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WINTER PRECIPITATION CLIMATE FORECAST AND TRENDS IN ARIZONA DURING THE 1997-98 EL NINO EVENT

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Abstract

The Climate Prediction Center (CPC) predicted that the 1997-98 ENSO pattern would result in a wetter than normal winter season across Arizona. January was predicted to be drier than normal, but the CPC called for near to above climatological normal precipitation totals by the end of the season. For this time period, more precipitation was forecast over southern Arizona than the northern part of the state. Precipitation records from 31 cooperative observer (co-op) sites around Arizona confirmed this forecast. Although the percent of normal forecast amounts are not precise for all locations, the general trends predicted by the CPC were relatively accurate. The drier than normal month of January was verified by data from the co-op sites. More than normal precipitation amounts for the four-month period from December through March fell across the state. Those areas receiving less than normal precipitation were generally in areas where downsloping terrain inhibited precipitation production. Southern Arizona received a greater proportion of precipitation than northern Arizona, closely matching the CC climate outlook predictions.

Introduction

The El Nino-Southern Oscillation (ENSO) event is the most important climate fluctuation on the short-range climatic time scale. ENSO is a shift between a cold and warm state of the tropical

Pacific Ocean on a scale of months to several years (Latif et al. 1994). El Nino is the warm phase of this shift and has been associated with anomalies in the tropical Pacific and in the global atmosphere. Some of these effects include reversals of ocean current systems (Firring et al. 1983), a redistribution of heat in the Pacific (Wyrtki 1985), variations in global sea-level pressure (Barnett 1985), and shifts in precipitation distribution (Ropelewski and Halpert 1989).

The 1997 ENSO signal was one of the strongest on record (see Fig. 1 from Wolter K., and Timlin, M.S., unpublished data). During this time, the tropical ocean surface temperatures were comparable in magnitude and areal extent to that of the 1982-83 El Nino, which the CPC considers to be the strongest warm episode of this century. The present El Nino was predicted several months before the observed ocean warming. The CPC has been studying this phenomenon for many years and its effects on temperature and precipitation patterns across the U.S. and globally. State-by-state analyses and impacts of El Nino were developed by studying the regional effects of moderate to strong warm episodes and identifying seasonal temperature and precipitation trends. The set of forecast charts used in this study were developed by the CPC and include the percent of normal precipitation and precipitation totals expected during the winter months of 1997-98. Historically, moderate to strong El Nino episodes have featured an increased frequency of occurrence of above normal precipitation over Arizona during November through March. According to statements issued by the CPC, for November-December, precipitation has tended to be greater in the southern part of the state. The tendency has been for the north to receive about 150% of normal precipitation during this time compared to 180% of normal in the south. For the January-March period, precipitation trends have averaged about 120% of normal in the north and 170% in the south. The following sections discuss the data used in this study and how the CPC climate outlooks characterized the precipitation trends in Arizona from December 1997 through March 1998.

The 1997-98 ENSO event

ENSO is the most important coupled ocean-atmosphere phenomenon causing global climate variability on the order of years. Monitoring the intensity of the 1997-98 ENSO and calculating the multivariate ENSO index (MEI) is based on the six primary observed variables in the tropical Pacific (Wolter, K., and Timlin, M.S., unpublished data). The six variables include sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. Positive values of the MEI represent ENSO events. Figure 1 shows the standardized departure of the MEI output from 1950 to 1997. The strongest warm ENSO episodes appear on this graph with either a high amplitude or long temporal duration. Six of the strongest ENSO events are shown on this graph during the years 1956-57, 1965-66, 1972-73, 1982-83, 1986-87, and 1991-92. Although the 1997-98 ENSO event is ongoing, at the time of this writing, it was predicted several months in advance and many public statements and advisories were issued by the CPC. A comparison of this ENSO event to other events of this century is shown in Fig. 2. The graph shows the standardized departure for these six strong ENSO events and how they compare to the current 1997-98 event. Each of the events begins around zero to -1 during the winter months, marking the start of the warm phase. In the following months, the 1997-98 event is shown to have a higher amplitude, or greater intensity, than the previous six moderate to strong warm episodes. The earlier events (1957-58, 1965-66, and 1972-73) are characterized by an early warming in the tropical Pacific and reached their standardized peak by the end of the first year. The more recent events (1982-83, 1986-87, and 1991-92), by contrast, required more time to mature and reached their standardized peak in the spring of the second year or later. The current ENSO of 1997-98 resembles the trends of the earlier ENSO episodes and reached its peak during the summer of the first year. The variables observed in the tropical Pacific intensified at a much greater rate than the previous ENSO signals, prompting the CPC to alert the public to the possible effects this ENSO may have on the weather across the U.S. and the world.

Data

The data used in this investigation include climatological precipitation values for selected locations in and around Arizona, actual precipitation amounts, and various seasonal forecasts issued by the CPC. These data were combined to assess the precipitation trends and climate forecast accuracy across Arizona during the ENSO winter of 1997-98. Climatological precipitation for December, January, February, and March for 31 sites were obtained from the Western Region Climate Center (WRCC) in Reno, NV. These locations were selected for their participation as Cooperative Observer (co-op) sites and include 29 stations within the state of Arizona and Gallup, N.M. and Las Vegas, NV. Table 1 contains a complete listing of the co-op sites, the actual precipitation amounts reported, and their climatological normals. Figure 3 shows the location of each co-op site on a topographic map of Arizona. The height contours of this map are shown in 120 m intervals and selected elevations are indicated. To fill in the data-sparse region of northwest Arizona, the co-op site in Las Vegas, NV was included in the data set. Similarly, data from Gallup, NM was included to increase the sample for the rugged terrain of the northeastern part of the state. Although beyond state borders, these locations were considered to be representative of the local climate in each of these regions. Co-op stations provide daily precipitation amounts to the National Weather Service (NWS). These data are compiled by the NWS office in Phoenix and are archived both at the WRCC and the National Climatic Data Center (NCDC). The CPC issued seasonal precipitation outlooks updated each month for one-, three-, and twelve-month periods. These charts indicated the expected amount of precipitation, as a percentage of the climatological normal, across the state based on the intensity of the ENSO signal in the tropical Pacific Ocean.

Discussion

Climatological annual precipitation maps for Arizona, shown in Fig. 4, clearly indicate that the elevated terrain significantly enhances the precipitation distribution across the state. The higher terrain of the Mogollon Rim and the isolated peaks in southeast Arizona assist with precipitation production. Climatological precipitation trends for Arizona indicate that the southern half of the state generally receives most of its winter precipitation during the month of December (see Table 1). Close inspection of the data listed in Table 1 reveals that of the 31 sites in this sample, the climatology of 14 locations conforms to this December maximum; nine of these sites are located in southern Arizona. Seven sites receive the highest proportion of their winter precipitation in January. It is difficult to qualify the common feature of these sites as they are distributed along the state borders or beyond. Four sites located within or very close to Yavapai County (which shares the same boundary as climate division 3 shown in Fig. 10) tend to receive the greatest amount of winter precipitation in February. March tends to bring the highest proportion of winter precipitation to the six remaining sites located primarily in northern Arizona. A subjective analysis of this precipitation trend is shown in Fig. 5. The contours in this figure represent the percent of climatological winter precipitation for each of the months between December and March.

This depiction of winter precipitation trends reveals that the southern part of the state generally receives most of its winter precipitation in December, central Arizona receives most of its precipitation in January and February; and in March, northern Arizona receives its greatest proportion of rain or snow. It is possible these trends are due to a seasonal northward retreat of the low pressure troughs bringing winter storms to the southwest.

