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

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

COLORADO CLIMATE CENTER

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 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

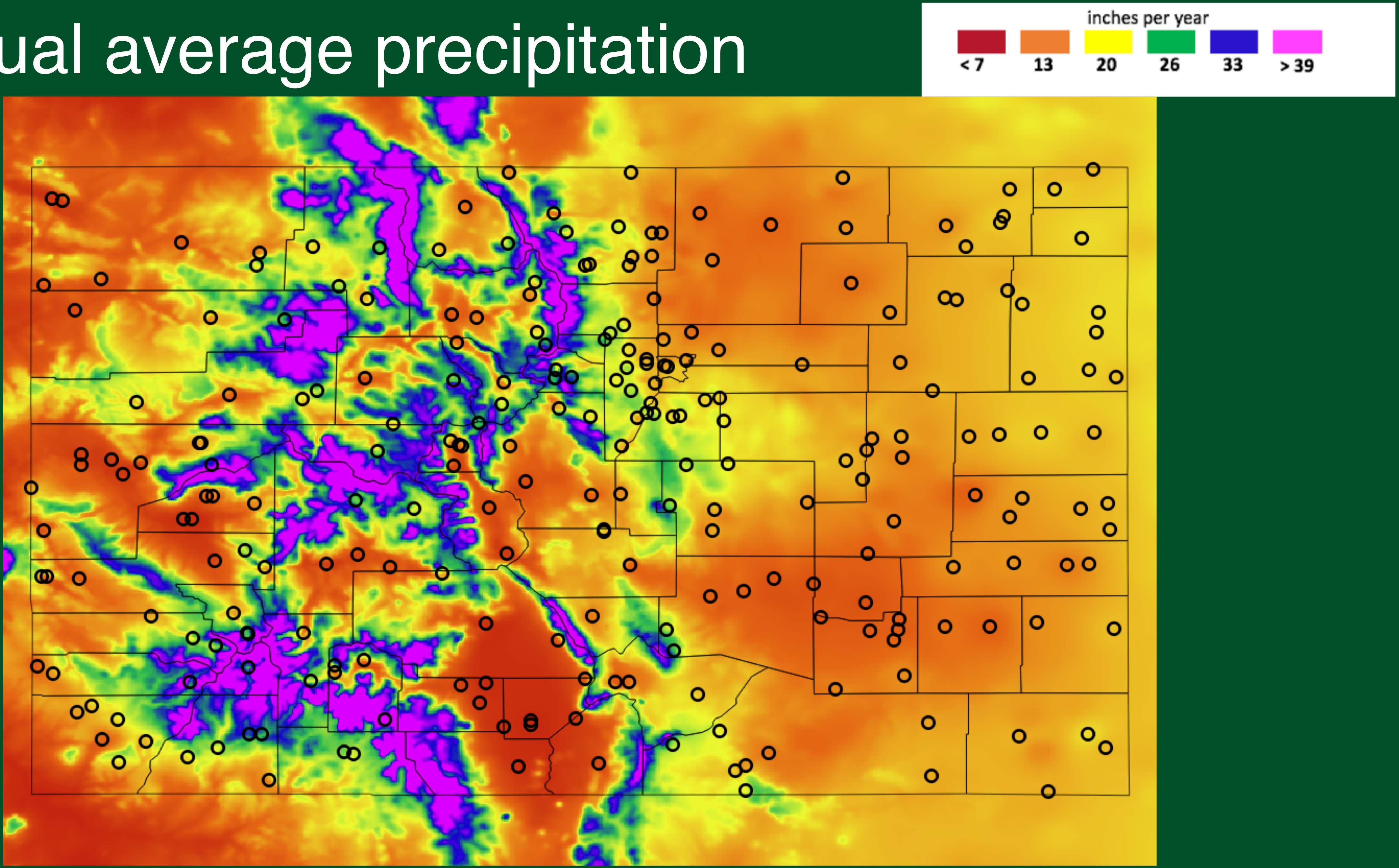
The Colorado Climate Center at CSU provides valuable climate expertise to the residents of the state through its threefold program of:

1) ***Climate Monitoring*** (data acquisition, analysis, and archiving)

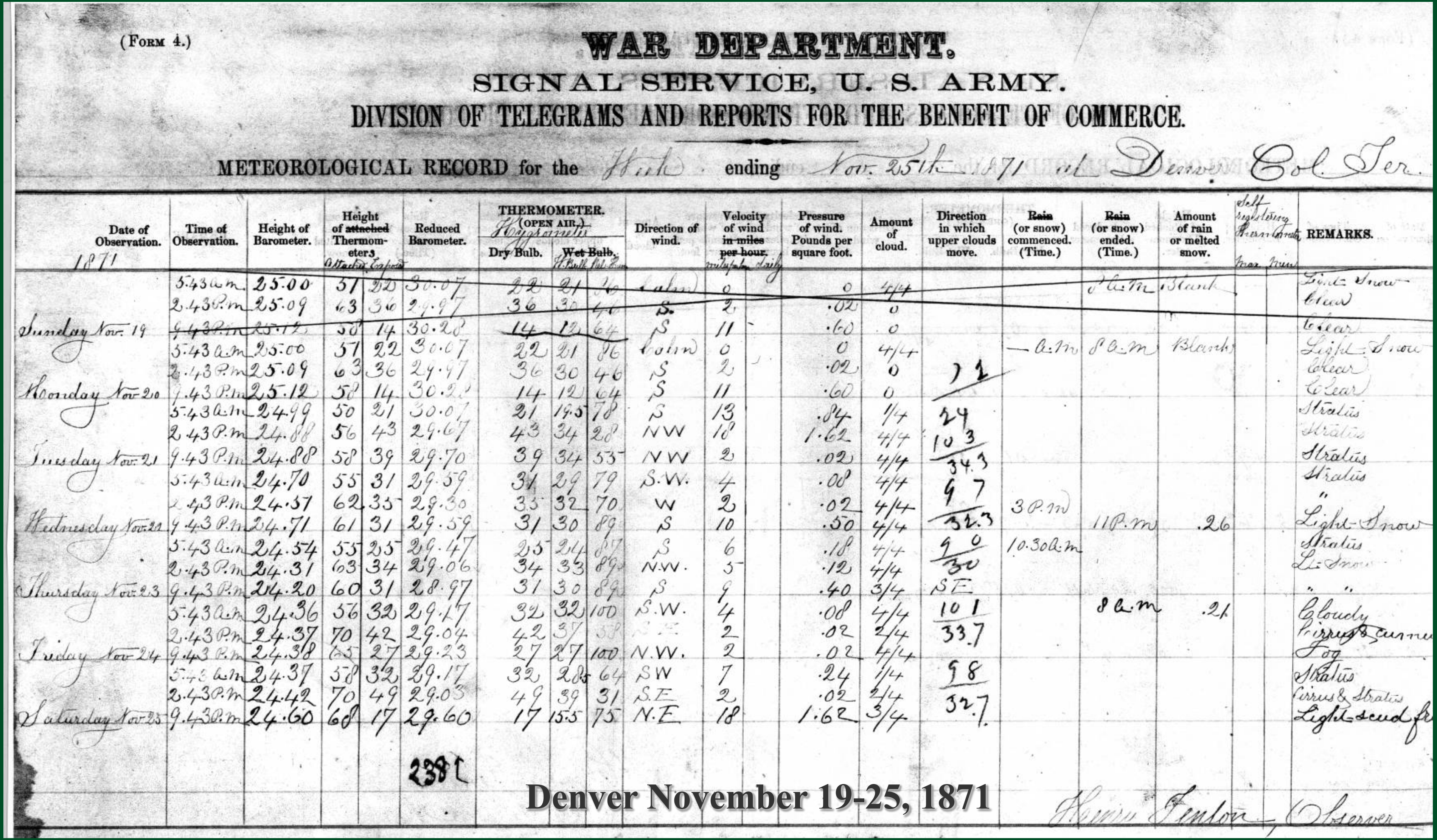
2) ***Climate Research***

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. 1871	Time of Observation.	Height of Barometer.	Height of ~~attached~~ Thermometers Attached	Exposed	Reduced Barometer.	Thermometer (open air.) Hygrometer Dry Bulb.	~~Wet Bulb.~~ W. Bulb	Rel. Hum.	Direction of wind.	Velocity of wind ~~in miles per hour.~~ mile/h	daily	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.	Self registering Thermometer Max	Min	REMARKS.
	~~5.43 a.m~~	~~25.00~~	~~57~~	~~22~~	~~30.07~~	~~22~~	~~21~~	~~86~~	~~Calm~~	~~0~~		~~0~~	~~4/4~~			~~8 a.m~~	~~Blank~~			~~Light Snow~~
	~~2.43 P.m~~	~~25.09~~	~~63~~	~~36~~	~~29.97~~	~~36~~	~~30~~	~~46~~	~~S.~~	~~2~~		~~.02~~	~~0~~							~~Clear~~
Sunday Nov. 19	~~9.43 P.m~~	~~25.12~~	~~58~~	~~14~~	~~30.28~~	~~14~~	~~12~~	~~64~~	~~S~~	~~11~~		~~.60~~	~~0~~							~~Clear~~
	5.43 a.m	25.00	57	22	30.07	22	21	86	Calm	0		0	4/4		— a.m	8 a.m	Blank			Light Snow
	2.43 P.m	25.09	63	36	29.97	36	30	46	S	2		.02	0	1 1						Clear
Monday Nov. 20	9.43 P.m	25.12	58	14	30.22	14	12	64	S	11		.60	0							Clear
	5.43 a.m	24.99	50	21	30.07	21	19.5	78	S	13		.84	1/4	24						Stratus
	2.43 P.m	24.88	56	43	29.67	43	34	28	NW	18		1.62	4/4	10 3						Stratus
Tuesday Nov. 21	9.43 P.m	24.88	58	39	29.70	39	34	55	NW	2		.02	4/4	34.3						Stratus
	5.43 a.m	24.70	55	31	29.59	31	29	79	S.W.	4		.08	4/4	9 7						Stratus
	2.43 P.m	24.37	62	35	29.30	35	32	70	W	2		.02	4/4		3 P.m					"
Wednesday Nov. 22	9.43 P.m	24.71	61	31	29.59	31	30	89	S	10		.50	4/4	32.3		11 P.m	.26			Light Snow
	5.43 a.m	24.54	55	25	29.47	25	24	87	S	6		.18	4/4	9 0	10.30 a.m					Stratus
	2.43 P.m	24.31	63	34	29.06	34	33	89	N.W.	5		.12	4/4	30						Lt. Snow
Thursday Nov. 23	9.43 P.m	24.20	60	31	28.97	31	30	89	S	9		.40	3/4	SE						" "
	5.43 a.m	24.36	56	32	29.17	32	32	100	S.W.	4		.08	4/4	10 1		8 a.m	.21			Cloudy
	2.43 P.m	24.37	70	42	29.04	42	37	58	S.E.	2		.02	2/4	33.7						Cirrus & Cumu
Friday Nov. 24	9.43 P.m	24.38	65	27	29.23	27	27	100	N.W.	2		.02	4/4							Fog
	5.43 a.m	24.37	58	32	29.17	32	28.5	64	SW	7		.24	1/4	9 8						Stratus
	2.43 P.m	24.42	70	49	29.03	49	39	31	S.E	2		.02	2/4							Cirrus & Stratus
Saturday Nov. 25	9.43 P.m	24.60	68	17	29.60	17	15.5	75	N.E	18		1.62	3/4	32.7						Light scud fr

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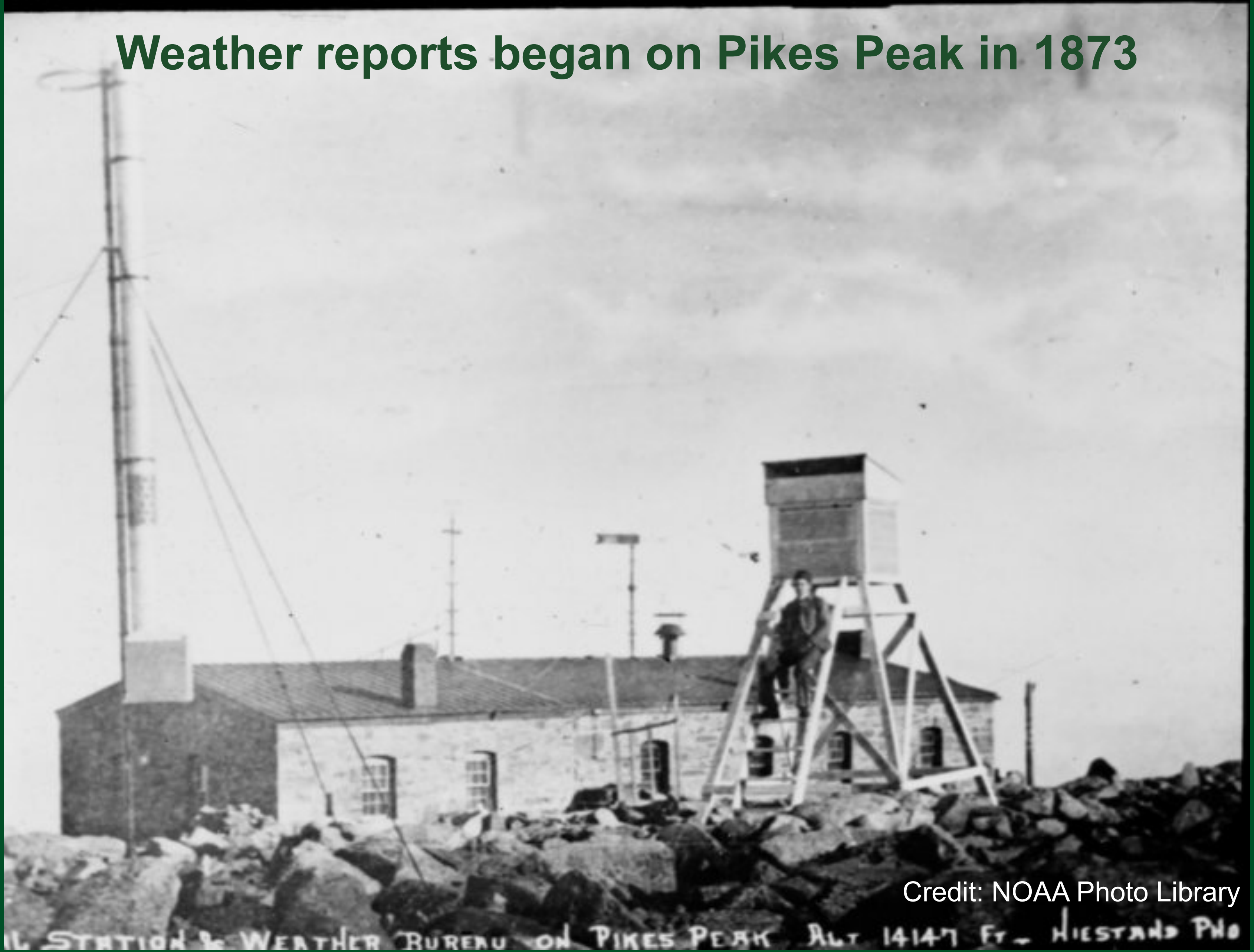
Henry Fenlon, Observer

Denver November 19-25, 1871

Weather reports began on Pikes Peak in 1873



Credit: NOAA Photo Library

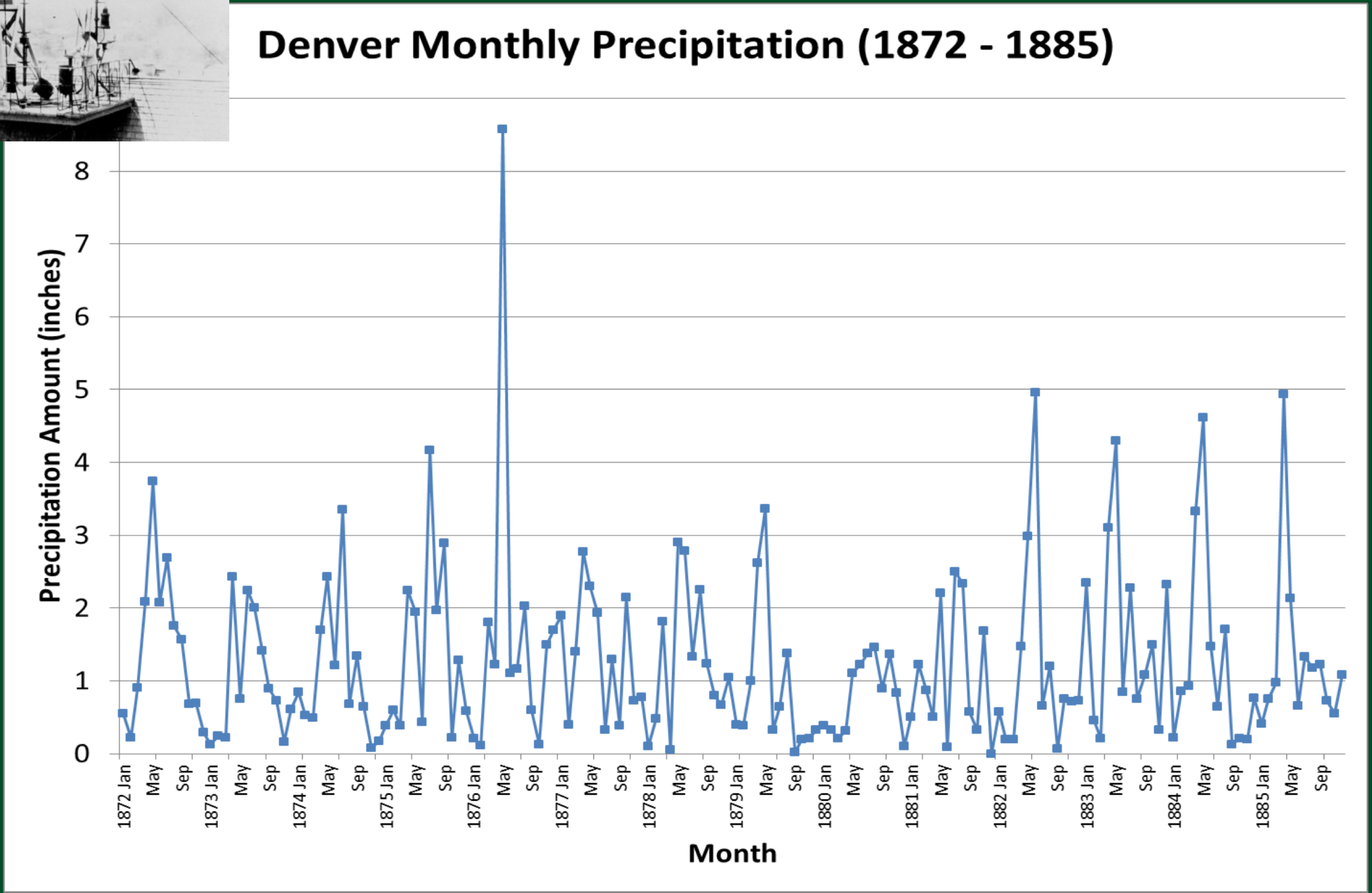
Reports were sent by telegraph every few hours

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..



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

PUBLISHED BY THE EXPERIMENT STATION
FORT COLLINS, COLORADO
1918

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.

YEARS OF STUDY SHOWS CLIMATE NOT CHANGING

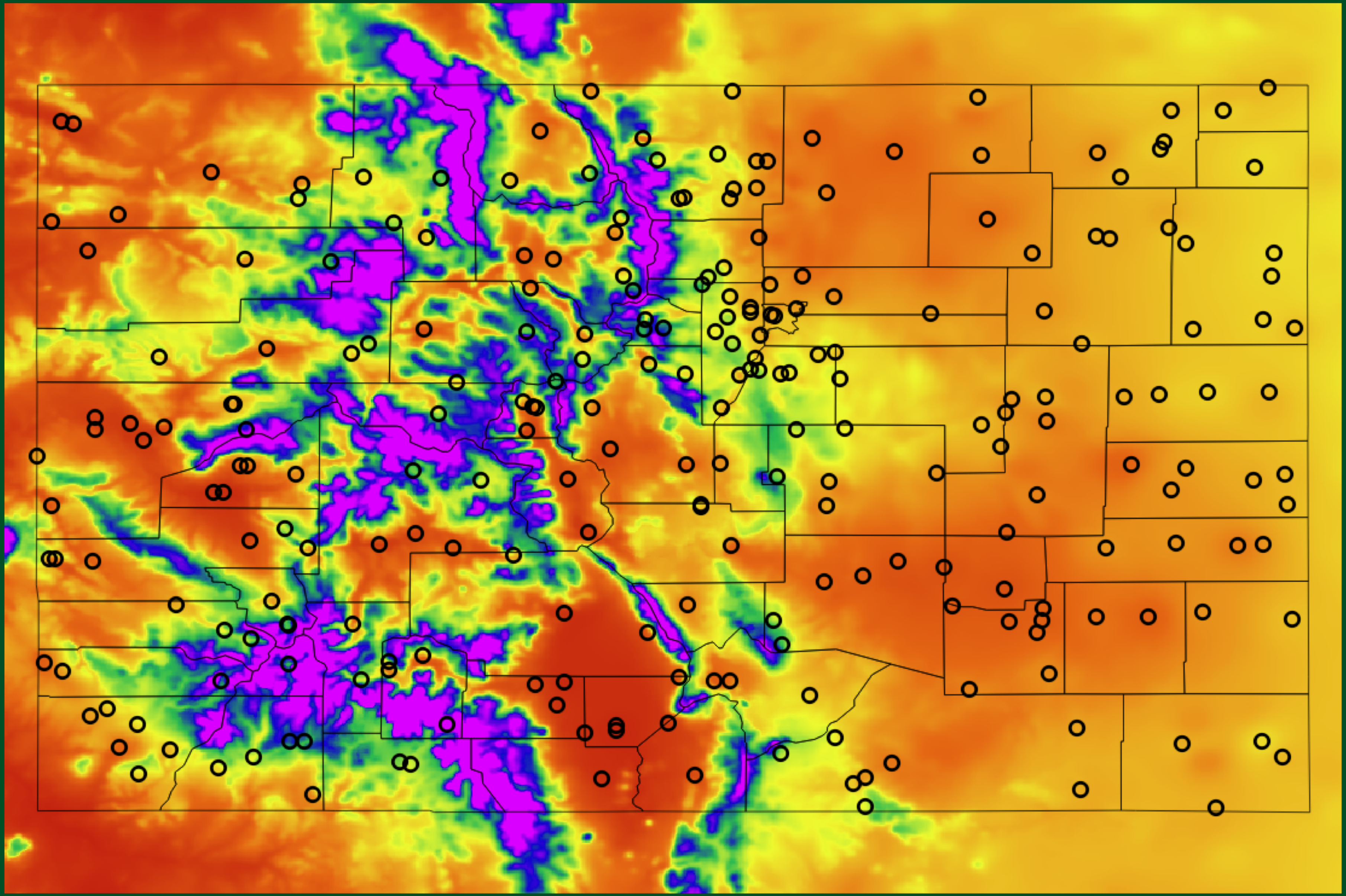
We often hear the statement made that the climate is changing, and the popular belief that such is the case can only be explained by the generally short and defective memories of people who through exposure to a few severe storms in the past, or inconvenience, or perhaps loss from a few of them, unintentionally 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

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

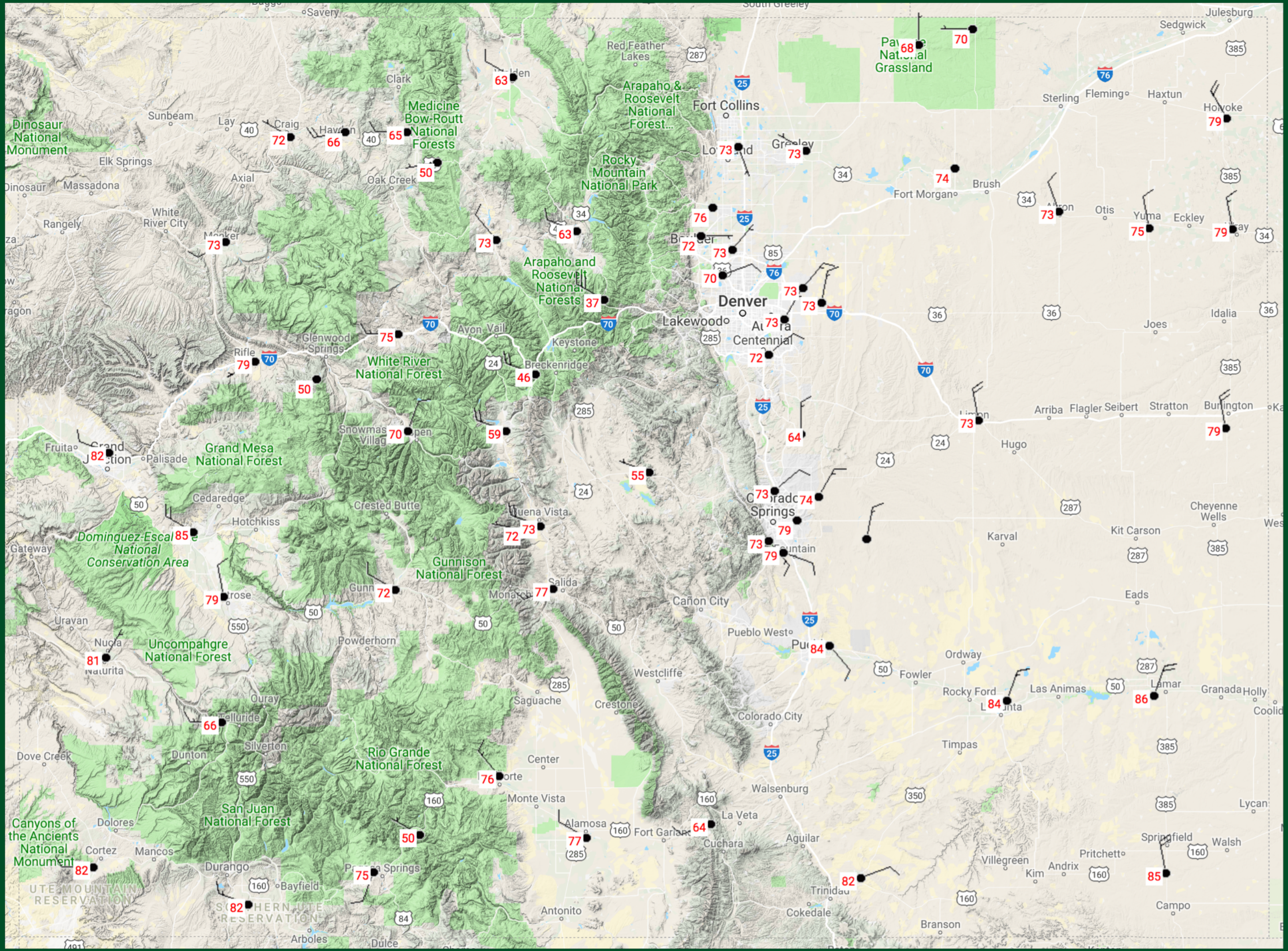
Let’s first look at where we get our data...

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

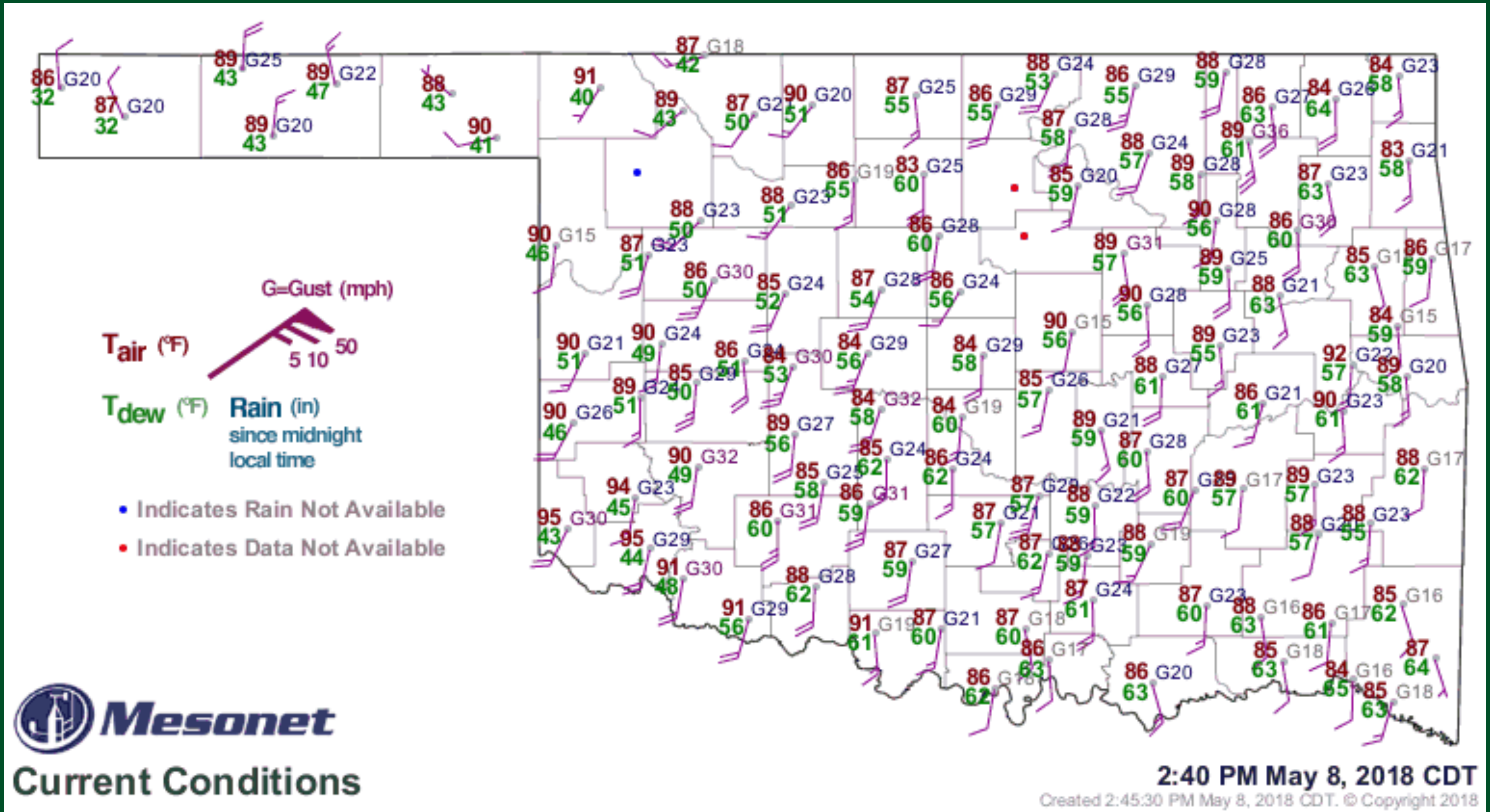


Map showing NWS stations (from mesowest.utah.edu)

Photo of an ASOS station

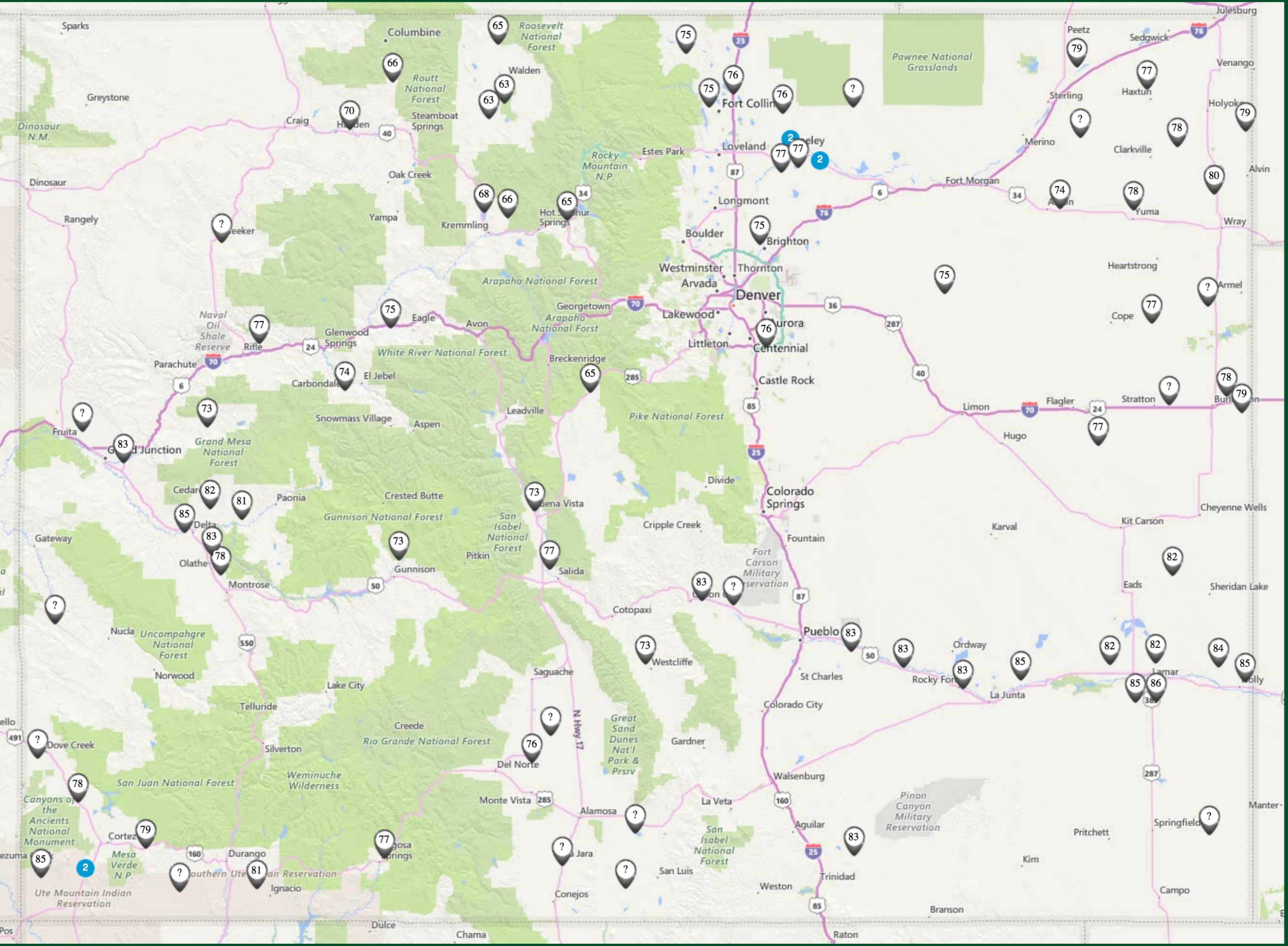
"Mesonets"

