Creation of a 50-Year Rainfall Database, Annual Rainfall Climatology, and Annual Rainfall Distribution Map for Guam

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Abstract

Since the early 1950s, there has been considerable interest in the rainfall on Guam, especially by the US military and the US Geological Survey (USGS). Since 1950, over 60 government-sponsored rain gauge sites have operated on Guam. Unfortunately, the length of record of most of the sites is short, in many cases incomplete, and in some cases unreliable.

The few rainfall distribution studies for Guam have been based on limited data. As a result, the rainfall distribution patterns have been greatly over-simplified or incorrectly analyzed, and the actual rainfall gradients have been largely ignored.

The purpose of this study is to evaluate the available data, then to use the acceptable data to build a 50-year rainfall database for selected sites on Guam. The resulting database provides a long-term rainfall climatology and an annual rainfall distribution map for the island.

Photo of Mt. Alutom, Guam, by S. Khosrowpanah

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1. Introduction.

Since the early 1950s, there has been considerable interest in the rainfall on Guam, especially by the US military and the US Geological Survey (USGS). This is apparent from the number of rain gauge sites established and maintained by the various agencies. In the mid-1950s, the US National Weather Service (NWS) established a a Meterological Observatory (WSMO) at Finagayan, Guam, which eventually became the site with the most complete database. This site was dis-established in March 1995 and the NWS moved to Tiyan (the site of the deactivated Naval Air Station). Since 1950, over 60 government-sponsored rain gauge sites have operated on Guam. Unfortunately, the length of record of most of the sites is short, in many cases incomplete, and in some cases unreliable.

While there have been a few rainfall distribution studies for Guam (e. g., Jordan 1955, and Natural Resources Conservation Service (NRCS) 1987), these studies have been based on limited data. As a result, the rainfall distribution patterns have been greatly over-simplified or incorrectly analysed, and the actual rainfall gradients have been largely ignored.

The purpose of this study is to evaluate the available data, then to use the acceptable data to build a 50-year rainfall database for selected sites on Guam. The resulting database provides a long-term rainfall climatology and an annual rainfall distribution map for the island.

The methodology used to construct and analyze the 50-year rainfall database from existing data is discussed in Section 2. The results of the analyses and a discussion of the rainfall patterns, long-term climatology, and decadal variations are presented in Section 3. Section 4 summarizes the results and identifies further research that is need.

2. Methodology

a. Data sources

For reasons of equipment standardization and calibration, and data reliability, only data from US and cooperating Government of Guam agencies were used. Numerous sources of documentation had to be used in order to recover these data. These sources included commercial rainfall databases (e.g., EarthInfo, Inc. 2000), official climatology documents (e.g., National Climatic Data Center (NCDC) 1956-99), previous studies (e.g., NRCS 1987), and original rainfall records (e.g., Navy, Air Force and NWS). Descriptions of the rainfall data used in this report, and associated metadata, are found in the Appendixes A, B and C.

While commercial databases were used as the initial database source, they contained many data gaps. Many of the NWS cooperative rain gauges and the military rain gauges did not meet the NCDC publishing deadlines. While they were eventually published as "late reports", the commercial databases did not capture these late data. These were extracted by the authors from available "late data" reports. Much of the military data did not even make the late reports, and these had to be recovered from military sources, often from old official (but unpublished) records. Most USGS data before 1980 was available in Beck (1980).

b. Database evaluation

Several methods and tools were used to evaluate the quality of the rainfall data. Beck (1980) did a good job in identifying periods when USGS rain gauges malfunctioned or were otherwise unreliable. In some cases, he made estimates to compensate for the problems. His estimates were used. Several of the USGS gauges were read only weekly or monthly, and the monthly readings were not always made at the end of the month. Values of nearby stations were used to proportion the rainfall for these sites into monthly estimates. Values of all stations were compared with nearby stations, with archived satellite data, with ENSO climatology (Trenberth 1997; Allen et al. 1996), with monsoon climatology (Lander and Guard 1998), and with tropical cyclone (TC) activity on and around Guam (Joint Typhoon Warning Center (JTWC) 1959-1997); JTWC (1991) to ensure physical consistency.

c. Database construction

The study used the longest, most reliable records (Fig. 1, and Appendixes A and B) to establish baseline relationships. These included Andersen AFB, NAS Agana, WSMO Finigayan, Umatac Village, and the Ylig River Filter Plant. Some stations were sufficiently near other stations that they could be used interchangeably (e.g., Fena Filter Plant and Naval Magazine; WSMO Finigayan and Naval Communications Station, Finigayan). In some data void areas, vegetation types and patterns and soil permeability characteristics were used to assess relative wetness and dryness in order to establish rainfall gradients and patterns. On several occasions, typhoons blew away rain gauges, and the rainfall had to be reconstructed based on surviving sites, past behavior, typhoon track and intensity information, and typhoon size and speed of motion. Two years, 1951 and 1981, had large gaps in the data, and considerable reconstruction was needed to build databases for these years. Finally, NEXRAD radar data were used to identify favorable cloud distribution patterns. NEXRAD data has only been available since 1993, but during its years of operation, it clearly shows some favorable cloud alignments with the island and its adjacent waters. The radar data were also used to help describe over-water and near-shore rainfall distribution, and to anchor over-water rainfall maxima east and west of the island

Two principal baseline databases were developed for this study. The databases were produced using the database program Microsoft EXCEL. The first is a 50-year database of the monthly rainfall (**MON**) values (designated Guam_AllStations.xls on attached CD), with each individual station occupying a new data sheet. An example of this database is shown in Fig. 2. The second is a 50-year database consisting of monthly data from most available Guam sites for a specific year (**Y-Y**) (Guam_YearToYear.xls on the attached CD), with each

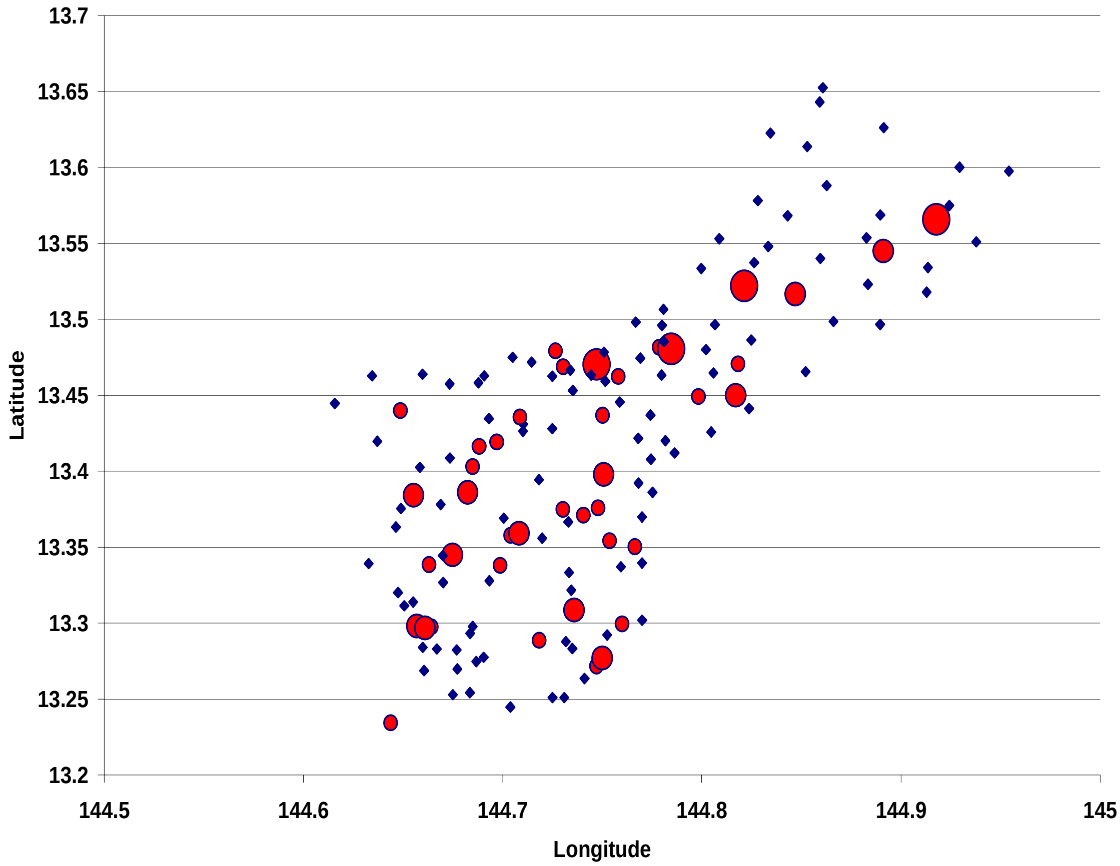


Figure 1. Sites used in the preparation of the rainfall chart shown in Fig. 4. Actual rain gages are at sites indicated by the red dots. Smallest red dots indicate a highly broken or less than 20 years of record; medium red dots indicate at least 20 years of nearly continuous and reliable rain records; large red dots indicate 50 years of nearly continous and reliable rain records. Small blue triangles are locations where rainfall amounts were interpolated for analysis of Fig. 4. Every location is listed in Appendix A, and the periods of record for sites with rainfall data are listed in Appendix B.

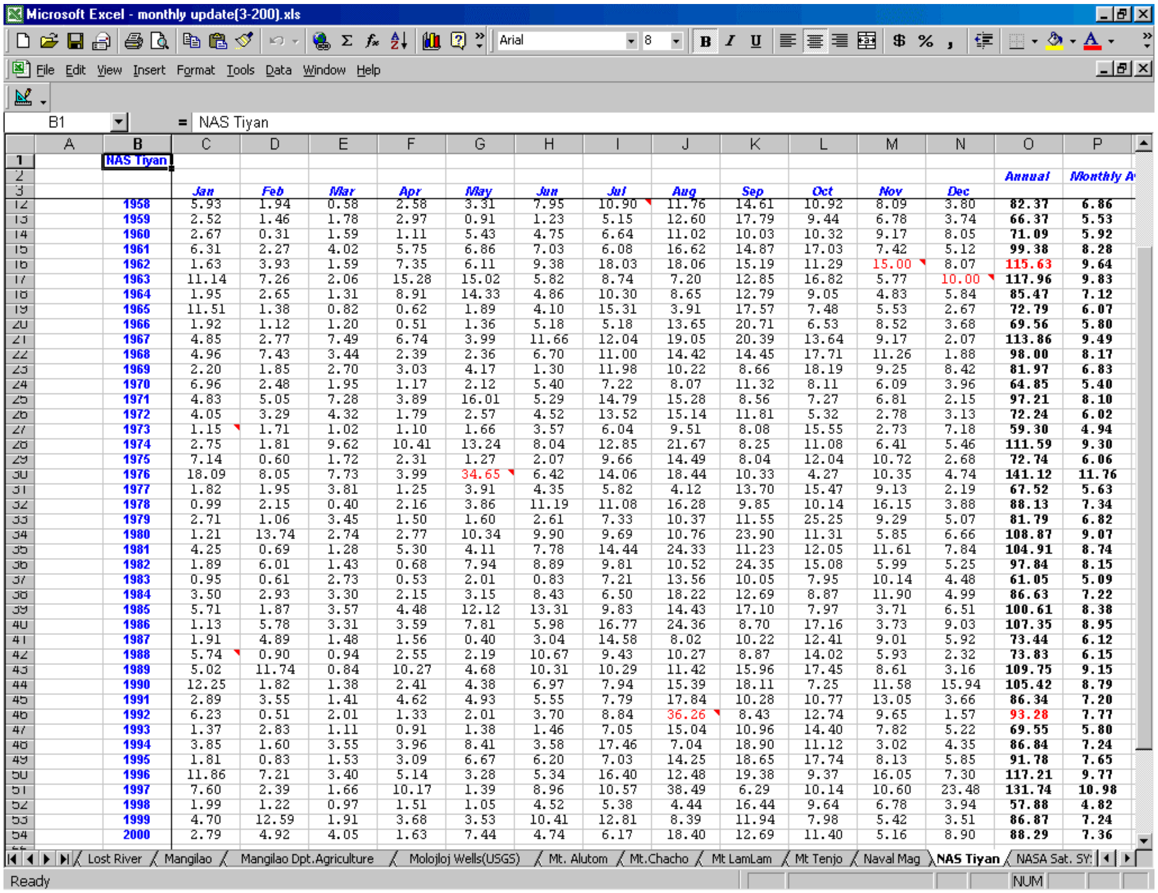
year comprising a new data sheet. An example of this database is shown in Fig. 3. The **MON** database was used primarily to ascertain missing data. This guided the search for sources to recover the missing data. This database was also used to verify the validity of site locations. For example, Fleet Weather Central (FWC) was collocated with the Naval Air Station until 1 January 1973 and with Nimitz Hill for the remainder of its existence. These two different sites are 8 km apart. The **Y-Y** database was used primarily to ascertain data quality and to reconstruct missing and unrepresentative data. This database allowed the easy comparison of nearby stations, in order to evaluate the data in terms of synoptic conditions, climatic conditions, and tropical cyclone and monsoon events.

