

### Science

- When I went to school, I got an education that was heavy on measuring, quantifying and understanding things.
- I thought that was what science was about. I was very naïve when I graduated and went out into the real world.
- Making a discovery and gaining understanding is just the first step for a scientist.
- Implementing that discovery can be a challenge.
- Challenges of implementing scientific discovery, one of which is if it has potential to negatively affect some powerful interest
  
- Historians have to get their facts from somewhere.
- In this case, many climate scientists have been studying our current drought and our drought history.
- So this is also a science lesson.
- And it is a poli-science lesson because many politicians have strongly held beliefs that trump what the historians and scientists have been discovering about our droughts.



One of the many problems faced in trying to apply science is organized disinformation campaigns.

**Controversy over health effects of smoking**

- When we want to know what facts are probably true, we should theoretically look for a consensus among scientists who are studying that field and are accepted by their peers as qualified.
- But sometimes it doesn't work out that way.
- The health effects of smoking is a prime example
- In the early 1950s, several studies demonstrated a causal relationship between smoking and lung cancer.
- Tobacco companies worried that these studies would reduce tobacco consumption. So they joined together and hired a public relations firm to start pushing back.
- They formed the Tobacco Industry Research Committee to cast doubt on studies linking smoking and cancer, and called for more research.
- The surgeon general (the head of the U.S. Public Health Service) released a report in 1964 confirming the causal link between smoking and cancer.
- The tobacco industry formed the Tobacco Institute, a trade association that acted as a lobby for the tobacco industry in Congress.
- This lobbying was generally successful, as the tobacco industry was well-funded and southern states relied on tobacco revenues.

**Controversy over global warming and burning fossil fuels**

- Later a consensus began to form that the burning of fossil fuels was the primary cause of global warming
- When this started to happen, the fossil fuels industry immediately began following the playbook of the tobacco industry.

**Controversy over opioids**

- Something similar happened with the safety of opioids, particularly OxyContin.
- Purdue Pharma's sales force aggressively marketed OxyContin while misrepresenting the risk of addiction.

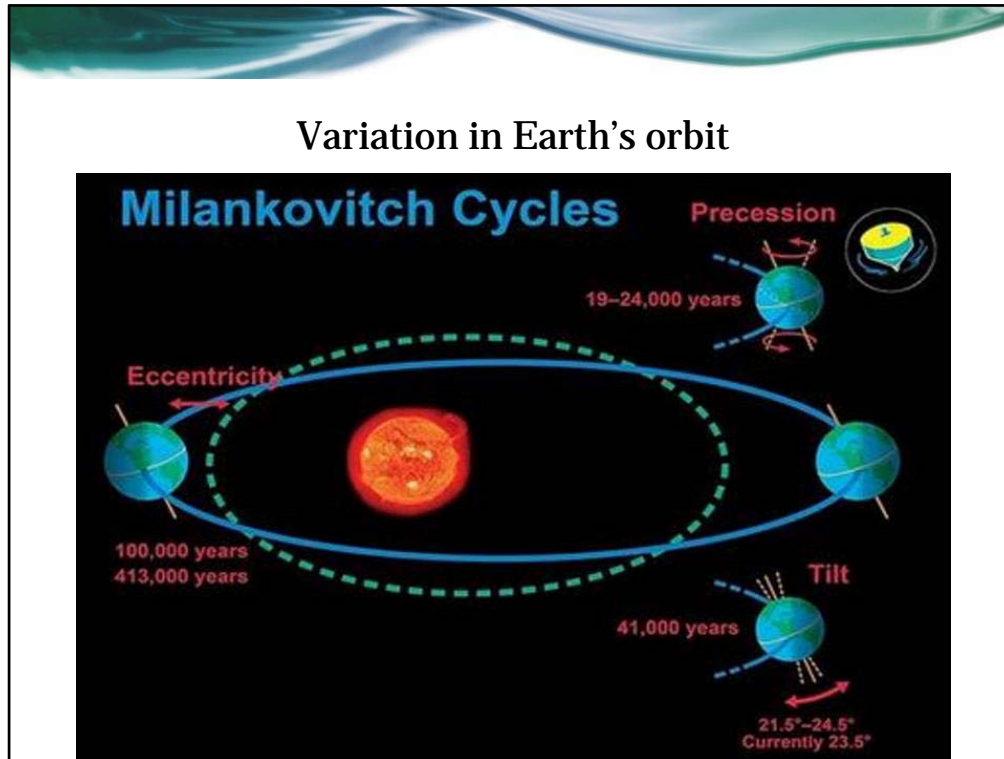
Whenever there is a disinformation going on, check to see where the money is coming from.

## Dangerous assumptions



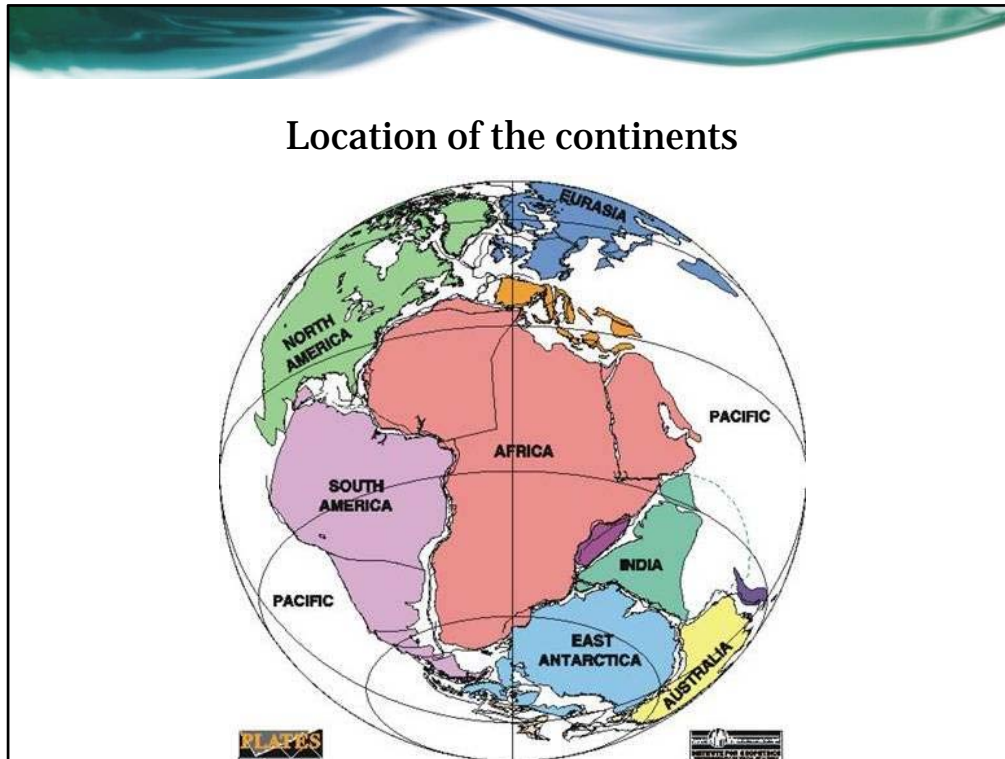
- That just represents some of the problems scientists face applying their discoveries.
- There are many things that make it hard for us to make a discovery or to understand the issue we are studying.
- One of the ways is our unstated and unexamined assumptions.
- Our assumptions can blind us to what we are trying to study.
- We make so many assumptions every day that we aren't even aware of.
- This is one of the biggest obstacles to the progress of science.
- We often assume that natural systems have always been the way they are at present.
- Climate change is a great place to look at how our assumptions get in our way.

## Variation in Earth's orbit



### Pleistocene Epoch

- The Pleistocene Epoch began 2.6 million years ago at the end of the Pliocene.
- During the Pliocene the earth climate system response shifted from a period of high frequency-low amplitude oscillation dominated by the 41,000-year period of Earth's obliquity to one of low-frequency, high-amplitude oscillation dominated by the 100,000-year period of the orbital eccentricity characteristic of the Pleistocene glacial-interglacial cycles.
- The last 2.6 million years have been characterized by over 11 major glacial periods (or ice ages) separated by short interglacial periods. The major glacial periods (or ice ages) have lasted about 100,000 years and the interglacial periods lasted about 10,000-20,000 years. We are living in one of those interglacial periods, the Holocene epoch.
- We were taught in school that the seasons are driven by the Earth's elliptical orbit, its 23.5 degree axial tilt, and its wobble, pointing from Polaris to Vega.
- A century ago, a Serbian astronomer, Milutin Milanković, calculated those three cyclical changes in the Earth's circumnavigation of the Sun, collectively known as the Milankovitch Cycles.
  - And he showed how those cycles could be used to predict when Earth enters into glacial periods.
  - These 3 cycles are variations in the Earth's eccentricity (elliptical orbit, 100,000 year cycle), axial tilt (41,000 year cycle), and precession (wobble, pointing to North Star, seasonal contrast, 23,000 year cycle).
  - Variations in these 3 cycles do not significantly affect the total amount of solar energy reaching Earth.
  - The variations in these 3 cycles do create alterations in the *seasonality* and *location* of solar radiation reaching the Earth's surface.



#### Permo-Carboniferous glaciation

- The continents are constantly on the move, floating on the molten mantle.
- Pangea, the last supercontinent, assembled in the southern hemisphere about 335 million years ago.
- The Permo-Carboniferous glaciation occurred when Gondwana, the southern part of Pangea, was located near the south pole.
- It lasted almost 90 million years between about 350-240 million years ago; this is the longest glacial epoch in the past 542 million years.

#### Permian-Triassic mass extinction

- Volcanoes in what is now Siberia erupted on a tremendous scale 250 million years ago, at the end of the Permian Period.
- The magma and lava that they belched forth produced huge amounts of CO<sub>2</sub>, heating the Earth.
- The surface of the ocean warmed by about 18°F.
- The increased warmth reduced oxygen in the ocean, asphyxiating the species living there.
- 96% of animals in the ocean went extinct, the worst mass extinction in Earth's history, and it happened over a few thousand years at most.
- The extinction of terrestrial species may have been nearly as extreme.
- The first dinosaurs appeared just after that extinction event.

#### Breakup up of Pangea

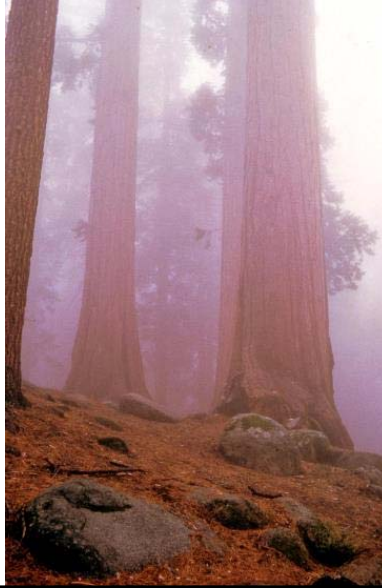
- Pangea gradually broke up between 200-140 million years ago.
- By 6 million years ago, the continents were almost in their current locations.
- Atmospheric CO<sub>2</sub> concentrations were generally over 1,000 ppm from about 240 to 66 million years ago, from the end of the Permo-Carboniferous glaciation through the end of the Mesozoic.

## Change in topography



- Santa Cruz used to be 150 miles south of Coalinga, opposite Bakersfield.
- Now it is 150 miles north of Coalinga, on the north side of Monterey Bay.
- There have been multiple elevations of the Sierra Nevada batholith. About half of the current elevation of the High Sierra in the Southern Sierra occurred in the past 5-10 million years, initiating the present cycle of erosion.
- The Central Valley used to be filled with an oceanic embayment, like the Gulf of California.
- The southern part of the bay was especially deep.
- Megalodon sharks used to thrive out in the valley between Visalia and Coalinga and further south.
- Adult megalodon were over 50 feet long, 2.5 times longer than the largest recorded great white shark (20 feet).
- They were 2.5 times bigger than a Tyrannosaurus rex (40 feet; 75,000 lb compared to 31,000 lb).
- They were one of the largest predators our planet has ever known.
- Megalodon dominated the oceans and inland seas like the Tulare Lake Basin 20 million years ago.
- The valley oceanic embayment began to fill with tremendous amounts of sediment about 5 million years ago.
- Several vertical miles of sediment accumulated in just a few million years.
- The San Joaquin Valley Basin has accumulated up to 6 vertical miles of marine and continental sediments.
- That is twice the height of Mt. Whitney.
- For comparison, the Marianas Trench, the deepest spot on earth, is about 6.8 miles deep.
- That sediment, especially the upper few thousand feet, is where our groundwater aquifer exists.

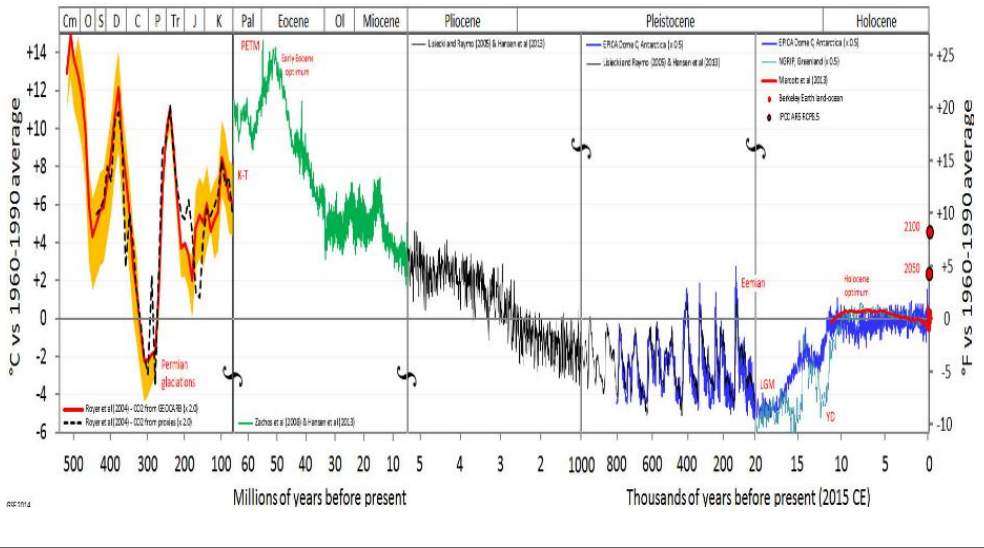
## Changes in vegetation



- The oldest giant sequoias are older than 3,200 years old, more than 30 feet in diameter.
- Giant sequoia groves feel ancient, like they have been there forever.
- But giant sequoia groves are recent arrivals to our mountains.
- The sequoia groves, the mixed conifer forest, and the wet Sierra meadows only began developing here about 3,000-4,500 years ago when the climate started to get cooler and moister.



# Change in global average temperature for last 540 million years



## Major factors affecting Earth's climate

- Variations in Earth's orbit around the Sun
- Movement of the continents
- Change in atmospheric CO<sub>2</sub> concentrations and other greenhouse gases

## Why should we care about ancient geologic time?

- We need time enough to get average temperatures to a range that is conducive to supporting human life.
- We need time enough to build California, otherwise we would be living in Utah.
- We need to get rid of the dinosaurs.

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## K-T Mass Extinction

- The Cretaceous-Tertiary (K-T) extinction was a sudden mass extinction of some three-quarters of the plant and animal species on Earth, approximately 66 million years ago.
- Almost all land animals larger than about 25 lbs, including dinosaurs became extinct in the event.
- This event marked the end of the Cretaceous period and with it, the entire Mesozoic Era, opening the Cenozoic Era that continues today.
- It is now generally thought that the K-T extinction was caused by the impact of a massive comet or asteroid 6 to 8 miles in diameter, which devastated the global environment.
- Many animals died on the day of the impact, but most died through a lingering impact winter which halted photosynthesis in plants and plankton.
- The impact crater for this comet or asteroid is buried underneath the Yucatan Peninsula in Mexico.
- The crater is about 83 miles in diameter and 12 miles in depth, well into the continental crust of the region.
- It is the second largest confirmed impact structure on Earth.

## PETM

- The Paleocene-Eocene Thermal Maximum (PETM) was an abrupt global warming event that occurred 56 million years ago at the beginning of the Eocene Epoch.
- The PETM was the warmest period of the last 66 million years.
- An enormous amount of carbon was released into the ocean and atmosphere in less than 10,000 years at the start of this event.
- The source is still not firmly determined.
- The most convincing hypothesis appears to be an initial perturbation which caused a warming of the ocean which then resulted in the release of methane clathrates from the seabed in a feedback loop.
- This led to a massive release of methane, greatly amplifying the initial perturbation.
- As a result of this carbon release, temperatures rose 9-15° globally.
- It was over 2.5° warmer than the 1960-1990 average temperature.
- Atmospheric CO<sub>2</sub> concentrations remained below 2,500 ppm throughout the event.
- There were drastic changes in precipitation, vegetation, and all the other effects associated with an increase in global temperatures.
- There were mass extinctions.
- The PETM is thought to be the last geological staging for the human-induced global warming that is happening now.
- The PETM is the only event in the last 66 million years that had a massive carbon release, and happened over a relatively short period of time.
- Nothing comparable has occurred in the more recent past to what humans are currently doing.
- Even the drama of the PETM falls short of our current period in at least one key respect: We are putting carbon into the atmosphere at an even faster rate than happened back then.