The climate outlook issued by the CPC was valid for the three-month period from December through February. A reproduction of this outlook is shown in Fig. 6 and indicates that the greatest amount of winter precipitation will generally cover the southwest portion of the state. This is shown in the figure as the area bounded by the 200% of normal precipitation contour. Areas to the northeast were forecast to receive less precipitation, but with all areas minimally receiving the climatological normal. Figure 7 shows a similar product valid for the month of March and indicates that the eastern to southeastern portions of the state were expected to receive ò200% of normal precipitation. Together, Figs. 6 and 7 suggest that southern Arizona was expected to receive significantly more than normal precipitation and more than northern Arizona during the 1997-98 winter season. Figure 8 depicts a subjective analysis (thick contours) of the percent of normal precipitation recorded by the 31 co-op sites across the state. Each site is represented in the figure with the actual percent of normal precipitation indicated above the station identifier. The thin solid contours represent the significant rises in terrain; the thin dashed contours represent some of the locally lower elevations of the Colorado Plateau. The percent of normal precipitation contours shown in this figure indicate that southern Arizona received the greatest proportion of precipitation between December and March. The 200% of normal precipitation contour generally follows the terrain outlining the Sonoran Desert region. Since this area receives little precipitation, the amount required to exceed climatological average is also relatively small. Additionally, analysis of the 500 hPa charts from the early winter season indicates that the average storm track was typically across southern Arizona or northern Mexico. The southerly displacement of the low pressure minima associated with these troughs shifts the location of precipitation accordingly. Two localized maxima in percent of normal precipitation in Fig. 8 are shown near Gila Bend (323%) and Lake Havasu City (301%), both within the southwestern quadrant of Arizona.

Local minima in percent of normal precipitation are shown in north-central and east-central Arizona. Given the topographic features characterizing these areas, it is likely that downsloping effects minimized the amount of precipitation reaching these areas. For example, 74% of normal precipitation at Page is due to downsloping into Glen Canyon. In east-central Arizona, St. Johns and Springerville both received 76% of normal precipitation. Downsloping on the lee side of the White Mountains, with the storm track generally approaching this area from the south to southwest, inhibited precipitation production in this region.

Despite the wetter winter season forecast by the CPC, the month of January was expected to be relatively dry. Figure 9 shows the percent of normal precipitation forecast by the CPC for January 1998. Southern Arizona was expected to receive approximately 25% of the climatological average with areas to the northwest receiving up to 75% of normal precipitation. Close inspection of the data in Table 1 reveals that 29 of the 31 co-op sites in this sample reported less precipitation than anticipated by the climatological figures. Lake Havasu City and Teec Nos Pos are the only two sites that received more than normal precipitation during the month of January. Sites in southeastern Arizona, including Safford, Tucson, Nogales, Willcox, and Douglas, collectively received approximately 13% of normal precipitation in January. Farther north, selected sites including Grand Canyon National Park (NP), Seligman, Williams, Flagstaff, and Sedona collectively received approximately 59% of normal precipitation in January. Despite these deficits in January, all of the stations identified by name in this segment, except Williams, received more than normal precipitation by the end of the winter season. Although the forecast issued was not precise for all locations, the drier than normal month of January was identified by the CPC.

To summarize the winter season precipitation forecast and trends, Fig. 10 shows the location of the 31 co-op sites and their distribution in seven arbitrarily numbered climate divisions defined by the CPC. Each region is considered to have homogeneous climate characteristics. It was difficult to ascertain the trends for division 4 since only one site is located within the boundary. Similarly, divisions 1 and 5 contain only two sites each for poor sampling distribution. Nonetheless, Table 2 shows the climatological average, the ENSO average, and the actual 1997-98 winter season precipitation by division. For comparison, the ENSO percent of normal, the 1997-98 season percent of ENSO-average and the actual 1997-98 percent of normal precipitation by division are listed. Compared to the 102-year climatology, it is clear that ENSO warm episodes tend to bring approximately 130% (climate division 2) to 175% (climate divisions 5 and 6) more precipitation than normal to Arizona. The 1997-98 ENSO period, as revealed by the 31 co-op sites in this study, was not as wet, bringing about 65% (climate division 2) to 122% (climate division 5) of the ENSO-average precipitation amounts. Compared to climatology, the 1997-98 winter season brought near normal amounts of precipitation to climate divisions 1 and 2, with 96% and 87% of normal, respectively. The wetter regions, climate divisions 5 and 6, received approximately 213% and 177% of normal precipitation, respectively. The precipitation trends during the winter season were forecast to be greater in southern Arizona and the data reported by the 31 co-op sites in this study support this prediction.

Conclusion

The 1997-98 ENSO pattern was forecast by the CPC to result in a wetter than normal winter season across Arizona. Within this time period, January was forecast to be drier than normal. By the end of the season, however, the state was predicted to receive near normal to above normal precipitation amounts. More precipitation was forecast over southern Arizona than the northern part of the state. Precipitation records from 31 co-op sites around Arizona confirmed this forecast. Although the percent of normal forecast amounts are not precise for all locations, the general trends predicted by the CPC were relatively accurate. The drier than normal month of January was verified by the complement of co-op stations. More than normal precipitation amounts for the months of December through February covered most of the state. Those areas receiving less than normal precipitation were generally found in areas where downsloping terrain inhibited precipitation production. Southern Arizona received a greater proportion of precipitation than northern Arizona, closely matching the CPC climate outlook predictions.

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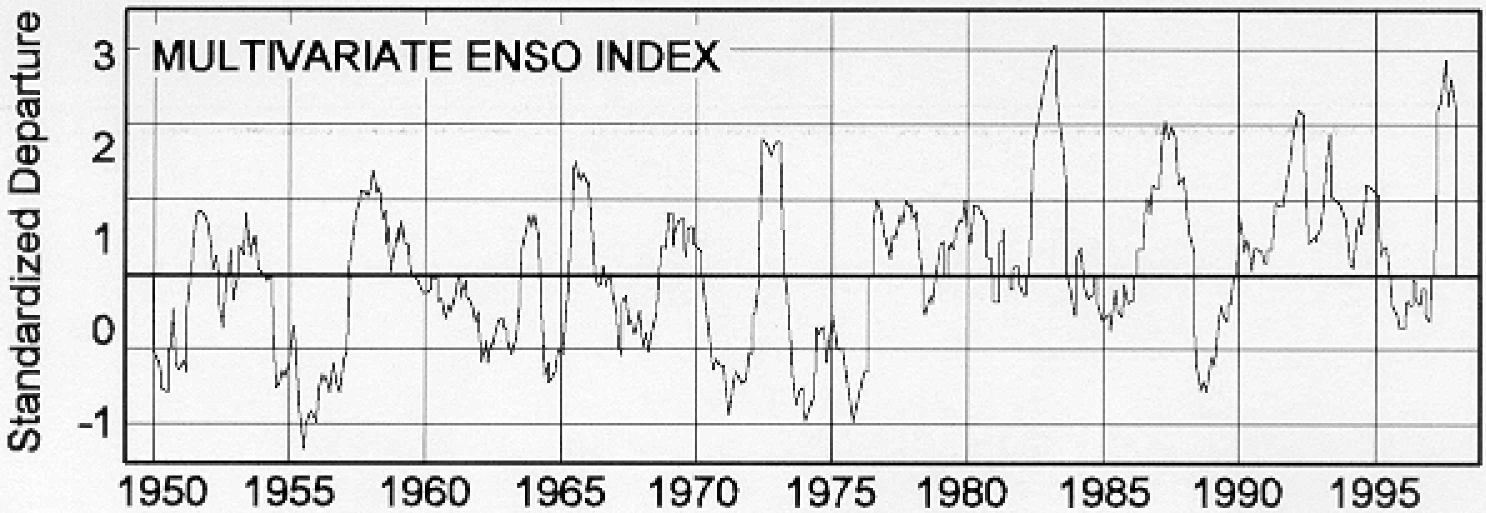

Figure 1. Multivariate ENSO Index (MEI) on the six main observed variables in the tropical Pacific ocean from 1950 to 1997. Positive values of the MEI represent the warm ENSO phase, or El Niño. From Wolter, K., and Timlin, M.S., (unpublished data).

