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**FACTORS AFFECTING SEASONAL AND ANNUAL
PRECIPITATION IN ARIZONA**

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Abstract

Seasonal and annual precipitation vary considerably in Arizona, primarily because of topographic influences. Precipitation data have been analyzed by several investigators over the years. Arizona has been subdivided into precipitation zones, and seasonal and annual precipitation isohyetal maps are available from several sources. Because of a paucity of raingages in the more mountainous regions, however, isohyetal lines in these regions have been largely estimated based on the assumptions of topographic influences. Now, with 158 raingages with 30 or more years of record, topographic factors can be combined with greater knowledge of the sources and paths of moisture into the state to better define annual and seasonal precipitation variability. Elevation and aspect appear to be the principal parameters for analyzing precipitation within the state, with the Mogollon Rim exerting the greatest influence on winter precipitation. Higher than anticipated summer rainfall in southeastern Arizona (based on elevation and aspect) suggest that sources and availability of atmospheric moisture may be a strong parameter in analyzing summer rainfall.

Introduction

The range of elevation (40 to 4200 m) in Arizona leads to a wide range of climatic conditions (Sellers, 1960). Much of the state receives less than 250 mm of annual precipitation. The region of highest precipitation crosses the central part of the state from southeast to northwest along the Mogollon Rim. In Arizona, precipitation is bimodal, with slow moving cold fronts providing lift for winter precipitation, and convective heating of moist tropical air producing summer rainfall. Both the Pacific Ocean and the Gulf of Mexico are now recognized as sources of moisture for precipitation in Arizona (Osborn and Davis, 1977). Winter snow and rain are generally low intensity events associated with slow moving cold fronts, although occasionally surges of

warm moist air can push into Arizona in the winter and produce convective activity within a general storm system. Orographic lifting along the Mogollon Rim in central Arizona (Fig. 1) dominates winter precipitation. Summer rains are primarily high intensity thunderstorms of short duration and limited areal extent, with the influence of elevation and aspect less apparent.

Previous Studies

The climate of Arizona with particular emphasis on precipitation and temperature was categorized by Sellers (1960) and Green (1964). Their publications included the prevalent facts and theories on the reasons for the extreme variability in annual and seasonal precipitation across Arizona. At that time, the Gulf of Mexico was considered the prime source of moisture for summer rain in Arizona. Hales (1973) first suggested that "surges" of moisture from the Pacific Ocean south of Baja California moving into Arizona from the south were important sources of summer thunderstorm rainfall. Osborn and Davis (1977) concluded that both the Pacific Ocean and the Gulf of Mexico could be important sources of moisture for summer rains in Arizona. Also, several investigators, including Sellers (1960) and Osborn (1985), have reported on the importance of tropical storms in pushing moist tropical air into Arizona.

Analysis

An isohyetal map of average annual precipitation for Arizona appeared in the 1941 United States Department of Agriculture (USDA) Yearbook, Climate & Man (Fig. 2). The map, which was developed from relatively few available precipitation records and from topographic considerations, is an excellent starting point for analysis of Arizona precipitation.

Precipitation records from 158 raingages operated more than 30 years (Fig. 3) have been adapted from Sellers et al. (1985) (Appendix A). The data were used to develop a similar isohyetal map of annual precipitation for Arizona (not shown). Although the recent map showed greater detail than the 1941 map, they were very similar. Both showed the strong influence of the Mogollon Rim in increasing precipitation in central Arizona (relative to elevation) and in decreasing precipitation in northeastern Arizona. Both maps showed higher precipitation amounts in the mountainous areas of south-eastern Arizona, although the differences, relative to elevation, were not as extreme as in central Arizona.

Osborn (1984) attempted to separate both seasonal and annual precipitation amounts for Arizona, based on available rainfall records, into zones which were well above (excess) or well below (deficit) average precipitation amounts (as defined by French, 1983) based strictly on elevation. In this paper, we have attempted to redefine the zones