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



COLORADO
CLIMATE
CENTER

CoAgMET



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

coagmet.colostate.edu

COLORADO
CLIMATE
CENTER

CoAgMET

- ❑ 85 stations
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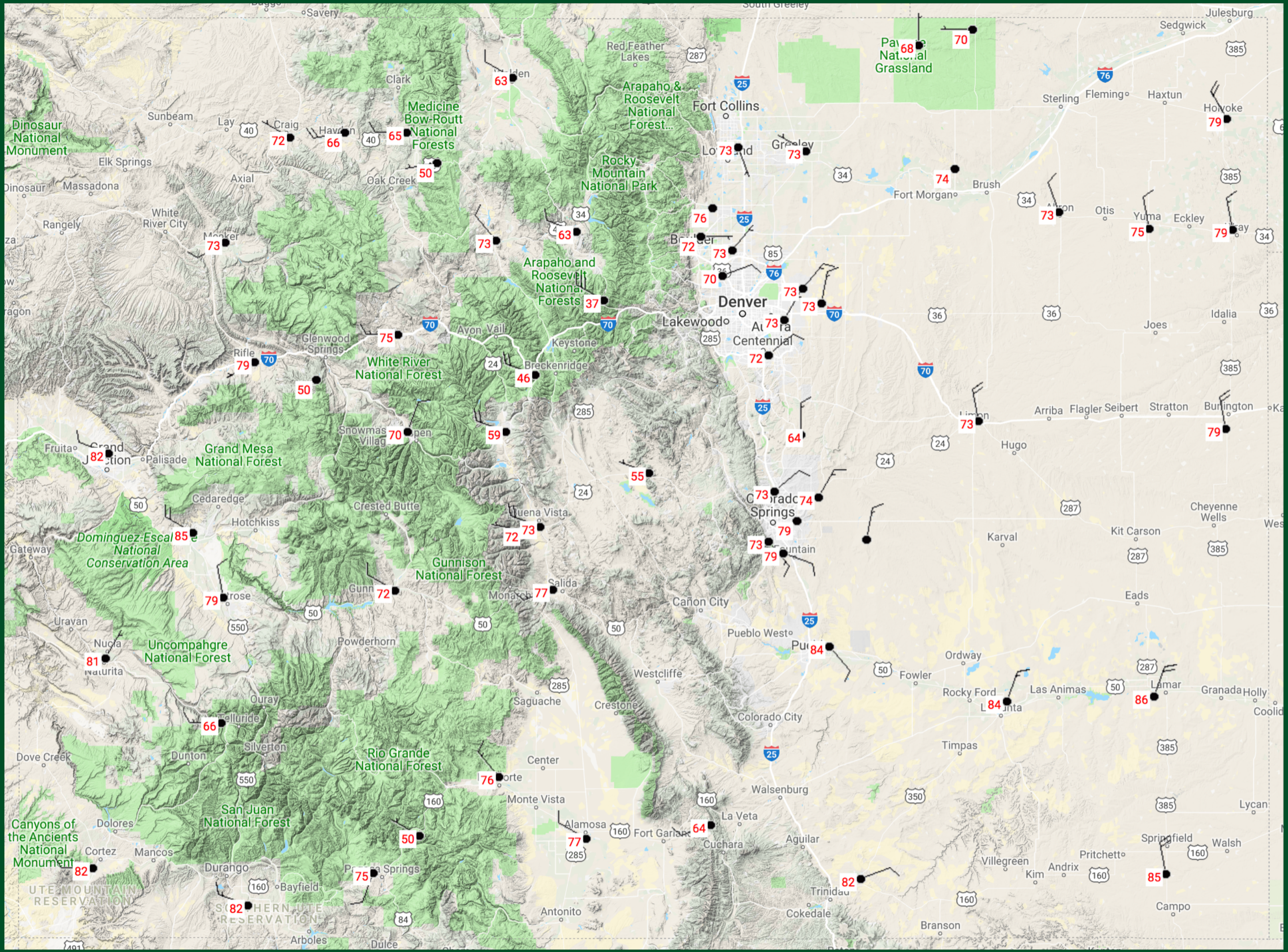
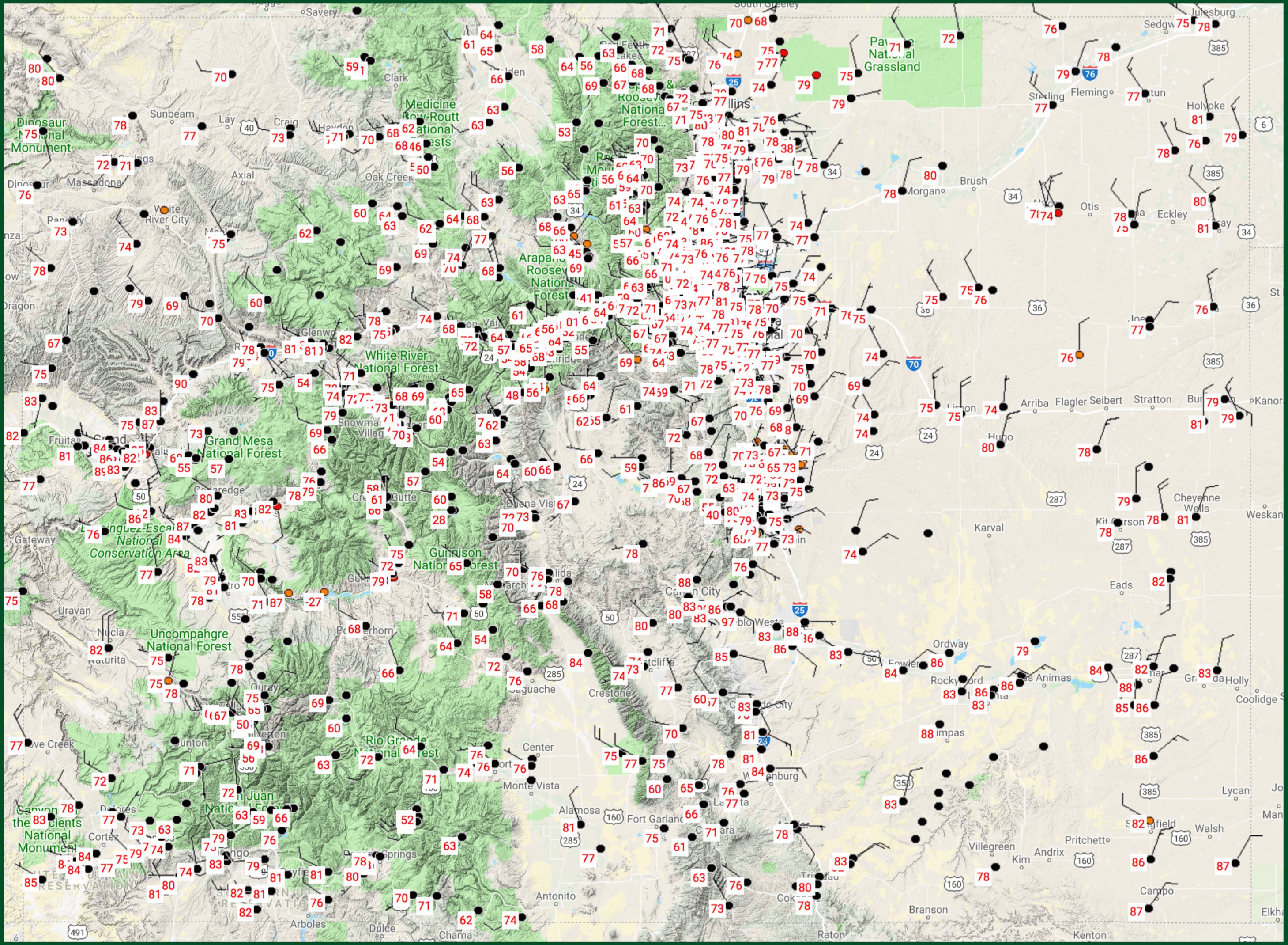
coagmet.colostate.edu

National Weather Service automated stations



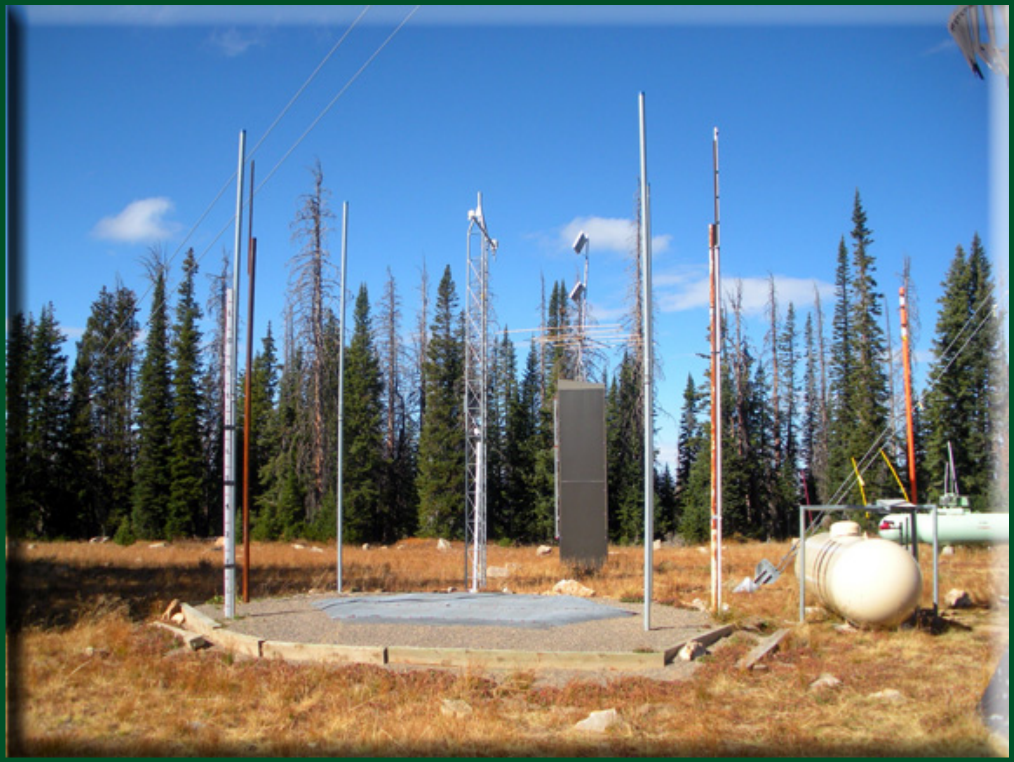
Map showing NWS stations (from mesowest.utah.edu)

NWS stations + CoAgMET + other networks

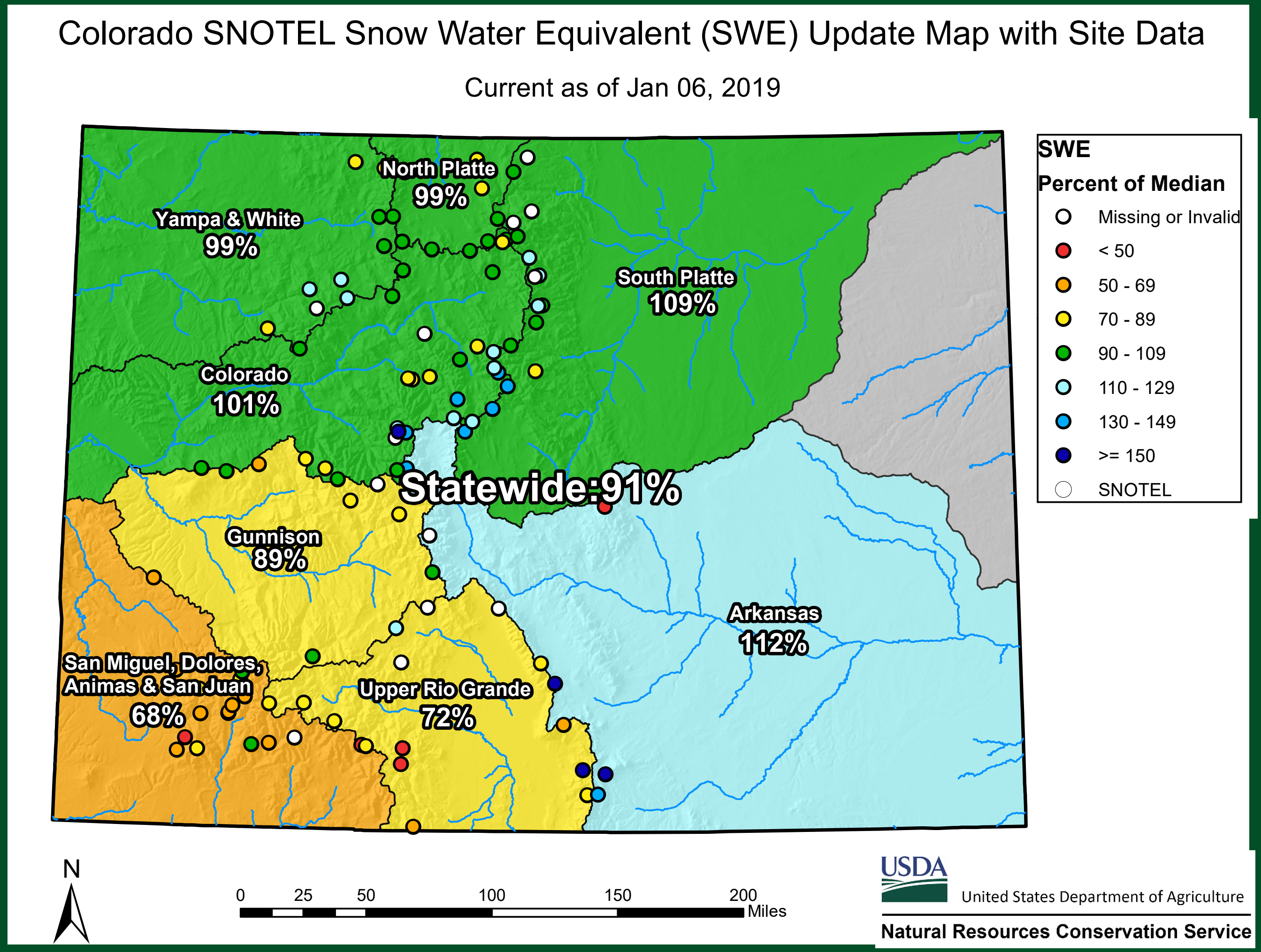


(from mesowest.utah.edu)

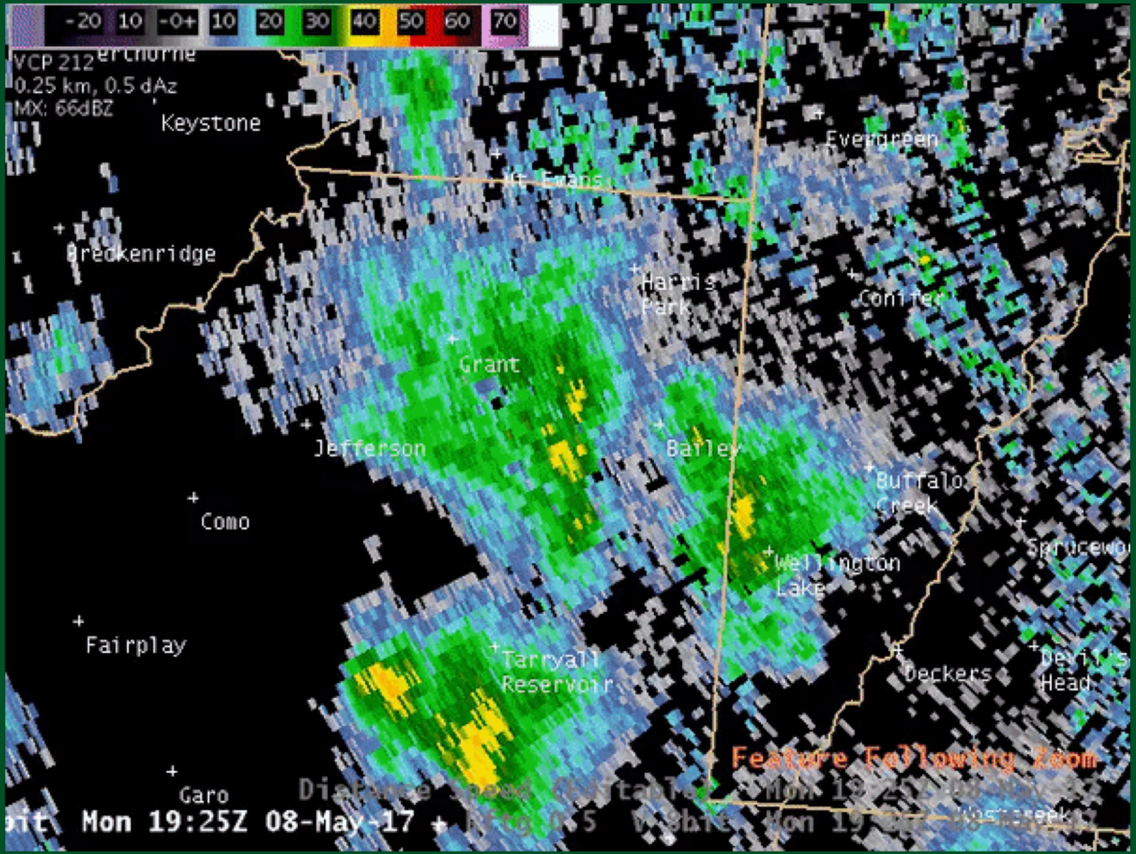
SNOTEL (Snow telemetry)



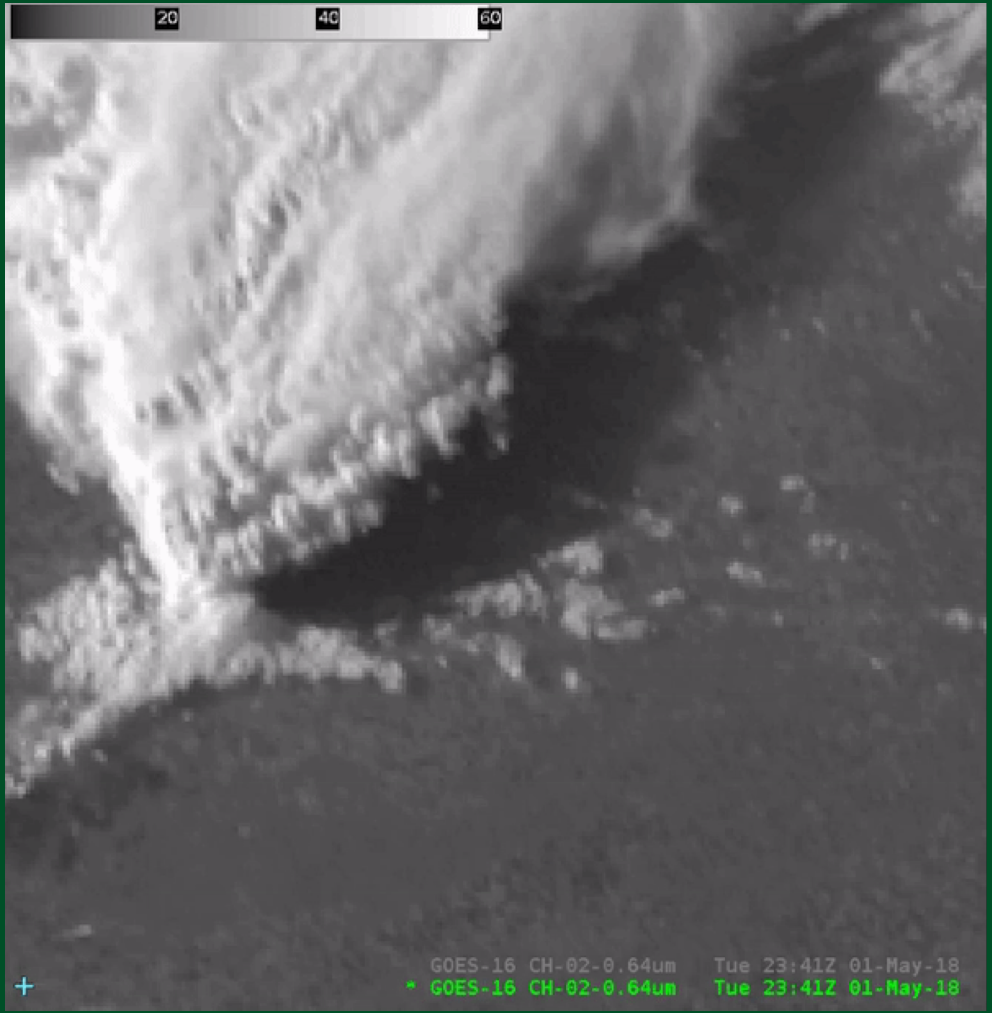
Tower SNOTEL site (10,500 ft, near Steamboat)
https://www.wcc.nrcs.usda.gov/siteimages/825.jpg



Remote sensing: radar and satellite

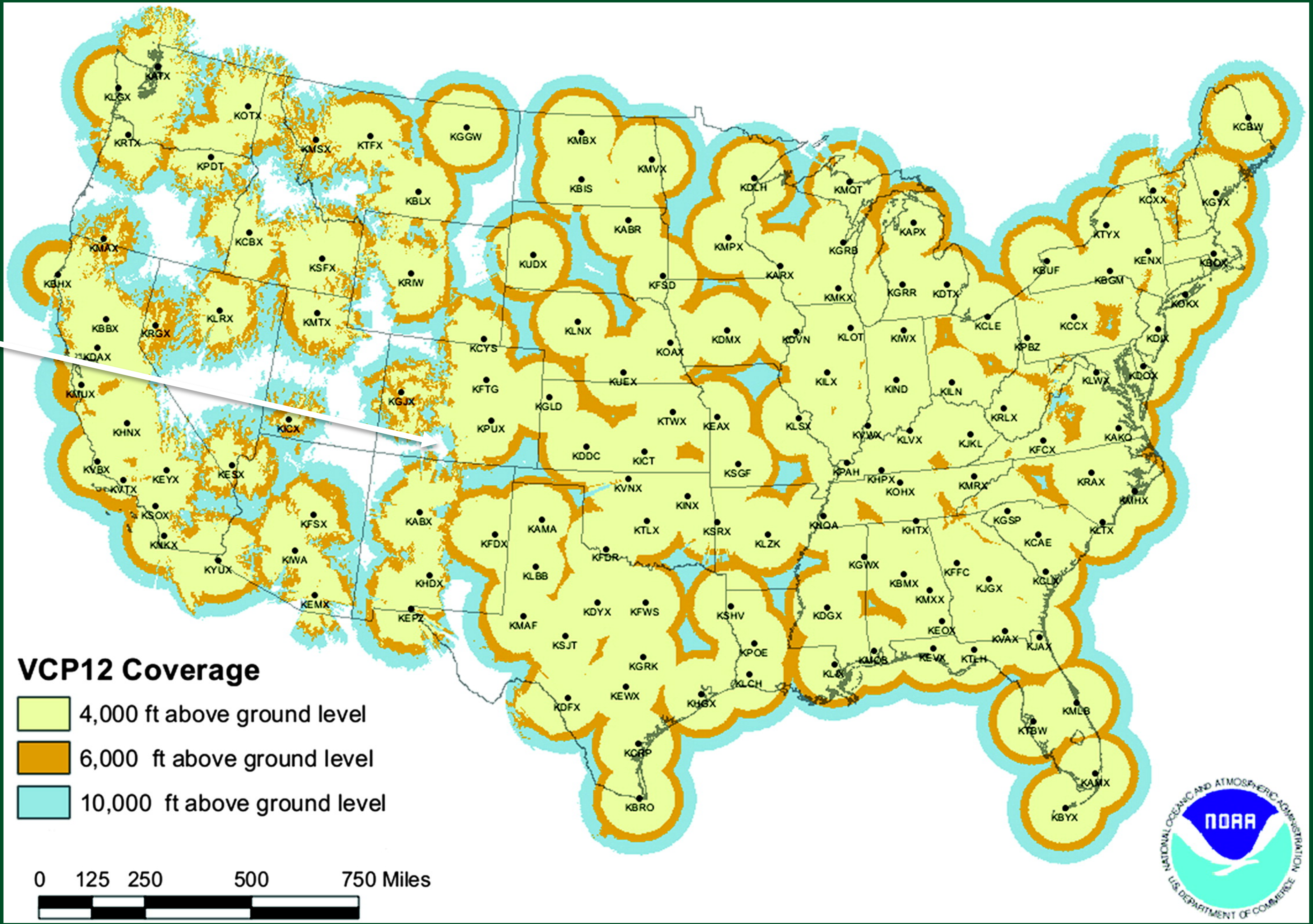


8 May 2017 hailstorm
https://twitter.com/NWSBoulder/status/993937075920625665



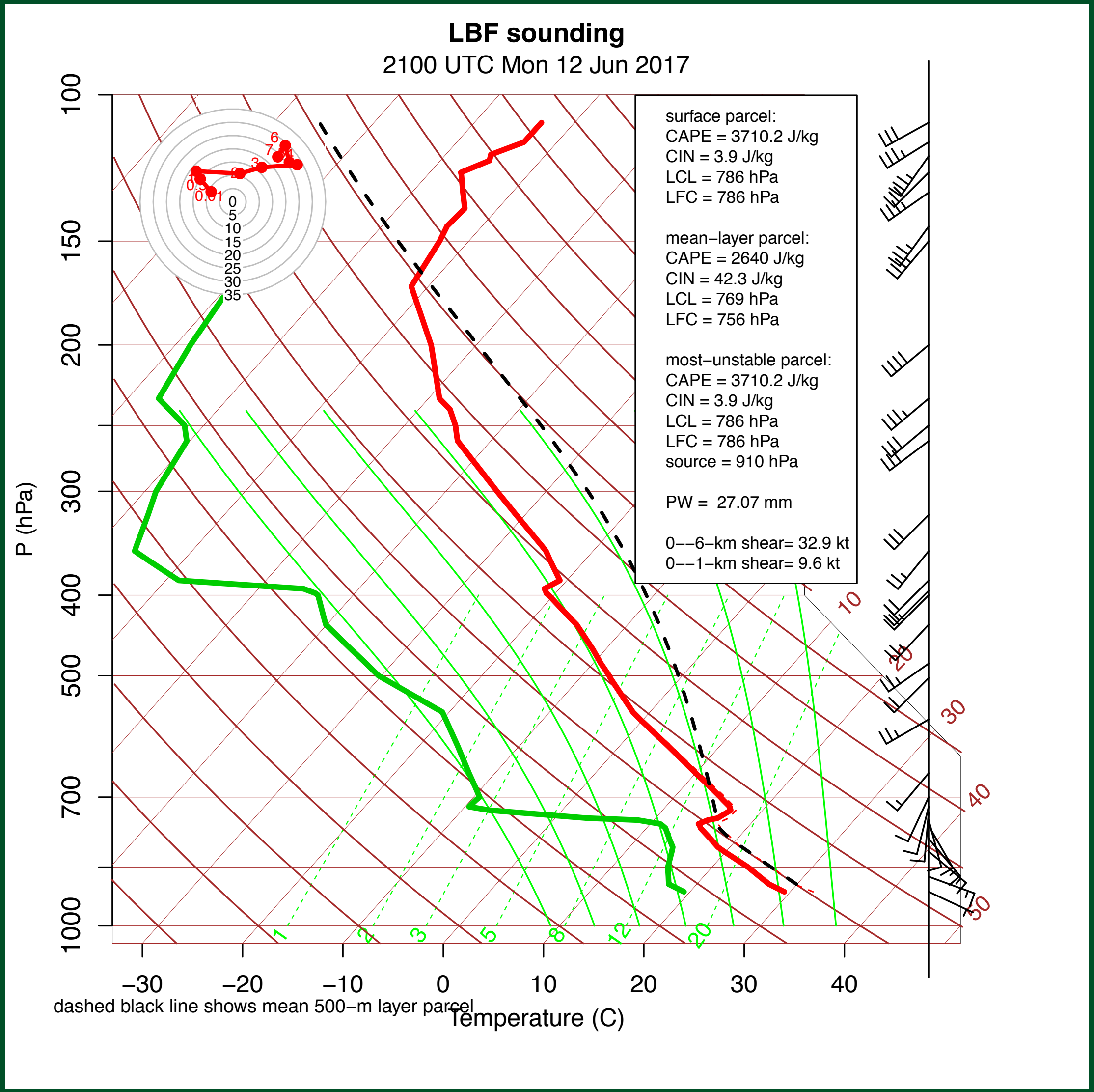
1 May 2018 storm in eastern Colorado
https://twitter.com/bill_line/status/991486848370466816

Mountains cause beam blockage for radars



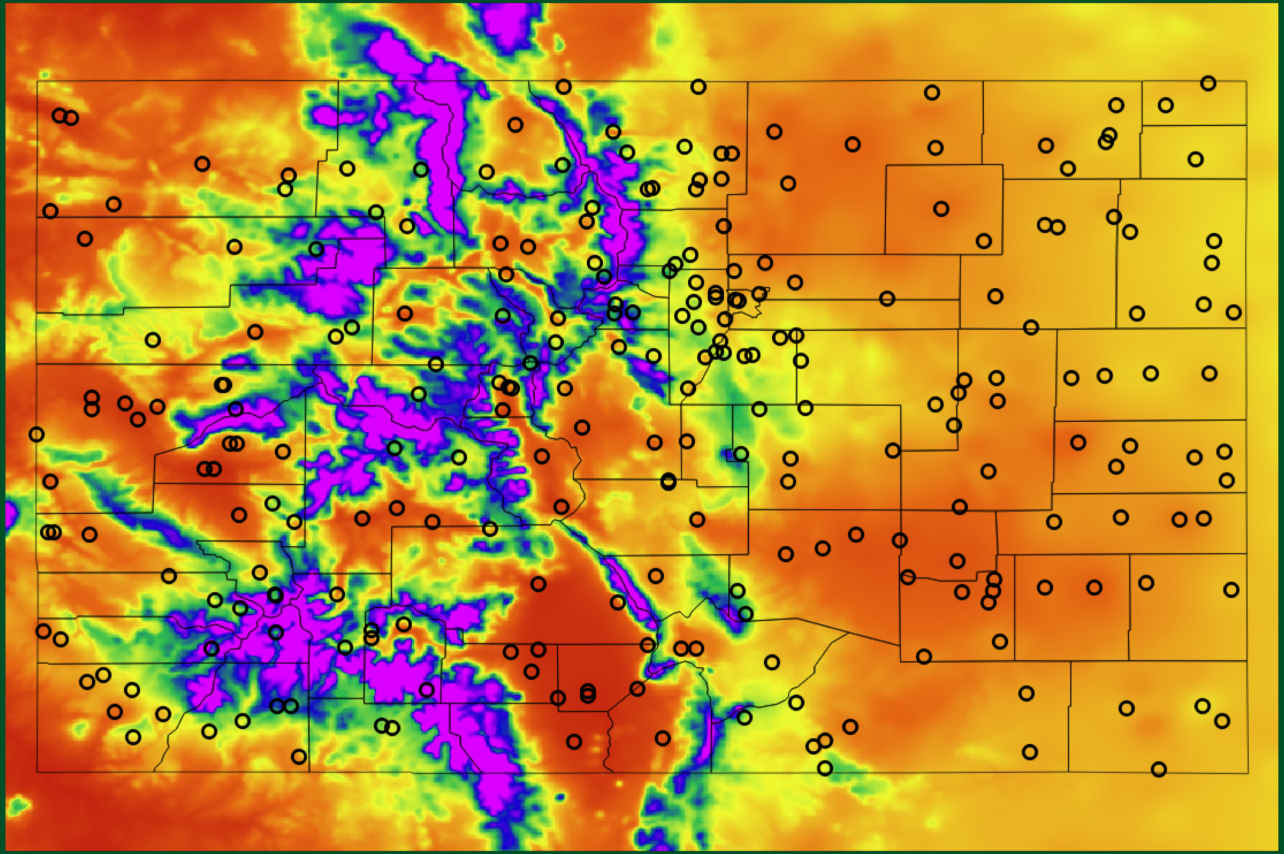
Upper-air data

Weather balloon launch during the PECAN field campaign, June 2015

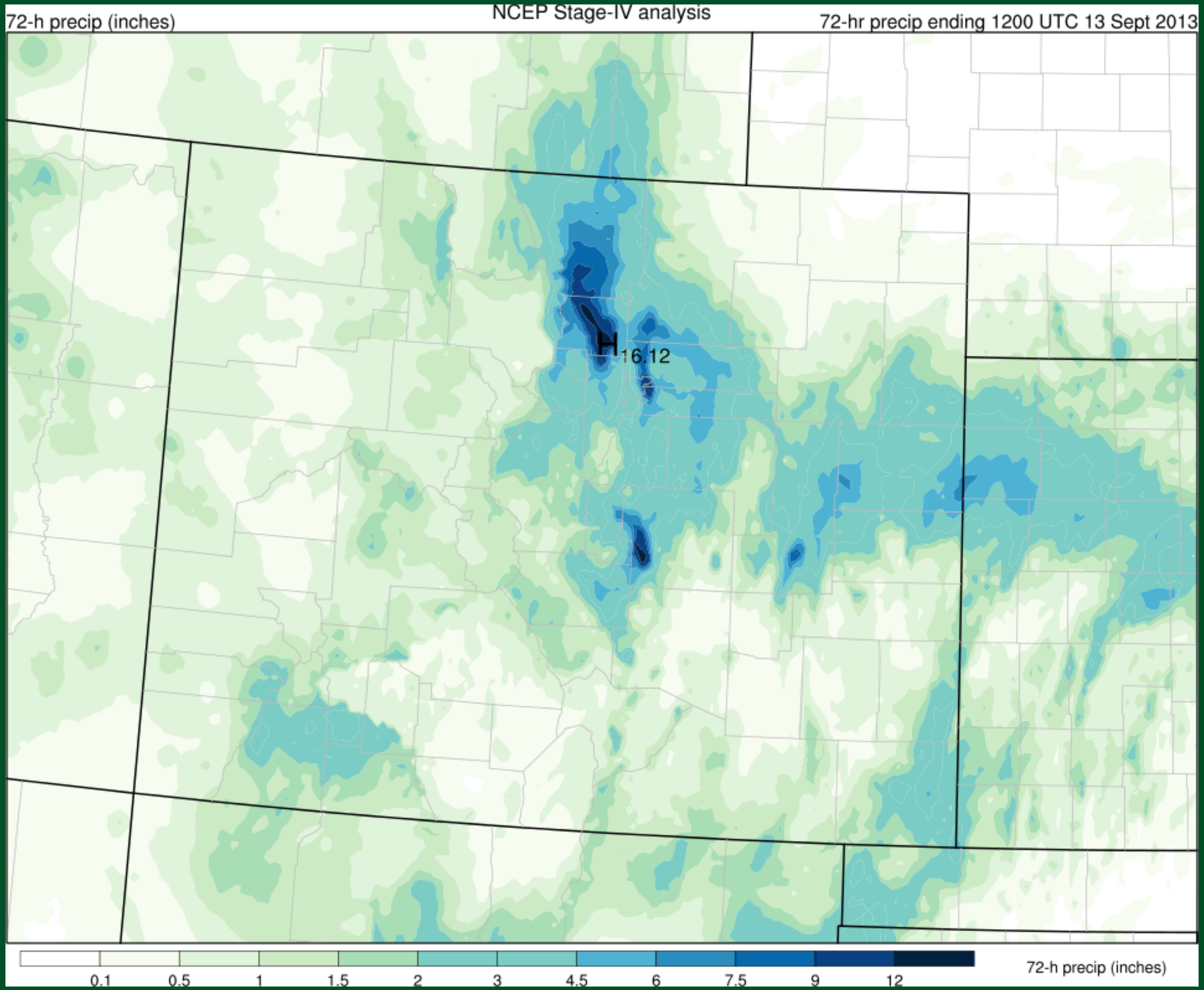


Skew*T* log *p* thermodynamic diagram

Putting them all together...