MEI for the 6 strongest historic ENSO warm episodes vs. the 1997-98 event

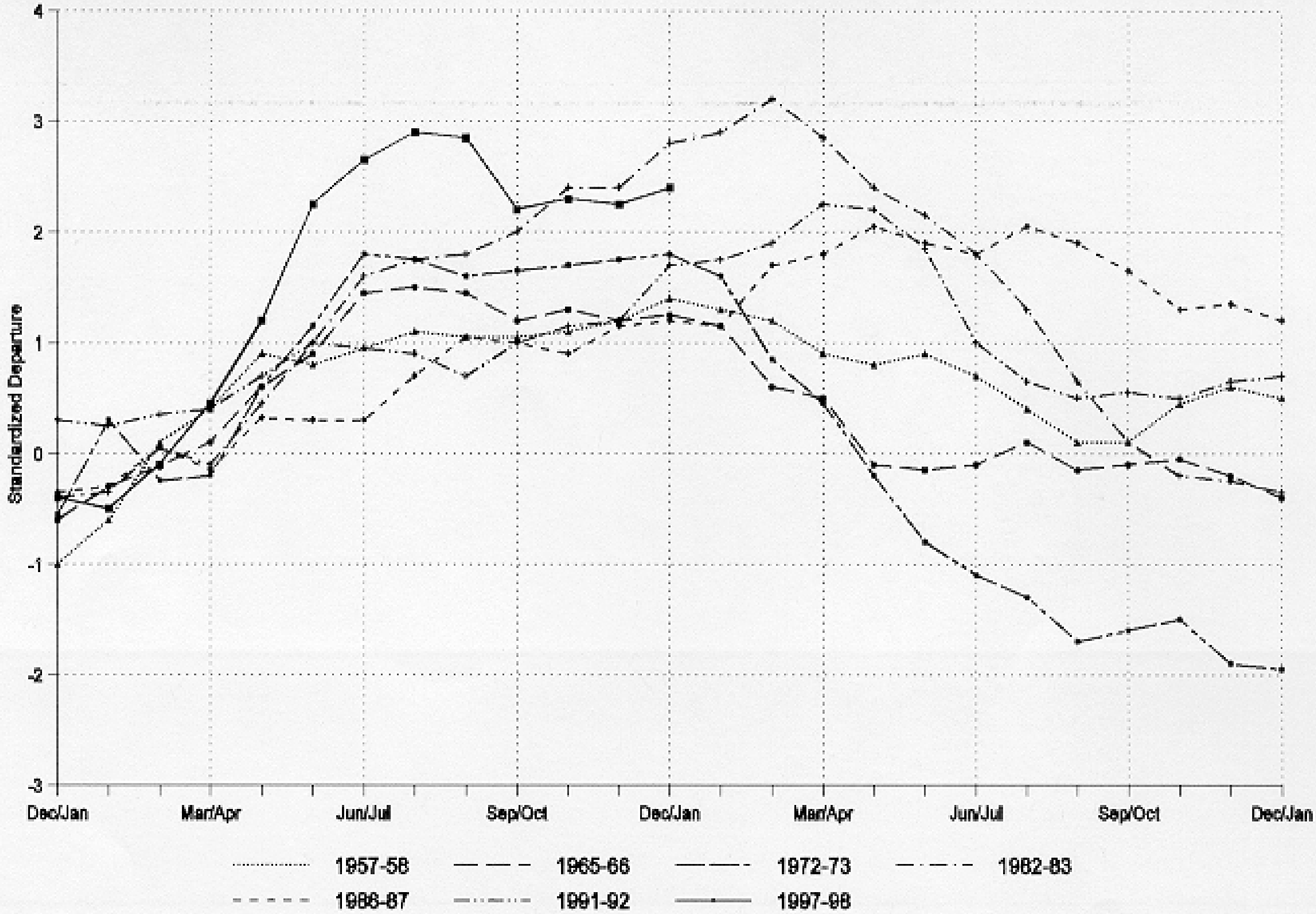

Figure 2. The MEI for the 6 strongest historic ENSO warm episodes compared to the 1997-98 event. Positive values of the standardized departure indicate the warm phase. The horizontal axis, shown in months, reveals the 1-2 year duration of each El Niño event. From Wolter, K., and Timlin, M.S., (unpublished data).