In applying the databases, users can use the entire, reconstructed database (**red and black**) or the unchanged data (**black**). The data values that were changed are in most cases shown in the comments, and can be reinserted if desired. Comments associated with reconstructed data frequently contain the phrase “estimated from nearby stations”. The reconstruction of the data is, admittedly, subjective. It considers the value of the data with respect to the values at other stations, then determines whether or not the differences are realistic based on past characteristics under similar synoptic conditions, climatic conditions, and the occurrence of tropical cyclone and monsoon events. When available, daily rainfall records were reviewed to better evaluate the existing monthly records.

Synoptic conditions consider various rainfall regimes, which have different spatial and temporal rainfall characteristics. Different rainfall regimes include trade wind, shearline, tropical thunderstorm, monsoon and peripheral typhoon, and typhoon core. Monsoon and El Niño conditions were separated into event intensity (weak, moderate, strong) where possible. Climatic conditions consider the values of equatorial sea surface temperature distribution and the value of the Southern Oscillation Index (SOI). El Niño years, El Niño +1 years (drought years), La Niña years, and El Niño neutral years have specific types of rainfall characteristics. Where possible, comments on monsoon and tropical cyclone activity are shown at the appropriate month on the **Y-Y** database.

Larger differences are acceptable in the dry season where trade wind showers are not so uniform, and in transition seasons, where thunderstorms and heavy rainshowers display favorable locations and high gradients. Large differences are less acceptable under monsoon conditions or dry-season shearline conditions, where the rainfall is more uniform. The proximity of tropical cyclone eyewalls and rainbands to the stations also plays a role in determining the acceptable range of differences from nearby and islandwide stations. The rainfall distribution, in many respects, is heavily dependent on wind speed and direction, but a comprehensive wind statification was beyond the scope of this study. Instead, the synoptic situation was used to ascertain the major wind effects. The reconstructed data are not expected to be exact, but are deemed considerably more accurate and representative than the replaced or missing data. Attached comments also give an indication of how much the raw data may be in error. For example, a comment may state: “8.53: too low by a factor of 3; estimated from nearby stations”. On several occasions, reconstructed missing data were later replaced with later discovered missing data and were, in nearly all cases, found to be very representative. In some cases, newly discovered USGS data, nearly collocated with a reconstructed source, was substituted for the reconstructed value. In these cases, the reconstructed value was also shown to be very representative. As more and more information was learned about the rainfall characteristics of each station, reconstructed data were sometimes refined to reflect the effects of these characteristics.

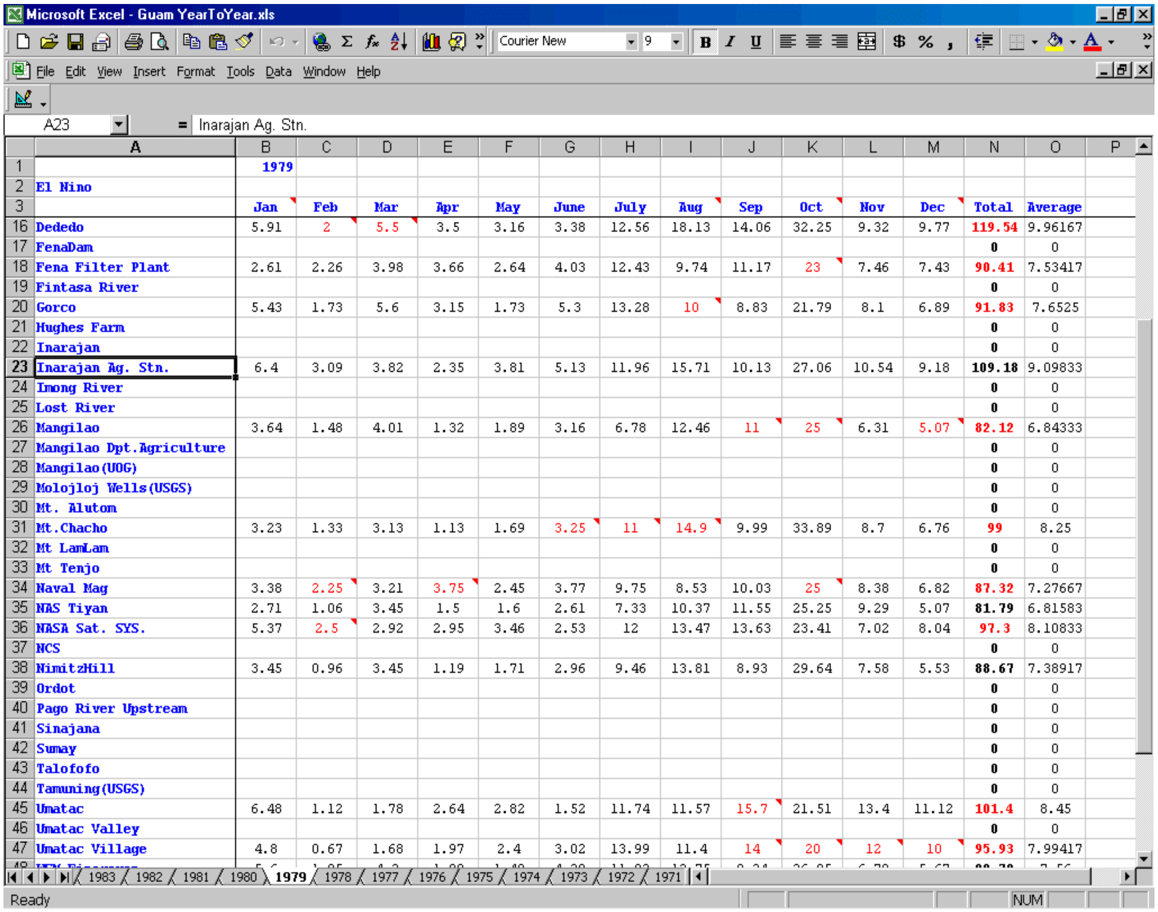
Once all of the quality changes were made in **Y-Y**, the **MON** database was modified with the changes in the **Y-Y** database. The **MON** database is treated as the primary 50-year monthly rainfall database for Guam.



NAS Tiyan

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Monthly A
1958	5.93	1.94	0.58	2.58	3.31	7.95	10.90	11.76	14.61	10.92	8.09	3.80	**82.37**	**6.86**
1959	2.52	1.46	1.78	2.97	0.91	1.23	5.15	12.60	17.79	9.44	6.78	3.74	**66.37**	**5.53**
1960	2.67	0.31	1.59	1.11	5.43	4.75	6.64	11.02	10.03	10.32	9.17	8.05	**71.09**	**5.92**
1961	6.31	2.27	4.02	5.75	6.86	7.03	6.08	16.62	14.87	17.03	7.42	5.12	**99.38**	**8.28**
1962	1.63	3.93	1.59	7.35	6.11	9.38	18.03	18.06	15.19	11.29	15.00	8.07	**115.63**	**9.64**
1963	11.14	7.26	2.06	15.28	15.02	5.82	8.74	7.20	12.85	16.82	5.77	10.00	**117.96**	**9.83**
1964	1.95	2.65	1.31	8.91	14.33	4.86	10.30	8.65	12.79	9.05	4.83	5.84	**85.47**	**7.12**
1965	11.51	1.38	0.82	0.62	1.89	4.10	15.31	3.91	17.57	7.48	5.53	2.67	**72.79**	**6.07**
1966	1.92	1.12	1.20	0.51	1.36	5.18	5.18	13.65	20.71	6.53	8.52	3.68	**69.56**	**5.80**
1967	4.85	2.77	7.49	6.74	3.99	11.66	12.04	19.05	20.39	13.64	9.17	2.07	**113.86**	**9.49**
1968	4.96	7.43	3.44	2.39	2.36	6.70	11.00	14.42	14.45	17.71	11.26	1.88	**98.00**	**8.17**
1969	2.20	1.85	2.70	3.03	4.17	1.30	11.98	10.22	8.66	18.19	9.25	8.42	**81.97**	**6.83**
1970	6.96	2.48	1.95	1.17	2.12	5.40	7.22	8.07	11.32	8.11	6.09	3.96	**64.85**	**5.40**
1971	4.83	5.05	7.28	3.89	16.01	5.29	14.79	15.28	8.56	7.27	6.81	2.15	**97.21**	**8.10**
1972	4.05	3.29	4.32	1.79	2.57	4.52	13.52	15.14	11.81	5.32	2.78	3.13	**72.24**	**6.02**
1973	1.15	1.71	1.02	1.10	1.66	3.57	6.04	9.51	8.08	15.55	2.73	7.18	**59.30**	**4.94**
1974	2.75	1.81	9.62	10.41	13.24	8.04	12.85	21.67	8.25	11.08	6.41	5.46	**111.59**	**9.30**
1975	7.14	0.60	1.72	2.31	1.27	2.07	9.66	14.49	8.04	12.04	10.72	2.68	**72.74**	**6.06**
1976	18.09	8.05	7.73	3.99	34.65	6.42	14.06	18.44	10.33	4.27	10.35	4.74	**141.12**	**11.76**
1977	1.82	1.95	3.81	1.25	3.91	4.35	5.82	4.12	13.70	15.47	9.13	2.19	**67.52**	**5.63**
1978	0.99	2.15	0.40	2.16	3.86	11.19	11.08	16.28	9.85	10.14	16.15	3.88	**88.13**	**7.34**
1979	2.71	1.06	3.45	1.50	1.60	2.61	7.33	10.37	11.55	25.25	9.29	5.07	**81.79**	**6.82**
1980	1.21	13.74	2.74	2.77	10.34	9.90	9.69	10.76	23.90	11.31	5.85	6.66	**108.87**	**9.07**
1981	4.25	0.69	1.28	5.30	4.11	7.78	14.44	24.33	11.23	12.05	11.61	7.84	**104.91**	**8.74**
1982	1.89	6.01	1.43	0.68	7.94	8.89	9.81	10.52	24.35	15.08	5.99	5.25	**97.84**	**8.15**
1983	0.95	0.61	2.73	0.53	2.01	0.83	7.21	13.56	10.05	7.95	10.14	4.48	**61.05**	**5.09**
1984	3.50	2.93	3.30	2.15	3.15	8.43	6.50	18.22	12.69	8.87	11.90	4.99	**86.63**	**7.22**
1985	5.71	1.87	3.57	4.48	12.12	13.31	9.83	14.43	17.10	7.97	3.71	6.51	**100.61**	**8.38**
1986	1.13	5.78	3.31	3.59	7.81	5.98	16.77	24.36	8.70	17.16	3.73	9.03	**107.35**	**8.95**
1987	1.91	4.89	1.48	1.56	0.40	3.04	14.58	8.02	10.22	12.41	9.01	5.92	**73.44**	**6.12**
1988	5.74	0.90	0.94	2.55	2.19	10.67	9.43	10.27	8.87	14.02	5.93	2.32	**73.83**	**6.15**
1989	5.02	11.74	0.84	10.27	4.68	10.31	10.29	11.42	15.96	17.45	8.61	3.16	**109.75**	**9.15**
1990	12.25	1.82	1.38	2.41	4.38	6.97	7.94	15.39	18.11	7.25	11.58	15.94	**105.42**	**8.79**
1991	2.89	3.55	1.41	4.62	4.93	5.55	7.79	17.84	10.28	10.77	13.05	3.66	**86.34**	**7.20**
1992	6.23	0.51	2.01	1.33	2.01	3.70	8.84	36.26	8.43	12.74	9.65	1.57	**93.28**	**7.77**
1993	1.37	2.83	1.11	0.91	1.38	1.46	7.05	15.04	10.96	14.40	7.82	5.22	**69.55**	**5.80**
1994	3.85	1.60	3.55	3.96	8.41	3.58	17.46	7.04	18.90	11.12	3.02	4.35	**86.84**	**7.24**
1995	1.81	0.83	1.53	3.09	6.67	6.20	7.03	14.25	18.65	17.74	8.13	5.85	**91.78**	**7.65**
1996	11.86	7.21	3.40	5.14	3.28	5.34	16.40	12.48	19.38	9.37	16.05	7.30	**117.21**	**9.77**
1997	7.60	2.39	1.66	10.17	1.39	8.96	10.57	38.49	6.29	10.14	10.60	23.48	**131.74**	**10.98**
1998	1.99	1.22	0.97	1.51	1.05	4.52	5.38	4.44	16.44	9.64	6.78	3.94	**57.88**	**4.82**
1999	4.70	12.59	1.91	3.68	3.53	10.41	12.81	8.39	11.94	7.98	5.42	3.51	**86.87**	**7.24**
2000	2.79	4.92	4.05	1.63	7.44	4.74	6.17	18.40	12.69	11.40	5.16	8.90	**88.29**	**7.36**

