Climate Variation at Flagstaff, Arizona's Mountain Town

Compiled from National Weather Service Data

Richard Hereford
November 2014

Version 1.8

Image courtesy of Greg Paulin, Southwest Aerial Photography, Flagstaff

Afternoon on a winter day in Flagstaff

Cover image courtesy of *Flagstaff Mountain Living* Magazine

November 29, 2014

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Preface

Climate is the average weather—the weather we expect. This informal report uses illustrations to summarize several features of climate variation at Flagstaff. These features are topics of daily conversation for residents and visitors, including the expected temperature (average maximum and minimum daily temperatures) and precipitation (rain and snow) for any day of the year. Most of us are interested in extreme weather and climate. On a given day, what was the hottest or coolest temperature, and what was the largest rainfall or snowfall? What is the probability of rain or snow on a particular day? Annual and seasonal variation is interesting. What were the wettest and driest years and seasons, how much snow fell in any year, and what years were the coolest and warmest. Have temperatures at Flagstaff increased over time due to global warming? is a question of substantial importance, the answer is yes.

And, how does and how will El Niño and La Niña, the drivers of short-term climate variation in the Southwest, affect conditions at Flagstaff? Specifically, what is the likelihood of above or below seasonal rainfall or snow given El Niño or La Niña conditions?

Particularly relevant is the ongoing drought that began in 1996 or 1999, depending on whether it's defined hydrologically or climatically; I'll use 1996 as the beginning because that's when precipitation declined substantially following a wet episode. Recent work refers to this dry spell as the Early 21st Century Drought (see *Proceedings of the National Academy of Science*, 2010, v. 107 no. 50, p. 21271-21276). Two important questions are what is the cause of the drought and when is it likely to end?

Flagstaff is fortunate to have a National Weather Service Forecast Office staffed by meteorologists. Since 1950, systematic measurements of temperature and precipitation as well as a variety of other weather data were collected at Flagstaff Airport and later at the Bellemont facility west of Flagstaff. These data, combined with earlier measurements collected in the city between 1893 and 1950, comprise a valuable record that spans 1893 to the present. But, the early part has numerous gaps or missing data and about 40 percent of the record is unavailable. Thus, the most useful data covers 1950 to the present, wherein the information (except snowfall) is essentially complete.

Any errors or omissions in this report are those of the author. Critical comments on the text and graphs by L. Sue Beard and Gordon B Haxel of the U.S. Geological Survey were helpful and appreciated.

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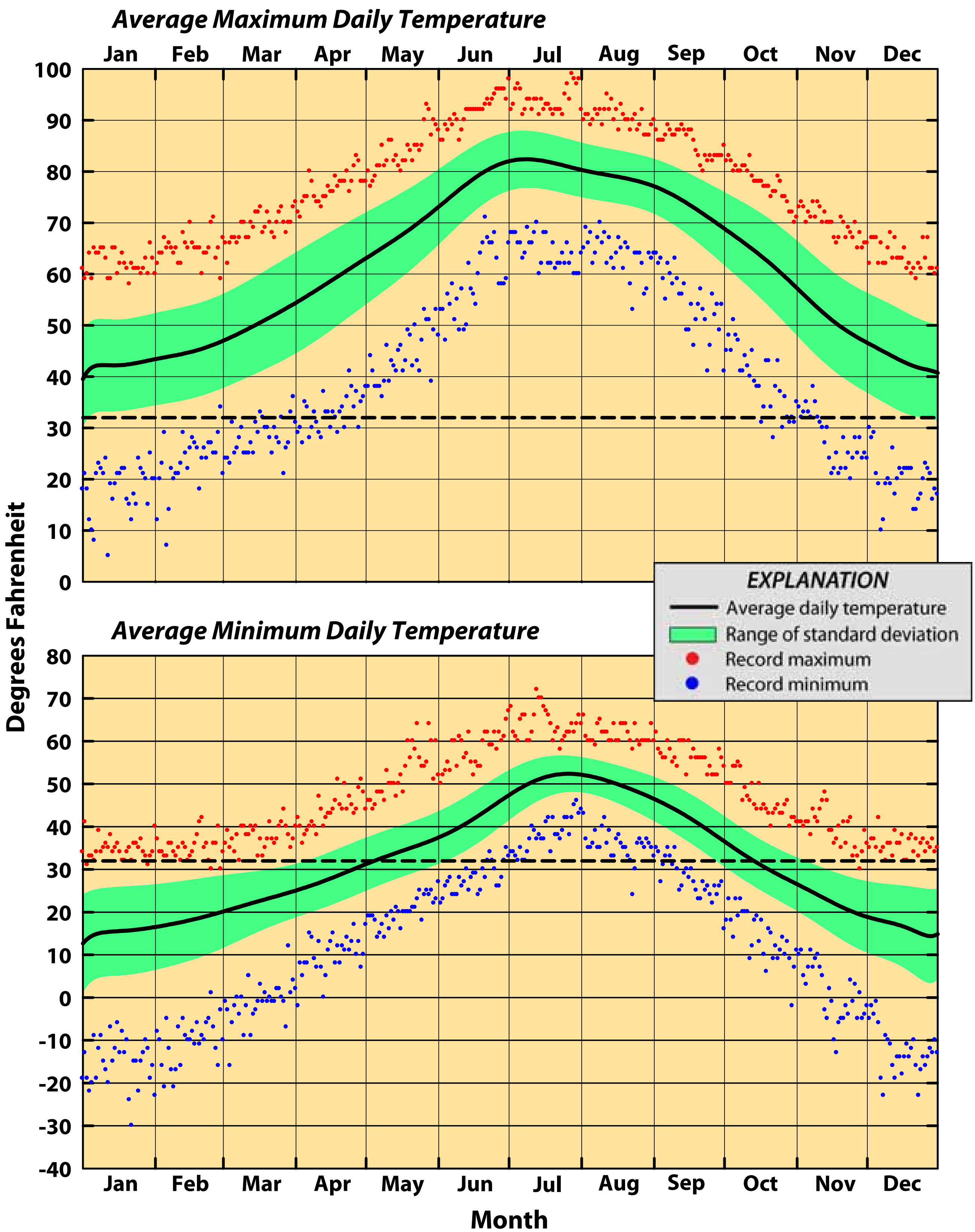


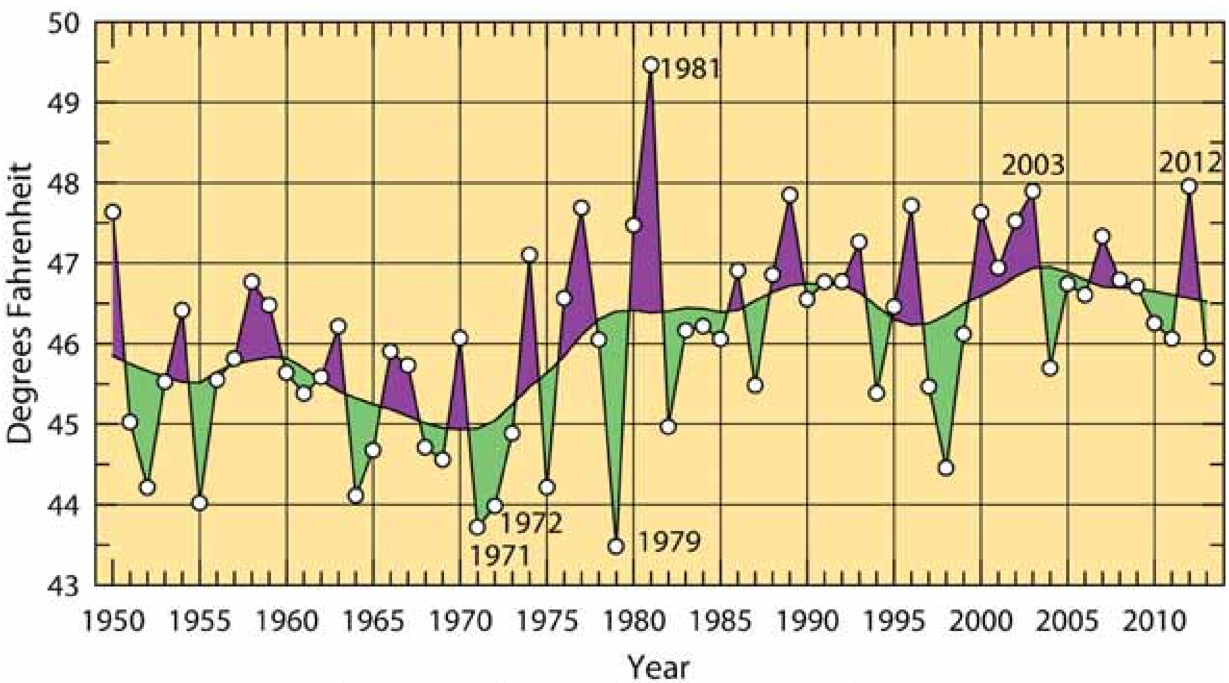
Annual Temperature Cycle

Period of record is 1893 to February 2014

Percent coverage = 73

Preceding Page—Temperature is measured twice daily once in the early morning before sunrise (minimum or nighttime temperature) and again in mid-afternoon (maximum or daytime temperature). Average daily temperatures gradually increase until early July then decrease until the end of the year tracking the solar heating cycle. Use these graphs to find the expected (that is average) and record temperature for any day and the duration of the frost-free season (intersection of the minimum curves with the dashed line). The actual temperature will usually be within the green band. Temperatures outside the band are well above or below normal and could tie or establish a new record if within the zone of the scattered circles.[1]

Summer temperatures in Flagstaff are pleasant, typically in the low 80s even in July. Record high temperatures in July are in the 90s, comfortably below 100 degrees. In late fall and winter, daytime temperatures are mild ranging from freezing in early winter to the mid-50s by winter's end. Although not so mild, daytime temperatures below freezing may occur from November through April. Below-freezing nighttime temperatures are typical from mid-October through April. Below zero temperatures may occur from early November through March.



