THE UNIVERSITY OF ARIZONA
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Guide to Southwest U.S. Station Climate Summaries

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Introduction

The southwest U.S. has a unique climate characterized by distinct wet and dry seasons that emerge throughout the annual cycle (Sheppard et al. 2002). In Arizona and New Mexico, the annual pattern of precipitation is characterized by rapid onset of the summer monsoon thunderstorm activity in late June that persists through late September and a more gradual onset of winter storms in late October that can persist through the spring. These two rainfall periods set the conditions for seasonal fire activity, streamflow and water supply, and rangeland conditions (Crimmins et al. 2017).

Drought monitoring is an important part of natural resource management. There are numerous drought-specific products and more general climate summaries available to support natural resource applications, including the US Drought Monitor (https://droughtmonitor.unl.edu/) and WestWide Drought Tracker (https://wrcc.dri.edu/wwdt/, Abatzoglou et al. 2017). Typically, these products either characterize drought conditions directly or report monthly to seasonal totals and deviations from averages for precipitation and temperature. Most do not leverage daily

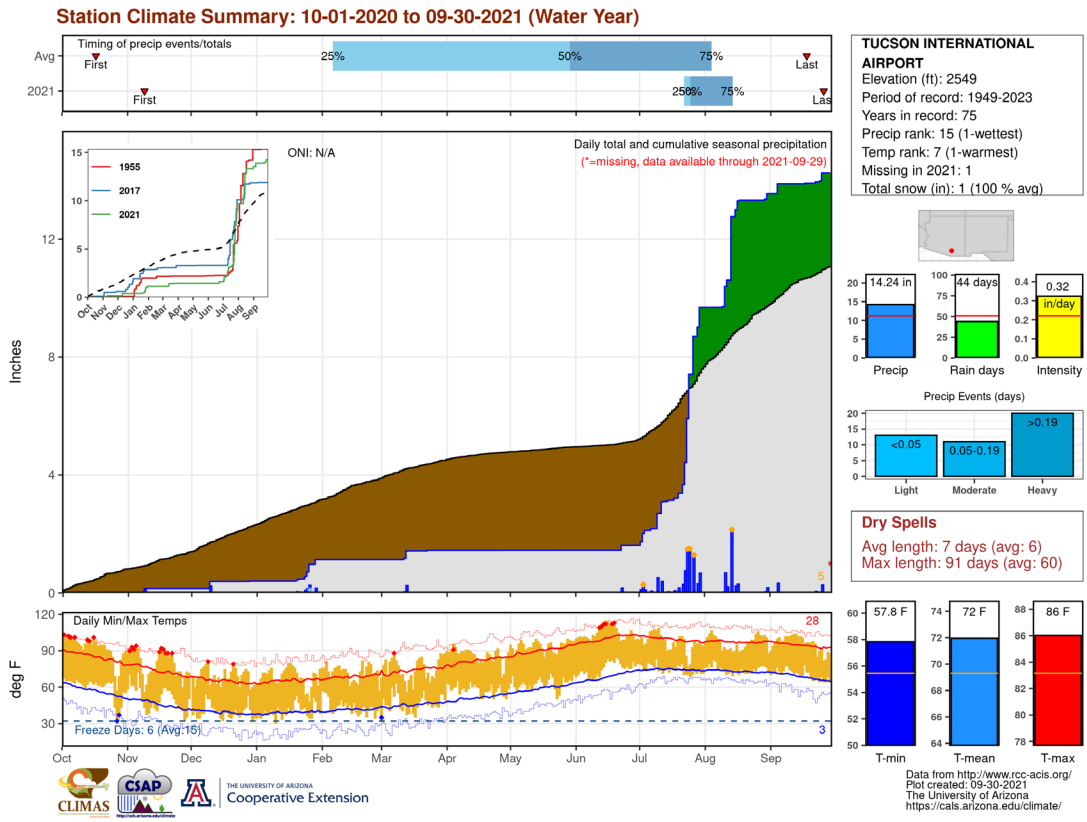


Figure 1. Example water year (2020-21) station summary plot for Tucson International Airport in Arizona.

