Report for 2002GU3B: A rainfall climatology for Saipan: distribution, return periods, and inter-annual variations.

There are no reported publications resulting from this project.

Report Follows:

PROJECT SYNOPSIS REPORT

Project Title

A rainfall climatology for Saipan: distribution, return periods, and inter-annual variations

Problem and Research Objectives

There are very few locations on Saipan where rainfall has been measured in a consistent manner for any appreciable length of time. A continuous 30-year daily rainfall record is often considered sufficient to compute baseline monthly and annual averages, and to make accurate estimations of the recurrence intervals of heavy rainfall events. Water resource managers of Saipan's groundwater and design engineers responsible for building structures to accommodate heavy rainfall require as input accurate rainfall statistics. Unfortunately, Saipan does not have a daily rainfall database that is anywhere close to 30 years for any location, and most of Saipan's rainfall databases are extremely piecemeal.

Research objectives of this project are to develop a rainfall data base for Saipan (using nearby island rainfall data as a proxy when Saipan data is missing or incomplete). From this data base the following aspects of the rainfall on Saipan are examined: (1) general rainfall statistics; (2) a summary of the annual distribution of rainfall, (3) an examination of the return periods of short-term high-intensity rainfall events, (4) the effects of tropical cyclones on the weather and climate of the island, and (5) an examination of inter-annual and inter-decadal variations in mean annual rainfall.

The CNMI and Guam are in an ENSO core region that features very dry conditions in the year following El Niño, and an increase in the level of threat from typhoons during an El Niño year. The long-term variations of rainfall on Saipan are very similar to those on Guam. As on Guam, the mean annual rainfall on Saipan varies substantially among locations on the island. As a first approximation, the heaviest rain tends to be at the higher elevations -- at Guam it occurs on the eastern slopes of the southern mountains and, at Saipan, it appears as if the mean annual rainfall is heaviest at stations in the central high ground (e.g., Capitol Hill and Mount Tagpochau).

The causes extreme daily rainfall events are typhoons, monsoon squall lines, and other so-called mesoscale weather systems that produce rain amounts that are largely independent of the island topography. The highest-intensity extreme rainfall events are caused by typhoons. This may be true for all intervals, from the peak 15-minute rainfall to the peak 24-hour rainfall. Because of typhoons, the probability distribution of 24-hour rainfall events is mixed (e.g., without typhoons, the return-periods for daily rainfall in excess of 10 inches would be much longer). Inter-annual variations of Saipan's rainfall are closely linked to the El Niño/Southern Oscillation (ENSO) phenomenon. To some extent, the occurrence of typhoons in Guam and in the CNMI is also linked to ENSO. Large inter-decadal variations in rainfall (and also in the distribution of typhoons) is noted. The causes of these remain a mystery.

Methodology

Data Base Development

Much of Saipan's rainfall database must be constructed, or assumed to be similar in character to that of nearby Islands such as Guam where reliable daily and monthly rainfall time-series exceed 30 years. Guard and Lander (2001) have constructed 30-year rainfall records for Saipan from existing data on Saipan (Table 1) and from analogies to the properties of the rainfall on Guam. The site selected for the construction was the Saipan International Airport (SIA). Despite having a shorter data record than the Saipan Loran station, SIA is an active site, is likely to remain an active site, and is concurrent with satellite imagery so that recent climatic knowledge can be used in the construction process.

Table 1. Name, elevation (feet), location, length of record (years), and the completeness (%) of record for the daily rainfall databases on Saipan.

Name of Site	Elevation (ft)	Location (lat/long)	Length (yrs)	% Complete
Post-War period				
Saipan International Airport	215	15°7'N-145°43'E	11/88-present	100%
Saipan Loran Station	10	15°8'N-145°42'E	01/54-12/78	64%
Capitol Hill	827	15°13'N-145°45'E	12/94-present	100%
Capitol Hill Fischer-Porter Rain Gauge	825	15°13'N-145°45'E	01/79-12/83	~60%
Saipan No. 2 (near CUC)/ Saipan Naval Station	499	15°13'N-145°44'E	02/60-07/63	83%
Kagman Community Center	80	15°12'N-145°47'E	01/84-10/84	~90%
Japanese period				
Garapan	N/A	15°12'N-145°43'E	01/32-12/37	100%
Chalan Kanoa	N/A	15°08'N-145°44'E	01/24-12/37	100%
Marpi	N/A	15°11'N-145°44'E	01/24-12/37	100%
Tanapag	N/A	15°11'N-145°43'E	01/24-12/37	100%
Mt. Tanabako (near bird Island Overlook	206.3 m (679 ft)	15°14'N-145°46'E	01/32-12/37	100%

Two independent methods were used to develop a database for SIA. The first entailed the acquisition of all available Saipan and regional data to derive a complete, continuous long-term SIA database. The possible length of the database was determined to be 47 years. The second method was more statistical, utilizing the close correlation between 11 years of SIA data and 11 years of smoothed Guam International Airport data. This technique provided an algorithm from which a representative SIA daily rainfall database could be derived. Mr. Charles Guard performed the former method and Dr. Mark Lander performed the latter.

