Too Much Water! Part 3

By John Benson

March 2023

1. Introduction

Part 2 of this series is summarized and linked below.

Too Much Water, Part 2: *The following description came from the original "To Much Water!" posted about a month ago (immediately listed below).*

"In general our planet has an almost fixed amount of water. But what isn't static is the water's state. At any given time it may be solid, liquid or gas (water-vapor), and it has a habit of changing from one to the others at all times."

Although the subject of this paper is quite different from the original, I will follow-up one the above quote by asking what happens when rivers leave the surface, and start flowing in the sky?

https://energycentral.com/c/gr/too-much-water-part-2

The above summarized and linked post was mostly about atmospheric rivers, as will be this one. However, where the prior "Too Much Water" post focused on the atmospheric rivers and similar storms that impacted California this winter, as well as their impact on the electric infrastructure, this one will mostly examine the potential causes of this unusual set of storms. In the prior post we also defined the primary cause (climate change), in this post we will dig a bit deeper.

This post will also dive deeply into ENSO – a major periodic climate pattern that strongly impacts the weather all over the world. The last post (in December) where we did a similar deep dive is summarized and linked below, its name is the "EN" in ENSO.

El Niño! *Most of my readers (sort of) know what El Niño is. I've written before about this, and I also am known to frequent a blog that covers the dynamic climate system El Niño is part of. At the beginning of their November Post they had some good descriptions of this system, and well as some information that will probably start to have some serious effects on the World's Weather. I will start this in Section 2 below, mostly use their words, and fill in with mine and those of a respected climatologist's as needed.*

https://energycentral.com/c/pip/el-ni%C3%B1o

Both this paper and "El Nino!" use similar charts, and at least one of them is exactly the same chart from the same source. However the chart in this past is several months newer, and shows a greater chance of us swinging into an El Niño pattern this summer.

Finally, the last section of this post will dive into the future worst-case storm that might impact the U.S. West Coast.

1.1. Update

As I'm writing this (March 20), a 12th atmospheric river this winter is approaching California.[1] Each of these has hit us with extra damage, including downed trees damaged buildings and power distribution grids (see picture below).

Floodwaters from an atmospheric river engulfed train cars, vehicles and homes week of March 6 in Pajaro, California after a levee broke. Photo: Josh Edelson / Getty Images.

2. The West Coast is Snowy (and wet)

Portland, Oregon received nearly a foot of snow in a single day in what proved to be its second-snowiest day in history. Mountainous areas of California experienced nearly unprecedented snowfall accumulations - more than 40 feet since the start of the season. At the airport in Flagstaff, Arizona, 11.6 feet have fallen this season, second only to the winter of 1948-49. Even Phoenix suburbs woke up on Thursday to a dusting of snow that covered cactuses and lush golf courses.[2]

What is going on with all the snow?

"This rain and snow bucked the trend and it's highly unexpected," said Ryan Maue, a meteorologist and former NOAA chief scientist. "It's like once-in-a-generation."

"The short answer is no, La Niña alone is not the main cause of this weather," said Daniel McEvoy, a researcher with the Western Regional Climate Center.

Bianca Feldkircher, a meteorologist for the National Weather Service, said a persistent blocking pattern over the Pacific Ocean plus cold air migrating south from the Arctic have created the conditions for widespread snowfall along the West Coast.

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[1] Nouran Salahieh, Rob Shackelford and Holly Yan, CNN, "Another atmospheric river will thrash storm-ravaged California, threatening more flooding and hurricane-force wind gusts," March 20, 2023, https://edition.cnn.com/2023/03/20/weather/california-atmospheric-river-monday

[2] Isabella O'malley, NBC Bay Area, "Meteorologist: West Coast Snowfall Is 'Once in a Generation'," March 2, 2023, https://www.nbcbayarea.com/news/california/west-coast-snowfall/3170182/

“Not only were you getting significant snowfall in areas that already see snow, you were also seeing snowfall on lower elevations in Southern California, which is super rare,” said Feldkircher.

For example, the forecast on March 1 warned of snowfall for parts of Phoenix, which Feldkircher said is “super unusual” for this time of year. And last week, Portland saw abnormally high snowfall rates and recorded nearly 11 inches — the second snowiest day in the city’s history.