Average Annual Temperature Trend

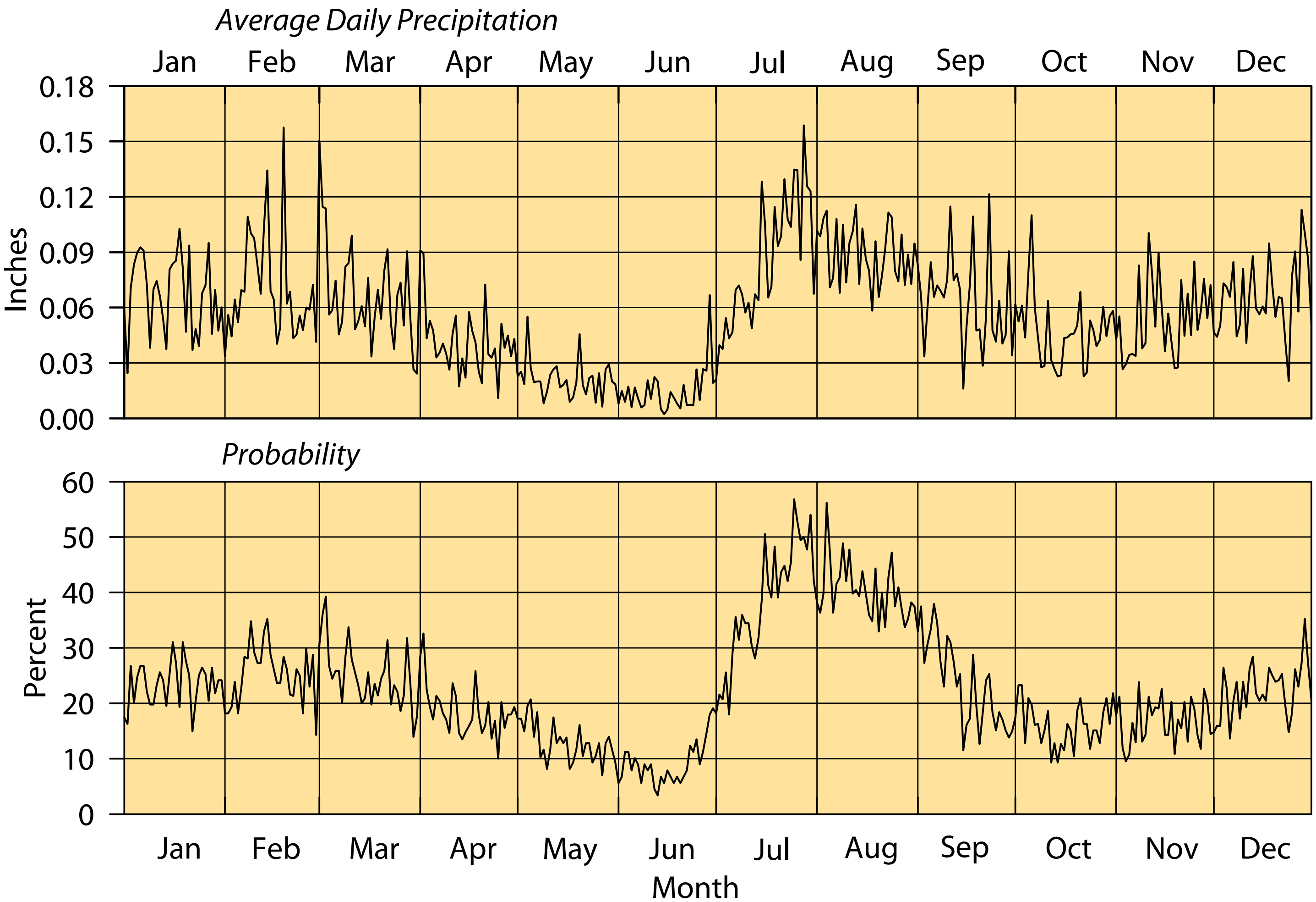
Increase of ~ 2 Degrees Since 1971

Period of record is January 1950 to December 2013

Percent coverage = 100

This graph and several to follow are time series, a type of plot that shows temperature or precipitation (or any other quantity) on the vertical axis plotted against time on the horizontal axis. These graphs reveal daily, seasonal, annual, and decadal climate variability.

Global warming is affecting Flagstaff's climate—average annual temperature increased at least 2 degrees since 1971.[2] This temperature time series closely matches global surface-temperature patterns since 1950 (see U.S. Geological Survey *Open-File Report 2007-1410* and *Journal of Geophysical Research*, 2006, v. 111, D12106). The apparent downturn beginning in 2004 is too short to be significant.



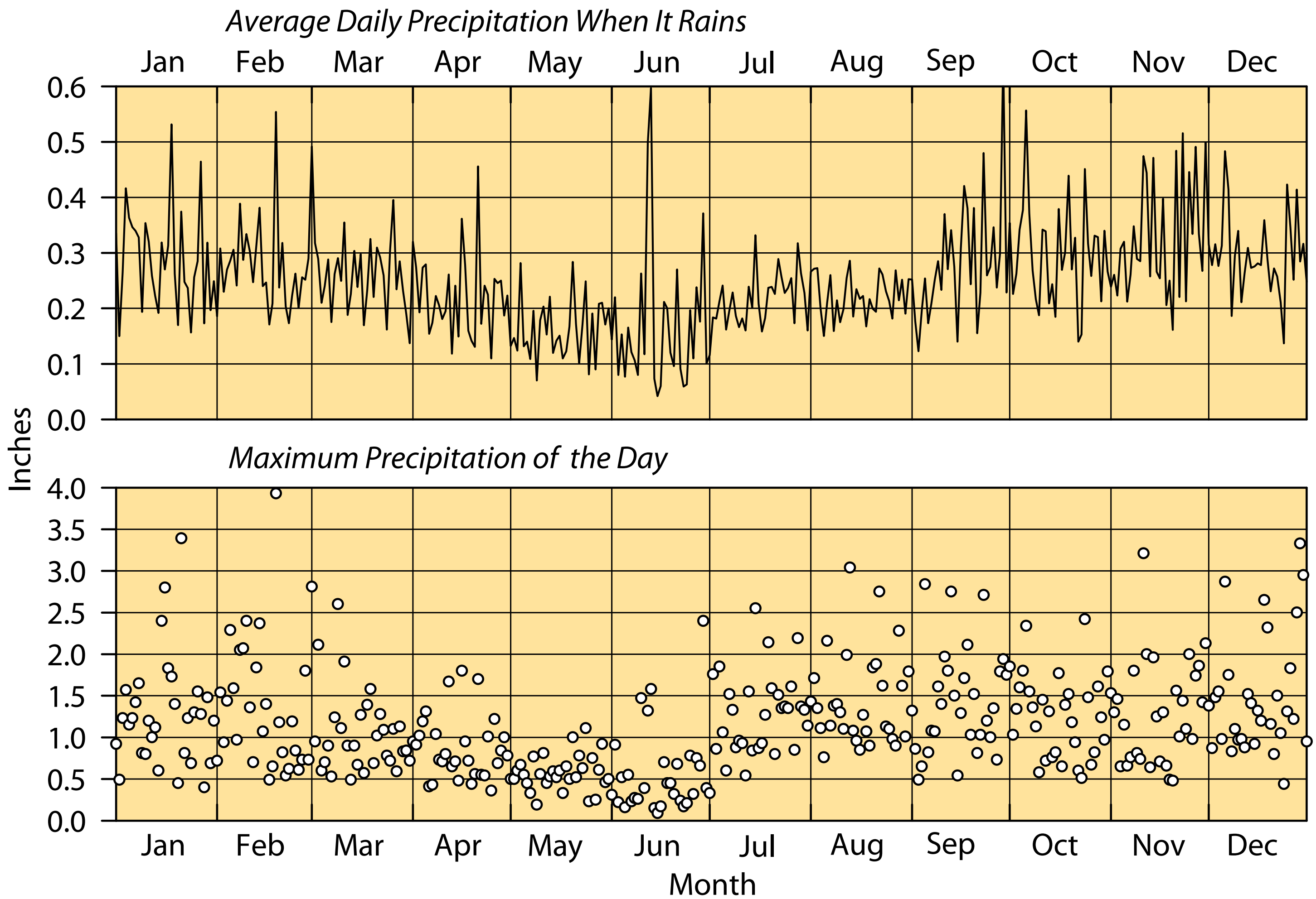
Annual Precipitation Cycle and Probability of Precipitation

Period of record is January 1893 to February, 2014

Percent coverage = 61

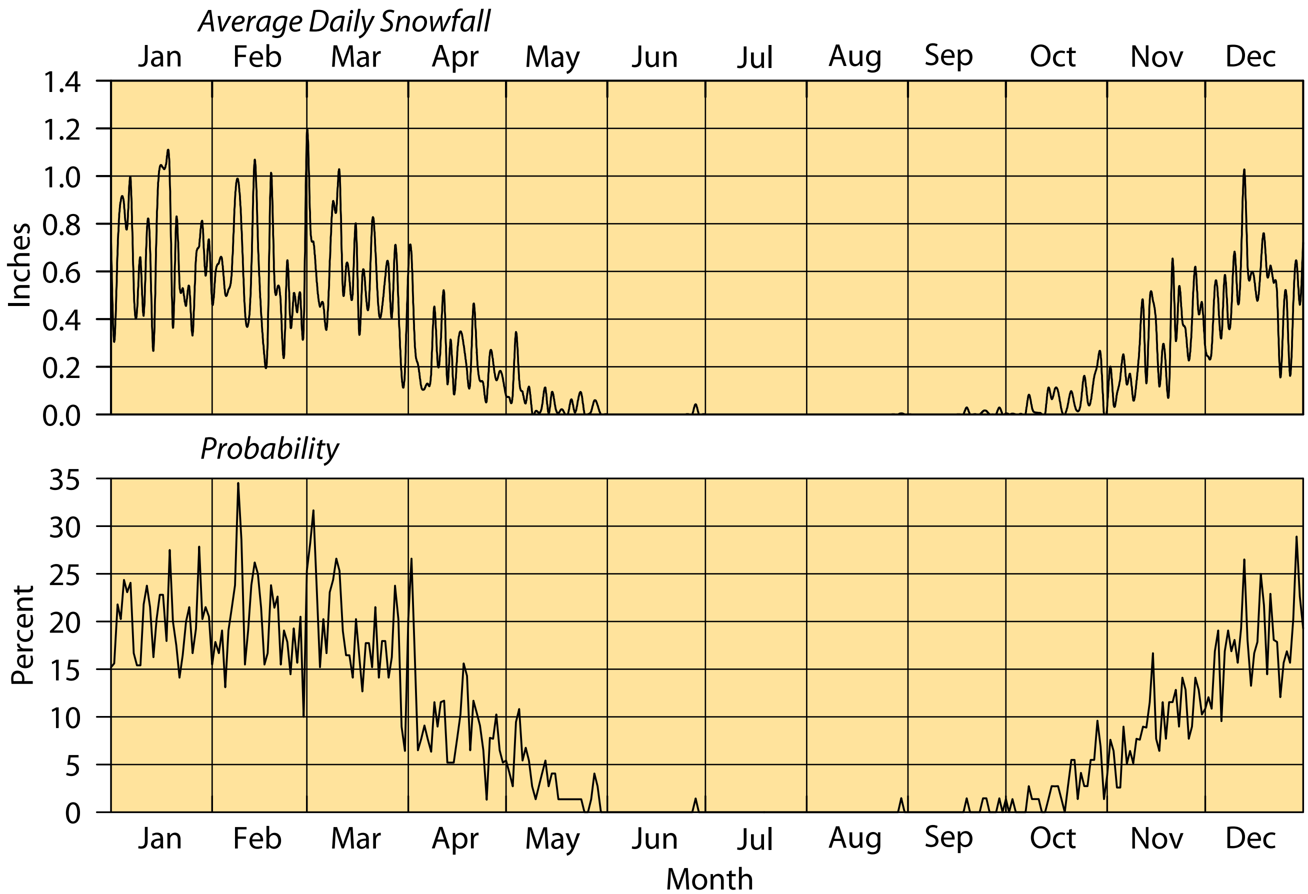
Flagstaff has two wet seasons: warm season rainfall from mid-June to mid-October, coinciding partly with the monsoon (North American monsoon), and cool season precipitation including snow from mid-October to mid-June. May and particularly June are consistently dry. Average rainfall amounts are extremely small ranging from 0 to 0.18 inches, because the divisor used in calculating the average includes days with no rain (see page 4 upper panel, average rainfall on days when rain occurs). The probability of moisture is consistently high—mostly above 50 percent—from mid-July through August; monsoonal rain, according to local tradition, tends to begin around July 4 with probability of 30–35 percent.