Location	Actual Precipitation (cm) DEC	JAN	FEB	MAR	TOTAL	Normal Precipitation (cm) DEC	JAN	FEB	MAR	TOTAL	Actual - Normal (cm) DEC	JAN	FEB	MAR	TOTAL	Percent of Normal
Las Vegas, NV	0.18	0.43	7.32	2.62	10.55	0.89	1.45	1.17	1.17	4.68	-0.71	-1.02	6.15	1.45	5.87	225
Lake Havasu City	1.57	1.14	5.59	0.74	9.04	0.51	0.84	0.53	1.12	3.00	1.06	0.30	5.06	0.38	6.04	301
Page	1.24	0.38	0.58	1.93	4.13	1.32	1.37	1.22	1.68	5.59	-0.08	-0.99	-0.64	0.25	-1.46	74
Teec Nos Pos	1.09	2.82	1.50	1.27	6.68	1.60	1.80	1.24	1.83	6.47	-0.51	1.02	0.26	0.56	0.21	103
Grand Canyon NP	3.53	2.67	7.98	6.22	20.40	4.04	3.43	3.25	3.73	14.45	-0.51	-0.76	4.73	2.49	5.95	141
Tuba City	0.74	0.33	2.21	2.11	5.38	1.40	1.07	0.94	1.52	4.93	-0.66	-0.74	1.27	0.59	0.45	109
Canyon de Chelly	1.63	1.17	4.42	2.13	9.35	1.62	1.50	1.12	1.68	5.92	0.01	-0.33	3.30	0.45	3.43	158
Gallup, N.M.	3.30	0.84	3.94	4.83	12.91	1.90	2.18	1.75	2.06	7.89	1.40	-1.34	2.19	2.77	5.02	164
Williams	3.48	0.33	7.32	9.22	20.35	5.31	5.31	5.56	5.26	21.44	-1.83	-4.98	1.76	3.96	-1.09	95
Flagstaff	4.67	3.30	5.66	9.50	23.13	5.26	5.38	5.59	5.82	22.05	-0.59	-2.08	0.07	3.68	1.08	105
Winslow	0.71	0.28	2.62	4.04	7.65	1.55	1.22	1.24	1.22	5.23	-0.84	-0.94	1.38	2.82	2.42	146
Holbrook	1.98	0.66	2.21	2.62	7.47	1.45	1.45	1.40	1.37	5.67	0.53	-0.79	0.81	1.25	1.80	132
St. Johns	1.45	0.56	1.22	2.18	5.41	1.88	1.80	1.55	1.88	7.11	-0.43	-1.24	-0.33	0.30	-1.70	76
Springerville	1.63	0.13	1.07	1.07	3.90	1.32	1.35	1.19	1.30	5.16	0.31	-1.22	-0.12	-0.23	-1.26	76
Show Low	5.56	1.65	3.48	4.50	15.19	5.08	3.30	3.35	3.48	15.21	0.48	-1.65	0.13	1.02	-0.02	100
Seligman	1.19	1.88	5.56	3.73	12.36	2.39	2.49	2.51	2.51	9.90	-1.17	-0.61	3.05	1.22	2.46	125
Sedona	5.26	3.94	9.40	8.92	27.52	4.19	5.41	4.78	5.16	19.54	1.07	-1.47	4.62	3.76	7.98	141
Prescott	5.94	2.16	4.98	5.28	18.36	4.32	4.55	4.78	4.42	18.07	1.62	-2.39	0.20	0.86	0.29	102
Bagdad	6.48	4.04	12.75	4.67	27.94	3.71	4.19	4.85	3.66	16.41	2.77	-0.15	7.90	1.01	11.53	170
Payson	7.80	2.84	14.25	9.12	34.01	5.33	5.94	4.95	5.87	22.09	2.47	-3.10	9.30	3.25	11.92	154
Parker	2.64	1.02	6.76	1.91	12.33	1.60	1.85	1.40	1.27	6.12	1.04	-0.83	5.36	0.64	6.21	202
Yuma	4.95	0.05	3.15	0.76	8.91	1.09	1.02	0.56	0.58	3.25	3.86	-0.97	2.59	0.18	5.66	274
Wickenburg	5.21	2.62	11.07	1.70	20.60	3.05	3.22	2.97	2.72	11.96	2.16	-0.60	8.10	-1.02	8.64	172.2
Phoenix	2.11	0.89	7.44	3.33	13.77	2.29	2.13	1.63	2.24	8.29	-0.18	-1.24	5.81	1.09	5.48	166
Gila Bend	2.46	0.13	12.04	5.84	20.47	1.78	1.57	1.47	1.52	6.34	0.68	-1.44	10.57	4.32	14.13	323
Casa Grande	3.63	1.78	9.68	3.99	19.08	2.51	1.91	1.98	1.91	8.31	1.12	-0.13	7.40	2.08	10.77	230
Safford	5.33	0.23	3.25	3.23	12.04	2.29	1.83	1.63	1.52	7.26	3.01	-1.60	1.62	1.71	4.78	165
Tucson	7.32	0.43	8.08	4.17	20.00	2.64	2.41	1.83	1.80	8.69	4.68	-1.98	6.25	2.37	11.31	230
Nogales	4.83	0.03	6.60	2.51	13.97	3.84	3.10	2.26	2.34	11.53	0.99	-3.07	4.34	0.17	2.44	121
Willcox	7.65	0.56	6.40	3.68	18.29	2.87	2.39	2.24	1.65	9.14	4.78	-1.83	4.16	2.03	9.15	200
Douglas	6.38	0.20	3.78	2.97	13.33	2.51	2.03	1.40	1.22	7.16	3.87	-1.83	2.38	1.75	6.17	186

Table 1. Actual and normal precipitation (in cm) for 31 cooperative observer sites around Arizona. Precipitation reports for December 1997 and January, February, and March 1998 and the period total (columns 1-5, respectively). Columns 6-10 indicate the climatological normal precipitation for each location. Columns 11-15 reveal the difference between the actual precipitation during this time and the normal precipitation. Column 16 indicates the percent of normal precipitation for each site from December through March.

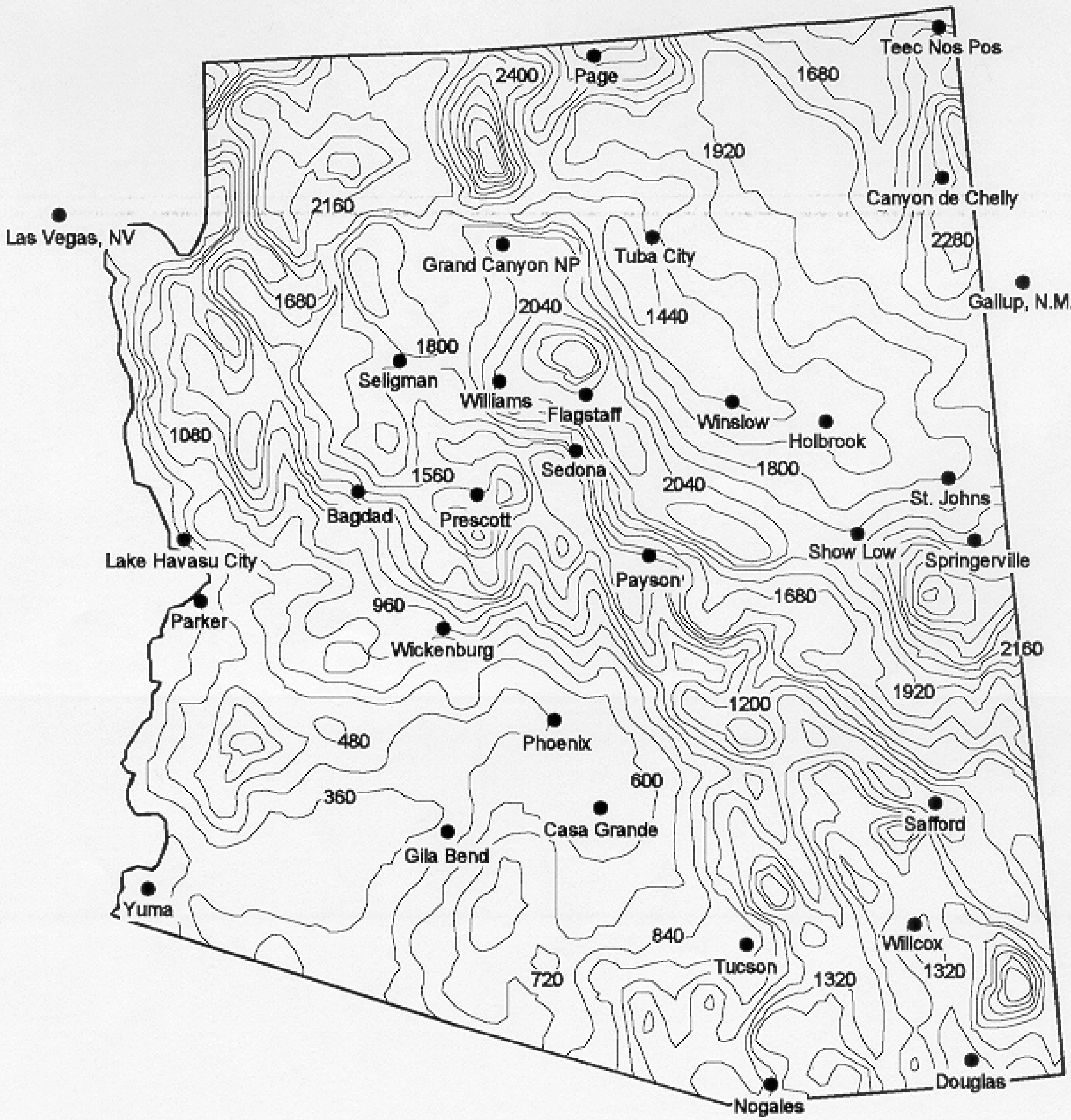

Figure 3. Topographic map of Arizona showing the location and distribution of the 31 cooperative observer sites recording daily precipitation for the National Weather Service. The height contours are in meters with selected elevations indicated. Interval is 120 m.