Because of the poor daily rainfall data record available for Saipan, a method was needed to construct a representative 30-year daily rainfall record. The method selected was to partially use characteristics of the more complete Guam rainfall record as a proxy for the Saipan record. To do this, relationships between the Andersen Air Force Base, National Weather Service Finagayan, and Naval Air Station/National Weather Service Tiyan locations on Guam and the Saipan International Airport location were determined through correlation analyses, and consideration of monsoon activity, typhoon activity, and ENSO influences. The commercial rainfall databases for Guam and Saipan had several gaps that were filled in by obtaining the data from National Climatic Data Center publications and from military records. Monsoon activity was taken from a study by Lander and Guard (1997) in which Guard determined the frequency distribution of strong, moderate, and weak monsoon surges affecting Guam from 1954 to1995. Because of the large scale of monsoon and ENSO activity, it was assumed that monsoon activity and ENSO influences acted on Saipan in a manner similar to Guam. This large scale behavior accounts for the close correlations found between SIA data and smoothed Guam data from 1989-1999 (Fig. 1). Typhoon activity was compensated for separately. In fact, the presence of typhoon activity in the Guam and the Saipan databases (unsmoothed data) acted to lower the rainfall correlations between the two islands. A single typhoon event can account for 10-15 percent of the total annual rainfall. The short period of record overlap between Saipan International Airport and Capitol Hill was used to assess relationships during lighter rainfall--trade wind and thunderstorm--regimes. The longer record of the Coast Guard Loran Station was used considerably in the construction of the International Airport record. Fortunately, the rainfall characteristics of the Loran Station location and the SIA location were found to be similar, although the SIA is around 5 percent drier.

The annual rainfall for the derived 47-year SIA database is 73.45 inches. This compares favorably with the 74.00 inches derived by the Pacific ENSO Applications Center for SIA from a shorter period of SIA rainfall. Decadal rainfall trends for the derived database were compared with those of Guam long term databases. When differences due to typhoon rainfall were compensated for, the Guam and SIA trends were found to be similar. However, SIA demonstrated greater decadal variation than Guam when the tropical cyclone rainfall is added. The decadal averages for SIA are:

1950's (6 years)	60.51 in
1960's	88.19 in
1970's	68.11 in
1980's	80.04 in
1990's	66.48 in

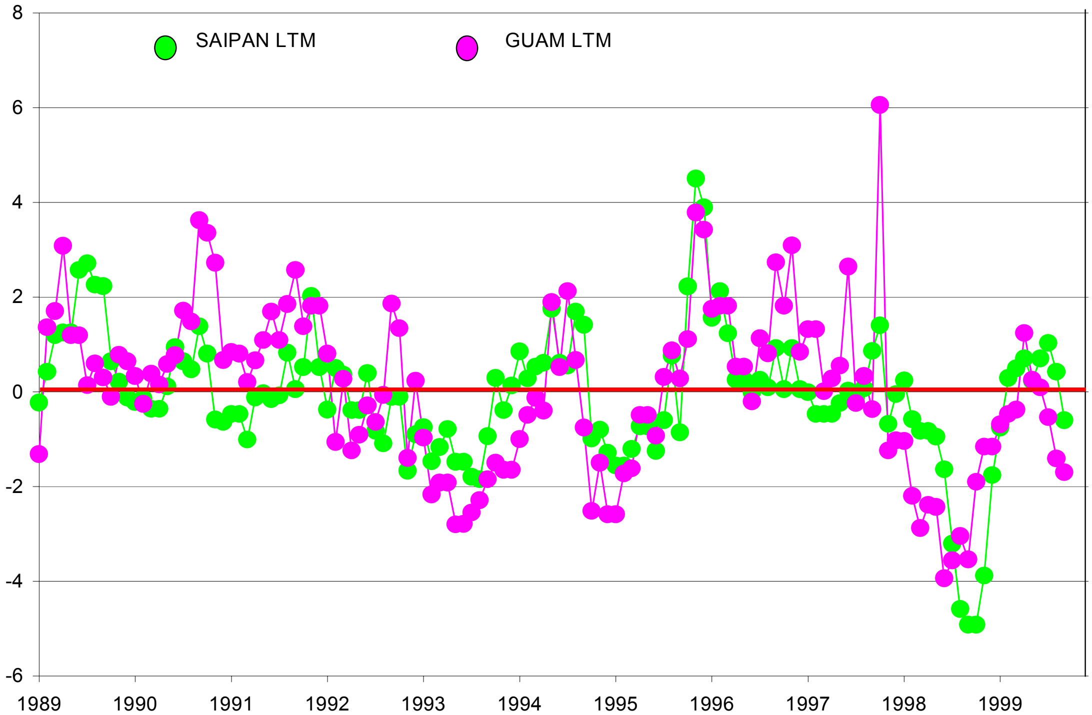

Figure 1. A five-month moving average of the monthly rainfall anomalies at Saipan (green dots) and at Guam (purple dots). The strong coherence between the rain on Guam and Saipan is largely a function of both locations reacting similarly to the status of ENSO, and receiving heavy rainfall from the same large-scale weather systems such as the monsoon. The driest year of record in this time series is 1998 at both Guam and Saipan. The drought in 1998 was a typical, but extreme, follow-on drought to a major El Niño (1997 was one of the strongest El Niño events ever recorded). The strong coherence of the long-term rainfall surpluses and deficits on Guam and Saipan enable one to use Guam's longer period of rainfall measurement to make some reasonable inferences of the character of the rainfall on Saipan based on the statistical properities of the rainfall on Guam.