## Eocene-Oligocene Mass Extinction

- The Oligocene Epoch began 34 million years ago at the end of the Eocene Epoch.
- The Eocene-Oligocene climate change consisted of:
  - A very deep and rapid 15°-40,000-year cooling occurred from 34.1 to 33.6 million years ago.
  - Ice began to build up significantly for the first time in Antarctica about 36 million years ago. The resulting increase in ice volume caused a 281 feet decrease in sea level between 35.7-33.5 million years ago.
  - The Eocene-Oligocene mass extinction event occurred about 33.5 to 33.7 million years ago, affecting primarily marine and aquatic organisms.
  - This extinction is assumed to have been caused by the rapid cooling.
  - This rapid cooling is speculated to have been caused by one or more of three large impact events that occurred about 35 million years ago:
    - Popigai crater in central Siberia near the Arctic Ocean which scattered debris as far as Europe. The impactor in this event has been identified as either a 5-mile-diameter chondrite asteroid, or a 3-mile-diameter stony asteroid. The impact occurred about 35.7 ± 0.2 million years ago. The impact left a crater with a diameter of 62 miles, it is the fourth largest impact crater on Earth.
    - Chesapeake Bay impact crater. This crater was formed by a very large meteor that impacted the Tidewater region of Virginia near present-day Richmond about 35.5 ± 0.3 million years ago. It is the largest known impact crater in the U.S. During the warm late Eocene, sea levels were high, and the impact site lay in the coastal shallows. The shock was covered with dense tropical rainforests, and the waters of the gently sloping continental shelf were rich with marine life that was depositing dense layers of fine from their microscopic shells. The fast-moving meteor punched a deep hole through the sediments, and into the granite continental basement rock. The meteor was completely vaporized, and the basement rock was fractured to a depth of 5.0 miles. The surrounding region suffered massive devastation. Within minutes, millions of tons of water, sediment, and shattered rock were cast high into the atmosphere for hundreds of miles along the East Coast. An enormous megabombardment equalled the land and possibly even reached the Blue Ridge Mountains. Modeling indicates that the crater probably had an initial diameter of about 25 miles, but today it is about 53 miles in diameter and 8 miles deep (in Antarctica the size of Rhode Island, and nearly as deep as the Grand Canyon).
    - Toms Canyon impact crater. This is a probable impact crater where one or more asteroids struck the Atlantic continental shelf about 100 miles east of Atlantic City, NJ. The crater dates to about 35 million years ago, and may have been formed by the same event as the larger Chesapeake Bay impact crater, 200 miles to the southwest at the mouth of Chesapeake Bay. Seismic reflection profiles show that the crater was formed by an object or objects which struck from the southwest at a glancing angle and formed a long, oval crater.

## Mid-Miocene Climate Optimum (MMCO)

- The Earth had been on a multi-million-year cooling trend, which was slow enough to allow the feedbacks in Earth's climate system to remain in equilibrium.
- But at 16.5 million years ago, the Earth lit a burn in that cooling trend, an abrupt episode of global warming that was in some ways comparable to what is happening today.
- This major geologic perturbation is attributed to the Mid-Miocene Climatic Optimum (MMCO).
- The MMCO was ushered in when the Columbia River Basalts that occur across a large part of Oregon and other western states were emitted in spectacular eruptions beginning 16.9 million years ago during the mid-Miocene.
- These eruptions released lava that generated a 2-million-year greenhouse shutdown in the Mid-Miocene Climatic Optimum (MMCO).
- Global temperatures increased 7° to 9°F above today's average temperatures.
- Sea levels rose 100 feet above today's level, and suddenly.
- Like today, the MMCO global warming was driven by large and rapid (geologically speaking) CO<sub>2</sub> emissions.
- That event then unfolded over a few hundred years.
- That's faster than the slow feedbacks of the Earth system, which put the climate system out of equilibrium and allowed a build-up of atmospheric CO<sub>2</sub>, accompanied by abrupt global warming.
- Much like today.

## Mid-Pliocene warm period

- The mid-Pliocene warm period occurred approximately 3.3 to 3 million years ago, as our Australopithecus ancestors like "Lucy" were proliferating in Africa.
- The mid-Pliocene warm period was caused by glacial retreating when North and South America came closer together; the Isthmus of Panama formed 2.8 million years ago, and Africa and Europe joined about 5.9 million years ago.
- This dramatically changed ocean currents, resulting in increased heat transport from equatorial regions to the poles.
- Atmospheric CO<sub>2</sub> concentrations were about 400 ppm.
- Atmospheric CO<sub>2</sub> levels were quite close to today.
- But that level was sustained over long periods of time, whereas CO<sub>2</sub> concentration today is increasing rapidly.
- In other words, Earth's movement toward Pliocene-like conditions may play out in the decades and centuries ahead of us.
- Global average temperatures in the mid-Pliocene warm period were about 4-5°F greater than today.
- The Arctic was much warmer than it is at present.
- The northern hemisphere ice sheet was ephemeral during the early and mid-Pliocene. This changed as global temperatures began to cool.
- Extensive glaciation over Greenland and the development of the Greenland Ice Cap began about 1 million years ago, in the late Pliocene.
- Mid-latitude glaciation probably also began sometime in the late Pliocene.
- The Western Antarctic ice sheet declined somewhat during the mid-Pliocene warm period. The Ross Sea opened up during the mid-Pliocene. But there was no significant decline in the land-based Eastern Antarctic ice sheet.
- Sea level rose during the mid-Pliocene warm period, primarily because temperatures resulted in less water being locked up in land-based ice sheets or glaciers. Global sea level is variously estimated as somewhere between 20-80 feet higher than today.

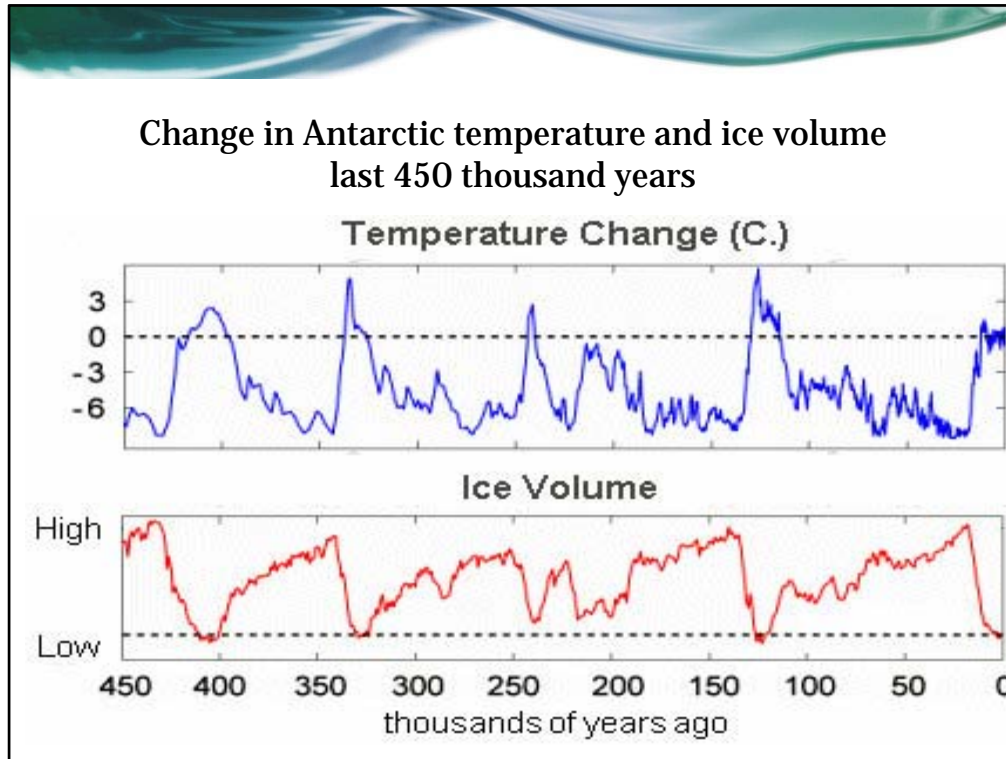
## Pleistocene Epoch

- The Pleistocene Epoch began 2.6 million years ago at the end of the Pliocene.
- During the Pleistocene the earth climate system response shifted from a period of high frequency-low amplitude oscillation dominated by the 41,000-year period of the orbital eccentricity to one of low frequency, high-amplitude oscillation dominated by the 100,000-year period of the orbital eccentricity characteristic of the Pleistocene glacial-interglacial cycles.
- The last 2.2 million years have been characterized by over 12 major glacial periods (or ice ages) separated by short interglacial periods. The major glacial periods (or ice ages) have lasted about 100,000 years and the interglacial periods lasted about 10,000-20,000 years. We are living in one of those interglacial periods, the Holocene epoch.
- We were taught in school that the seasons are driven by the Earth's elliptical orbit, its 23.5 degree axial tilt, and its wobble, pointing from Polaris to Vega.
- A century ago, a brilliant astronomer named Milutin Milankovitch discovered that the major glacial periods (or ice ages) have lasted about 100,000 years and the interglacial periods lasted about 10,000-20,000 years. We are living in one of those interglacial periods, the Holocene epoch.
- Milankovitch showed how those cycles could be used to predict when Earth enters into glacial periods.
- These 3 cycles are smaller than the Earth's orbital eccentricity (glacial cycle, 100,000 year cycle), axial tilt (41,000 year cycle), and precession (wobble, pointing to North Star, seasonal contrast, 23,000 year cycle).
- Variations in these 3 cycles do not significantly affect the total amount of solar energy reaching Earth.
- The variations in these 3 cycles do create alterations in the seasonality and location of solar radiation reaching the Earth's surface.
- Atmospheric CO<sub>2</sub> concentrations oscillated between about 180 and 280 ppm through the glacial-interglacial cycles of the Pleistocene ice ages.

- Glacial periods end abruptly because of two feedback loops:
  - Release of seabed methane and CO<sub>2</sub> (greenhouse gases) into the atmosphere as the ocean warms. Atmospheric CO<sub>2</sub> concentrations decreased during glacial periods in part because the deep ocean stored more CO<sub>2</sub> due to changes in either ocean mixing or biological activity. Lower CO<sub>2</sub> levels weakened the atmosphere's greenhouse effect and helped to maintain lower temperatures. Warming at the end of the glacial periods liberated CO<sub>2</sub> from the ocean, which strengthened the atmosphere's greenhouse effect and contributed to further warming.
  - Ice-albedo feedback
- The interglacial period that preceded the last glacial period, the Wisconsin, is known as the Eemian period or Marine Isotope Stage 5e.
  - It lasted from about 129,000 to 116,000 years ago.
  - Average temperatures in the Eemian period were similar to average temperatures today.
  - The last time sea level was higher than today was during the Eemian period.
- The maximum ice extent (the Last Glacial Maximum) occurred about 20,000 years ago at the peak of the Wisconsin glacial period.
  - Historically low sea levels were reached during the Last Glacial Maximum.
  - Over the past 20,000 years, sea level has risen some 400-410 feet

#### **Current atmospheric CO<sub>2</sub> concentrations**

- The Wisconsin glacial period ended 11,700 years ago, marking the end of the Pleistocene Epoch.
- Since then, Earth has been in an interglacial period called the Holocene Epoch.
- CO<sub>2</sub> levels averaged about 280 ppm from 1880–1900 at the dawn of the Industrial Revolution; that is the pre-industrial baseline.
- Readings from the Mauna Loa Observatory in Hawaii found that atmospheric CO<sub>2</sub> concentrations exceeded 410 ppm averaged across an entire month in April 2017; that was the first time this has occurred since record-keeping began in 1958.
- The Paris Agreement emphasized the need to limit global average temperature increase to well below 2°C above preindustrial levels and pursue efforts to limit the increase to 1.5°C.
- The National Highway Traffic Safety Administration produced a DEIS in July 2018 for fuel-efficiency standards for cars and light trucks built after 2020.
  - The analysis in that document projected that atmospheric CO<sub>2</sub> concentrations would rise from the current 410 ppm to 789 ppm by 2100 if the world were to take no action to curb emissions.
  - Such an increase in CO<sub>2</sub> would be expected to increase global mean surface temperature by 3.5°C (6.3°F) by 2100.
  - This would be equivalent to atmospheric CO<sub>2</sub> concentrations last seen at the Eocene-Oligocene extinction event (750 ppm), greatly exceeding the levels that occurred in the mid-Pliocene warm period (400 ppm) and the MMCO (500 ppm).



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- Glacial periods end abruptly because of two feedback loops:
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  - Ice-albedo feedback
- Currently, Earth is in an interglacial period that began about 20,000 years ago when the ice was at its maximum and the ocean was at its lowest.
- Yosemite Valley and Kings Canyon were carved out during roughly 7-8 glacial periods between 1 million and 250 thousand years ago.
- Erosion during these glacial periods completed much of the filling in of the valley floor, above the Corcoran Clay.
- For context, the most recent common ancestors of all living humans lived between roughly 100,000 and 160,000 thousand years ago. This is where all of our lineages converge.
- Our ancestors emerged from Africa between 50,000 and 80,000 years ago.
- The earliest ancestors of Native Americans are generally believed to have arrived in North America less than 17,000 years ago.
- Although there is some evidence that humans were living near San Diego about 130,000 years ago, eating mastodon.
- The last glacial period, the Wisconsin, occurred from about 116,000 to 11,700 years ago.
- Glacial moraines from this period are very visible in Giant Forest around Lodgepole.
- Vast ice sheets covered much of the Northern Hemisphere and Antarctica during the Wisconsin.
- The maximum ice extent (the Last Glacial Maximum) occurred about 20,000 years ago at the peak of the Wisconsin glacial period.
- At that point, sea level was about 400-410 feet lower than it is today because so much water was locked up in ice sheets.
- Deglaciation gradually began in the Northern Hemisphere between about 17,000 to 18,000 years ago.
- Our deeper valley wells are tapping water that is about 10,000 years old.
- This water dates from when the Wisconsin glacial period was ending, and the last of all that ice was melting.
- Sea level began rising abruptly about 12,500 years ago when deglaciation began in Antarctica.
- The Mount Toba supervolcano eruption in Indonesia occurred about 75,000 years ago.
- It is the largest known eruption on Earth in at least the last 25 million years.
- The eruption spewed a huge amount of ash and sulfur dioxide into the atmosphere.
- The eruption would likely have caused a global volcanic winter of 6-10 years.

## Pleistocene Epoch — 2.6 million to 11,700 years ago

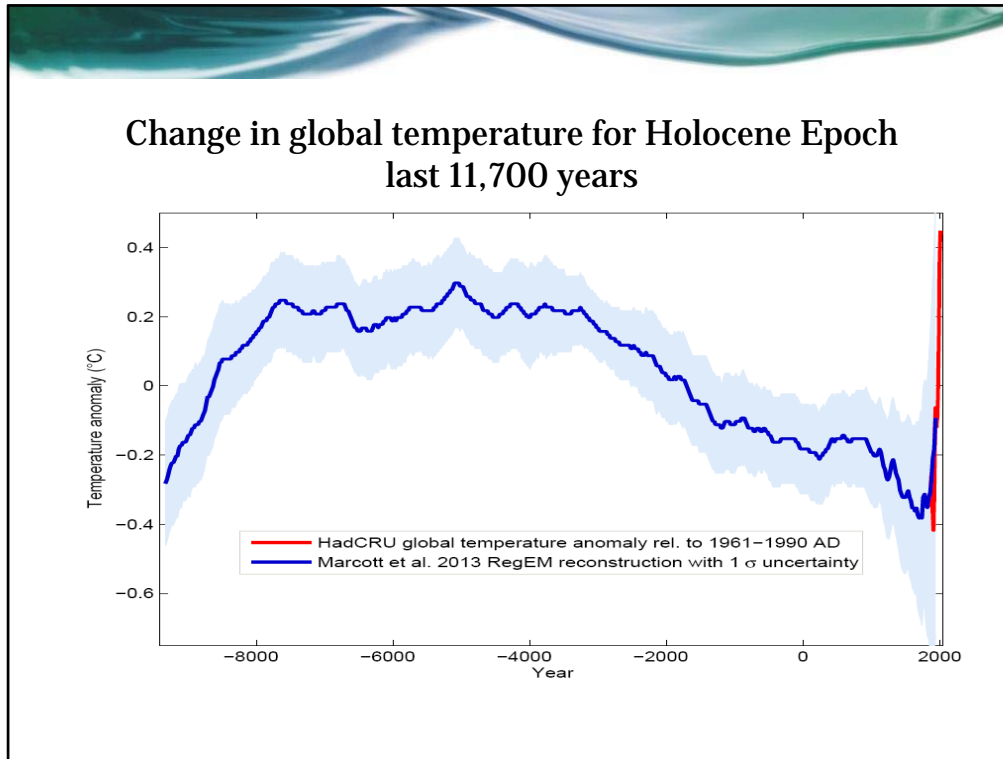


- The Pleistocene epoch lasted from 2.6 million to about 11,700 years ago.
- A supernova 2.6 million years ago, about 165 light-years away, pelted Earth for decades with a torrent of cosmic rays. Many species, including megalodon, went extinct at this time, at about the beginning of the Pleistocene.
- With the loss of this predator, the baleen whales began to prosper.
- North America's climate was colder and wetter during the Pleistocene than at present.
- The Pleistocene's overall climate was essentially a continuous El Niño.
- Much of North America was covered by thick sheets of ice.
- At maximum glacial extent during the Pleistocene, 30% of the Earth's surface was covered by ice.
- This is when Yosemite Valley and Kings Canyon were carved and the big delta fans were built out into the San Joaquin Valley.