PRISM technique, prism.oregonstate.edu



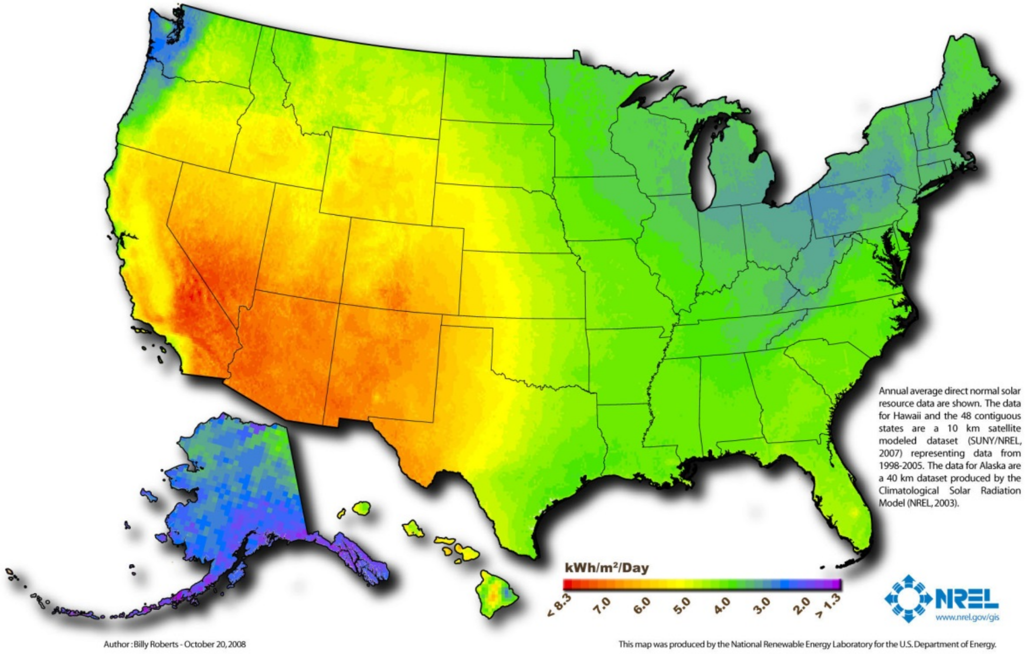
NOAA multi-sensor precipitation analysis (radars + gauges)
(3 days ending 13 Sept 2013)

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

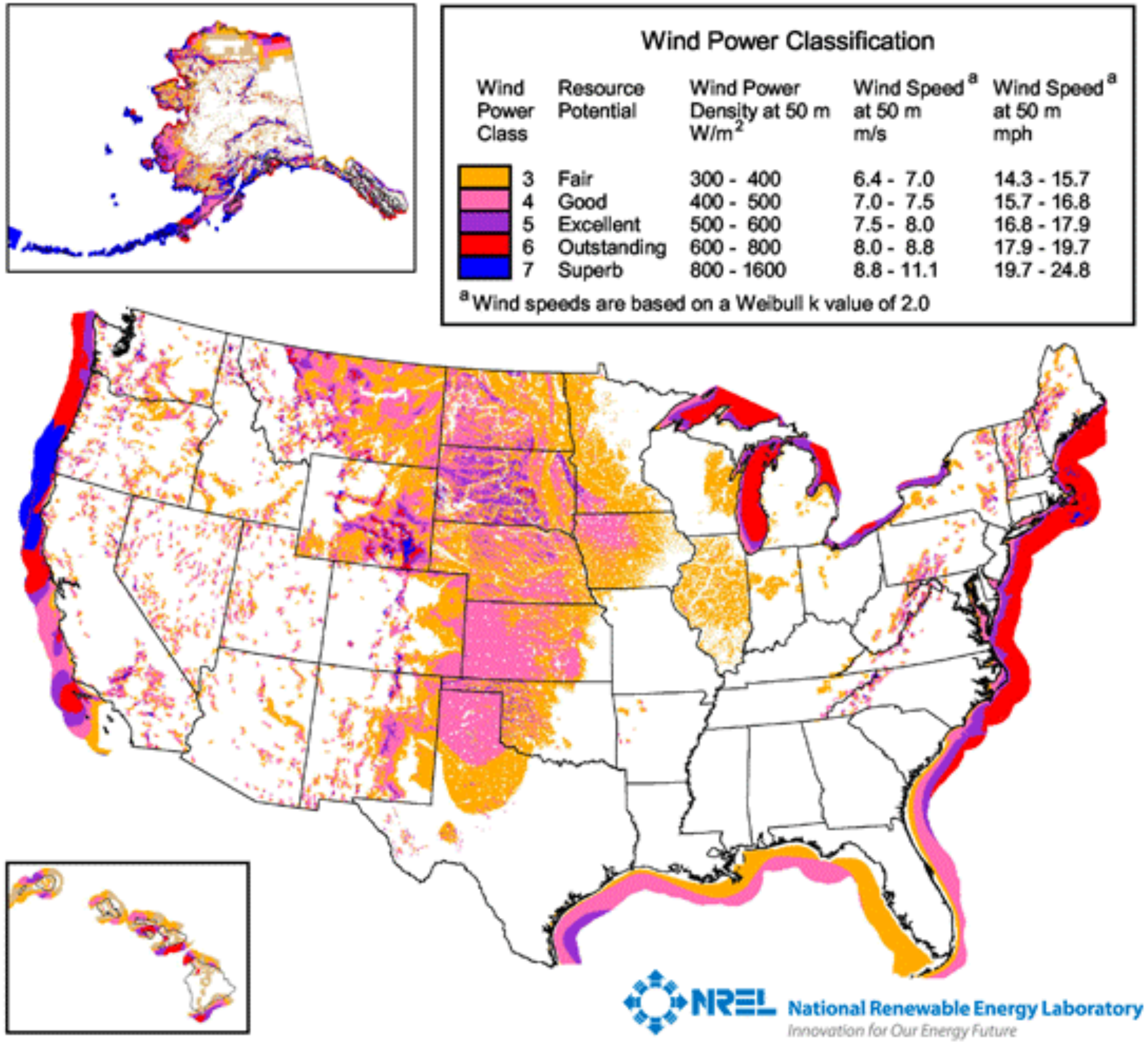

What have we learned from 130 years of continuous climate monitoring?

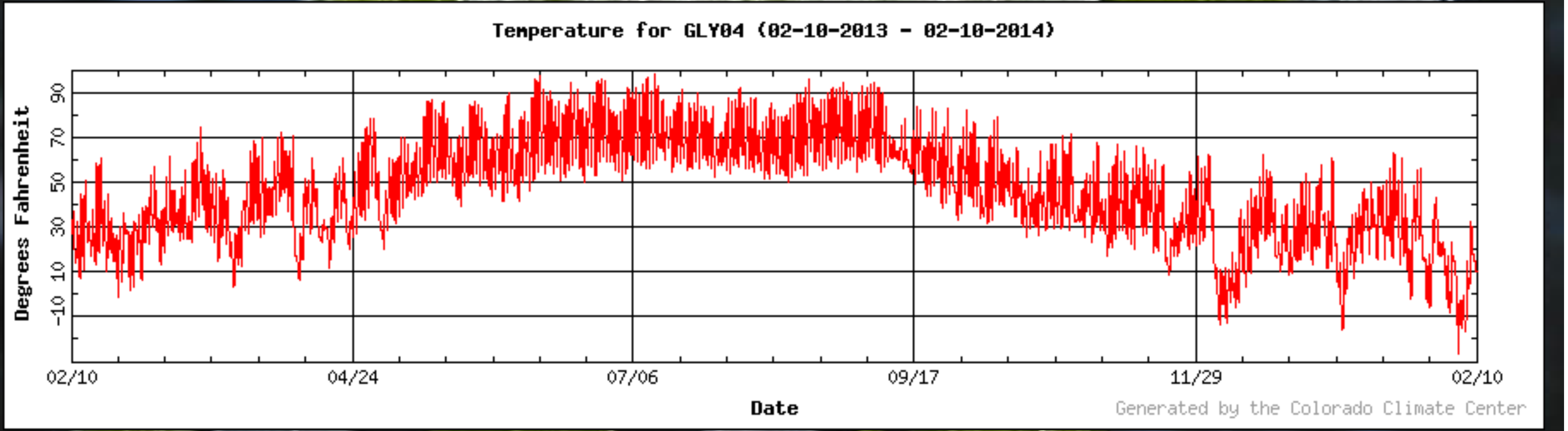
Colorado is a sunny place.
People like sunshine!
So does vegetation – to a point.



National Renewable Energy Laboratory: www.nrel.gov

The winds blow, but not as persistently as some places

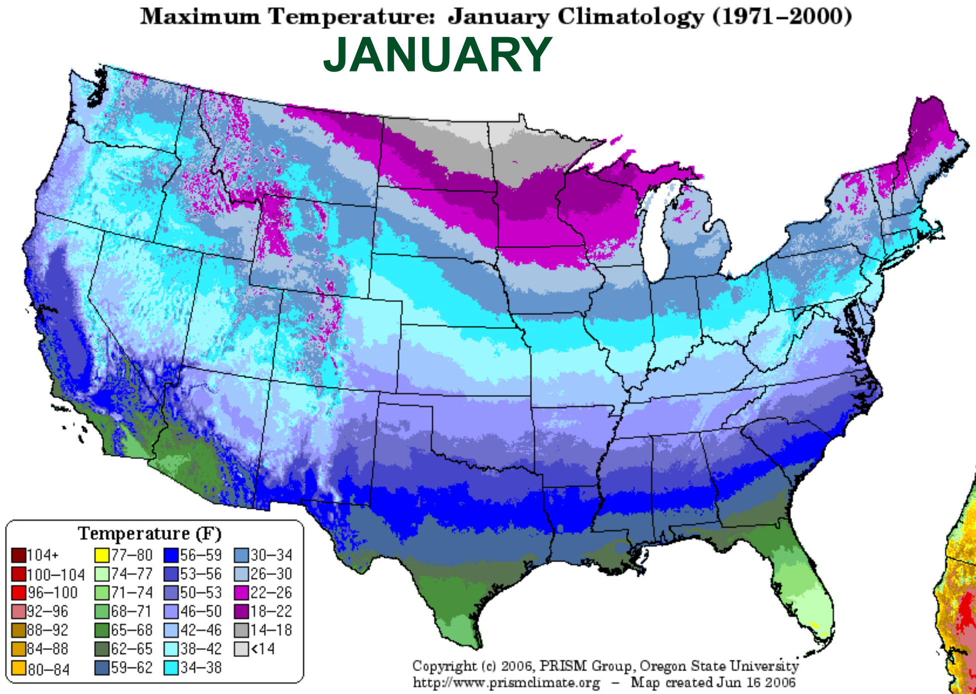




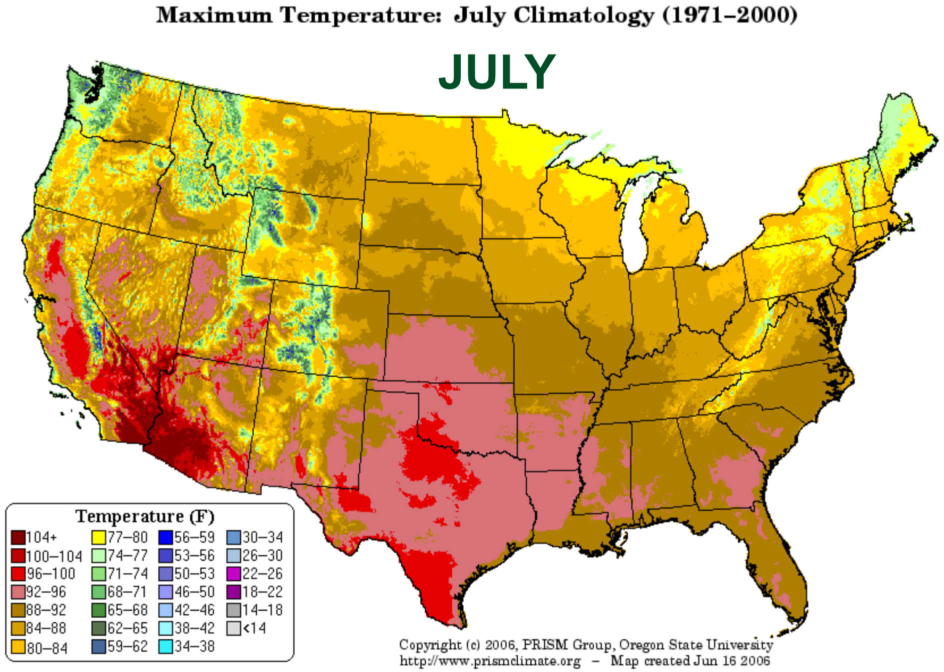
We always experience large seasonal and diurnal temperature variations

Complex temperature variations due to elevation and topography

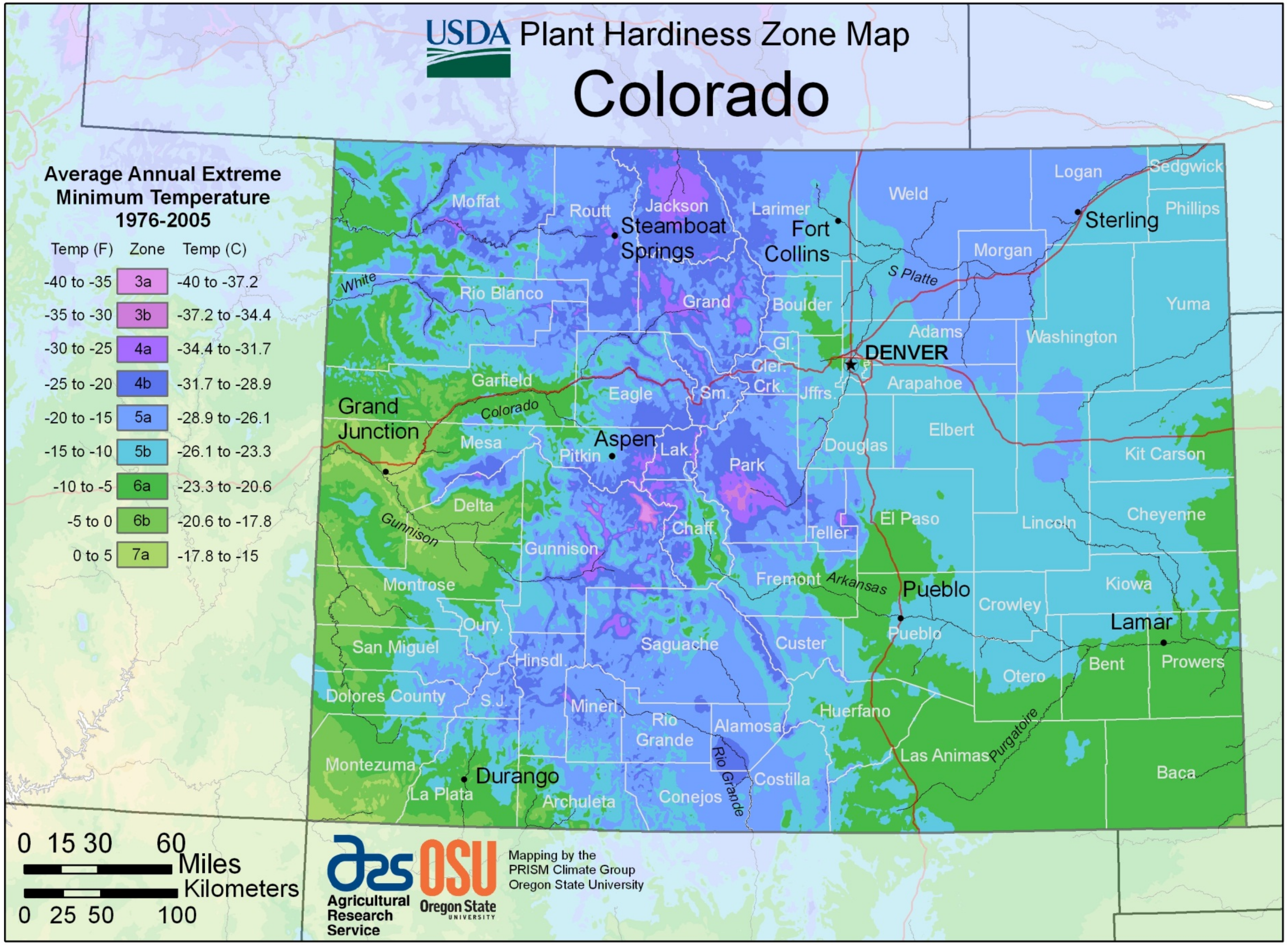
JANUARY



JULY

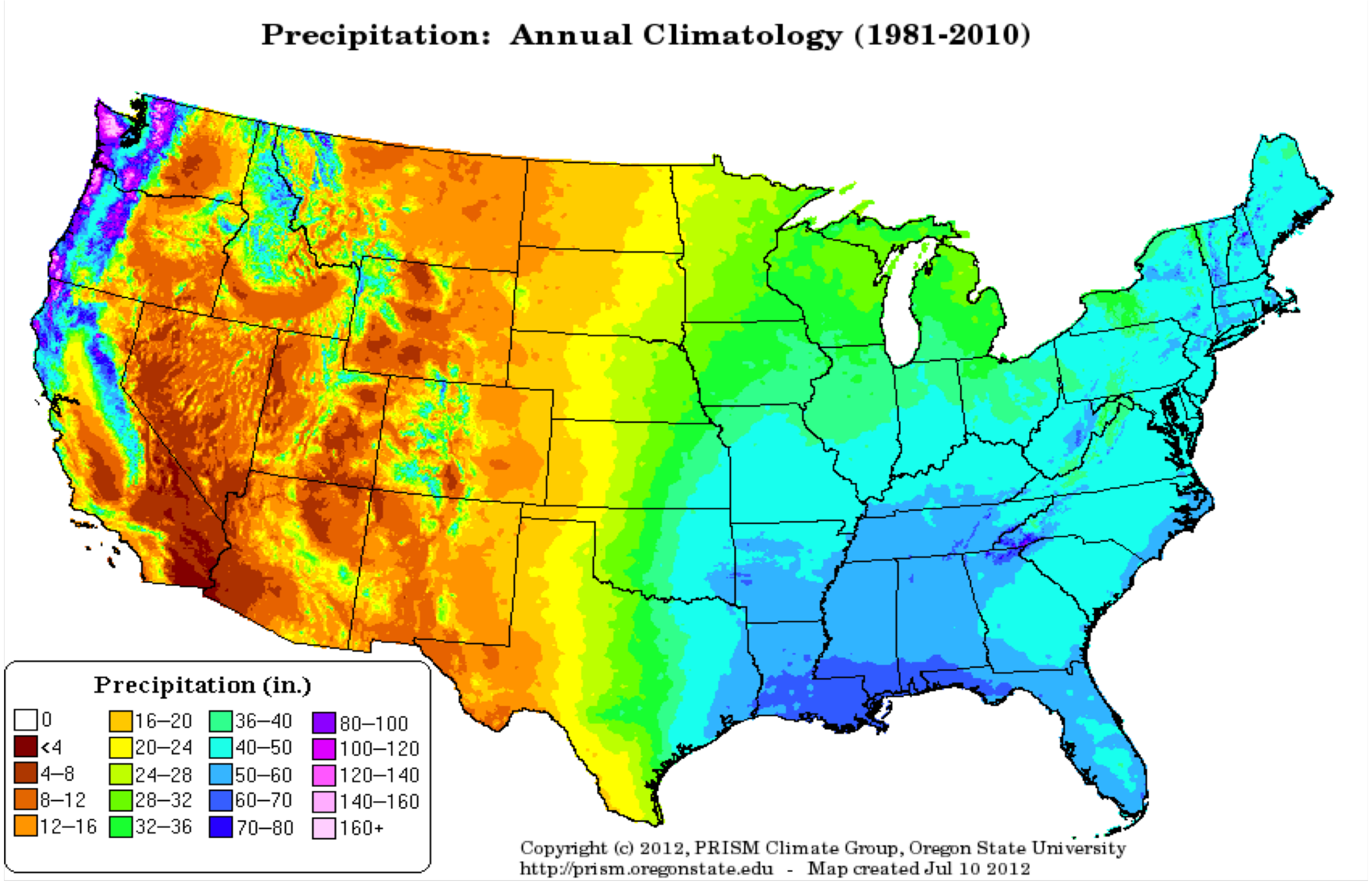


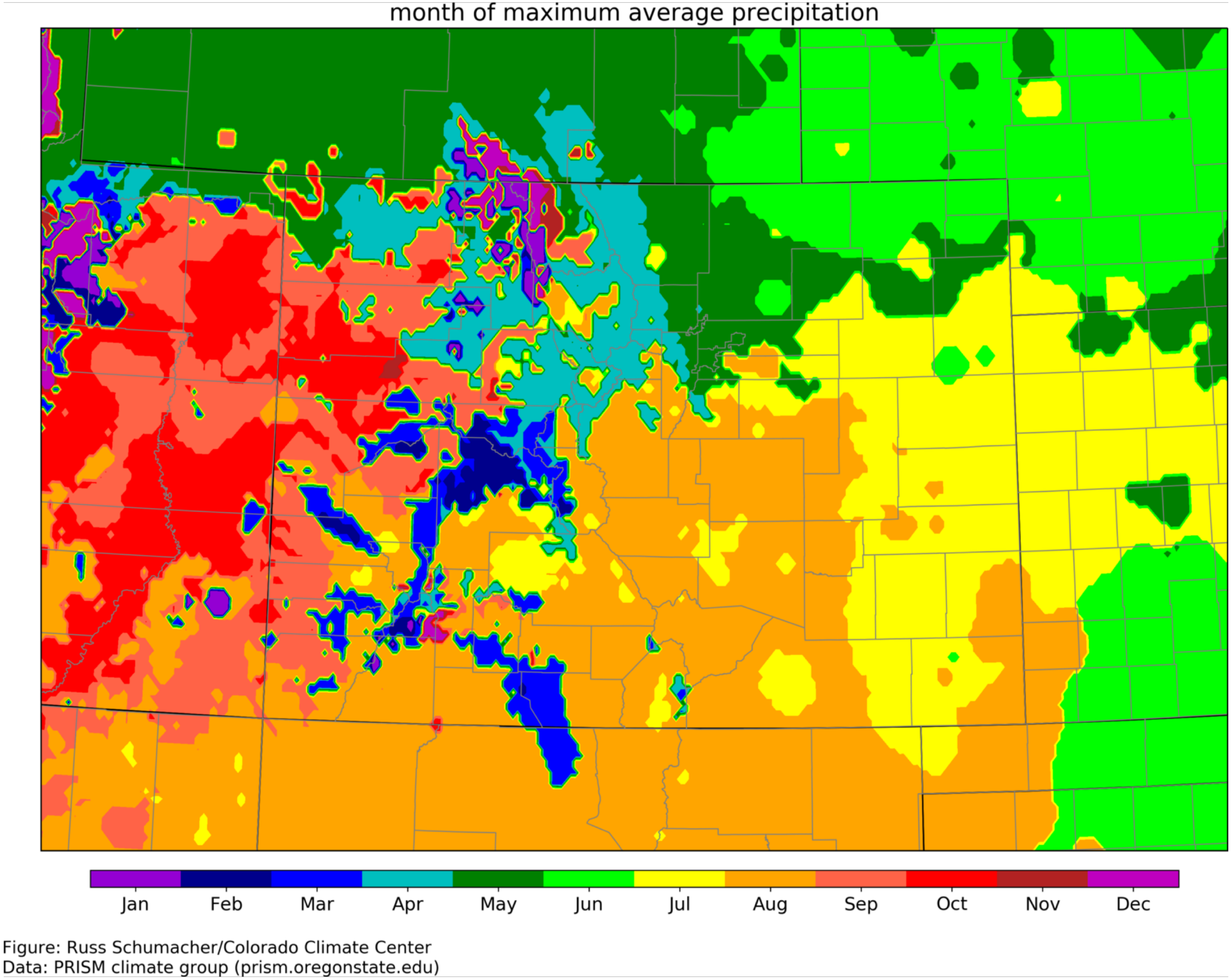
Usually colder in the mountains!



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
Moffat
Routt
Jackson
Steamboat Springs
Larimer
Fort Collins
Weld
Logan
Sedgwick
Sterling
Phillips
Morgan
S Platte
White
Rio Blanco
Grand
Boulder
Yuma
Gl.
Adams
DENVER
Washington
Cler. Crk.
Arapahoe
Garfield
Eagle
Sm.
Jffrs.
Grand Junction
Colorado
Elbert
Mesa
Aspen
Pitkin
Lak.
Douglas
Kit Carson
Park
Delta
Gunnison
Chaff.
Teller
El Paso
Lincoln
Cheyenne
Gunnison
Montrose
Fremont
Arkansas
Pueblo
Kiowa
Crowley
Lamar
Oury.
San Miguel
Saguache
Custer
Pueblo
Hinsdl.
Bent
Prowers
Otero
Dolores County
S.J.
Minerl.
Rio Grande
Alamosa
Huerfano
Montezuma
Las Animas
Purgatoire
Durango
Costilla
Baca
La Plata
Archuleta
Conejos
Rio Grande
0 15 30 60 Miles
0 25 50 100 Kilometers
Agricultural Research Service
Oregon State University
Mapping by the PRISM Climate Group Oregon State University

We get rain and snow – but often not enough



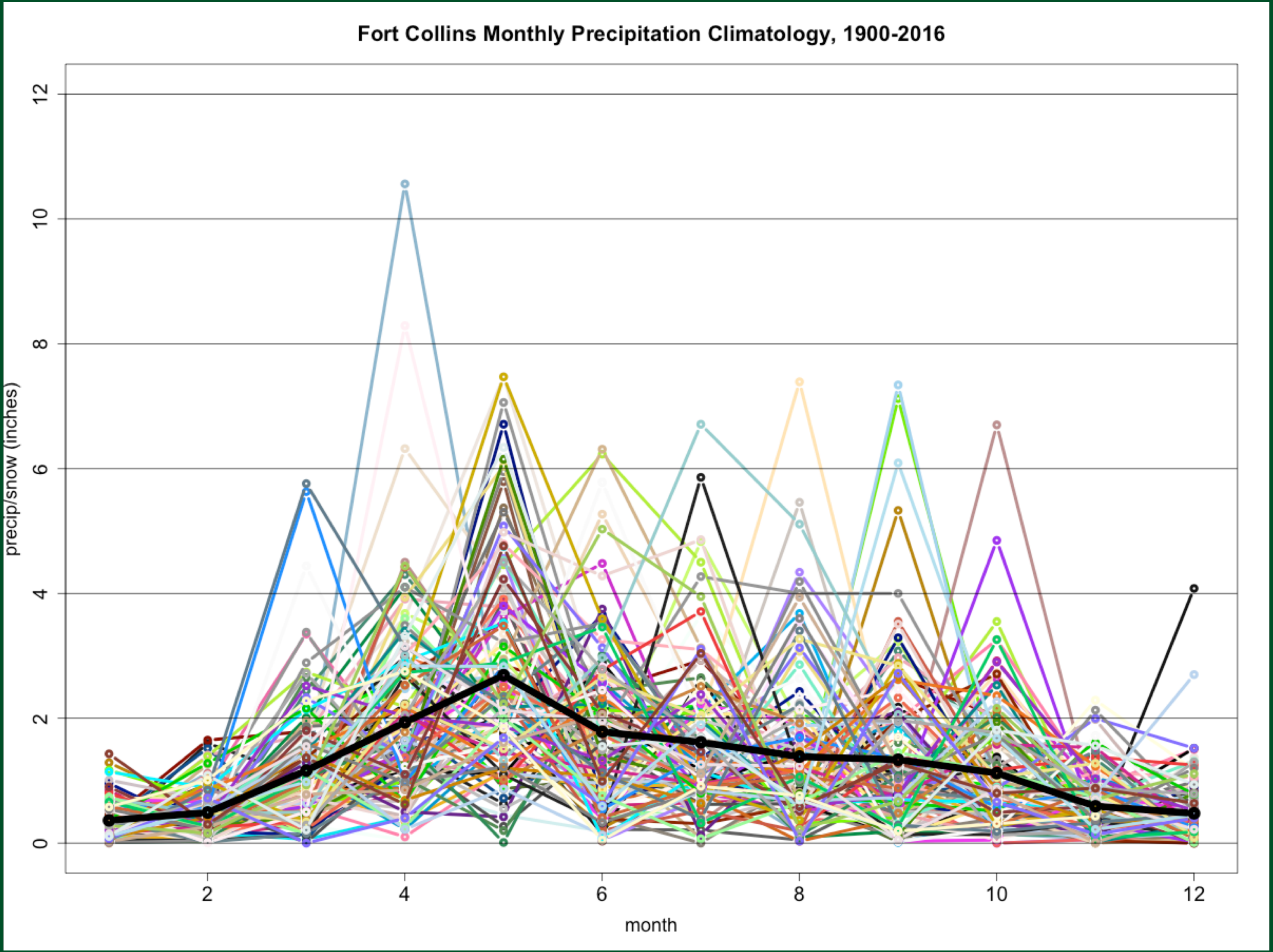


Seasonal precipitation in Colorado varies greatly from place to place

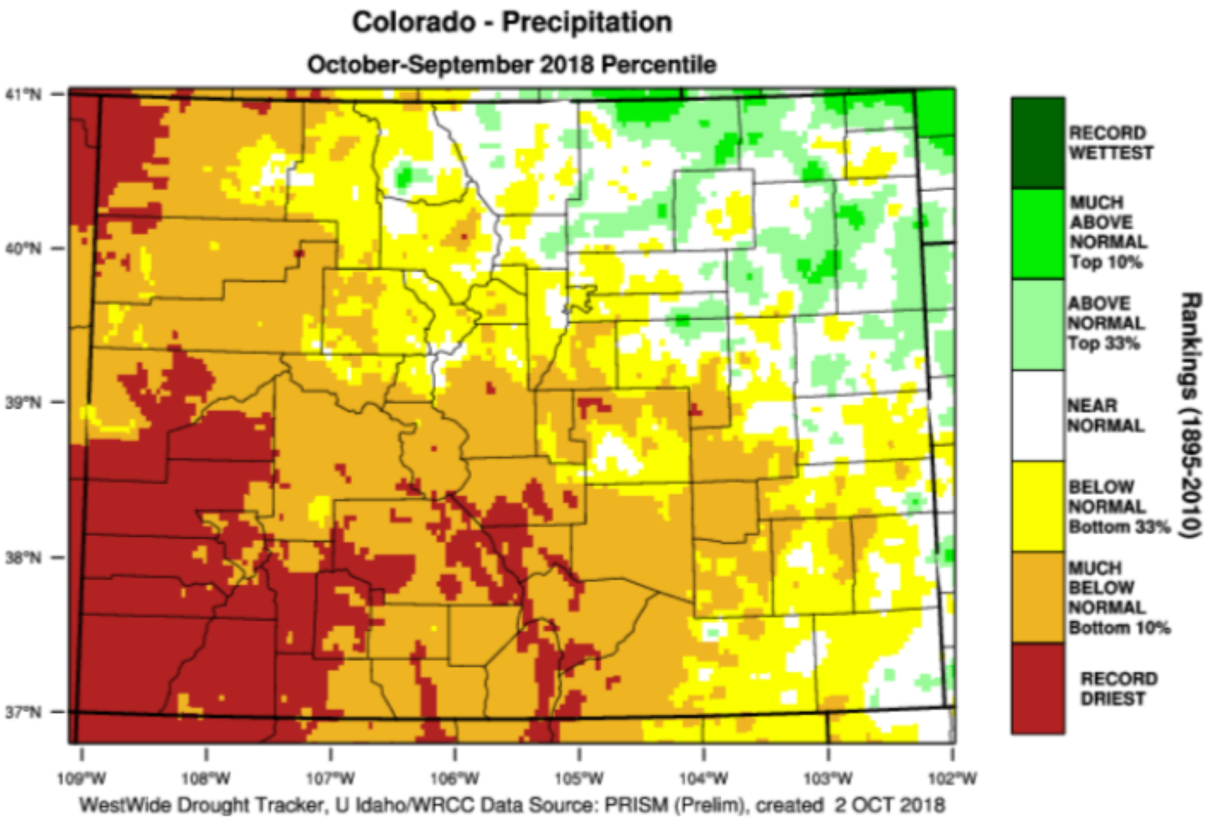
Month of maximum average precip
Data: PRISM Climate Group, prism.oregonstate.edu

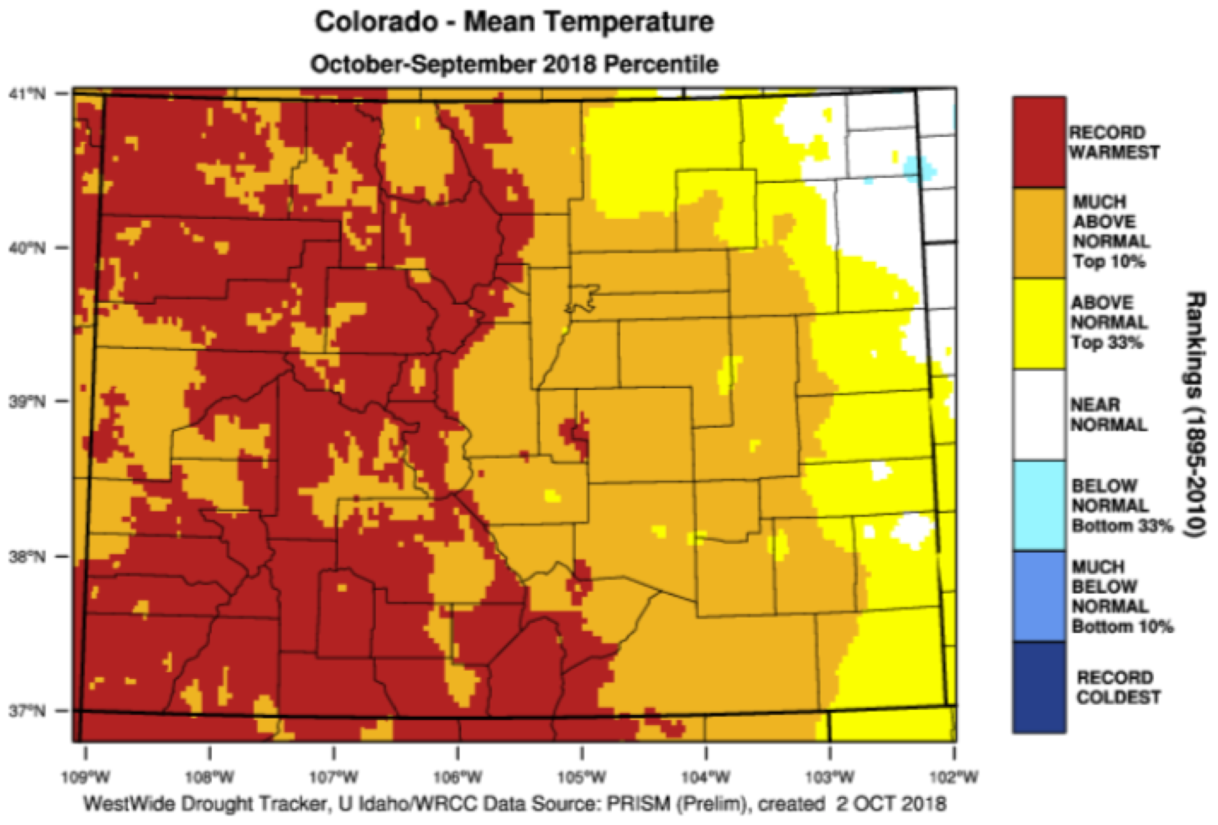
Year-to-Year Variations in Precipitation are Huge

No two years are ever the same



Water Year 2018: One to forget!