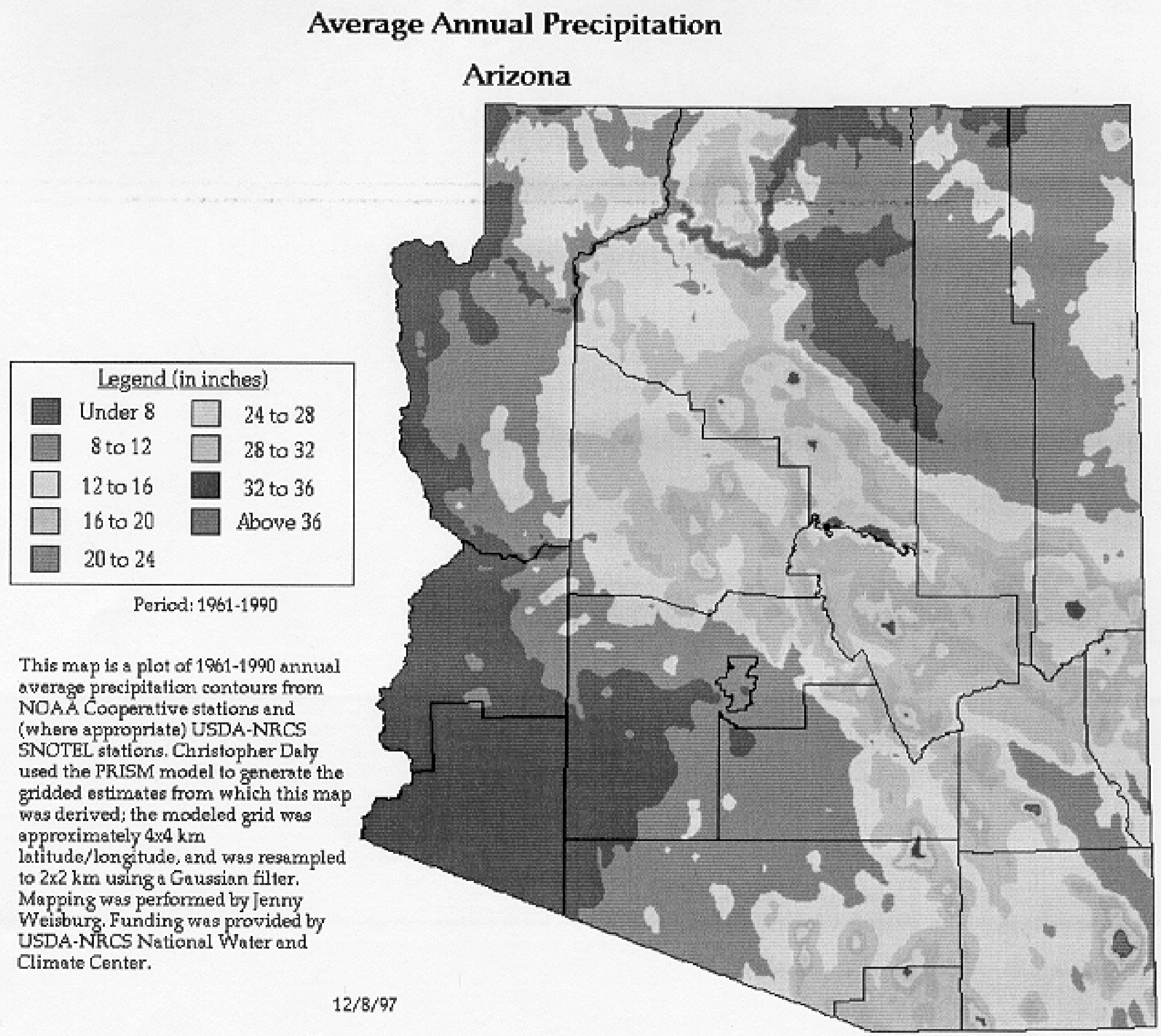

Figure 4. Annual climatological precipitation across Arizona. Precipitation contours are in inches. These contours closely match changes in elevation across the state.

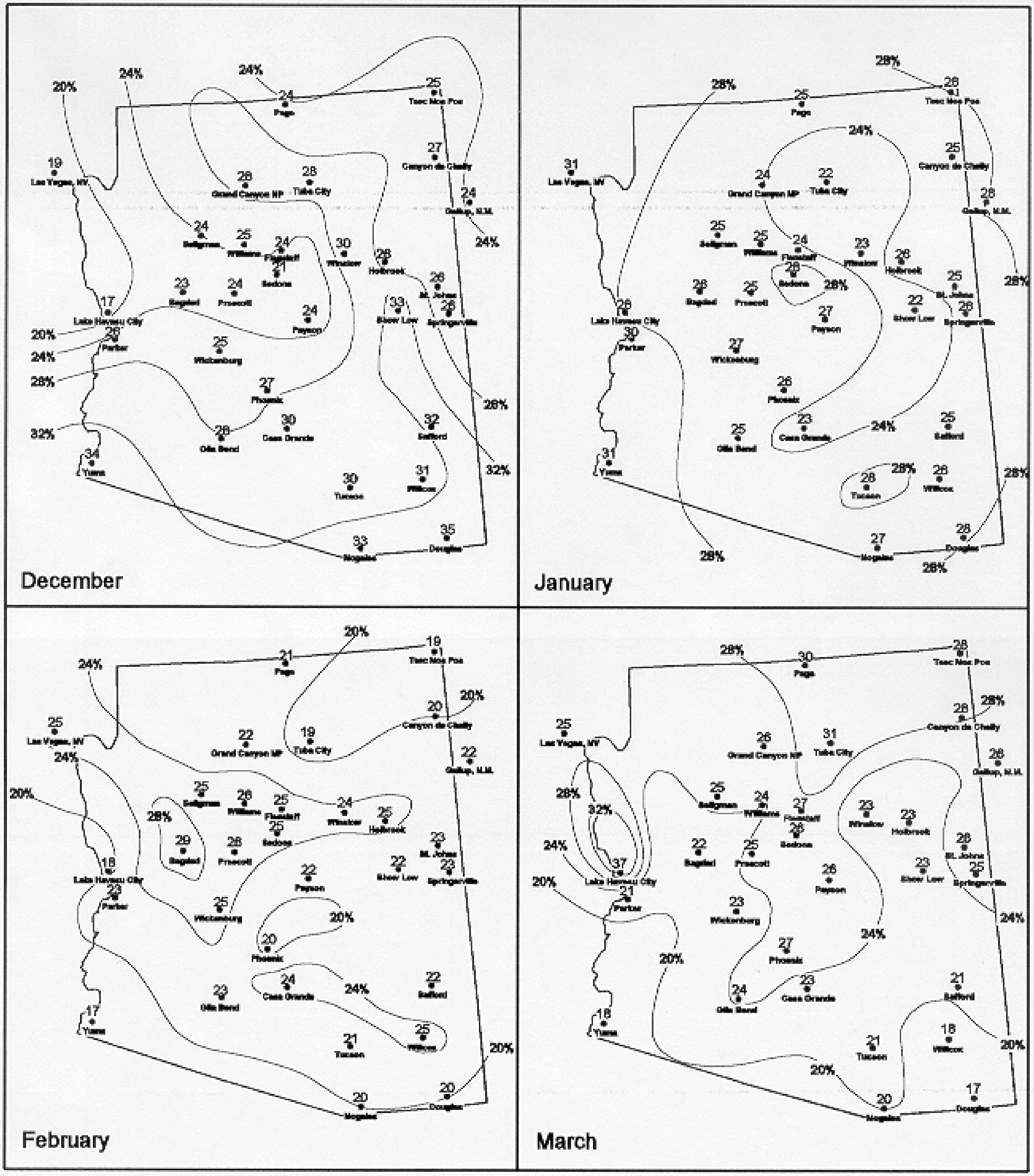

Figure 5. Percent of climatological winter precipitation by month in Arizona. Thin lines represent a subjective analysis of contours of percent of winter precipitation for December -March. The general precipitation trend shown reveals that southern Arizona tends to receive most of its winter precipitation in December; in March, northern Arizona generally receives its greatest proportion of winter precipitation. These amounts are

generally receives its greatest proportion of winter precipitation. These amounts are based on the climatological precipitation figures shown in Table 1.