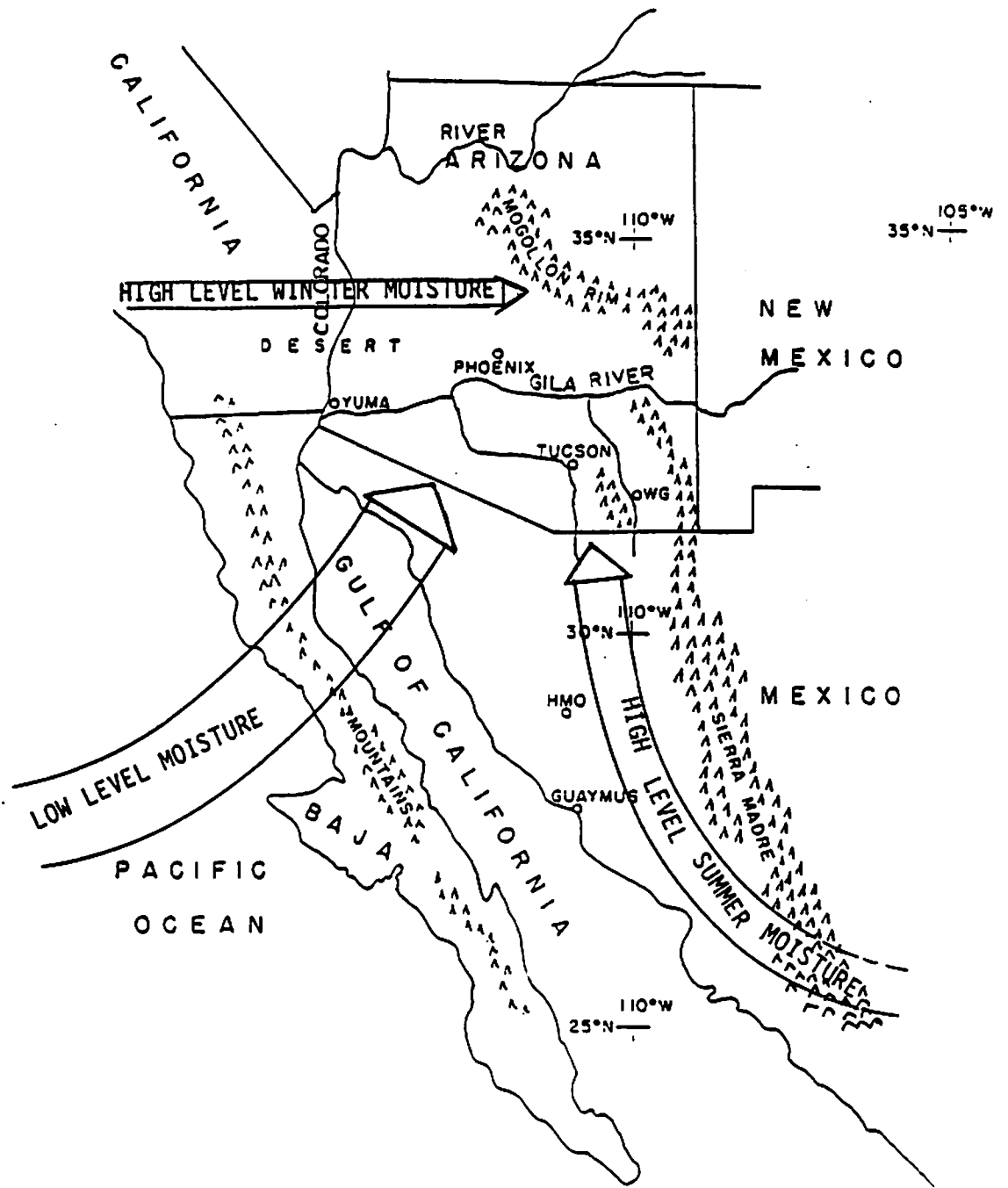


Figure 1. Sources of moisture for Arizona precipitation.