Figure 2. Example of the **MON** database for NAS Tiyan. Dark blue dates indicate that the data were checked twice or more from two or more data sources. Black data are original, verified data. Red data are data that were missing and had to be constructed, or data that were assessed to be too high or two low and were reconstructed. Red data in the bold annual total column indicates that data for one or more months was constructed/reconstructed. Red triangles indicate that the data sample has an attached comment.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1		1979													
2	El Nino														
3		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total	Average
16	Dededo	5.91	2	5.5	3.5	3.16	3.38	12.56	18.13	14.06	32.25	9.32	9.77	**119.54**	9.96167
17	FenaDam													**0**	0
18	Fena Filter Plant	2.61	2.26	3.98	3.66	2.64	4.03	12.43	9.74	11.17	23	7.46	7.43	**90.41**	7.53417
19	Fintasa River													**0**	0
20	Gorco	5.43	1.73	5.6	3.15	1.73	5.3	13.28	10	8.83	21.79	8.1	6.89	**91.83**	7.6525
21	Hughes Farm													**0**	0
22	Inarajan													**0**	0
23	Inarajan Ag. Stn.	6.4	3.09	3.82	2.35	3.81	5.13	11.96	15.71	10.13	27.06	10.54	9.18	**109.18**	9.09833
24	Imong River													**0**	0
25	Lost River													**0**	0
26	Mangilao	3.64	1.48	4.01	1.32	1.89	3.16	6.78	12.46	11	25	6.31	5.07	**82.12**	6.84333
27	Mangilao Dpt.Agriculture													**0**	0
28	Mangilao(UOG)													**0**	0
29	Molojloj Wells(USGS)													**0**	0
30	Mt. Alutom													**0**	0
31	Mt.Chacho	3.23	1.33	3.13	1.13	1.69	3.25	11	14.9	9.99	33.89	8.7	6.76	**99**	8.25
32	Mt LamLam													**0**	0
33	Mt Tenjo													**0**	0
34	Naval Mag	3.38	2.25	3.21	3.75	2.45	3.77	9.75	8.53	10.03	25	8.38	6.82	**87.32**	7.27667
35	NAS Tiyan	2.71	1.06	3.45	1.5	1.6	2.61	7.33	10.37	11.55	25.25	9.29	5.07	**81.79**	6.81583
36	NASA Sat. SYS.	5.37	2.5	2.92	2.95	3.46	2.53	12	13.47	13.63	23.41	7.02	8.04	**97.3**	8.10833
37	NCS													**0**	0
38	NimitzHill	3.45	0.96	3.45	1.19	1.71	2.96	9.46	13.81	8.93	29.64	7.58	5.53	**88.67**	7.38917
39	Ordot													**0**	0
40	Pago River Upstream													**0**	0
41	Sinajana													**0**	0
42	Sumay													**0**	0
43	Talofofo													**0**	0
44	Tamuning(USGS)													**0**	0
45	Umatac	6.48	1.12	1.78	2.64	2.82	1.52	11.74	11.57	15.7	21.51	13.4	11.12	**101.4**	8.45
46	Umatac Valley													**0**	0
47	Umatac Village	4.8	0.67	1.68	1.97	2.4	3.02	13.99	11.4	14	20	12	10	**95.93**	7.99417

Figure 3. Example of the **Y-Y** database for 1979. Black data are original, verified data. Red data are data that were missing and had to be constructed, or data that were assessed to be too high or two low and were reconstructed. Red data in the bold annual total column indicates that data for one or more months was constructed/reconstructed. Red triangles indicate that the data sample has an attached comment. Comments in the month row indicate typhoon and monsoon activity. Upper left text (blue) indicates the ENSO status.

d. Analysis

Annual data were plotted for each year from 1950 through 1999. The southern part of the island had more observation sites from 1950 through 1979. The northern half of the island had more observation sites during the last half of the 50-year period. Isohyet analyses were conducted for each year. As more and more information was revealed about rainfall distribution and patterns from the analyses, a reanalysis was conducted for each map to fine-tune the annual rainfall distribution. This process was performed by each investigator. The analyses were very similar. Discrepancies were discussed and resolved into a single consensus analysis. The mean annual rainfall map was developed by selecting 150 points on Guam that included all of the rain gauge sites. These 150 sites are shown in Figure 1 and listed in Appendix A. The 50, 1-year values for each of the 150 points were then averaged to derive a 50-year value. These rainfall values were then plotted at the appropriate 150 locations, and an analysis was conducted in the same manner as for the individual annual analyses. The resulting, fine-tuned analysis produced the 50-year annual rainfall distribution map for Guam (Figs. 4 and 5). The results are somewhat preliminary since only a few monthly and seasonal analyses were accomplished in this study. A more complete monthly and seasonal analysis will be accomplished in a follow-on study. Data for individual stations is archived in the attached CD.

To understand the entire island rainfall distribution, it was necessary to determine the nearby ocean rainfall as well. For each year, an ambient, background over-ocean rainfall was determined. This rainfall was governed by the overall synoptic conditions, uninfluenced by the island. Then, qualitative off-shore rainfall distributions were constructed as revealed by radar imagery. The radar indicates a large rainfall maximum northwest of Orote Point and a lesser maximum east of south-central Guam (e.g., Fig. 6). The offshore western maximum is hypothesized to be the result of the convergence of flow around the island during ambient flow that is northeasterly through southeasterly. More research is needed to explain the maximum rainfall east of the island.

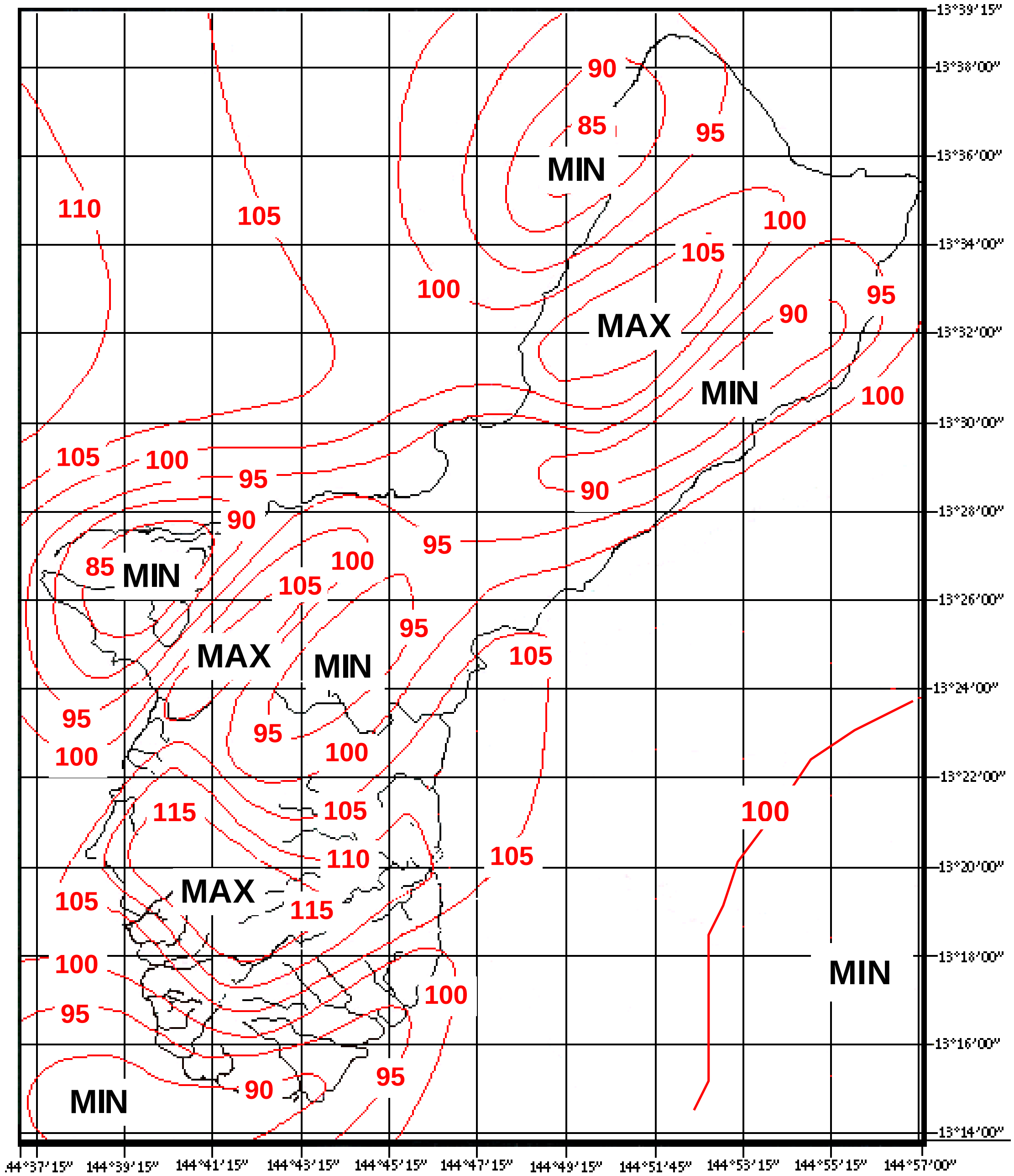


Figure 4. Annual rainfall distribution map for Guam based on the compositing of 50 annual analyses from the newly developed 1950-1999 rainfall database. Isohyets are in inches.

