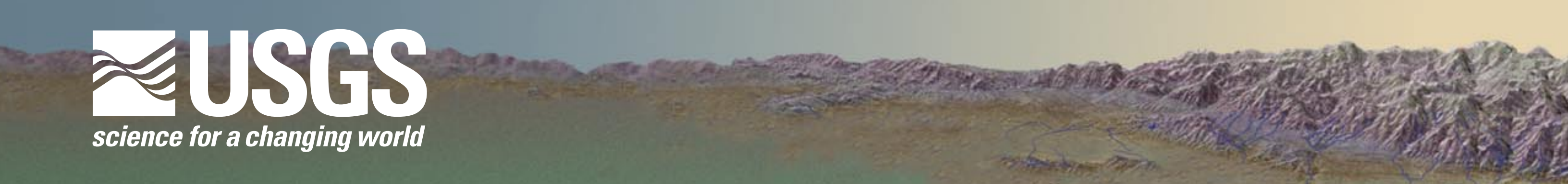

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Precipitation History of the Mojave Desert Region, 1893–2001

The Mojave Desert region covers 152,000 km² of the Southwestern United States. Recent studies by U.S. Geological Survey (USGS) and other scientists suggest that the region may become drier for the next 2 to 3 decades, in a pattern similar to mid-20th century dry conditions. Because the region's population has increased rapidly since the mid-1950s, a repeat of such a dry episode could have severe consequences not only for residents but also for the desert's diverse and fragile ecosystems.

Diverse topography, complex geology, and distinctive plant communities characterize the Mojave Desert region. The desert covers 152,000 km² of eastern California, southern Nevada, the southwest corner of Utah, and northwest Arizona (fig. 1). On the west and southwest, the Mojave Desert is bounded by the Sierra Nevada and the San Gabriel and San Bernardino Mountains. These imposing mountains alter the prevailing westerly winds and intercept moisture derived from the Pacific Ocean, producing a rain-shadow effect and arid conditions on the lee side of the mountains. The regional climate and topography of the Mojave (Rowlands, 1995) strongly influence the distribution and abundance of its diverse and fragile desert plant communities.

