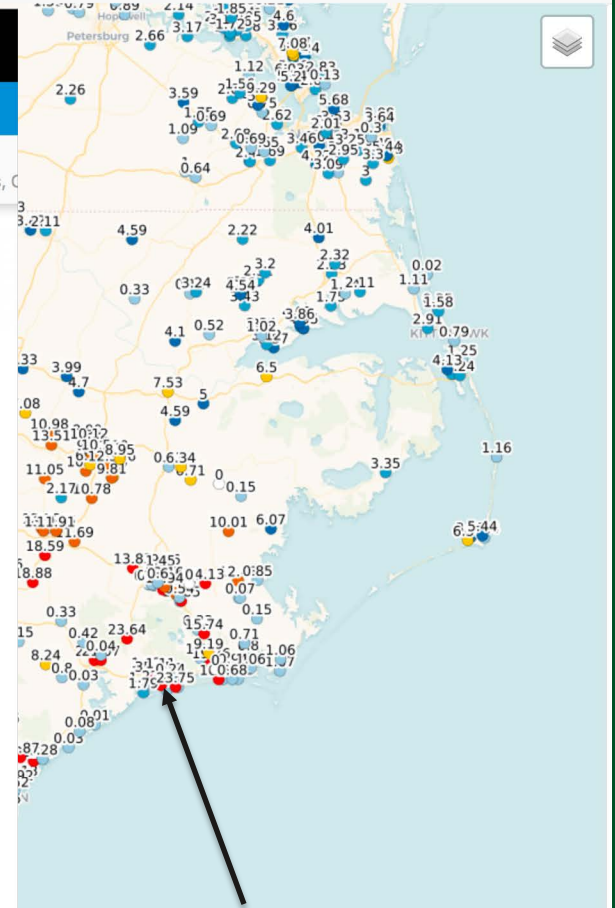
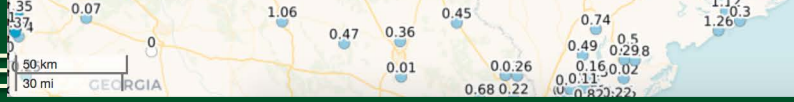
What It's Like to Measure 34 Inches of Rain in a Hurricane

By Bob Henson · September 18 2018 01:15 PM EDT · weather.com



01:09
NC Woman Measures 3 Feet of Rain from Florence
A woman in North Carolina measured exactly 34.00 inches total from Wednesday to Monday during Hurricane Florence.

At a Glance



35.05" in 7 days
Swansboro, NC

Thank you!

<http://climate.colostate.edu/>
russ.schumacher@colostate.edu

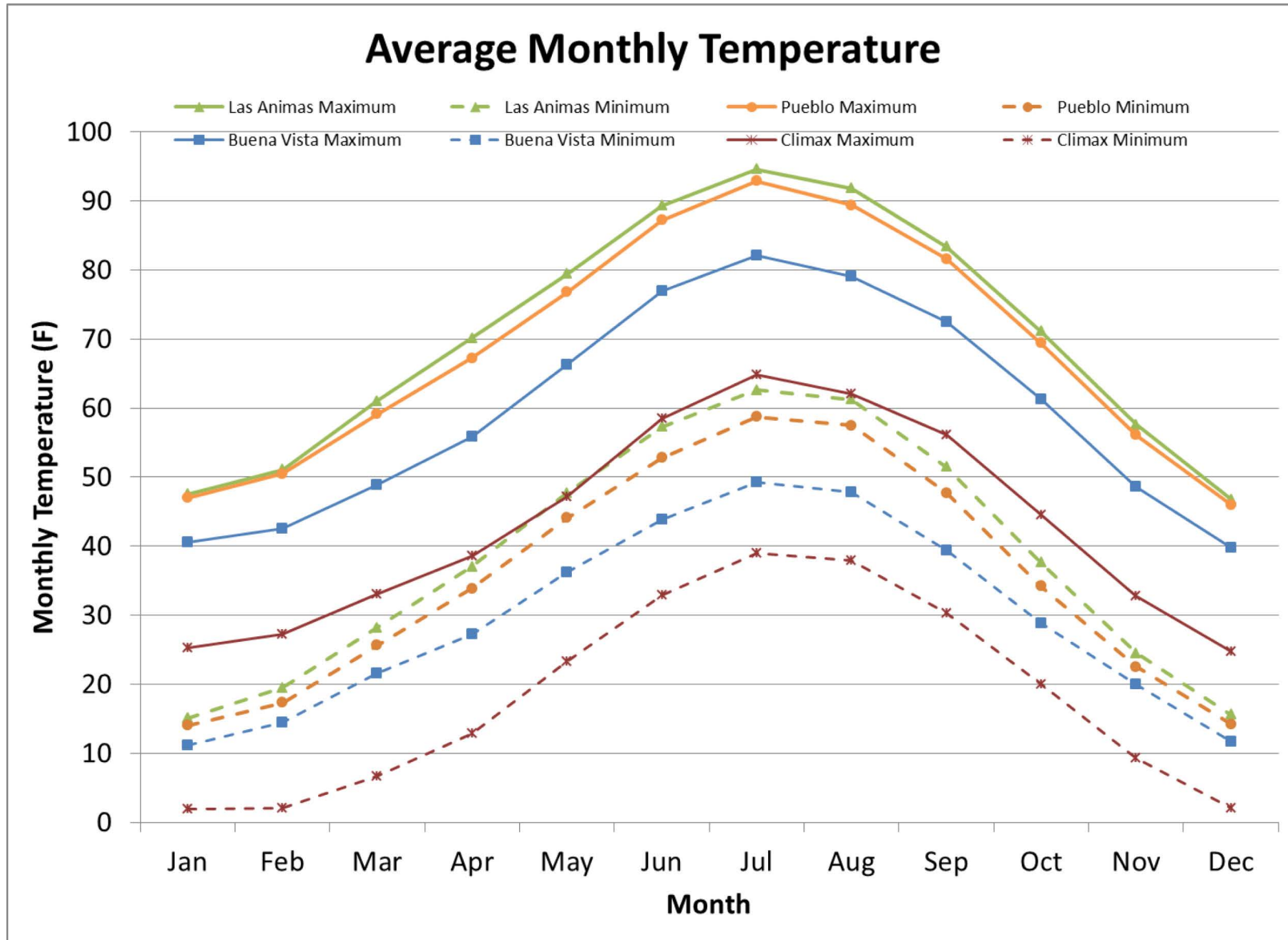
**Follow us on Facebook and
Twitter! @ColoradoClimate**