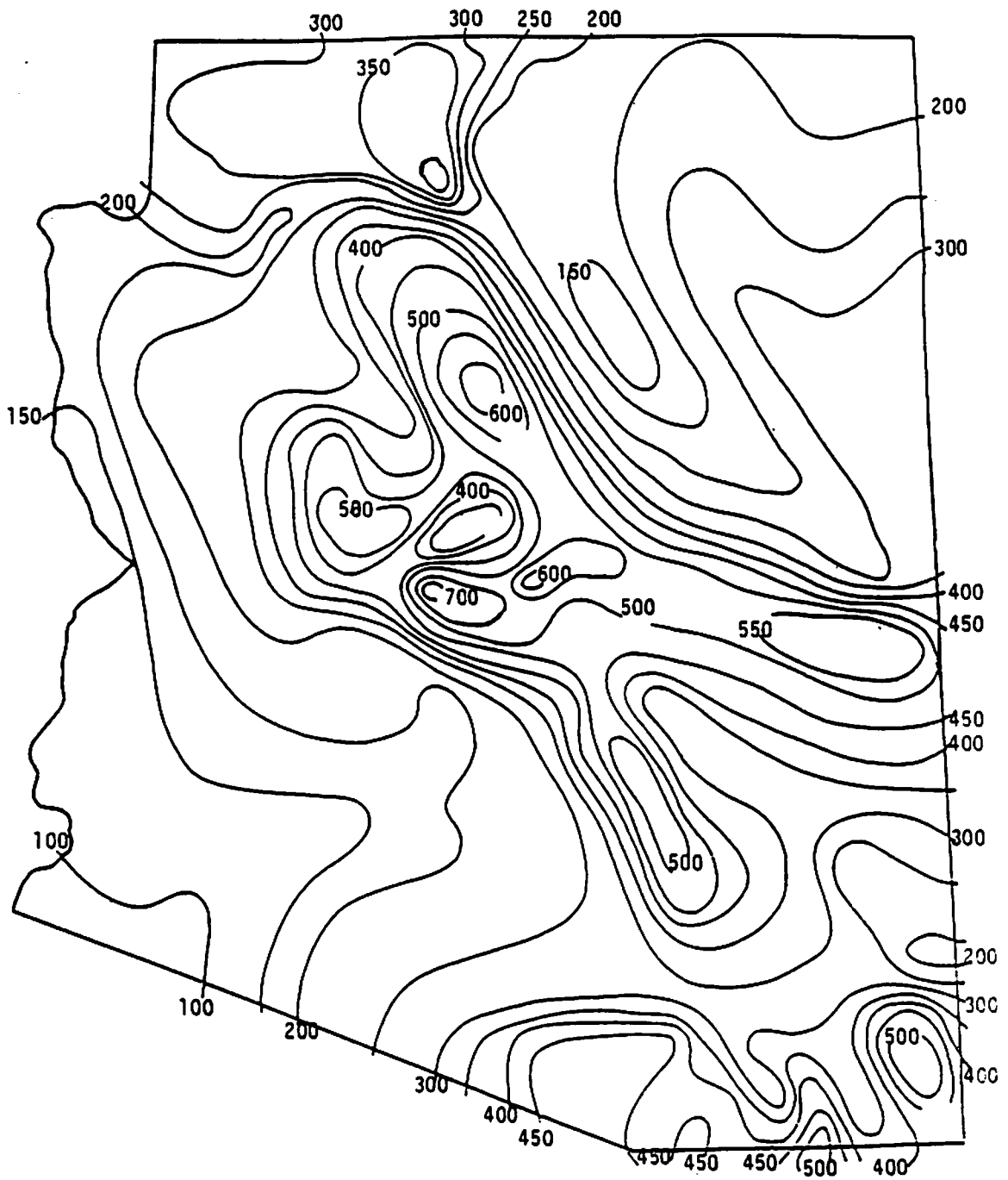


Figure 2. Average annual precipitation for Arizona(mm) reproduced from USDA 1941 Yearbook, CLIMATE AND MAN.

STATE OF ARIZONA: LOCATION OF RAINGAGES

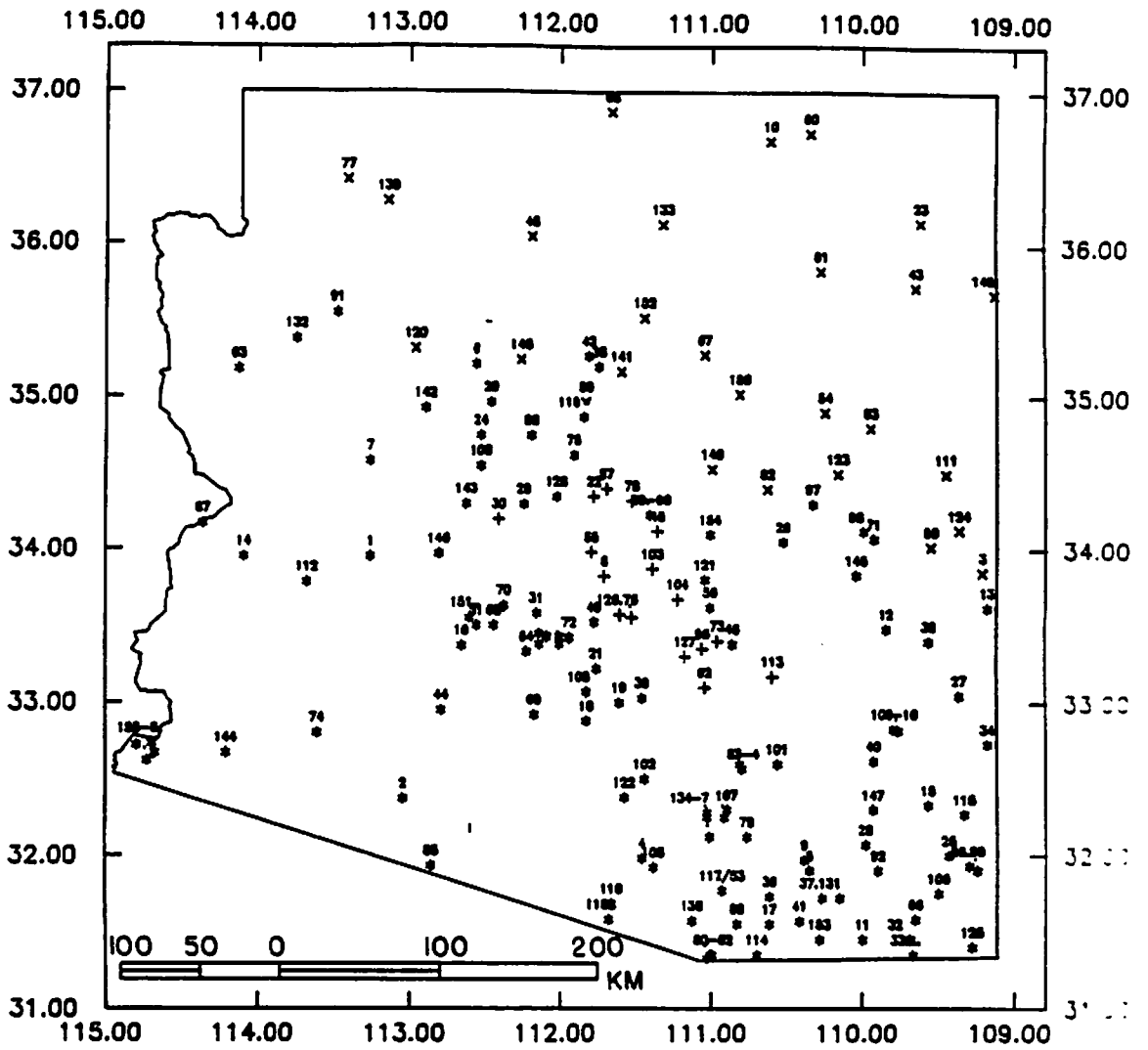


Figure 3. Raingages used in analysis. Excess stations (+), deficit stations (x), and transition stations (*).

of above (excess) and below (deficit) average rainfall as plotted against elevation for winter, annual and summer periods (Figs. 4, 5, 6 and Appendix A).