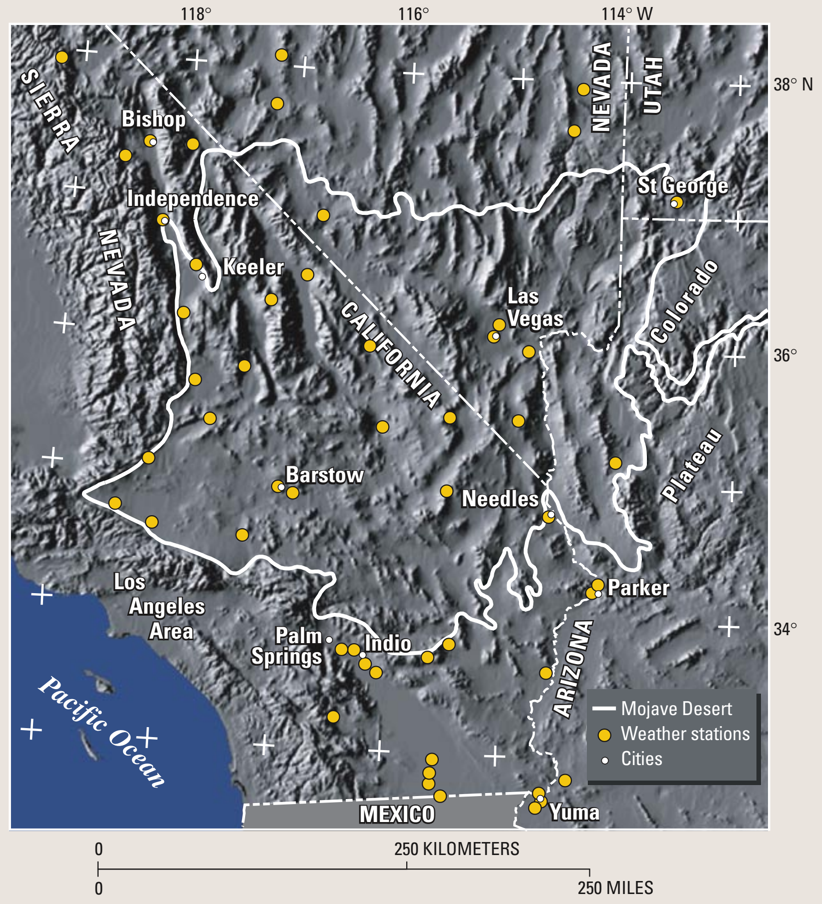

Figure 1. Mojave Desert region and the 52 weather stations used in the precipitation history.

The Annual Precipitation Cycle

The annual precipitation cycle shows two distinctive patterns that approximately divide the region along the 117°W meridian, which is near Barstow, California. A biseasonal pattern prevails at 90% of the weather stations used to collect data in this study that lie east of 117°, whereas a winter-dominant pattern is typical of 70% of the stations lying west of 117° (fig. 2). In both cases, May and June are consistently dry, accounting for less than 5% of annual rainfall. October through April precipitation of the winter dominant pattern accounts for 82% of the annual total, whereas the biseasonal pattern accounts for 66%. During the warm months of July through September, 13 and 29% of the annual total falls in the winter-dominant and biseasonal patterns, respectively.

Cool-season precipitation is the most important and extensive source of rain in the desert region. Rainfall is widespread and of relatively long duration during the cool season. Warm-season precipitation results largely from convective precipitation in the form of thunderstorms. Although rather infrequent, the most dramatic precipitation source is tropical cyclones and hurricanes (often referred to as chubascos) that drift across the region from off the coast of Baja California. These typically occur late in the warm season and are accompanied by widespread and severe flash flooding. The extent and magnitude of warm-season rainfall strongly influences the distribution of desert vegetation. The relative abundance of cacti, many

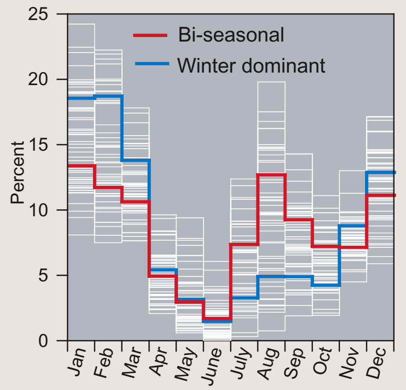

Figure 2. Precipitation cycle of the Mojave Desert region showing average monthly precipitation as a percentage of total annual precipitation. White lines are the precipitation cycles of individual stations. The two heavy lines are the dominant patterns.

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2004

yuccas, agaves, and agave-like plants is much greater where warm-season rainfall is abundant (Rowlands, 1995).

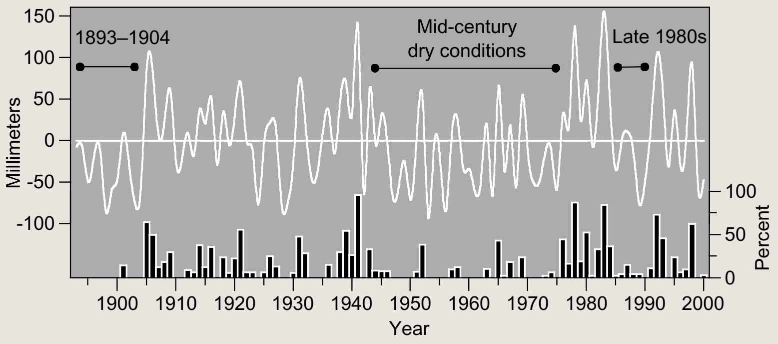

Figure 3. Average deviation of annual precipitation (that is, the average deviation from the mean of the reporting stations) and bar graph showing percent of stations having precipitation more than 68% of normal.