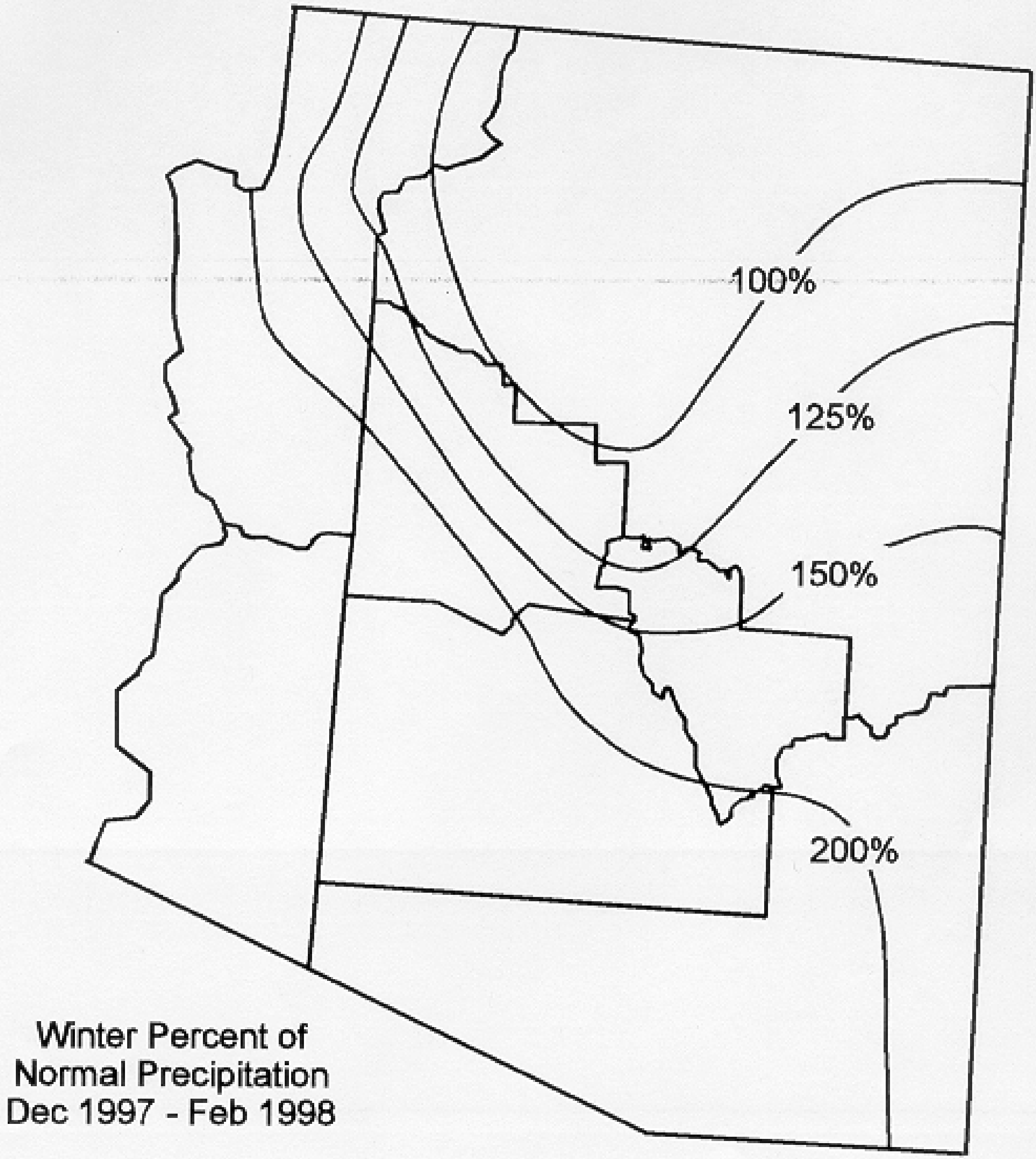

Figure 6. The percent of normal precipitation forecast by the Climate Prediction Center (CPC), NOAA for December 1997 through February 1998. The outlined areas represent the climate divisions each considered to have homogeneous climate characteristics. The southwest portion of Arizona was expected to receive over 200% of normal precipitation. The northern portion of the state was forecast to receive near normal precipitation.