The excess zone for winter precipitation is clearly defined (Fig. 4). All winter excess stations are located on the south slopes of the Mogollon Rim and other central Arizona ranges. Deficit stations are located north and northeast of the Mogollon Rim. Deficit and excess stations as defined by winter precipitation, are shown on all three maps.

The excess and deficit stations also stand out on the isohyetal map of annual precipitation, but not as clearly as for the winter precipitation (Fig. 5). The ranges in amounts between deficit and excess stations for the same elevations are considerably reduced for annual precipitation, suggesting less variation in summer than in winter precipitation. Also, for annual precipitation, quite a few transition stations could be considered excess stations.

Therefore, as expected, there is considerable overlapping of excess and transition stations in the plot of summer rainfall versus elevation (Fig. 6). About 10 transition stations plot above the best fit line for excess stations. Interestingly, all of these clearly excess stations are located in southeastern Arizona and have a southerly aspect.

Discussion

The relatively higher amounts of summer rainfall as opposed to winter precipitation in southeastern Arizona may be explained by the paths, quantity, and persistence of flows of moist air into Arizona (Fig. 1). Low-level moisture can flow into Arizona from the southwest at any time, depending on the relative position of a low pressure area or trough over California, and a corresponding high pressure ridge east of Arizona. In the winter, such conditions are not as common as in the summer and change more rapidly than in the summer. The exception is when a tropical storm is caught up in the counter clockwise flow around a California low. In these cases, there may be a strong flow of very moist tropical air into Arizona, and heavy rains can occur. However, even when the flow of moist air in the winter is persistent, the upper levels usually are relatively cold and dry. The upper level winter winds from the west tend to be cold and dry throughout the winter.

In the summer, persistent flows of moist low level air from the Pacific and moist high level air from the Gulf of Mexico can combine to provide Arizona with an excellent supply of moisture for rainfall. Higher afternoon air temperatures near the ground along with the broken topography add to the probability of significant thunderstorm rainfall. Southeastern Arizona may be best located for realizing the optimum summer rainfall conditions, and this may account for the increased amounts of summer rainfall respective to Central Arizona and the Mogollon Rim.

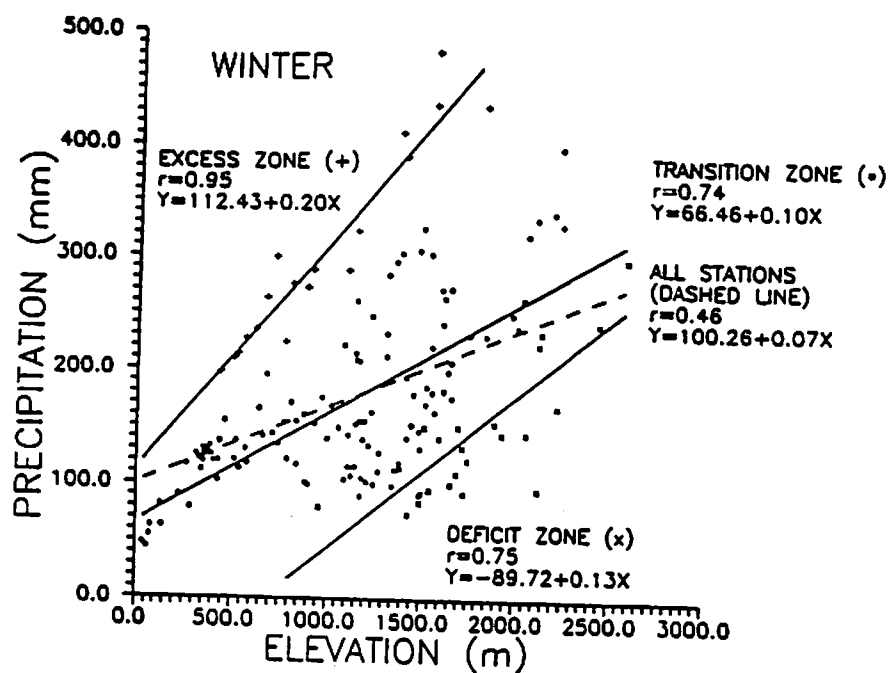


Figure 4. Arizona winter precipitation.