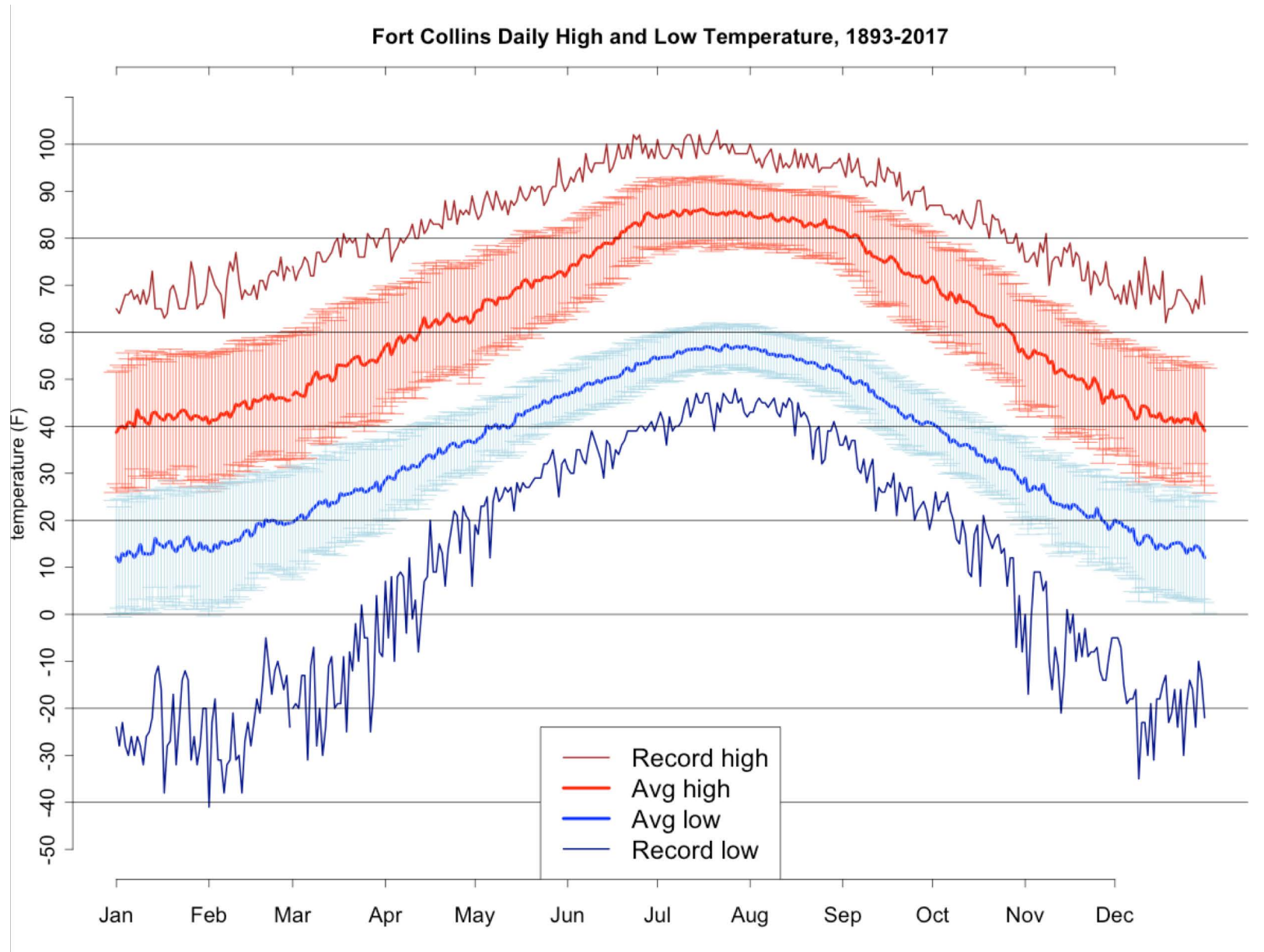
COLORADO CLIMATE CENTER

Providing information and expertise on Colorado's complex climate

The annual cycle of Colorado Temperatures



But this is how daily weather, over time, defines our climate



Seasonal Precipitation in Colorado varies greatly from place to place

Water Year Average Precipitation for Selected Stations
E-W transect along I-70