With respect to human-induced climate change, meteorologists say it's challenging to nail down what part it is playing in the West Coast's peculiar winter season.

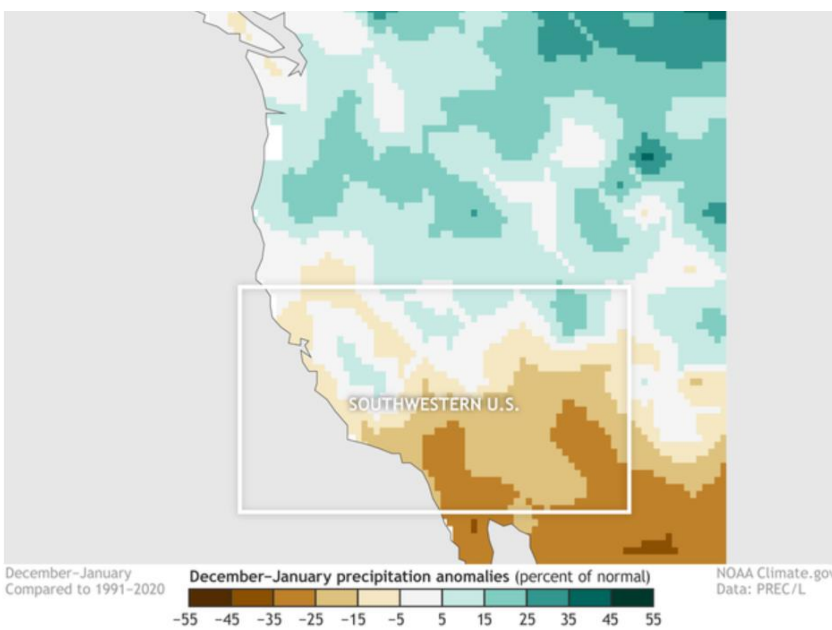
But increasingly extreme weather is expected as global temperatures rise. “Heat produces moisture, moisture produces storms, and heat and moisture bind to produce even more severe storms,” Feldkircher said.

Forecasting technology keeps getting better. So much better, it may even soon be able to forecast extreme events with higher accuracy. “In the near future, I do not think climate will cause issues with our weather forecasting capabilities,” said Maue.

Although many regions struggled with the challenging winter conditions, some are welcoming the much-needed moisture.

The recent precipitation is a blessing for some relief from the drought that has persisted in the Southwest.

Author’s comment: I looked at several NOAA websites to try to gain more insight to what was happening. I did find a nice graphic to explain that the normal pattern for La Niña is drier than normal on the West Coast (below on the next page). However, the above excerpt is, overall, the best explanation.



The figure on the left is the average December–January precipitation anomalies (percent of the 1991-2020 climatology) for all La Niña events from 1951-2020, defined as La Niña occurring in December–February. Places where precipitation was less than the 1991-2020 average are brown; places where precipitation was above average are blue-green The white box defines the Southwest U.S. region (32° - 40° N, 109°-125° W) that is the focus of further investigation. NOAA Climate.gov image, based on precipitation data from NOAA’s Precipitation Reconstruction over Land (PREC/L).

2.1. Bomb Cyclone?

What I saw on the radar image on the television looked like a small hurricane crossing over the San Francisco Peninsula. Was it a Bomb Cyclone? Not exactly.

The low-pressure centers — some containing hurricane-like eyes — exhibited what's known as the Fujiwhara effect, in which storms cycle around each another before sometimes merging or going separate ways. In this case, the low-pressure zones consolidated as they made landfall near San Francisco.[3]

The latest in a seemingly endless parade of winter storms is beginning to ease in California, slogging eastward Wednesday after unleashing damaging winds that cut power to more than 250,000 customers and led to at least two fatalities Tuesday.

As the storm made landfall around the Bay Area on Tuesday evening (March 21), its structure and strength — bearing resemblance to a hurricane — astonished meteorologists. And while the storm technically wasn't a hurricane, it produced similar impacts.

The winds, which gusted up to 70 mph at the coast and over 100 mph near mountain summits, downed scores of trees and power lines, some of which blocked roads and toppled onto vehicles. The strong gusts also stirred up the ocean, sending big waves crashing into the coast.