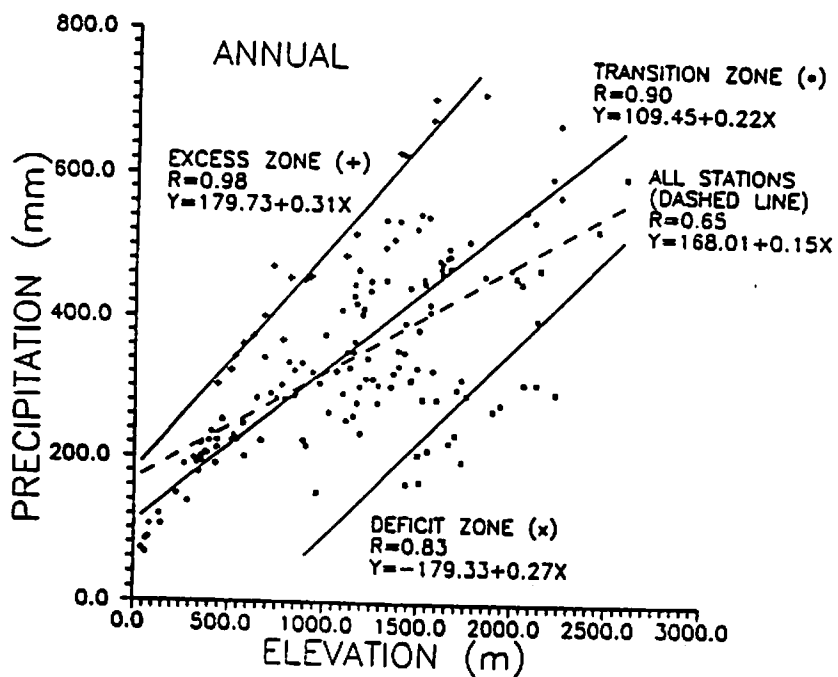


Figure 5. Arizona annual precipitation.

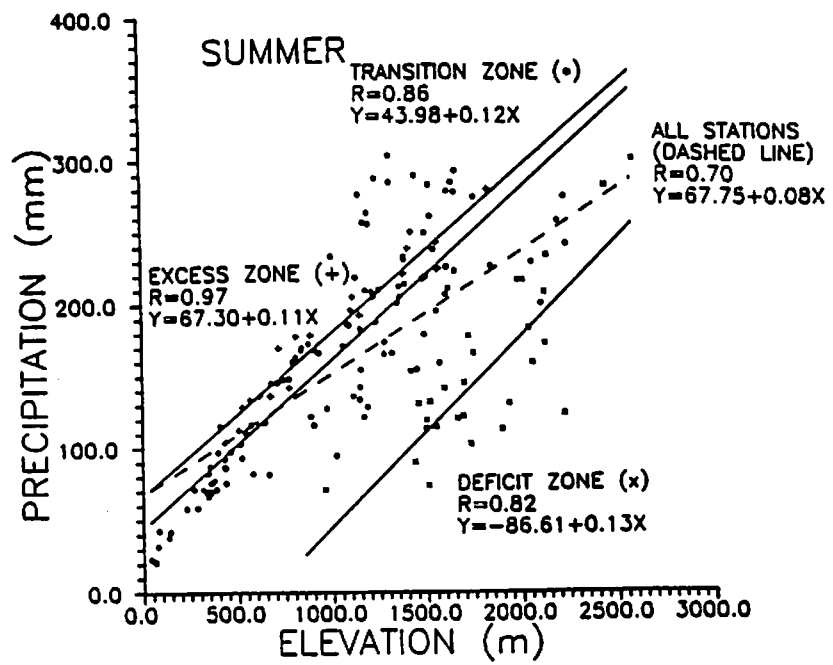


Figure 6. Arizona summer precipitation.

Conclusion

There are a wide range of precipitation amounts for the same elevations for both winter and summer rainfall. The Mogollon Rim and other central Arizona mountain ranges appear to be the dominant factor in establishing both excess and deficit zones for the winter months. Excess stations appear to be the result of aspect (southerly exposure) and orographic lifting, whereas the deficit stations are largely north of the Mogollon Rim in a rain shadow.

A combination of increased high level moist summer air and the relative proximity to both the Pacific Ocean and the Gulf of Mexico may explain why summer rainfall at many stations in southeastern Arizona for the same elevation exceeds summer rainfall along the Mogollon Rim.

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Appendix A: Location and data of climatological stations in Arizona with at least thirty years of record 1960-1982.