Different source regions and atmospheric circulation patterns supply moisture during the cool and warm seasons. Monsoonal rain results from a seasonal reversal of atmospheric circulation that transports marine tropical moisture into the Flagstaff region from the Gulf of Mexico, the Gulf of California, or both. Cool season precipitation results largely from cyclones of the North Pacific Ocean, which is the moisture source. The cyclones occur in conjunction with global scale low-pressure systems and with the polar and subtropical jet streams that transport moisture eastward into the Southwest.



Average Daily Precipitation and Maximum Precipitation of the Day

Average daily rainfall on days when rain (or snow) fell is highly variable. Daily rainfall amounts are 0.2 to 0.3 inches for the wet seasons, and record rainfall amounts tend to occur during the two wet seasons. The largest daily rainfall was 3.93 inches on February 19, 1993. Larger daily rainfall amounts occur locally, but they are not part of the Flagstaff record.

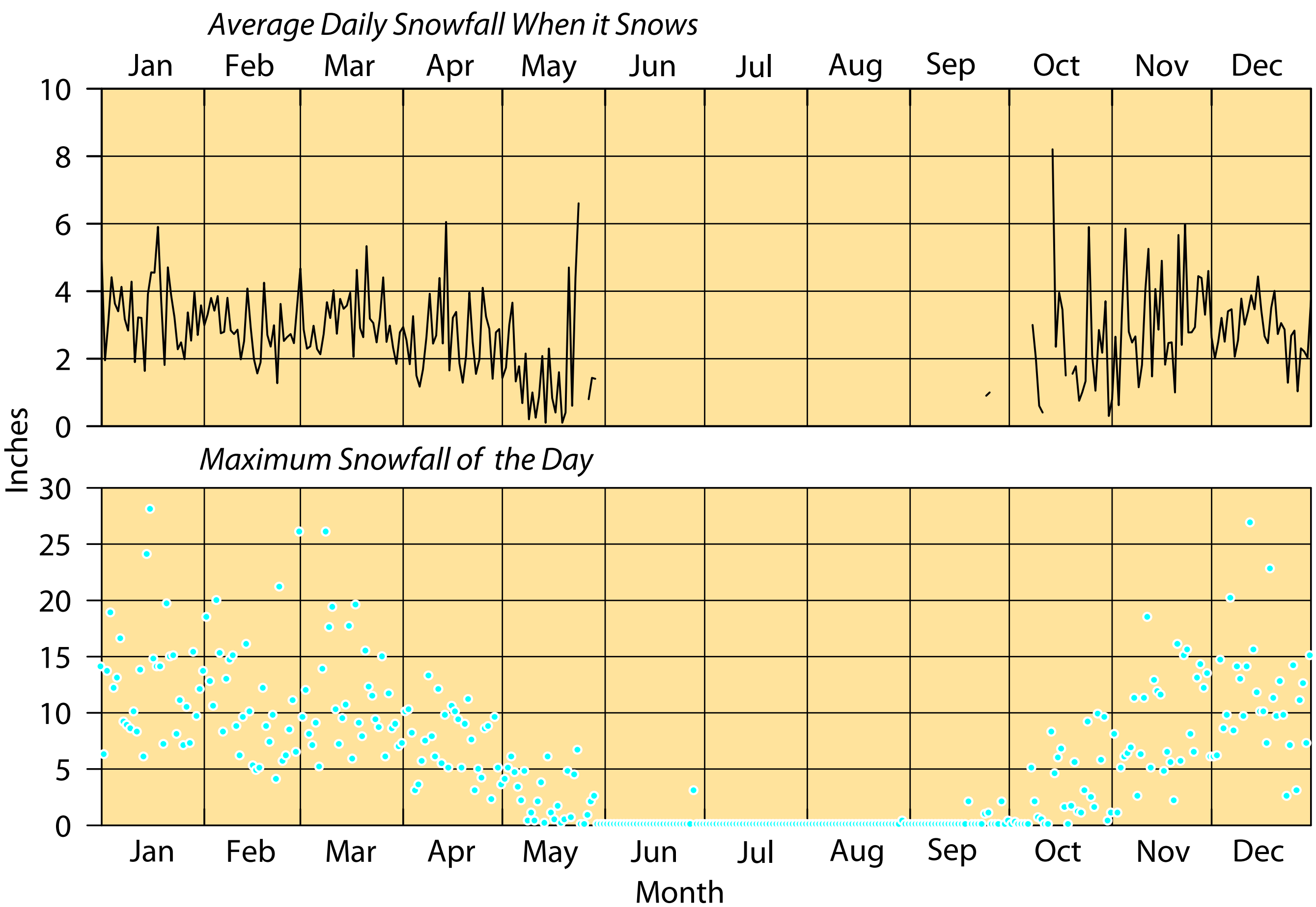


Annual Snowfall Cycle October 1 to May 31 and Probability of Snow

Period of record is January 1, 1893 to February 24, 2014

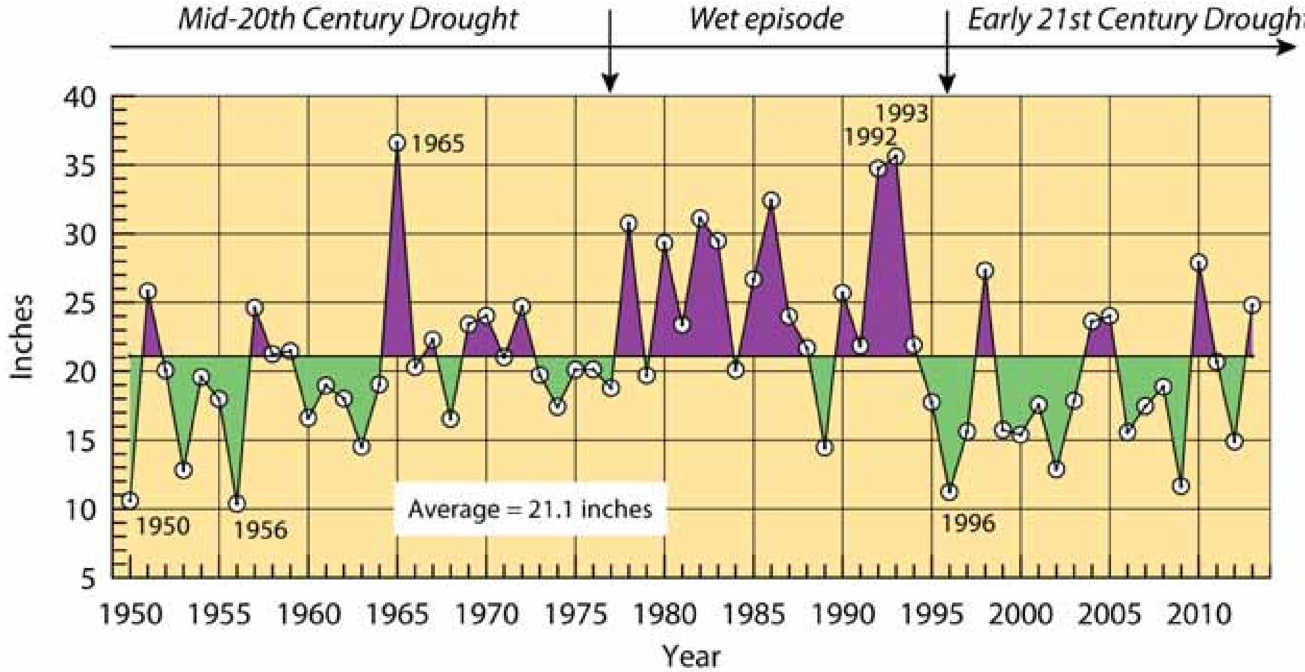
Percent coverage = 62

The annual snowfall cycle runs from October 1 to May 31, although a few inches have fallen in late June, late August, and mid- to late September. The daily probability of snow averages about 20 percent in mid-December through March, when snowfall declines abruptly.



Average Daily Snowfall and Maximum Snowfall

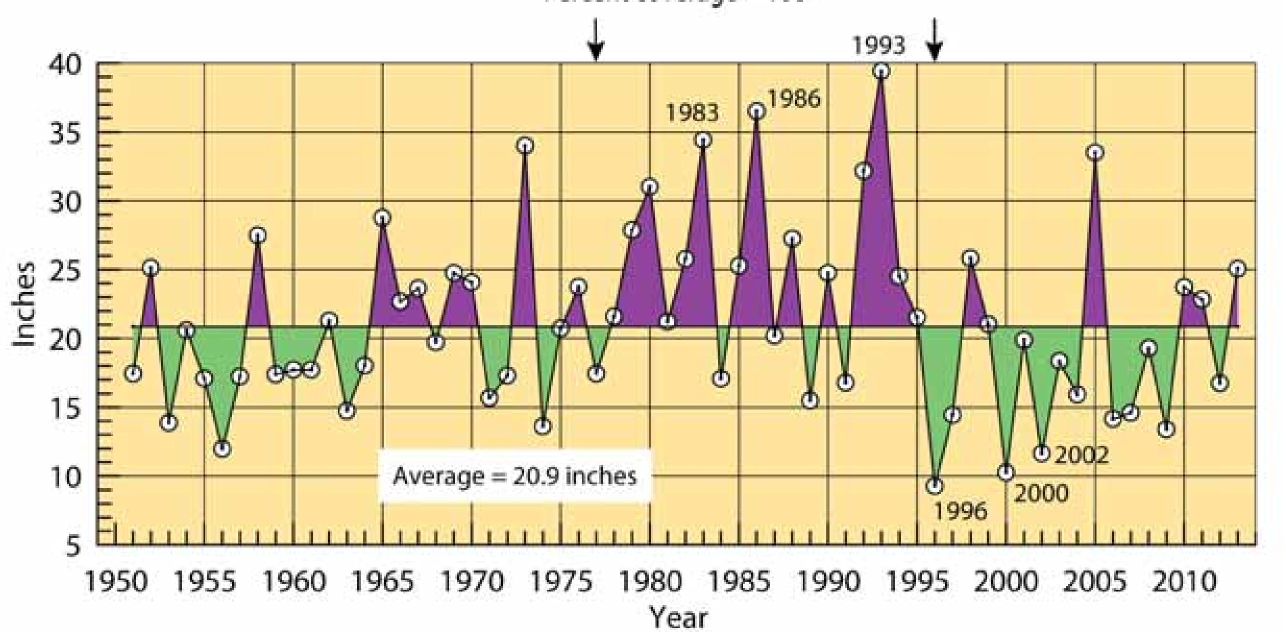
Average daily snowfall on the days when snow falls is typically between 2 and 4 inches. Record daily amounts greater than 20 inches have occurred 8 times.