Precipitation History, 1893–2001

Annual Precipitation

Daily precipitation amounts from 52 weather stations in the Mojave Desert region were the raw data used in the analyses. Precipitation time series were developed from digital and archival records. The former are available commercially and the latter are available on microfiche from National Oceanographic and Atmospheric Administration (NOAA). None of the stations have data for the entire 1893–2001 period. Average annual precipitation in the Mojave calculated with data from the 52 stations (fig. 1) ranges from 34 to 310 mm/yr, with a long-term average of 137 mm/yr. The driest year was 1953, and 1941 and 1983 were the two wettest (fig. 3). Long-term annual precipitation varied substantially during the 20th century. Four multidecadal precipitation regimes are apparent: 1893–1904, 1905–1941, 1942–1975, and 1976–1998. The choice of limiting dates for these regimes is somewhat subjective; the mid-century dry conditions in the desert region may have begun in 1946. Regardless of the exact dates, the mid-century was clearly dry and was sandwiched between two wetter episodes. The period 1976–1998 was the wettest of the 20th century, broken only by the relatively short, intense drought of 1989. Droughts and dry conditions are distinguished from the two wet episodes by the sparse number of stations reporting precipitation substantially above normal (fig. 3).

These long-term variations are largely contemporaneous with well-known droughts elsewhere in the Southwest, specifically an 11-year drought from 1893–1904 and a mid-century dry spell from 1942–1977. The early part of the mid-century dry regime (1942–1956) is recognized as a drought throughout the Southwest (Gatewood, 1962). In the Mojave Desert region and adjacent Colorado Plateau (fig. 1), precipitation increased somewhat after 1953 (1956 in the Colorado Plateau; Hereford and others, 2002), although it did not reach the levels of the early and late 20th century. Statistical analysis shows that average precipitation during the early and mid-century dry conditions was significantly less than the two wet episodes.

Seasonal Precipitation

Cool-season precipitation (calculated from October 15 to April 15) averages 95 mm/season, with a range of 27 to 249 mm/season (fig. 4 upper). The five driest seasons were 1904, 1934, 1951, 1972, and 1990; the five wettest were 1941, 1978, 1983, 1992, and 1993. The mid-century dry conditions are evident in the cool-season time series between 1945 and 1977. The period 1978–1998 is clearly the wettest of the 20th century. As with annual precipitation, statistical analysis shows that the early drought and mid-century dry conditions had significantly less precipitation than the wet episodes.

Warm-season precipitation (calculated from July 4 to October 14) ranges from 0.5 to 125 mm/season and averages 35 mm/season (fig. 4 lower). The two driest years were 1928 and 1944, although several others were nearly as dry. The wettest were 1939, 1976, 1983, and 1984. Although the early drought and mid-century dry conditions are visibly evident in the time series, the precipitation is not significantly ($P>0.05$) less than the two wet episodes. Nevertheless, the post-1975 period is notable for having three unusually wet seasons (1976, 1983, and 1984) with more than half of the stations reporting rainfall well above normal (that is, greater than one standard deviation).

Mojave Desert Precipitation and Global Climate

Precipitation variability in the Mojave Desert region is linked spatially and temporally with events in the tropical and northern