## Pleistocene Epoch

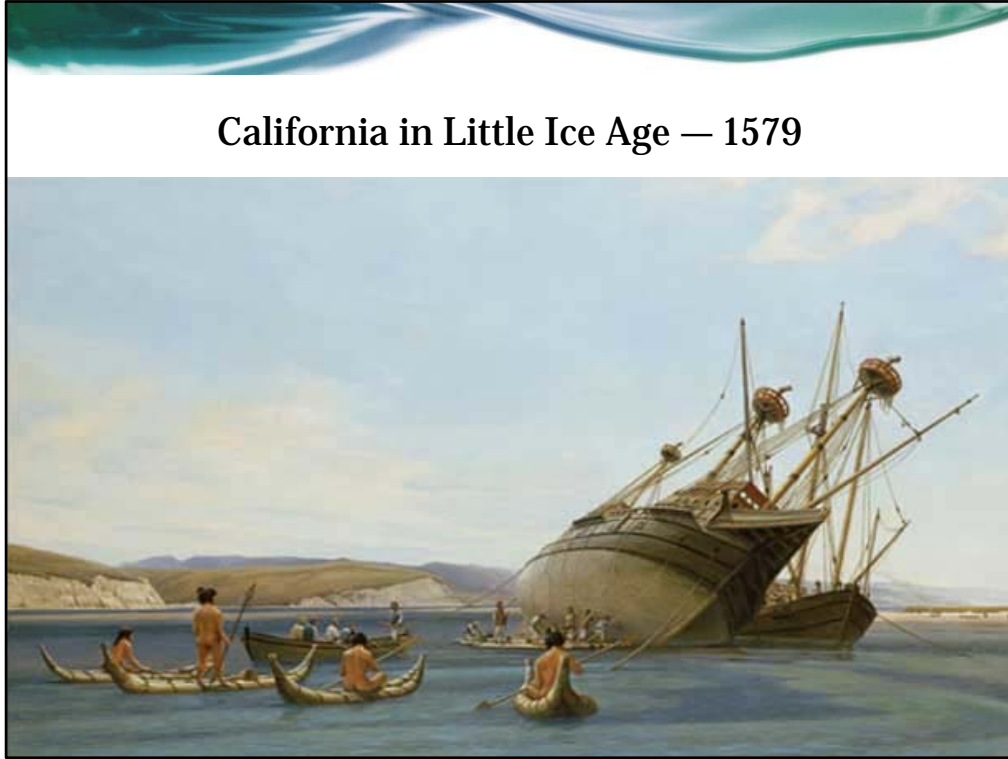


- The cold climate of the Pleistocene marked the doom of the Megalodon sharks.
- Cold-adapted animals such as mammoths and mastodons lived in California during the Pleistocene.
- The late-Pleistocene (30,000 years ago) animals are well represented at La Brea tar pits in Los Angeles.
- This cold climate is now clearly in our rear-view mirror. Warmer times are ahead for California.



- The warmer the temperature, the more water plants need to avoid stress.
- This graph covers the entire Holocene Epoch, an interglacial period, about 11,700 years.
- A group of researchers from Harvard and Oregon State created this graph by combining 73 different reconstructions of temperatures from around the world.
  - From 11,700–7,000 years ago, the vegetation of the Tulare Lake Basin resembled that of the Great Basin, pinyon–juniper–oak woodland in the foothills, with greasewood on the salt flats near the lake. The upper watersheds consisted of open pine forests and dry meadows with very few giant sequoias.
  - A very dry period set in at the end of this warming period; it covered all North America. For example, from 7900 to 7500 years ago, the lake levels in the Great Lakes dropped dramatically, up to 66 feet below their outlets, so that they became disconnected from each other. Each lake became a closed basin, like the Tulare Lake Basin. Their overflow rivers, including the Niagara River (which flows from Lake Erie to Lake Ontario), ran dry during this period.
  - From 7,000–4,500 years ago, the Tulare Lake basin was drier, and there was widespread increase in fire frequency. Great Basin-like vegetation (both woodland and greasewood) was generally replaced by drought-tolerant grassland and flowering plants.
  - A cooling (and moister) period began about 3,000–4,500 years ago. This is when the sequoia groves, the mixed conifer forest, and the wet Sierra meadows began developing. Fire was relatively infrequent in the upper watersheds prior to 4,500 years ago, apparently due to low fuel levels.
  - The Medieval Warm Period or Medieval Climatic Anomaly lasted from about 950–1250 A.D. The western Sierra was droughty and often fiery during the Medieval Warm Period; it had the most frequent fires of any period during the last 3,000 years. During that period, extensive fires burned through parts of Giant Forest at intervals of about 3–10 years.
- Then the cooling trend resumed.
- The Little Ice Age lasted from approximately 1275–1850.
- Niagara Falls froze over and stopped flowing in March 1848 for the only time in recorded history.
- The 5000-year cooling trend ended abruptly with the rapid warming of the 20th Century.
- American settlement in the San Joaquin Valley began in 1850, right at the end of Little Ice Age.
- A lot of this recent increase has been in nighttime temperatures.
- Many people have observed the decrease in valley fog, apparently due to warmer nighttime temperatures.
- Wildfires used to lay down at night due to higher humidity; that has been happening less often since 2008.
- Today our lowest nighttime temperatures are about 28°.
- But a century ago, valley towns like Fresno and Visalia recorded temperatures as low as 11°.
- The red line shows where temperature is today.
- The big temperature swings in the Pleistocene were due to the variation in the Earth's orbit. That is not the case with the dramatic temperature increases that have occurred since 1970.
- It has been 3 million years since temperatures were substantially warmer than this for a sustained time.
- So far, the average global temperature has risen 1°C above the pre-industrial baseline (1880–1900 average).
- Most of this increase has occurred since 1970.

## California in Little Ice Age — 1579



Sir Francis Drake sailed up the western coast of North America in 1579, searching for a possible northeast passage back to the Atlantic.

- Drake found the northern California coast so cold in early June that his men had difficulty bearing it. Six men could hardly do the work of three, so stiff was the rigging from ice. Meat was frozen shortly after it came out of the fire. He came ashore briefly, possibly at Oregon Dunes near Coos Bay.
- Discouraged by the extreme cold, Drake then went down the coast. He found that the coastal hills along Northern California were snow-covered, even in June.
- Drake sought a good harbor, and eventually came into what is thought to be Drakes Bay at Point Reyes National Seashore.
- He stayed there for five weeks from June 17 until July 23. They found the harbor extremely cold, even in June and July. If they had not had outside work to do, they would have been content to keep their winter clothes on or to stay in their beds. The natives seemed to treat this cold weather as being normal.

## California in Little Ice Age — October 1831



We have five firsthand accounts of what conditions were like in California during the Little Ice Age. The first four were by early Spanish and English groups, working along the coast.

Captain Bonneville sent the Walker Party from the Great Salt Lake in search of the Pacific Ocean.

- They succeeded in their mission, following the San Joaquin River downstream until they reached the head of San Francisco in the vicinity of Pittsburg (5 miles west of Antioch) on November 13, 1833.
- A week later, on November 20, 1833, they reached the Pacific near Half Moon Bay.
- In the process, they were surprised to encounter the Sierra Nevada.
- They crossed the Sierra in October 1833. Their probable route was about 6 miles north of Ebbetts Pass, generally parallel to the route of present-day Highway 4.
- Leonard described encountering a lot of old and consolidated snow as they crossed the Sierra in October 1833:

*In some of these ravines where the snow is drifted from the peaks, it never entirely melts, and may be found at this season of the year, from ten to one hundred feet deep. From appearance it never melts on the top, but in warm weather the heap sinks by that part melting which lays next the ground. This day's travel was very severe on our horses, as they had not a particle to eat...but the most of the distance we this day traveled, we had to encounter hills, rocks and deep snows. The snow in most of the hollows we this day passed through, looks as if it had remained here all summer, as eight or ten inches from the top it was packed close and firm — the top being loose and light, having fell only a day or two previous.*

The Walker Party encountered snow that was persisting from year to year. They were crossing the Sierra near the end of the Little Ice Age. There is no longer persistent snow in that area; conditions have changed dramatically in the last 180 years.



## Visalia - Main St at Court St in 2010



- This is the main intersection that Visalia was built around.

## Visalia - Main St at Court St in 1863

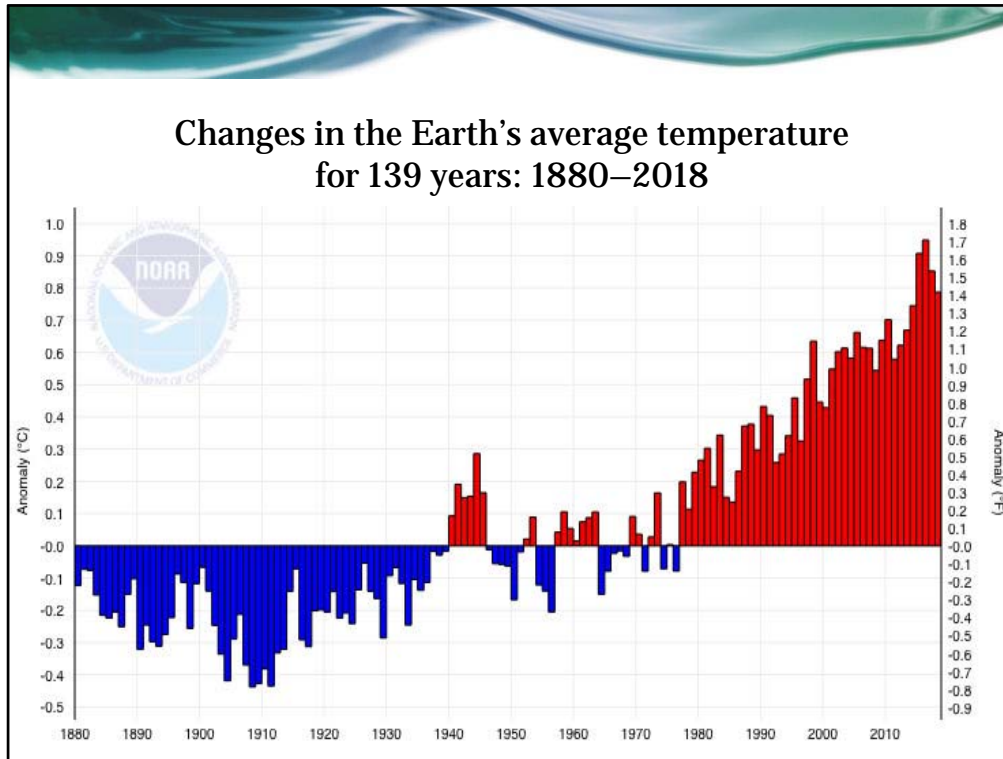


- Visalia was founded in 1852.
- This is one of the earliest pictures of the town.
- The Butterfield Stage route from St. Louis to San Francisco ran down this street from October 1858 until March 1861.
- Point out the town water pump at center right.
- The Little Ice Age ended in roughly 1850, just as Visalia was founded.
- Our climate has changed a lot in the 170 years since then.

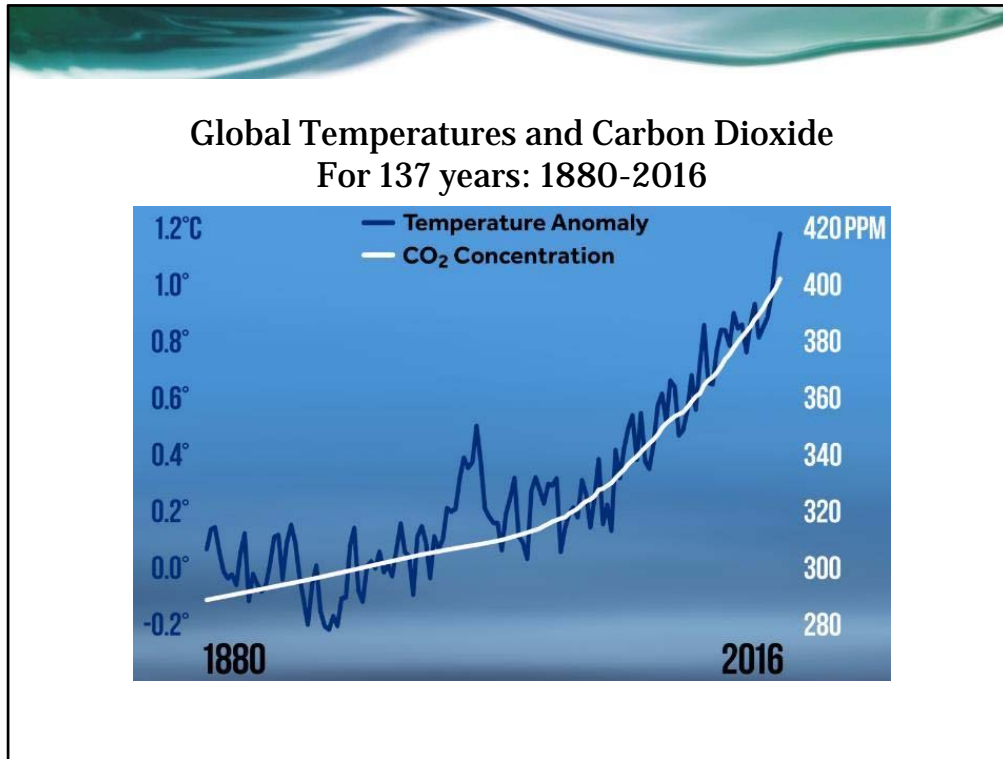
## Melting of Sierra glaciers Lyell Glacier 1883 - 2015



- Visalia was founded in 1852, right at the end of the Little Ice Age.
- The glaciers in the Sierra have advanced and retreated with each of the various ice ages.
- The Sierra glaciers reached their maximum extent during the Little Ice Age about 1850.
- Lyell Glacier was discovered by John Muir in 1871, and was the largest glacier in Yosemite National Park.



- This chart from NOAA compares each year (1880–2018) to the 20th-century average.
- It shows the global land and ocean temperature average, but the change in the U.S. is similar.
- 2018 was the 42nd year in a row (1977-2018) with global land and ocean temperatures above the 20th-century average.
- Each of the last 3 decades has been warmer than the decade before.
- Temperature has been climbing since the end of the Little Ice Age in 1850.
- The years 2015–2018 were all slightly more than 1°C above the pre-industrial baseline (1880–1900 average).
- The Paris Agreement on climate change seeks to keep global temperatures at no more than 2°C above the pre-industrial threshold, and preferably no more than 1.5°C.
- U.S. average temperature has increased by 1.3°-1.9°F since 1895, and most of this increase has occurred since 1970.
- A lot of this recent increase has been in nighttime temperatures.
- Many people have observed the decrease in valley fog, apparently due to warmer nighttime temperatures.
- Wildfires used to lay down at night due to higher humidity; that has been happening less often since 2008.
- Today our lowest nighttime temperatures are about 28°.
- But a century ago, valley towns like Fresno and Visalia recorded temperatures as low as 11°.



- CO<sub>2</sub> is one of the primary greenhouse gases (along with methane, nitrous oxide, and ozone).
- Greenhouse gases like CO<sub>2</sub>, methane, and ozone trap heat and drive global warming.
- CO<sub>2</sub> levels averaged about 280 ppm from 1880–1900 at the dawn of the Industrial Revolution; that is the pre-industrial baseline.
- This was when temperatures reached a minimum, and ice reached a maximum at the end of the Little Ice Age at about 1850.
- CO<sub>2</sub> levels have now increased about 46% and are back at mid-Pliocene levels (400 ppm), heading for Miocene levels (500 ppm).
- The rate has been increasing, with the decade of the 2010s rising faster than the 2000s.
- Planetary CO<sub>2</sub> levels have been this high or even higher in the planet's history — but it has been a long time.
- The rate of change now is far faster than what Earth has previously experienced.
- In the mid-Pliocene warm period more than 3 million years ago, they were also around 400 ppm — but Earth's sea level was at least 66 feet higher, and the planet was even warmer than it is now.
- The 400 ppm CO<sub>2</sub> level in the Pliocene was sustained over long periods of time, whereas today the global CO<sub>2</sub> concentration is increasing rapidly.
- In other words, Earth's movement toward Pliocene-like conditions may play out in the decades and centuries ahead of us.
- Earth's CO<sub>2</sub> levels, temperatures, and sea levels tend to rise and fall together.
- If current trends continue, Earth appears to be headed back toward a period like the mid-Pliocene or even the Miocene.
- The National Climate Assessment released in 2017 found:
  - It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.
  - For the warming over the last century, there is no convincing alternative explanation supported by the extent of the observational evidence.

**Visalia – Palace Hotel Building  
Main St at Court St in 2019**



- This building is on the north side of Main St at Court St.
- It is known as the Palace Hotel Building.
- It opened in October 1876, right after the Battle of Little Bighorn.
- It is over 140 years old; it has witnessed most of Visalia's history.
- It is the oldest commercial building still in use in the southern San Joaquin Valley.