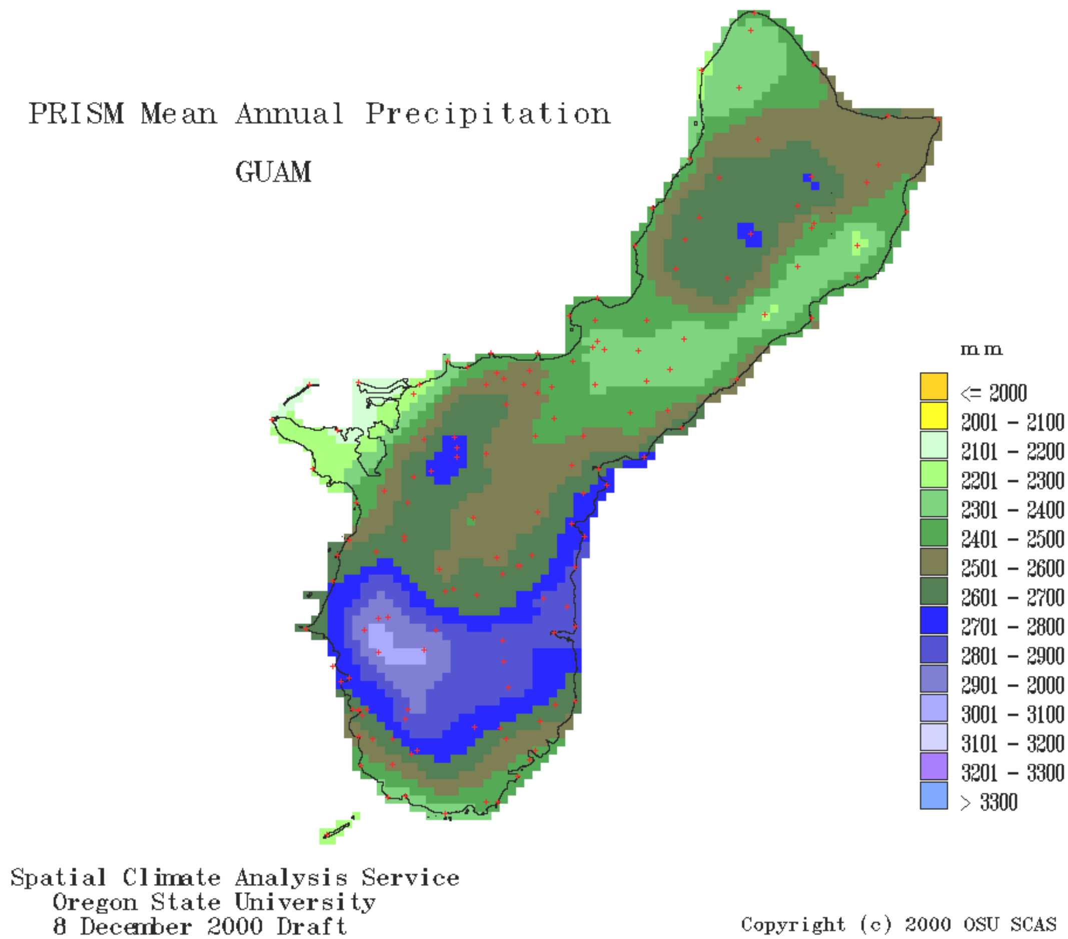


Figure 5. Annual rainfall distribution map for Guam based on the compositing of 50 annual analyses from the newly developed 1950-1999 rainfall database. Isohyets are in millimeters at the indicated color-coded intervals. This map was produced by the Spatial Climate Analysis Service (Oregon State University) using the **MON** rainfall data as input.

3. Results and Discussion

a. Rainfall patterns and a long-term annual rainfall distribution map for Guam

The annual rainfall distribution maps for Guam (Figs 4 and 5) show that the major rainfall patterns are generally oriented north-northeast—south-southwest, with maxima and strong rainfall gradients located along the western and southern mountains. Another maximum lies in the central part of the north end of the island. Minima lie in the center of the island, southwest of Mount Santa Rosa, south of Ritidian Point, and over extreme southern Guam. Again, these are oriented in a general northnortheast--southsouthwest manner. Year-to-year similarities and differences were found to coincide with varying synoptic situations. The greatest deviations from the average map occurred when tropical cyclone events had a major contribution to the rainfall.

Radar and satellite imagery indicate the presence of two significant off-shore maxima. One is in a northeast-southwest oriented band with a western boundary that begins about 50 km east of south-central Guam. Another is a more concentrated area of enhanced rainfall stretching in a narrow band from the western tip of Orote Point to about 50 km northwest of Orote Point (e.g., Fig 6). While not yet rigorously quantified, event-by-event examinations reveal that rainfall totals offshore to the west of the Orote Point are substantially greater than those on the island. Most lightning flashes observed from Guam are offshore west of Orote Point. An offshore minimum of rainfall is commonly observed on radar between Guam's eastern shore and the previously mentioned maximum 50 km out to sea. This is often manifested in the decay of showers and thunderstorms as they move toward the island from the east or southeast. The analysis of the average annual rainfall over the open ocean, unperturbed by the island, is estimated to be about 100 inches.

b. Rainfall climatology

At the Taguac Weather Service Meteorological Observatory (WSMO), the mean annual rainfall during the period 1957-92 was 101.84 inches with a standard deviation of 22.2 inches. The mean dry-season (January through June) rainfall was 31.63 inches with a standard deviation of 16.62 inches; the mean wet-season (July through December) rainfall was 70.21 inches with a standard deviation of 9.79 inches. The wet-season/dry-season split of the annual total is thus about 70% and 30%, respectively. The driest annual total in the time series is the 67.06 inches recorded in 1983. The WSMO was deactivated in 1995, so it was not recording during 1998—which, at other long-term stations, was Guam's driest year in the past century. The wettest annual total in the time series is the 165.91 inches recorded during 1976. The wettest dry season (93.89 inches) occurred in 1976, and the driest dry season (9.59 inches) occurred in 1983. The wettest wet season (92.08 inches) occurred in 1962, and the driest wet season (50.50 inches) occurred in 1973. Nearly all extremely dry years on Guam occur during the year following an El Niño event.

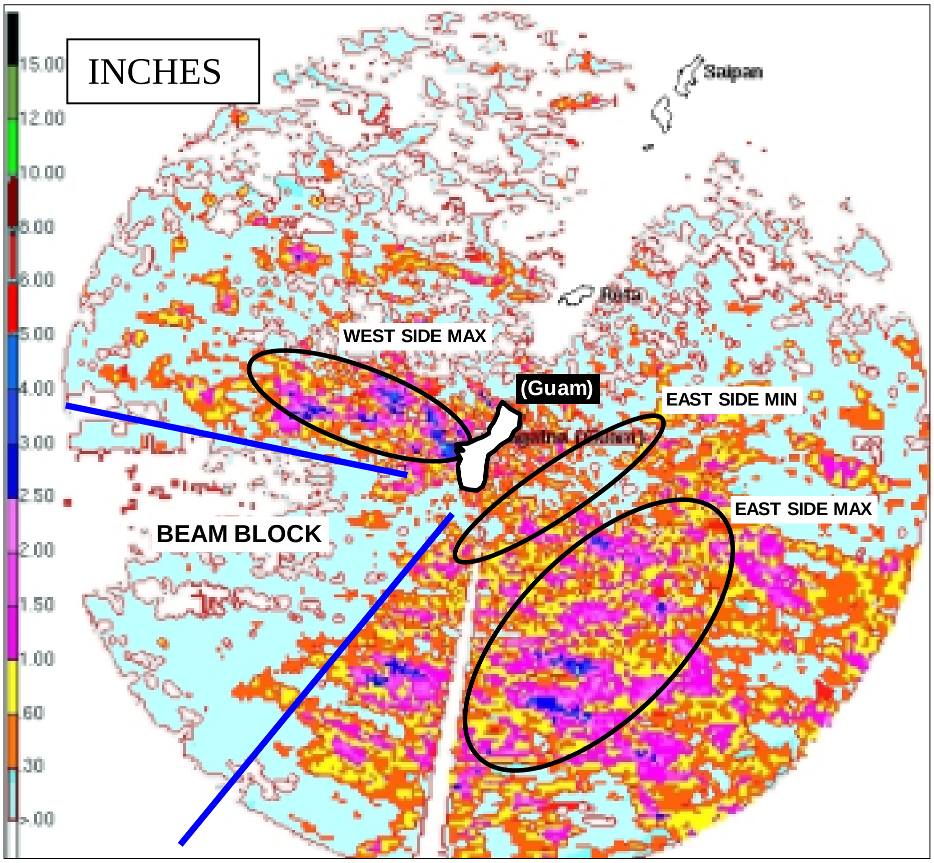


Figure 6. Three days of integrated rainfall (22 May 2002 through 25 May 2002) showing the possible effect of Guam on the large-scale rainfall pattern in a condition of widespread showers. Note the concentration of rainfall on the lee side of the island (western side in east wind conditions), and the banded swaths of max and min rainfall to the east of Guam.

The lowest mean (4.06 inches) and median (2.66 inches) monthly rainfall occurs in March. The highest mean monthly rainfall (15.17 inches) occurs in August; however, the highest median monthly rainfall (14.40 inches) occurs in September. Monthly rainfall values below one inch have occurred in February through June. Monthly rainfall values above 20 inches have occurred in January, May, July, August, September, October, and December. The lowest value of the monthly time series of the rainfall at the Taguac WSMO is the reading of 0.50 inches during April 1965. The highest monthly value is the 40.13 inches recorded during May 1976, of which Typhoon Pamela contributed 27.01 inches—Guam's record 24-hour rainfall.

A five-month moving average of the monthly rainfall anomaly at the WSMO for the period 1960-99 (Fig. 7) shows high year-to-year variability. Much of this year-to-year variability is related to the irregular recurrence of El Niño, with some of the driest years occurring in the year following EL Niño (e.g., 1966, 1973, 1983, 1988, and 1998).