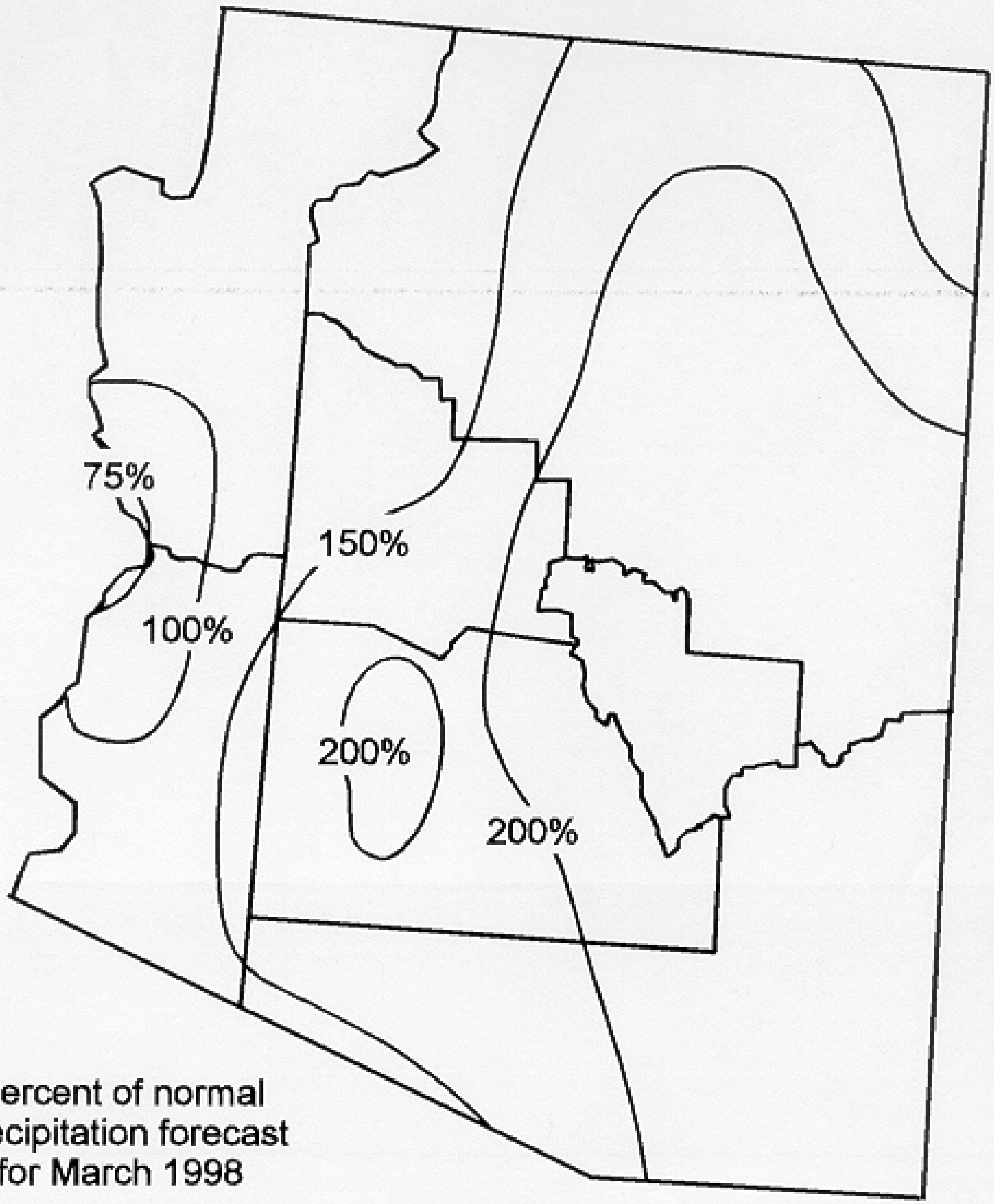

Figure 7. Same as Figure 4 except for March 1998. The most precipitation was forecast to cover the east-central through southeastern part of the state. Near normal precipitation was forecast over western Arizona.

Arizona.

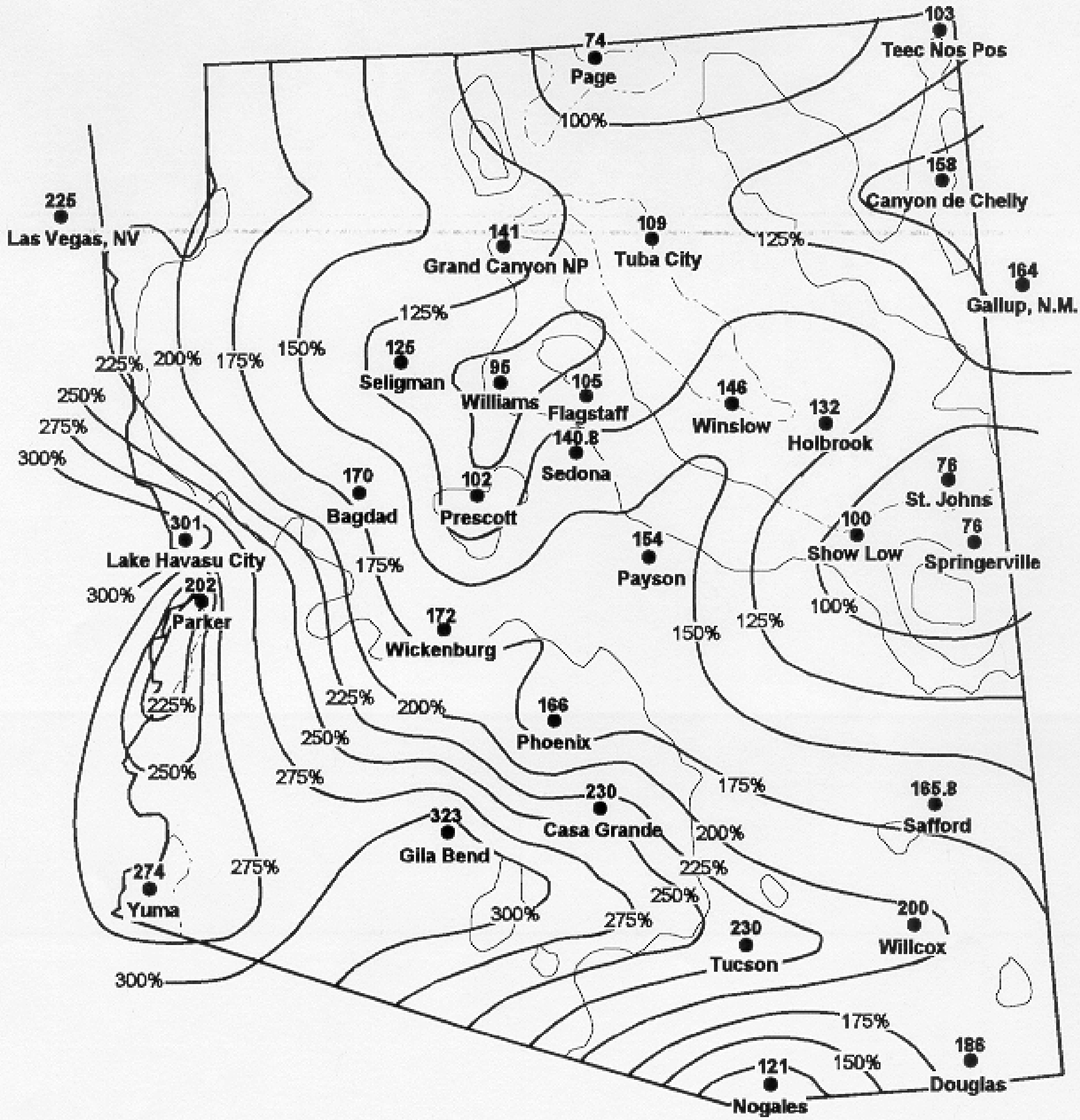

Figure 8. The percent of normal precipitation distribution during December 1997 through March 1998. The number above each station identifiers represents the percent of normal precipitation recorded during this period. The heavy solid contours represent a subjective analysis of the percent of normal precipitation. The thin solid contours identify the prominent topographic features of Arizona. The thin dashed contours indicate lower elevations where downsloping minimizes precipitation production.

The thin dashed contours indicate lower elevations where downsloping minimizes precipitation production.