Spatial Distribution of annual rainfall

The distribution of rainfall on the island of Saipan is affected to some degree by the topography, and the mean annual rainfall totals among recording stations on Saipan differ by as much as 15 inches (380 mm). The region in the vicinity of Saipan's international airport receives the lowest annual total of about 75 inches (1900 mm). The highest measured annual average of approximately 90 inches (2300 mm) occurs at Capitol Hill, and extends along the high ground from Marpi to Mount Topachau. In order to arrive at an annual rainfall distribution chart for Saipan, the rainfall at recording stations was first compared to simultaneous readings at Capital Hill – the wettest among all of Saipan's rain recording sites. Normalizing the stations to Capital Hill (where Capital Hill = 1.00) resulted in the distribution of Fig. 1.

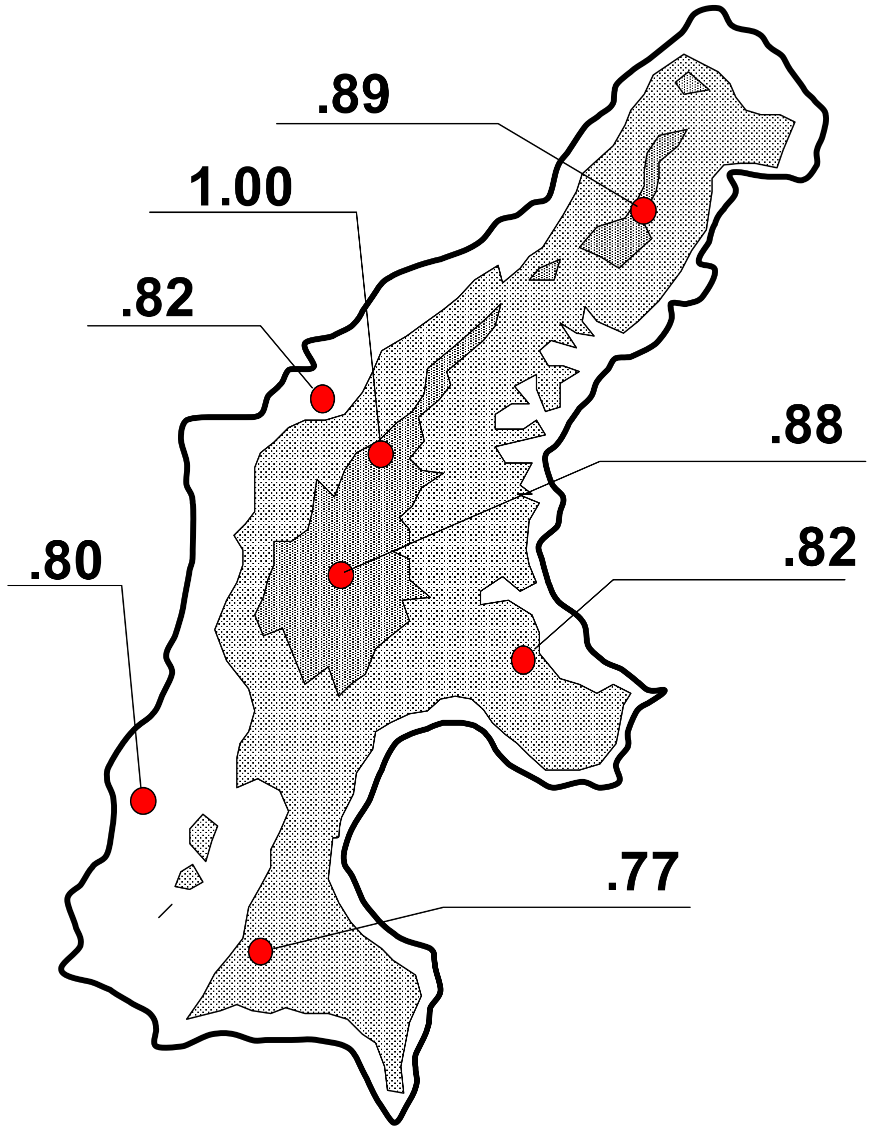

Figure 2. Rainfall at several sites on Saipan normalized to the rainfall at Capital Hill, where the annual rainfall at Capital Hill = 1.00.

The next step was to convert the percentages in Fig. 2 to actual rainfall in inches per year. The data for sites in Fig. 2 are based on the post-war rain records. Some other stations have been added based on inter-comparisons of stations in the Japanese record of 1924-37. This process resulted in the annual rainfall amounts shown in Fig. 3. Contours are drawn using this data to arrive at the presentation in Fig. 4.