Calendar Year Precipitation

Period of record is January 1950 to December 2013

Percent coverage = 100

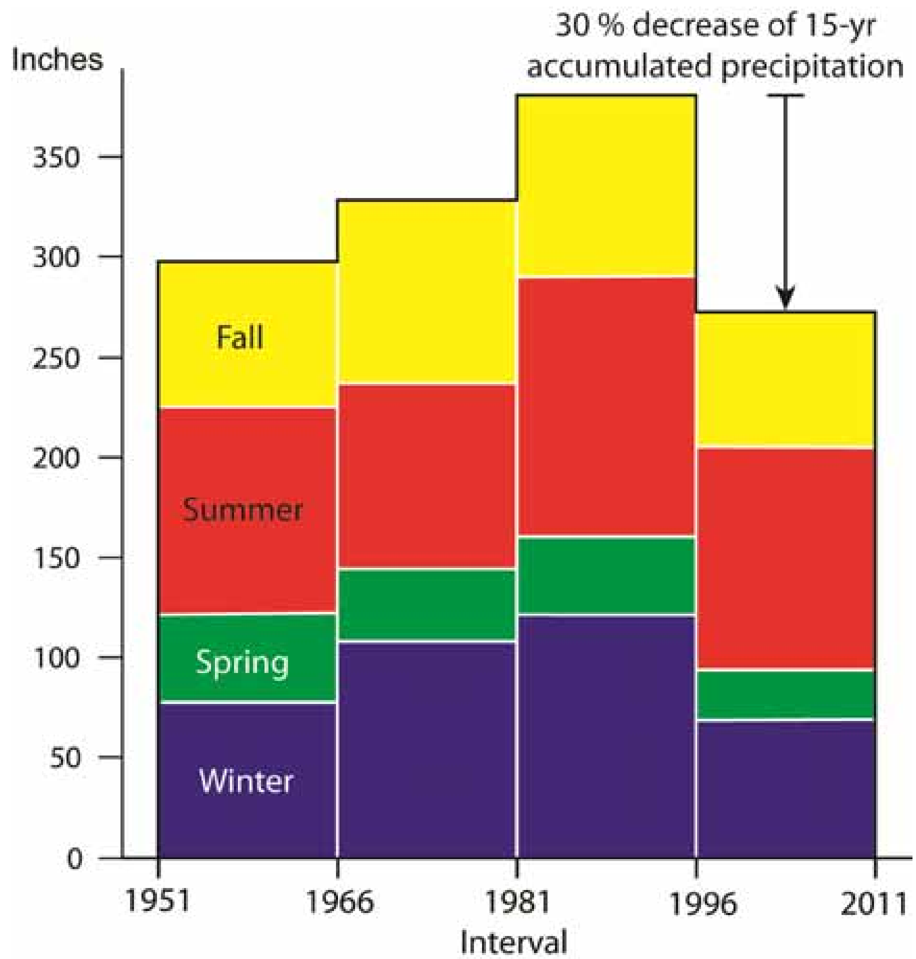


Water Year Precipitation

Period of record is October 1951 to September 2013

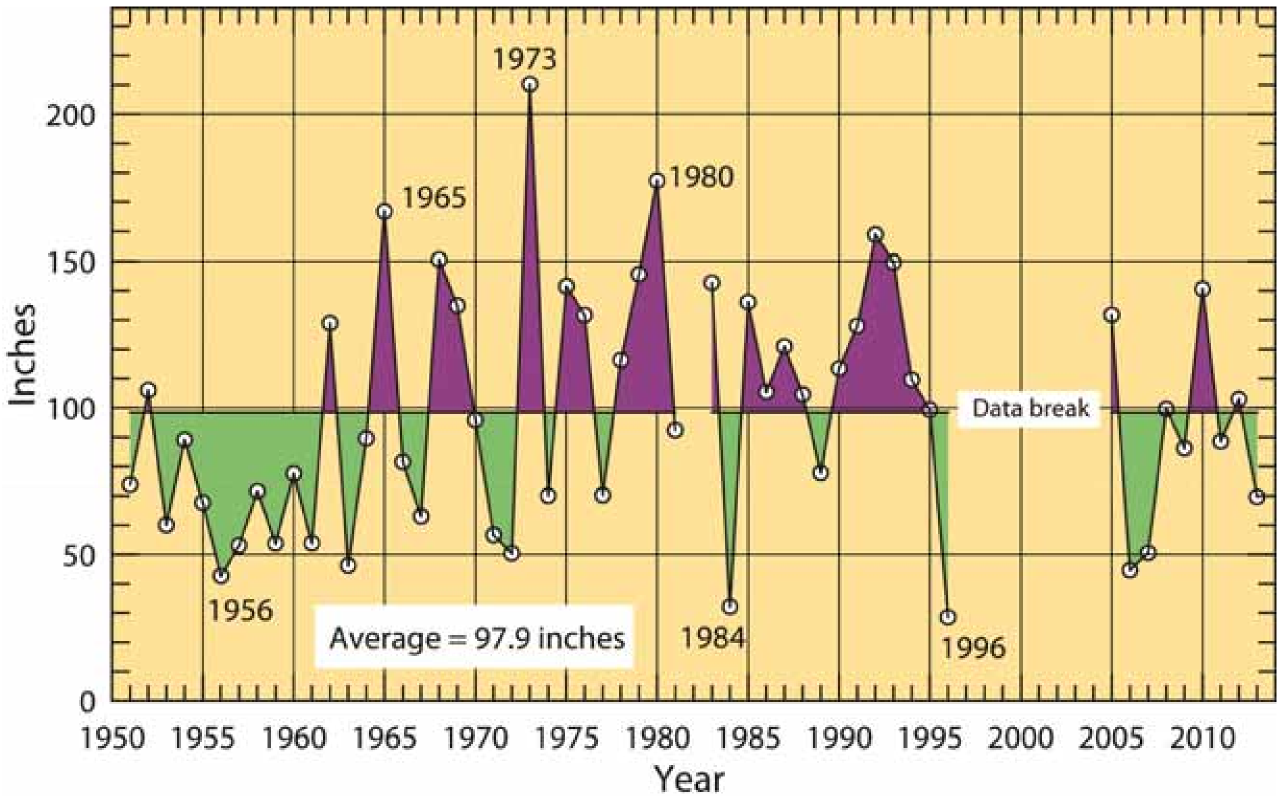
Percent coverage = 100

These time series show the two accounting periods commonly used for total annual precipitation—the calendar year and the water year (October 1 to September 30 of the following year). The accounting periods differ substantially in detail, and it's important to specify which one is being considered. In particular, the wettest and driest years are different in time and amount and the year-by-year amounts differ as well. The water year accounting period aligns with the October through September annual precipitation cycle illustrated on page 3. The water year is preferred for hydrological purposes because the cycle is not artificially split at January 1. Both of them, however, reveal the ongoing Early 21st Century Drought, the Wet episode of the late 1970s to mid-1990s, and the latter portion of the Mid-20th Century Drought of the early 1940s to mid-1970s.



Accumulated 15-year Precipitation by Season
in Four 15-Year Intervals,
1951 to 2011

Affect of the Early 21st Century Drought on accumulated precipitation is shown by the reduced height of the rectangle on the right side of the plot. The maximum decrease is 30 percent when compared with the preceding 1981 to 1996 interval. Note the decreased fall, winter, and spring moisture of the latest interval 1996 to 2011. These decreases account for most of the change, because summer moisture is essentially unchanged.



Seasonal Snowfall (October 1 to May 31)

Period of record is October 1, 1950 to May 31, 2013

Percent coverage = 90

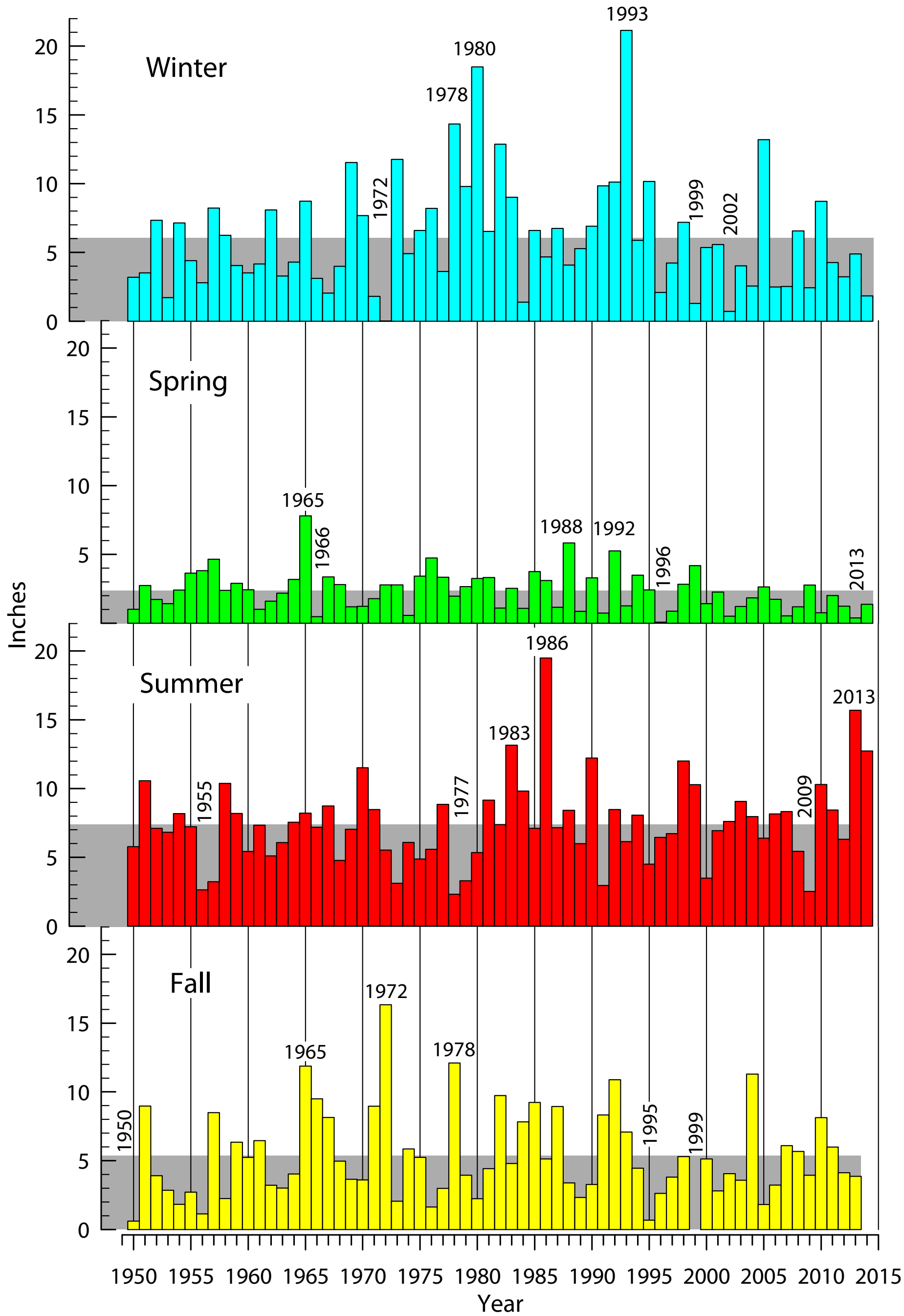
The largest snowfall in a single season was 210 inches in 1973. The single largest snowstorm was in December 1967 (1968 snow season) when 84 inches fell in only eight days; but accumulated snowfall for 1968 was not record breaking. Only 28.5 inches fell in 1996, signaling the beginning of the ongoing drought.