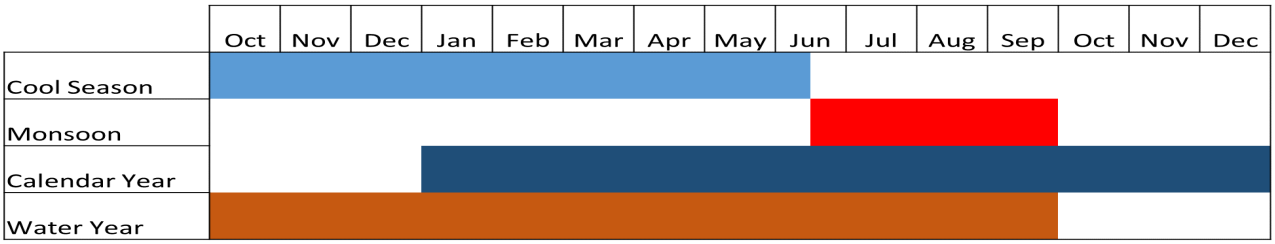


Table 1. Time periods covered by the four different summary plots available.

data and reveal the more subtle shifts in the timing, type, intensity and frequency of precipitation and associated temperature variability. These measures, however, are important to track given the unique hydroclimate of the southwest U.S. and to anticipate potential drought impacts as they emerge in real time.

To support the monitoring and climate tracking needs of natural resource managers, agricultural producers and decision makers working in the southwest U.S., we developed station-based climate summary plots that depict numerous metrics of precipitation and temperature variability using daily data (Figure 1, https://cals.arizona.edu/climate/misc/stations). Plots are available for four periods: two seasons relevant to the unique precipitation seasonality of the southwest U.S. ('cool season' from October to mid-June and 'monsoon season' from mid-June to September) and two annual periods used in typical climate monitoring activities (calendar year from January to December and water year from October through September, Table 1).

In addition to supporting ongoing climate and drought monitoring activities within University of Arizona Cooperative Extension (https://cals.arizona.edu/climate/), the climate summary plots have been used to summarize monsoon activity by flood control districts (FCDMC, 2021), to characterize climate variability important to invasive species for weed management (Scheuring and Chamberland 2020) and to track precipitation timing in support of range management (personal communication M. Marques 2016) and regional climate variability (McMahan, 2020).

There are more than 100 Arizona and New Mexico stations available on the climate summary website. With four different summary periods (seasonal and annual) and historical periods of record ranging from 30 to 100 years, there are more than 20,000 individual station-season-year plots available.

Where do the data come from?

The climate summaries use station data accessed through the Regional Climate Centers-Applied Climate Information System (RCC-ACIS, https://www.rcc-acis.org/index.html). The types of stations available through RCC-ACIS include NOAA Cooperative Observer (COOP, https://www.weather.gov/coop/overview) sites, airport weather stations, and select NRCS snow telemetry (SNOTEL, https://www.nrcs.usda.gov/wps/portal/wcc/home/aboutUs/monitoringPrograms/automatedSnowMonitoring/) sites (Guido 2009a, 2009b, 2010). Long-term records from 'threaded' station (NOAA ThreadEx, https://threadex.rcc-acis.org/) observations--which create a single record from multiple sites in close proximity covering different time periods--are available for some locations in the Southwest, including Albuquerque, Flagstaff, Kingman, Winslow, Lake Havasu City, Oracle, Phoenix, Roswell, Tucson and Yuma. Threaded stations are denoted by the appending of the word 'Area' to the station record.

All summaries are based on daily total precipitation, daily snowfall, and minimum and maximum temperature observations. Observation times vary by station; most NOAA-COOP observations are taken at 7 a.m. local time and NOAA-NWS stations at airports are taken at midnight local time. Stations selected to be included in these summaries have actively available observations within the past 30 days (most stations have near-real time data availability).