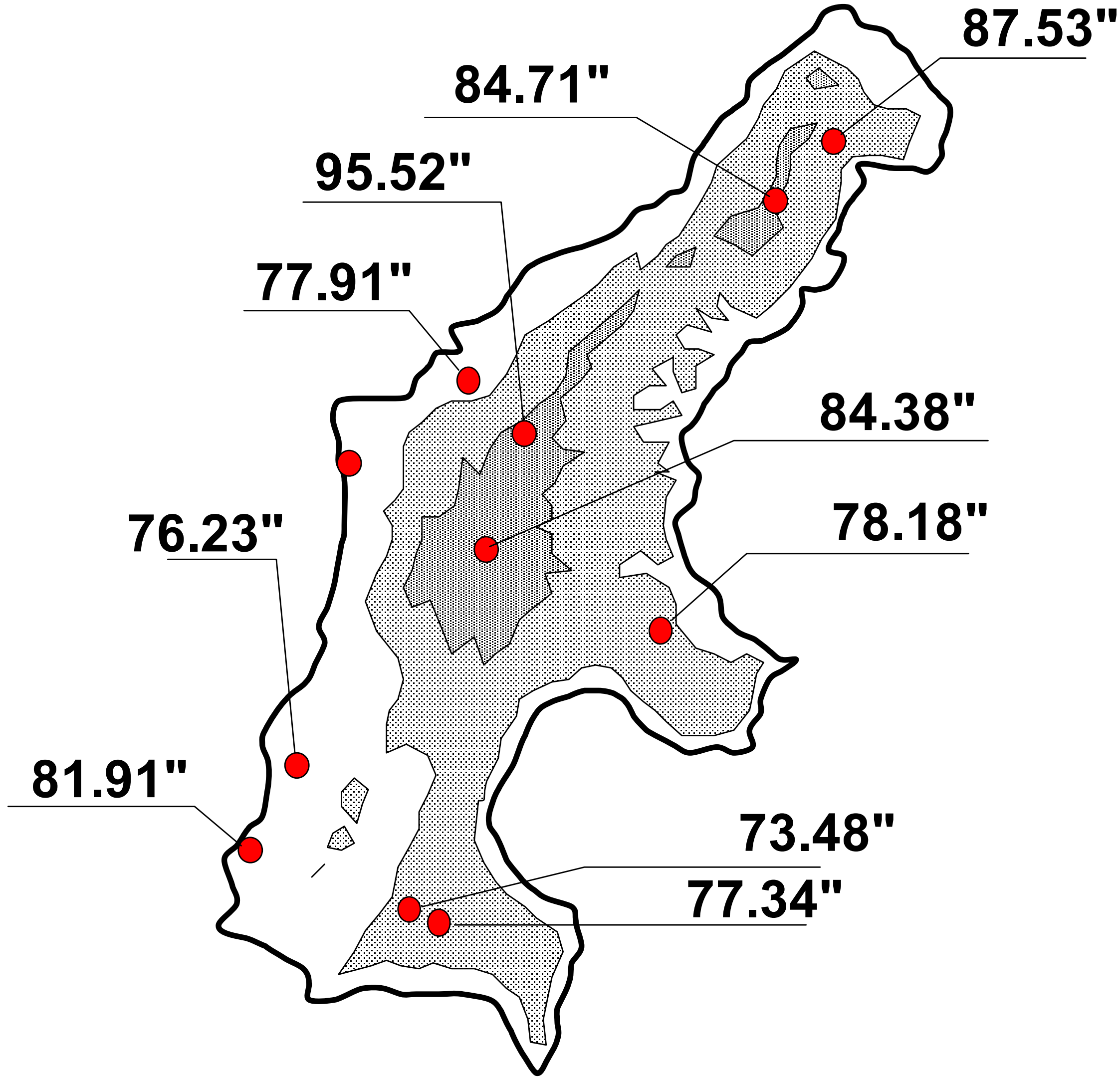

Figure 3. Mean annual rainfall at selected sites on the island of Saipan.