(Image courtesy of Northern Arizona University, Cline Library)

The weather station at Flagstaff Airport was snowbound after the record 84-inch snowfall of late December 1967, a minimum value because high winds during the storm reduced the measured accumulation. The storm effectively paralyzed Flagstaff and the governor declared a state of emergency.[3]

(Image courtesy of Greg Paulin, Southwest Aerial Photography, Flagstaff)

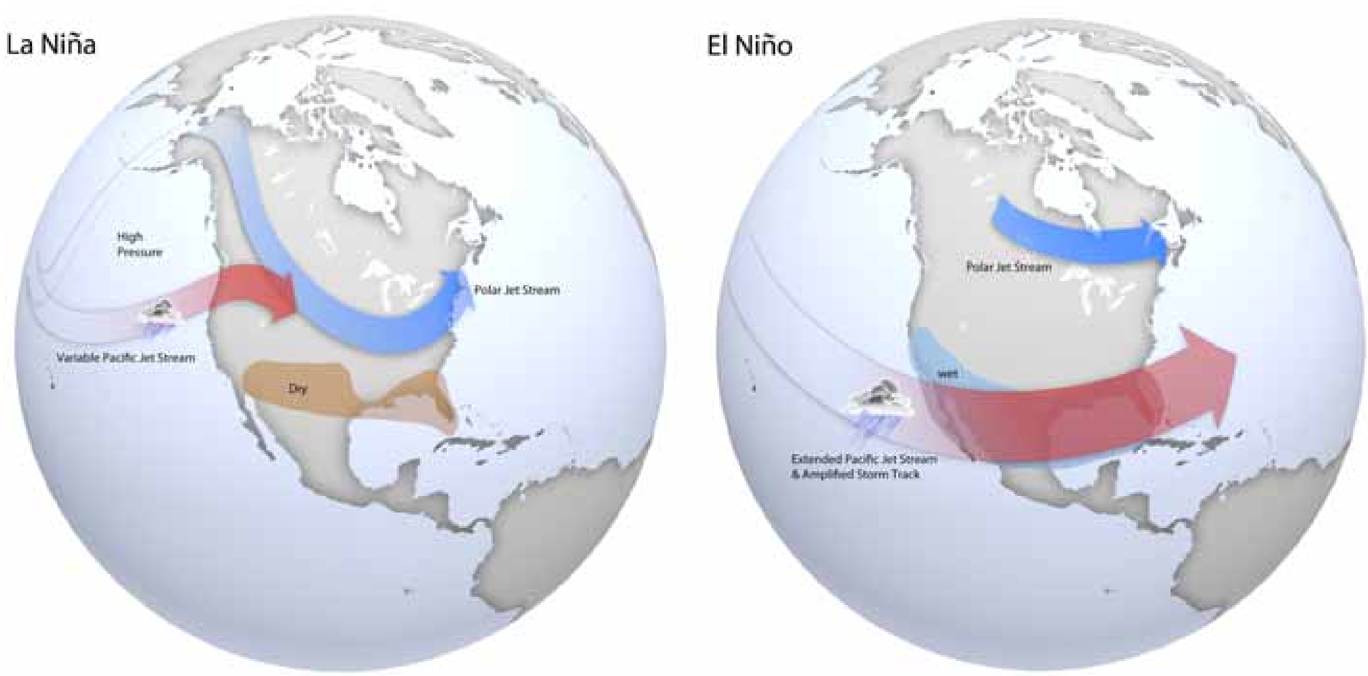
This aerial view of Flagstaff from the southeast shows extensive flooding in low-lying areas of the Rio de Flag in the Continental Country Club area (foreground) caused by record-breaking rain falling on snow in February 1993.



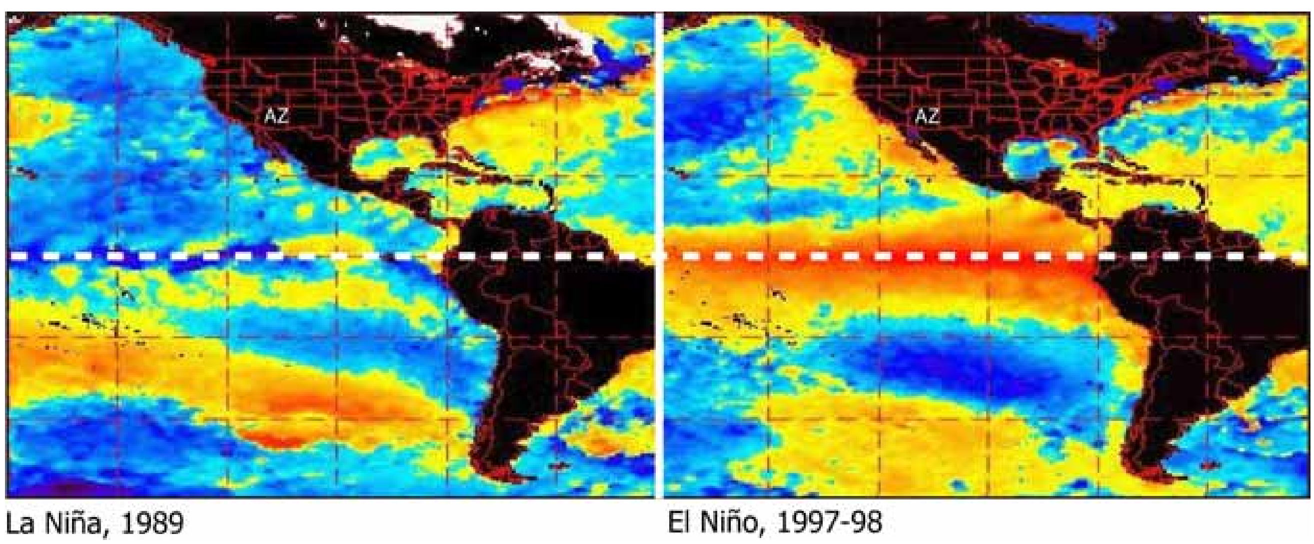
Precipitation Variability by Season

Grey Pattern Highlights Below Average Precipitation

These graphs show variation of seasonal precipitation with a common scale (0 to 22 inches) to emphasize the relative contribution of each season to the average annual total. Winter contributes 30, spring 10, summer 35, and fall 25 percent of the annual precipitation. Winter is the most important season in terms of runoff (photograph page 18) and reservoir storage. Winters 1973 to 1995 were unusually wet averaging 8.6 inches. However, beginning in 1996, average precipitation decreased sharply to 4.4 inches at the beginning of the Early 21st Century Drought. Average spring precipitation is typically 2–3 times less than the other seasons reflecting the pre-summer dryness of May and June (page 3). Summer rainfall, surprisingly, shows the least variability of all with no long-term change except for several record setting wet summers beginning in 1983. Fall is highly variable, although a long-term downward shift began in 1995, including the completely dry fall of 1999. Fall and winter account for most of the 30 percent decline of accumulated precipitation beginning in 1996 (page 8).

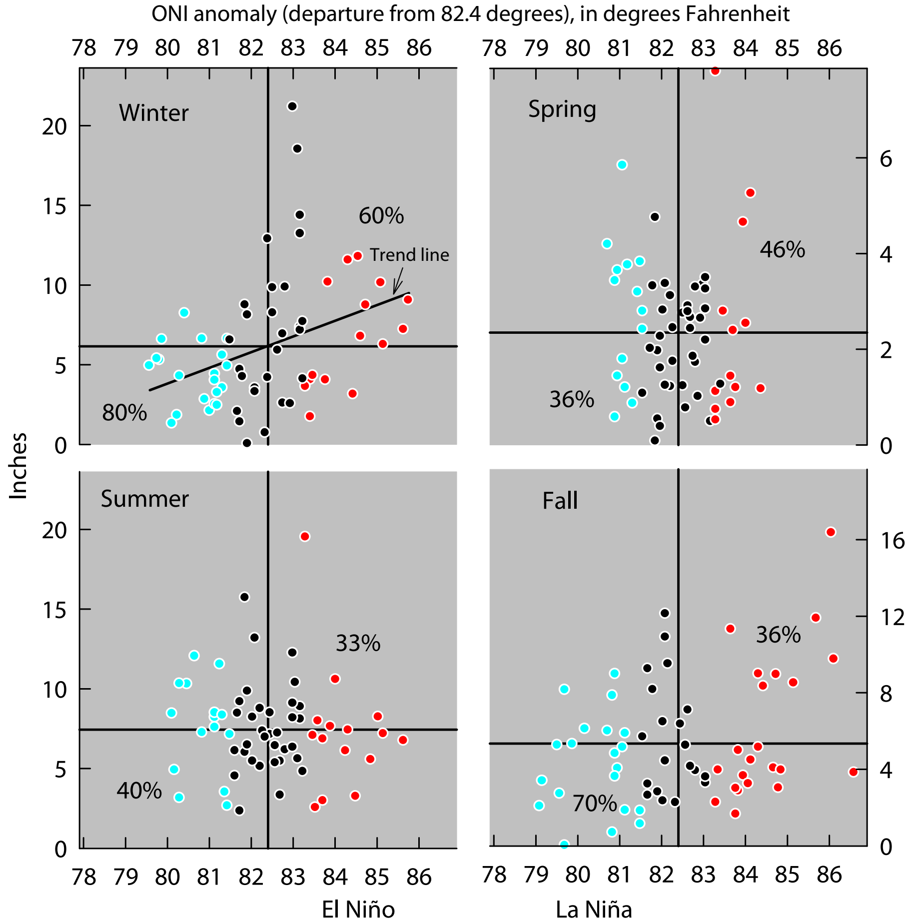


La Niña and El Niño May Alter the Path of the Jet Stream
Promoting Dry or Wet Weather in the Southwest
(Image Courtesy of *Earth* Magazine, American Geosciences Institute)



Sea-Surface Temperature Patterns
Bluish–cool; orange and red shades–warm
(Image courtesy of National Weather Service, Southern Region Headquarters)

Like much of the Southwest,[4] Precipitation at Flagstaff (pages 7–9, 11) is controlled to a limited extent by El Niño and La Niña activity. El Niño and its complement La Niña are global-scale climate phenomenon collectively referred to as the El Niño-Southern Oscillation (ENSO). A seesaw pattern of atmospheric pressure between the equatorial Eastern and Western Pacific Ocean (the Southern Oscillation) and corresponding changes of sea-surface temperature (SST) identify El Niño and La Niña. Changes of SST from cool to warm (El Niño) and vice versa (La Niña) in this region are signs of ENSO activity. During La Niña, cool SST off the west coast of North America promotes dry weather with high atmospheric pressure and reduced convection. Low pressure and cloud formation favor wet weather during the elevated SST of El Niño. In terms of atmospheric pressure and SST, El Niño and La Niña are opposites. Their effect on Flagstaff's climate, however, is far from opposite, because not every El Niño is particularly wet nor is every La Niña especially dry.