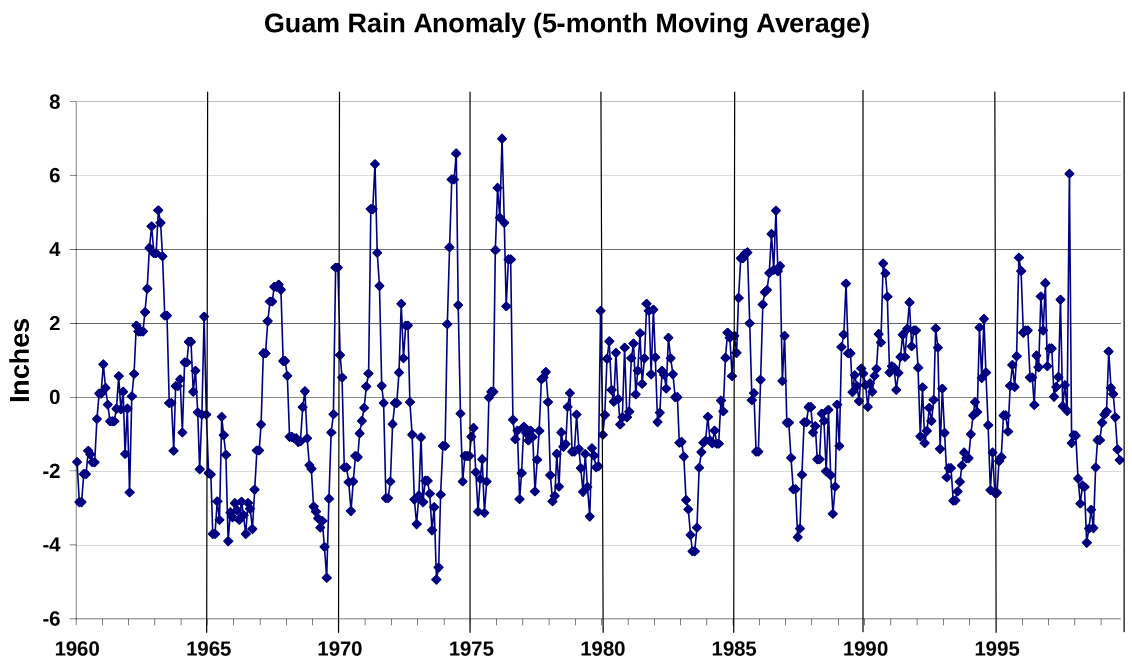


Figure 7. A five-month moving average of the monthly rainfall anomaly at the WSMO, Taguac, Guam.

c. Inter-decadal variations

There is intense pressure on the scientific community to predict the long-term fate of earth's climate (e.g., global warming); and further, to show the impact of such long-term climate change at regional scales (e.g., the tropical Pacific islands, Antarctica, and the world's grain belt). It has been suggested by some (e.g., Morrissey and Graham 1996) that the hydrologic cycle of the western Pacific may change in a warmer world in a manner that would see tropical islands in the northwest part of the basin (e.g., Yap, Palau, Guam and the CNMI) become drier while islands of the central equatorial and South Pacific (e.g., Kiribati southeastward through the Society Islands) become wetter. As research continues on the problem of long-term climate change, attention has recently been focused on climate fluctuations at periods of one to several decades. These inter-decadal climate variations are troubling because they may mask, or may be mistaken for, longer-term climate changes. A plethora of local and regional climate patterns have been defined, for example: the Pacific Decadal Oscillation (PDO) (Minobe 1997), the North Atlantic Oscillation (NAO) (Uppenbrink 1999), and the Southern Oscillation. Nearly all of these have prominent inter-decadal variations. Any projections of a change in the hydrologic cycle in the western Pacific in a warmer world must take account of the presence of susbstantial inter-decadal variations of rainfall, as observed on Guam.

The 50-year record allowed some assessment of interdecadal variations in Guam's rainfall. The 1950s was a very dry decade, as indicated by the sharp downward slope of the running acculululations of rainfall anomalies shown in Fig. 8. The late 1960s to the mid-1970s were slightly drier than the long-term average, while the 1980s through the early 1990s were slightly wetter than the long-term average The period 1960-65 was very wet as indicated by the sharp rise of the running accumulation of the rainfall anomalies shown in Fig. 8. The distribution of these long-term trends are consistent at both Tiyan and Andersen AFB (the two stations with the longest complete rainfall records on Guam). Superimposed on the long-term rise and fall of the integrated rainfall are sharp peaks and troughs that are primarily associated with ENSO: the period from the end of the El Niño year through the year following El Niño tends to be very dry.

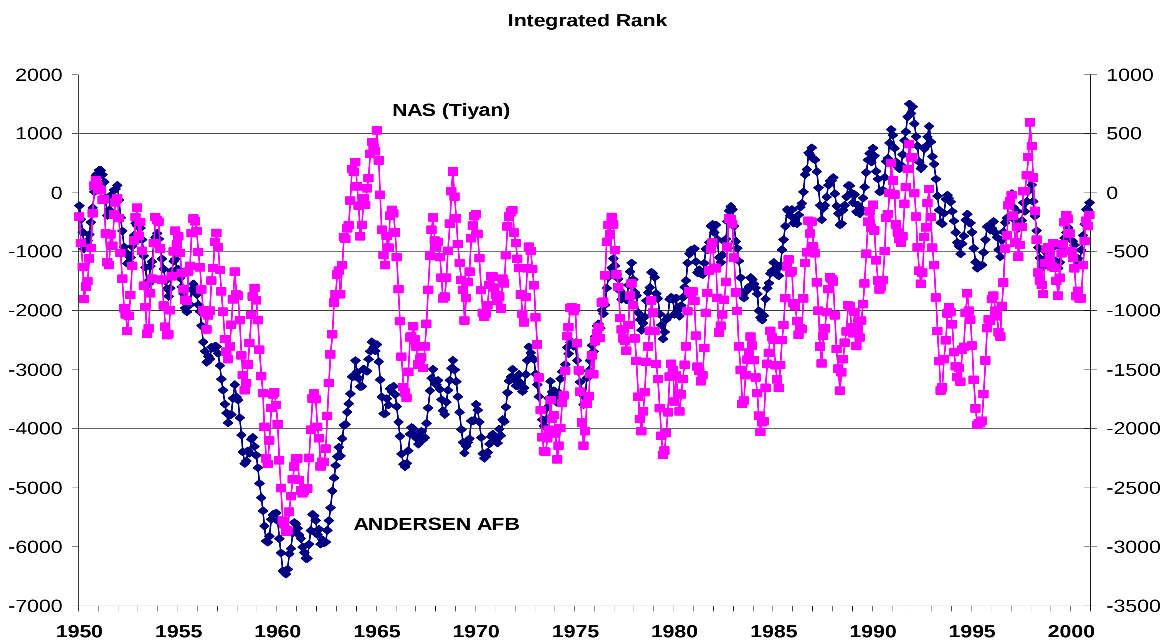


Figure 8. Running accumulations of the rank (lowest month = -305, highest month = +306) of each month's rainfall for the period 1950 to 2000 (annual cycle not removed). Complete records were available from Andersen AFB and from the Naval Air Station (NAS) at Tiyan. Prominent features include the extreme dryness of the 1950s and a very wet period in the early 1960s. Recent prominent rainfall fluctuations include relative dryness from late 1992 through 1995, and a wet period during 1996 and 1997. These fluctuations are related to El Niño.

d. Comparisons with earlier annual rainfall distribution maps

Figure 9 shows the annualy rainfall distribution analysis of Jordan (1955) and Figure 10 shows that of NRCS (1987). There are several differences between the distributions indicated by these studies and the distributions from our study. That of Jordan for the dry season and the wet season of 1952 shows two maxima over the southern mountains and another maximum over northern Guam in the dry season (Jan-Apr), but very small amounts of rain. The wet season (Jul – Oct) had much more rain that was more widespread in distribution with smaller rainfall gradients (as a percentage of the maximum).

The analysis of the NRCS is for the entire year, and uses many years of data. The rainfall distribution is qualitatively similar to that of both Jordan and this study. However, when compared with the analysis in this study, several differences are apparent. The maximum area in the south is much larger in NRCS analysis. In addition, the isohyets across central Guam are perpendicular to those in our analysis (i.e, orientation of the isohyets is east-west as opposed to northeast-southwest orientation of our isohyets). Furthermore, our analysis indicates several maxima and minima on the island, and the maximum rain region in southern Guam extends further to the coast.

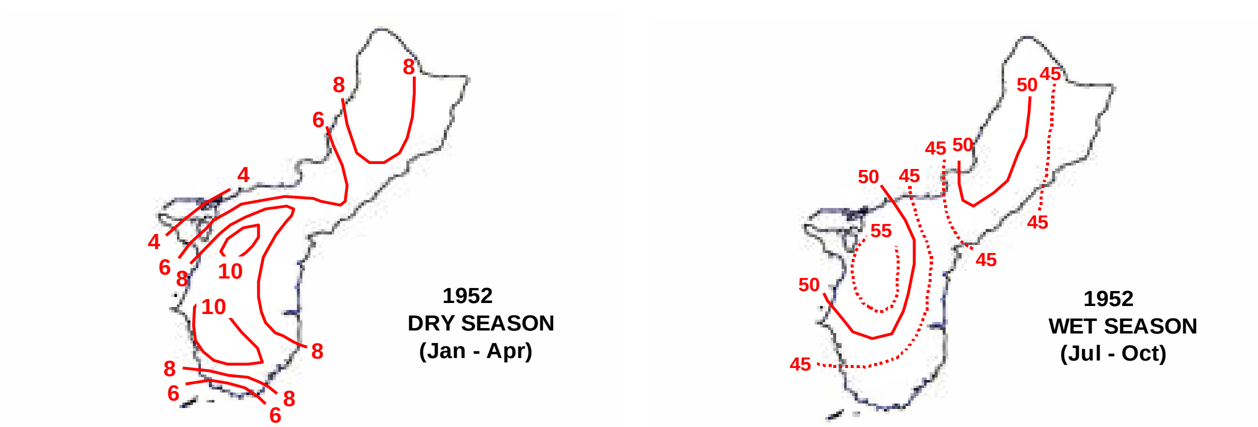


Figure 9. Guam's rainfall distribution during the dry season (left panel) and the wet season (right panel) of 1952 as analyzed by Jordan (1955).

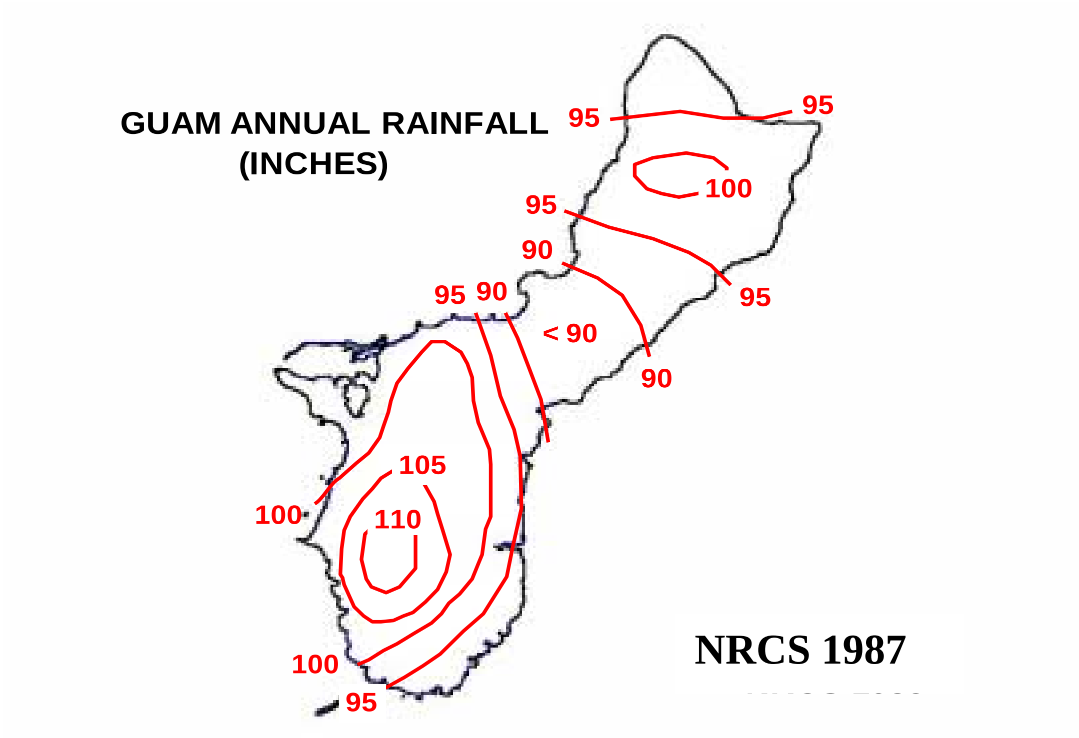


Figure 10. Guam annual rainfall (inches). This map, produced by the Natural Resources Conservation Service (NRCS) (1987), is currently used as the official rainfall distribution for Guam building codes and storm drainage practices.