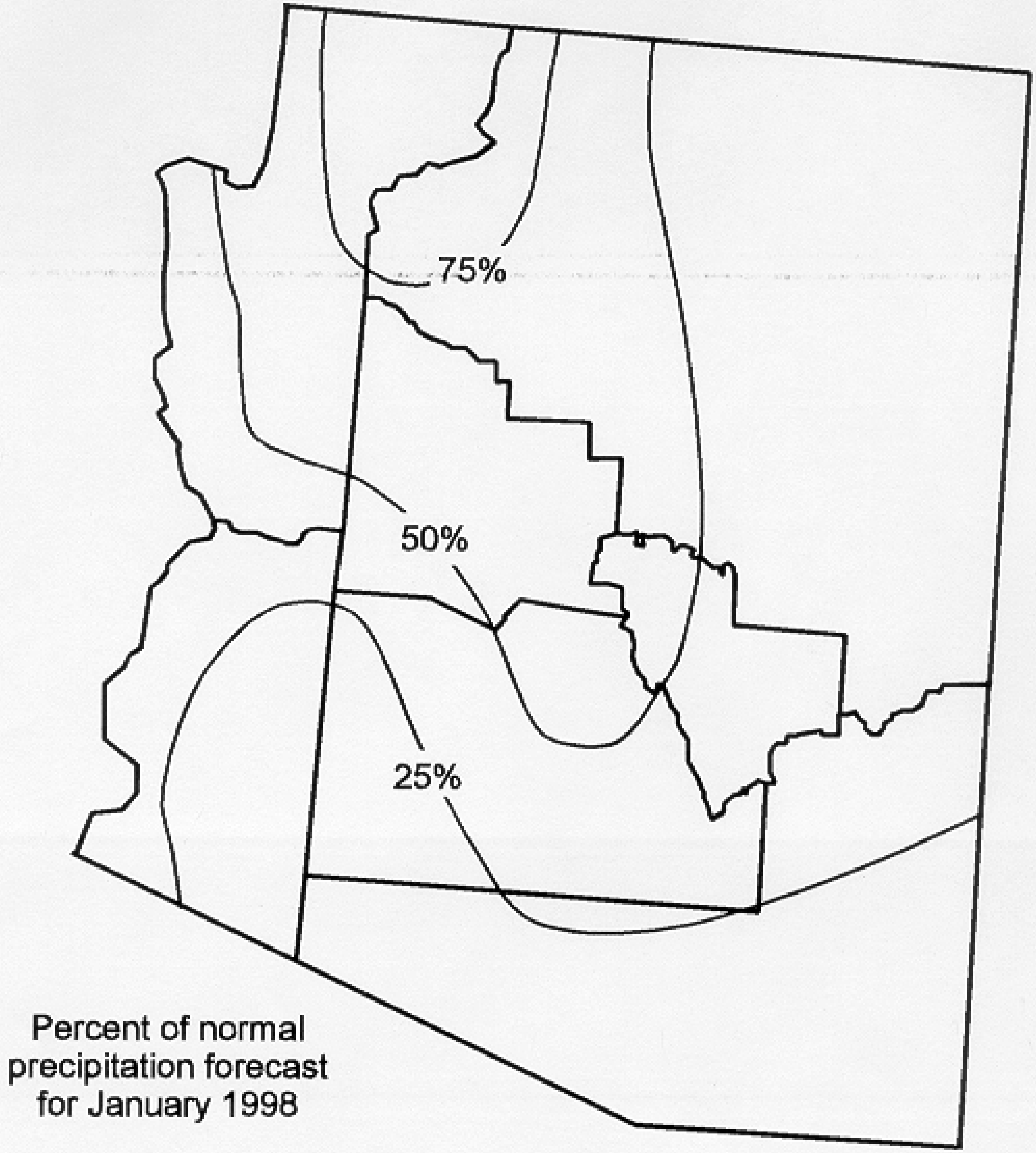

Figure 9. Same as Figure 4 except for January 1998. Arizona was expected to receive below normal precipitation across the state during this month.

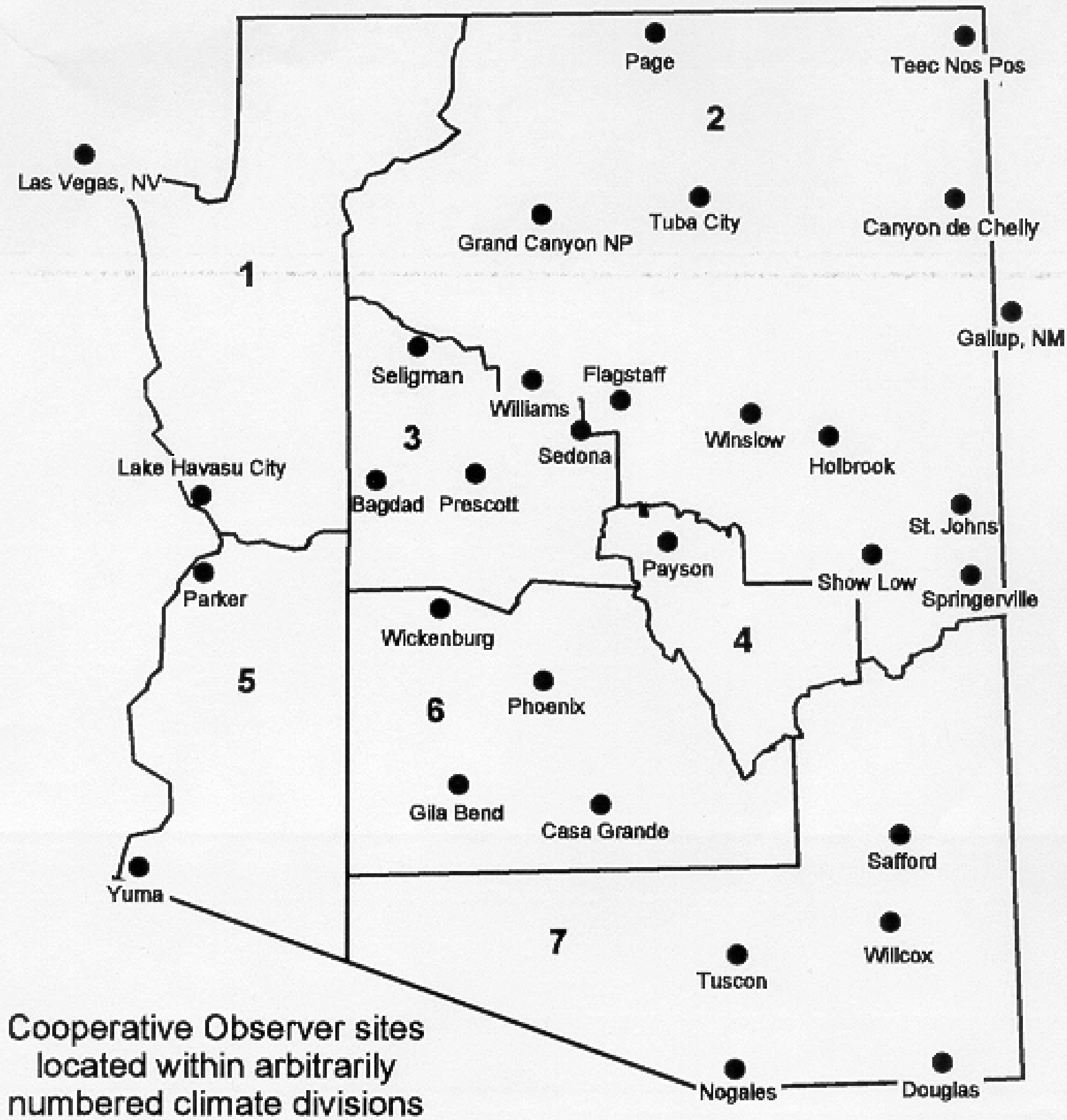

Figure 10. The distribution of cooperative observer sites within the arbitrarily numbered climate divisions (numbers in large bold print). Climate division 4 is represented by one site; divisions 1 and 5 by two sites.

Climate division 4 is represented by one site, divisions 1 and 3 by two sites.

ENSO Years: 1914-15, 1918-19, 1940-41, 1957-58, 1965-66, 1972-73, 1982-83, 1986-87, 1991-92

Climate Division	102-Yr Avg (cm)	ENSO Avg. (cm)	97-98 ENSO Avg (cm)	ENSO Pcnt of Normal (%)	97-98 Pcnt of ENSO-Avg (%)	97-98 Pcnt of Normal (%)
1	10.22	14.88	9.80	146	66	96
2	12.55	16.76	10.92	134	65	87
3	15.19	21.67	21.54	143	99	142
4	19.94	30.66	34.01	154	111	171
5	4.98	8.69	10.62	174	122	213
6	10.44	18.21	18.48	174	101	177
7	10.03	17.78	15.53	177	87	155

Table 2. 102-Year Normal vs. ENSO-average precipitation (in cm) by climate division in Arizona from December 1997 through March 1998. Column 1 indicates climate division number. Column 2 reveals the normal precipitation representative of the climate division. Column 3 represents the ENSO-average precipitation recorded for the 9 events this century. Column 4 shows the average precipitation in each climate division computed from the 31 co-op sites in this study. Column 5 shows the percent of normal precipitation associated with the 9 ENSO events. Column 6 reveals the percent of ENSO-average precipitation contributed by the 1997-98 event. Column 7 represents the percent of normal precipitation occurring during the 1997-98 El Niño event.