Oceanic Niño Index (ONI) and Seasonal Precipitation, 1950 to 2013

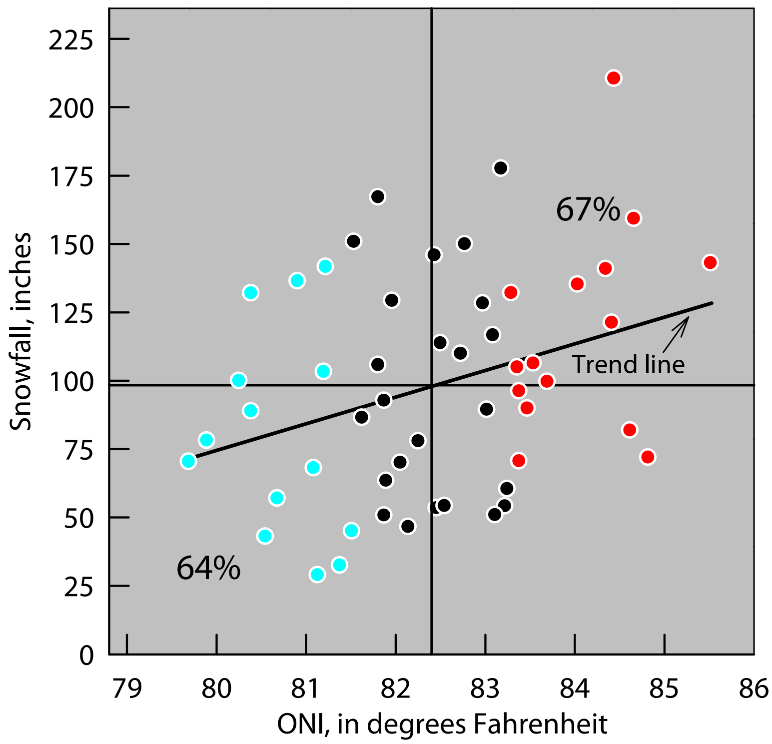
Showing Percent of Seasons with Above Average (Below) Precipitation during El NIño (La Niña)

Red symbol–El Niño; cyan–La Niña; black–neutral

These graphs show the relation between the average Oceanic Niño Index (the ONI anomaly)[5] and accumulated seasonal precipitation. The number of seasons with above and below normal precipitation at Flagstaff is expressed as a percentage for El Niño and La Niña, respectively. The ONI measures SST change relative to 82.4 degrees (28 degrees Celsius). SSTs are monitored in a rectangular shaped area—the oceanic Niño region aligned east to west and measuring 680 by 3,420 miles—straddling the equator 2,700 miles off the coast of Ecuador. A positive ONI anomaly indicates warm temperatures and El Niño conditions; *wet* weather (upper-right quarter *above* the horizontal lines) in winter is possible in the Southwest and Flagstaff. On the other hand, a negative ONI anomaly indicates cooler SST and La Niña conditions; *dry* weather (lower-left quarter *below* the horizontal lines) is expected in winter and fall. Neutral conditions, those with ONI between plus and minus 0.9 degrees (0.5 Celsius degrees) relative to 82.4 degrees, have no systematic affect on precipitation. Some of the wettest and driest seasons, as well as extreme rain and snowfall events, have occurred during neutral ONI. Since 1950, 46 percent of accumulated precipitation is attributed to neutral conditions; El Niño and La Niña contributed 30 and 24 percent.

Generally, winter moisture including snowfall is likely to be *above* normal during El Niño and is quite likely to be *below* normal during La Niña. Spring and summer tend toward *above* normal moisture during La Niña, whereas fall precipitation is usually *below* normal.

The National Climate Data Center[6] forecasts El Niño conditions during winter 2015. So, historically at Flagstaff *above* normal winter moisture occurred in 60 percent of the winters. Conversely, if La Niña conditions prevail, the occurrence of *above* normal precipitation in previous seasons is only 20 percent (100 – 80 = 20 percent). If El Niño had developed in summer 2014, *above* normal moisture would be unusual, as only 33 percent of previous El Niño-summers exceeded normal.

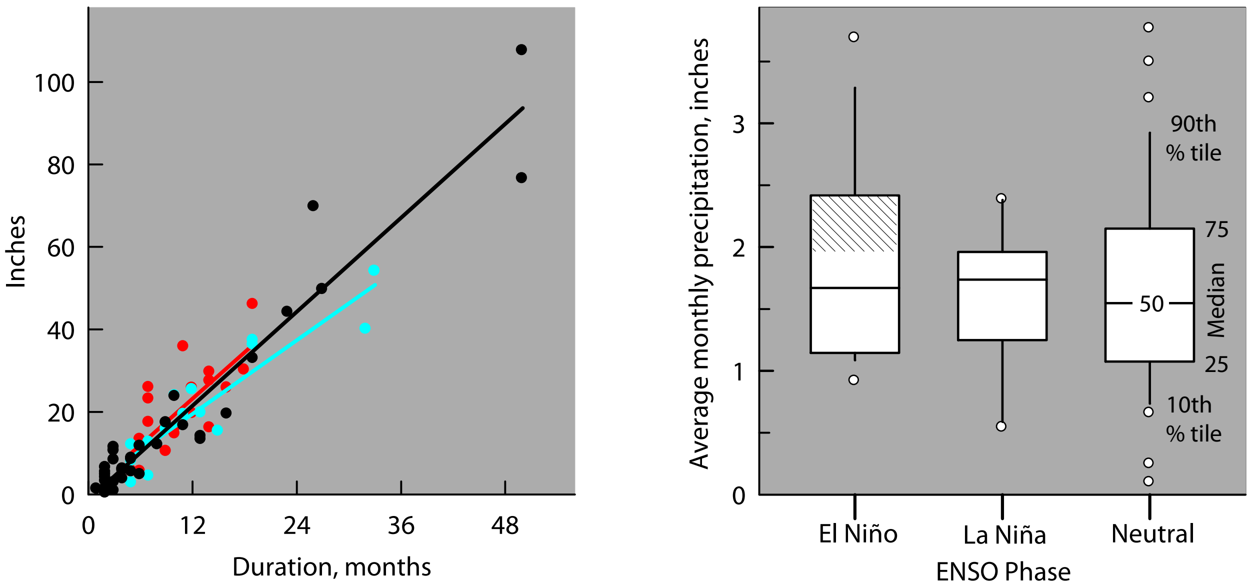


October to May Oceanic Niño Index (ONI) and Snowfall, 1951 to 2013

Showing Percent of Seasons with Above (Below) Average Snowfall
during El Niño (La Niña)

Red symbol–El Niño; cyan–La Niña; black–neutral

This graph is similar to those on page 13, except this one treats snowfall of the October through May snow season. The trend line shows the increase of snowfall with increasing ONI. A relatively strong El Niño (high value of ONI) results in more snowfall, although the trend is weak and not very useful for prediction. Above average snowfall during El Niño occurred in 65 percent of the snow seasons. Above average snowfall during La Niña has occurred in only 36 percent of the seasons, or 5 times. Neutral ONI has produced widely variable snowfall ranging from the fourth smallest to the second largest.



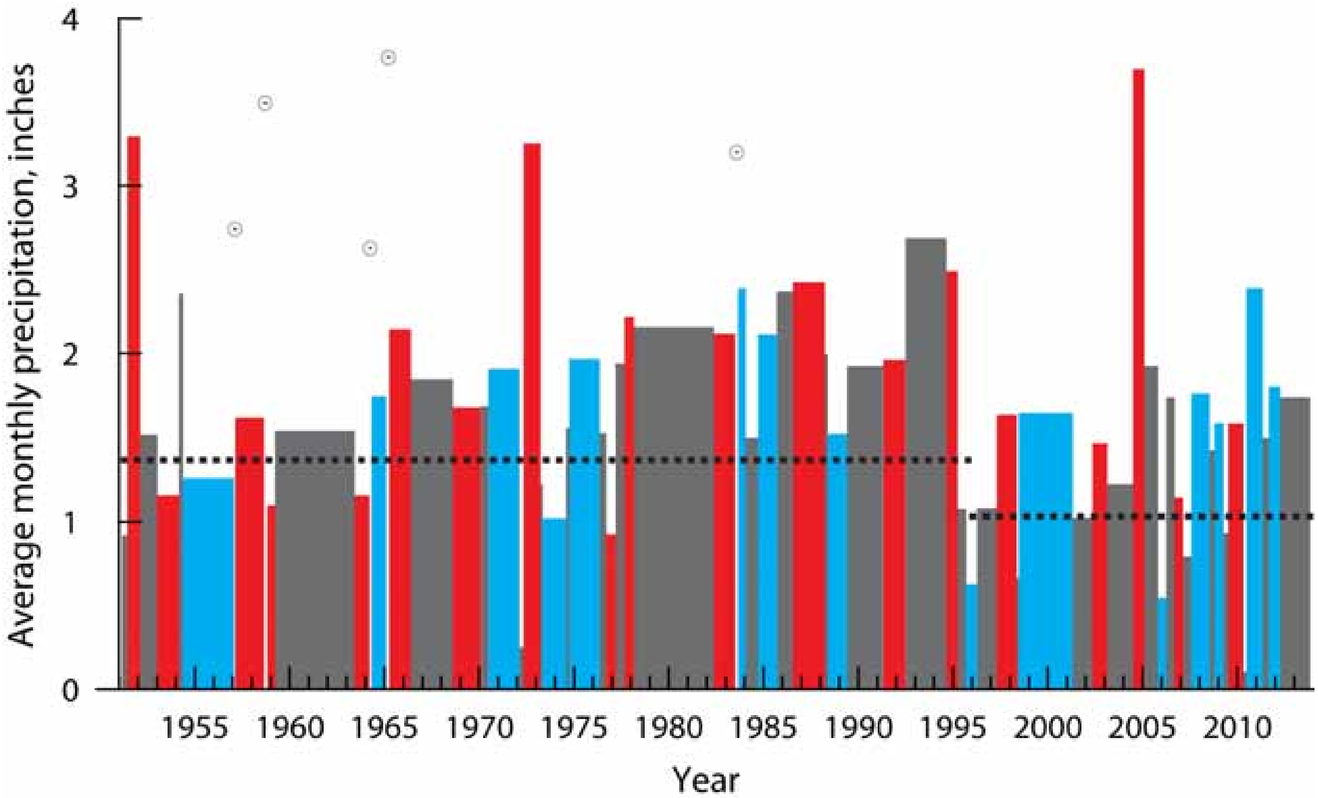
ENSO Phase and Accumulated Precipitation

Showing Dependence of Accumulation on Duration (left) and
Range of Precipitation (right) of Each Phase Adjusted for Duration

Red symbol–El Niño; cyan–La Niña; black–neutral

Perhaps the most important factor controlling the amount of precipitation is the duration of the particular ENSO phase (left panel); a longer phase produces larger amounts. Duration ranges from 5 to 20, 5 to 33, and 1 to 50 months for El Niño, La Niña, and neutral, respectively. Comparison of precipitation amounts among the three phases requires normalization to a common duration of one month, which yields average monthly precipitation. Doing this (box plots right panel) indicates that El Niño generally produces wetter conditions than La Niña even though the median precipitation of La Niña and El Niño are similar. The excess of El Niño over La Niña moisture is shown by the pattern in the El Niño box. The neutral phase has produced the driest and wettest climate, but this phase also falls short of El Niño.