## Visalia at dawn of Industrial Revolution–1903

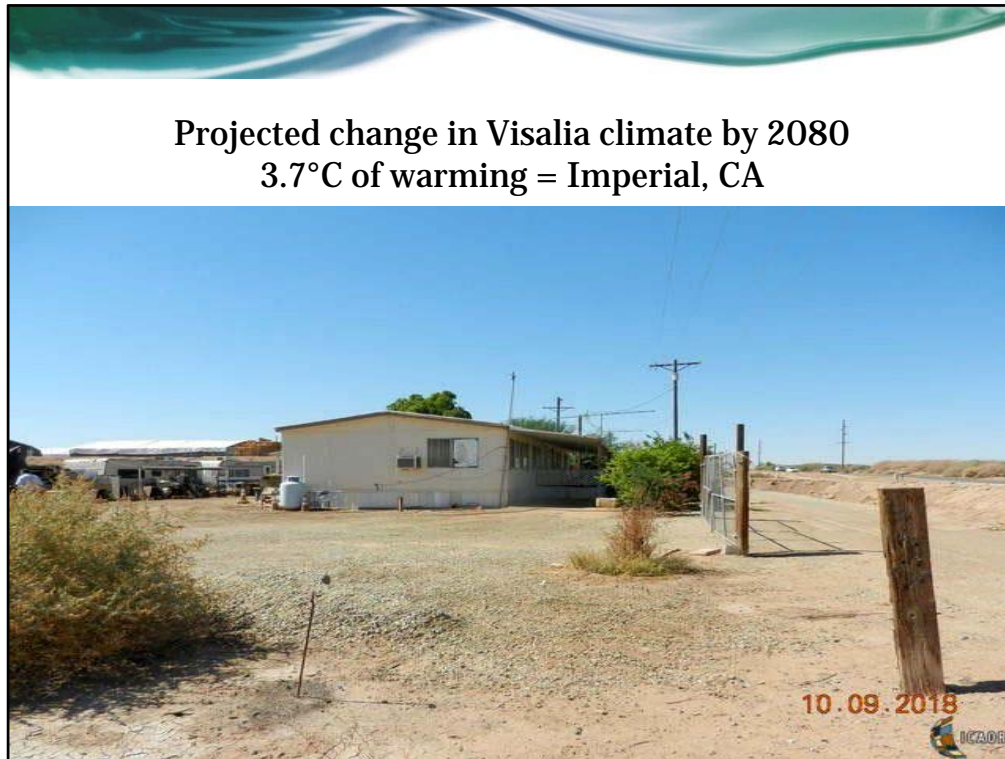


- Ringling Bros Circus parade view east on Main St at Court St at the Palace Hotel on September 25, 1903.
- Visalia in 1900 had a population of about 3,000.
- Train service began in Visalia in 1874, but the first car didn't appear in Visalia until about 1902.
- People tended to get around largely on foot, by bicycle, and by horse until about 1910-15.
- Most people heated their houses and businesses with wood.
- The Hammond powerhouse in Three Rivers started generating electricity in June 1899.
- The grist mill at Main and Santa Fe Streets was powered by a mill wheel using water from Mill Creek beginning in 1853 for many years.
- Visalia didn't have much in the way of factories until well after 1900.
- The Visalia Steam Laundry with over 30 employees and home delivery was one of the biggest factories.



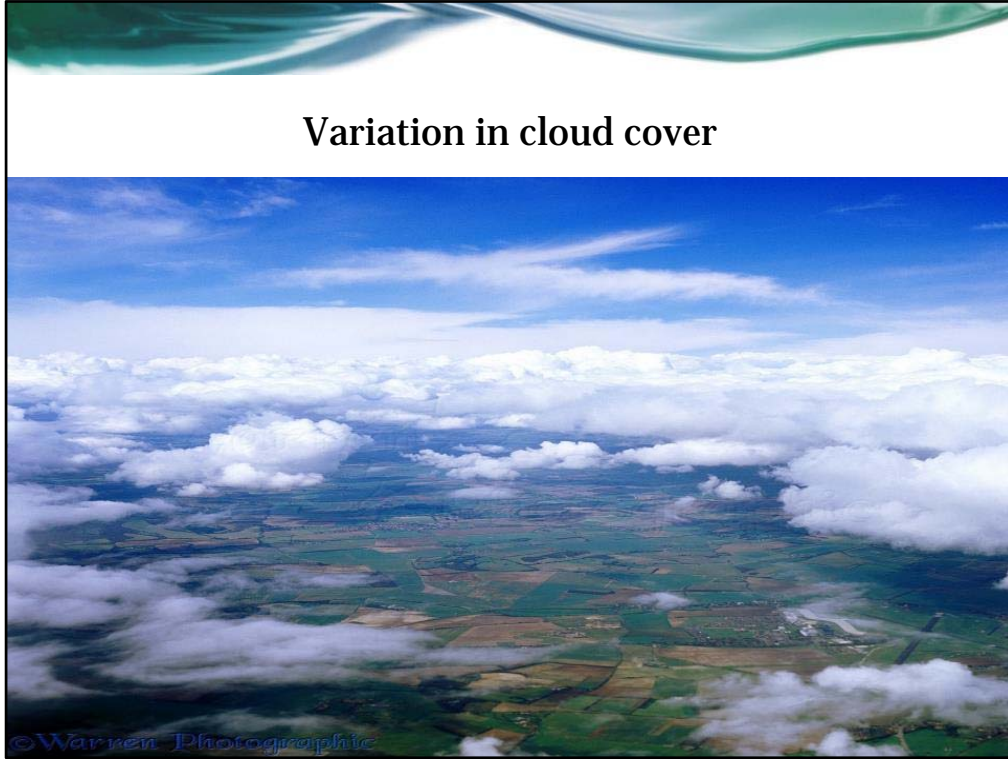
- RCP4.5 is a climate scenario with a significantly reduced emission rate of CO<sub>2</sub> and other greenhouse gases. It is similar to that envisioned by the 2015 U.N. Paris Climate Agreement.
- A study by Matt Fitzpatrick and others published in the February 2019 issue of the journal Nature Communications and identified the city that most resembles the 540 cities would look like by 540 under this scenario.
- Lamont, SE of Bakersfield, most resembles what the climate of Visalia will be in 2080 in the RCP4.5 climate scenario with a 1.8°C warming.
- The Paris Agreement on climate change seeks to keep global temperatures at no more than 2°C above the pre-industrial threshold, and preferably no more than 1.5°C.
- The world's leading climate scientists, the UN Intergovernmental Panel on Climate Change (IPCC), warned in October 2018 that that the ½° difference between 1.5 and 2°C would cause a huge increase in impacts.
- The IPCC report showed Even 2°C of warming would cause considerable loss of life and suffering. It would kill coral reefs whose fish feed millions, elevate the risk of floods, wildfires, droughts, heat waves, and hurricanes. and cause several feet of sea-level rise and threats to the world's low-lying island nations and coastal cities.
- The October IPCC report warned that the World has only a dozen years to bring down greenhouse gas emissions or it will be inevitable that global temperatures will go above the 1.5°C threshold.
- Emissions must be reduced by a quarter by 2030 to keep warming to no more than 2°C above pre-industrial levels and for 1.5°C emissions would have to be halved.
- 2°C was viewed as the worst case a few years ago. Now that is starting to look like the best case.





- RCP8.5 is the current business as usual climate scenario, the present high emission rate of CO<sub>2</sub> and other greenhouse gases.
- A study by Matt Fitzpatrick and others published in the February 2019 issue of the journal Nature Communications and identified the city that most resembles the 540 cities would look like by 2100 under this scenario.
- The town of Imperial in the Imperial Valley most resembles what the climate of Visalia will be in 2080 in the RCP8.5 climate scenario with a 3.7°C warming.
- The present high emission rate of CO<sub>2</sub> and other greenhouse gases (current climate scenario RCP8.5), will lead to a 3.7°C (7°F) warming by 2100. Round it off to 4°C.
- Without a dramatic change in public opinion and resolve, the RCP8.5 scenario is the best estimate of where our future lies.
- 4°C of warming would result in:
  - the destruction of the world's coral reefs
  - massive loss of animal species
  - catastrophic extreme weather events
  - meters of sea-level rise (eventually, several hundred feet) that would challenge our capacity for adaptation
  - It would mean the end of human civilization in its current form.
- The U.N. says that a 4.3°C of warming would mean:
  - \$600 trillion in damages from climate impacts by 2100. That is double all of the wealth that exists in the world today.
  - Our agriculture would be about half as bountiful by 2100, so the same plot of land would be producing about half as much yield in a world where we would have at least 50% more people to feed.
  - There would be at least 100 million climate refugees by 2050 and far more by 2100.

## Variation in cloud cover



- Clouds and particles in the atmosphere acts like a shield, letting through some sunlight but reflecting a lot more back into space.
- But this is not a constant.

### 1816 Year with a Summer

- Mount Tambora Indonesia erupted in 1815, heaving some 12 cubic miles of earthen matter to a height of more than 25 miles.
- This was the world's largest volcanic eruption in over 1600 years.
- It was 100 times bigger than Mount St. Helens.
- Coarse particles soon rained out, but finer ones traveled the high winds in a spreading cloud.
- This global veil, high above rain clouds, reflected much sunlight back into space, cooling the planet.
- The giant cloud of minuscule particles spread around the globe, blocked sunlight and produced three years of planetary cooling.
- As a result of the Tambora eruption, 1816 became known as the Year without a Summer; it was a global volcanic winter.
- The northeastern part of North America and northern Europe were severely affected.
- Frosts in the northeastern U.S. in May 1816 killed off most of the crops that had been planted.
- Killer frosts ravaged New England farms in July and August, 1816.
- The loss of crops resulted in widespread famines and further deaths.
- I remember reading vivid accounts of crop failure and hardship in coastal North Carolina.
- This was the last great subsistence crisis in the Western world.

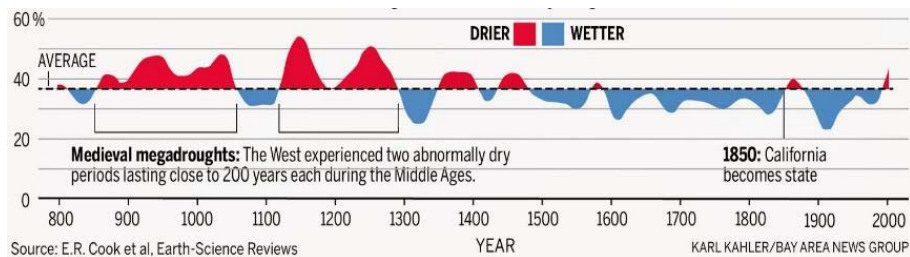
### K-T Mass Extinction

- The Cretaceous–Tertiary (K–T) extinction was a sudden mass extinction of some three-quarters of the plant and animal species on Earth, approximately 66 million years ago.
- Almost all land animals larger than about 50 lb, including dinosaurs became extinct in this event, but our small mammal ancestors survived.
- This event marked the end of the Cretaceous period and with it, the entire Mesozoic Era, opening the Cenozoic Era that continues today.
- It is now generally thought that the K–T extinction was caused by the impact of a massive comet or asteroid 6 to 9 miles in diameter, which devastated the global environment, mainly through a lingering impact winter which halted photosynthesis in plants and plankton.
- The impact crater from this comet or asteroid is buried underneath the Yucatan Peninsula in Mexico.
- The crater is about 93 miles in diameter and 12 miles in depth, well into the continental crust of the region.
- It is the second largest confirmed impact structure on Earth.

### PETM

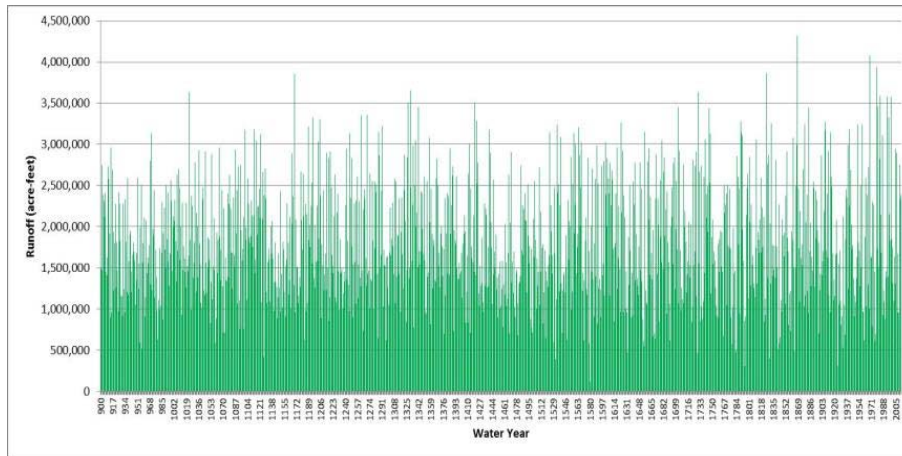
- The Paleocene-Eocene Thermal Maximum (PETM) was an abrupt global warming event that occurred 56 million years ago at the beginning of the Eocene Epoch.
- The PETM was the warmest period of the last 66 million years.
- An enormous amount of carbon was released into the ocean and atmosphere in less than 10,000 years at the start of this event.
- The source is still not firmly determined.
- The most convincing hypothesis appears to be an initial perturbation which caused a warming of the ocean which then resulted in the release of methane clathrates from the seabed in a feedback loop.
- This led to a massive release of methane, greatly amplifying the initial perturbation.
- As a result of this carbon release, temperatures rose 9-16°F globally.
- It was over 25°F warmer than the 1960-1990 average temperature.
- Atmospheric CO<sub>2</sub> concentrations remained below 2,500 ppm throughout the event.
- There were dramatic changes in precipitation, vegetation, and all the other effects associated with an increase in global temperatures.
- There were mass extinctions.
- It took about 150,000 to 200,000 years for the Earth's climate to get back to normal after the PETM.
- The PETM is widely recognized by scientists as the best geological analog for the human-induced global warming that is happening now.
- The PETM is the only event in the last 66 million years that had a massive carbon release, and happened over a relatively short period of time.
- Nothing comparable has occurred in the more recent past to what humans are currently doing.
- Even the drama of the PETM falls short of our current period in at least one key respect: We are putting carbon into the atmosphere at an even faster rate than happened back then.
- Recent simulations show that a major part of the PETM could have been the loss of cloud cover.
- CO<sub>2</sub> levels are projected to reach 1,200 ppm before the end of the century under the current climate scenario RCP8.5, the present high emission rate of CO<sub>2</sub> and other greenhouse gases.
- A study by Tapio Schneider and others published in February 2019 Nature Geoscience looked at what might happen to stratocumulus clouds when the atmosphere gets that warm. Their study suggests that stratocumulus clouds will be lost, resulting in runaway warming and 8°C (14°F) warming in addition to the 3.7°C (7°F) warming caused by increased greenhouse gases.

## Variation in PDSI over 1204 years: 800–2003 Western United States



- This chart is based on a study published by Edward Cook in 2007.
- It shows Palmer Drought Severity Index conditions, a measure of plant stress or drought severity for the entire West.
- The Cook study was based on tree-ring reconstruction from forest plots from east Texas up to Montana to the Pacific.
- Many of those basins, including the Great Basin and Merced River Basin, experienced two megadroughts before the Little Ice Age (1275–1850):
  - A 243-year megadrought that lasted from AD 832–1074.
  - A 178-year megadrought that lasted from AD 1122–1299.
- There is no evidence that those droughts were in the San Joaquin River Basin.

## Variation in runoff over 1113 years: 900–2012 Upper San Joaquin River — Millerton Lake



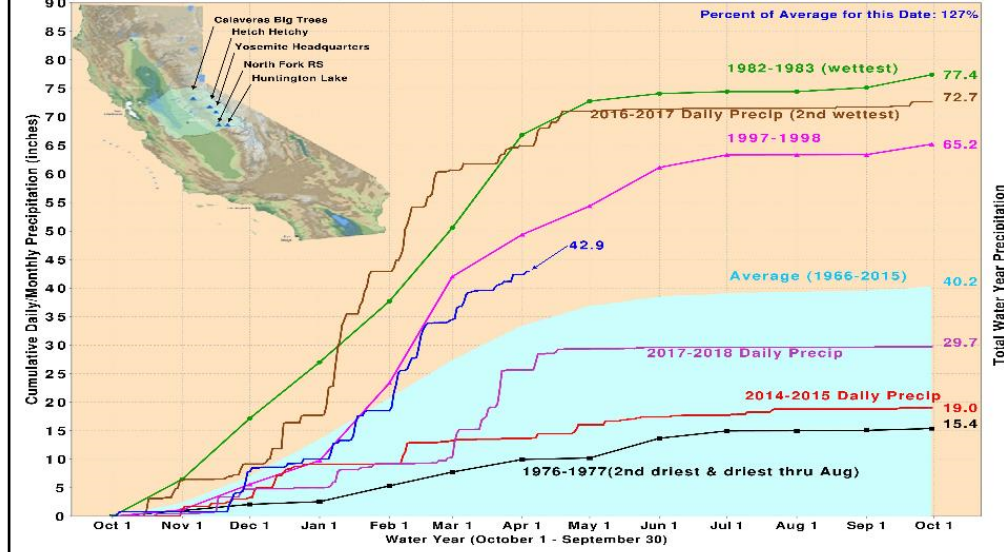
- So what is putting all the water stress on plants; what is driving up PDSI?
- Let's start with the history of precipitation.
- This is based on tree-ring reconstruction.
- This is the REALLY big picture. The graph is way too busy to read from a distance.
- But it shows you what kind of data is available.
- The biggest drought year during this period was 1580.
- The tree ring for that year is barely detectable.
- That year is the low flow-of-record on every river in the Southern Sierra.
- When we set a record low flow in 2015; that was #2 to the year 1580.
- When you look at the top dozen drought years, only three of our droughts since 1894 make that list: 2015, 1977, and 1924. It is a reminder of how severe a drought can be in a given year.
- Studies show that although our precipitation is very variable, there is no long-term trend, and no repeating pattern.
- There were two megadroughts in the Great Basin and Merced River Basin before the Little Ice Age:
  - A 243-year megadrought that lasted from AD 832–1074.
  - A 178-year megadrought that lasted from AD 1122–1299.
- There is no evidence that those droughts were in the San Joaquin River Basin.
- The trend in precipitation has been relatively steady since 1300, and probably since 900.
- There may have been a decrease in precipitation in the last three decades.