The San Francisco and Monterey Bay Area were among the hardest hit by the storm, but much of the southern two-thirds of the state endured both strong winds and heavy precipitation. Rain showers lingered Wednesday morning following widespread amounts of at least 1 to 3 inches from the Bay Area to San Diego, which set records in some instances and triggered flooding and the need for high-water rescues. Some additional snow was also expected Wednesday in the mountains, many of which have seen historic amounts this season.

Satellite and radar imagery revealed a region of clearing near the storm center, which allowed an interval of blue skies and sunshine as the center of the storm moved overhead.

3. No More La Niña!

The above section title was taken directly from the Climate.gov March 2023 ENSO update. El Niño is the warming phase of the sea temperature and the Southern Oscillation is accompanying atmospheric cycling.

La Niña—the cool phase of the El Niño-Southern Oscillation (ENSO) climate pattern—has left the building! After a year and half of non-stop La Niña, the tropical Pacific ocean-atmosphere system has transitioned to neutral, allowing NOAA to issue its "Final La Niña Advisory". What can we expect for ENSO through the summer and into next fall and winter? I'll get to that![4]

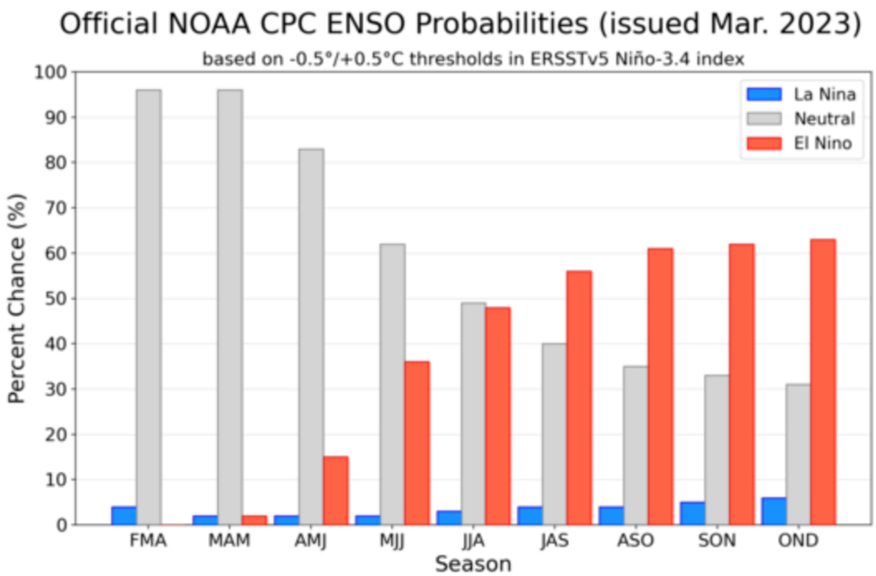
… We're often going on and on here at the ENSO Blog about how ENSO is a seasonal phenomenon, meaning the ocean and atmosphere criteria must be met for several consecutive months in order to qualify as La Niña or El Niño. The same is not true for neutral conditions, however. Once the tropical Pacific ocean-atmosphere system is showing signs of decoupling, such as a monthly Niño-3.4 index value warmer than -0.5°C, we can say that neutral conditions have likely arrived.

[3] Ian Livingston, The Washington Post, "Incredible images of a hurricane-like storm that walloped California," https://www.washingtonpost.com/weather/2023/03/22/california-storm-bomb-cyclone-hurricane/

[4] Emily Becker, Climate.gov, "March 2023 ENSO update: no more La Niña!" March 9, 2023, https://www.climate.gov/news-features/blogs/march-2023-enso-update-no-more-la-ni%C3%B1a

The forecaster consensus is indeed very confident that neutral conditions will remain through the spring. We know what you're really interested in, though—will El Niño develop? If we can anticipate an El Niño, we can anticipate an increased likelihood of its impacts on weather and climate. In contrast, a continuation of neutral conditions means the tropical Pacific Ocean will not be an actor on the world's climate stage. The lack of El Niño or La Niña means that there is no seasonal-scale influence from the Pacific to push around the global atmospheric circulation and influence seasonal climate patterns.