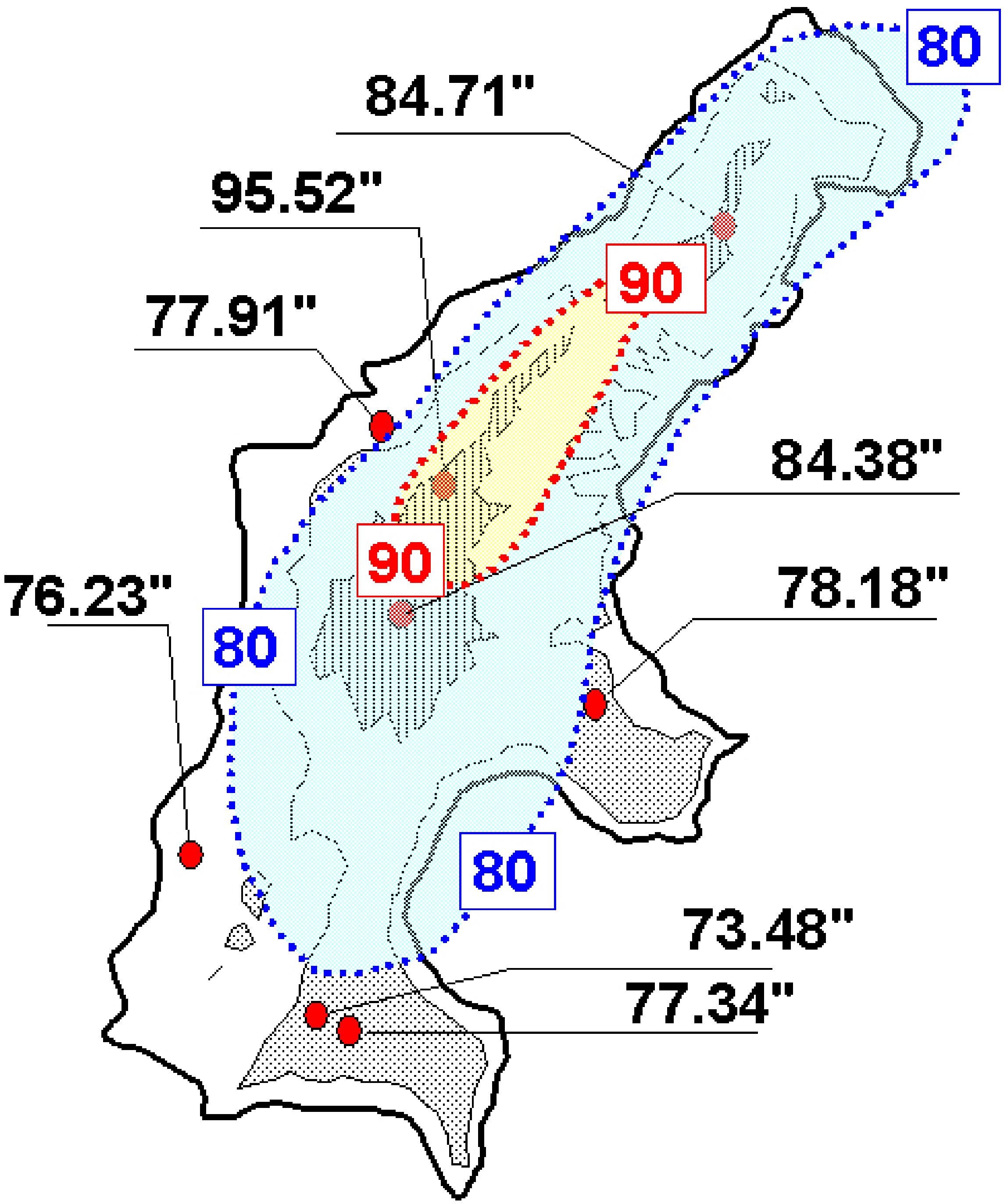

Figure 4. Contours of mean annual rainfall (in inches per year) on the island of Saipan based on the data in Figure 6. (Mean annual rainfall at selected post-war sites is indicated).

Return periods of short-term high-intensity rainfall events

Since the rainfall records on Saipan are so short and/or incomplete, calculations of return periods of extreme rain events may only be crudely estimated. The more complete record of rainfall on Guam allows for a comparison by proxy; however, the large-scale rainfall totals drop steadily with latitude (Fig. 5), and Saipan' annual rainfall is about 20 inches less than that of Guam (Fig. 6).

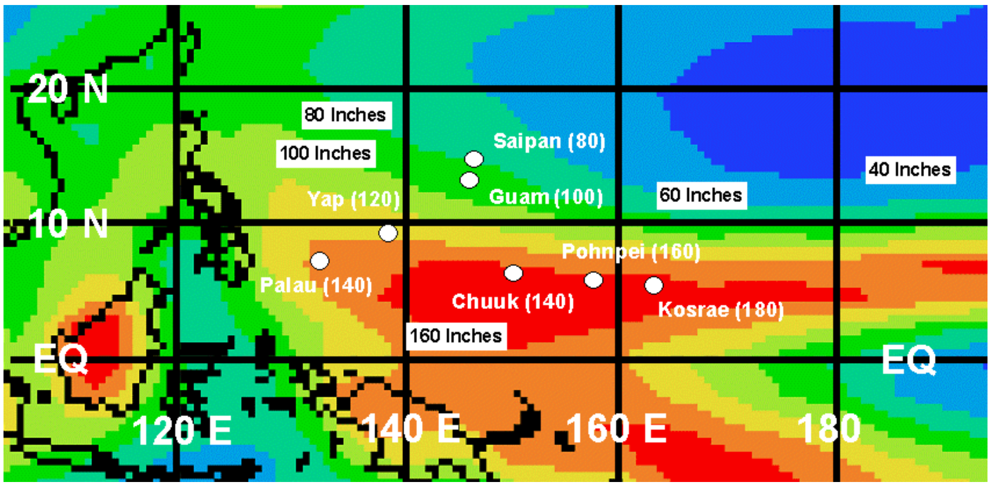

Figure 5. Mean annual over-water rainfall in Micronesia. Colors indicate rainfall pattern (amounts as labeled: red = 160 inches per year, orange = 140, yellow = 120, light green = 100, dark green = 80, teal = 60, light blue = 40, and within the blue there is a bit less than 40 inches of annual rainfall). Mean annual over-water rainfall at selected islands is indicated. Image adapted from figure on website URL http://orbit35i.nesdis.noaa.gov/arad/gpcp/

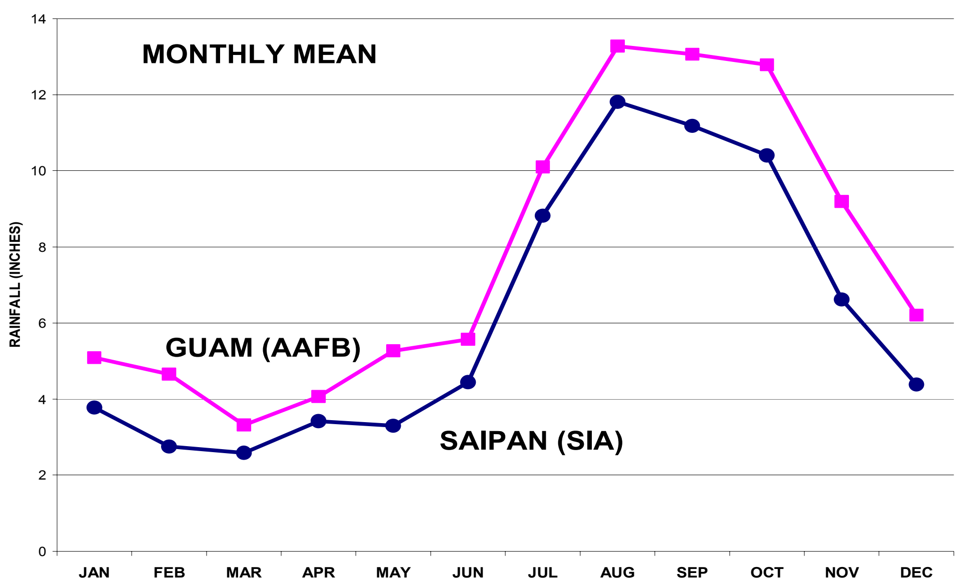

Figure 6. Monthly mean rainfall at Saipan International Airport and at Guam's Andersen Air Force Base (in inches). Note that in every month of the year, Guam (located further south) gets about 2 inches more rain than at Saipan.