2nd driest water year on record for Colorado

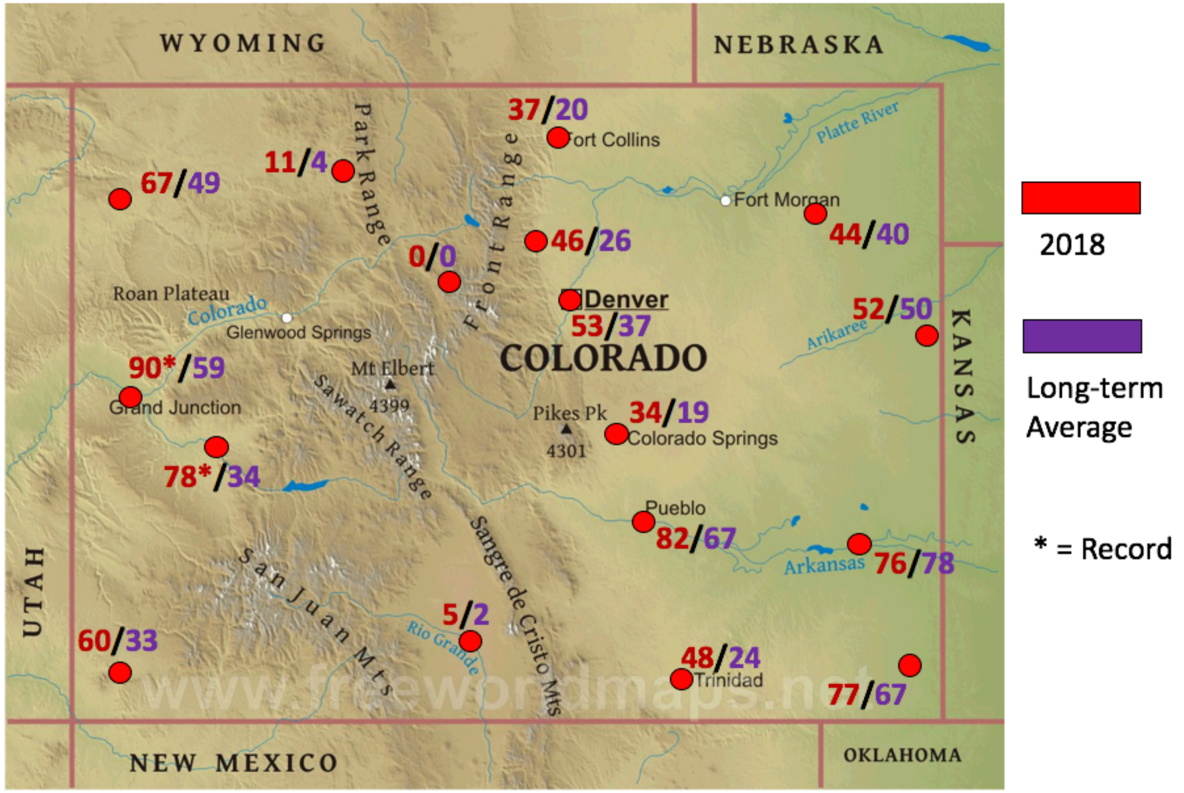
3rd warmest water year on record for Colorado

Water Year 2018: One to forget!

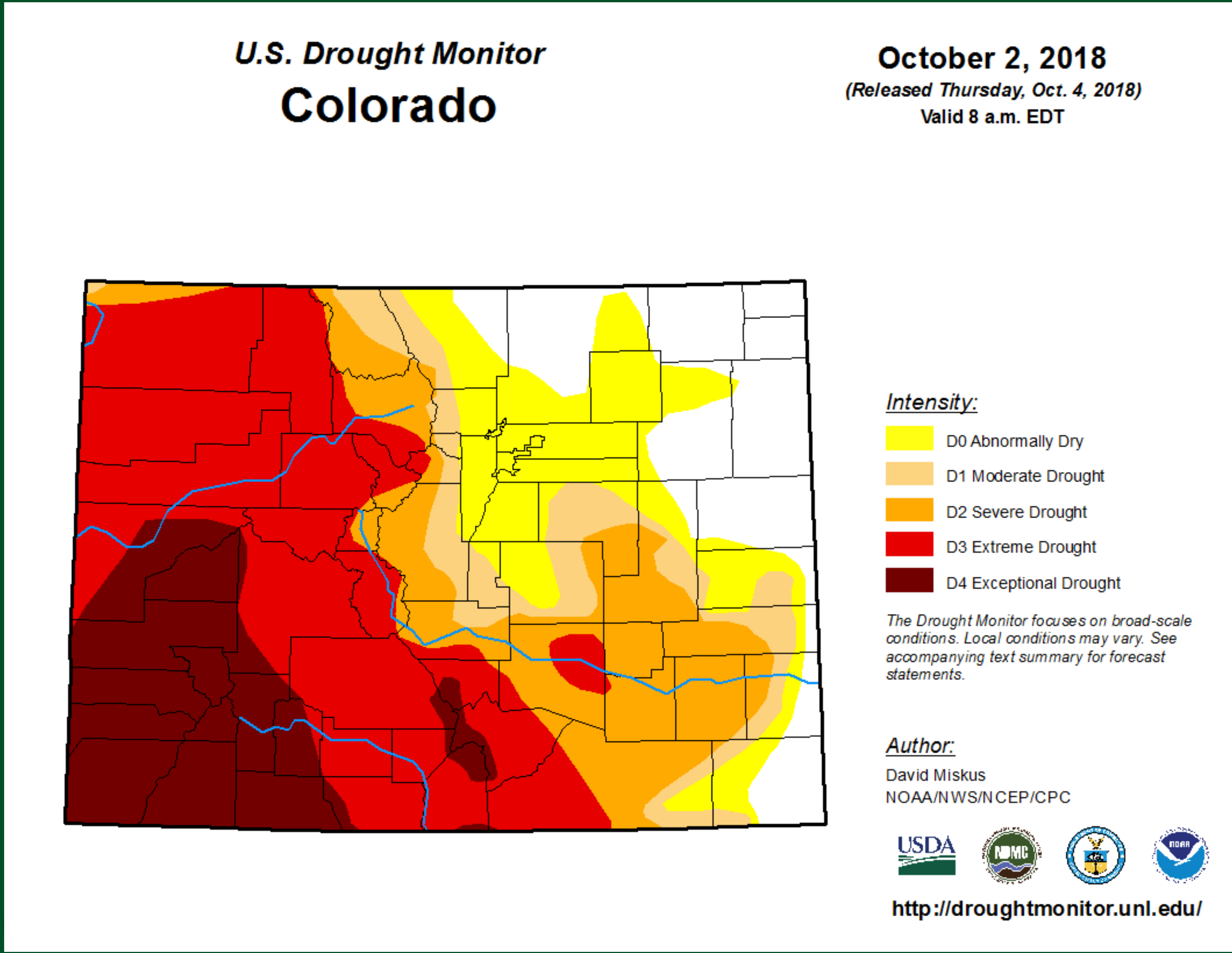
	90° days	Rank	Normal	Record	Record Year
Denver	53	7th of 70	37	67	2012
Fort Collins	37	10th of 121	20	57	2012
Boulder	46	10th of 104	26	60	1952
Colorado Springs	34	T4th of 70	19	49	2012
Pueblo	82	T7th of 65	67	90	2000
Burlington	52	40th of 85	50	88	1954
Lamar	76	T66th of 114	78	129	1934
Walsh	77	9th 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!



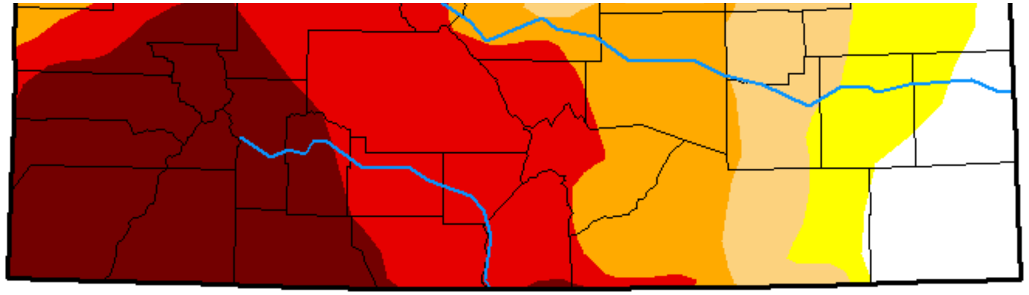
Water Year 2019: Off to a better start, but still reasons for concern

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

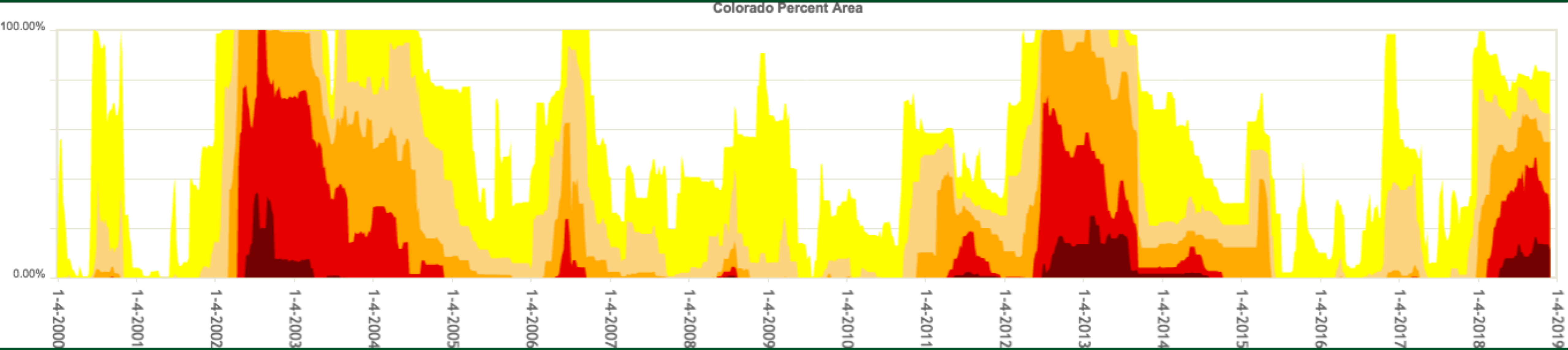


The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
David Miskus
NOAA/NWS/NCEP/CPC

http://droughtmonitor.unl.edu/

COLORADO



Colorado Percent Area
100.00%
0.00%
1-4-2000
1-4-2001
1-4-2002
1-4-2003
1-4-2004
1-4-2005
1-4-2006
1-4-2007
1-4-2008
1-4-2009
1-4-2010
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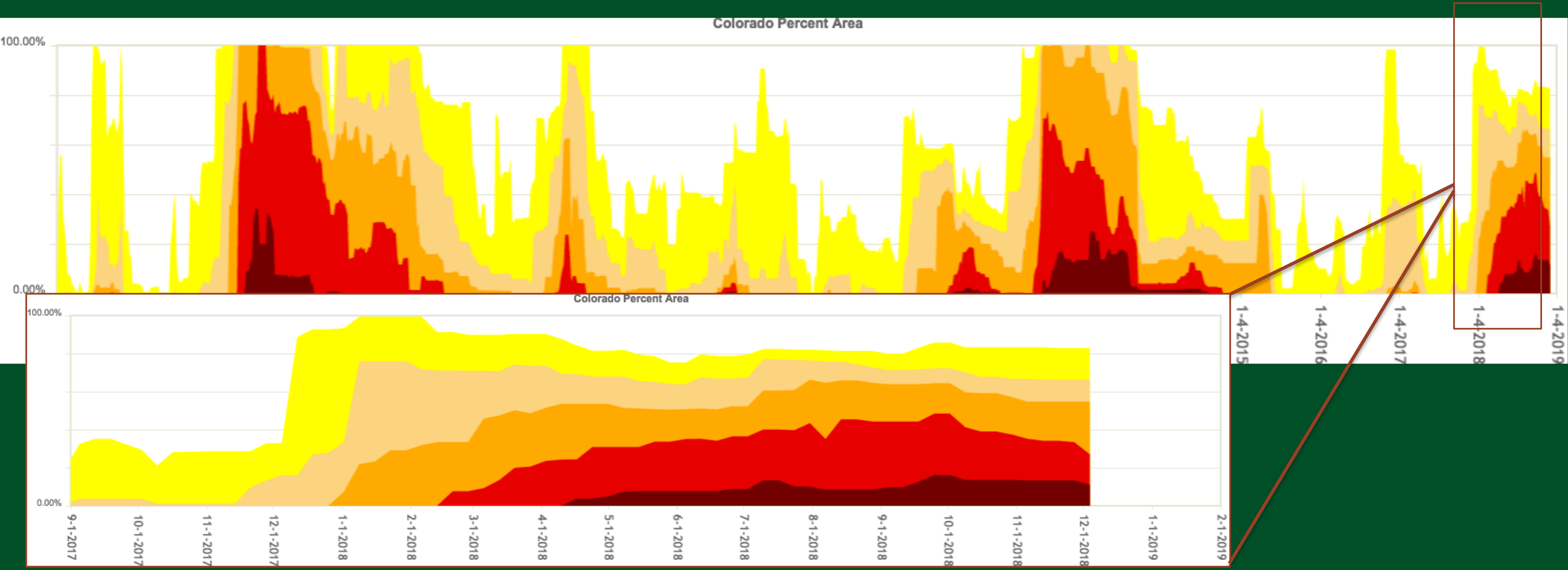
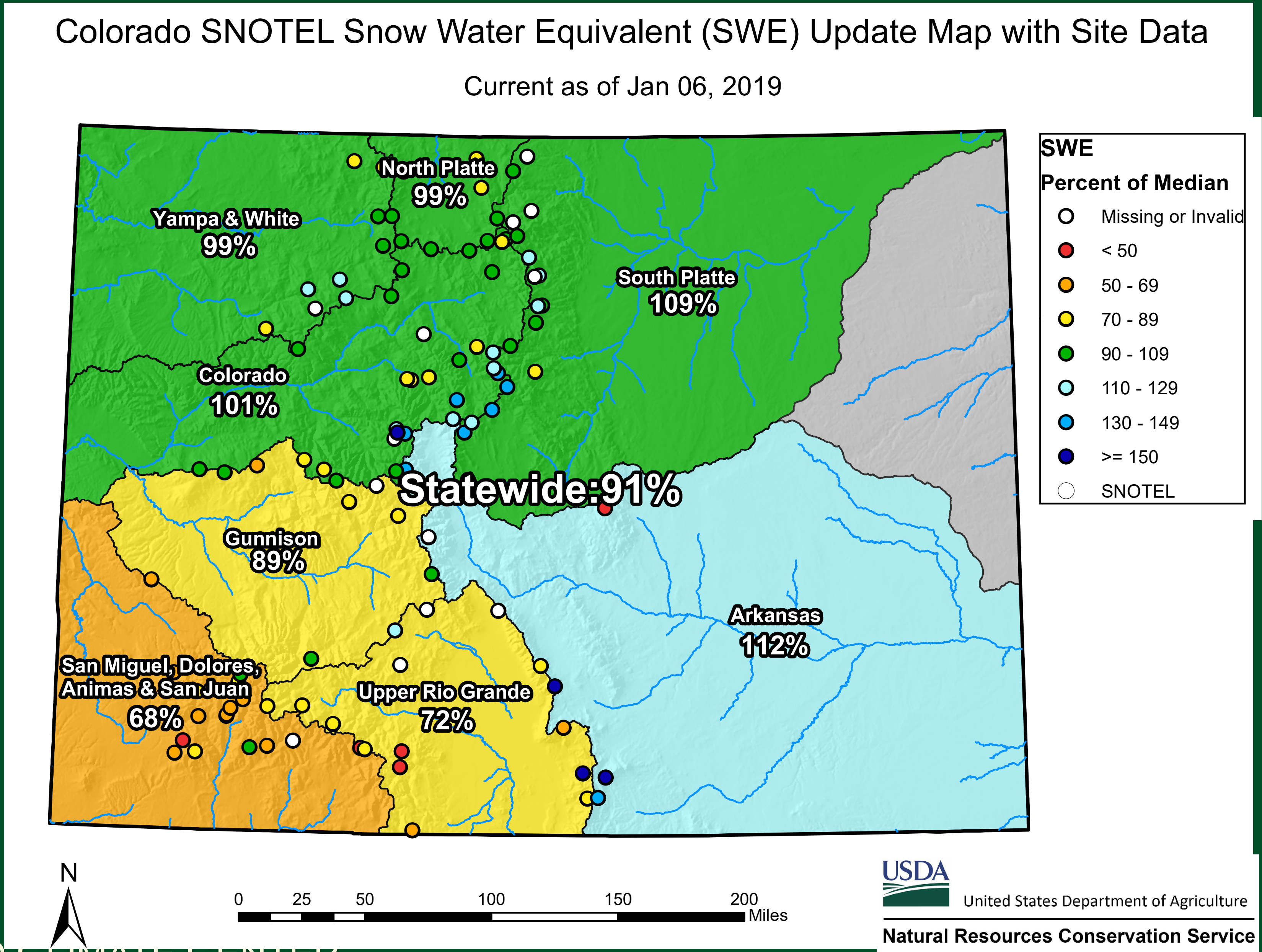
1-4-2017
1-4-2018
1-4-2019

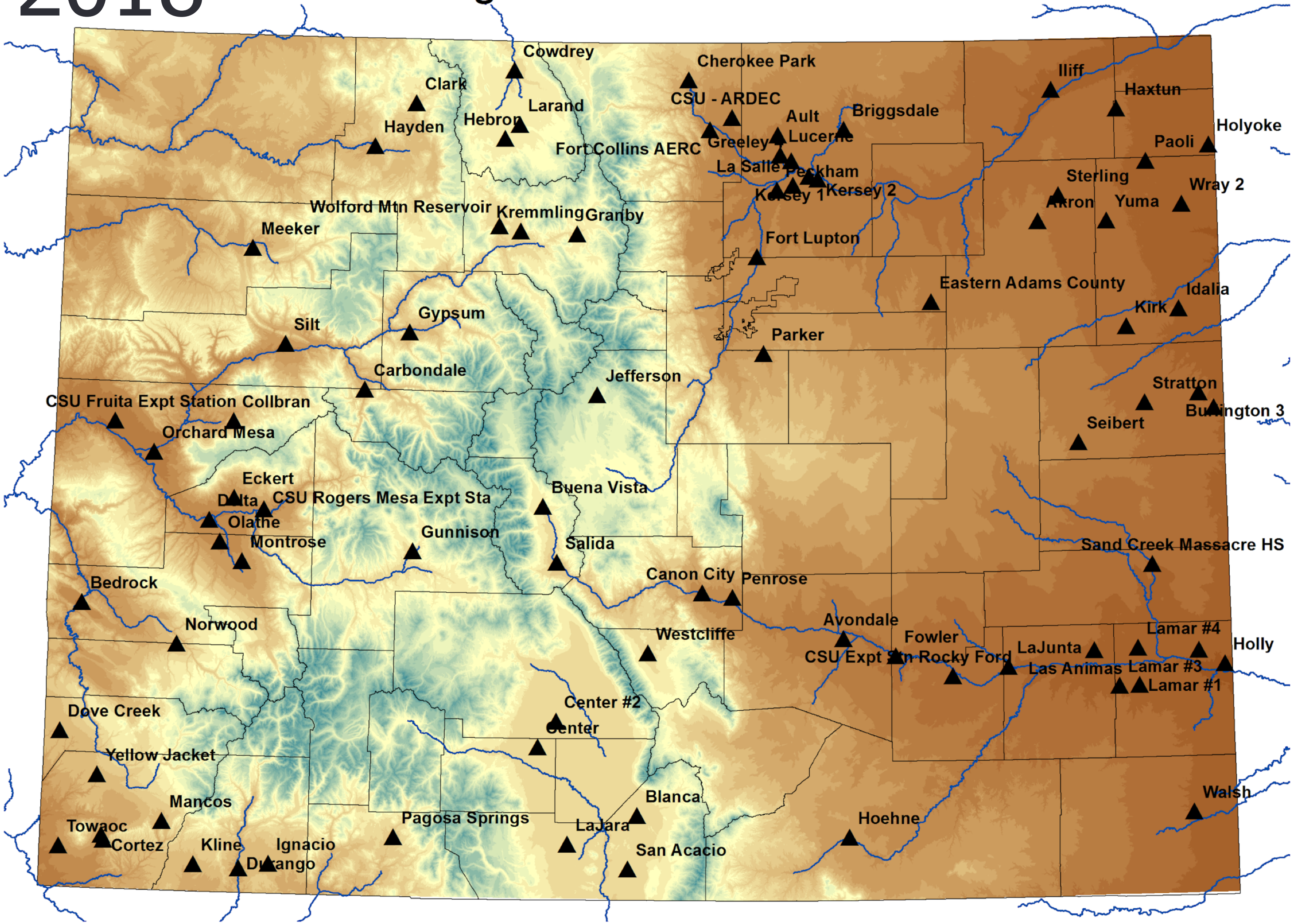

Colorado Percent Area
100.00%
0.00%
1-4-2015
1-4-2016
1-4-2017
1-4-2018
1-4-2019
Colorado Percent Area
100.00%
0.00%
9-1-2017
10-1-2017
11-1-2017
12-1-2017
1-1-2018
2-1-2018
3-1-2018
4-1-2018
5-1-2018
6-1-2018
7-1-2018
8-1-2018
9-1-2018
10-1-2018
11-1-2018
12-1-2018
1-1-2019
2-1-2019

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

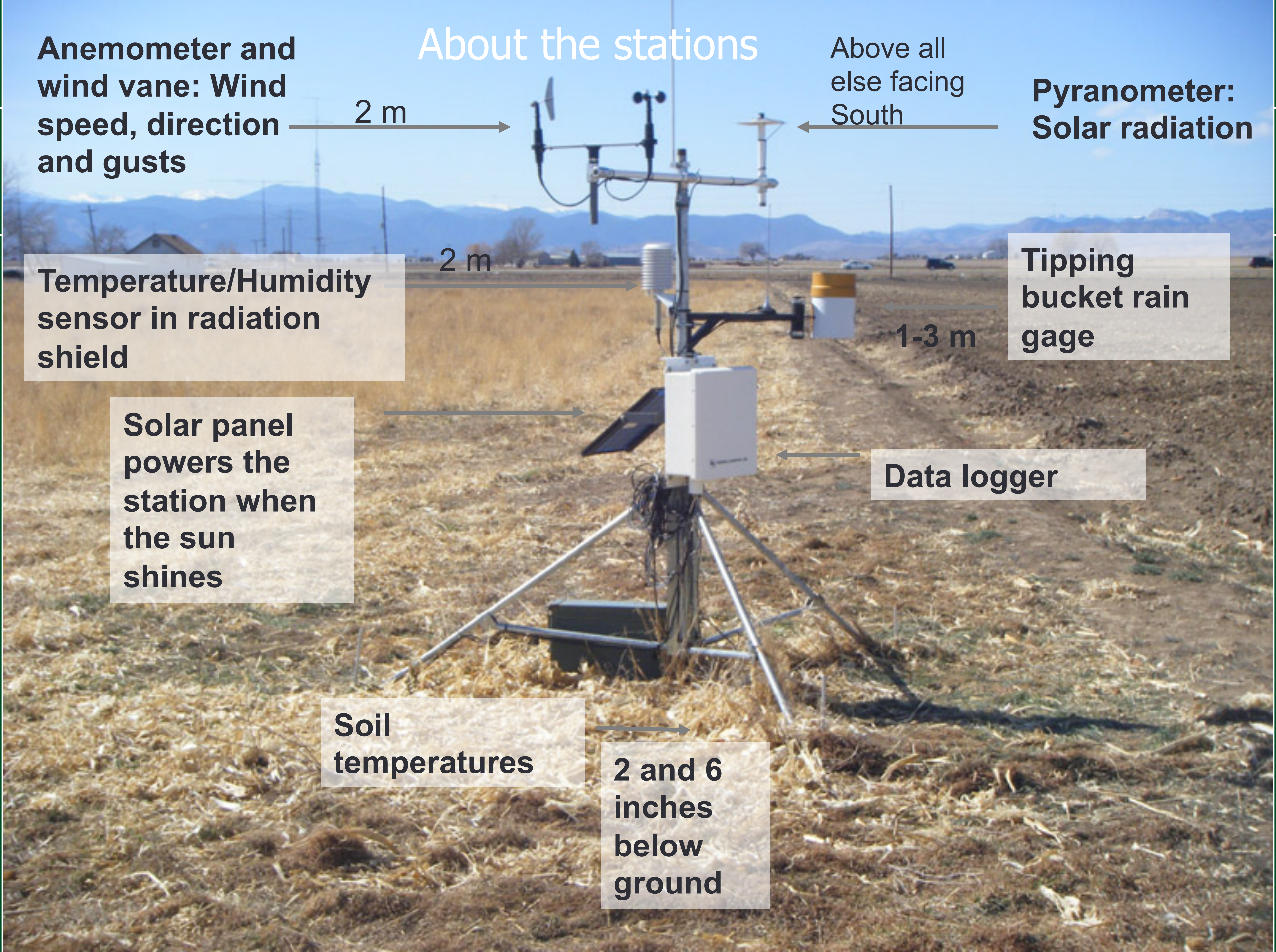


2018

CoAgMET Station Locations



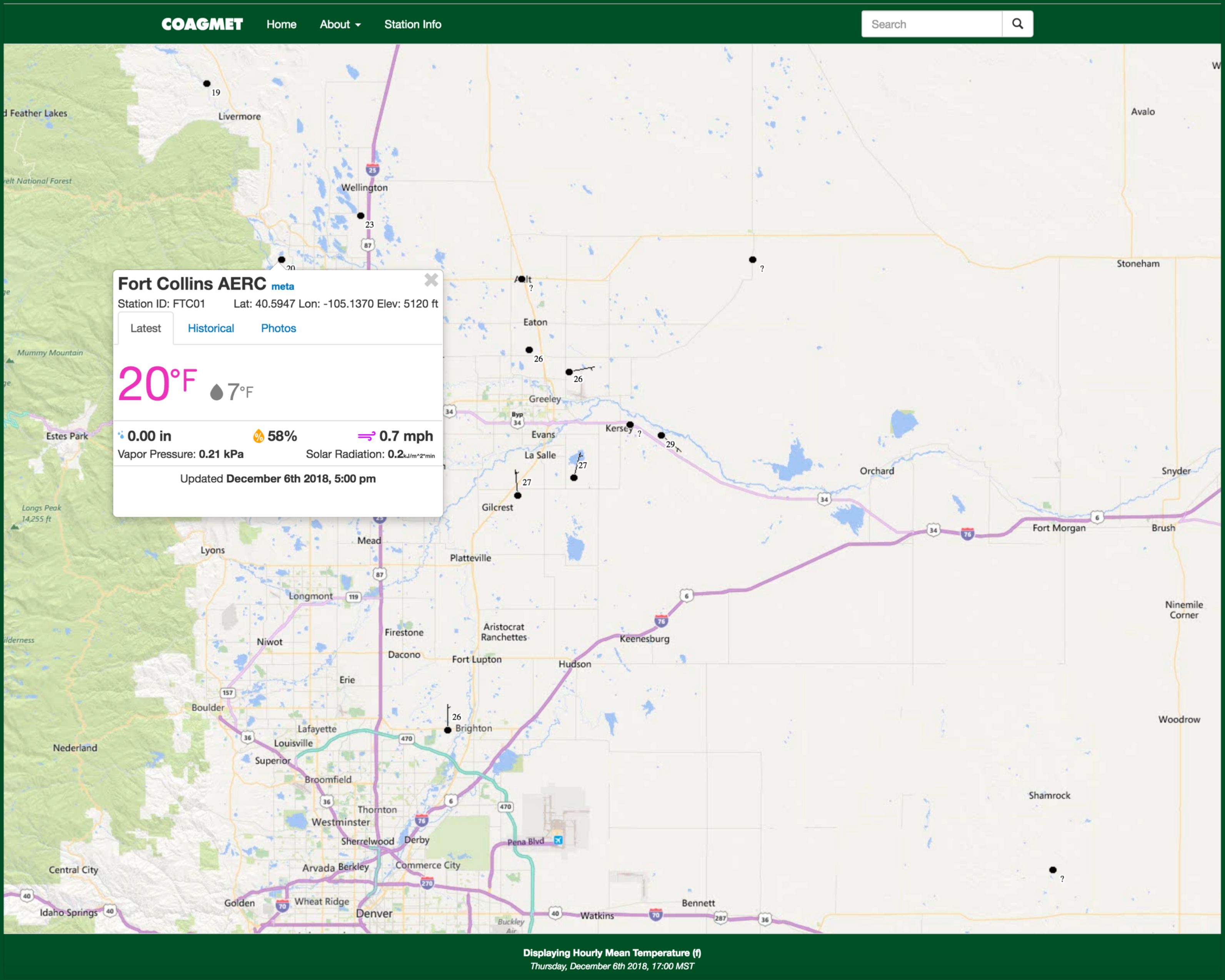
About the stations



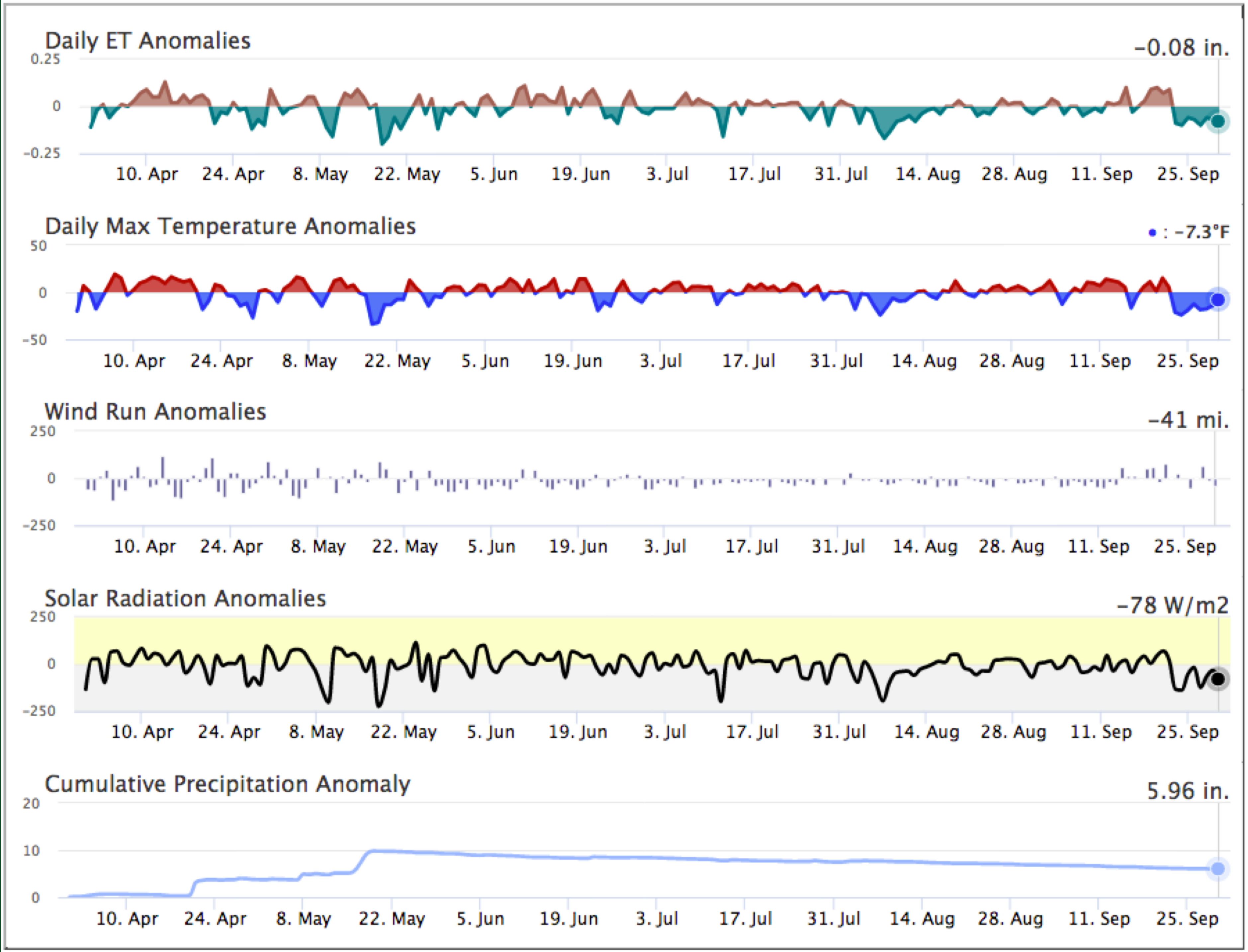
CoAgMET

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

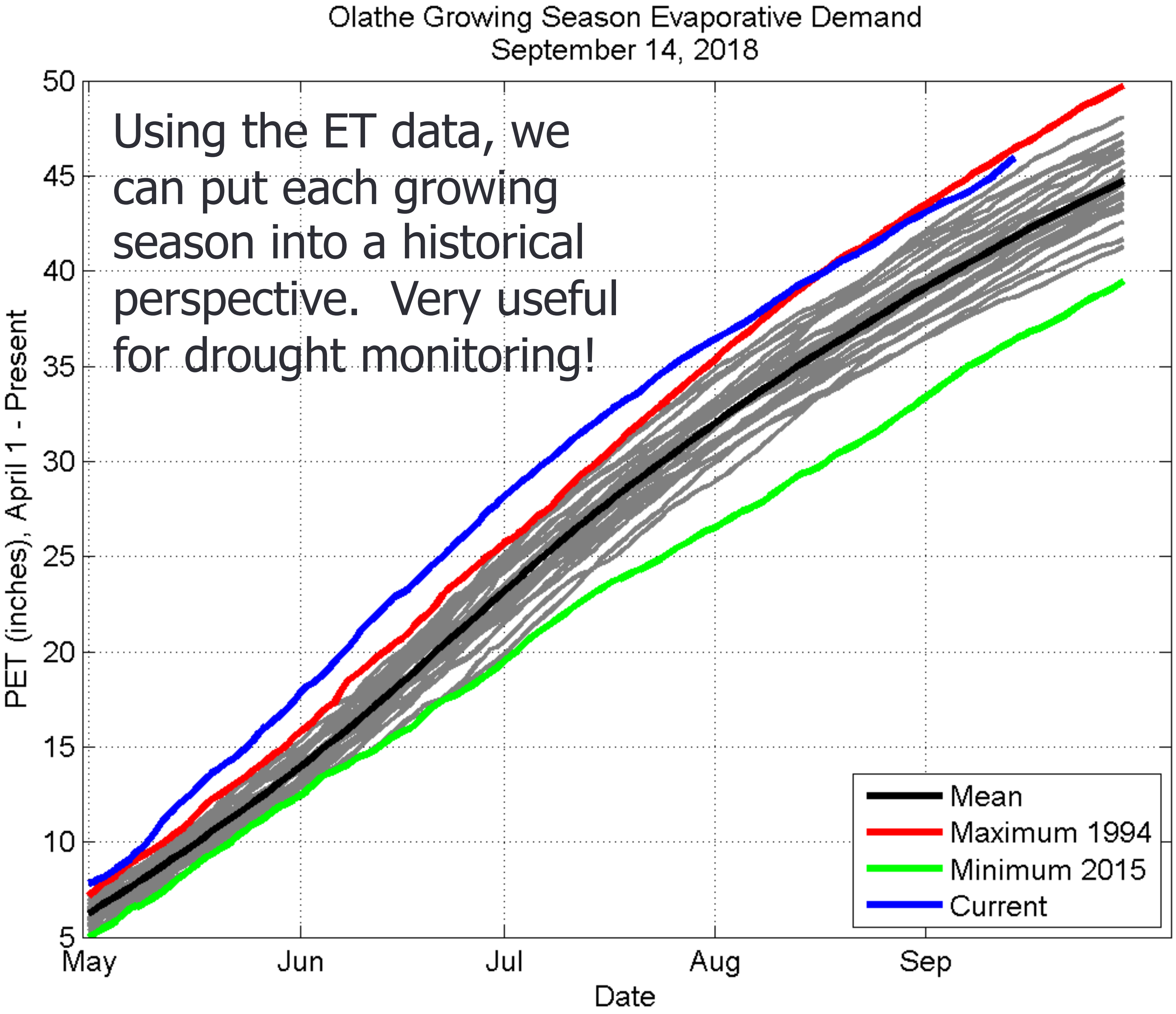
coagmet.colostate.edu

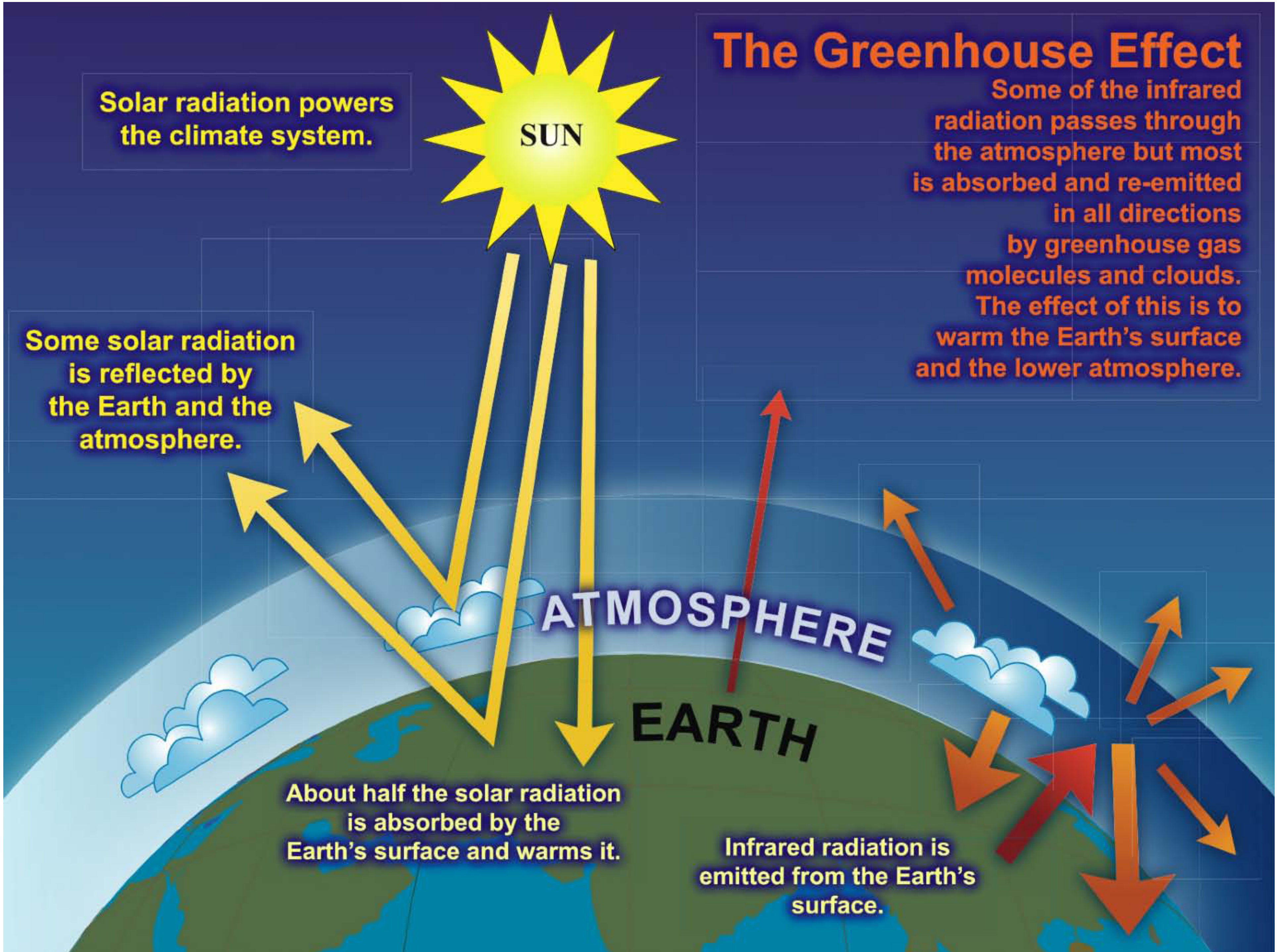


Growing season summaries at long-term stations: Lucerne (2017)