Two factors that may influence accumulated precipitation are when in the year an El Niño begins and the magnitude (relatively high or low ONI) of the El Niño. Accumulated winter precipitation including snowfall relates directly to the strength of El Niño as measured by average ONI. In addition, the beginning of an El Niño relates weakly to when the phase begins; large accumulations have occurred when El Niño developed in May and July. This increased precipitation is probably because El Niño reached its peak in phase with the fall through winter-wet season.



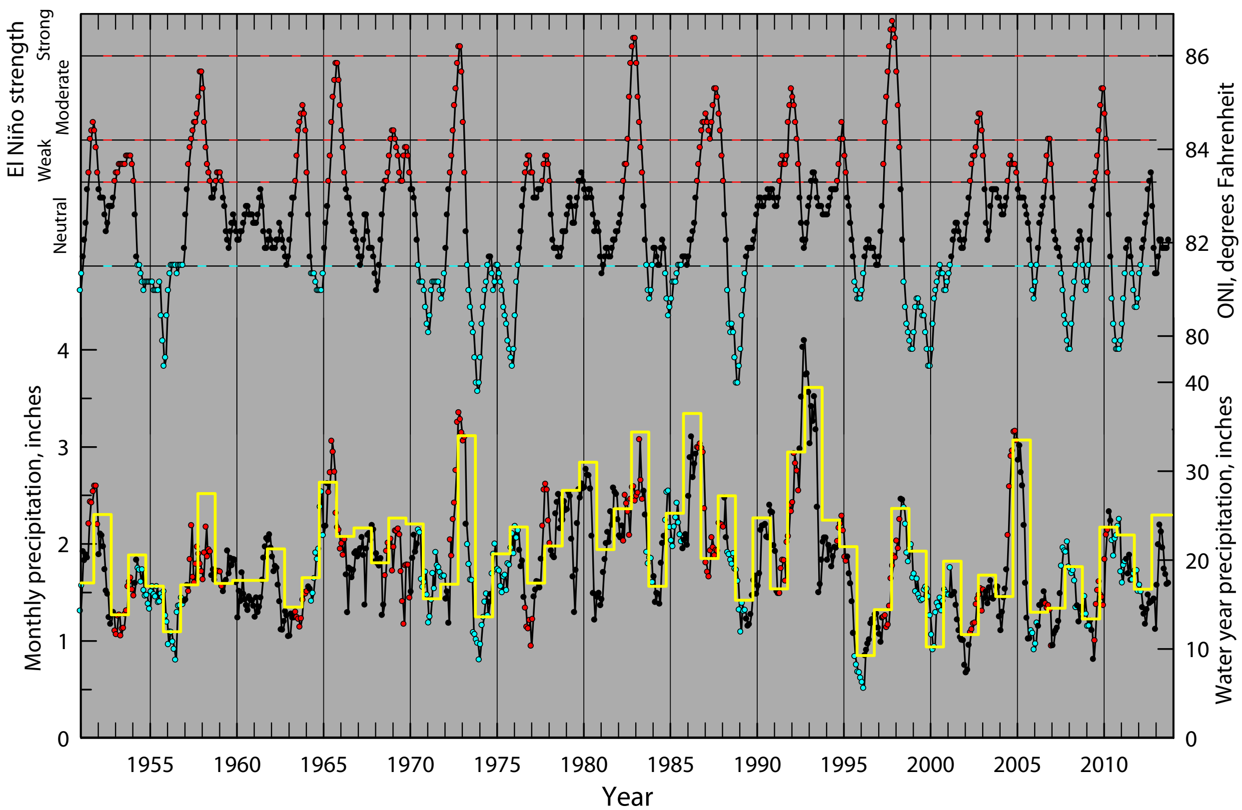
Precipitation and ENSO Phase

Showing 24 Percent Decrease in Median Precipitation (dashed line)
Red symbol–El Niño; cyan–La Niña; gray–neutral; circles–neutral outliers

In this time series, the color, width, and height of the rectangles correspond to ENSO phase, duration, and average monthly precipitation, respectively. A striking feature of the time series is the abrupt and persistent 24 percent downward shift of median precipitation in 1996 (dashed line right side), once again marking the beginning of the Early 21st Century Drought. The drought relates to a decrease in the duration of La Niña and El Niño as well as an increase in La Niña events. Both events were shorter, with the exception of the La Niña centered on 2000, potentially drier, and El Niño was less frequent—in other words, La Niña-like conditions prevailed during the drought. In the midst of this dryness, however, is the brief El Niño of July 2004 to January 2005, which was particularly wet producing an unusually moist fall 2004 and winter 2005 (page 11). This increased moisture was regional and synchronized with the fall and winter wet seasons. The timing and plentiful moisture produced spectacular flower displays in the low deserts of the Southwest, particularly Death Valley.

The graph also shows the time between ENSO events and the succession from one phase to the other. A neutral phase, almost by definition, separates El Niño from La Niña, and of course a neutral phase will intervene between any two consecutive El Niño or La Niña. Since 1951, the time between El Niño, La Niña, and neutral events has ranged from 1 to 5, 1.1 to 10, and 0.6 to 1.4 years, respectively.

The overall appearance of this time series seems to contradict conventional wisdom about the precipitation amounts of El Niño and La Niña. La Niña appears to be relatively wet and not much different from El Niño. But, as described on page 16, La Niña on average lasts longer than El Niño, and it may at times produce more accumulated precipitation; this is also true of the neutral phase which out produces La Niña.



Oceanic Niño Index (ONI) and Precipitation by Month and Water Year

Red symbol–El Niño; cyan–La Niña; black–neutral; yellow line–water year precipitation

These time series illustrate the complicated relations among monthly Flagstaff precipitation,[7] water year precipitation, and the ONI. Strictly speaking, the ONI and precipitation at the monthly level are unrelated. Even when aggregated into annual time scales (yellow line), the correspondence between ONI and precipitation is modest at best. However, on a month-by-month basis and at certain times, two important patterns are apparent in the plots: the *wettest* months are linked in time to the warmest El Niño events (1965, 1973, 1983), and the *driest* months correspond with the coolest La Niña events (1956, 1974, 1989, 1996, 2000, 2006).

In terms of dry spells lasting several years or longer, the dry years of the early 1950s (page 7) resulted from persistent La Niña conditions and ineffective weak-to-moderate strength El Niño. Beginning in 1996, the Early 21st Century Drought is notable for having the three driest years and for being the driest episode of the 65-year record. This aridity resulted from seven La Niña events, three of which were strong and lengthy; relatively dry neutral conditions; and five brief weak-to-moderate strength El Niño. Record below average precipitation characterized the weak-to-moderate strength El Niño of May 2002 to February 2003; the brief El Niño of 2007 was extremely dry. In contrast, the apparently unremarkable El Niño of 2004–05 produced substantial water year precipitation, but drought relief, if any, was brief. A moderate strength El Niño in 2010 produced above average snowfall (page 9), which again failed to provide relief from long-term drought.

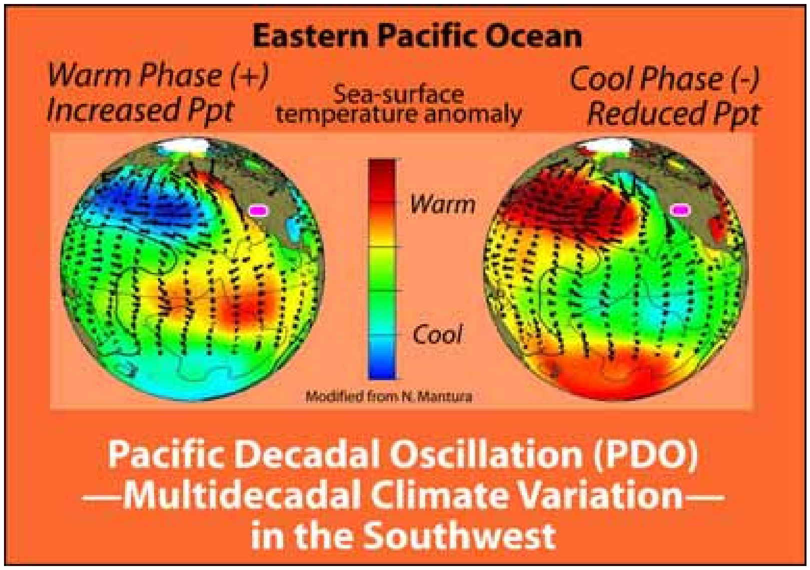
Reduced average monthly precipitation during the drought (page 16) in the late 1990s was contemporaneous with a decrease of median ONI of 0.54 degrees (0.3 Celsius degrees), which is apparent in the ONI plot shown above. This reduced SST is also tied to a recent pause in the rate of global warming, which is a leveling of warming that began around 2000.[8] We again see that Flagstaff's climate is influenced by global-scale phenomena. In terms of precipitation, the influence is profound and prolonged. But, if past climate patterns are repeated, the end of the drought is inevitable and could occur in less than a decade.

Overall, the 1980s to mid-1990s were unusually wet with the exception of 1989 (pages 7 and 11). This excess moisture is related to a sequence of three moderate-to-strong El Niño events and several runs of relatively wet neutral conditions. La Niña during the wet spell produced below normal precipitation in 1984, 1987, and 1989. The La Niña of 1989 (page 12 lower left panel) was strong, brief, and produced widespread drought conditions in the West; precipitation in Flagstaff was 75 percent of normal.

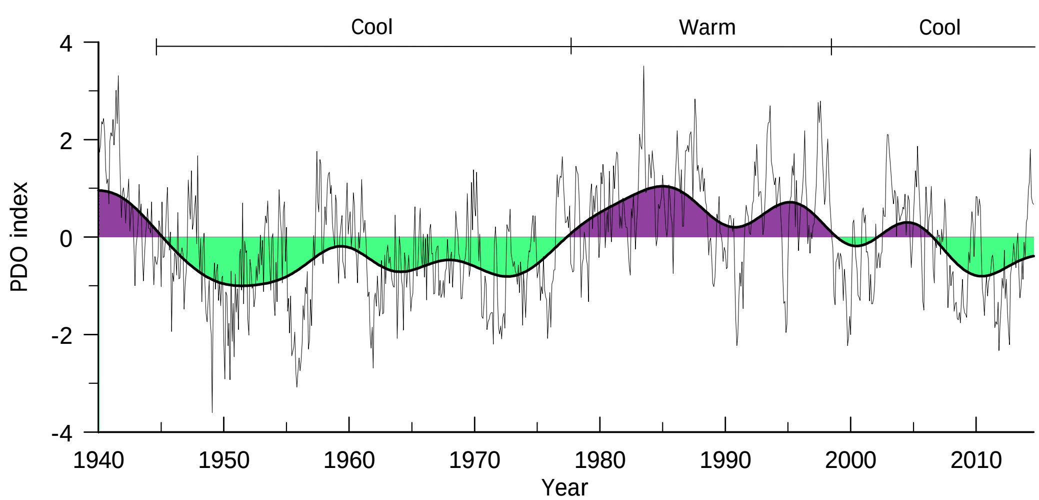
Record or near record events resulted from various states of the ONI. The record snowstorm of December 1967 (page 10), for example, occurred near the end of a 27-month neutral phase. The 210-inch record snowfall of 1973 (page 9) was during the strong 1972–73 El Niño. The unusual snowfall was followed by an extended La Niña that lasted 34 months until April 1976; this links to near record dry precipitation in water year 1974 (page 7), reduced precipitation thereafter, and above normal snowfall in 1975–76. Neutral ONI from January 1979 to April 1982 is associated with the record cold of 1979 (page 2) and the deep snowfall of 1980. The strong 1983 El Niño produced the second wettest water year, including record summer rainfall and above normal snowfall. A moderate-strength El Niño from May 1991 to June 1992 peaked in January 1992, producing well above normal precipitation in water year 1992. This was followed in 1993 by the wettest year on record during neutral conditions. The strong El Niño of May 1997 to April 1998 (page 12 lower right panel), perhaps the strongest ever recorded[9], resulted in slightly above normal precipitation at Flagstaff.