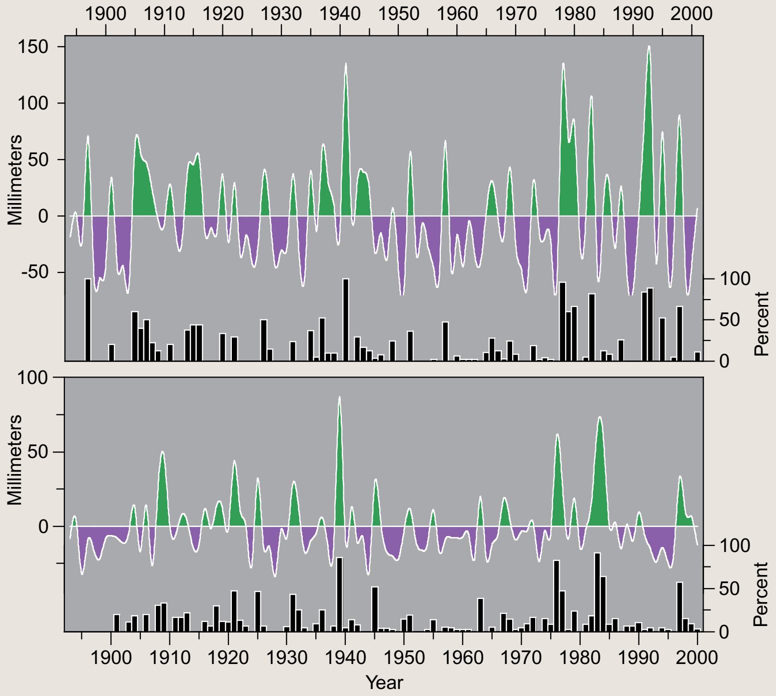

Figure 4. Average deviation of cool- (upper) and warm-season (lower) precipitation. Bar graphs same as figure 3.

Pacific Oceans. Specifically, episodes of unusually wet or dry climate result from interrelated global-scale fluctuations of sea-surface temperature (SST), atmospheric pressure, and atmospheric circulation patterns (Cayan and others, 1999). These fluctuations operate on two time scales, providing an important means of understanding and predicting precipitation patterns. Short-term climate variation, with a period of 4 to 7 years, is associated with El Niño and La Niña activity as expressed by several indicators, including the Southern Oscillation Index (SOI) and equatorial SST. Multidecadal climate variation follows a pattern best expressed by the Pacific Decadal Oscillation (PDO), a phenomenon of the North Pacific Ocean (Mantua and Hare, 2002).

Short-term Variation—El Niño and La Niña

The SOI is the standardized difference in sea-level atmospheric pressure between Darwin, Australia, and Tahiti. A sustained negative value of the SOI signals the large-scale, anomalous warming of SST in the tropical eastern Pacific Ocean. This phenomenon is generally referred to as El Niño, a term originally applied to the weak, seasonal (usually late December), warm, and south-flowing current off the coast of Peru. Warm SST in the eastern equatorial Pacific Ocean and sustained negative SOI indicate El Niño conditions, whereas cool SST and sustained positive SOI indicate La Niña conditions. The fully developed interaction between atmosphere and ocean is termed ENSO (El Niño-Southern Oscillation). El Niño conditions tend to bring wet winters to the Southwest and increased streamflow through southerly displacement of storm tracks, although drought may also occur, whereas La Niña conditions reliably bring dry winters (Cayan and others, 1999).

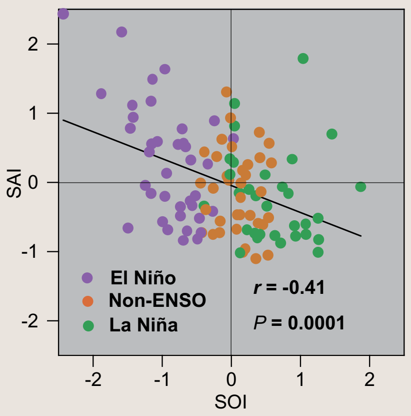

Figure 5. Standardized anomaly index (SAI) of cool+warm-season precipitation (classified by type of El Niño-Southern Oscillation or ENSO activity) as a function of the average Southern Oscillation Index (SOI).