Return-period calculations for Guam rainfall (Fig. 7) yield a mixed distribution, with typhoons causing all daily rainfall events in excess of 10 inches.

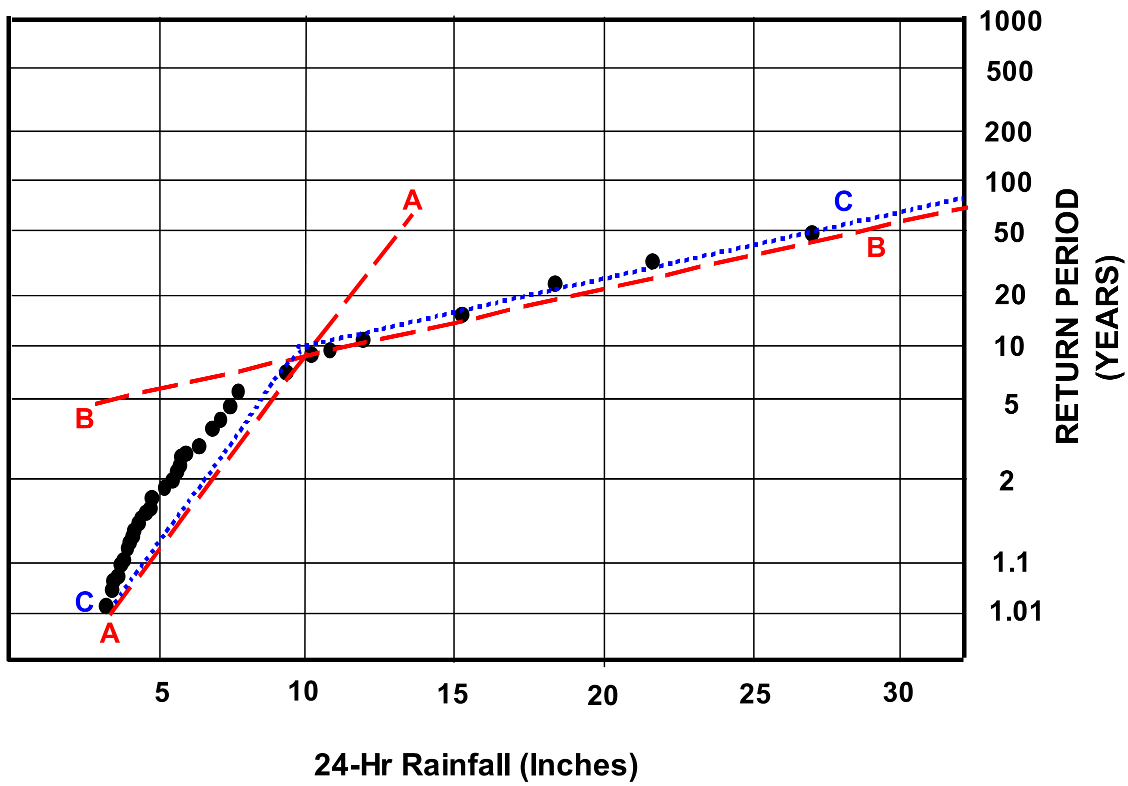

Figure 7. Return period for 24-hour rainfall totals computed for Guam. The change of slope of the lines that fit the individual realizations indicates that there is a mixed distribution of rainfall causes. This is indeed the case, as all rainfall totals in excess of 10 inches on this chart were caused by the direct passage of typhoons over the island. A conservative approach to estimating the return periods for 24-hour rainfall amounts on Guam would be to follow the blue curve "C-C" that has a breakpoint at the intersection of lines "A-A" and "B-B". The breakpoint value is 10 inches in 24 hours at the 10-year return period. Thus, one would estimate that at least one day in each year would have at least ~ 3.50 inches of rain. Similarly, the return period for 10 inches in 24 hours is 10 years, the return period for 20 inches of rain in 24 hours is 25 years, etc.

A similar return-period analysis of the extreme 24-hour rain rates using Saipan's more incomplete record (Fig. 8) yield a very wide range of possible values than center on the results for Guam.