## Atmospheric river — February 20, 2017



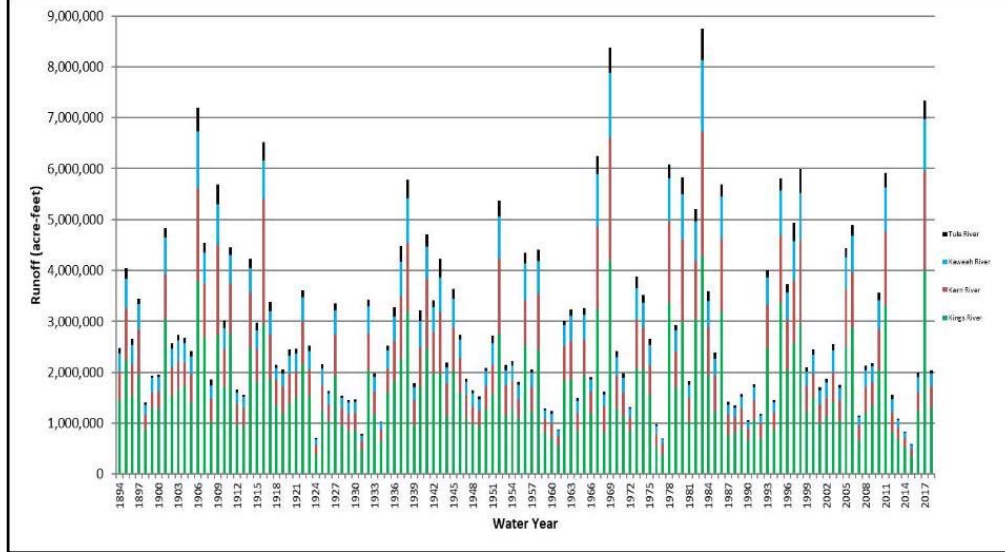
- Atmospheric rivers are the source of nearly half of California's precipitation, and they cause the large majority of our major serious floods.
- This was a typical pineapple express type of atmospheric river.
- Pineapple Expresses are a subset of atmospheric rivers, distinguished primarily by the source of the water vapor and the strength of the southwesterly trending vapor-transport atmospheric river extending toward the West Coast.
- About 30% of atmospheric rivers fall into the Pineapple Express category.
- There is now quite a bit of evidence that future droughts here will be warmer (greater water demand) and more intense, (less water supply) yet will be interrupted by increasingly powerful atmospheric river storms.
- The number of atmospheric rivers is projected to increase faster than their average intensity.
- Some research suggests that atmospheric rivers could become up to twice as common as they are now in parts of California by the end of the century, though this is still a matter of scientific debate.

## San Joaquin River Basin 5-Station Precipitation Index As of April 4, 2019



- Think of this chart as representing a giant rain gage for the San Joaquin River Basin that is being filled starting October 1 at the beginning of the water year.
- Average precipitation for that basin is 40.8 inches per year.
- 2015 was right in line with our long-term average.
- 2014 was half our average.
- In 1924, our driest year since settlement, the basin received less than half the average amount. 1977 was only a tidge more.
- 1924 wasn't just the driest year ever; it was the middle of a 17-year megadrought, the most severe in at least 11 centuries.
- Precipitation in 1580 was only 36% of 1924. It doesn't get any drier than 1580.
- In 1983, our wettest year ever, the basin received nearly twice the average amount.
- The blue line shows conditions to date for 2017, halfway between 1998 and 1983.
- Runoff for our 4 rivers for water year 2017 was 7.3 million acre-feet.
- That makes this one of the 20 largest runoff years since settlement began in 1850.
- Runoff in 2017 was the third largest since record-keeping began in 1894.
- There has been no decrease in patterns conducive to very wet years for the state, and these patterns may be increasing.

## Variation in runoff over past 125 years: 1894–2018 Conditions changed 30 years ago



- Runoff is a reflection of precipitation
- Only about 24% of the 13.6 million acre-feet that falls as average total precipitation becomes runoff.
- This chart shows runoff of our 4 big rivers, stacked one on top of the other.
- The long-term average flow is 2.9 million acre-feet per year.
- Precipitation and runoff in our area are extremely variable; we seldom have “normal.”
- There are more dry years than wet years.
- That is true for our basin and for the state as a whole.
- When there is a wet year, it can be very wet indeed.
- Point out the 17-year-long megadrought of 1918–34.
- Point out the 2000–04, 2007–09, and 2012–15+ droughts.
- These last 3 droughts can be thought of as a 16-year dry spell, interrupted by two short bursts of intense rainfall.
- We got another burst of intense rainfall during the winter of 2016-17.
- Those wet periods occurred because our precipitation has high variability.
- Just like in the 1920s, we keep wondering if the drought has really ended.
- If we look at this from California’s perspective, we have experienced 3 droughts of relatively average duration: the 2000–04, 2007–09, and the 2012–15+ droughts.
- However, if we were to step back and look at the bigger picture, we are really on the edge of a record-setting megadrought.
- More area in the Western U.S. has persistently been in drought during the 16-year period from 2000–15 than in any other 16-year period since recordkeeping began in 1895.
- It is probably the worst 16-year period in more than 850 years, since about the 1150s.
- 1987 marked a big change in our precipitation.
- Precipitation during the previous nine-year period (1978-1986) had been 39% above the long-term average.
- In 1987, we entered a three-decade-long period of relatively dry years.
- It began with the six-year drought of 1987–92.
- We are only aware of 10 droughts in the last 11 centuries that have lasted 6 or more years.
- Ranchers during this period made insurance claims from SCC because precipitation was less than 50% of what they thought was average. But what really was average precipitation?
- 1983 was 297% of the long-term average. The national park chose that year to determine safe yield for Giant Forest’s surface water system.
- We built the new water plant and began operating it for this supposed safe yield. What did we get? We got OOPS — an Outcome Outside Planned Scenario.
- It was a good lesson about the importance of identifying what average really is.
- I’ll be talking about 3 big changes that have occurred since the mid-1980s.
- But that doesn’t mean that a climate change necessarily occurred at that point.
- It could be that the last 3 decades are different than previous decades.
- It could be that a long-term trend first became noticeable in the mid-1980s and is getting more severe.
- It could be both.
- SGMA requires that groundwater sustainability plans rely on the best available science to quantify the water budget for the basin in order to provide an understanding of historical and projected hydrology and water supply.
- DWR’s best management practices don’t provide any advice about how to implement that requirement, what the pitfalls are.
- Whenever we use past data to make a statement about current or future conditions (like safe yield), the first step is to consider whether we can safely assume that this past data is representative of current conditions.
- For example, when DWR prepared the Water Available for Replenishment Report in 2017, they used 1967 through 2012 precipitation data to estimate the average amount of runoff available under current conditions.
- They made the unstated assumption that the precipitation and surface runoff for the period 1967 through 2012 is representative of current conditions.
- But that is not a reasonable assumption.
- Multiple studies have shown that conditions have changed in the last three decades; data for the decades prior to the mid-1980s is not reflective of conditions in the decades since then.
- Several studies have shown that the first 9 decades of this period were essentially a steady state.
- There was no trend up or down.
- Then one or more things happened to our climate about 3 decades ago in the mid-1980s.
- The trend since then has been different than the trend of the previous 9 decades.
- It is common to use all available past data to estimate current conditions. More data is always better.
- But that is only true if we are currently in a stable condition; nothing is changing.
- This is especially true for the Pacific Southwest Climate Subregion and the Tulare Lake Hydrologic Region.

## Trough in Polar Jet Stream The Cause of Most of California's Big Storms

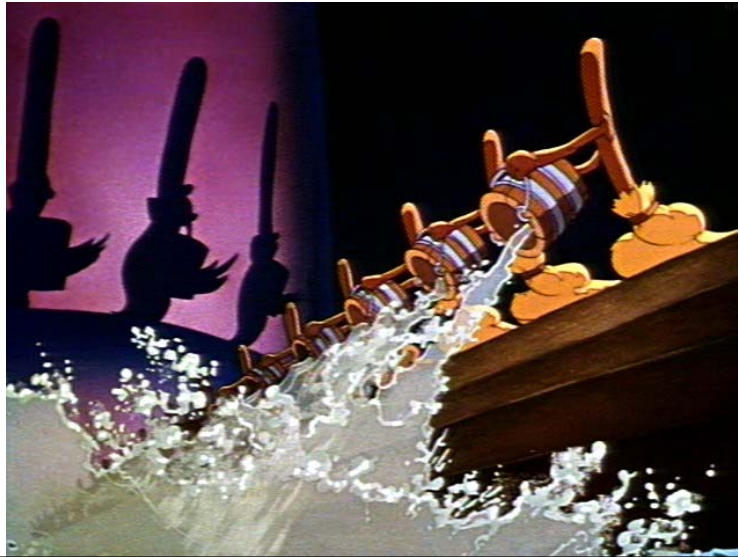


### Cause of big winter storms

- A jet stream trough is a big bend or wave in the jet stream.
- These troughs or low-pressure areas bring down cold air from the Arctic.
- As storms come across the Pacific, they follow the boundary of these troughs.
- The trough serves to steer storms, directing them into Washington, Oregon, or California.
- California only gets a handful of storms in a typical winter.
- More than  $\frac{1}{2}$  of our annual precipitation (and in many years  $\frac{3}{4}$  of our precipitation) occurs in 5-7 storms.
- The big storms dump a lot of water.
- They either come or they don't; our dependence on these few storms is why it's feast or famine in California.

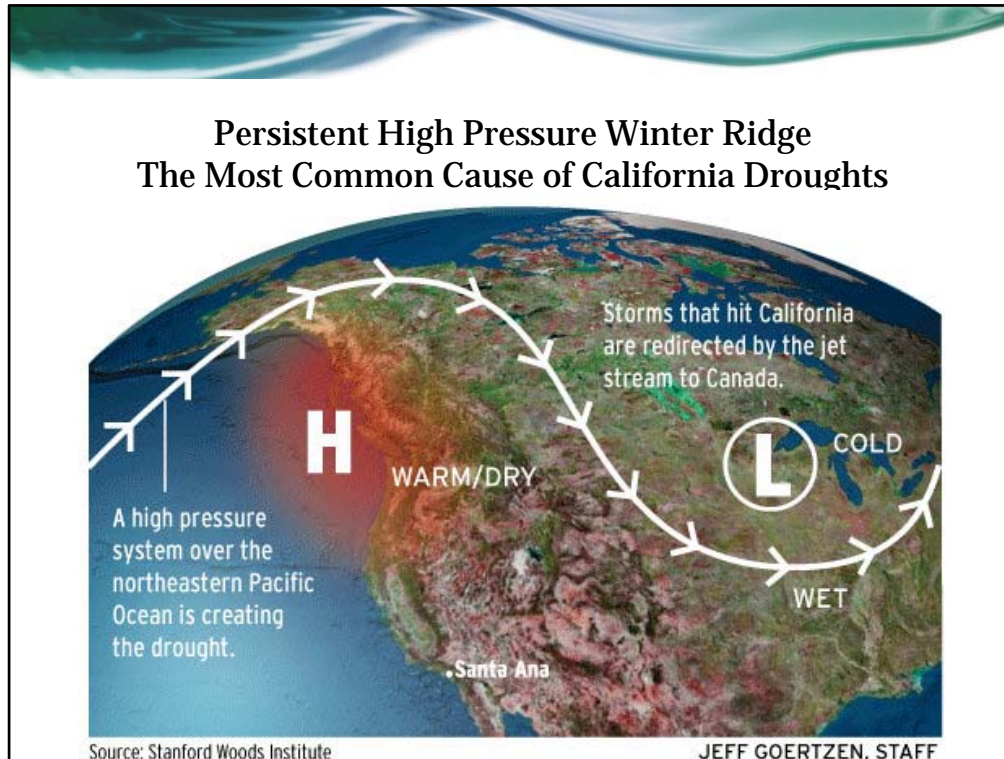


## 200-Year Severe Storm Sequence 1861-62 Storm



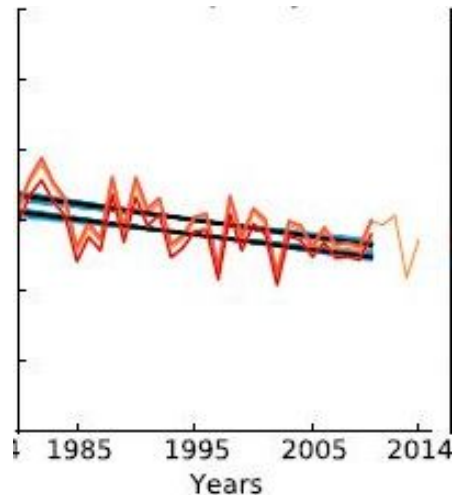
### Severe storm sequence

- On rare occasions, the jet stream trough settles over California for an extended period and brings us far more than our usual half-dozen big storms.
- The water delivery system gets turned on, but doesn't turn off. Much like in *The Sorcerer's Apprentice*.
- In the past, this has happened about every 200 years or so.
- The trough that formed in 1861-62 funneled a relentless system of low pressure systems into California for almost two months; an extraordinary amount of time by California standards.
- These low-pressure systems were spinning counter-clockwise.
- The southern end of these storms, as they got closer to California, pulled in sub-tropical moisture from Hawaii or from west of there.
- This warm moist air was drawn into this very intense cold low-pressure system.
- The clash of that warm moist air with those cold low-pressure systems made for spectacular rainfall events in the Sierra.
- The warmth and the moisture provide energy to these storms.
- So a series of energetic storms came pounding into the Sierra, providing a series of spectacular rainfall events.
- Between December 1861 and January 1862, California experienced a truly extraordinary meteorological event: a more than 40-day long onslaught of extremely moist atmospheric river storms that led to widespread inundation on a massive scale.
- Nearly every river, stream, and creek between central Oregon and the Mexican border experienced significant flooding during this event, which brought dozens of inches of rain even to California's drier low-lying coastal areas over the course of just a few weeks, and well over 100 inches of rain (over 8 feet) along the western slopes of the Sierra Nevada over a two month period.
- The Central Valley was transformed into an inland sea 20–60 miles wide, stretching 400 miles from the base of the Tehachapis to Redding.
- Vast swaths of land in Los Angeles and Orange Counties were underwater.
- Paleoclimate analysis of sediments from California's coastal river systems suggests that events of a similar magnitude have happened many times in the region's deeper past—approximately every 200 years.
- The UCLA study found that the risk of an extreme 40-day precipitation event similar in magnitude to that which caused the 1862 flood are likely to be about 5 times as frequent as the historic average (1895-2017) in both Northern and Southern California by the end of the century (2070-2100).

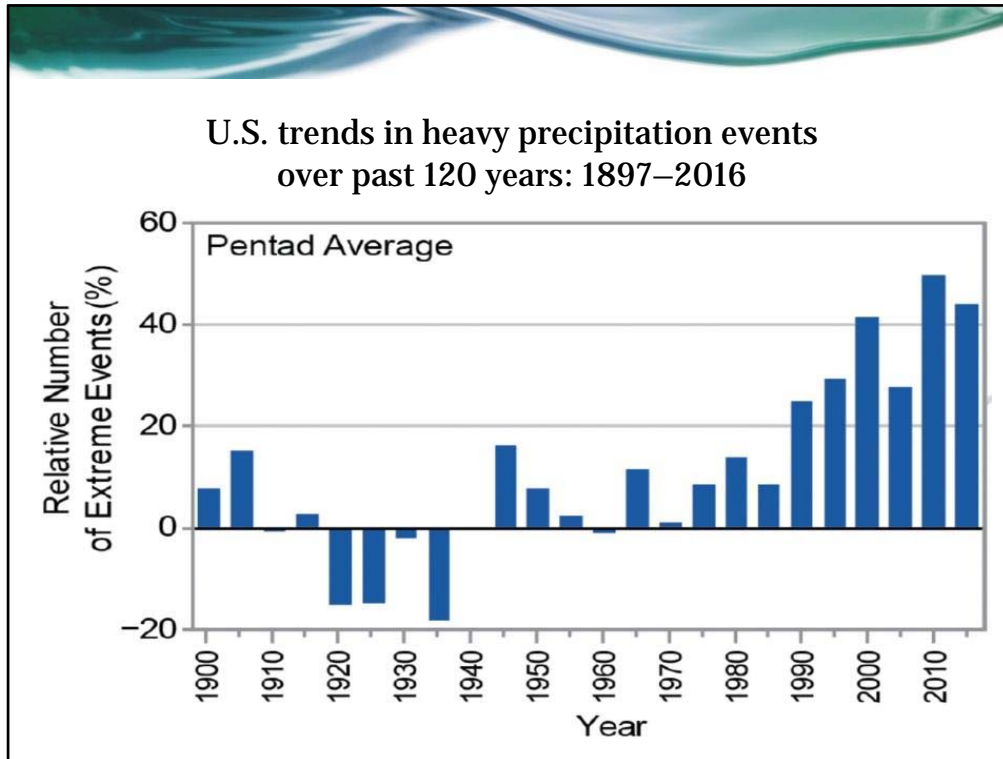


- Sometimes an unusually persistent high pressure ridge will develop in the winter off the West Coast, deflecting the Polar jet stream north of its typical winter position along the West Coast.
- This is a very strong ridge of high pressure along the entire West Coast, from southern California all the way to the Alaskan arctic.
- When this ridge is present, eastward-moving Pacific storms that appear destined for California often veer north before they penetrate very far into the state.
- Because the storm track stops short, northern watersheds get more precipitation than southern watersheds.
- This ridging pattern has preceded some of the worst West Coast droughts.
- The 1934 drought was caused by a high pressure ridge over the West Coast.
- Such a ridge preceded the first year of the 1976–77 drought.
- It was the cause of the dry winters of 2013–14 and 2014–15.
- Diversion of the Pacific storm track by unusually persistent winter ridges is the most common cause of California droughts.
- The three patterns that tend to bring the most wet weather to the Southwest all involve low pressure systems centered in the North Pacific just off the coast of Washington, typically during the winter.
- California relies on the rain and snow that falls when the jet stream dips south—and it does this for relatively short intervals—sending storm systems barreling toward us.
- The most important of these storms are associated with atmospheric rivers.
- Atmospheric rivers are the source of nearly half of California’s precipitation, and they cause the large majority of our major serious floods.
- This dependence of California’s entire water supply upon the occurrence of just a few atmospheric river events each winter means that a surplus or deficit of just one or two such storms can quickly increase the risk of flood or drought in any given year.
- As a result, diversion of the Pacific storm track by unusually persistent winter ridges is the most common cause of California droughts.
- Research has shown that the high pressure ridge has become more pronounced and persistent during the last 3 decades (1982–2015).
- As a result, drought years (warm years with few low-pressure weather systems) have occurred more often during the last 3 decades.
- A 2016 study from Stanford, Northwestern, and Columbia confirmed with high confidence that increasingly frequent atmospheric patterns conducive to extreme drought in California are increasing.
- However, there has been no decrease in patterns conducive to very wet years, and these patterns may be increasing.
- This observed increase in dry/wet extremes (and less average) is consistent with climate model projections for California in the 21st century.
- It was not apparent from this study whether overall precipitation has been changing or not.