The effect of ENSO on Flagstaff's precipitation is evidently not straightforward. Moisture is likely to be near or above normal during El Niño, but *below* normal precipitation may happen during weak-to-moderate strength El Niño, particularly in 1953, 1964, 1977, 2007, with record-breaking dryness in 2002. La Niña, on the other hand, is likely to produce below normal precipitation, and all except one of the record dry years occurred during La Niña. But, normal to slightly *above* normal precipitation is possible as in 1976, 1985, 1999, and 2011. Neutral conditions yield wide variation in moisture from among the driest to some of the wettest, ranging in duration from individual storms to annual accumulations.

Snowmelt runoff plunging nearly 120 feet over Grand Falls of the Little Colorado River, April 1, 2010. The 2010 El Niño produced above normal snowfall in northern Arizona that contributed to spring runoff at the falls 30-miles northeast of Flagstaff.

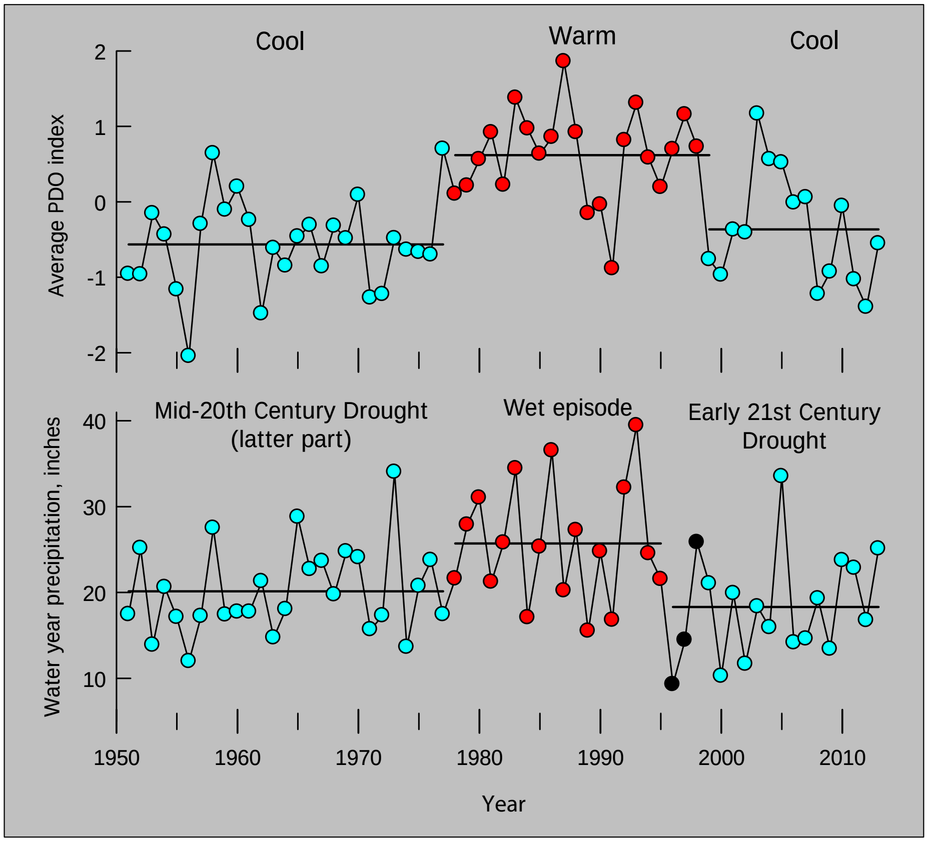


We've seen how ENSO influences Flagstaff's precipitation through alternating phases of sometimes wet El Niño and mostly dry La Niña. These follow one another roughly every three to four years after passing through a neutral phase. However, another oceanic cycle with oscillating warm and cool episodes also affects global climate, including the Southwest. These oscillations are decadal lasting roughly 15 to 30 years. The maps above illustrate the warm and cool phases of the Pacific Decadal Oscillation[10] as expressed in the Eastern Pacific Ocean. The Southwest is the pink ellipse and arrows represent surface wind directions. Defined in 1997, the PDO's influence on global climate is not as well known as ENSO's, and the details of how PDO affects climate worldwide are still debated. Nevertheless, interaction of the PDO and ENSO is the likely cause of the recent leveling of global warming as well as the Early 21st Century Drought in the Southwest. A second long-term oscillation of SST, the Atlantic Multidecadal Oscillation (AMO),[11] is involved as well, but only the PDO is considered in the following discussion.



Phases of the PDO Since 1940

As with ENSO in the Southwest, during the warm phase of the PDO, relatively wet El Niño-like conditions tend to prevail, and during the cool phase, drier La Niña-like climate is likely. The net effect of the PDO on Southwest climate is alternating wet and drought-like climate lasting a decade or more. Since about 1999, the PDO has been in a cool phase resulting in cool SST in the tropical and northeastern Pacific and high sea-level atmospheric pressure off the west coast of North America. High pressure equates to reduced convection, less precipitation, and persistent drought in certain regions such as the Southwest.



Phases of the Pacific Decadal Oscillation and Precipitation, 1951-2013

Showing Relation of PDO Phase to Wet and Drought Episodes
Solid horizontal lines–average PDO and precipitation
Red symbol–warm (wet); cyan–cool (dry); black–transitional

These time series show the influence of PDO on decadal precipitation at Flagstaff. The recent warm phase of the PDO is clearly linked to the wet episode of the late 1970s to mid-1990s. In contrast, the two recent cool phases of the PDO relate to the Early 21st Century and the Mid-20th Century droughts (page 7). With this information, we may speculate as to when the present drought will end. The PDO will inevitably shift to a warm phase, ending the 16 years of La Niña-like conditions that have persisted since 1999. Historically the PDO oscillates between phases every 15 to 30 years. Thus, the end of the drought could be near, replaced by relatively moist conditions within a few years. In the worst-case scenario, however, the current drought could persist for another 14 years if the flip-flop of the PDO is running on a 30-year schedule. What's required to end the cool phase is a massive influx of warm water into the Eastern Pacific Ocean, such as the very strong El Niño of 1997–98 (page 12 lower right panel).

During the recent warm phase of the PDO, Earth's temperature increased in lock step with rising concentrations of atmospheric carbon dioxide and other greenhouse gases. But, warming apparently stalled during the ongoing cool phase even as carbon dioxide rose to record levels. To deniers of anthropogenic climate change this meant that climate models were wrong and that global warming disappeared. Indeed, the climate models did not allow for natural climate variation like the PDO, which was largely responsible for their inability to replicate the pause in the rate of warming. Climate scientists maintain that heat is still building up in the climate system, although not in the atmosphere. Recent work has shown that the missing heat is absorbed in the deeper levels of the ocean while cooling the SST of the eastern Pacific.[8] Global warming continues unabated, although surface global temperatures are not recording the excess heat stored in the oceans.

Notes with Selected References

1—Daily data were analyzed for the graphs on pages 1 and 3–8. The data are available free of charge from the National Climate Data Center-Climate Data Online at www.ncdc.noaa.gov/cdo. The records of daily precipitation, snowfall, and temperature at Flagstaff total more than 119,000 days.

A comprehensive review and statistical analysis of Flagstaff's temperature, precipitation, and other weather-related parameters are given in Staudenmaier and others, **Climate of Flagstaff, Arizona (Revision 6)** (2009, *NOAA Technical Memorandum WR-273*, 75 p.). Results shown herein may differ slightly from those in WR-273 due primarily to how missing data are treated in the calculations and whether seasons are defined by months or dates (i.e., Winter defined as January to March [herein] or December 21 to March 20).

2—Monthly climate data, available from the source listed above, were analyzed for the graphs on pages 2, 11, 13–17, and 20.

3—Platt Kline in **Mountain Town** (1994, Northland Publishing, Flagstaff, p. 466) lists the 1967 snowstorm and the record accumulation of 1973 (page 9) among "The Big Snows" of Flagstaff's first 100 years.

4—A readable and timely paper on Southwest climate, particularly Arizona's, is Sheppard and others, **The Climate of the US Southwest** (2002, *Climate Research*, v. 21, p. 219–238).

5—The ONI data are available at:

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml.

El Niño and La Niña are defined using a three-month running average of the Oceanic Niño Index. Five consecutive months of ONI above or below the threshold temperature of 0.5 Celsius degrees define El Niño and La Niña, respectively. For this analysis, each year of the four seasons was assigned to El Niño, La Niña, or neutral if at least two months were of the same phase. Note that El Niño and La Niña are separated by at least one month of neutral conditions. Other seasonal classification schemes may lead to different results.

6—http://www.climate.gov/news-features/blogs/enso/details-june-2014-enso-discussion

7—Monthly precipitation is smoothed with an 11-month running average. This suppresses precipitation variability for visual comparison with the ONI and has the effect of indicating precipitation in months that none was recorded, such as winter 1972 and fall 1999, concealing the most extreme affect of La Niña—zero precipitation in a given season or month.

8—The pause in global warming and ONI are described at:

https//www.climate.gov/.../.../why-did-earth-surface-temperature-stop-rising-past-decade

Also see: Tolleson, **The Case of the Missing Heat** (2014, *Nature*, v. 505, p. 276–277) and Trenberth and Fasullo, **An Apparent Hiatus in Global Warming?** (2013, *Earth's Future*, v. 1, p. 19–32)

9—See *National Climate Data Center Technical Report No 98–02*

10—PDO data and graphics are available from Nate Matura at:
http://www.atmos.washington.edu/~mantua/abst.PDO.html

11—The effects of ENSO, PDO, and the AMO on Southwest climate are analyzed in Chylek and others, **Imprint of the Atlantic Multi-decadal Oscillation and Pacific Decadal Oscillation on Southwestern US Climate** (2013, *Climate Dynamics*, v. 43, p. 119–129). These author's argue that the current drought could end within 3 to 5 years followed by increased precipitation. Readers should note that the AMO and PDO are statistically correlated, but the atmospheric and oceanic processes linking the two are not understood, as Chylek and others point out.