Many of our computer climate models are predicting a transition into El Niño sometime later this year. However, right now is a very tricky time of year for the models, due to the "spring predictability barrier." ENSO events peak in the winter and tend to decay and transition in the spring, so models often don't have a lot of strong signals to go on…



NOAA Climate Prediction Center forecast for each of the three possible ENSO categories for the next 8 overlapping 3-month seasons. Blue bars show the chances of La Niña, gray bars the chances for neutral, and red bars the chances for El Niño. Graph by Michelle L'Heureux.

Our forecaster consensus does reflect the increased chance of El Niño, with chances around 60% by the fall. However, the spring predictability barrier, together with the still somewhat-La Niña-ish atmosphere and the lack of strong physical signs such as a large amount of warmer-than-average subsurface water in the tropical Pacific, mean we're not yet hoisting an El Niño Watch.

One fun little nugget of information is that, in our historical record dating back to 1950, we have not gone more than four years in a row without an El Niño. If we don't have an El Niño in 2023–24, that will be five years! However, 73 years is a short record for a phenomenon that has decade-to-decade variability, so this is more of an interesting factoid than anything…

4. ARkStorm 2.0: Increasing Risk of a Megaflood?

I came across a very good meteorological site focused on the US West Coast. Apparently, this site is managed by a widely published meteorologist:

Dr. Daniel Swain is a climate scientist in the Institute of the Environment and Sustainability at the University of California, Los Angeles (U[5]CLA), and holds concurrent appointments as a Research Fellow in the Capacity Center for Climate and Weather Extremes at the National Center for Atmospheric Research and as the California Climate Fellow at The Nature Conservancy of California.

I came across one of his posts that reviewed historical Megafloods in California, and explored the chances of one of these in the future or even more of these in the future.

Research Summary by Daniel Swain: *This special Weather West article focuses on new peer-reviewed scientific research, co-led by Xingying Huang and me, that we recently published in the journal Science Advances. This research, as well as the following blog post distillation of it, represent the first phase of the ongoing ARkStorm 2.0 effort to better understand and characterize the risks associated with potentially catastrophic California floods in a warming climate.*[6]

In recent years, California has experienced more than its fair share of historically severe drought, water scarcity, and devastating wildfires. But delving back farther into the historical and geophysical record makes clear that the Golden State is also a region highly susceptible to occasional, but extraordinary, very large flood events. Such floods don't happen every year; in fact, in the past they didn't even occur every lifetime—large floods in the past half century or so, including the regionally devastating events in 1969, 1986, and 1997—still pale in comparison to those apparent in the paleoclimate record.

Perhaps the most obvious precedent for a California megaflood event occurred in 1861-1862, a multi-week super-soaker storm sequence that later came to be known as the "Great Flood of 1862" (GF1862). That event—which inundated vast swaths of the then-nascent state of California including a ~300 mile long stretch of the Central Valley, large portions of the modern-day Los Angeles metro, and virtually every narrow river valley throughout the state—is widely considered the benchmark for a "plausible worst case scenario" flood in contemporary California. (It is important to point out, though, that even 1862 is not the largest physically possible flood event in this region—there is evidence from coastal and bay river sediment deposits of multiple larger events in the past millennium.) It was precisely this event that provided the motivation for an extreme storm and catastrophic flood scenario back in 2011—known as "ARkStorm"—that was developed by a broad consortium of scientists from the USGS, University of California, Desert Research Institute, and other institutions.

Ultimately, it was found that such a modern recurrence would result in widespread, catastrophic flooding throughout California—likely causing much greater damage, disruption and economic losses than a large-magnitude earthquake near one of California's major urban areas.

Building on the original ARkStorm scenario, we developed two brand new megastorm scenarios as part of "ARkStorm 2.0": a historical (ARkHist) & warmer future scenario (ARkFuture) aimed at more systematically characterizing the plausible range of megastorm and extreme flood events that might befall California both in the present era and in the future. We wanted to revamp ARkStorm for two primary reasons.