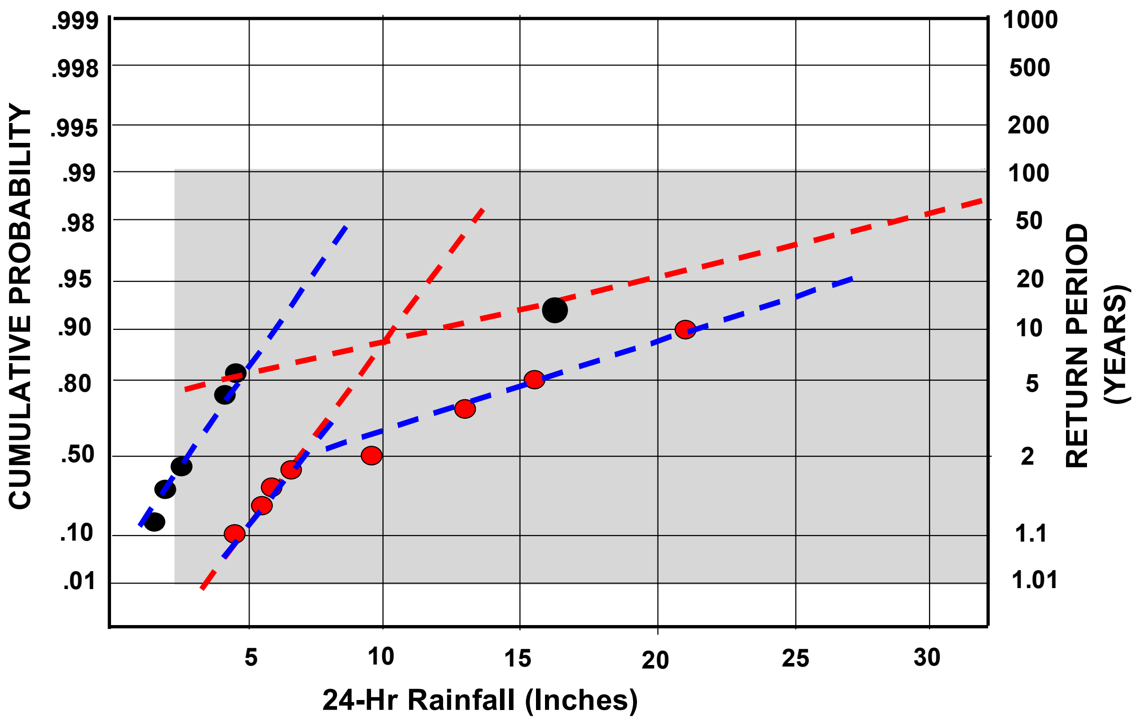

Figure 8. Method-of-moments (ranking method) computations of 24-hour return period extreme rainfall events using Saipan data. Black dots are from the record at Susupe, and red dots are from the record at Capital Hill. The Capitol Hill record contains an unusual number of typhoon-associated rainfall events that occurred in the 1990's. Guam's 24-hour return period curve is shown by the dotted red line.

Previous studies have shown that the return periods of extreme 24-hour rainfall events on Saipan to be a function of elevation, similar to the pattern of mean annual rainfall. The highest of extreme rainfall events on Saipan (as at Guam) are caused by typhoons. Data collected in typhoons on Saipan (Fig. 9) and on Guam (Figs. 10 and 11) show no topographical variation.

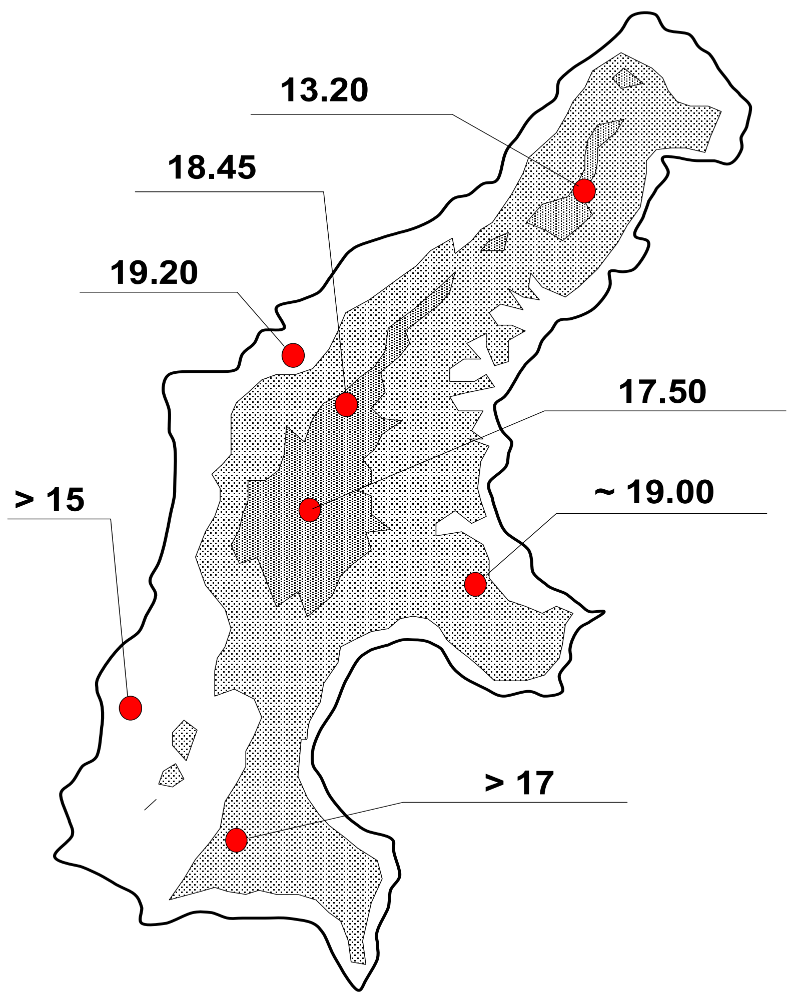

Figure 9. Twenty-four hour rainfall during Typhoon Steve, August 08, 1993. Note that the extreme rainfall totals are not a function of elevation. A similar distribution of heavy 24-hour rainfall was experienced on Saipan just one year later (not shown) during the passage of Typhoon Wilda by the island.