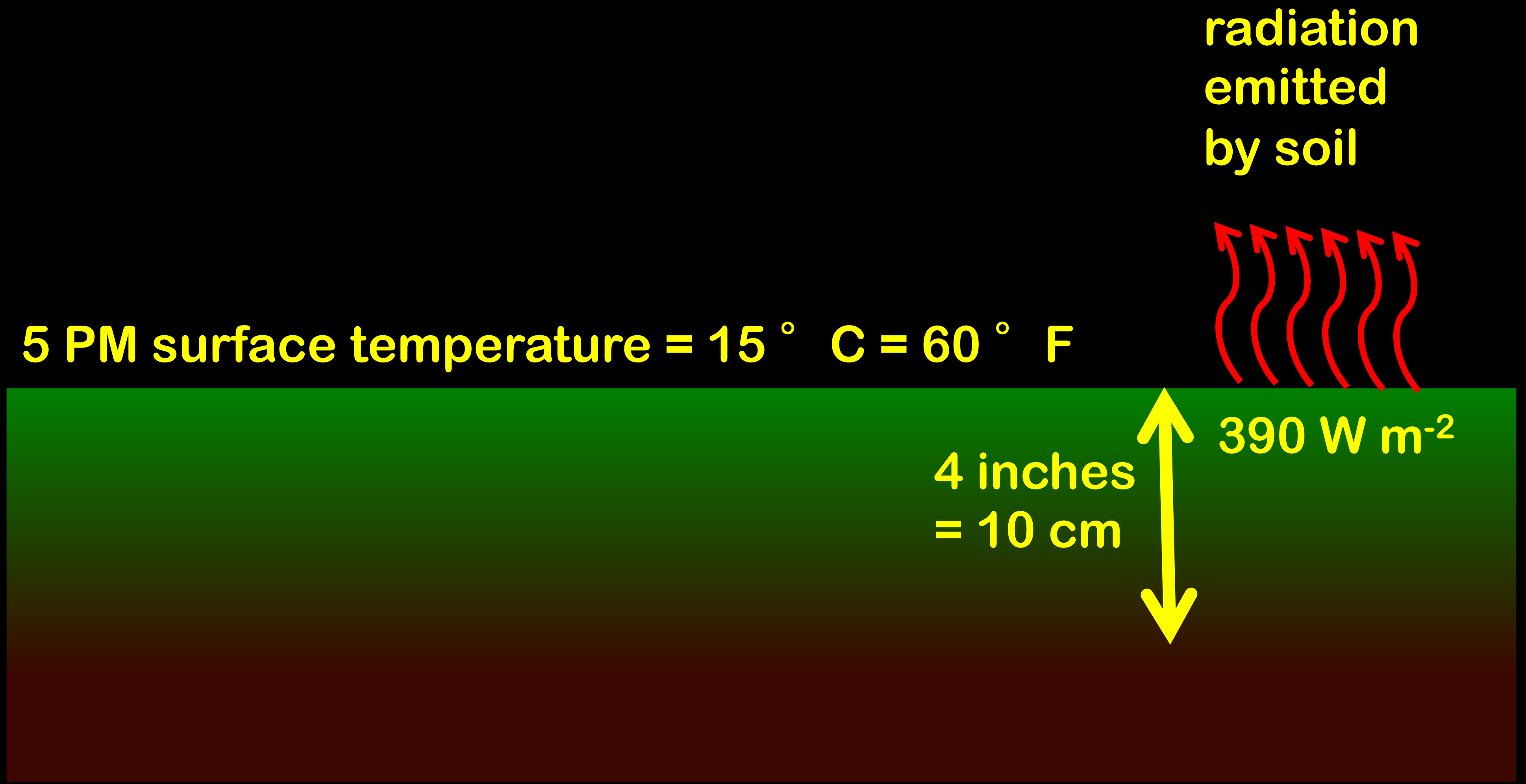
http://climate.colostate.edu/2017ET/et_summary_lcn_anom.html


Olathe Growing Season Evaporative Demand
September 14, 2018
Using the ET data, we can put each growing season into a historical perspective. Very useful for drought monitoring!
PET (inches), April 1 - Present
50
45
40
35
30
25
20
15
10
5
May
Jun
Jul
Aug
Sep
Date
Mean
Maximum 1994
Minimum 2015
Current

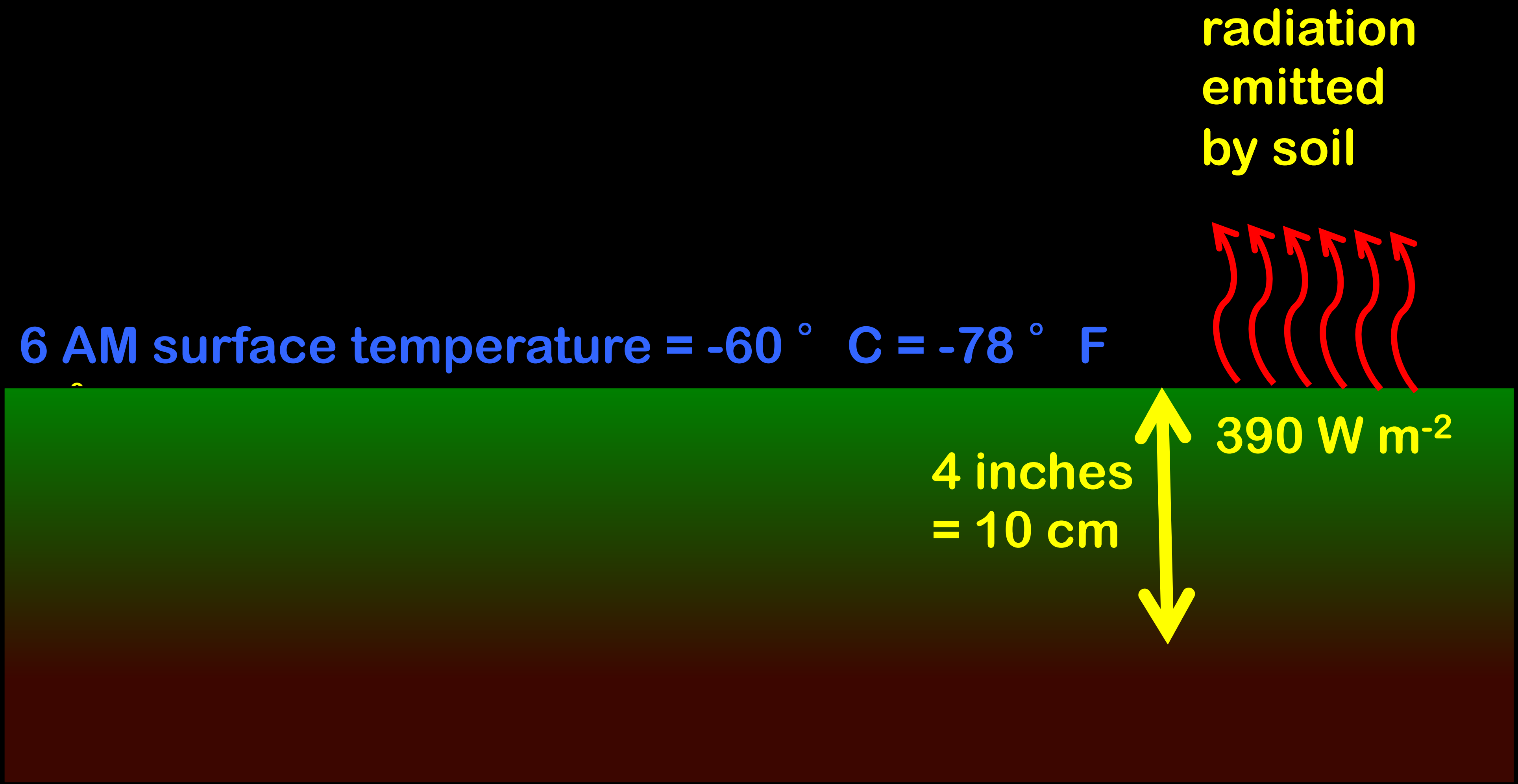


(illustration to follow courtesy of Scott Denning, CSU ATS)

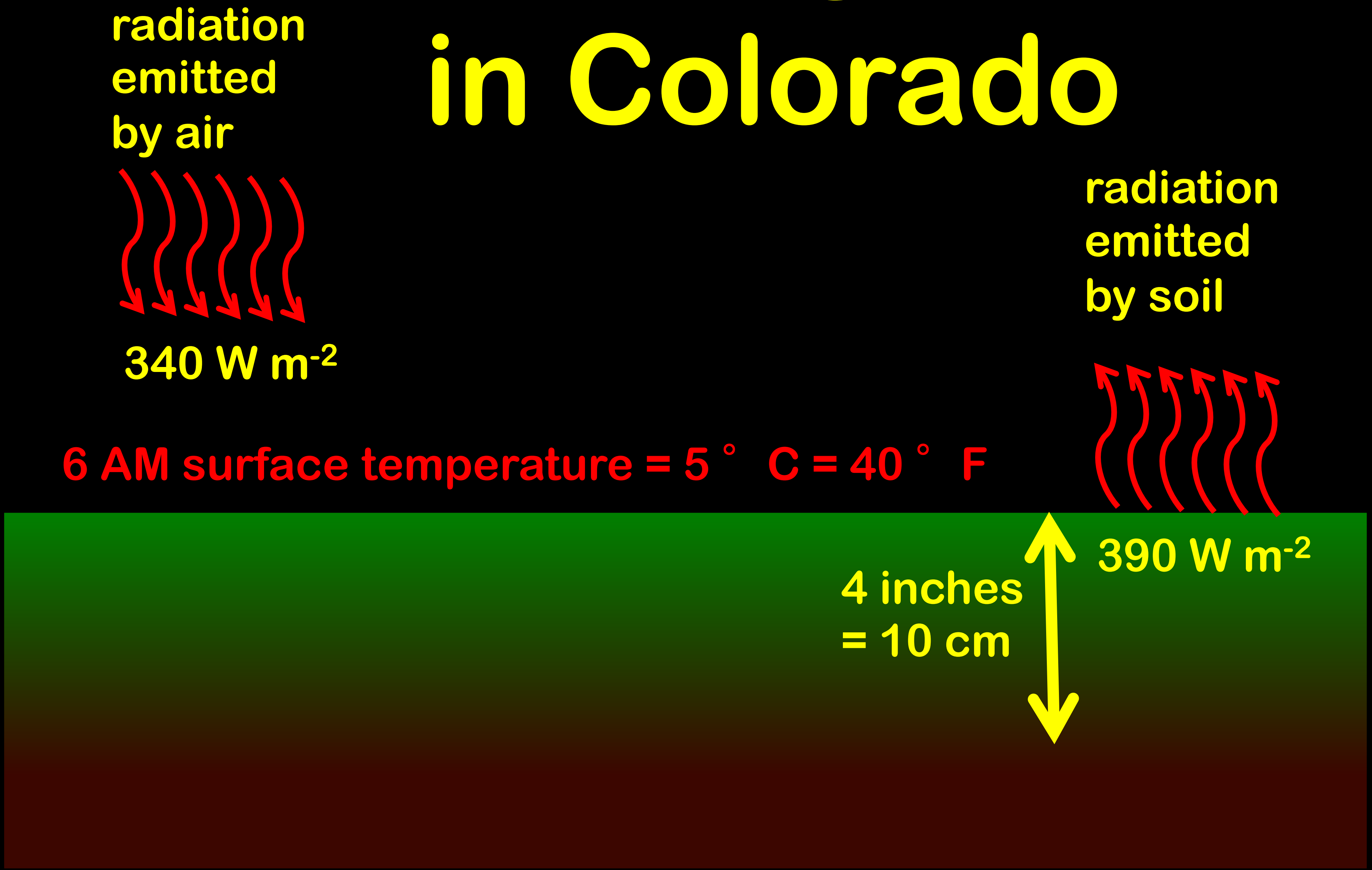
Fall Night in Colorado

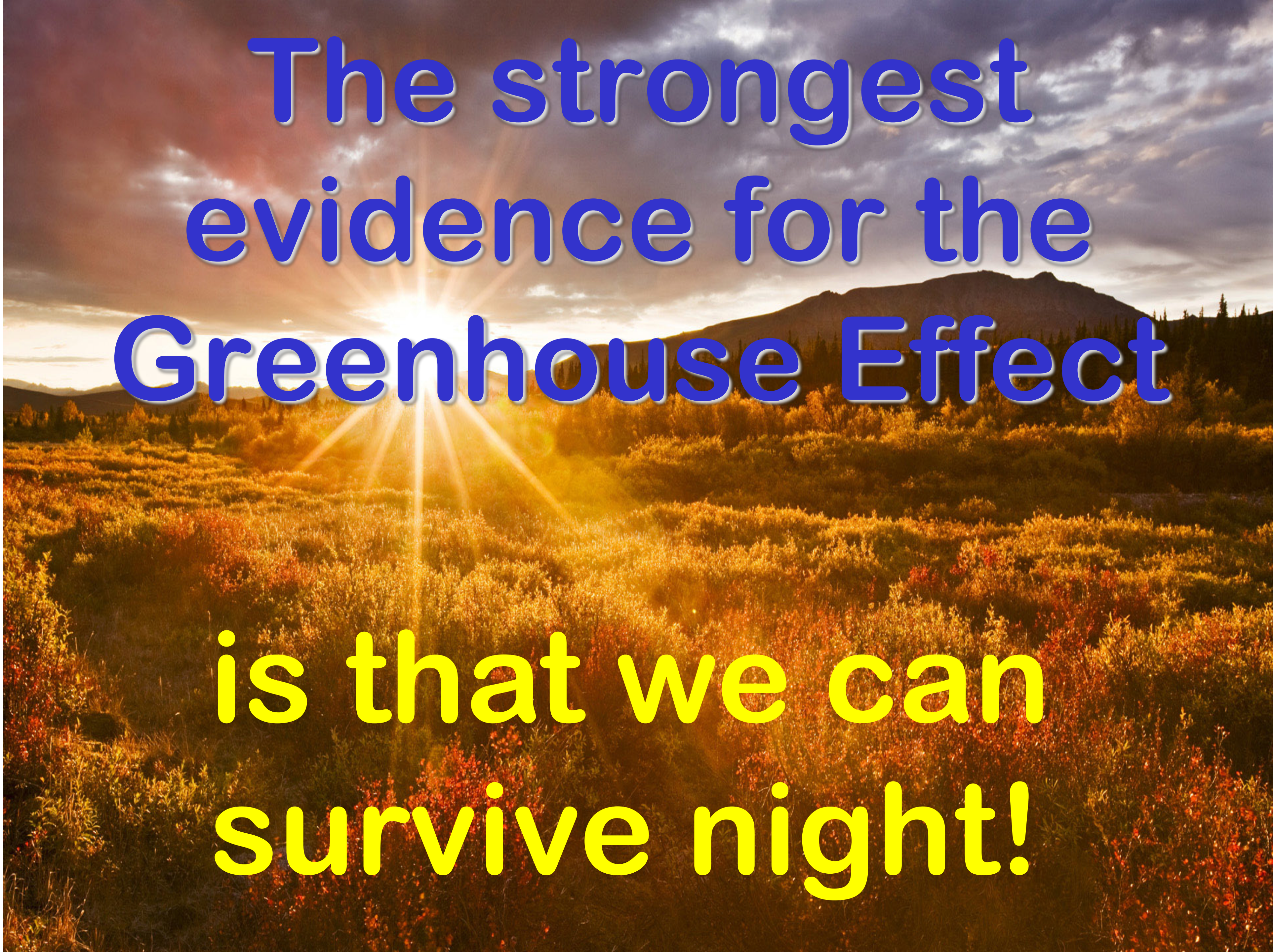


Fall Night in Colorado

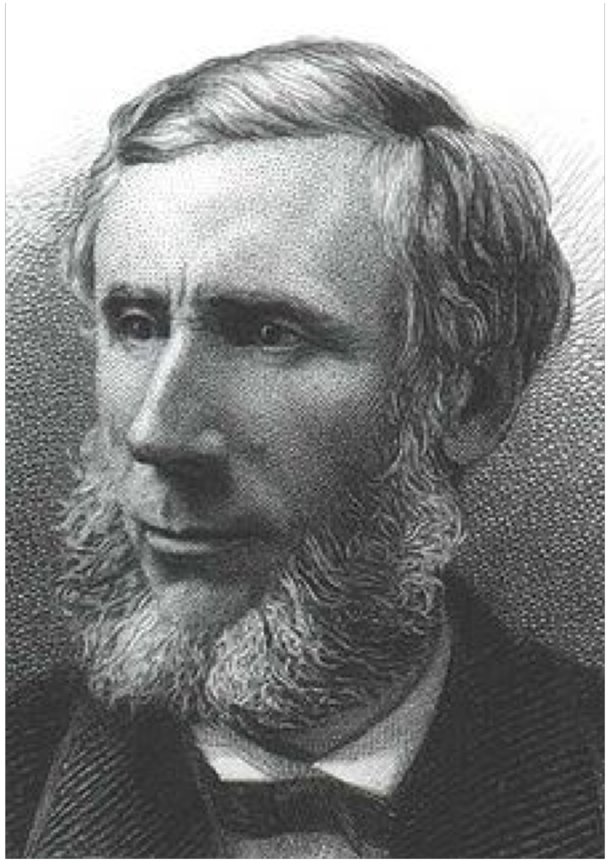


Fall Night in Colorado




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 CO_2 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”

WRONG!

It’s because we know that when we add heat to things, they warm up

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:

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

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 at a specified velocity

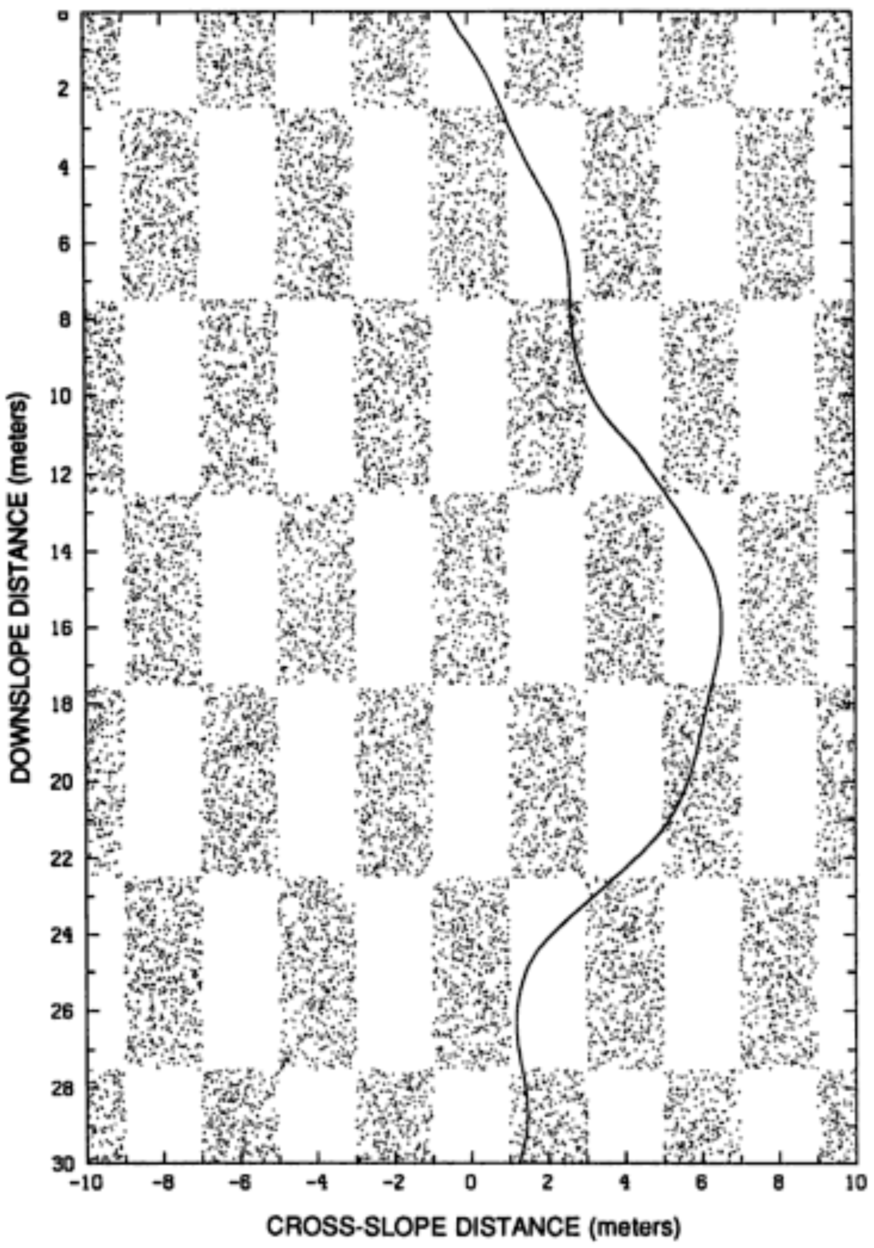
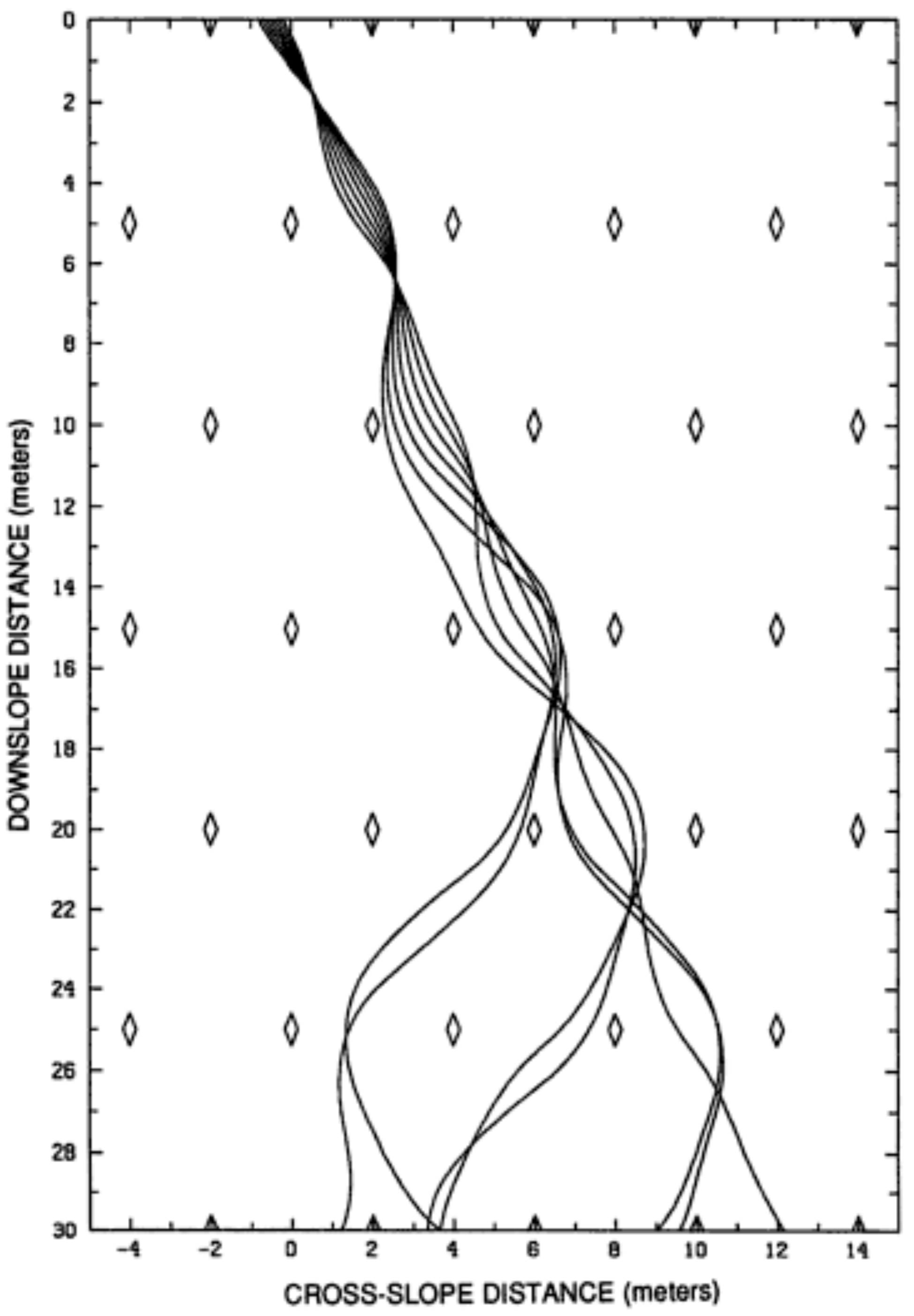


Figure 6. A top view of a section of the model ski slope, with the path of a single board sliding down it. The shaded rectangular areas of the slope project above a simple inclined plane, while the unshaded areas project below.

From Lorenz, *The Essence of Chaos*

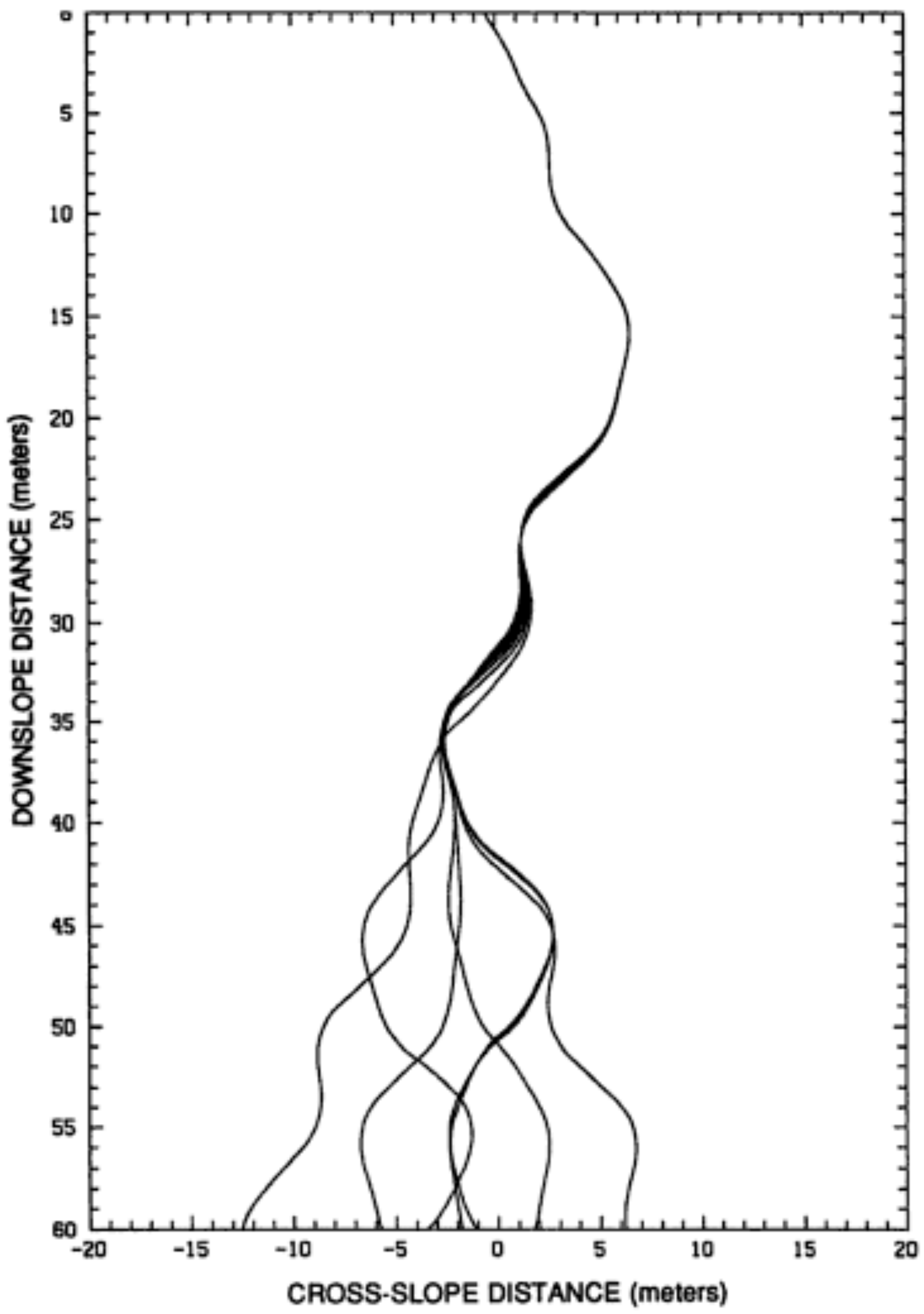
Space the boards 10 cm apart and push down the slope at identical velocity



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

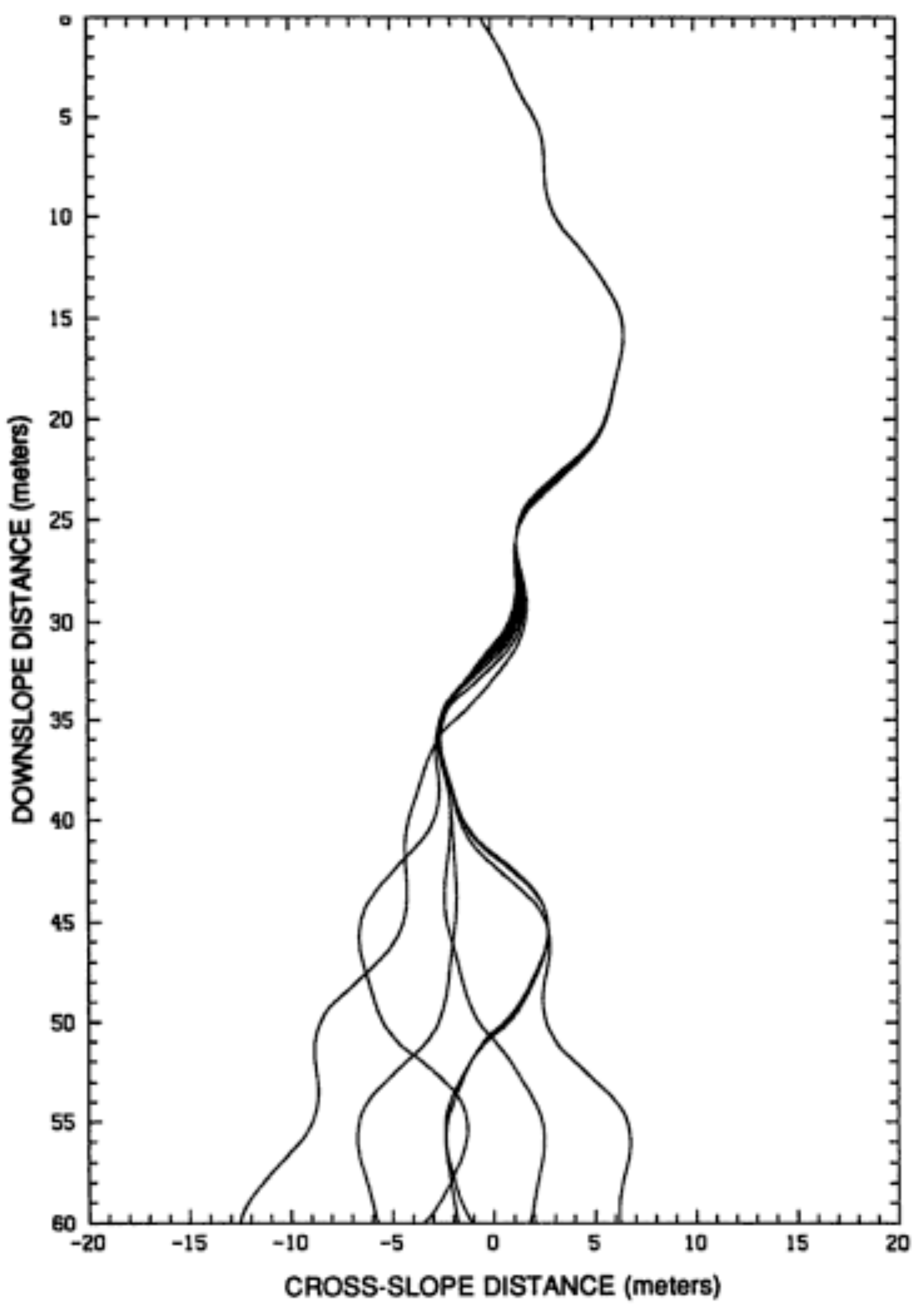


From Lorenz, *The Essence of Chaos*

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

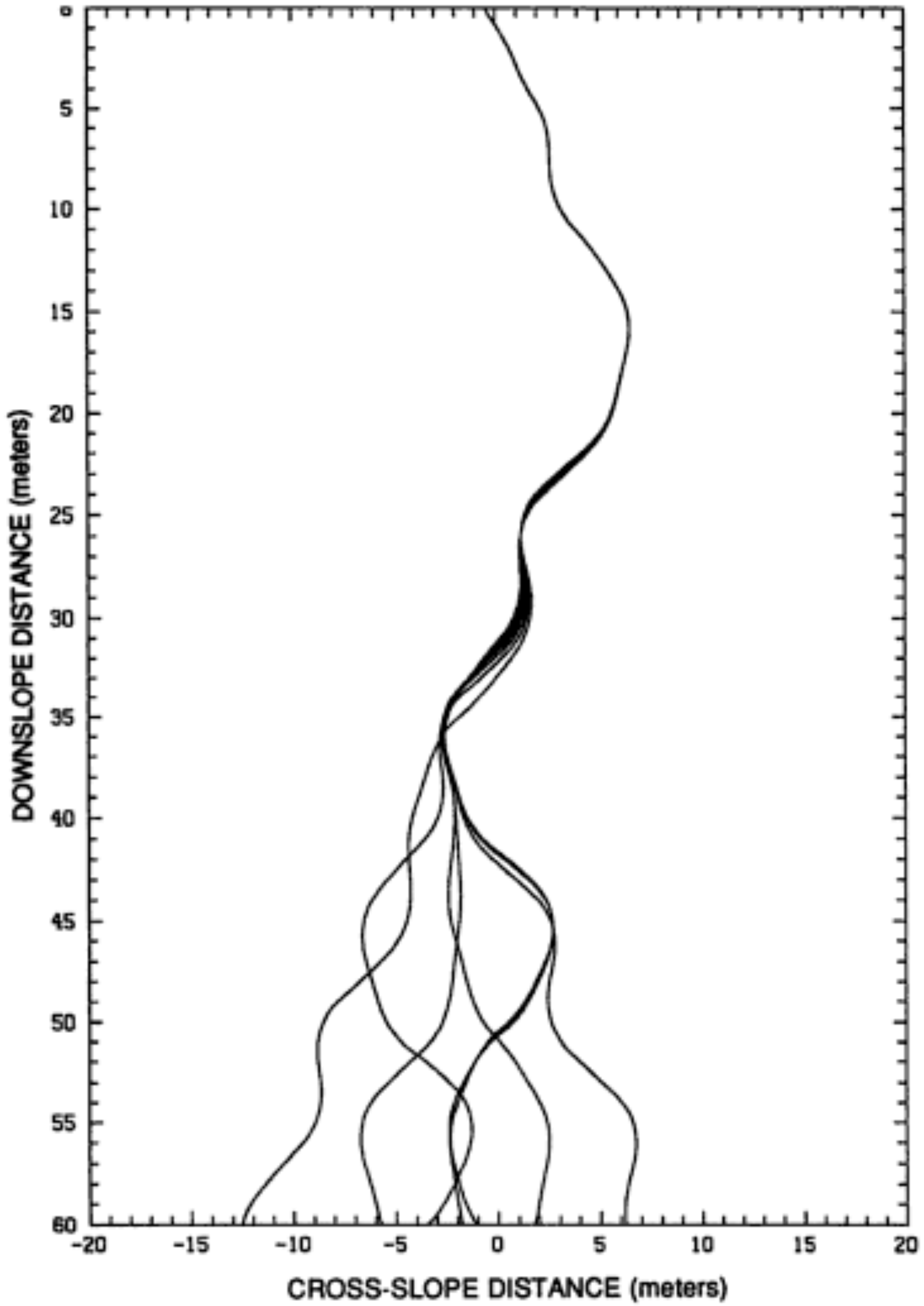
And if you pushed lots and lots of boards, you'd get a pretty good idea of where they tend to finish – this is akin to climate modeling, where you don't care about the weather on a given day, but about the *statistics* of the weather over long time periods