No.	Station Name	Period of Record	Longitude	Latitude	Elevation (ft)	Average Precipitation (in)		
						Annual	Summer	Winter
1	Aguila	05/24-12/82	110.737	33.95	561.	222.76	31.79	140.97
2	Ajo	05/14-12/82	110.953	32.37	537.	224.23	111.00	113.23
3	Alpine	10/04-12/82	114.787	33.35	2444.	522.49	230.67	242.32
4	Anvil Ranch	07/48-12/82	112.337	31.79	338.	287.27	169.93	117.35
5	Apache Power Company	07/23-12/82	113.653	31.79	1125.	326.39	215.44	107.35
6	Asn Fork	04/02-09/75	111.437	35.22	1567.	323.34	159.26	164.08
7	Bagdad	05/25-08/73	110.737	34.38	1143.	348.74	135.60	215.14
8	Barclott Gap	09/39-12/82	112.237	33.32	505.	322.89	112.52	210.06
9	Benson	01/00-05/75	113.620	31.97	1090.	399.86	185.17	104.37
10	Betataxin	07/48-12/82	113.387	36.58	2221.	292.61	123.44	169.16
11	Bisbee	01/00-12/82	114.003	31.45	1858.	468.38	291.34	177.04
12	Black River Pines	07/48-12/82	114.153	33.48	1941.	457.96	226.31	231.65
13	Blue	11/03-12/82	114.820	33.62	1756.	506.22	273.30	232.92
14	Bouse	01/52-12/82	109.903	33.75	283.	137.92	58.67	79.25
15	Bowie	01/00-12/82	114.437	32.33	1145.	258.57	142.49	116.08
16	Buckeye	01/00-12/82	111.337	33.37	265.	198.72	71.63	117.09
17	Canelo I NM	01/10-12/82	113.387	31.55	1519.	452.63	281.69	170.94
18	Casa Grande	01/00-12/82	112.170	32.38	428.	212.34	92.46	119.89
19	Casa Grande Ruins NM	03/06-12/82	112.387	33.00	433.	223.27	86.11	137.16
20	Cedar Glade	02/15-01/54	111.537	34.97	1417.	348.49	153.67	194.82
21	Chandler Heights	07/48-12/82	112.237	33.22	434.	212.09	75.69	136.40
22	Childs	09/15-12/82	112.220	34.35	808.	453.64	177.80	275.84
23	Chino	12/08-11/70	114.387	36.15	1668.	233.17	122.17	111.00
24	Chino Valley	07/48-12/82	111.470	34.75	1448.	308.10	154.94	153.16
25	Chiricahua NM	01/09-12/82	114.570	32.00	1515.	460.30	277.37	183.13
26	Cibecue	06/27-01/79	113.470	34.05	1515.	475.49	210.82	264.67
27	Clifton	01/00-12/82	114.637	33.05	1055.	323.20	170.94	149.36
28	Cocise Power House	01/00-12/54	114.020	32.07	1274.	277.11	165.35	111.76
29	Cordes	07/48-12/82	111.753	34.30	1149.	363.73	154.43	209.30
30	Crown King	12/14-12/82	111.587	34.20	1829.	711.71	278.64	433.07
31	Deer Valley	01/50-12/82	111.337	33.59	383.	204.22	71.63	132.59
32	Douglas FAA Airport	07/48-12/82	114.320	31.45	1249.	310.64	210.06	100.58
33	Douglas Selter	12/03-03/73	114.337	31.25	1211.	311.15	208.28	102.37
34	Duncan	05/01-12/82	114.320	32.75	1109.	251.97	136.14	115.32
35	Eagle Creek	01/28-07/73	114.437	33.40	1554.	406.91	225.04	181.26
36	Elgin S N	10/12-01/70	113.387	31.73	1494.	361.25	248.92	132.33
37	Fairbank I S	07/09-03/73	113.737	31.72	1177.	289.72	209.85	90.17
38	Flagstaff WSO Airport	01/50-12/82	112.253	33.29	2104.	575.18	290.66	334.52
39	Florence	09/08-12/82	112.537	33.03	459.	252.22	97.79	154.43
40	Fort Grant	01/00-09/74	114.070	32.62	1485.	323.64	179.07	147.57
41	Fort Huachuca	02/00-12/81	113.337	31.57	1422.	290.91	249.43	141.48
42	Fort Valley	01/09-12/82	112.197	35.27	2237.	370.74	241.05	329.69
43	Ganado	07/48-12/82	114.353	35.72	1922.	276.61	131.06	145.34
44	Gila Bend	01/00-12/82	111.203	32.95	325.	148.34	69.17	90.17
45	Gisela	01/16-12/82	112.637	34.12	854.	451.26	178.36	272.50
46	Globe	01/31-12/82	113.137	33.38	1932.	408.13	185.93	222.25
47	Gould's Ranch	01/15-08/60	111.253	33.33	351.	194.32	75.59	119.13
48	Grand Canyon 1965	09/03-08/57	111.807	36.05	2122.	396.75	172.72	224.03
49	Granite See-Can	01/00-09/79	112.220	33.52	404.	225.46	115.32	119.32