### Change in frequency of rain-producing weather types Pacific Southwest Subregion (1980-2010)



- During the 30-year period 1980-2010, the frequency of rain-producing weather types in the Pacific Southwest subregion decreased at -7% per decade, using 1980 as a baseline.
- The Pacific Southwest subregion lost approximately 25% of its precipitation during the 30-year period 1980-2010 due to the decrease of rain-producing weather types.
- This means that our subregion received 25% less precipitation on average in 2010 than we were receiving 30 years earlier in 1980.
- That trend appears to be continuing.
- This suggests that the precipitation regime for our region is decreasing; the safe yield for each decade is lower than for the previous decade.
- Whatever the cause, the precipitation and runoff regime for our basin has apparently changed.
- As a result, years prior to the mid-1980s can't be used when calculating what our current safe yield is.
- This is the supply side of the equation.



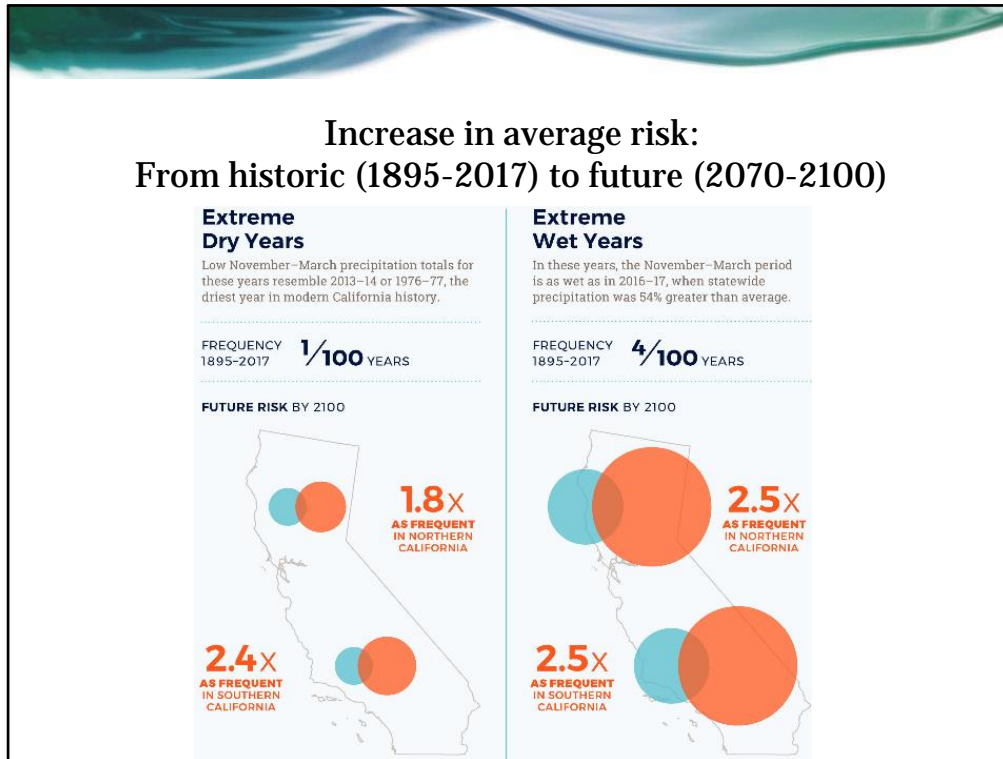
- Storms like this are so big that back in the old days (1901-1960), you would only expect to see an average of one such storm every 5 years.

The 2014 National Climate Assessment found:

- Heavy precipitation events are increasing nationally, especially over the last 3 to 5 decades.
- The largest increases are in the Midwest and especially in the Northeast; there is virtually no increase in our region.
- Increases in the frequency and intensity of heavy precipitation events are projected for all U.S. regions.

The 2018 National Climate Assessment found:

- The frequency and intensity of heavy precipitation events are increasing in most continental regions of the world.
- These trends are consistent with the expected physical responses to a warming climate.
- Heavy precipitation events will very likely continue to increase in frequency and intensity throughout most of the world.
- This has implications for how fast and when water comes off the upper watersheds, how erosive flood events are, how much sediment accumulates behind dams, how much sediment is delivered to recharge basins, etc.
- Climate change exacerbates and amplifies the risk of naturally occurring heat waves, droughts, wildfires, sea level rise, and hurricanes.
- We don't expect to see an increase in the average number of hurricanes in the future.
- But we do expect to see an increase in the average amount of precipitation and in the size of storm surges.
- Hurricanes in a warmer climate are likely to become more intense.

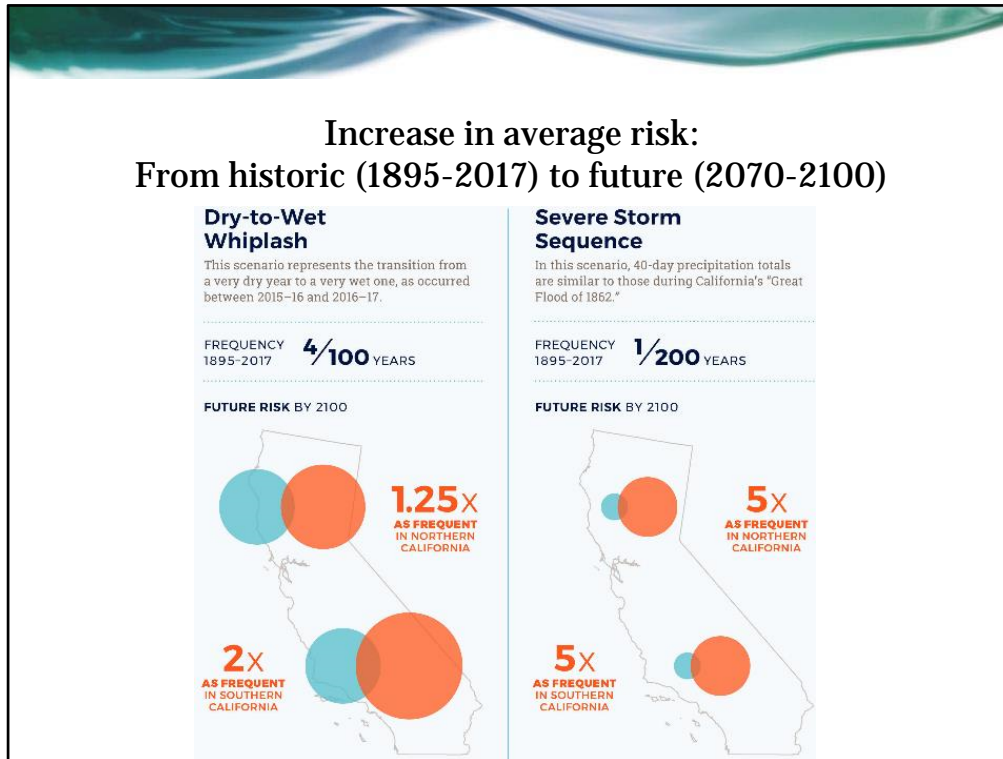


### Extreme wet years

- This chart is also from that 2018 UCLA study led by Daniel Swain; it is based on the RCP8.5 business as usual scenario.
- Statewide, precipitation in the 2016-17 November-March rainy seasons was 54% greater than the 1895-2017 average.
- Historically (1895-2017), very wet November-March rainy seasons similar to 2016-17 have occurred about four times per century.
- The UCLA study found that such extremely wet years are likely to be about 2.5 times as frequent as the historic average (1895-2017) in both Northern and Southern California by the end of the century (2070-2100).
- The increase in the frequency of extremely wet years began about 2000.

### Extreme dry years

- Statewide, precipitation in the 1976-77 and 2013-14 November-March rainy seasons were the driest years ever during the 1895-2017 period.
- Historically (1895-2017), very dry November-March rainy seasons similar to 1976-77 and 2013-14 have occurred about once per century.
- The UCLA study found that such extremely dry years are likely to be about 1.8 times as frequent as the historic average (1895-2017) in Northern California and 2.4 times as frequent in Southern California by the end of the century (2070-2100).
- The increase in the frequency of extremely dry years began in the early 1980s shortly after global temperatures began to rise.
- There was no predicted change in the future frequency of multi-year dry spells (such as experienced during the recent 2013-2016 drought).
- That is essentially because 21st century droughts in California will have a greater propensity to be interrupted by brief but very wet interludes.
- This is looking at drought solely as a period of reduced precipitation.
- On the other hand, there is already abundant evidence that rising temperatures are increasing the likelihood and intensity of multi-year droughts in California through increased evaporation and snowpack loss, even in the absence of precipitation changes.

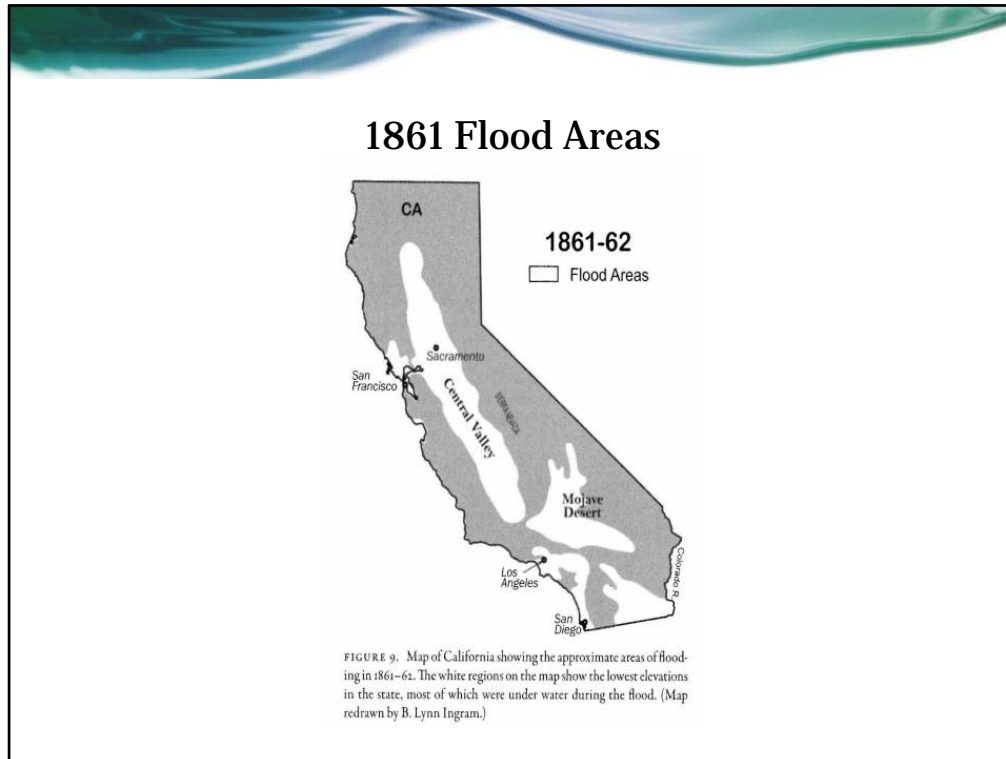


#### Dry to wet whiplash

- This chart is also from that 2018 UCLA study led by Daniel Swain.
- This represents the transition from a very dry year similar to 2015-16 to a very wet year similar to 2016-17
- Historically (1895-2017), transition from a very dry year similar to 2015-16 to a very wet year similar to 2016-17 have occurred about four times per century.
- The UCLA study found that these dry-to-wet whiplash events when there is a transition from a very dry year similar to 2015-16 to a very wet year similar to 2016-17 are likely to be about 1.25 times as frequent as the historic average (1895-2017) in Northern California and 2 times as frequent in Southern California by the end of the century (2070-2100).
- The increase in the frequency of these dry-to-wet whiplash events began in the early 1980s shortly after global temperatures began to rise.

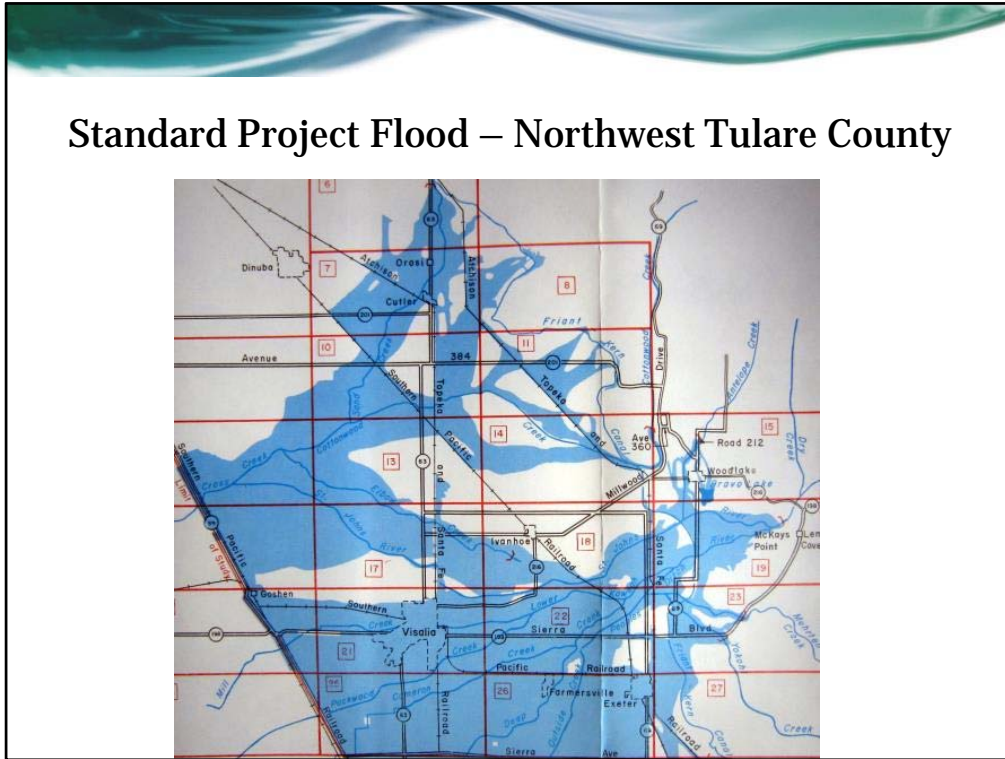
#### Severe storm sequence

- Between December 1861 and January 1862, California experienced a truly extraordinary meteorological event: a more than 40-day long onslaught of extremely moist atmospheric river storms that led to widespread inundation on a massive scale.
- Nearly every river, stream, and creek between central Oregon and the Mexican border experienced significant flooding during this event, which brought dozens of inches of rain even to California's drier low-lying coastal areas over the course of just a few weeks, and well over 100 inches of rain (over 8 feet) along the western slopes of the Sierra Nevada over a two month period.
- The Central Valley was transformed into an inland sea 20–60 miles wide, stretching 400 miles from the base of the Tehachapis to Redding.
- Vast swaths of land in Los Angeles and Orange Counties were underwater.
- Paleoclimate analysis of sediments from California's coastal river systems suggests that events of a similar magnitude have happened many times in the region's deeper past—approximately every 200 years.
- The UCLA study found that the risk of an extreme 40-day precipitation event similar in magnitude to that which caused the 1862 flood are likely to be about 5 times as frequent as the historic average (1895-2017) in both Northern and Southern California by the end of the century (2070-2100).
- On our current emissions trajectory, at least one occurrence of an 1862-level precipitation event is more likely than not over the next 40 years (between 2018 and 2060), with multiple occurrences plausible between now and the end of the century.
- In practical terms, this means that what is today considered to be the 200-year flood—an event that would overwhelm the vast majority of California's flood defenses and water infrastructure—will become the 40-50 year flood in the coming decades.