The period of record for each station is based on the most recent contiguous block of years with minimal missing data (<120 days missing in a given year). Some stations have observations from early in the last century with a large gap in time until observations were resumed. In these cases, the early part of the record is dropped from the dataset and only the most recent part of the dataset is retained. This ensures that averages and totals are based on serially complete parts

of the record, but may be shorter periods than are reported in other climate datasets and resource pages (e.g. Western Regional Climate Center).

Caution should be used when interpreting stations with shorter period of records (< 30 years). The statistics of these stations will not capture any potential longer-term shifts in climate (e.g. temperature trends) and are not directly comparable to nearby stations with longer records. A best practice is to use stations with longer records (>50 years) if you are interested in gauging changes in precipitation or temperature values associated with longer-term climatic trends.

How do I interpret the climate summary plots?

The station-based climate summary plots use daily observations and calculate numerous metrics for each of the four climate periods previously mentioned: calendar year (Jan. 1-Dec. 31), water year (Oct. 1-Sep. 30), cool season (Oct. 1-June 14) and monsoon (June 15-Sep. 30). The plot itself consists of various graphs, metrics, and statistics calculated from daily observations relative to the period (e.g., calendar year vs. water year) of the summary. The current plots have missing values corresponding to the future days in the selected period. However, the metrics reporting totals and averages are relative to the full period averages and totals. Thus, these metrics are most appropriate when the season or year is complete but can be monitored as the period evolves (for example, total precipitation). Missing values due to missed observations are flagged with red asterisks on the cumulative precipitation plot and the missing day total is listed in the 'station information' block. Seasons or years with many missing observations need to be interpreted carefully as their calculated metrics will likely be underestimated.

The figures are updated every morning after midnight with data available through the previous day for most stations. The summary plot consists of several connected individual plots and text boxes (Figure 2). For example, the timescale along the bottom of the daily temperature plot defines the timescale for the daily precipitation and timing plots stacked above. Information on each of these sub-plots and text boxes is described below:

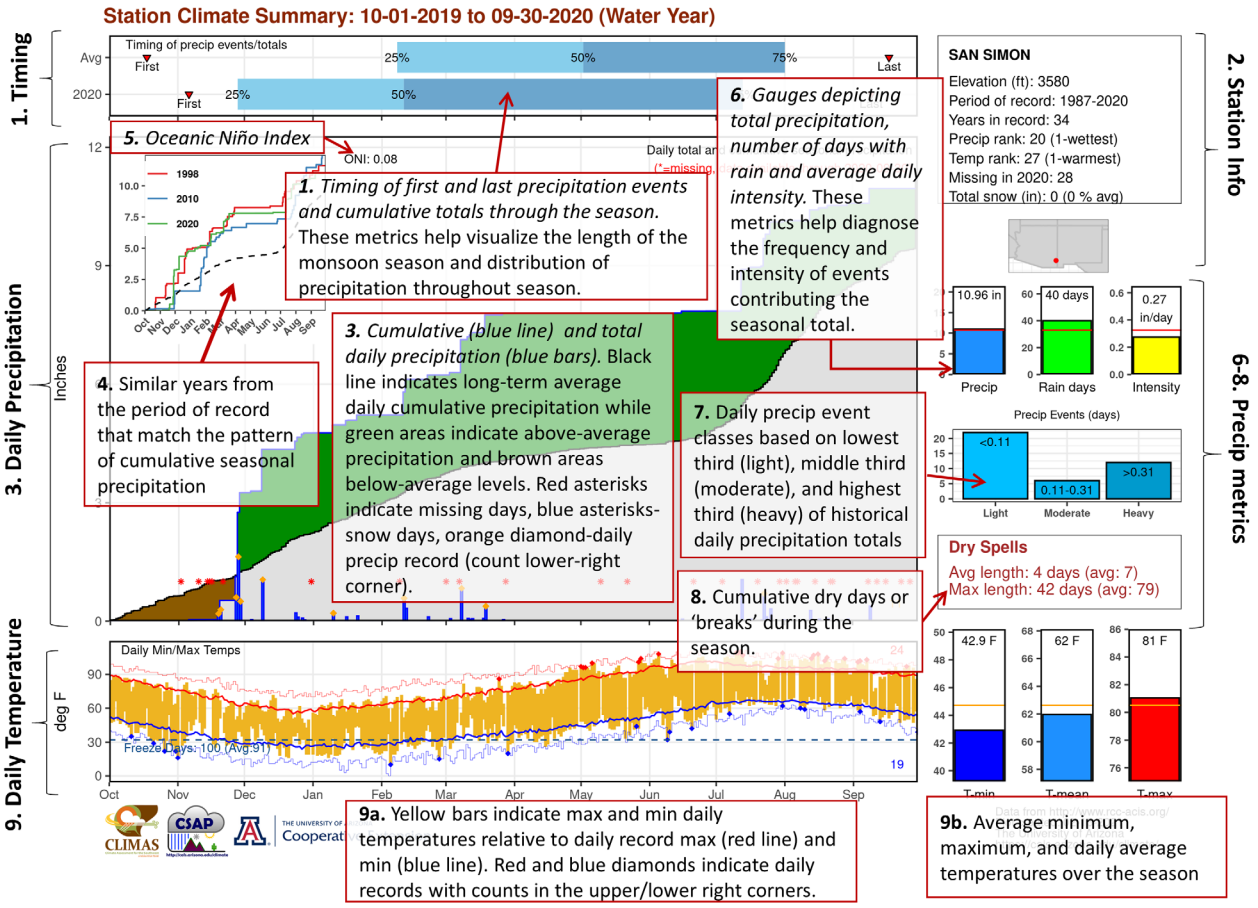


Figure 2. Annotated station climate summary plot (numbers correspond to bulleted list of descriptions below)

1. **Timing:** These horizontal bars represent the average (top) and current year (bottom) timing of cumulative precipitation amounts. The first and last days of rainfall are noted with inverted red triangles. The first colored segment of the bar represents the timing of when 25% of the seasonal total has occurred relative to the date axis at the bottom of the plot. The middle and last segment represent the timing of the 50% and 75% cumulative totals respectively.
2. **Station information:** The text block at the upper right provides information about the station, including its elevation and period of record used to calculate climatological values. The "Precip rank" and "Temp rank" represent how the current period value ranks in the historical record. The rank is ordered with '1' denoting the wettest and warmest for precipitation and temperature, respectively. The number of missing days in the current period and total observed snow is also listed in the station information block. Ranks are most accurately interpreted at the end of the period (e.g., monsoon, water year, etc.).
3. **Daily precipitation:** The center part of the figure shows daily precipitation activity (blue bars) and the corresponding cumulative total precipitation (blue line). The long-term average of the cumulative daily precipitation is shown with the black line. If the cumulative amount is above the long-term average, the area above the long-term average is colored green. If the cumulative amount is below the average line, the area is colored brown. Days with missing observations are flagged with red asterisks.
4. **Similar years:** The small box inset in the upper left corner of the cumulative precipitation plot displays two years that have the most similar pattern to the current cumulative precipitation trace. The similarity is determined by the minimum Euclidean distance (least difference) of cumulative precipitation patterns between the current year and all other years in the historical record for the station. This algorithm will find the two years in the historical record that match the shape (timing and amount) of the current cumulative precipitation most closely. .
5. **ONI (Oceanic Niño Index):** This value is the period average of the ONI. The average is calculated from the monthly values during the period. For example, the ONI value on a 'Cool Season' plot is the average of monthly ONI values between October and May. Negative and positive values less than -0.5 and greater than 0.5 indicate La Niña conditions and El Niño conditions, respectively. ONI data is from the National Oceanic and Atmospheric Administration Climate Predictions Center, (NOAA-CPC; https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/detrend.nino34.ascii.txt)