50	Greer	07/48-12/82	114.455	34.02	2588.	598.42	298.70	299.72
51	Griggs 3 W	01/50-12/82	111.437	33.50	354.	193.80	69.09	124.71
52	Heber Ranger Station	08/50-12/82	113.370	34.40	2009.	456.18	216.92	229.27
53	Helvetia Santa Rita Es	06/16-04/50	113.070	31.77	1311.	496.57	283.46	213.11
54	Holbrook	01/00-12/82	113.753	34.90	1545.	211.33	114.81	96.52
55	Horseshoe Dam	07/48-12/82	112.203	33.98	616.	372.11	136.91	233.20
56	Intake	07/06-04/52	112.987	33.62	677.	340.87	145.54	195.33
57	Irving	01/51-12/82	112.303	34.40	1147.	515.11	192.28	322.83
58	Jerome	01/60-12/82	111.803	34.75	1599.	479.04	206.76	272.29
59	Junipine	07/48-06/82	112.170	34.97	1562.	704.34	224.54	479.31
60	Kayenta	06/15-03/78	113.553	36.75	1727.	195.83	102.36	93.47
61	Keams Canyon	08/48-12/82	113.720	35.82	1894.	267.72	113.03	154.69
62	Kelvin	07/48-12/82	112.953	33.10	564.	360.93	133.86	227.08
63	Kingman	05/01-07/67	109.870	25.18	1017.	263.14	94.74	168.40
64	Laveen 3 SSE	07/48-12/82	111.770	33.33	340.	195.07	82.80	112.27
65	Lees Ferry	04/16-12/82	112.337	36.87	957.	150.88	70.87	80.01
66	Leslie Canyon	05/16-01/60	114.353	31.58	1360.	318.77	205.23	113.54
67	Leupp	07/48-04/81	112.953	35.28	1433.	164.59	89.92	74.68
68	Litchfield Park	08/17-12/82	111.553	33.50	314.	197.10	71.37	125.73
69	Maricopa 8 SSE	01/00-12/58	111.820	32.92	427.	189.74	86.87	102.87
70	Marionette	07/13-09/64	111.620	33.63	349.	200.41	70.10	130.30
71	McNary	08/33-12/82	114.070	34.07	2231.	670.81	273.56	397.26
72	Mesa Experiment Farm	01/00-12/82	112.053	33.42	373.	206.50	77.72	128.78
73	Miami	02/14-12/82	113.037	33.40	1098.	484.38	196.09	288.29
74	Mohawk	07/00-05/51	110.387	32.80	138.	105.41	42.16	63.25
75	Montezuma Castle NM	10/38-12/82	112.087	34.62	969.	303.53	127.76	175.77
76	Morson Flat	08/23-11/82	112.470	33.55	525.	342.65	128.78	213.87
77	Mount Trumbull	10/19-12/77	110.587	36.42	1695.	296.93	145.54	151.38
78	Natural Bridge	01/00-11/72	112.470	34.32	1404.	626.62	238.25	388.37
79	N Lazy H Ranch	07/48-12/82	113.237	32.12	930.	319.53	166.12	153.42
80	Nogales-Post June '48	07/48-12/82	113.003	31.35	1156.	417.32	265.18	152.15
81	Nogales-Thru June '48	01/00-06/48	112.970	31.33	1189.	402.34	262.64	139.70
82	Nogales 6 N	10/52-12/82	112.987	31.35	1145.	427.99	275.08	152.91
83	Oracle	01/00-03/49	113.203	32.57	1356.	508.00	212.09	295.91
84	Oracle 2 SE	02/50-12/82	113.187	32.60	1384.	534.16	230.89	303.28
85	Organ Pipe Cactus NM	07/48-12/82	111.157	31.93	511.	224.03	103.12	120.90
86	Paradise	01/06-08/37	114.703	31.93	1654.	485.14	276.61	208.53
87	Parker	02/00-12/82	109.637	34.17	130.	119.89	38.35	81.53
88	Patagonia	07/21-12/77	113.170	31.55	1255.	449.58	286.00	163.58
89	Payson RS	03/09-02/74	112.587	34.23	1478.	525.24	217.42	305.82
90	Payson	11/40-12/82	112.587	34.23	1497.	544.32	219.20	325.12
91	Peach Springs	07/48-11/82	110.520	35.55	1515.	282.96	132.08	150.66
92	Pearce	03/50-09/80	114.103	31.90	1347.	300.23	200.91	99.31
93	Petrified Forest NP	07/48-12/82	114.053	34.80	1658.	221.74	120.40	101.35
94	Phoenix MSFO Airport	07/48-12/82	111.903	33.43	340.	178.05	66.55	111.51
95	Phoenix City	07/48-12/82	111.853	33.45	330.	190.50	69.09	121.41
96	Pinal Ranch	01/00-05/73	112.937	33.25	1378.	629.92	220.98	408.94
97	Pinedale	06/12-12/68	113.670	34.30	1981.	467.36	216.92	250.44
98	Pinetop Fish Hatchery	07/48-12/82	114.003	34.12	2195.	596.90	257.05	339.85
99	Portal	01/14-03/55	114.753	31.90	1524.	446.53	260.10	166.44
100	Prescott	01/00-12/82	111.470	34.25	1649.	495.81	222.76	273.05
101	Redington	07/48-12/82	113.437	32.60	874.	332.99	172.47	160.53
102	Red Rock 6 SSE	07/08-10/73	112.553	32.50	567.	246.89	116.59	130.30
103	Reno Ranger Station	11/15-04/73	112.503	33.87	712.	469.39	169.67	299.72
104	Roosevelt 1 NW	07/05-10/52	112.770	33.67	672.	399.80	136.40	263.40