4. Summary and Further Research

A careful analysis of all available rainfall data collected by US and Government of Guam agencies since 1950 reveals that the rainfall distribution patterns on Guam are much more complex than previously indicated. In addition, the data show that the rainfall gradients and the patterns are strongly influenced by the northeast-southwest orientation of the island, the shape of the island, and the terrain of the island.

The analysis of annual rainfall over the open ocean, unperturbed by the island, is found to be about 100 inches. The analysis further shows that there are several rainfall maxima and minima on the island. The maxima are in the north-central part of Guam, down the western mountains, across the southern mountains, and up the southeast coastline. The minima are located southwest of Mount Santa Rosa to Tiyan, south of Ritidian Point, Orote Point to Cabras Island, south-central Guam east of Fena Lake and northeast toward Barrigada, and southwestern Guam and Cocos Island. The strongest rainfall gradients are located along and parallel to the major mountain ranges. Strong gradients are also seen where terrain produces a rain shadow. Mount Santa Rosa and Mount Barrigada produce strong rain shadows, primarily during northeasterly and easterly flow during the drier months.

In the future, Guam's NEXRAD may prove to be crucial in solving once and for all, and in very high detail, the spatial pattern of rainfall near and over Guam. A coordinated effort to acquire and analyze the radar data for monthly, seasonal, and annual rainfall distributions is recommended. Also, when enough data has been collected, one may further analyze the radar data for rainfall patterns segregated by meteorological criteria (e.g., windspeed and direction). The radar has already shown that the common assumption that rainfall on Guam is governed largely by elevation – as it is on most of the Hawaiian Islands – is wrong during most major precipitation events (Fig. 11a,b). For example, rainfall during typhoons is hardly affected by the topography of Guam at all. These most extreme of Guam's rain events have rainfall distributions that are related to the structure of the typhoon. During direct passages of typhoons over Guam, the heaviest rain tends to fall in the regions just near the edge of the eye, where the longest duration of heaviest rain is experienced. There are slightly lower amounts in areas that experience the eye, and rapid drop-off of amounts as one moves outward from the eye wall cloud (Fig. 12a,b).

Even though the NEXRAD could provided extensive spatial coverage of Guam's rainfall, an expansion of rain gage coverage on Guam (or keeping the existing gages operating) is necessary to establish the numerical value of short- and long-term rainfall amounts. Rain gages are still very important even with precipitation-estimating radar, since the radar rain-rate algorithms often yield erroneous rainfall magnitudes (usually underestimates of 10-15%), while producing an accurate representation of the spatial pattern and gradients of rainfall. Also, there are several places on Guam, and just offshore of the island, where beam blockage prevents NEXRAD from obtaining accurate rain-rate measurements. The National Weather Service is continuing to expand its cooperative observer network, and the UOG is expanding its on-campus rain gage network and other cooperating observers around the island. Though often overlooked in the age of ground radar and space-based rain-rate retrievals, the necessity of a surface rain gage network should not be underestimated.

Further studies, will provide monthly and seasonal (wet, dry, and spring and fall transitions) rainfall distribution maps, and will reveal differences in rainfall distribution patterns during El Niño, La Niña, and "normal" years.

Also of interest are the highest values of short-term rainfall rates. It is likely that the peak short-term (1-hr, 3-hr, and 6-hr) rain events, and the peak daily rain totals occur during the direct passages of typhoons over the island. During the year 2002, Guam experienced the eye passage of two typhoons: Chataan (July) and Pongsona (December). Each of these typhoons produced phenomenal short-term rainfall rates that exceeded currently accepted 100-yr return-period values (Guam Storm Drainage Manual 1985). Hourly rainfall rates in excess of 6 inches were measured in the peak accumulation regions of each of these typhoons. Three-hourly rates approached 15 inches, and 24 hour totals were in excess of 20 inches (Fig. 13a). Some stream flows were at record levels in each of these typyhoons. As a first approximation, the swath of heaviest rain in a typhoon is found at that location that takes the longest path through the eye wall cloud, and does not go into the rain-free eye (Fig. 13b). An analysis of peak rain rates on Guam and Saipan is planned in a separate report.

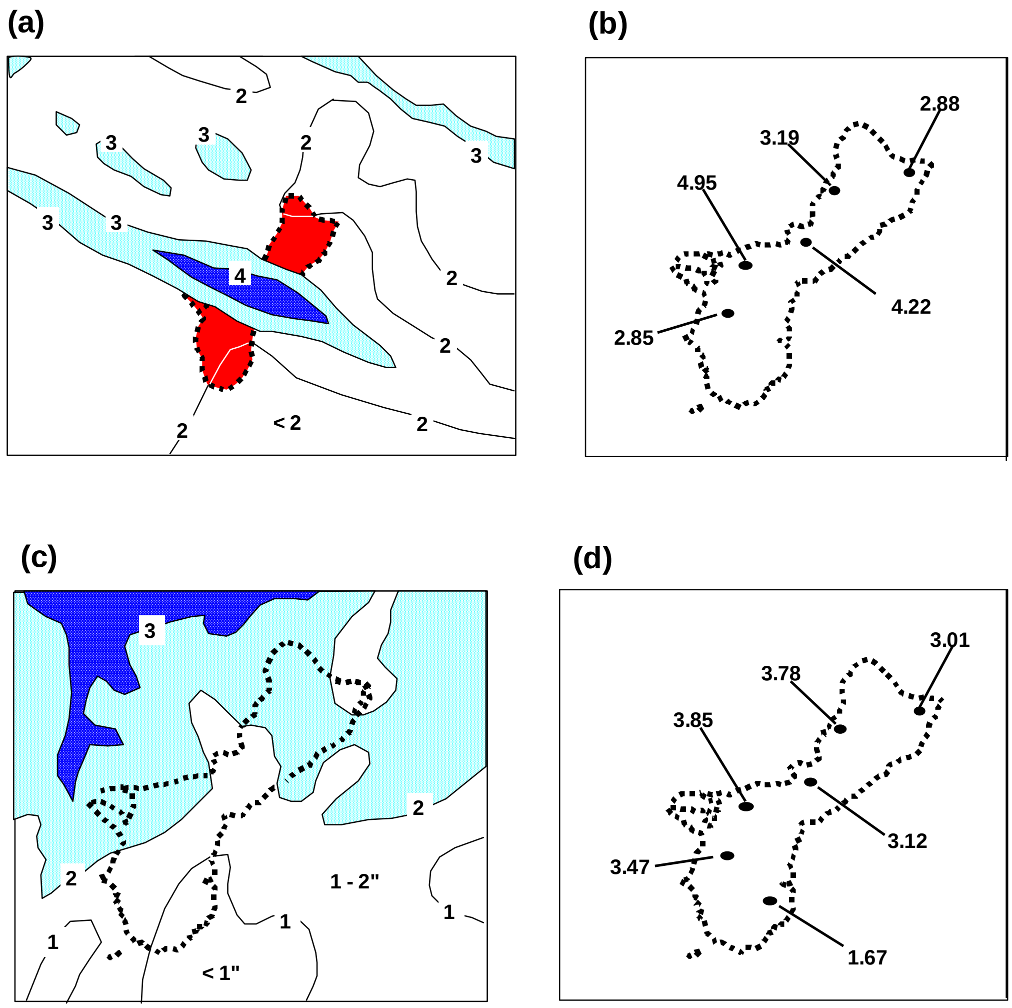
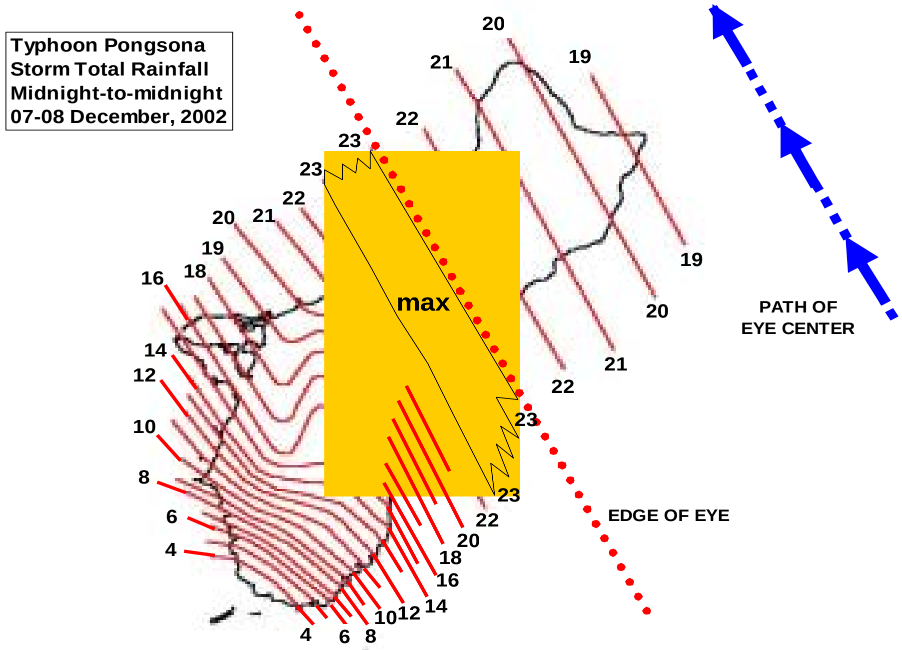


Figure 11. Rainfall deposited on Guam during the near passage of tropical cyclones. (a) Rainfall associated with near passage of typhoon Wilda as estimated by NEXRAD during the period 0220 UTC – 2147 UTC 24 October, 1994. Outer contour is 2 inches, light blue inidicates 3 to 4 inches, dark blue indicates 4 inches or more. (b) The rainfall measured on Guam during the same time period. (c) Rainfall associated with the near passage of Tropical Storm Verne as estimated by NEXRAD during the period 0420 UTC 18 Oct – 0105 UTC 20 October. Outer contour is 2 inches, light blue indicates 2 to 3 inches and (a) lue indicates 3 inches or more. (d) The rainfall measured on Guam for the same p



(b)

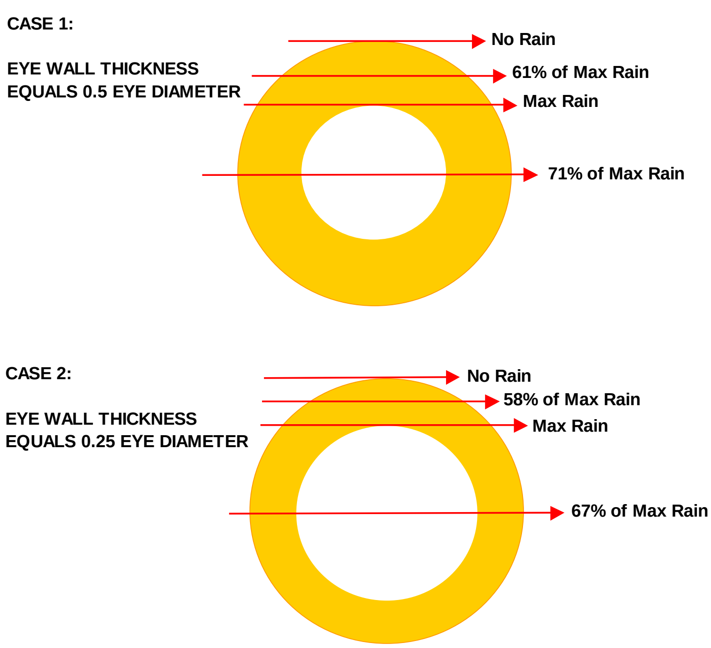


Figure 12. (a) Rainfall measured during the passage of Typhoon Pongsona over Guam. (b) Schematic diagram shows rainfall expected as a function of path taken through eye wall.