6. **Precip/Rain Days/Intensity Plots:** These bar plots indicate the total seasonal precipitation, number of rain days (days>0.01" precipitation), and average precipitation intensity. The latter is calculated by dividing the total precipitation by the number of rain days (any day with precipitation, including snow, is considered a rain day). Like all the metrics, these values are either for the entire period if the period is complete or through the current day as stated at the top of the figure. The red lines indicate the long-term average values for each metric.
7. **Precip events:** Observed precipitation events within the period are categorized into three intensity categories of light, moderate, and heavy that are based on the terciles of the historical distribution in the period of record. In other words, in a period of record with 99 observations, the light category threshold is defined by the value of the lowest 33rd observation (all rainfall values equal to or less than this value are grouped in the "light category). The upper threshold for the moderate category is the 66th observational value. Rainfall events that are larger than this value are grouped into the heavy category. The bar plots indicate the count of days that fall into each of these categories and the labels on the bars indicate the range of values for each tercile. Like the other metrics, the counts are either for the whole period if it is complete or through the most recent update day as stated at the top of the figure.
8. **Dry spells:** The number of days between precipitation events (daily precipitation ≥ 0.01") are summarized as "dry spells". The average length dry spell is the average number of days of all the dry spells in the current period, while the 'avg' value in parentheses indicates the long-term average dry spell length for climatological context. The maximum length is the longest run of days between precipitation events within the current period, while the 'avg' value in parentheses is the long-term average. These dry spell values are either for the whole period if it is complete or through the most recent update day. The 'max dry spell' metric does not account for dry spells that cross seasons or years.
9. **Daily temperatures:** Daily minimum and maximum temperatures are displayed as yellow bars with the top indicating the observed daily maximum and the bottom corresponding to the observed daily minimum temperature (9a). The thick red and blue lines indicate