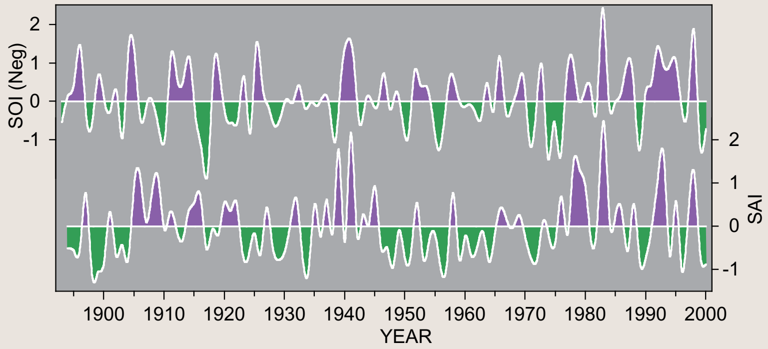

Figure 6. Time series (upper) of average negative Southern Oscillation Index (SOI) (El Niño-like conditions have positive values) and SAI of cool+warm-season precipitation (lower).

Total seasonal precipitation (cool+warm season) is inversely correlated with the SOI averaged from the June preceding the season to May of the season (SOI leads total seasonal precipitation by four months). This inverse correlation (fig. 5) is shown with precipitation in standardized form (the SAI or standardized anomaly index with mean=0 and standard deviation=1) and coded by the type of ENSO activity (El Niño, La Niña, and non-ENSO or background climate). Although the strength of the correlation is relatively weak (r=–0.41), the probability that no relation exists between the SOI and precipitation is extremely small. In the Mojave Desert region, La Niña conditions produced above normal precipitation in only 27% of cases, whereas El Niño conditions produced above normal precipitation in 55% of cases, and the precipitation amounts were significantly larger than the precipitation associated with La Niña. Regardless of the modest correlation, precipitation tracks the SOI in time reasonably well with notable exceptions of 1909, 1919, 1925–1926, and 1939 (fig. 6).

Long-Term Variation—The PDO

Recent and possible future climate variation related to the PDO and other ENSO-like indicators of multidecadal climate variability is a recently developed tool for climatological research. The PDO is related to SST and atmospheric pressure of the North Pacific Ocean (Mantua and Hare, 2002). Changes in these parameters evidently trigger sharp transitions from one climate regime to another, altering the climate of North America for periods of 2 to 3 decades (Zhang and others, 1997; McCabe and Dettinger, 1999). During the warm PDO phase, the SST off the coast of western North America is relatively warm, whereas it is relatively cool during the negative phase. These multidecadal swings in SST that modulate precipitation of the Mojave Desert region also affect important oceanic fisheries, causing decades-long changes in landings of sardines, anchovies, and salmon (Chavez and others, 2003).

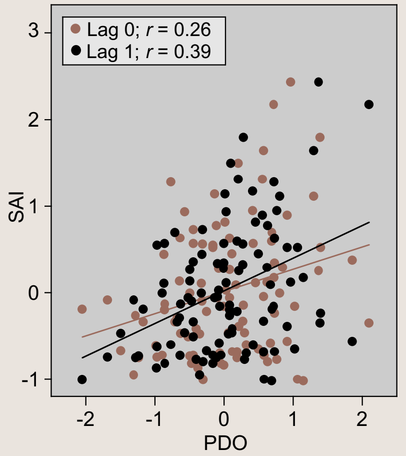

Figure 7. Standardized anomaly index (SAI) as a function of average Pacific Decadal Oscillation (PDO) during the year preceding (lag 1) and year of (lag 0) cool+warm-season precipitation, 1900–2000.