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[5] Weather West, About, https://weatherwest.com/about

[6] Daniel Swain and Xingying Huang, Weather West, "ARkStorm 2.0: Climate change is increasing the risk of a California megaflood," Aug 11, 2022, https://weatherwest.com/archives/16626

First, the original ARkStorm did not consider climate change, and recent evidence suggested that warming may be substantially altering the characteristics of and risks associated with such an event. Second, there have been numerous advances in climate, weather, and hydrologic science over the past decade or so that would allow for much more comprehensive and detailed assessment of the overall likelihood of such events as well as their local-scale details. So motivated, we spent the last few years coordinating research and experiments (with many of the original ARkStorm team members, plus some new folks)—and the paper discussed in this blog post represents the culmination of the extreme storm scenario design and implementation, which I co-led along with Xingying Huang…

4.1. ARkStorm 2.0 megastorm scenarios

For ARkStorm 2.0, we wanted to use the latest science and modeling tools to develop physically realistic month-long megastorm and subsequent potential megaflood scenarios for California. In ARkStorm 1.0, the underlying atmospheric scenario was composed of a synthetic concatenation of two severe historical regional California flood events in 1969 and 1986, plus an extra day of storm stalling for good measure. This provided ample opportunity to explore the consequences of an extremely wet storm sequence in California, but it remained unclear whether a stalling storm sequence like this was actually plausible in the real world. So for ARkStorm 2.0, we did not limit our investigation to the historical record. Instead, we leveraged an existing climate model large ensemble (CESM-LENS) that includes 40 independent replications of both the 20th century and the projected future (21st century). That allowed use to explore a much larger "synthetic" sample size composed of hundreds of model-years for both the present and future era—giving us a better sense of the types of month-long storm sequences that are plausible on multi-centennial timescales.

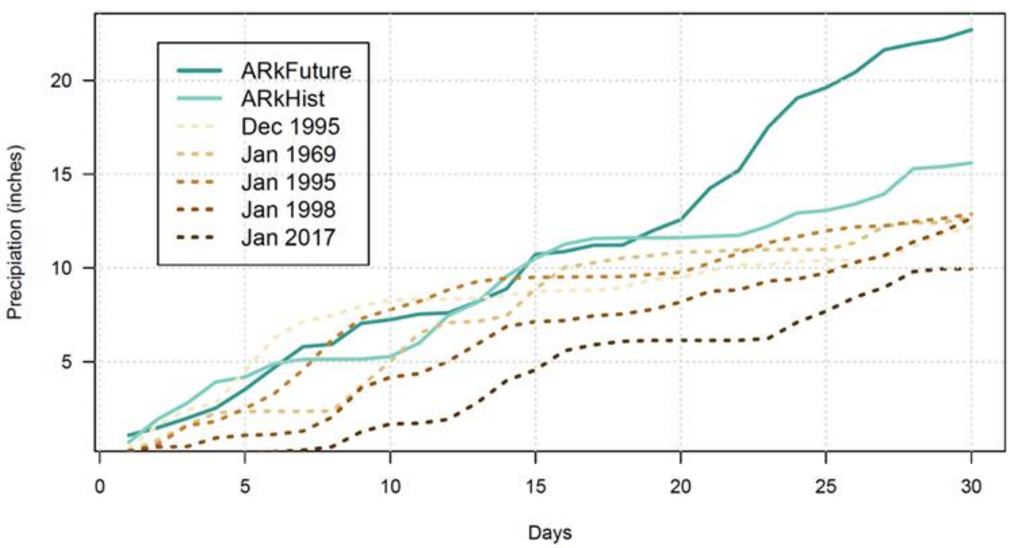
From there, we selected our ARkHist and ARkFuture scenarios from among the top three 30-day statewide precipitation accumulations in both the present and warmer future eras. We then embedded a high-resolution weather model (WRF with grid boxes 3km on a side) within the climate model data to produce detailed "synthetic weather forecasts" for California during both scenarios. These high-resolution weather-within-climate model simulations are the basis for most of the discussion that follows.

We find that both ARkHist and ARkFuture scenarios would bring an extreme amount of precipitation to nearly all of California, though the ARkFuture scenario would be considerably worse. When compared to all historical 30-day statewide precipitation accumulations going back to the early 1950s, ARkHist exceeds them all (though by a relatively modest amount), and brings slightly less precipitation than was likely observed during the wettest 30-day period of the Great Flood of 1862.