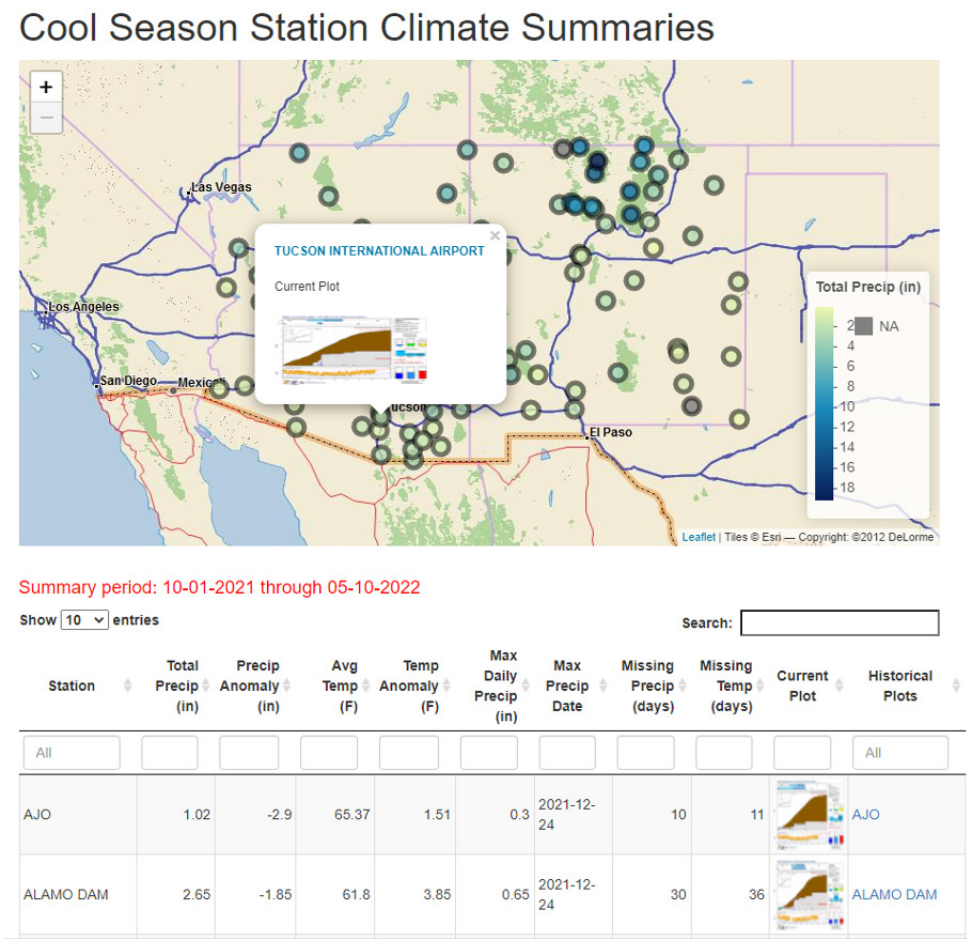


Figure 3. Example station climate summary access page

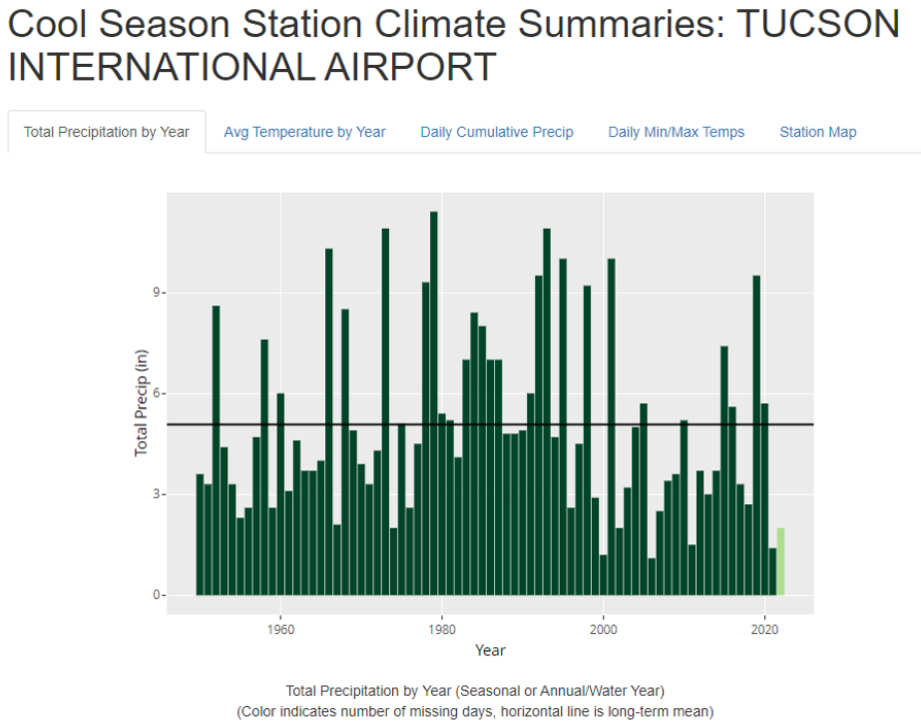


Figure 4. Historical climate time series summary page for station-period selection

the long-term averages for the daily minimum and maximum, respectively, while the thin red and blue lines depict the highest and lowest temperature for each day recorded in the historical record, respectively. A summation of the number of freezing events is also tallied at the bottom left of this box; the long-term average for the total number of freeze days is displayed in parentheses. The period averages for minimum, average, and maximum are displayed as bar plots to the right (9b). The full period average values for these metrics are indicated as the orange line at the bars' mid-points.

Navigating the Station Climate Summary Website

The organization of the site is by period timescale, which can be accessed at https://cals.arizona.edu/climate/misc/stations/. On this main page are links for each of the four timescales (Calendar Year, Water Year, Cool Season, or Monsoon) and a link to access the climate summaries station page (https://cals.arizona.edu/climate/misc/stations/stn.html). The climate summaries station page provides direct access to all of the different timescale summaries for a specific station.

The summary pages for each of the four periods (e.g. Water Year, Monsoon, etc.) display an interactive map of precipitation totals for the current summary period and a sortable, summary table below the map (Figure 3). The summary table shows climate metrics for each station for the current period. Placing cursor over the points on the map pops up a window of the current plot for each station with a link to the historical plots. Clicking on that point anchors the popup window and makes the links available to click. Thumbnails of current plots are also available in the sortable table as well as a link to the station history page ('Historical Plots' column) for that timescale.

Clicking on the station name in the "Historical Plots" column in the table will bring you to a summary page for that station and timescale, listing summary plots and metrics for all available years.