Precipitation in the desert region is modestly but significantly correlated with the average PDO (computed from October to September) in the year preceding (lag 1) and the year of the cool+warm (lag 0) season (fig. 7). The three regime shifts of the PDO are largely in-phase with the annual and seasonal precipitation time series, particularly since the mid-1940s (fig. 8). The mid-century dry conditions show this in phase relation, which coincides with a period of low indices and a prolonged cool phase of the PDO. The early neutral to positive phase of the PDO is associated, although in a complicated manner, with

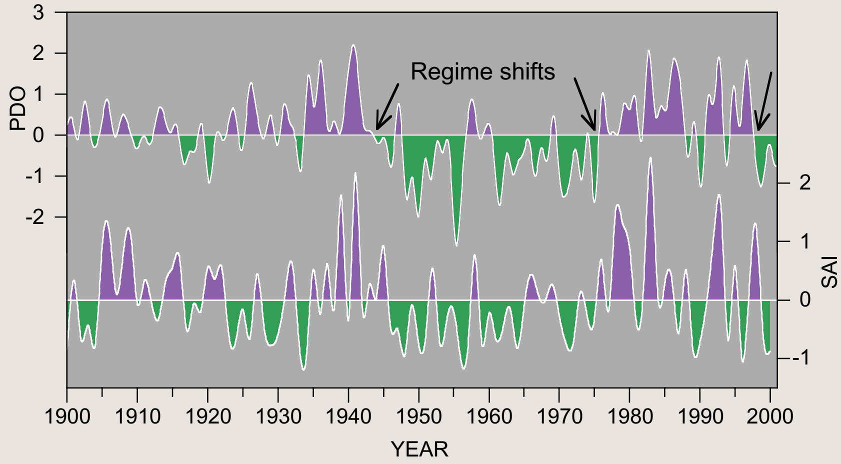

Figure 8. Time series of average monthly Pacific Decadal Oscillation (PDO) (upper, smoothed) and standardized anomaly index (SAI) of cool+warm-season precipitation (lower). Arrows indicate regime shifts of the PDO.

the relatively wet conditions during the early half of the century. The strong warm phase of the PDO beginning around 1977 is readily associated with the wet climate beginning in 1978. Of particular interest is the downward shift in the PDO beginning in 1999 with concomitant decreased precipitation that has continued through the winter of 2002 with only slight relief in winter 2003. The unusually dry climate in the Mojave Desert region since 1998 is likely associated with a nearly continuous belt of high pressure in the northern mid-latitudes that produced drought conditions elsewhere in the United States, the Mediterranean region, southern Europe, and central Asia. This global-scale drying was evidently related to unusually cool and persistent SST in the eastern Pacific Ocean (Hoerling and Kumar, 2003). The weather, SST, and surface-pressure patterns of the past several years suggest that a transition to another PDO regime is presently underway (Gedalof and Smith, 2001). This transition could affect the climate of the Mojave Desert region.

Implications

Precipitation in the Mojave Desert region varied substantially during the past century. This multidecadal variability has implications for ecosystem processes and land management, because precipitation strongly affects the recovery rates from natural and human disturbances (for example, the results of studies of floral and faunal population dynamics and the affects of grazing are dependent on the prevailing climate). Inferences and projections based on these studies may not be valid or may need adjustment or reappraisal if applied during a different, potentially drier climate regime.

Recent trends in Mojave Desert precipitation and the PDO suggest that climate of the region may become drier for the next 2 to 3 decades in a pattern that could resemble the mid-century dry conditions. Although there are many uncertainties and assumptions, including using a single index (PDO) to predict multidecadal climate variability (Schmidt and Webb, 2001; Gedalof and others, 2002), it is important to consider the potential affects of climate variation on the human and natural resources of the region. Water resources were heavily affected during the early part of the 1942–1977 dry conditions, and the population of the region has increased greatly since the mid-1950s, substantially increasing the demand for water in an arid region and creating the possibility of severe or catastrophic consequences if such a drought were repeated.

The work of USGS and other scientists is leading to a better understanding of the past and probable future climate of the Mojave Desert region. This work is only part of USGS efforts to provide information critical to creating policies for the informed management of land, energy, and other resources. These efforts are also helping to protect lives and property from drought, landslides, and other natural hazards.

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Edited by James W. Hendley II
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