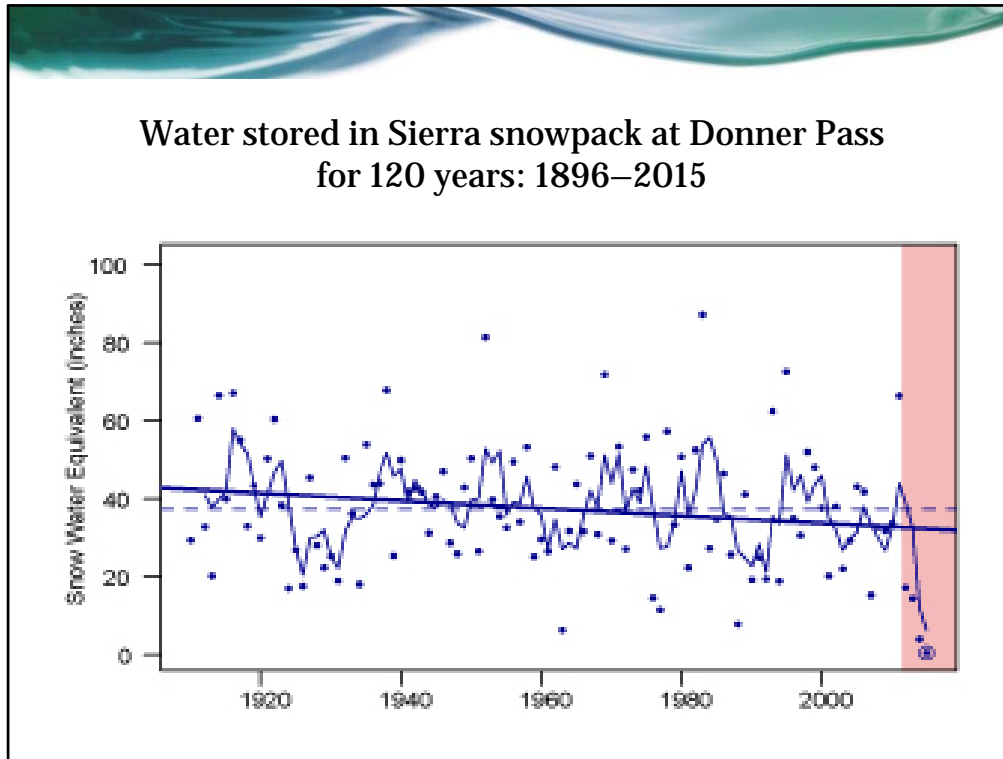
- The 1861 flood is the most famous flood to have struck Oregon and California.
- This was a rain flood, as opposed to a snowmelt runoff flood.
- The December 1861 storm system resulted in a series of floods that stretched from the Columbia River to Mexico; a region over 1,000 miles wide.
- The storm system were likely the result of an intense atmospheric river, or a series of atmospheric rivers.
- The storms dumped an incredible amount of precipitation on the state.
- The mining community of Sonora in the Gold Country received 8½ feet of rain in a 74–day period.
- The water literally could not flow out of the rivers through Carquinez Strait fast enough, so it just backed up.
- The Central Valley was transformed into an inland sea 20–60 miles wide, stretching 400 miles from the base of the Tehachapis to Redding.
- Most of the white areas on this map were under water during the flood.
- Vast swaths of land in Los Angeles and Orange Counties were underwater.

## Standard Project Flood – Northwest Tulare County

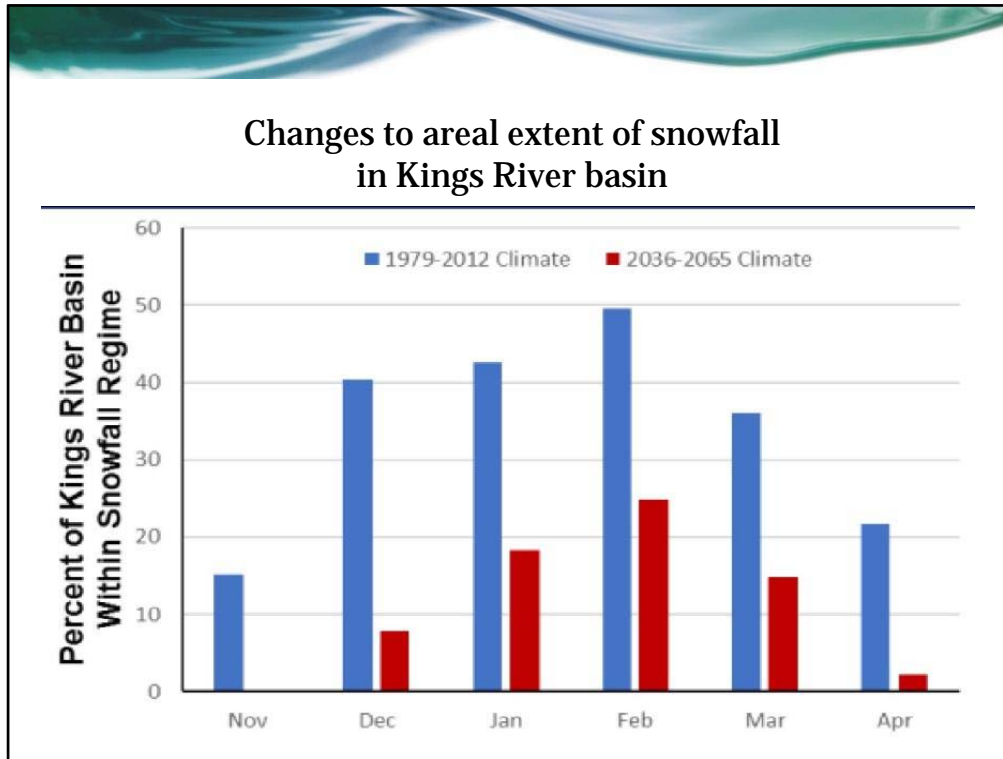


- This is the Army Corps' estimate of how much of northwest Tulare County would be flooded during the standard project flood.
- The study area extends from Highway 99 on the west to Highway 137 and Lindsay on the south.
- The standard project flood is a rare event, but one that could reasonably be expected to occur.
- It's bigger than the 1966 flood. Think of it like the 1861 flood or the 1867 flood, our two biggest floods in historic times.
- This flood projection assumes that Terminus Dam on the Kaweah is in operation.
- The standard project flood, with Terminus Dam in operation, would be of somewhat greater magnitude than the December 1955 flood without Terminus Dam.
- The Corps no longer uses the term "standard project flood" when assessing flood risk potential.
- But this flood study gives a good illustration of what the effects of a very large flood would be like, even with Terminus Dam in operation.
- It is a reminder of how important downstream levees are.





- One other result of rising temperature is its effect on the Sierra snowpack.
- This graph is from a 2016 Stanford study led by Daniel Swain.
- It shows Snow Water Equivalent as of April 1.
- The red shaded regions depict the 2013-2015 drought
- We rely on that snowpack for 30% of our water.
- There was more than 37 million acre-feet of snow in the entire Sierra at the end of March in 2011.
- There was only about one million acre-feet at the end of March in 2015.
- The amount of water stored in the Sierra Nevada snowpack reached its lowest level in over 500 years in 2015.
- Partly this was due to record warm temperatures in the winter on 2014–15.
- The vast majority of California’s precipitation falls as rain and snow in the winter months.
- The rain fills the reservoirs, while the snow accumulates in the mountains, effectively acting as another reservoir.
- The snowpack gradually releases the water during the spring and summer.
- Precipitation in the Sierra isn’t like in the Rockies.
- In the Sierra, it tends to be right on the borderline between rain and snow.
- It only takes a slight warming to turn the precipitation to rain.
- For every five degrees of warming, the freezing point of a storm, or the altitude of the “snow level” will rise by a thousand feet, driving the snowpack higher into the mountains.
- If rain falls on top of snow, it diminishes the snowpack further by melting it and triggering earlier runoff.
- Overall the freezing level in the Sierra has been going up, especially in the spring.
- The coldest winter temperatures in the Sierra in the winter of 2014–15 were above freezing on average. That was the first time this had occurred since recordkeeping began.
- What this warming trend means is that:
  - There will be more winter runoff because storms will have higher freezing points
  - more water is lost through sublimation (direct evaporation without melting)
  - melting is starting to occur earlier at higher altitudes
  - runoff is starting earlier; this will be an increasing trend
- California’s snowpack has shrunk by 10% on average since World War II.
- Historically (1915-2003), 2/3 of the state’s snowfall equivalent has been at mid-elevations, below 8200 feet.
- Based on the current temperature trend, snowfall equivalent (SFE) is projected to decline 50% statewide by the end of the 21st century.



- This slide and modeling work was done by Mohammad Safeeq at UC-Merced.
- This chart reflects snowfall in the Kings River basin above Pine Flat.
- The bars show the *average* areal extent of snowfall for the particular month being illustrated.
- Future projection are based upon the RCP8.5 scenario using a 20-model GCM mean (Klos et al. 2014).
- We got a lot of tropical moisture during the winter of 2016-17; that always drives the snowline higher.
- Precipitation and snowpack were both well above average in California during the winter of 2016-17.
- However, Sierra snow water equivalent lagged overall precipitation.
- For example, in early March Northern Sierra snow water equivalent was 145% of average (vs 202% of average) for overall precipitation.
- This effect has been particularly pronounced at middle-elevation regions where wintertime temperatures are more “marginal” for frozen precipitation than at colder, higher elevations.
- While this winter has certainly been colder than recent (record warm) ones, conditions have still been near to above average across most of the state.
- More importantly, conditions have been considerably warmer than during most of California’s historically wet winters.
- If the world (including the United States) were to work aggressively to limit CO<sub>2</sub> and other greenhouse gas emissions, global temperatures might rise “only” 2°C (3.6°F) by 2100. But even before the United States backed out of the Paris Accord, we were well on our way to a 4°C (7.2°F) temperature rise by 2100. That is very similar to the RCP8.5 scenario that the 2017 UCLA study was based on. Without a dramatic change in public opinion and resolve, that seems to be the best estimate of where our future lies.

The snowpack in the Central and Southern Sierra has been decreasing since record-keeping began; the rate of decrease has been greater in recent decades. This decrease in snowpack storage is projected to continue through the end of the century.

The Kings River Basin seems to be a bit ahead of the Kaweah, Tule, and Kern in planning for how to adapt to the melting of their snowpack.

Safeeq has modeled the effect of this temperature increase in the Kings River Basin. Based on modeling, April 1st snowpack in the Kings River Basin above Pine Flat averaged about 1.5 MAF during the 2000-2014 period. Under a 4°C warming scenario, storage is projected to shrink by 47% (a reduction of 0.7 MAF), leaving a snowpack of only 0.8 MAF by 2100.

So what happens to this 0.7 MAF of lost snowpack? Put another way, we are going to get an increase in flows on the Kings River prior to April of 0.7 MAF; what do we do with that water? We don’t want it to flow out of the basin. We want it to be available for use later in the year.

So it seems like we need to have a plan to store that water (either in surface reservoirs or in subsurface storage) so that it can be used later in the year. Nobody is looking at storing this water in surface reservoirs.

Eric Osterling said that significant groundwater recharge capacity currently exists on the valley floor of the Kings River Basin and can be taken advantage of through planning alone. The top priority of GSAs is to develop additional groundwater recharge capacity to take advantage of any excess flows as a sustainability strategy under SGMA.

The above is largely being done on a GSA by GSA planning basis with relatively minimal coordination. There isn’t any overall planning effort to ensure that there will be sufficient groundwater recharge capacity to handle the projected increase in runoff.

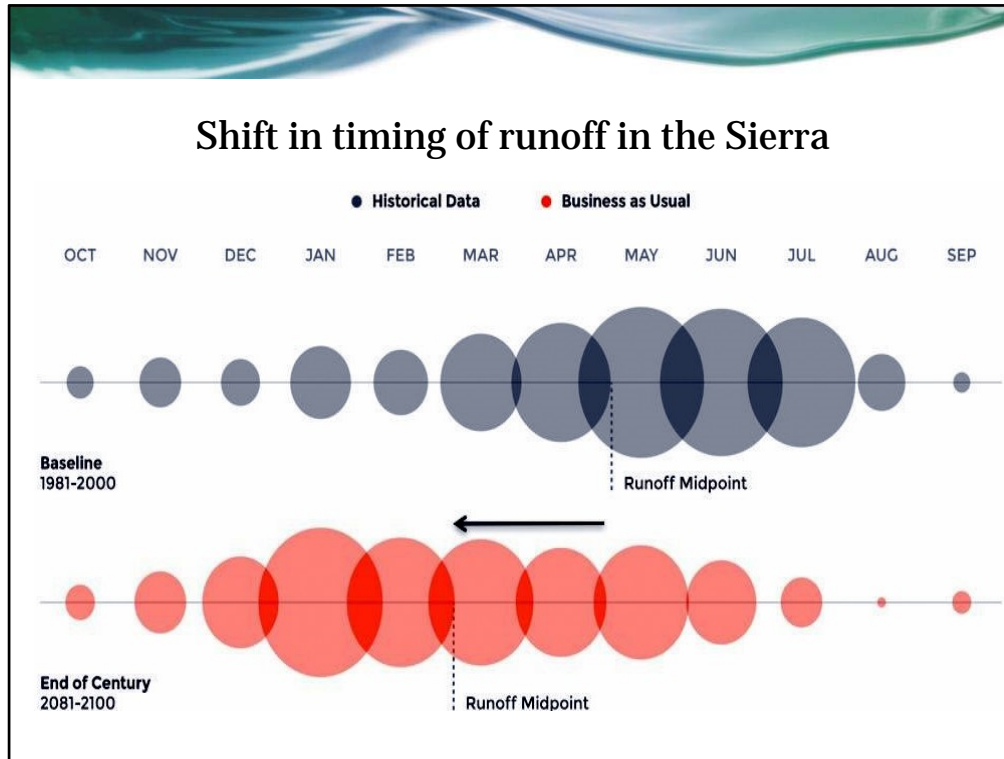
They don’t feel that any formal coordinated planning effort is needed on the Kings. The expectation is that with all the GSAs doing their own planning efforts as part of SGMA, this will all work out in the end. All that extra water can be put somewhere in most years.

Although there is no formal coordinated planning for this on the Kings, there is a planning effort and always has been, just not in the formal sense of something with a fancy name and publicized. Water managers are working together informally on the issue of snowpack melting and the need for increased groundwater recharge.

That sounds better than “on a wing and a prayer,” but I can’t really tell how much better.

From talking with Matt Hurley, I get the impression that GSAs in the Kaweah, Tule, and Kern River Basins intend to follow the same general path as those in the Kings. But they seem to be a good bit further behind in their planning and there may be even less coordination in these basins than in the Kings.

- Projected loss of snowpack loss in Kings River Basin is 0.7 MAF. If this is representative of loss throughout the Tulare Lake Basin (a very big assumption), then total loss would be roughly 1.2 MAF.

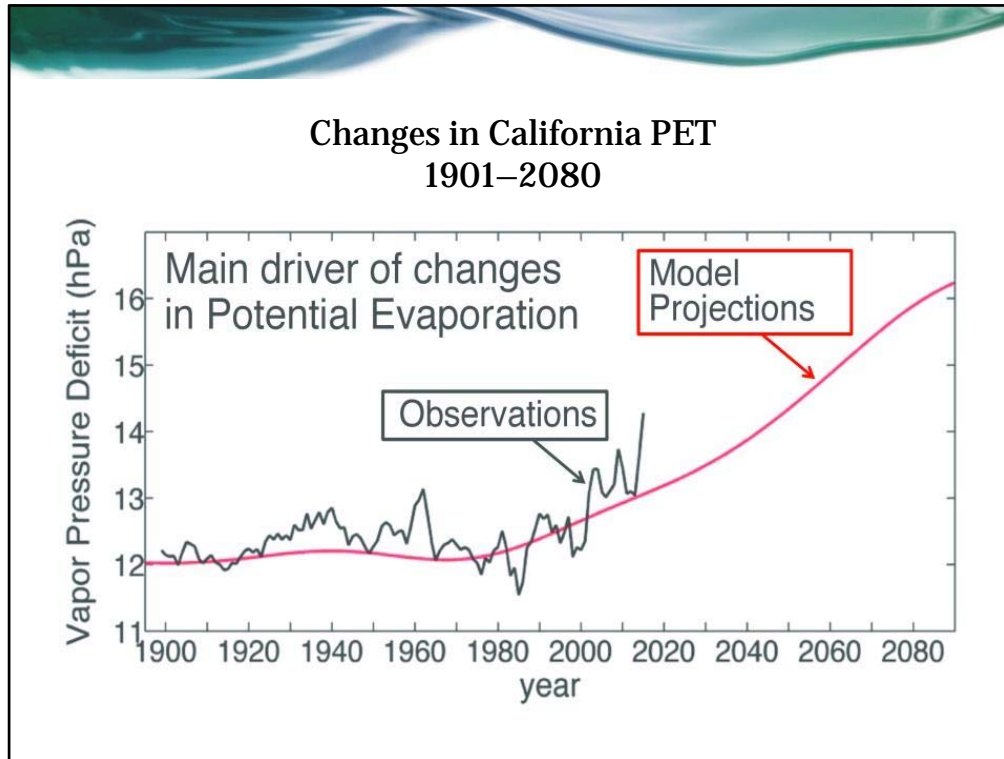


- This slide is from Rebecca Ash at UCLA. It reflects average runoff for the entire Sierra.
- It is based on work by UCLA climate scientist Alex Hall and colleagues which predicted that by 2100, the runoff midpoint for snow and rainwater — the time of year by which half of a year's precipitation leaves the mountains as runoff — could be an average of 50 days earlier than it is now, and 90 days earlier in some locations.
- The predicted changes could be most pronounced at elevations of 6,000 to 8,000 feet .
- That research was based on climate scenario RCP8.5, the present high emission rate of CO<sub>2</sub> and other greenhouse gases. This scenario will lead to a 3.7°C (7°F) warming by 2100.
- Without a dramatic change in public opinion and resolve, the RCP8.5 business as usual scenario is the best estimate of where our future lies.
- One implication of this change in the timing of runoff is how we use the federal reservoirs to store water.
- The gross-pool capacity for each reservoir is divided into two components: a flood-control pool and a conservation pool.
- During the winter flood season, the reservoir is drawn down to the conservation pool.
- That leaves the flood-control pool available to catch any potential flood.
- If the reservoir catches a flood during the flood season, it has to release that water fairly soon so that the flood-control pool will then be available to catch the next potential flood.
- Once the risk of flooding is largely past, the dam is then partially closed, and the reservoir begins to fill.
- With luck, the reservoir will be nearly full by about the end of May.
- This dual use of the reservoirs is possible because the flood season historically occurs before the runoff season.
- But increasing temperature is now pushing the runoff midpoint nearly 2 months earlier in the year.
- While the flood season is staying at the same place.
- So when the flood season ends and it is time for the reservoirs to start catching the runoff, most of that water will have already flowed downstream.
- The amount of water stored behind the reservoirs will be significantly reduced as runoff moves earlier in the year.
- The 4 federal reservoirs in the Tulare Lake Basin have a combined current capacity of 1,627,900 acre-feet.
- As we lose the ability to store runoff in the reservoirs, additional storage will need to be provided downstream.