From Lorenz, *The Essence of Chaos*



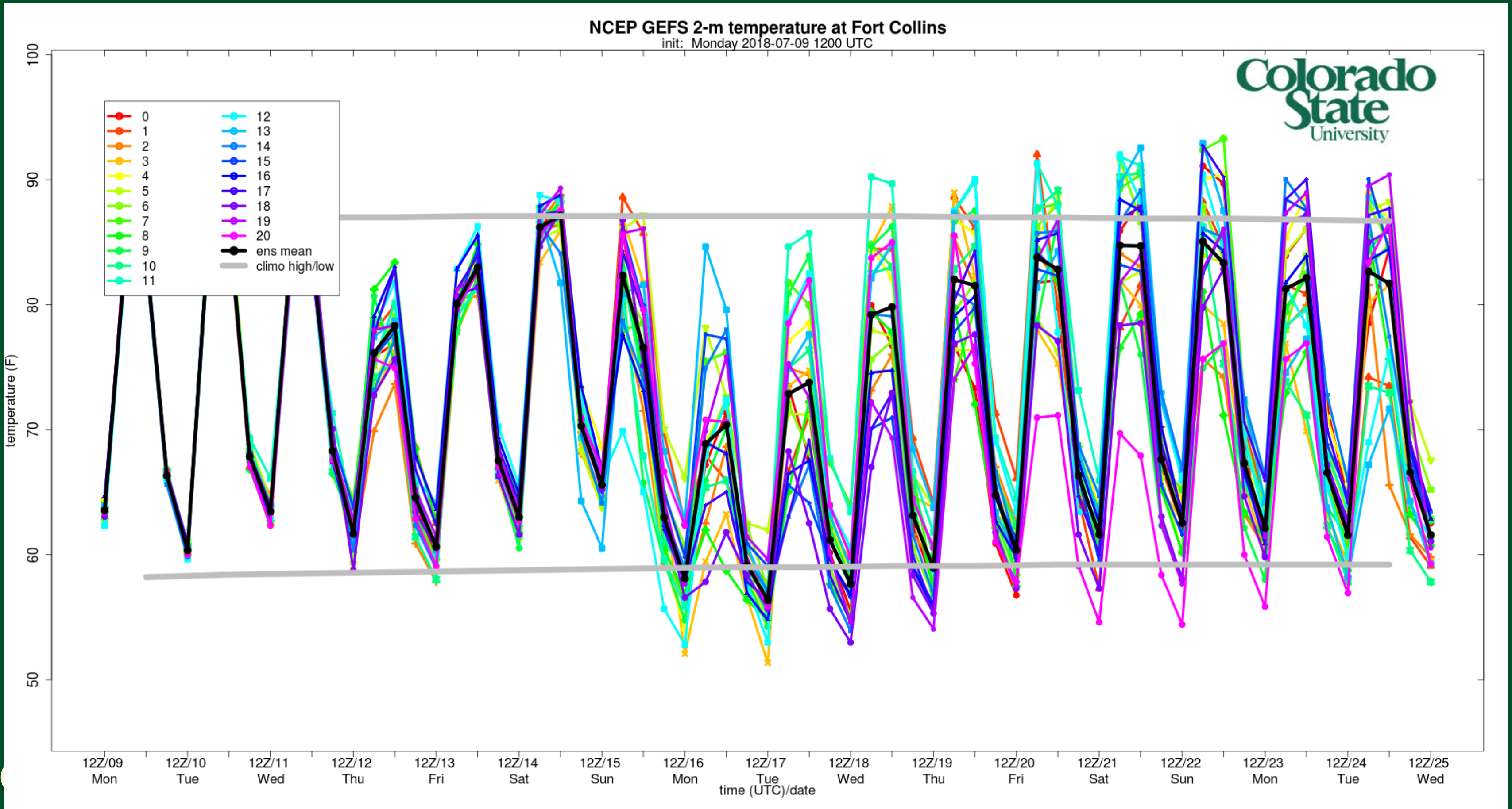
And if you changed the steepness of the hill, or removed some of the moguls, you'd expect some rather different outcomes...

From Lorenz, *The Essence of Chaos*



Ensembles of models

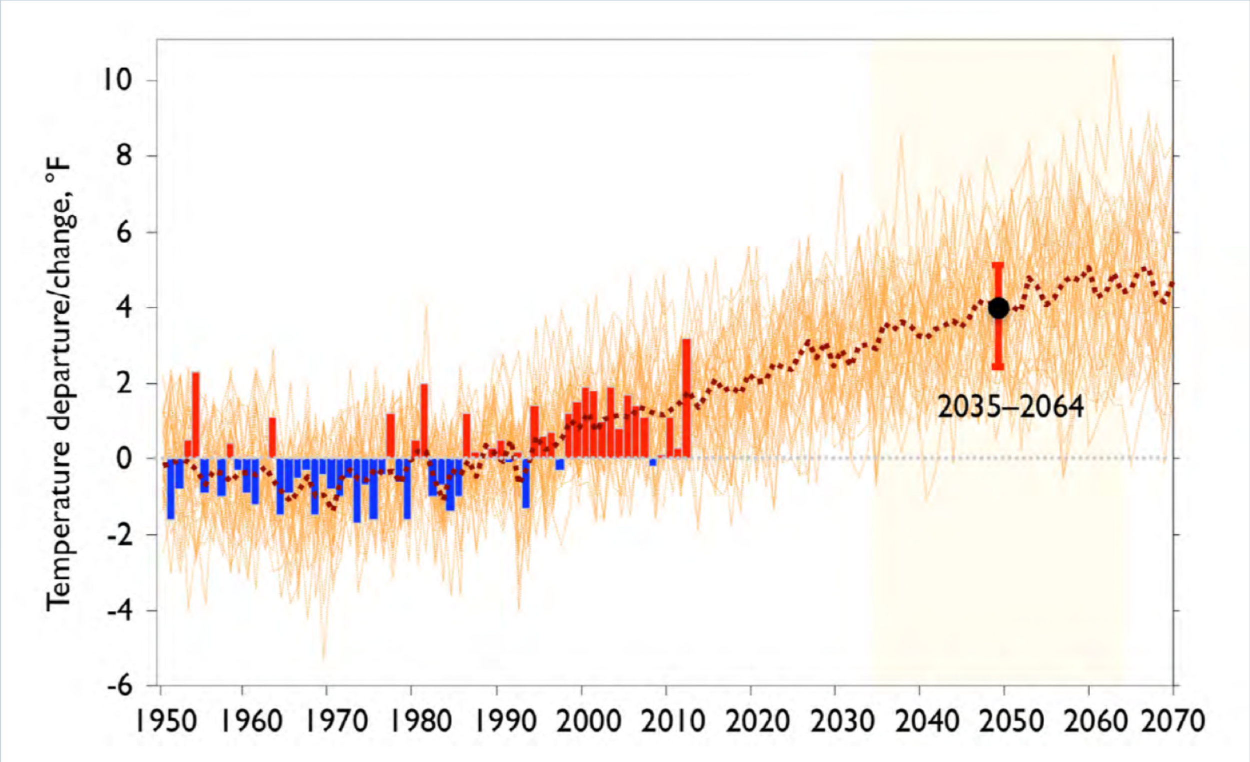
- In both weather and climate modeling, we want to use ‘ensembles’ – multiple models with some small changes to the initial conditions, or the parameters in the model – in principle this gives a good representation of the range of possible outcomes, best and worst case scenarios, etc.

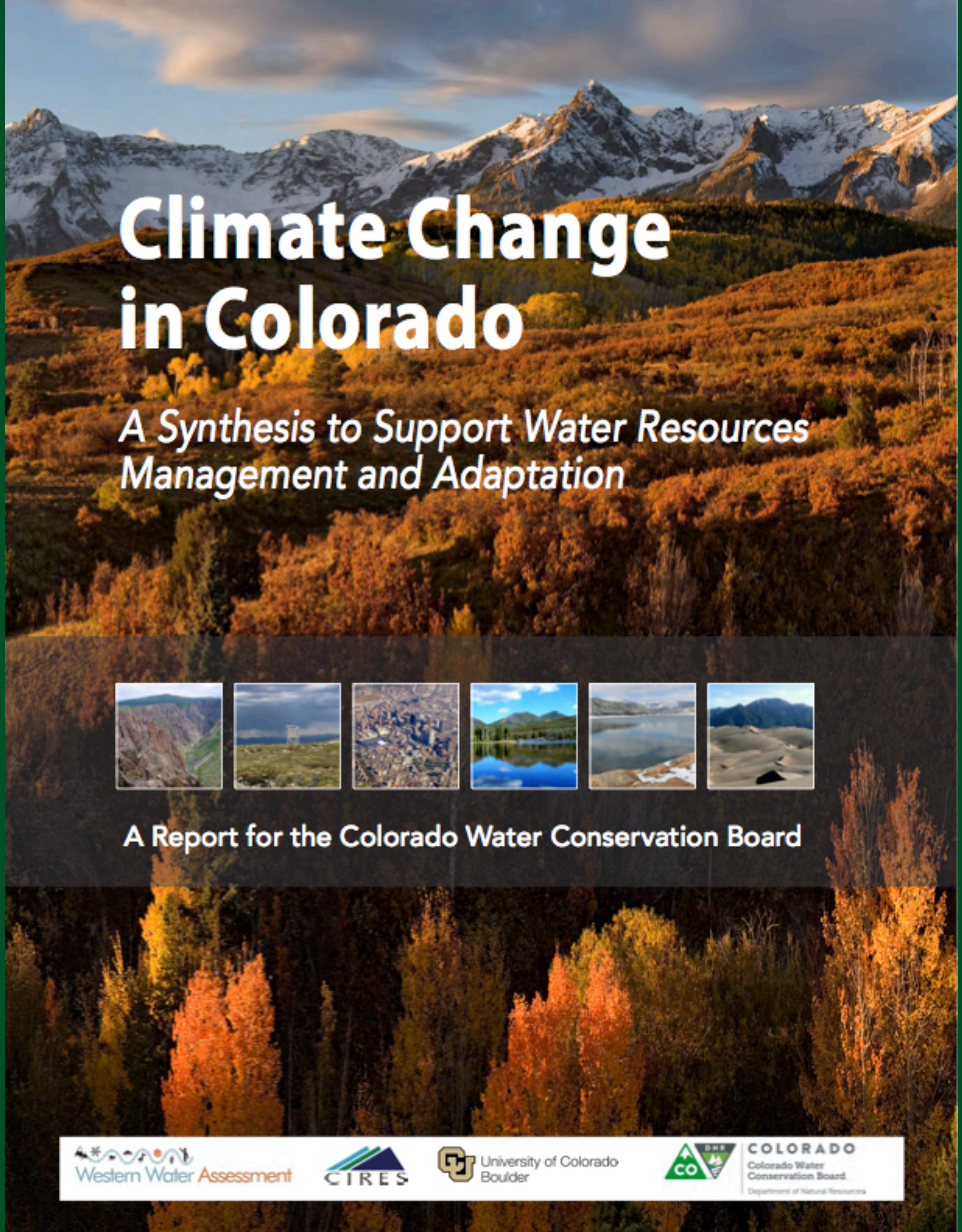


Ensembles of models

- 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

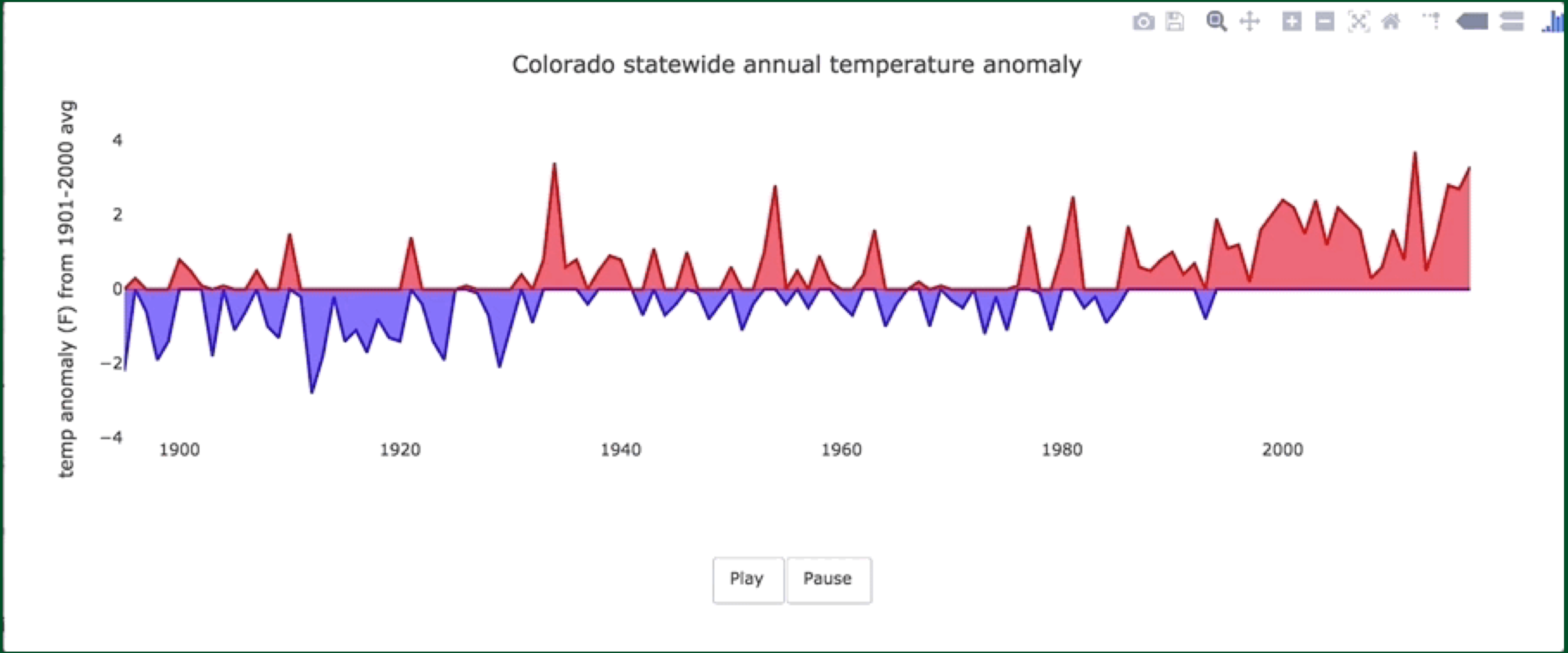


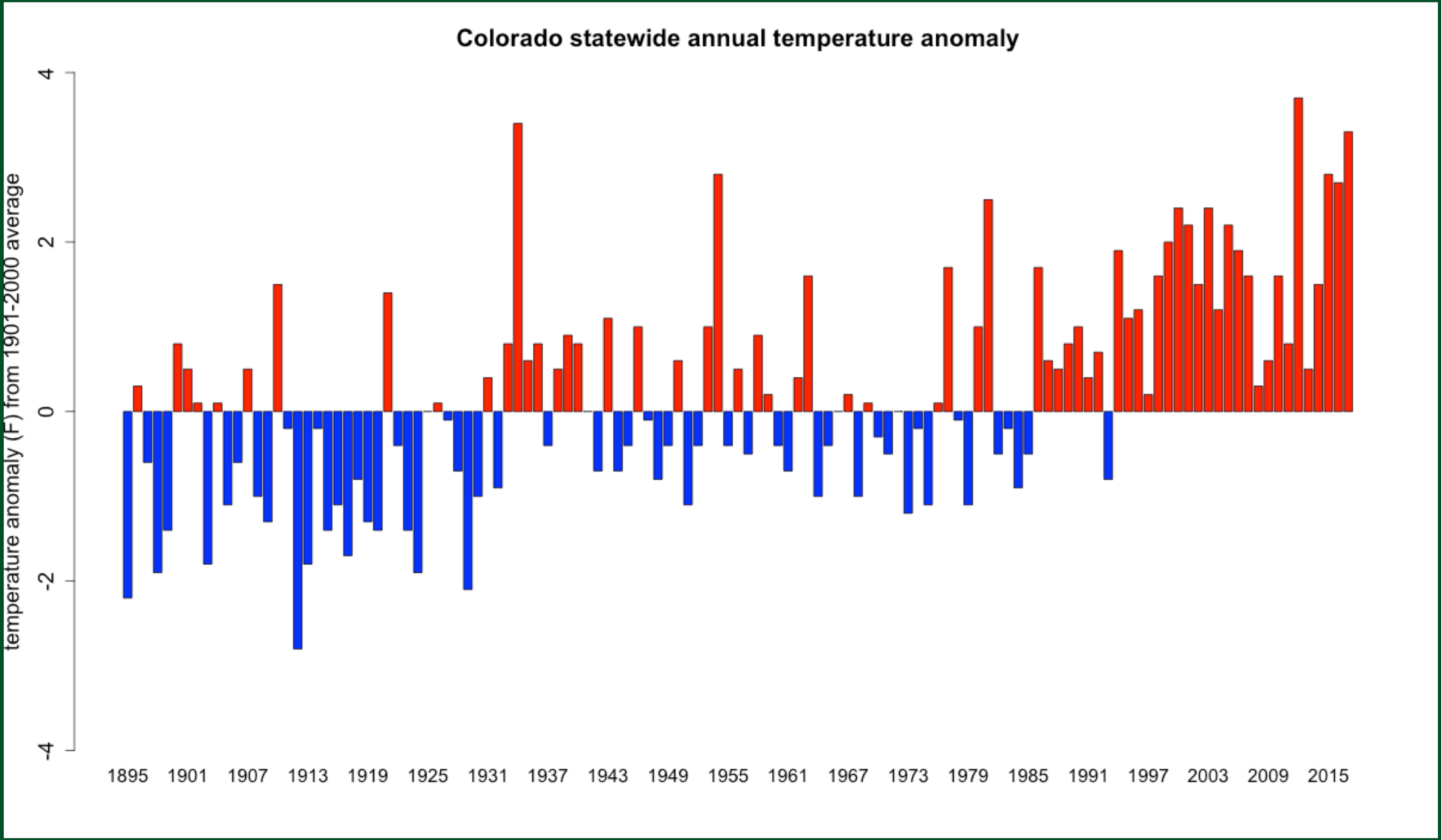


Recommended reading – some of the following is based on this report

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

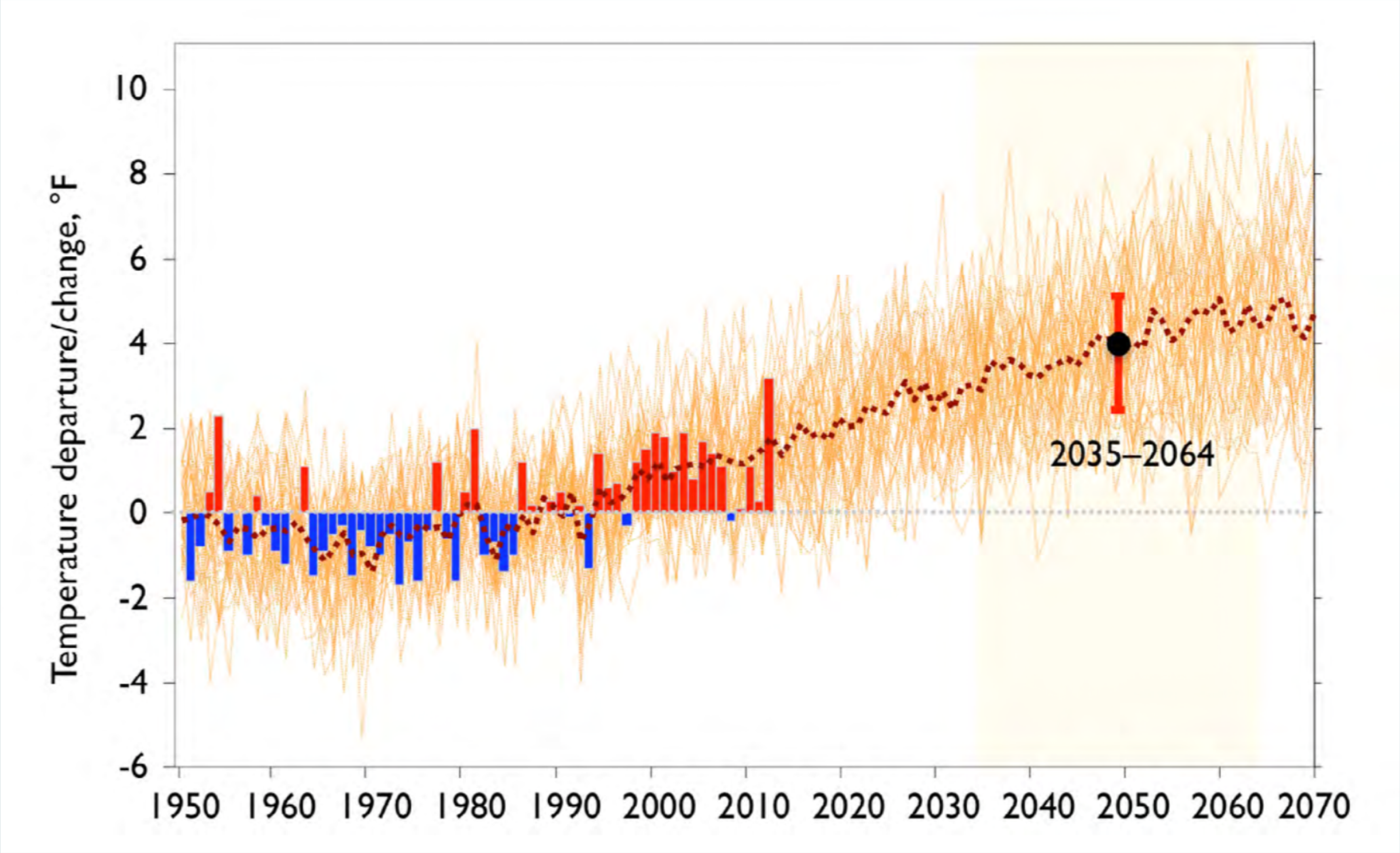
Statewide temperatures, 1895-2017





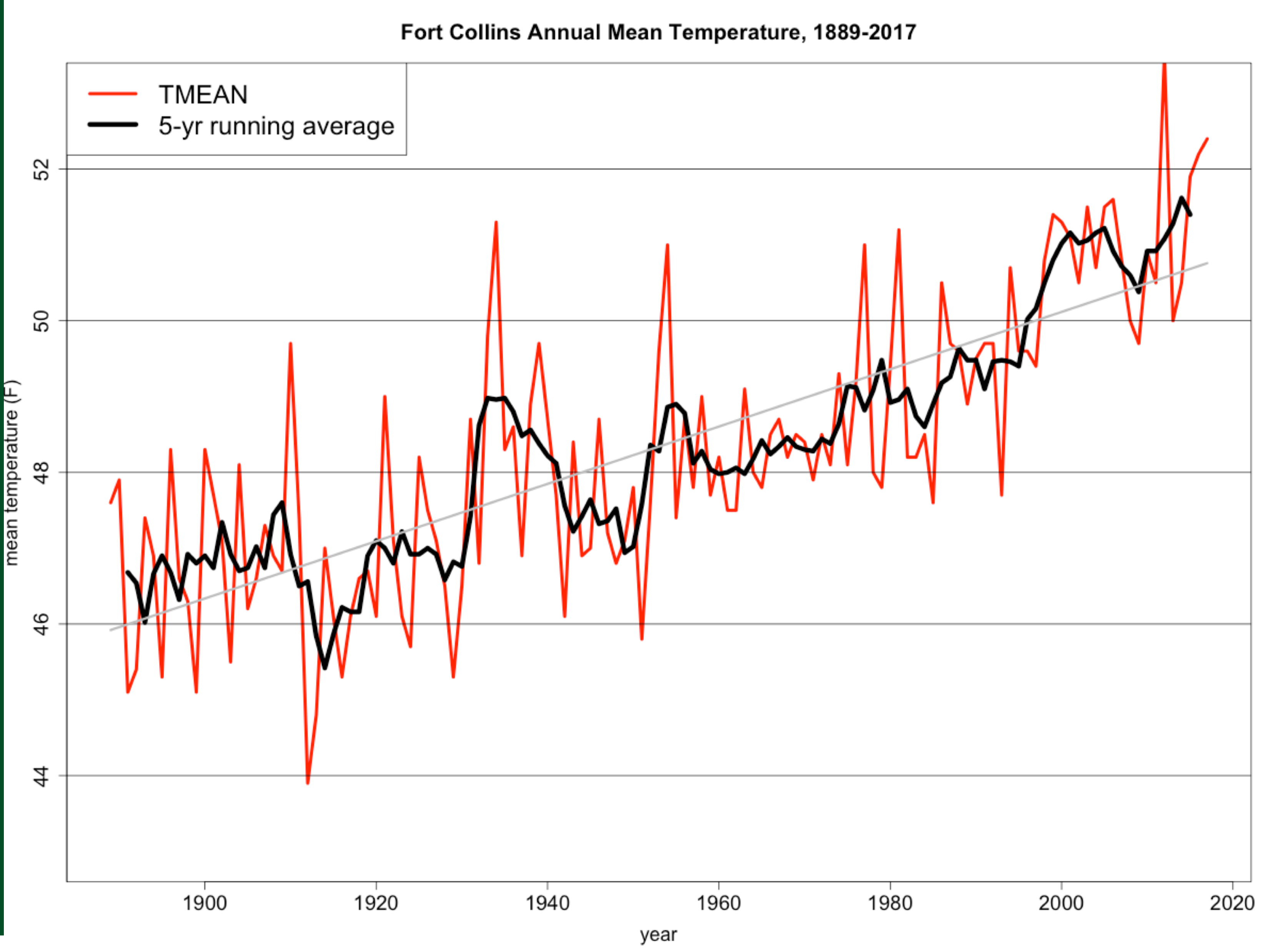
Updated through 2017

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



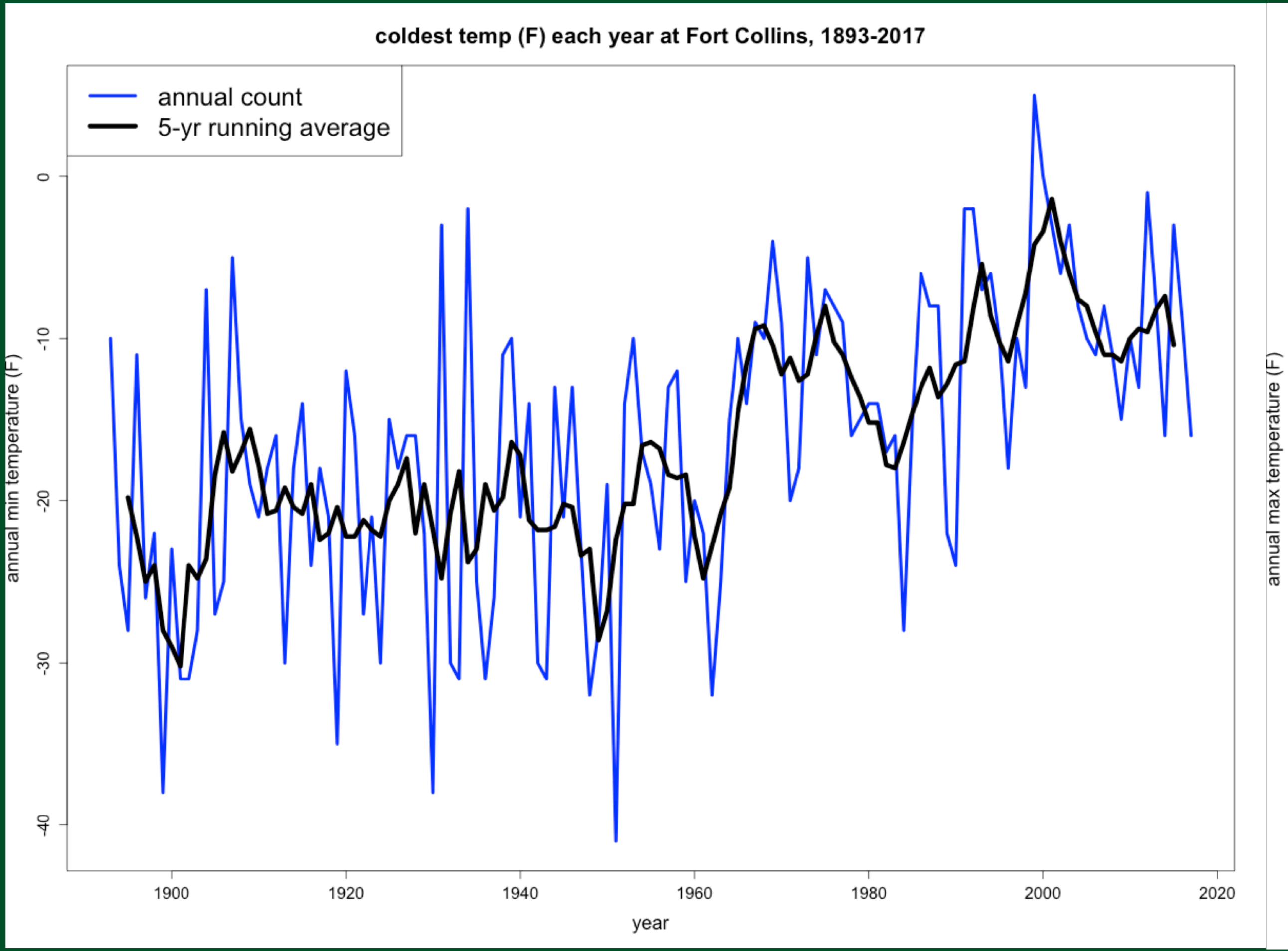
Average temperature increase of 2.5-5°F, for middle-of-the-road emissions scenario

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

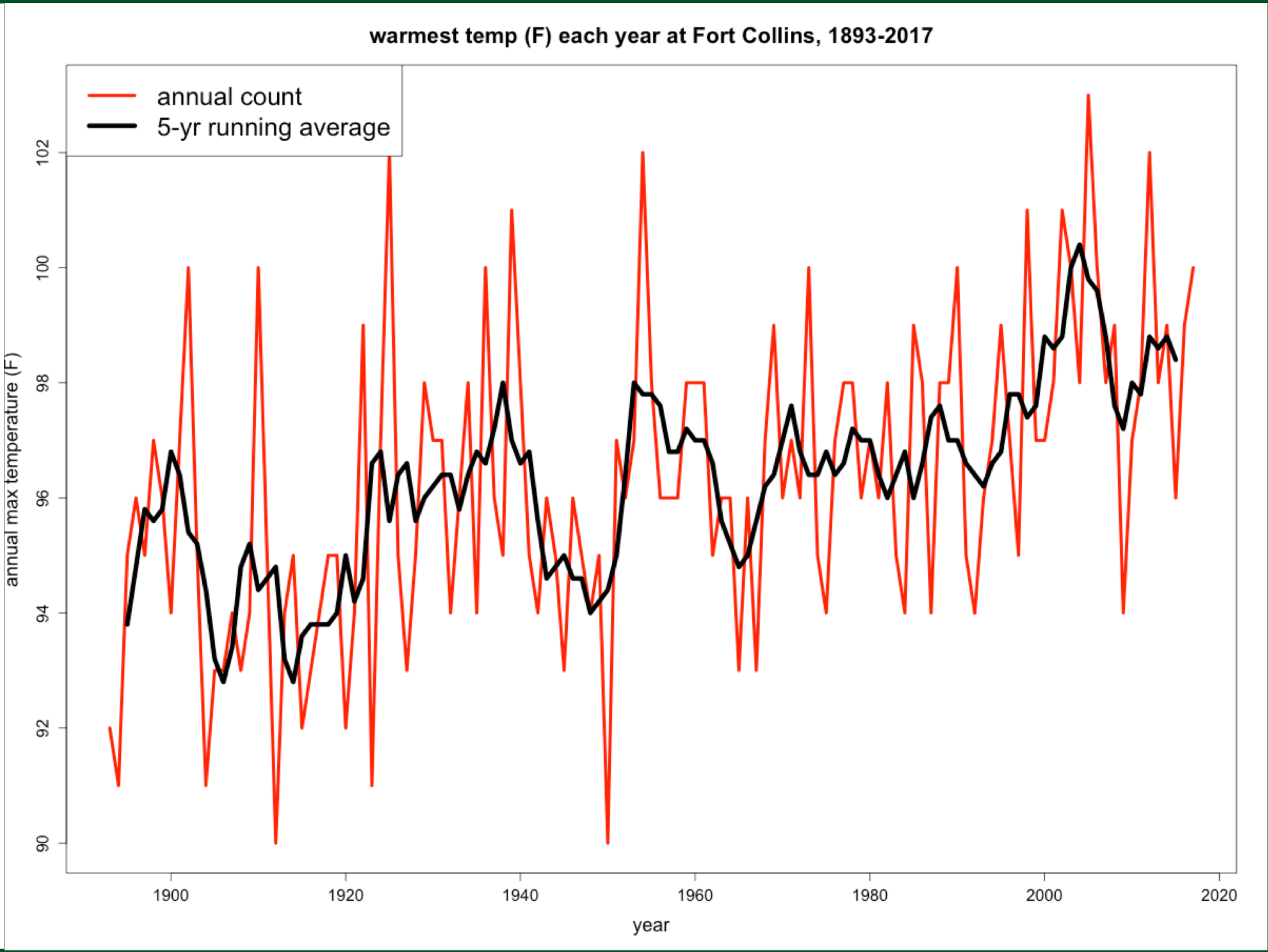


Mean: 48.3 F
Std Dev: 1.9° F
Warmest Year: 53.5° F (2012) **2017 was 2nd warmest at 52.4° F** **2018: 51.2, 11th warmest**
Coolest Year: 43.9° F (1912)