The tabs at the top of the page provide access to several interactive plots including (Figure 4):

- Total precipitation by year: Bars represent total precipitation for each year of the timescale on this page (e.g. Water Year or monsoon). The color of the bars indicates the number of missing days with lighter colors indicating more missing values. Years with large numbers of missing days may have artificially low total precipitation values.
- Average temperature by year: Points on the line plot represent the timescale average temperature for each year while the color represents the number of missing days. Years with a large number of missing days may have artificially high or low values.
- Daily cumulative precipitation: The line plots on this tab are the daily cumulative total precipitation for each year in the period of record for the station. Individual years can be added or removed by clicking on them in the legend. Missing days will show up as breaks in the cumulative lines.
- Daily minimum and maximum temperatures: This tab has the daily observed high and low temperature displayed for each year of the station's period of record. Individual years can be added or removed by clicking on them in the legend. Missing days will show up as breaks in the lines.

The final tab shows an interactive map with the station location. Each of the plots displays values with a mouse hover and supports zooming, panning, and image capture.

Each period specific station history page (Figure 5) has a sortable table with several climate metrics like total precipitation and average temperature for each year. The period of record averages are displayed in a separate table above. Clicking on the anomalies tab displays an additional table of differences of these various climate metrics from the long-term averages. The plot thumbnail also links directly to the plot for that given year.

Each station has its own quick look summary page as well where current plots from all timescales are displayed on separate tabs as well as access to the station history pages. These station pages can be bookmarked to provide quick access to all plots and data for any stations of interest.

Example uses of the station climate summary website

As has been described above, there are numerous ways to access real-time and historic charts for multiple seasons at over 100 stations across Arizona and New Mexico. The plots themselves were designed to be downloaded to use in reports and presentations or linked to through other websites. Some example uses include:

- Bookmarking or linking to a station climate summary page for a nearby station for tracking hydroclimate: This one-stop page will provide information on real-time climate statistics for the four different timescales and provides direct links to historical data and plots (https://cals.arizona.edu/climate/misc/stations/stn.html)

Period of Record Averages

Total Precip (in)	Total Precip Days	Avg Temp (F)	Freeze Days	Total Snow (in)	Max Dry Spell (days)	Avg Dry Spell (days)	Heavy Rain Days
11.1	50.5	69.2	14.9	0.9	61.1	6.3	17.7

Summary Stats | Anomalies

Show 10 entries Search:

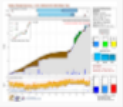
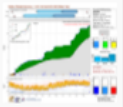
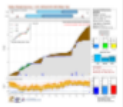
Year	Total Precip (in)	Total Precip Days	Avg Temp (F)	Freeze Days	Total Snow (in)	Max Dry Spell (days)	Avg Dry Spell (days)	Heavy Rain Days	Missing Precip (days)	Missing Temp (days)	Plot
1950	10.6	48	68.2	22	1.4	47	7	14	0	0	
1951	7.8	43	69.6	15	2.8	91	8	17	0	0	
1952	14.2	59	68.2	20	3.4	31	5	26	0	0	
1953	7.7	44	68.7	23	0.5	47	6	14	0	0	

Figure 5. Table of historical metrics and plots on station history page

- Downloading and saving the most recent seasonal summaries for a set of stations in a region for monitoring reports: Some agencies (for example flood control districts) prepare end-of-season reports to document weather and climate impacts (FCDMC, 2021). The charts can and have been used in ongoing climate monitoring efforts like the Southwest Climate Outlook (https://climas.arizona.edu/swco)
- Quickly researching past climate conditions for different seasons, stations, and years: The sortable tables and interactive plots allow for a user to make quick assessments and detailed comparisons between past years. This can be helpful in assessing how past winter seasons with varying phases of the El Niño-Southern Oscillation (ENSO) evolved and how the timing of precipitation varied in past monsoon summer seasons.

This effort will continue to grow and evolve with more stations added and new metrics added or refined. The intention is to make these summary plots as useful as possible for ranchers, farmers, natural resource managers, and drought monitoring experts working in the southwest U.S.

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