ARkFuture brings dramatically more precipitation than anything observed in California over the past century, and likely exceeds the precipitation observed in 1862 by some margin. Using the full climate model ensemble, we estimate that ARkHist has about a ~90-100 year recurrence interval in the 1995-2005 era climate; ARkFuture-level events did not occur in the historical climate so likely have recurrence intervals exceeding 400 years in the 1996-2005 climate. Hence, our two scenarios can qualitatively be interpreted as "extreme" and "very extreme," respectively…

Both ARkHist and ARkFuture feature a weeks-long parade of atmospheric river (AR) storms during the winter months. Some of these are fairly cold ARs; others are very warm events with deep subtropical connections (i.e., classic "Pineapple Express"-type storms). Over the course of 30 days, these storms bring phenomenal amounts of precipitation. In ARkHist, much of the Sierra Nevada sees 40-55 inches of liquid equivalent (with a maximum of about 85 inches!); the Coast Ranges generally see 25-35 inches; and the Central Valley 10-25 inches; and Southern California anywhere from 15-25 inches along the coast to 25-35 inches in the Transverse Ranges. In ARkFuture, precipitation accumulations are even higher: much of the Sierra Nevada sees 55-70 inches of liquid equivalent (with a maximum of about 126 inches!!); the Coast Ranges generally see 30-45 inches; and the Central Valley 15-35 inches; and Southern California anywhere from 20-35 inches along the coast to 40-55 inches in the Transverse Ranges. Overall, on a statewide basis, precipitation during ARkFuture is about 45% higher than during ARkHist. Although the largest absolute precipitation increases in ARkFuture occur where you would expect (in already wet, orographically[7] favored mountain areas), the largest relative increases actually occur elsewhere—often in low-elevation and historically rain-shadowed areas. Incredibly, these amounts would represent fully 60% and 71% of California's average precipitation for the entire Water Year in just 30 days!

California Average Cumulative Precipitation (inches)



ARkFuture and ARkHist cumulative precipitation time series (statewide California average) compared to the most extreme events observed historically (since 1951) (Graphic by Daniel Swain using the gridded nCLIMDIV dataset from NOAA, obtained via the Climate Engine)

In addition to these enormous 30 day precipitation accumulations, we also find that these events would bring especially high precipitation intensities (that is, very heavy precipitation during a single hour or day). In ARkHist, at least 8 of 30 days are considered "heavy precipitation days" (HPDs) in coastal areas, and at least 14 of 30 days in mountain areas; in ARkFuture, HPDs increase to 16 days in coastal areas and 20 days in mountain areas (with some parts of the Sierra Nevada and southern Cascades seeing an astonishing 30 of 30 HPDs).

[7] Rainfall enhanced by storms rising over hills and mountains.

But we find even larger increases in the occurrence of "heavy precipitation hours" (HPH): a ~220% increase in HPHs statewide, and a northward shift in the maximally affected region from the southern California Transverse Ranges to the Sierra Nevada and Santa Lucia Mountains. These very large increases in extremely heavy precipitation days and hours would have major implications for flash flood and debris flow risk—especially in a state simultaneously experiencing a large increase in large and intense wildfire activity (which greatly amplifies the risk of both such hydrologic hazards).

We also consider the thermal profiles of these megastorm events in these scenarios, and their implications for snowpack and subsequent runoff. At the very highest elevations of the Sierra Nevada, both present (and, somewhat strikingly, even future) scenarios produce truly enormous snowfalls. Above about 9,500 feet elevation, a few areas receive over 3 feet of snow water equivalent (SWE) during ARkHist—translating into 23-25 feet of actual snowfall (!!). But since some melting does occur during warmer phases of the storm (including some rain-on-snow events), the maximum SWE "on the ground" is 12-15 inches liquid equivalent—likely translating to well over 100 inches of actual snow depth in these locations. In the historical scenario, there is also very heavy snow accumulation down to about 5,000 feet in elevation (with a few bursts of snow to much lower elevations).