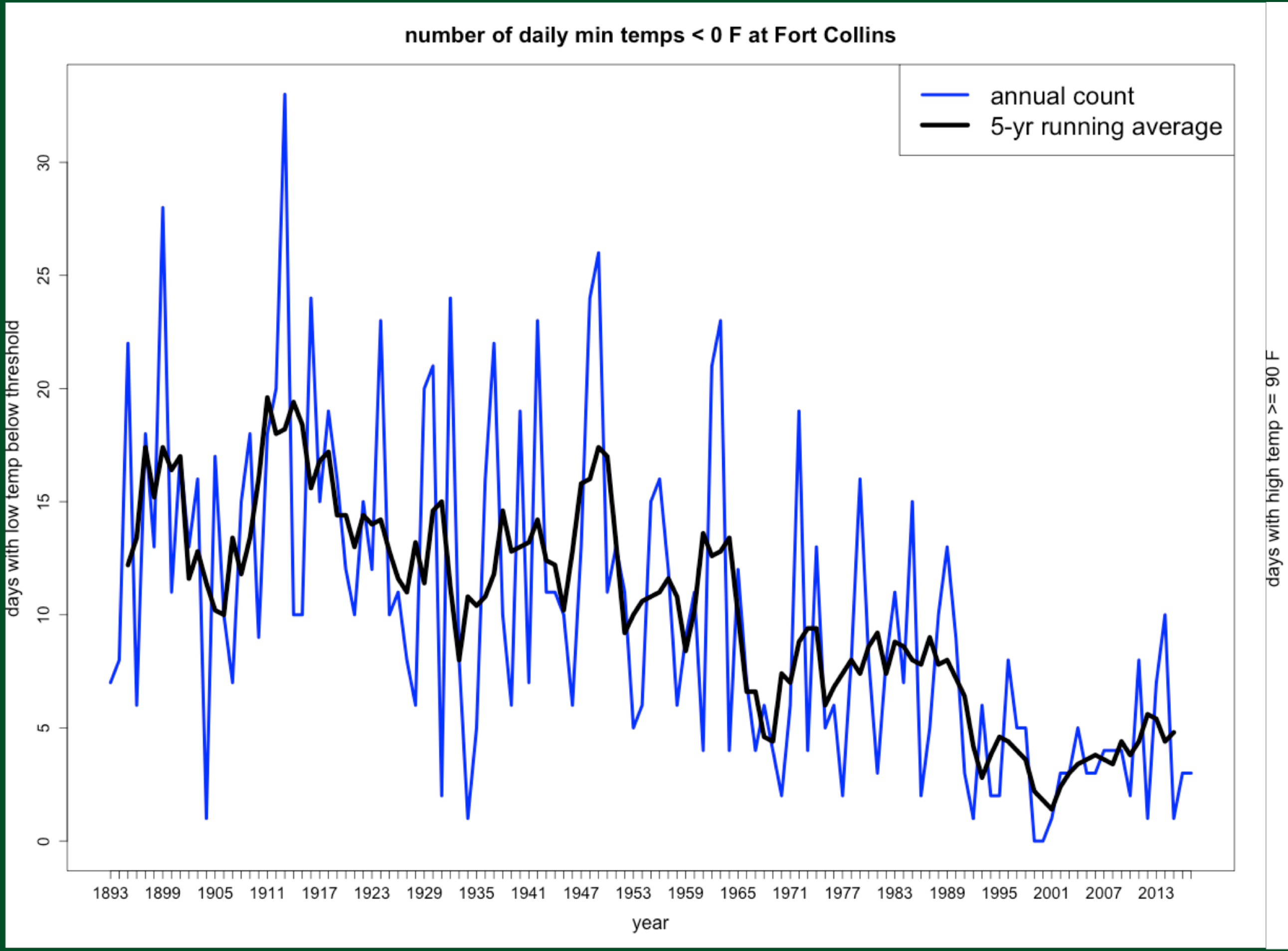
Lowest temperature of each year



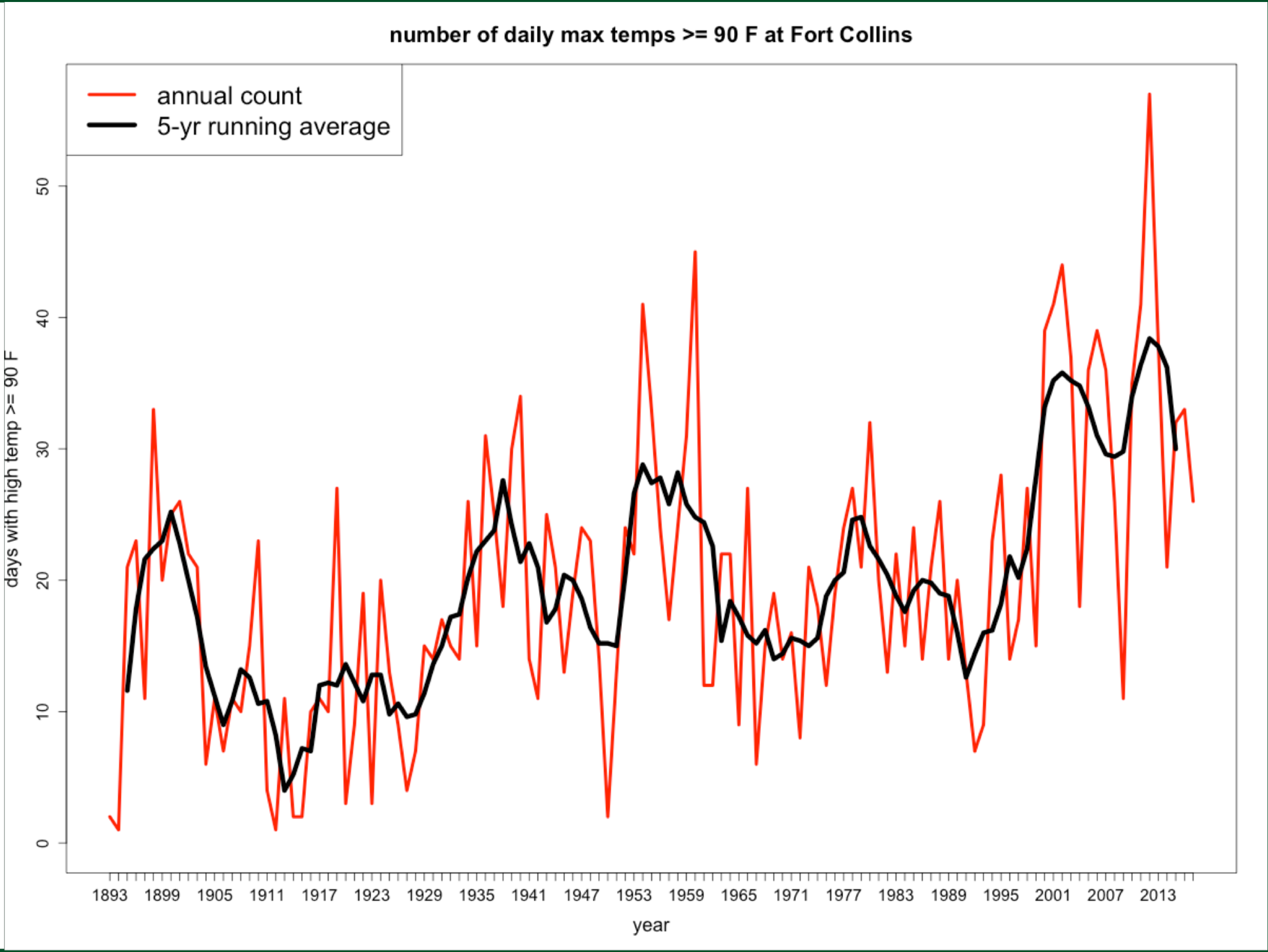
Highest temperature of each year

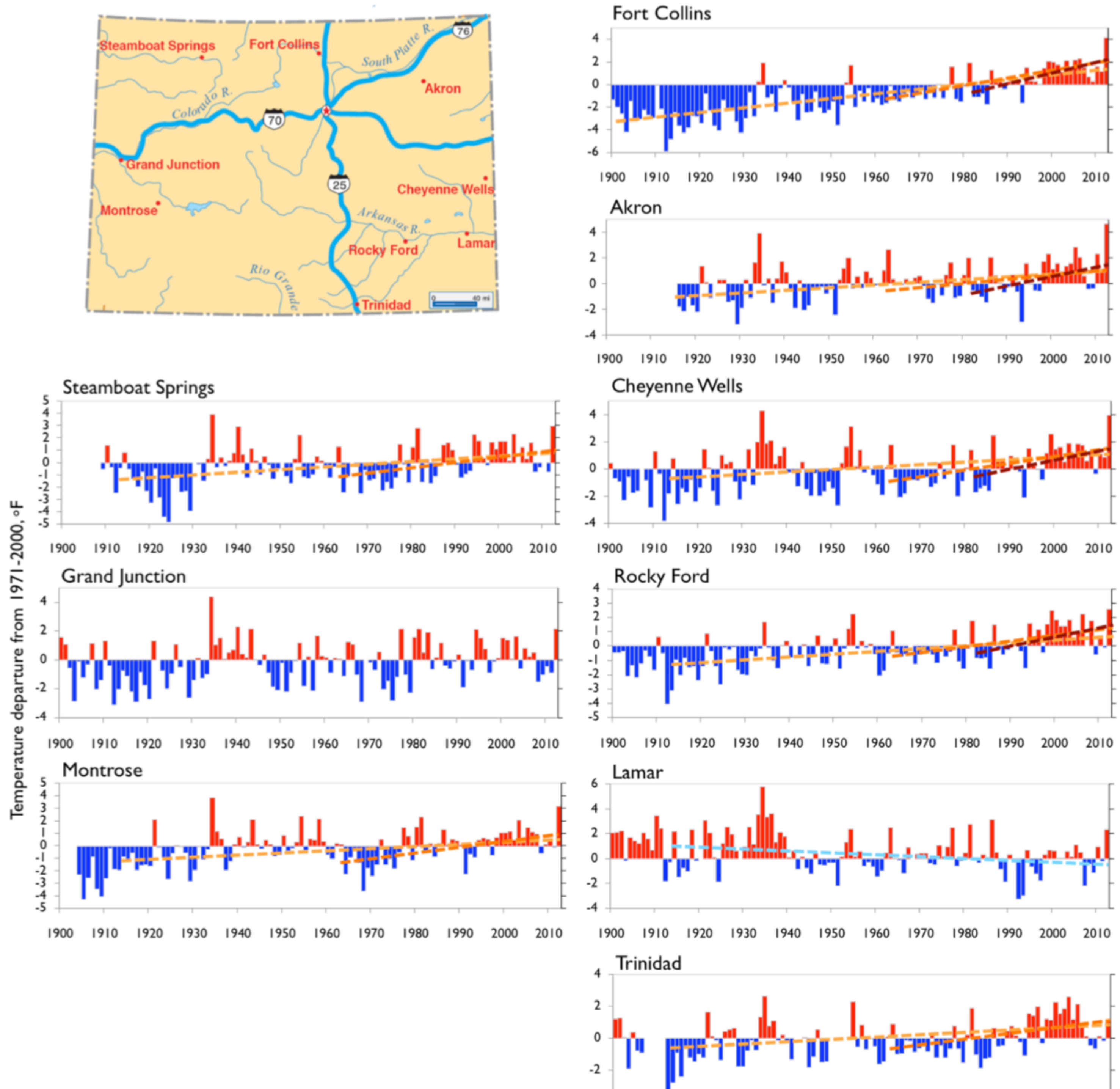


Number of below-zero nights



Number of 90-degree days





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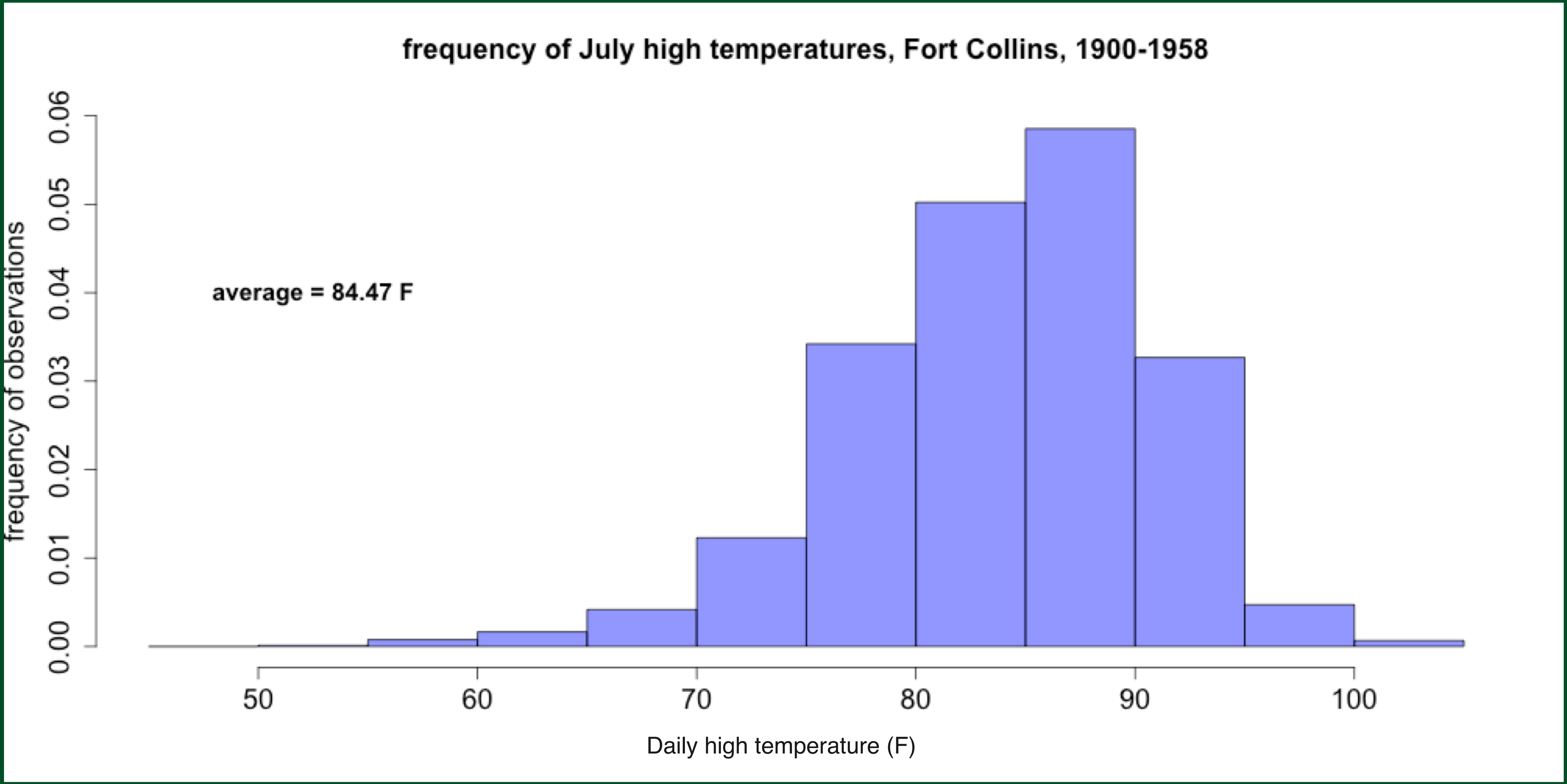
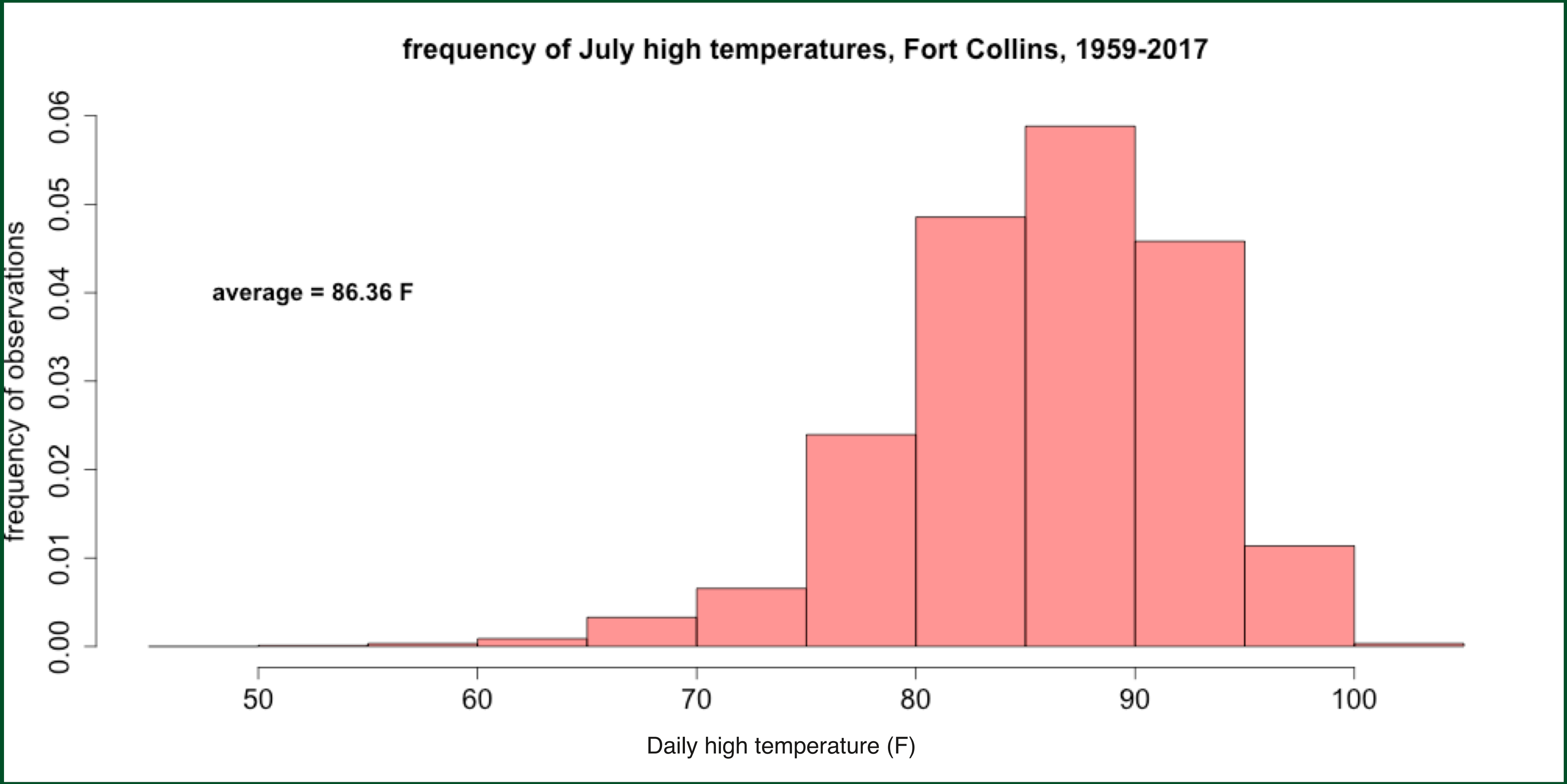
Trends around the state: temperature

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?

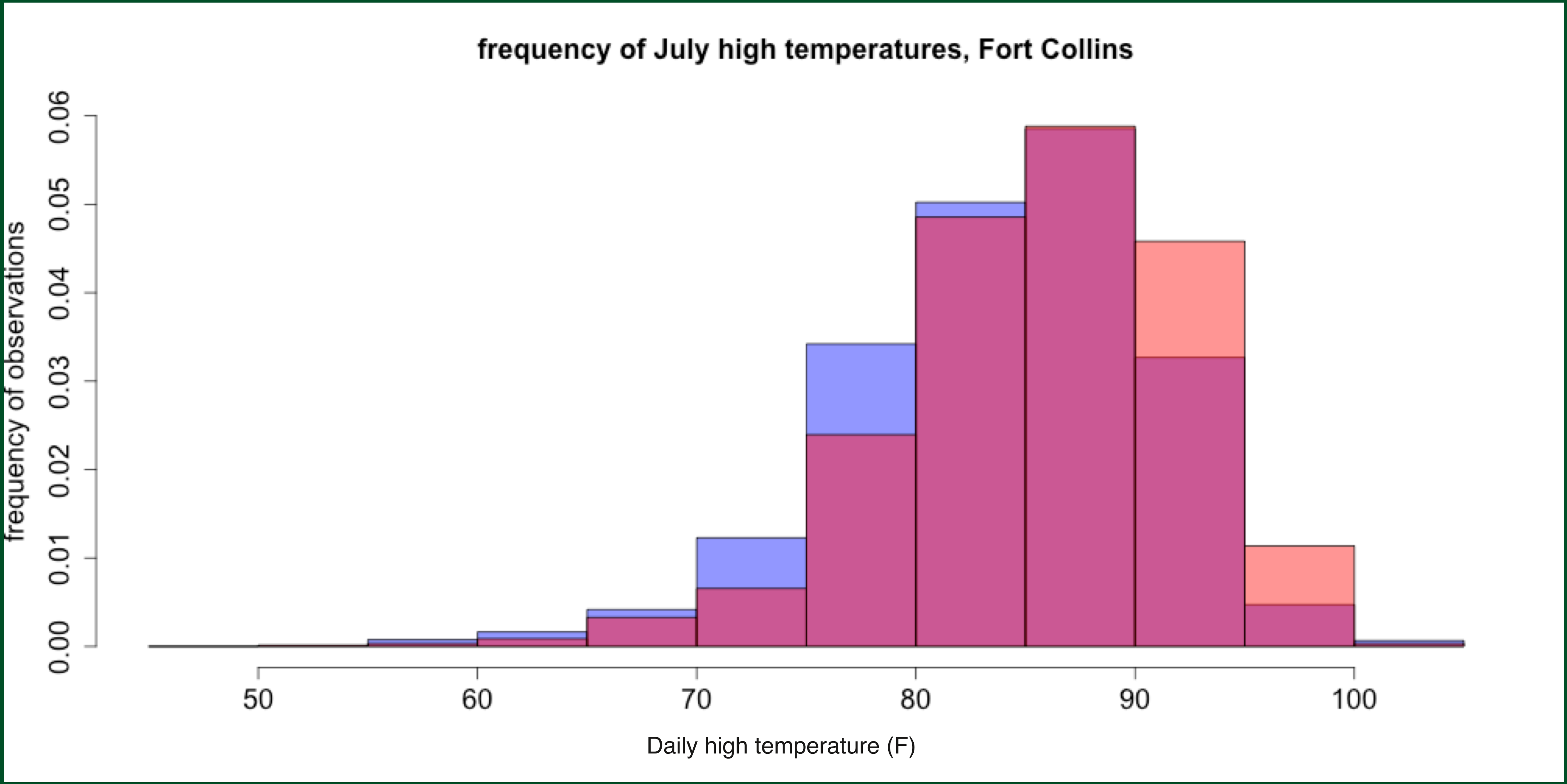
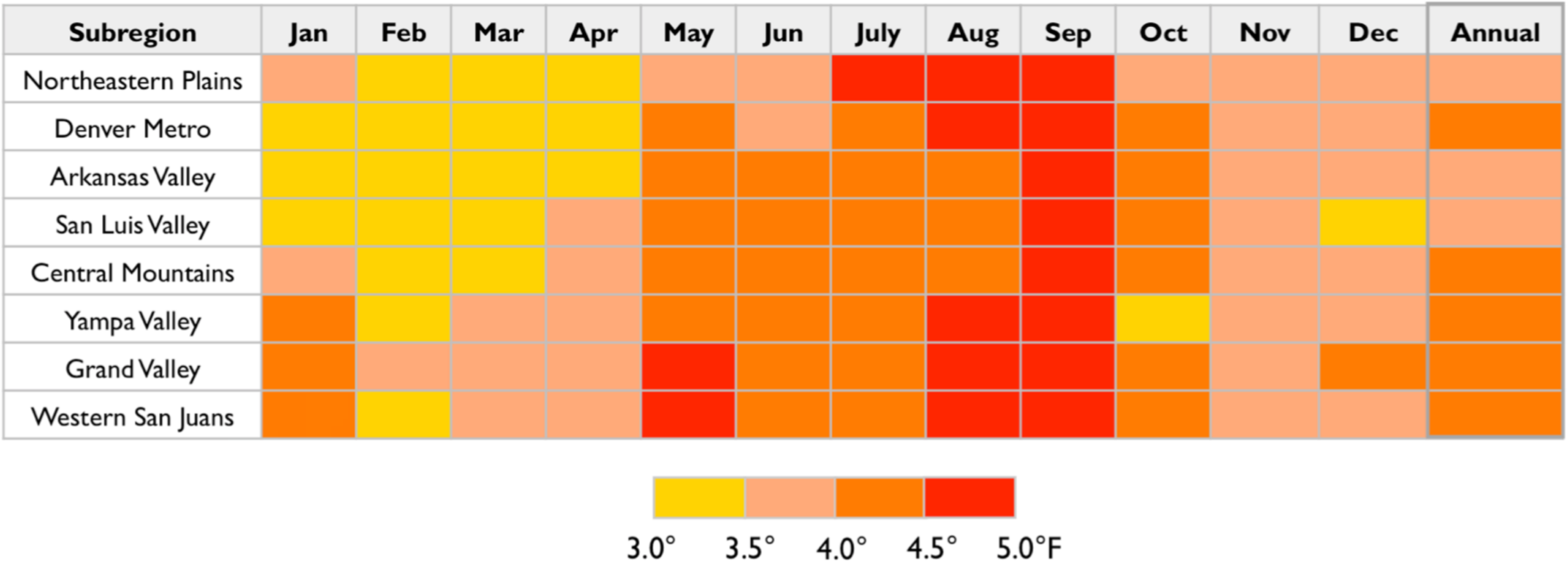
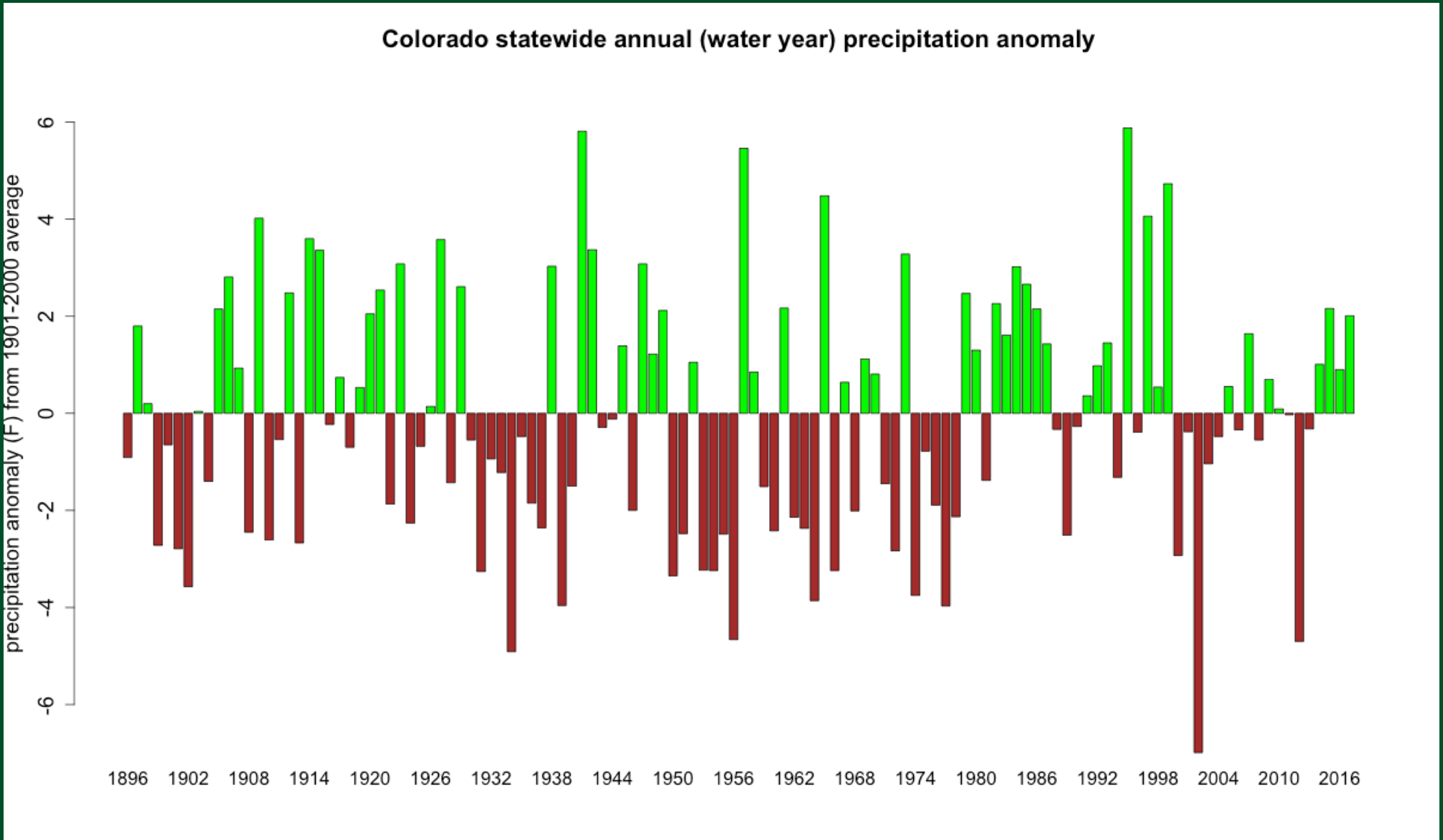
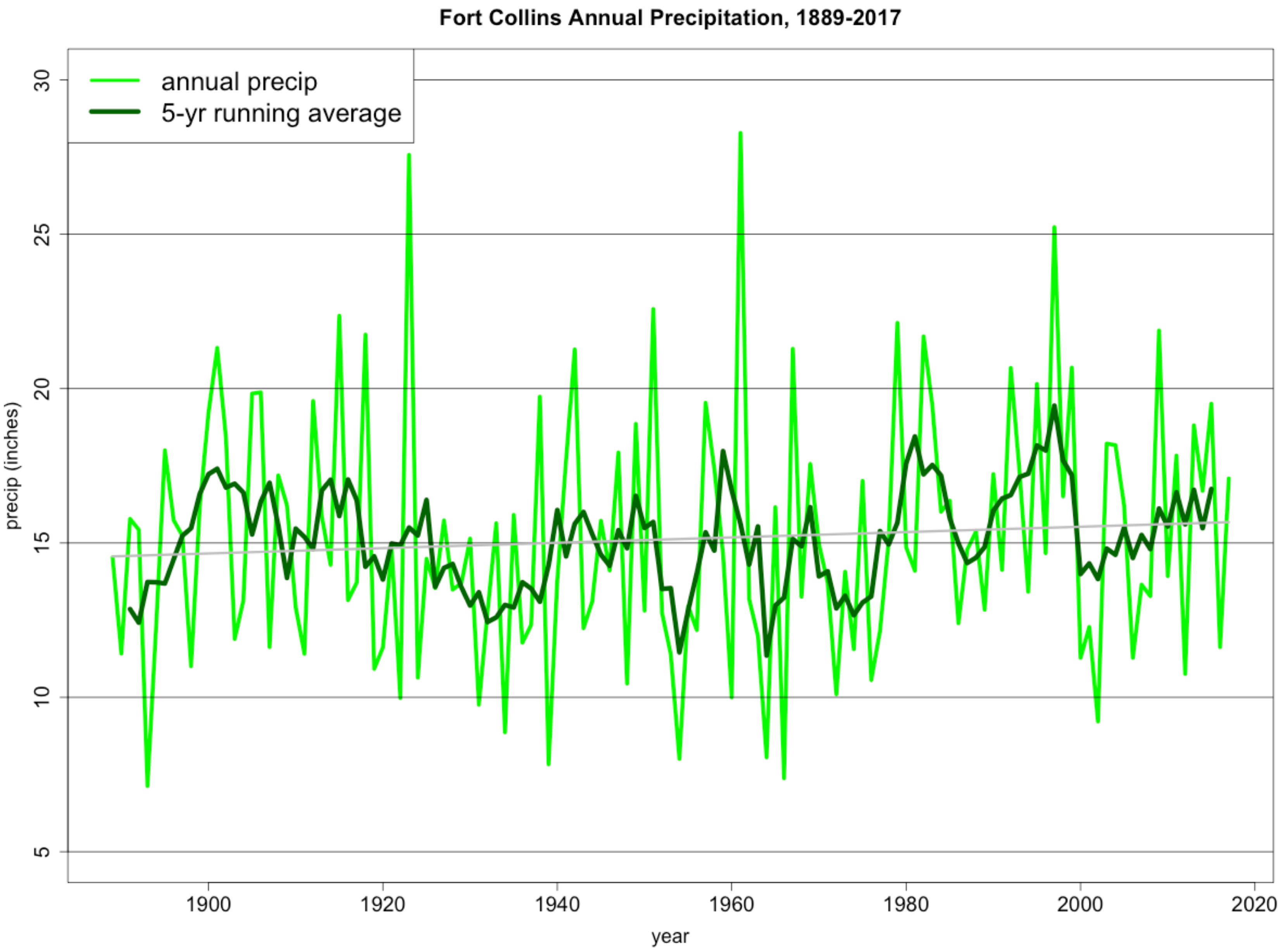


TABLE 5-1. Projected monthly temperature change for eight subregions under RCP 4.5 for 2035–2064



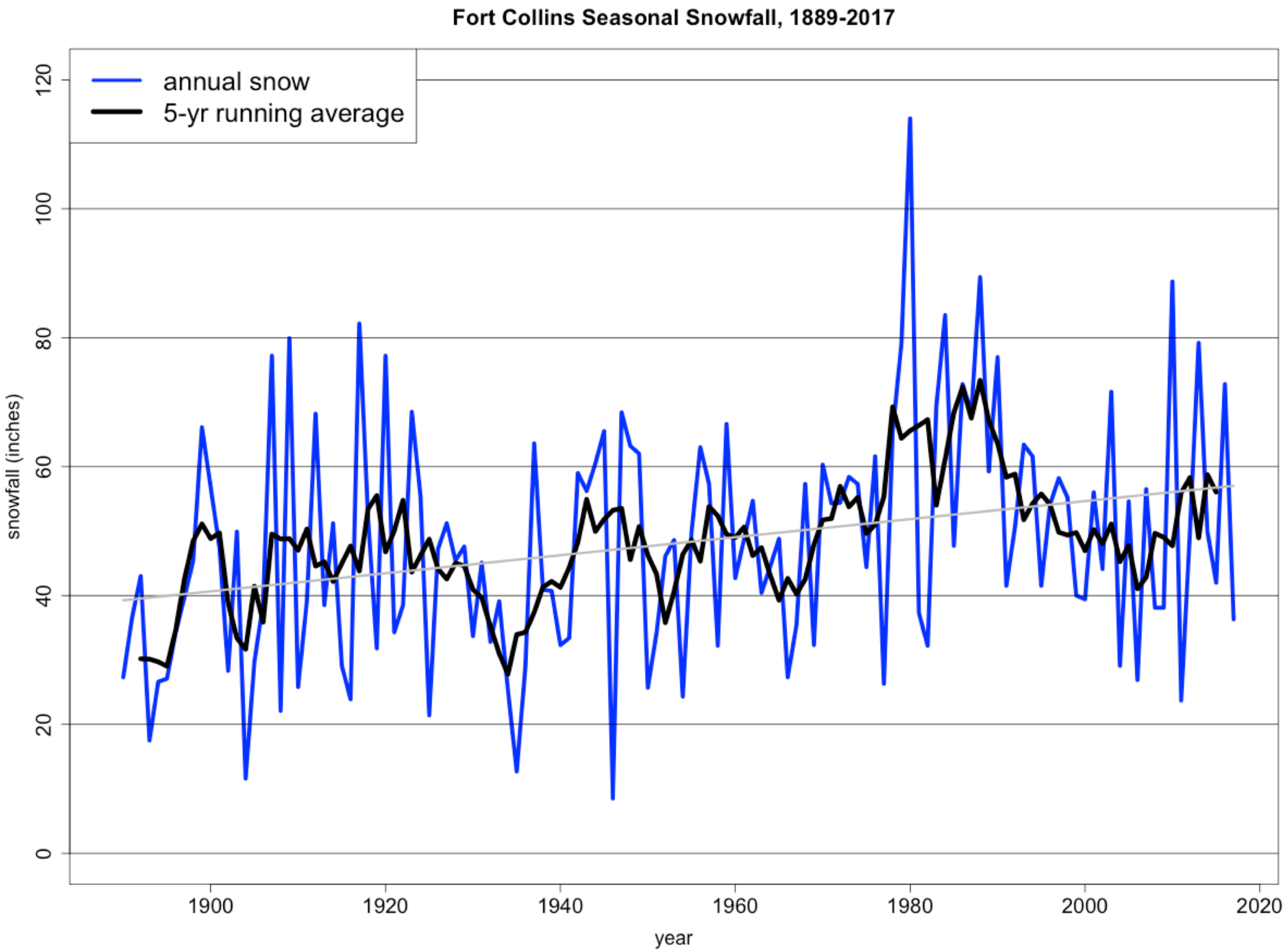
Precipitation is a lot more complicated...