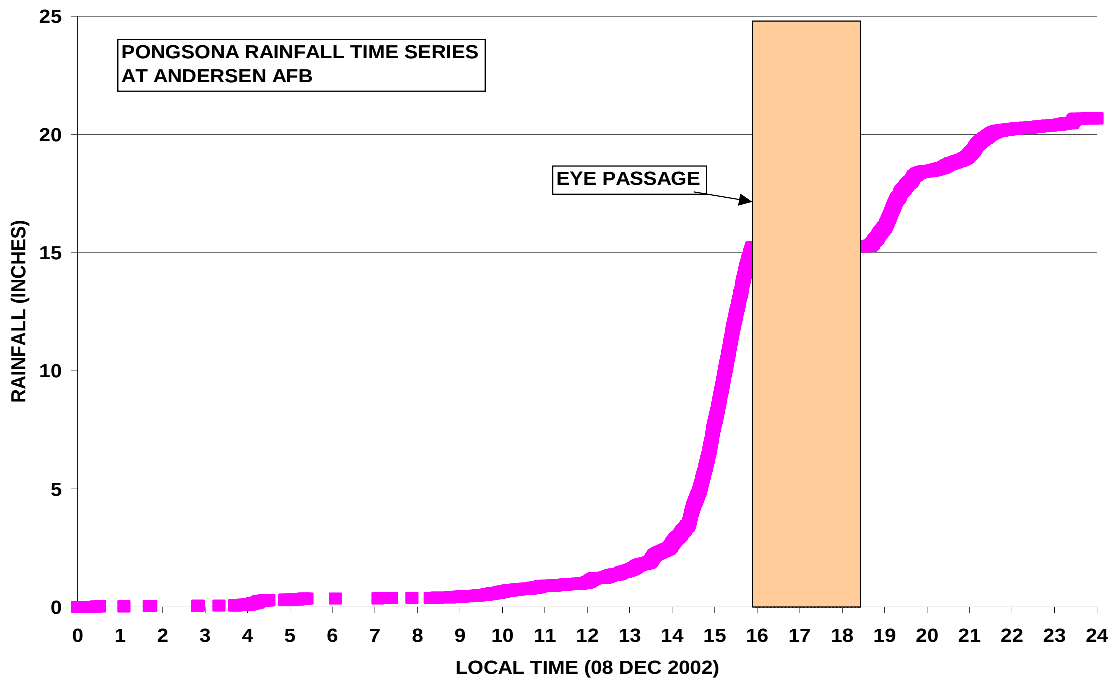


Figure 13. A time series of the rainfall accumulated at Andersen AFB during the passage of Typhoon Pongsona. Note the cessation of rain as the eye passes over. Rain rates exceeded 7 inches per hour in the first half of the storm. (Data Source: NASA TRMM rain gage network).

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APPENDIX A

Rainfall data locations

	Location	Latitude	Longitude
1	Cocos Island	13.234415	144.643848
2	Inarajan	13.2717	144.7472
3	Inarajan Ag Station	13.277	144.75
4	Umatac Fire Station	13.298191	144.656907
5	Umatac Village	13.295318	144.661625
6	Umatac #6 Village	13.2981	144.6603
7	Umatac Valley	13.297591	144.664199
8	Umatac PUAG	13.283	144.667
9	Fintasa River	13.2833	144.735
10	Inarajan-NASA	13.308594	144.73594
11	Malojloj	13.299521	144.760062
12	Mt. LamLam	13.338467	144.663041
13	Almagosa Springs	13.344943	144.674793
14	Imong River	13.338038	144.698812
15	Camp Dealey	13.350265	144.766428
16	Fena Dam	13.357854	144.704002
17	Fena River	13.355967	144.719829
18	Lost River	13.3591	144.7083
19	Talofofo	13.354222	144.753663
20	Talofofo Golf Course	13.3667	144.733
21	Hughes Farm	13.3708	144.7419
22	Windward Hills	13.374968	144.730295
23	Agat	13.384318	144.655363
24	Naval Magazine	13.3836	144.6828
25	Fena Filter Plant	13.3861	144.6825
26	Ylig Filter Plant	13.3978	144.7508
27	Apra Heights	13.4031	144.685
28	Gorco Refinery	13.4164	144.6883
29	Mt. Tenjo	13.419318	144.697097
30	Mt. Alutom	13.431113	144.710307
31	Pago River	13.4217	144.7681
32	Sumay	13.439938	144.648746
33	BMP Camp 2	13.4347	144.6931
34	Mt. Chacho	13.43566	144.708635
35	Pago River (upstream)	13.4369	144.7503
36	Mangilao Ag Station	13.4492	144.7983
37	Mangilao Forest Service	13.45	144.817
38	Piti	13.4583	144.6878
39	Piti Agricultural Station	13.4628	144.6908
40	Nimitz Hill	13.470269	144.747228
41	Agana Springs	13.462356	144.758041
42	Adelup Reservoir	13.468739	144.730401
43	Adelup Point	13.479199	144.726611
44	Fort Apugan	13.462515	144.72498
45	Agana Navy Yard	13.478515	144.750893
46	Barrigada Booster Station	13.4745	144.7692
47	Tamuning (ACEORP)	13.4817	144.7786
48	Naval Air Station A	13.4806	144.7847
49	Naval Air Station B	13.480186	144.802139
50	Tamuning (USGS)	13.4853	144.7811
51	Naval Medical Center	13.4961	144.78
52	Harmon Field	13.496432	144.806517
53	Dededo (PUAG)	13.5167	144.8469

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54	NCTAMS Finagayan	13.568177	144.843033
55	Yigo Agricultural Station	13.5431	144.89
56	Yigo Animal Quarantine St	13.545	144.8911
57	NWS ObsTaguac	13.537261	144.826247
58	Andersen AFB a	13.574922	144.[illegible]
59	Andersen AFB b	13.5658	144.[illegible]
60	Ritidian Point	13.652445	144.[illegible]
61	Mt. Machanao	13.643179	144.859266
62	Northwest Field Sat	13.613745	144.852883
63	Tarague Beach	13.626111	144.891363
64	Tagua Point	13.600119	144.929325
65	Pati Point	13.597589	144.954154
66	Anao Point	13.551009	144.937806
67	Lujuna Point	13.517826	144.91284
68	Pagat Point	13.496695	144.889553
69	Taguan Point	13.465647	144.852102
70	Fadian Point	13.441228	144.823785
71	Lates Point	13.42577	144.804701
72	Pago Point	13.412061	144.786375
73	Pago Bay	13.420219	144.781722
74	Ylig Point	13.38609	144.77526
75	Ylig Bay	13.392127	144.768292
76	Togcha Point	13.369952	144.770023
77	Ipan Point	13.33961	144.770015
78	Talofofo Bay	13.337152	144.759447
79	Nomna Point	13.302045	144.770044
80	Agfayan Point	13.26357	144.741146
81	Guijen Point	13.251087	144.730971
82	Aga Point	13.251087	144.725072
83	Liquon Point	13.244846	144.703868
84	Achung Bay	13.254251	144.683605
85	Jaotan Point	13.252968	144.675055
86	Geus River Gauge St	13.269929	144.67723
87	Merizo Pier	13.268871	144.660606
88	Toguan Bay	13.284119	144.659929
89	Umatac Bay	13.296829	144.660349
90	Foucha Point	13.311535	144.650602
91	Cetti Bay	13.313844	144.655134
92	Pinay Point	13.320256	144.647439
93	Facpi Point	13.339322	144.632733
94	Nimitz Beach Park	13.363262	144.646498
95	Gaan Point	13.375574	144.649063
96	Apaca Point	13.402592	144.658468
97	Apuntua Point	13.419777	144.637093
98	Orote Point	13.444572	144.615804
99	Sasa Bay	13.45745	144.673379
100	Cabras Island	13.463968	144.659781
101	Asan Bay	13.471798	144.714576
102	Asan Point	13.475095	144.70498
103	Oka Point	13.498153	144.766796
104	Ypao Point	13.50656	144.780736
105	Puntan Dos Amantes	13.533499	144.799708
106	Tanguissan Point	13.553061	144.808805
107	Haputo Point	13.578163	144.828162
108	Uruno Point	13.622623	144.834386
109	Mt. Santa Rosa	13.534046	144.913456
110	Mt. Barrigada	13.486436	144.824875
111	Mt. Macajna	13.453203	144.735257
112	Mt. Alifan	13.378189	144.668965
113	Mt. Almagosa	13.344429	144.669946
114	Mt. Jumuyong Manglo	13.32682	144.670148
115	Mt. Bolanos	13.297872	144.684965

116	Mt. Ilicho	13.293196	144.683722
117	Mt. Schroeder	13.282463	144.677014
118	Mt. Sasalaguan	13.277452	144.690489
119	Mt. Finansanta	13.274729	144.686831
120	Mt. Patsud	13.292186	144.75247
121	Perez Acres	13.523073	144.883376
122	Latte Heights	13.498576	144.8[illegible]
123	NCTAMS Barrigada	13.470617	144.8[illegible]
124	San Antonio Barrigada	13.464633	144.805894
125	Chalan Pago	13.436947	144.774259
126	Ordot	13.445568	144.758775
127	Sinajana	13.459379	144.751526
128	Upper Sigua Falls	13.426352	144.710179
129	13° 20 ‘ --144° 44’	13.333333	144.733333
130	Junction Rt 4A & Rt 17	13.371048	144.740581
131	Junction Rt 1 & Rt 3	13.522044	144.821312
132	Lower Sigua Falls	13.428191	144.724991
133	Tarzan Falls	13.394522	144.718269
134	Talofofo Falls	13.321676	144.734515
135	Inarajan Falls	13.288708	144.71848
136	Fintasa River Falls	13.287864	144.73172
137	Imong River Falls	13.328058	144.693371
138	Morrow Lake	13.369092	144.700528
139	Maina	13.466456	144.734027
140	Agana Heights	13.463282	144.744449
141	Y-sengsong	13.540133	144.859489
142	South Finagayan	13.547951	144.83345
143	Potts Junction	13.588081	144.862704
144	Chaguian	13.568724	144.889585
145	Mataguak	13.553608	144.882745
146	Junction Rt 2A & Rt 5	13.408724	144.673463
147	Baza Gardens	13.375783	144.747966
148	Yona	13.407952	144.774474
149	Toto	13.463325	144.779835
150	Glass Breakwater Mid	13.46281	144.634475