105	Ruby Star Ranch	02/59-12/82	112.412	31.92	1199.	248.74	294.93	147.76
106	Rucker Canyon	05/17-12/82	114.503	31.75	1637.	483.36	283.46	195.90
107	Sasmo Canyon	07/46-09/82	112.103	32.30	805.	334.01	163.32	170.49
108	Sacaton	04/08-10/82	112.170	33.07	392.	222.25	97.23	124.97
109	Safford	01/00-06/73	114.203	32.93	284.	224.03	122.17	101.85
110	Safford Exp Farm	08/48-12/82	114.237	32.82	900.	215.90	116.08	99.82
111	Saint Johns	08/01-12/82	114.553	34.50	1747.	239.80	166.12	122.68
112	Salome & SE	01/02-04/57	110.320	33.78	576.	200.41	92.30	118.11
113	San Carlos Reservoir	07/46-12/82	113.403	33.17	772.	366.27	141.99	224.28
114	San Rafael Ranch	07/22-03/63	113.303	31.35	1445.	440.69	228.04	152.65
115	San Simon	01/00-07/62	114.670	32.27	1183.	234.70	128.52	106.17
116	Santa Margarita	06/17-11/50	112.337	31.68	1196.	410.72	255.02	155.70
117	Santa Rita Exp Range	05/50-11/82	113.070	31.77	1311.	534.92	302.01	232.92
118	Sasabe 7 NW	12/50-12/82	112.320	31.58	1166.	464.57	256.03	208.53
119	Sedona RS	07/48-12/82	112.153	34.87	1317.	450.60	166.12	264.48
120	Seligman	12/04-12/82	111.037	33.32	1591.	282.96	141.48	141.48
121	Sierra Ancha	11/13-09/79	112.953	33.80	1554.	575.64	242.32	433.32
122	Silver Bell	02/06-04/74	112.420	32.38	835.	322.58	167.89	154.69
123	Snowflake	01/00-12/82	113.837	34.50	1720.	311.40	178.05	133.35
124	Springerville	04/11-12/82	114.637	34.13	2123.	305.56	208.53	97.03
125	Stephens Ranch	12/23-03/82	114.720	31.40	1219.	339.85	205.23	134.62
126	Stewart Mountain	07/48-12/82	112.387	33.57	433.	302.25	104.65	197.61
127	Superior	07/20-12/82	112.820	33.30	913.	455.93	167.39	288.54
128	Sycamore RS	07/19-12/59	111.970	34.35	1231.	435.61	187.45	248.16
129	Tempe Veg Res Farm	01/26-12/82	111.987	33.38	360.	201.93	75.95	125.98
130	Tempe	01/05-06/52	111.987	33.43	351.	217.93	87.63	130.30
131	Toaestone	07/00-12/82	113.853	31.72	1384.	351.79	232.41	119.38
132	Truxton Canyon	07/48-03/80	110.253	33.38	1154.	277.11	121.67	155.45
133	Tuba City	01/00-12/75	112.670	36.13	1504.	166.88	73.41	93.47
134	Tucson Canabell Farm	02/49-12/82	112.970	32.28	710.	289.56	145.54	144.02
135	Tucson Magnetic Descy	07/46-12/82	113.087	32.25	770.	301.75	148.34	153.42
136	Tucson Univ of Ariz	01/00-12/82	112.970	32.25	741.	282.70	147.57	135.13
137	Tucson WSO Airport	07/48-12/82	112.987	32.12	789.	291.69	160.02	121.67
138	Tuacacacori NM	07/48-12/82	112.870	31.57	996.	373.13	232.92	140.21
139	Tweep	07/48-12/82	110.953	36.28	1455.	310.39	130.81	179.58
140	Wallace RS	05/16-04/59	113.003	34.53	2135.	468.12	233.68	234.44
141	Walnut Canyon NM	10/50-12/82	112.403	35.17	2033.	448.06	183.64	264.41
142	Walnut Creek	12/15-12/82	111.103	34.93	1551.	417.07	195.33	221.74
143	Walnut Grove	01/00-12/82	111.370	34.30	1147.	444.25	182.63	261.62
144	Wellton	03/22-12/80	109.787	32.67	75.	105.66	42.93	62.74
145	Whiteriver	02/00-12/82	113.953	33.55	1699.	467.87	225.31	242.06
146	Wickenburg	05/05-12/82	111.157	33.97	637.	293.21	119.11	165.10
147	Willcox	01/00-12/82	114.070	32.36	1277.	302.01	172.74	129.27
148	Williams	07/02-12/82	111.737	33.25	2657.	549.40	229.36	320.04
149	Window Rock 4 SW	03/37-12/82	114.370	33.68	2057.	305.31	159.51	145.80
150	Winslow WSO Airport	01/00-12/82	113.187	33.02	1492.	304.99	113.54	91.44
151	Wittman	12/23-11/66	111.387	33.55	515.	250.38	93.22	137.16
152	Wupatki NM	07/46-12/52	112.553	33.82	1496.	204.47	119.35	85.09
153	Y Lightning Ranch	01.39-12/82	113.720	31.45	1387.	323.93	213.87	115.06
154	Young	07/02-09/64	112.787	34.16	1539.	540.25	237.49	302.77
155	Yuma Citrus Station	07/02-12/82	109.370	32.62	53.	53.82	30.23	53.59
156	Yuma Vallev	11.30-12/82	109.203	32.72	57.	71.37	33.37	46.01
157	Yuma WSO Airport	07.46-12/82	109.320	32.67	59.	65.79	31.34	44.45
158	Yuma	07.46-12/82	109.203	32.72	57.	71.37	33.37	46.01