In ARkFuture, we find major changes in mountain snowfall patterns due to warming temperatures and increased freezing levels. The primary precipitation type during the 30 day period shifts from snow (ARkHist) to rain (ARkFuture) at lower to middle elevations (4,000 – 6,500 feet), but remains primarily snow above about 7,000 feet. This results in an interesting "dipole" pattern of snowfall changes, with large or total (>50%) disappearance of snow accumulation as high as 6,500 feet but large increases in snow accumulations at very high elevations (above 8,000-9,000 feet) due to greatly increased moisture and temperatures that are just cold enough for snow. (In ARkFuture, a few isolated and remote peaks at the highest elevations of the southern Sierra Nevada accumulate around 70 inches of liquid equivalent SWE—translating to over 30 feet of exceptionally wet and heavy (~5:1 ratio) snowfall).

As we have experienced as recently as December 2021, exceptionally heavy snowfalls in the Sierra Nevada can cause significant transportation and infrastructure damage in their own right—so this appears to be a continued consideration at relatively high elevations even in a much warmer climate (and certainly so in the present climate).

Author's comment: forget 2021, look at what the snowfall on March 1, 2023 did in Yosemite Valley (pictures on next page). By the way Curry Village is at roughly 4,000 feet, the same altitude as my mountain home in Arnold, CA. This isn't even the high Sierras (above 7,000 feet). Also, I was unable to get to my home in Arnold during early March – the first time in 24-years of owning this home.

Left to right: Before and after photos of the Curry Village tent cabins from February versus the recent snow seen on March 1, 2023. (Images via Eric Brooks & Yosemite National Park)

But the primary concern with these future snow changes in ARkFuture relative to ARkHist is the implications for greatly increased runoff into rivers and streams—and subsequent increases in flood risk. And, indeed, we find exceptionally large increases in runoff during ARkFuture that greatly exceed precipitation increases, especially within watersheds draining the western slopes of the Sierra Nevada. In the Sacramento and San Joaquin watersheds, peak ARkFuture runoff is as much as 200-400% higher than ARkHist runoff (despite precipitation totals that are "only" ~50% higher). We attribute this directly to the increased instantaneous runoff from precipitation, which in the future scenario falls primarily as liquid rain vs. solid, accumulative snow to elevations as high as ~6,500 feet (or higher, during some portions of the storm)...

Altogether, it appears that the plausible worst case scenario storms in a warming climate are likely to produce massive precipitation accumulations, but even more exceptional runoff in relative terms due to profound changes in mountain hydrology brought about by decreasing snow fraction (something co-lead author Xingying Huang and colleagues previously termed the "Double Whammy Effect"). This has particularly large implications for the Sacramento and San Joaquin River flood plains (as well as their upstream tributaries)—a part of the state where millions of Californians now live atop ancient flood deposits. Flood risk during an event like either of these scenarios will bring widespread and severe flood risk to nearly the entire state, but the extreme increases in projected surface runoff in the Sacramento and San Joaquin basins are of particular concern given the confluence of high pre-existing risk in these regions and a large population that has never experienced flooding of this magnitude historically.

4.2. Megastorm risk in Moderate-to-Strong El Niño Events

There has been much discussion over the years, both within and outside of the scientific literature, regarding the linkage between El Niño/Southern Oscillation (ENSO) and California hydroclimate. Some observers have recently claimed that ENSO's influence on California rainfall has been overstated—and, if one considers only simple correlations and long-term average relationships between simple ENSO metrics and California precipitation, there is perhaps some truth to these claims.

However, a new wave of research using more sophisticated and physically-based metrics of ENSO intensity has recently led to considerable advances in this area. To make a long story short: it turns out that ENSO is indeed a very important (likely the single most important!) discernable predictor of California hydroclimate on seasonal and even multi-annual timescales.

But this relationship is asymmetric: El Niño has a more consistent relationship to CA hydroclimate than does La Niña, and the strength of this relationship is itself non-linear: weak ENSO events generate little if any meaningful signal, but moderate to strong ones generate a substantial signal...

We considered the top 4 events during both the historical and future climate periods in the climate model large ensemble. And this is where things get interesting: all eight of the largest simulated 30-day “megastorm” events occurred during El Niño conditions of some magnitude—and 7 out of 8 of these occurred during moderate to strong El Niño events.

Final author’s comment: See section 3 above. We are definitely swinging to ENSO-neutral, and the probably an El Niño condition. Whether this will be a moderate-to-strong El Niño remains to be seen.