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APPENDIX B

Period of record for selected rainfall stations

Period of Record	**AAFB**	**Aceorp Tamuning**	**Adelup PT**	**Adelupe res**	**Agana Spring**	**Agat**	**Almagosa Sp**
Start	Jan-50	Jan-50	Jan-50	Jan-52	Jan-52	Jul-78	Jan 1950 - Dec 1970
End	Dec-00	Jan-51	Dec-51	Dec-52	Aug-57	Dec-00	Jan 1972 -Dec 1975
							July 1992 - Dec 1975
Period of Record	**Apra Heights**	**Barrigada BS**	**BPM Camp 2**	**Camp Dealey**	**Cocos Island**	**Dededo**	**Fena Dam**
Start	Jan-50	Oct-51	Jan-50	Jan-50	Jan -1956 to Jan-1966	Jul-78	Jan -1950 tp Dec- 1970
End	Dec-53	Dec-54	Jun-53	Dec-50	Jan 1981 to Apr-1982	Dec-00	Jan 1972 to Dec 1974
							Jan -1980 to Dec-1982
							Jan -1985 to Dec 1985
							Jan 1987 to Sep 1989
							Jan 1995 to Dec 1995
							Jan-98
							Jan 1999 to Apr 1999
Period of Record	**Fena Filter Plant**	**Fintasa River**	**Gorco**	**Hughes Farm**	**Inarajan**	**Inarajan AG Stn**	**Imong River**
Start	Jan 1951 to Dec 1979	Jan-51	Jul-72	Jan-59	Jan 1950 to Dec 1950	Jul-78	Jan 1972 to Dec 1972
End	Jan 1988 to Dec 1988	Dec-66	Dec-79	Dec-61	Jan 1981 to Jul 1981	Dec-00	Jan 1988 to Dec 1988
	Jan 1991 to Dec 1992				Sep 1981 to Oct 1981		
Period of Record	**Lost River**	**Mangilao**	**Mangilao Dpt. Agriculture**	**Malojloj Wells (USGS)**	**Mt Alutom**	**Mt. Chacho**	**Mt Lamlam**
Start	Aug-51	Jan-70	Jan-70	Jul-72	Jan 156	Jan 1973 to Dec 1979	Jan-50
End	Dec-51	Dec-00	Dec-70	Dec-72	Dec-59	Jan 1988 to Dec 1995	Dec-50
Period of Record	**Mt Tenjo**	**Naval Mag**	**NAS Tiyan**	**Nasa Sat SYS**	**NCS**	**Nimitz Hill**	**Pago River Upstream**
Start	Jan-50	Jan 1950 to Mar 1952	Jan-50	Jan 1973 to Dec 1991	Jan-50	Jan 1951, Mar 1951	Jan 1951, Mar 1951
End	Feb-56	Jan 1956 to mar 1958	Dec-00	Jan 1993 to Dec 1994	Dec-59	Aug 1951 to Dec 1997	Aug 1951 to Feb 1967
		Jan 1973 to Dec 1974		Mar-99		Oct 2000 to Dec 2000	Oct 2000 to Dec 2000
		Dec-75					
		Jan 1976 to May 1976					
		Jan 1978 to Dec 1998					
Period of Record	**Sumay**	**Talofofo**	**Tamuning**	**Umatac**	**Umatac Valley**	**Umatac Village**	**WSM Finegayan**
Start	Jan-50	Jul 1965 to Dec 1969	May 1951, Sep 1951,Dec 1951	Jan 1950 to Jan 1981	Jan-73	Jan 1950 to Dec 1980	Oct-56
End	Dec-61	Jan 1995 to Dec 1995	Jan 1952 to Dec 1952	Jan 1982 to Dec 1998	Dec-74	Jan 1988 to Dec 1988	Dec-94
		Sep 1996 to Dec 1996	Jan 1953 ,				
		Jan 1997 to Dec 1997	Jul 1953 to Jan 1966				
		Sep 2000 to Dec 2000					
Period of Record	**Wind Hills**	**Ylig Water Plant**	**Yigo**	**Yigo Agricultural Stn**	**NWS Duplicate**	**FWC Duplicate**	
Start	Dec 1961 to Dec 1962	Jan 1951, Mar 1951,	Apr 1952 to Aug 1952	Apr 1952 to Aug 1952	Oct-57	Jan 1950 to Dec 1979	
End	Jan 1974 to Dec 1979	Jan 1952 to Dec 1952	Jan 1959 to Dec 1964	Jan 1959 to Sep 1964	Dec-80	Jan 1995 to Dec 1998	
	Jan 1988 to Dec 2000	Oct 1953 to Dec 1953	Jul 1978 to Dec 2000				
		Jan 1954 to Mar 1955					
		Jan 1956 to Dec 1975					

Period of Record	Mt Tenjo	Naval Mag	NAS Tiyan	Nasa Sat SYS	Pago River Upstream
Start	Jan-50	Jan 1950 to Mar 1952	Jan-50	Jan 1973 to Dec 1991	Jan 1951, Mar 1951
End	Feb-56	Jan 1956 to mar 1958	Dec-00	Jan 1993 to Dec 1994	Aug 1951 to Feb 1967
		Jan 1973 to Dec 1974		Mar-99	Oct 2000 to Dec 2000
		Dec-75			
		Jan 1976 to May 1976			
		Jan 1978 to Dec 1998			
Period of Record	**Sumay**	**Talofofo**	**Tamuning**	**Umatac**	**WSM Finegayan**
Start	Jan-50	Jul 1965 to Dec 1969	May 1951, Sep 1951,Dec 1951	Jan 1950 to Jan 1981	Oct-56
End	Dec-61	Jan 1995 to Dec 1995	Jan 1952 to Dec 1952	Jan 1982 to Dec 1998	Dec-94
		Sep 1996 to Dec 1996	Jan 1953 ,		
		Jan 1997 to Dec 1997	Jul 1953 to Jan 1966		
		Sep 2000 to Dec 2000			
Period of Record	**Wind Hills**	**Ylig Water Plant**	**Yigo**	**Yigo Agricultural Stn**	
Start	Dec 1961 to Dec 1962	Jan 1951, Mar 1951,	Apr 1952 to Aug 1952	Apr 1952 to Aug 1952	
End	Jan 1974 to Dec 1979	Jan 1952 to Dec 1952	Jan 1959 to Dec 1964	Jan 1959 to Sep 1964	
	Jan 1988 to Dec 2000	Oct 1953 to Dec 1953	Jul 1978 to Dec 2000		
		Jan 1954 to Mar 1955			
		Jan 1956 to Dec 1975			

APPENDIX C

A comparison of Guam's longest rain records (monthly means) with other islands of Micronesia.

Average	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Johnston(Hawaii)	1.56	1.66	2.38	2.46	1.98	1.00	1.02	2.14	2.20	3.16	4.25	3.12	26.93
PagoPago(AMS)	12.59	12.76	11.26	12.04	9.92	7.38	6.28	6.71	6.69	10.79	10.84	14.54	121.80
AAFB(Guam)	5.70	5.22	4.09	4.87	6.60	6.34	10.92	13.42	13.32	12.89	9.09	5.97	98.43
NAS(Guam)	4.45	3.74	2.98	3.91	6.05	6.47	10.53	13.73	13.49	12.04	8.20	5.39	90.98
WSMO(Guam)	5.55	5.11	4.45	4.71	7.10	6.49	11.78	14.59	15.02	12.74	9.06	6.44	103.04
UMATAC (Village)	5.22	3.57	3.40	3.98	5.87	6.31	10.71	14.40	14.69	13.15	9.95	5.99	97.26
Ylig River (Filter)	4.88	3.48	3.26	4.16	5.46	5.84	10.63	13.40	14.05	12.71	9.11	6.26	93.04
Capitol Hill (CNMI)	4.00	3.00	2.50	3.50	5.50	5.80	9.00	12.50	13.50	12.00	7.30	4.80	83.40
Rota Airport(CNMI)	5.28	4.67	3.69	4.53	6.33	6.21	10.44	13.19	13.37	12.67	8.64	5.68	94.70
Saipan Intl Airport(CNMI)	3.20	2.40	2.00	2.80	4.40	4.65	8.10	12.50	13.50	10.80	5.80	3.85	74.00
Tinian(CNMI)	4.00	3.00	2.50	3.50	5.50	5.80	9.00	12.50	13.50	12.00	7.30	4.80	83.40
Wake(Marshalls)	1.16	1.60	2.23	2.51	1.74	3.19	4.02	6.16	5.07	4.33	2.79	1.78	36.58
Ailinglapalap(Marshalls)	6.50	4.69	6.19	8.92	10.58	10.61	11.72	10.82	12.13	12.88	11.73	9.98	116.75
Chuuk (WSO)	10.68	6.18	8.34	12.35	12.23	11.72	12.10	14.57	11.53	13.42	10.33	10.84	134.31
Kapingamarangi (Pohnpei)	10.45	10.27	13.88	13.59	10.34	7.25	10.43	6.16	5.89	4.82	8.19	8.75	110.02
Koror(Palau)	10.70	9.12	8.20	8.67	11.99	17.27	18.04	14.95	11.86	13.87	11.32	11.98	147.97
Kwajalein(Marshalls)	4.56	3.23	4.10	7.55	9.98	9.62	10.44	10.11	11.83	11.91	10.66	8.10	102.09
Kosrae(Kosrae)	14.39	16.35	18.67	21.66	18.80	19.00	17.00	16.50	17.20	16.20	15.90	14.50	206.17
Majuro WSO(Marshalls)	8.43	6.15	8.28	10.28	11.18	11.59	13.00	11.52	12.42	13.84	12.80	11.85	131.34
Nukuoro(Pohnpei)	11.75	10.55	13.60	15.00	14.75	12.20	14.40	11.35	11.00	10.75	12.00	12.00	149.35
Pingelap(Pohnpei)	12.36	12.21	14.49	17.15	17.06	16.26	15.93	14.86	14.97	14.81	14.24	13.37	177.71
Pohnpei WSO(Pohnpei)	13.07	10.80	13.54	16.44	19.12	17.14	18.39	16.53	16.06	16.71	15.74	15.22	188.76
Polowat(Chuuk)	8.00	6.25	6.25	6.00	9.00	12.50	14.00	15.00	13.25	12.00	9.25	9.2	120.70
Tamil(Yap)	7.33	5.98	5.96	5.76	9.06	12.69	14.54	15.20	13.51	11.97	9.07	8.99	120.06
Ulithi(Yap)	6.23	5.08	5.07	4.90	7.70	10.79	12.36	12.92	11.48	10.17	7.71	7.64	102.05
Utirik(Marshalls)	3.88	2.75	3.49	6.42	8.48	8.18	8.87	8.59	10.06	10.12	9.06	6.89	86.79
Wotje(Marshalls)	4.33	2.91	3.90	7.17	9.48	9.14	9.92	9.60	11.24	11.31	10.13	7.70	96.83
Woleai Atoll(Yap)	10.68	7.50	8.30	11.00	12.20	13.00	14.00	14.70	11.70	13.60	10.80	11.45	138.93
Yap WSO Ap(Yap)	7.33	5.98	5.96	5.76	9.06	12.69	14.54	15.20	13.51	11.97	9.07	8.99	120.06