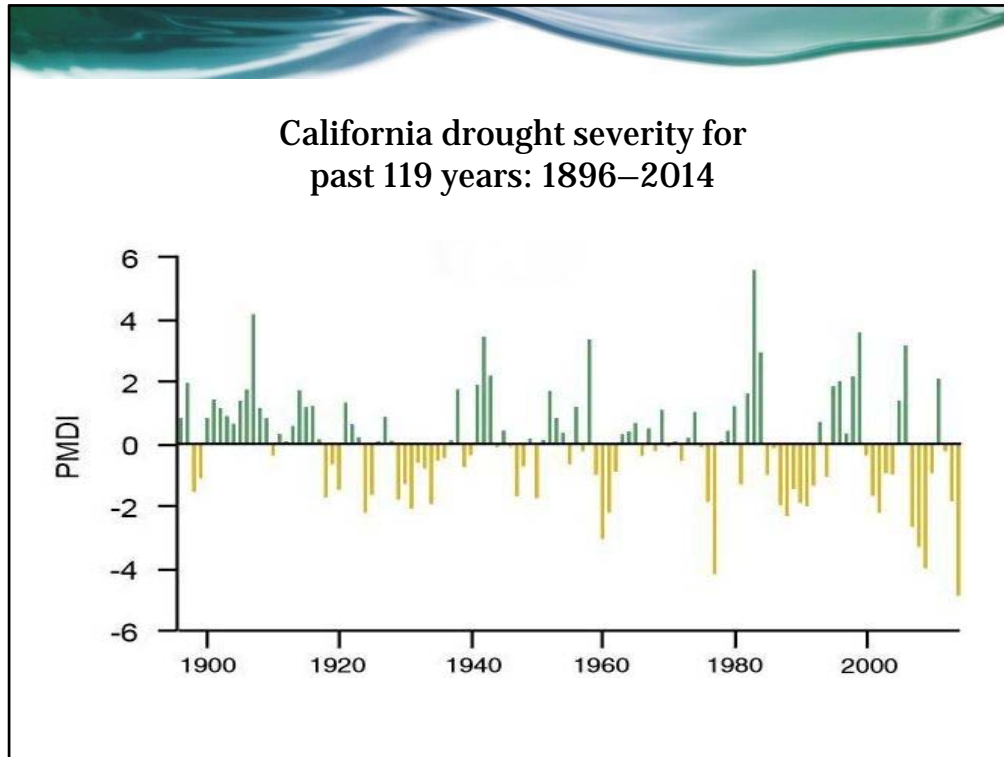
**Drought —  
When water supply is inadequate to meet demand of plants**



- A third way of looking at drought is a period of time when our water supplies are inadequate to meet the water demand of plants.
- Water demand, from a plant's point of view, is the supply it needs to avoid stress.
- Plants lose water vapor through their leaves and needles; they are natural vaporizers.
- The term for this is transpiration or, more generally, evapotranspiration (ET).
- Water vapor is invisible, but it constitutes an enormous amount of water.
- The Tulare Lake Basin loses 23 million acre-feet of water through evapotranspiration in an average year.
- All the water we use each year is converted to ET and sent over the Sierra; that's why we are not immersed under a giant lake.
- Think of evapotranspiration like a straw that runs from the canopy to the roots.
- The suction in that straw is called potential evapotranspiration (PET).
- Potential in this sense is how much water would be sucked back up that straw to the canopy if supply were readily available down in the root zone.
- The hotter the temperature, the greater the suction in that straw.
- On a hot day, PET is like a giant sucking sound.
- The higher the temperature, the more water plants need to avoid water stress. Just like humans.
- The water supply that comes up that straw in response to PET, gets vaporized through the leaves and needles.
- If plenty of water comes up that straw, the plant is happy.
- PET is the amount of water plants need to avoid stress.
- But in drought conditions, plants may not be able to get all the water that they need.
- If there isn't enough water supply available in the root zone to meet demand (PET), the plant is under water stress.
- The difference between demand (PET), and supply (actual ET), is how much water stress the plant is under.
- That is how much additional water supply would be needed to make up for the water deficiency.
- That difference between PET and actual ET is the size of the drought from the viewpoint of plants.
- Initial studies suggest that the conifer biomass in the upper watersheds would have had to be reduced by at least 50% to provide enough water during the recent drought to make the remaining trees resilient and able to resist bark beetles.
- If you're involved in SGMA and using reference evapotranspiration, you can think of PET as being one step closer to reality.

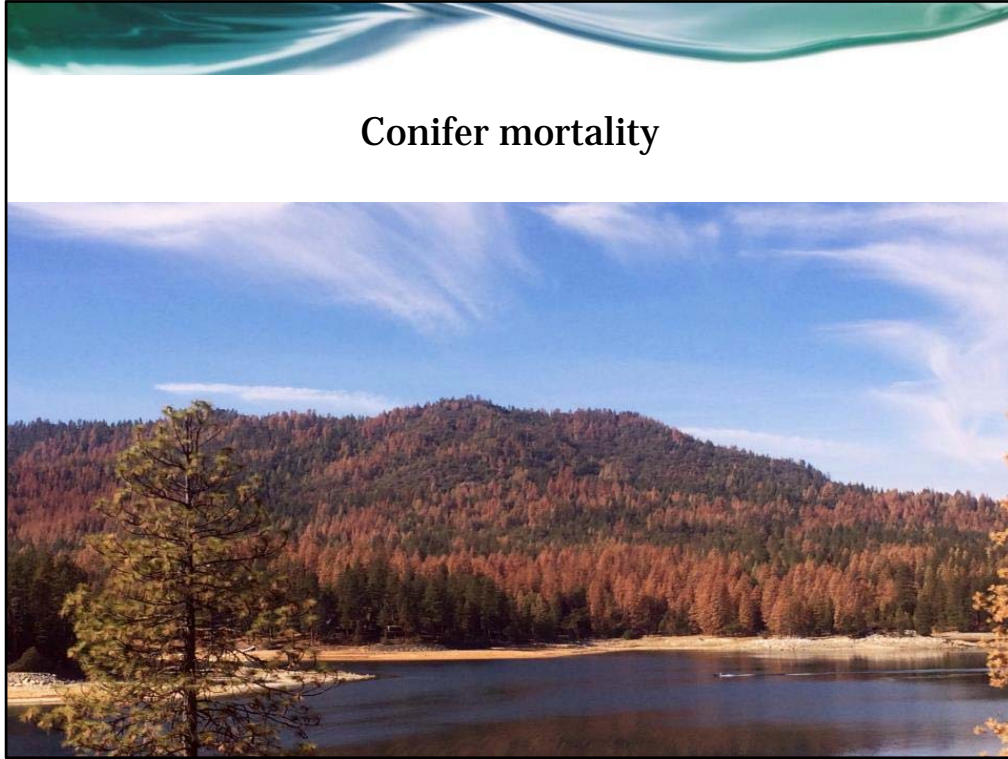


- This is the demand side of the equation; demand is just as important as supply.
- This graph is from a 2015 study led by Park Williams of Columbia University.
- It shows the statewide changes in potential evapotranspiration since 1901.
- PET is the amount of water plants need to avoid stress.
- PET started climbing at an increased rate in the mid-1980s.
- The 2015 Williams study essentially replicated the 2015 Stanford study.
- They found that precipitation is the primary driver of droughts in California, but temperature has become a large and growing component.
- The 2012–2014 drought would have been a fairly bad drought no matter what. But it was made worse by the increase in temperature and potential evapotranspiration. They calculated that about 15% to 20% of the 2012–2014 drought was due to the effects of increased temperature and potential evapotranspiration.
- The odds of California suffering droughts at the far end of the scale, like the 2012–2014 drought, have roughly doubled over the past century.
- Temperatures in California are forecast to continue increasing over at least the next few decades. Potential evapotranspiration is also forecast to continue increasing.
- Our climate is changing, but it is still highly variable.
- A 2016 study led by Daniel Swain at Stanford showed that we still periodically get short periods of intense rainfall; the frequency of those really wet periods has not been decreasing in recent decades.
- Currently, these are periods when short bursts of intense rainfall overpowers the effects of potential evaporation. Several studies have shown that those periods have been getting shorter as temperature and potential evapotranspiration increase.
- The Williams study found that by the 2060s, 50 years from now, more or less permanent drought conditions will set in. By then, potential evaporation will overpower virtually all the short bursts of intense rainfall.
- Supply (precipitation) will no longer be able to compensate for the increased demand (PET). PDSI will always be negative.



- This is a statewide graph; done in 2015 by a team of Stanford researchers led by Noah Diffenbaugh.
- PDSI combines water supply and demand into a single index.
- Positive PDSI is good. But plants can't make use of any available moisture above the 0 line.
- Negative PDSI represents soil moisture deficiency or plant stress. That is drought.
- Point out the two times when short bursts of intense rainfall have briefly broken through our current 16-year dry spell; they were able to compensate for the increasing PET.
- Most severe droughts have occurred when conditions were both warmer and drier than average.
- Dry years have been twice as likely to produce a severe drought if they occur in a warm year.
- Severe droughts have occurred twice as often in the last two decades as in the previous century.
  - During the first century (1896–1994), only 27% of dry years resulted in severe droughts.
  - During the last two decades (1995–2014), 55% of dry years resulted in severe droughts.
- This doubling in the risk of severe droughts has occurred despite statewide precipitation staying the same.
- The other half of the PDSI equation is demand, driven by temperature.
- The number of warm years has been twice as high in the last two decades as in the previous century.
  - During the first century (1896–1994), 45% of years were warm years.
  - During the last two decades (1995–2014), 80% of years were warm years.
- The odds of a dry year occurring in a year that is warm have doubled in the last two decades.
- That means the probability of a dry year producing a severe drought has doubled in the last two decades.
- The future with continued rising temperatures? Virtually every dry year will be warm.
- The frequency of severe droughts will increase.
- There is now quite a bit of evidence that our future droughts will be warmer and more intense, yet will be interrupted by increasingly powerful atmospheric river storms.

## Conifer mortality



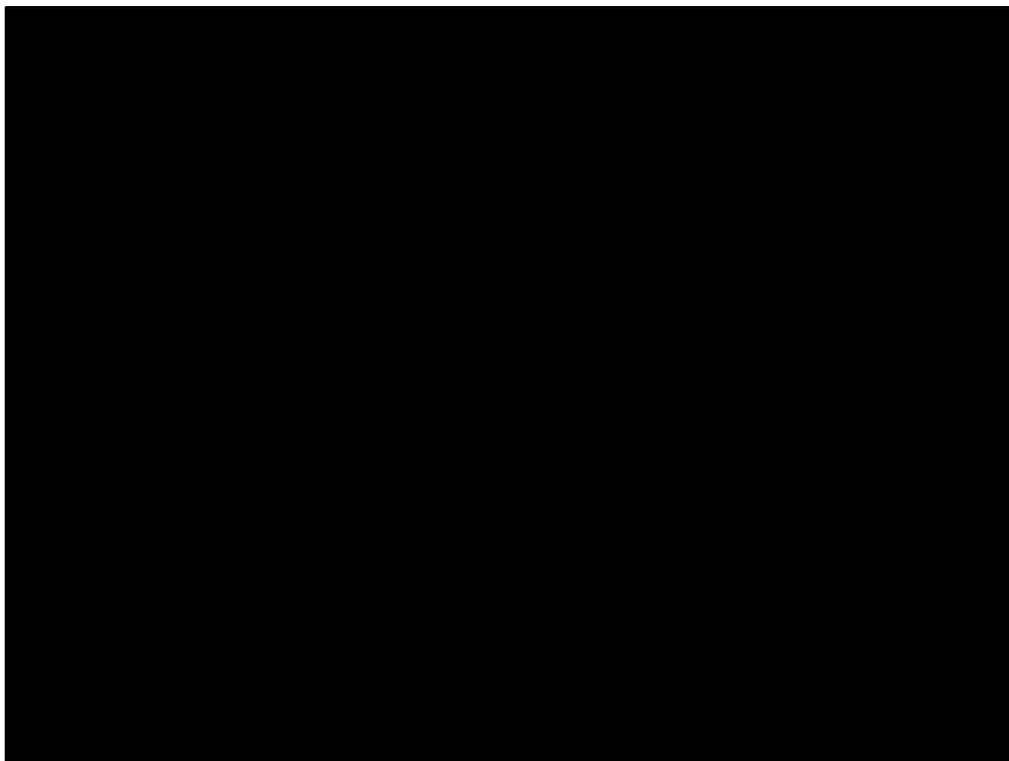
- This picture of pine mortality due to western pine beetle attack was taken in the Sierra National Forest.
- Sustained high PDSI levels during the 2007–09 and 2012–15+ droughts severely stressed conifers throughout the Southern Sierra.
- Drought-related moisture stress predisposes white firs and pines to successful attack by bark beetles.
- Conifer mortality was particularly apparent in the lower montane zone (3000–6000 foot elevation), involving virtually all conifer species, even some giant sequoias.
- The US Forest Service estimated that about 129 million trees died on 8.9 million acres of California between 2010-2017.
- Among other things, this has raised fuel loads and the risk of large wildfires.
- The current episode of beetle-caused mortality is much higher than what occurred in the 1918-34 and 1976–77 droughts.
- From an ecological perspective, this mortality event is roughly equivalent to a hot, patchy fire.
- Bark beetles, under epidemic population levels, are not very selective thinning agents.
- They are a crude tool, but the result is more or less what land managers want to accomplish, especially in the face of global climate change.
- The mortality significantly reduces stand density in a mosaic patchwork.

## The future for blue oak woodlands



- This is a picture on Tejon Ranch by Daniel Griffin.
- It appears that blue oaks will be significantly impacted by the effects of global climate change.
- Tejon Ranch protects 14,000 acres of blue oak woodlands.
- Only Fort Hunter Liggett and Wind Wolves Preserve contain larger tracts of blue oaks.
- A vulnerability analysis was conducted in 2011 for blue oaks on Tejon Ranch under possible future climate scenarios.
- It predicted a general decline in climatic suitability for oaks on Tejon Ranch by mid-century, and further reductions by the end of the century.
- The overall trend was movement upslope and toward north-facing aspects.
- Blue oaks are predicted to lose between 70-80% of their range on the ranch by mid-century.
- The percentage of stable range for blue oaks is predicted to be between 10-16% by mid-century and less than 2% by the end of the century.
- This change in suitable range for blue oaks occurs under warmer-wetter and warmer-drier climate scenarios.
- It is driven largely by the increase in PET, a function of rising temperatures.







## Paris Agreement

- The Paris Agreement was designed to keep the planet from warming more than 1.5°C above preindustrial levels by 2100.
- The U.S. submitted a climate-action plan to achieve that goal.
- The U.S. plan set the goal of reducing greenhouse gas emissions by 26% to 28% below 2005 levels by 2025.
- Current U.S. policies are projected to reduce emissions by only 11 to 13% below 2005 levels by 2025.
- The present rate of emissions will lead to a 3.7°C (7°F) warming by 2100.

- The primary greenhouse gases are CO<sub>2</sub>, methane, nitrous oxide, and ozone.
- Most greenhouse gases come from burning fossil fuels like oil, coal, and natural gas, but they also come from using fertilizers, raising livestock, and maintaining landfills.
- The U.S. is the world's 2nd-largest carbon emitter, after China. Together, the two countries accounted for 45% of the world's CO<sub>2</sub> emissions in 2014. The Paris Agreement was the first climate accord that both superpowers agreed to.
- Even meeting the U.S. target under the Paris Agreement would, however, be "Insufficient" to limit warming to 2°C, let alone 1.5°C.
- RCP8.5 is the current business as usual climate scenario, the present high emission rate of CO<sub>2</sub> and other greenhouse gases.
- The present high emission rate of CO<sub>2</sub> and other greenhouse gases (current climate scenario RCP8.5), will lead to a 3.7°C (7°F) warming by 2100. Round it off to 4°C.
- Without a dramatic change in public opinion and resolve, the RCP8.5 scenario is the best estimate of where our future lies.



## **The Green New Deal has five goals**

- 1. ACHIEVE NET-ZERO GREENHOUSE GAS EMISSIONS** by 2030 through a fair and just transition for all communities and workers.
- 2. CREATE MILLIONS OF HIGH-WAGE GOOD JOBS AND ENSURE PROSPERITY AND ECONOMIC SECURITY** for all the people of the United States.
- 3. INVEST IN INFRASTRUCTURE AND INDUSTRY** of the United States to sustainably meet the challenges of the 21st century.
- 4. SECURE A SUSTAINABLE ENVIRONMENT FOR ALL** with clean air and water, climate and community resilience, health food and access to nature.
- 5. PROMOTE JUSTICE AND EQUITY** by stopping current, preventing future, and repairing historic oppression of frontline and vulnerable communities.

To learn more about the Green New Deal, see the YouTube videos of the town hall that Chris Hayes hosted in the Bronx in March 2019 with Alexandria Ocasio-Cortez and a number of subject matter experts.