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



Mean: 48.1”
Std Dev: 18.3”
Record High: 114.0” (1979-80)
Record Low: 8.5” (1945-46)

COLORADO
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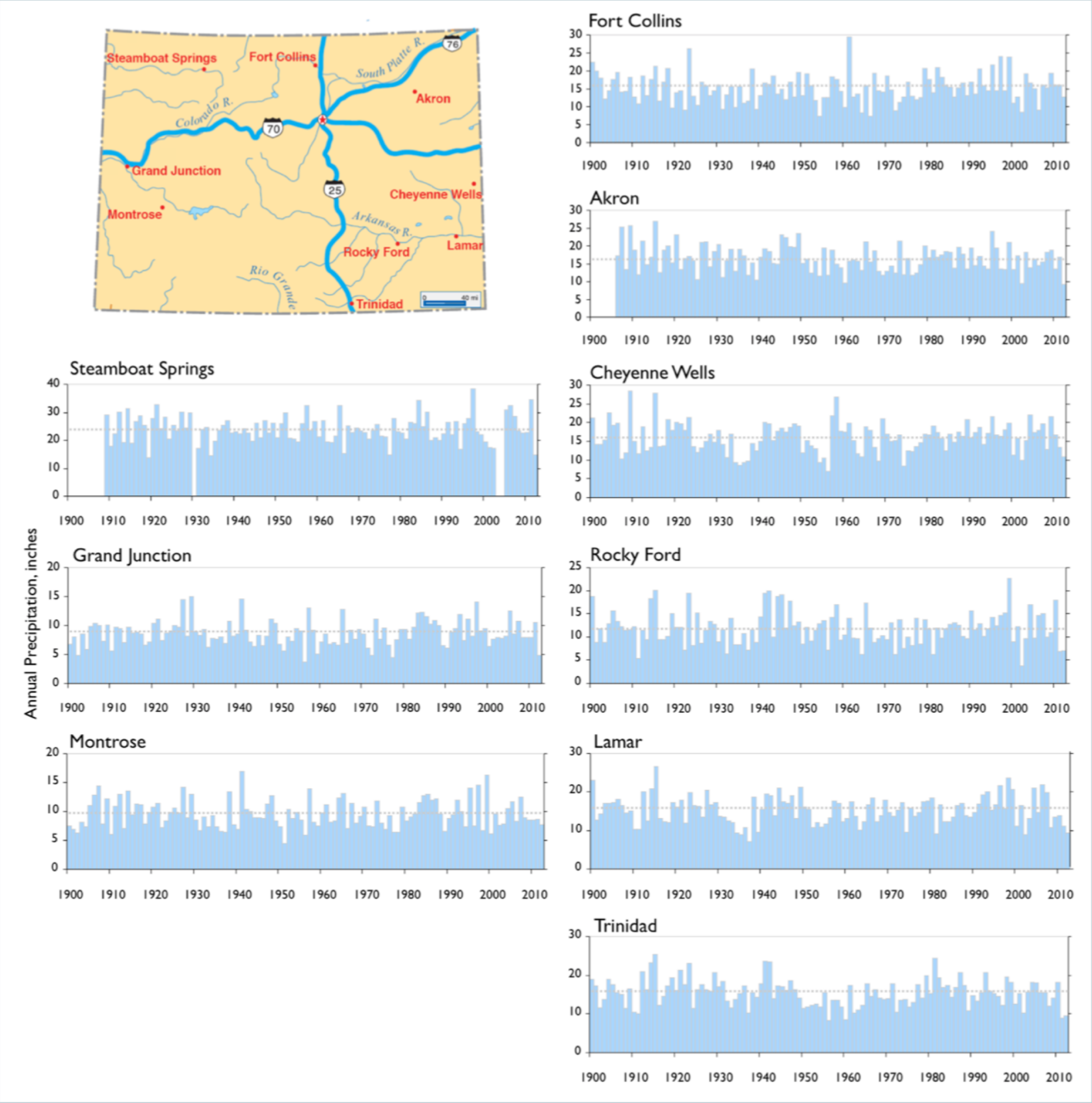
CENTER

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

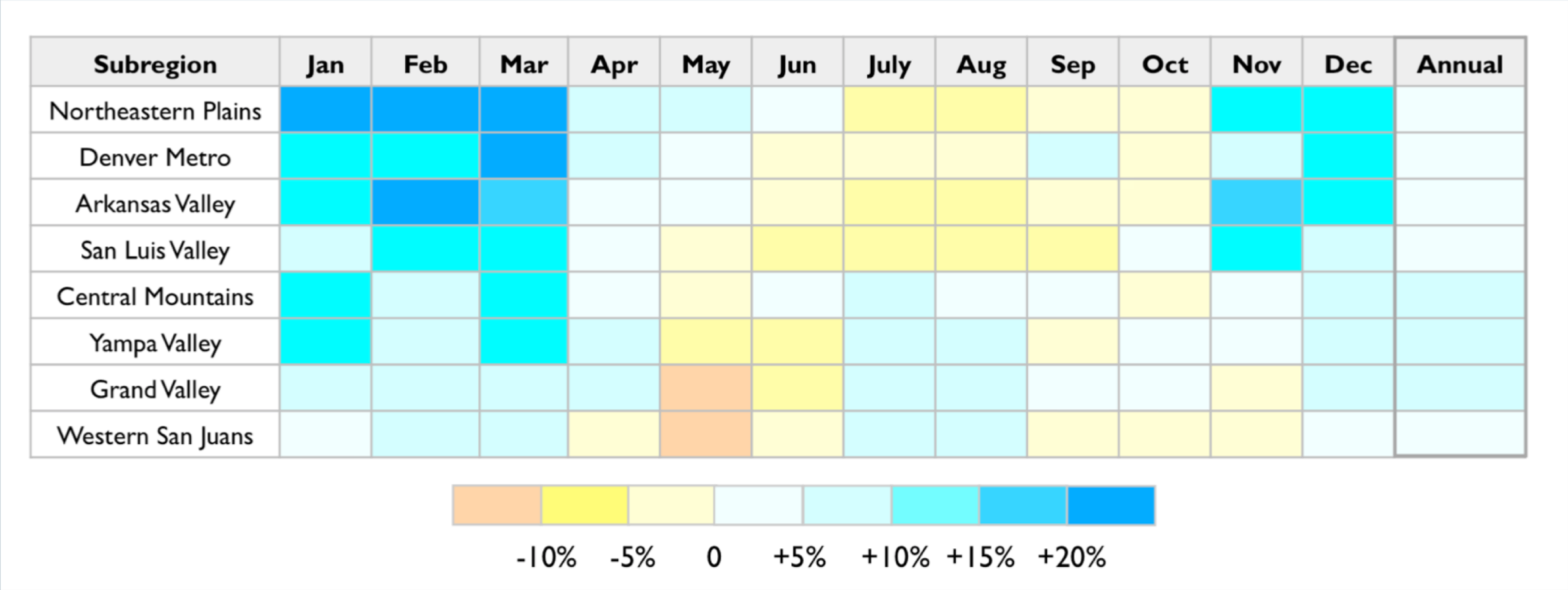


Trends around the state: precipitation

From “Climate Change in Colorado” report, 2014: http://wwa.colorado.edu/climate/co2014report/

Precipitation is a lot more complicated...

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



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

FIGURE 5-1. Projected temperature and precipitation for the western U.S. under RCP 4.5 for 2035–2064

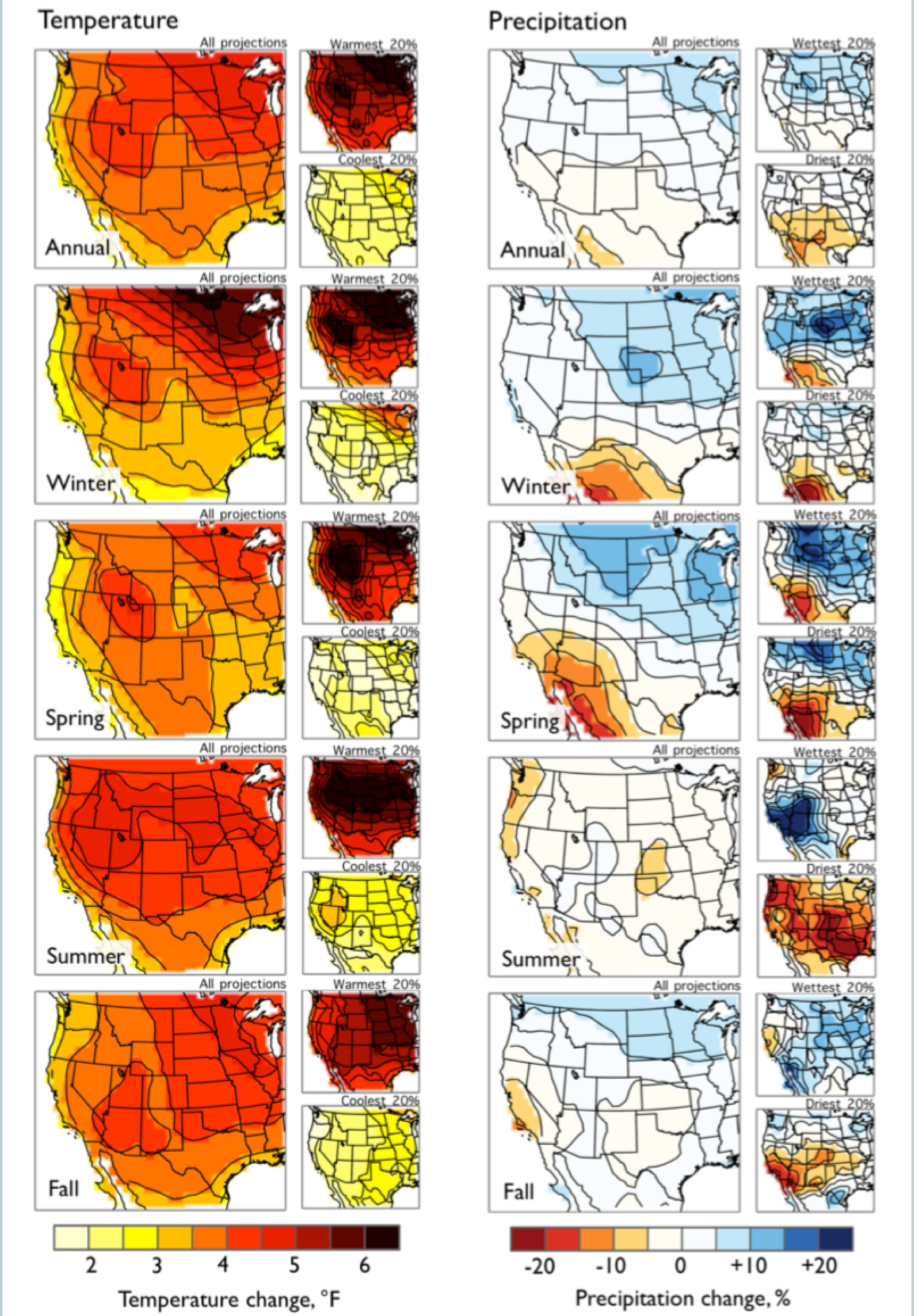
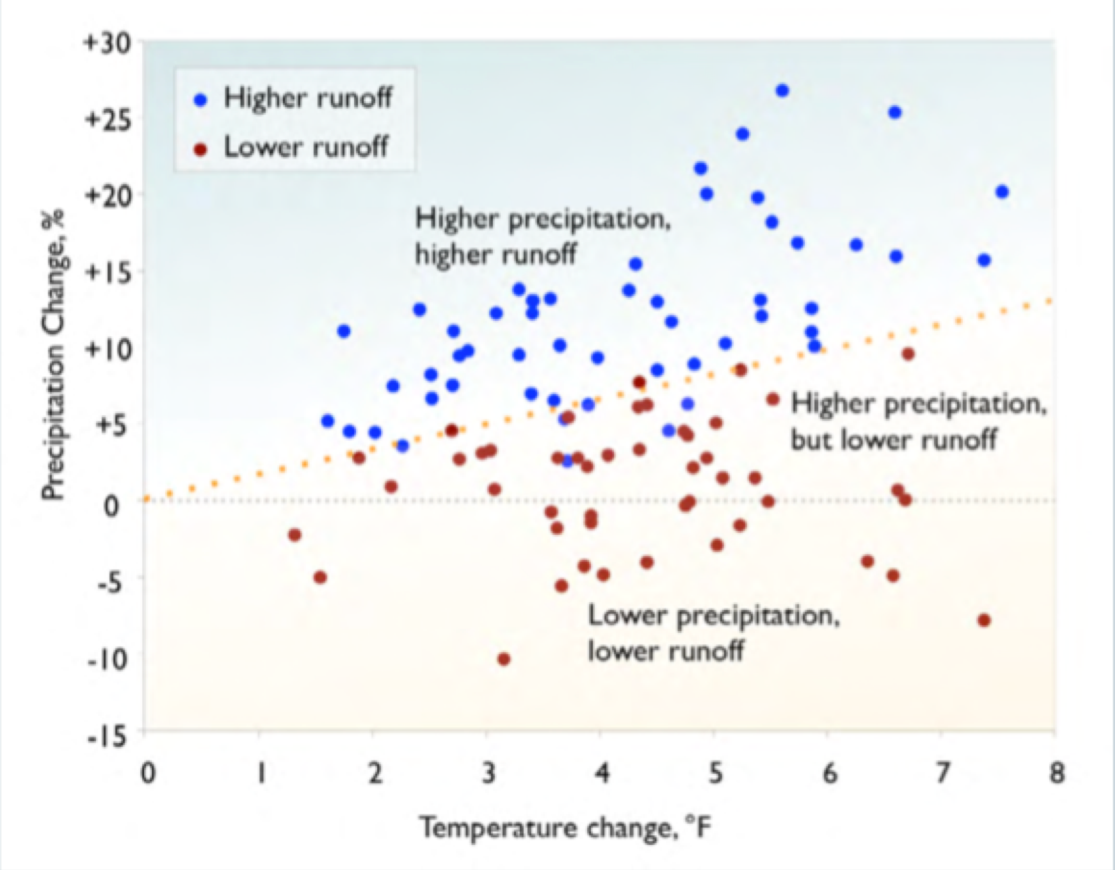


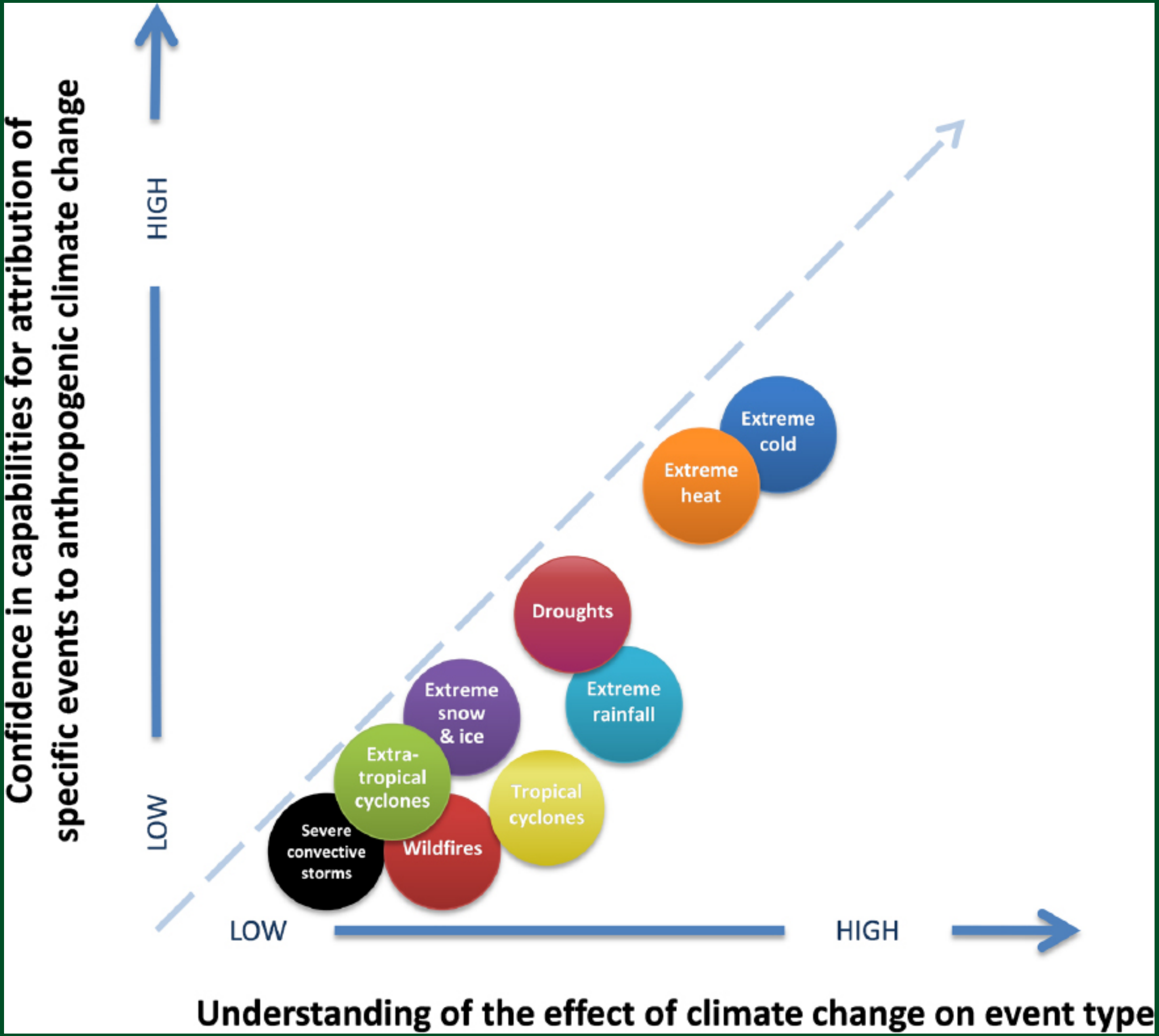
FIGURE 5-14. Direction of projected annual runoff change for the Colorado River as a function of projected temperature change and precipitation change



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.

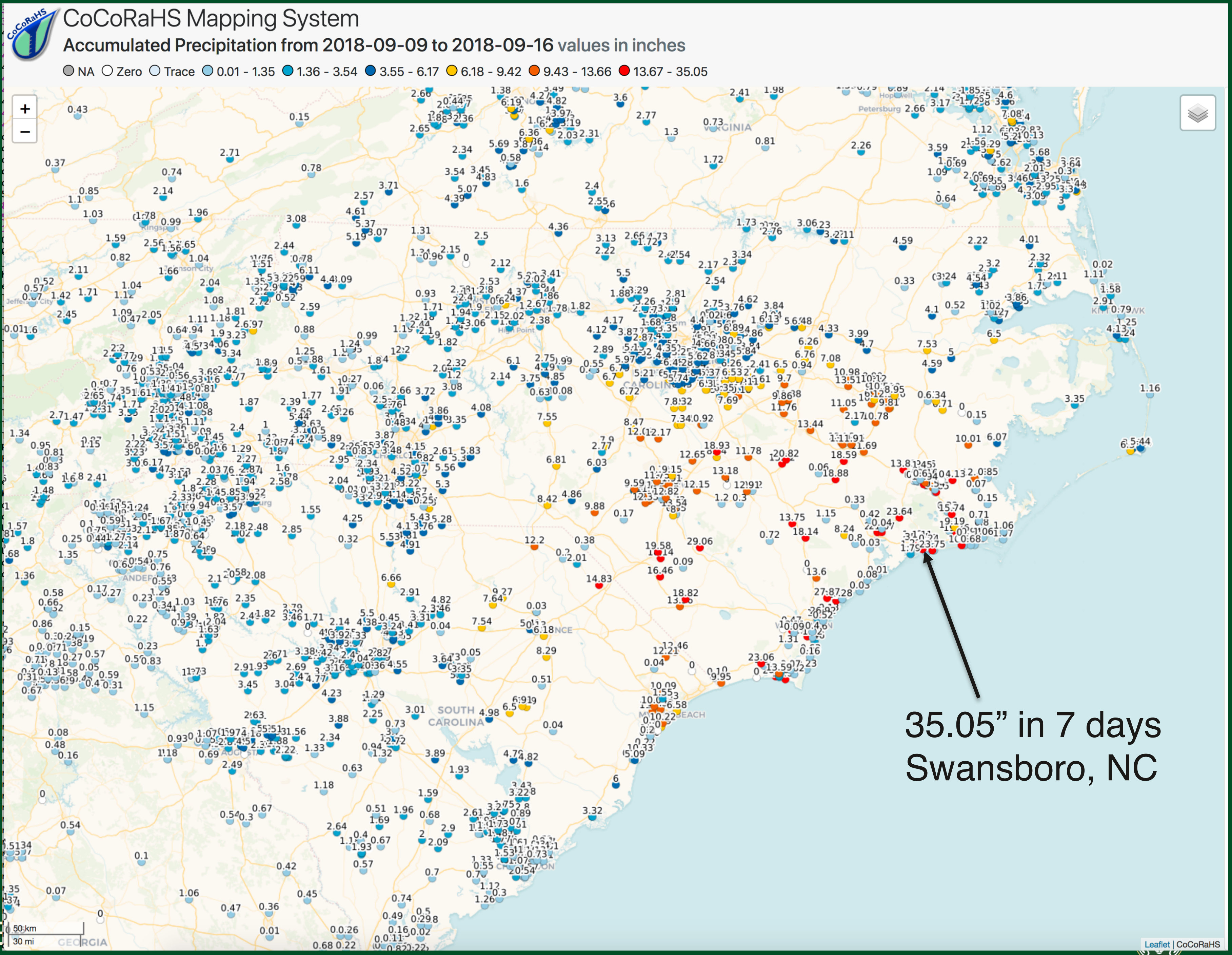
And finally, the all-important question: "Do you have a rain gauge?" (and a snowboard!)

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

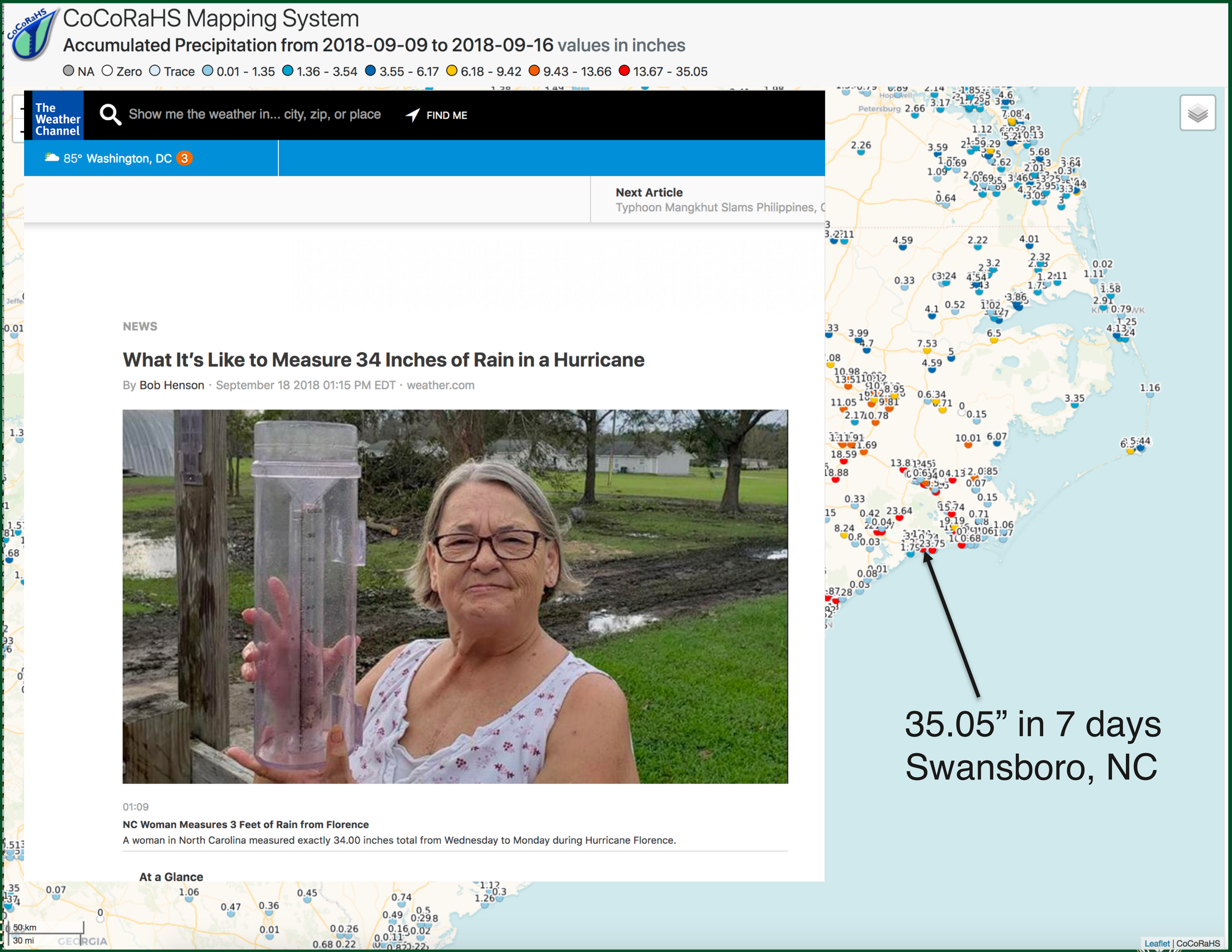
http://www.cocorahs.org

or see me today

CoCoRaHS data in Hurricane Florence, September 2018



CoCoRaHS data in Hurricane Florence, September 2018



Thank you!

http://climate.colostate.edu/

russ.schumacher@colostate.edu

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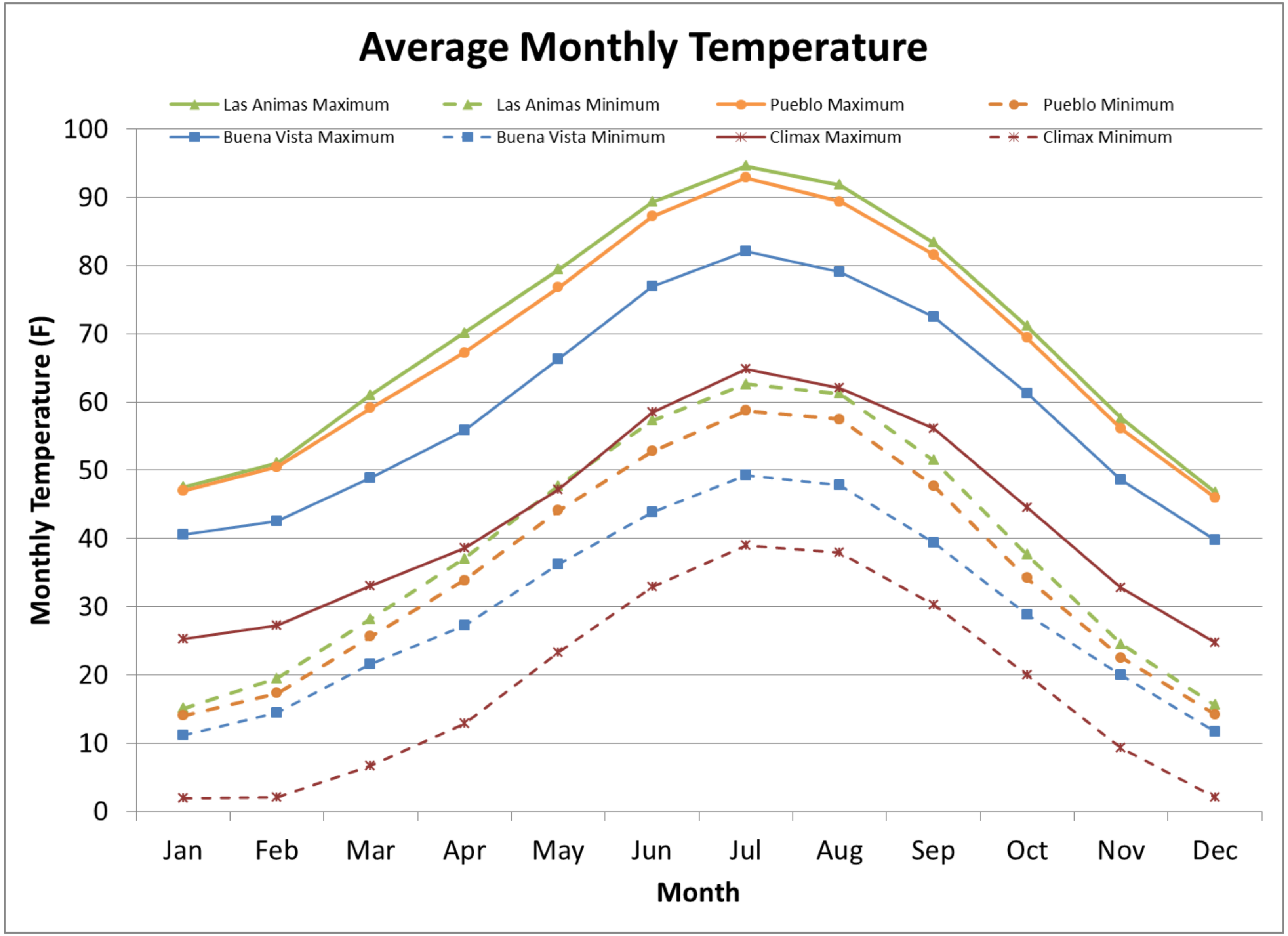
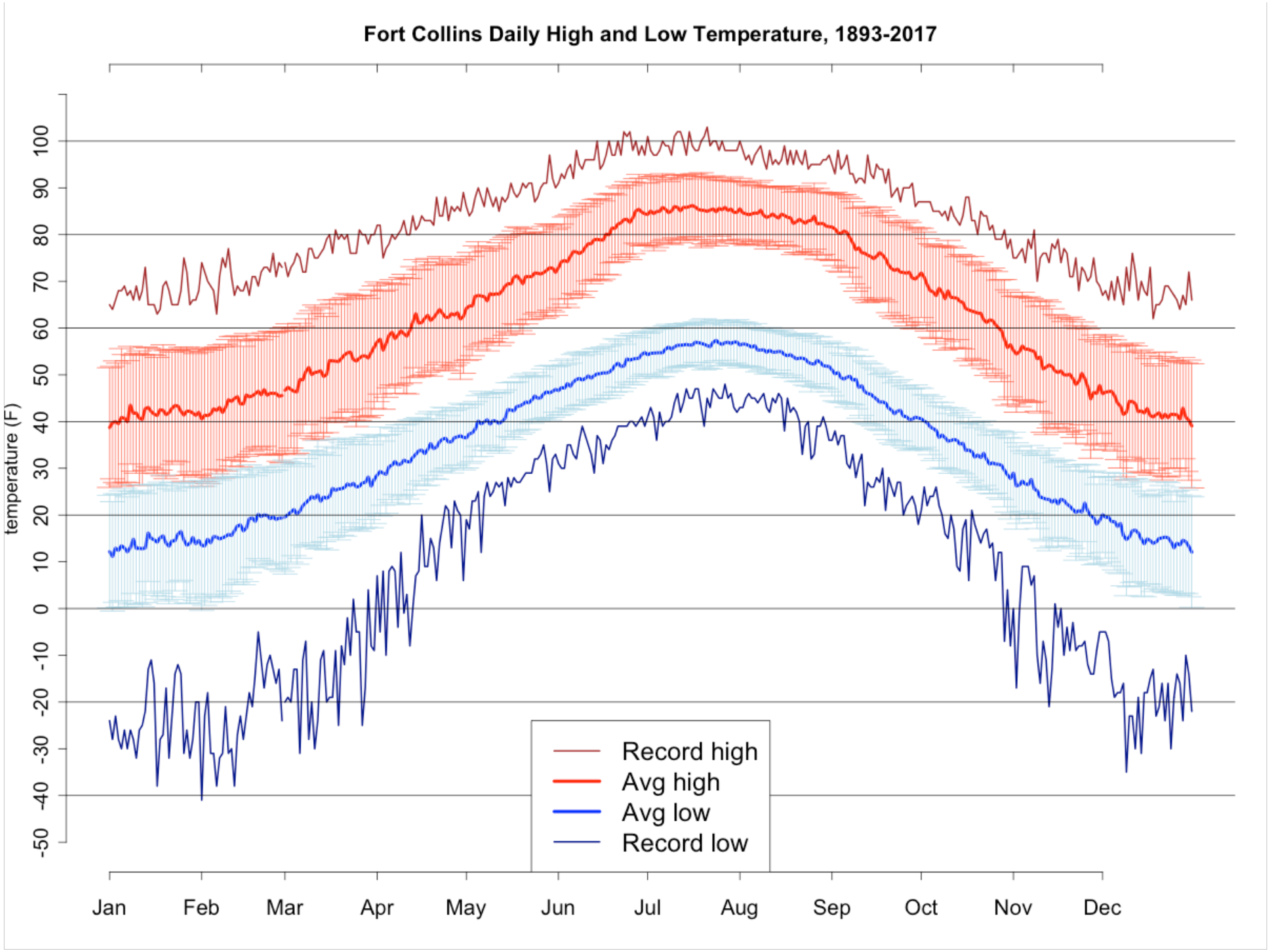
COLORADO CLIMATE CENTER

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