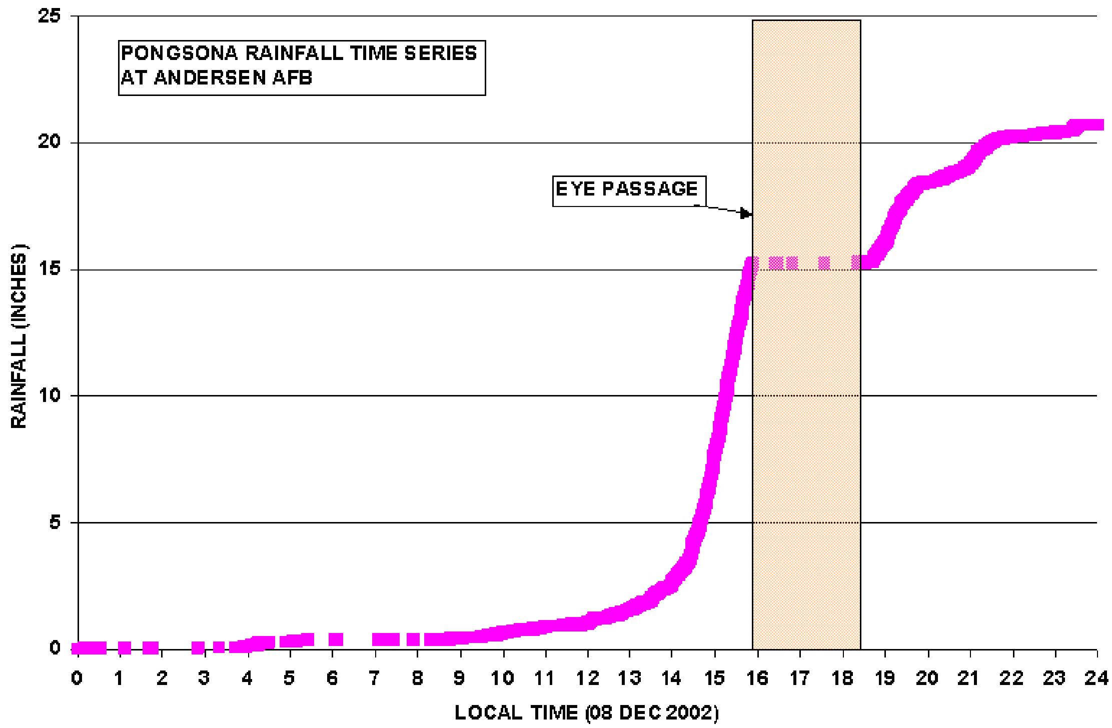

Figure 10. Time series of rainfall at Andersen Air Force Base during Typhoon Pongsona.

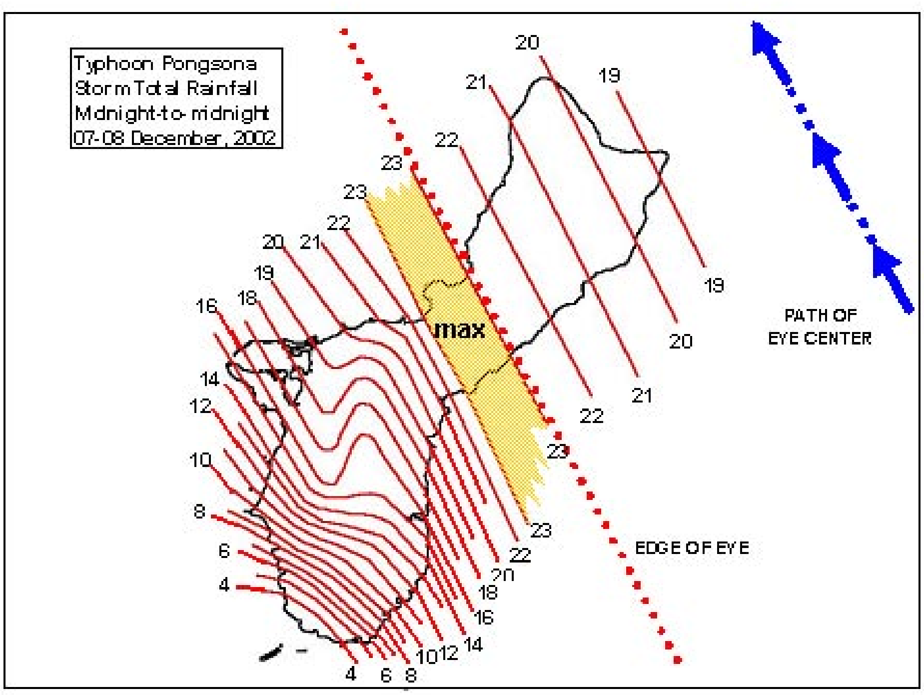

Figure 11. Analysis of 24-hour rainfall distribution in inches during the passage of Typhoon Pongsona over Guam.

In both typhoons Chataan (July 2002) and Pongsona (December 2002) on Guam, the rains recorded by newly installed electronic gages exceeded the 100-year event (Fig. 12). The 100-year event was exceeded at all intervals up to the 12-hour rainfall. It is thus possible that typhoon rains are responsible for the highest of extreme rainfall rates at all time intervals. Historically, typhoon rainfall has not been adequately measured. The typhoon frequency on Guam is approximately the same as it is in Saipan (Fig. 13), although during the 1990's Guam has experienced an unusual spate of typhoon strikes!

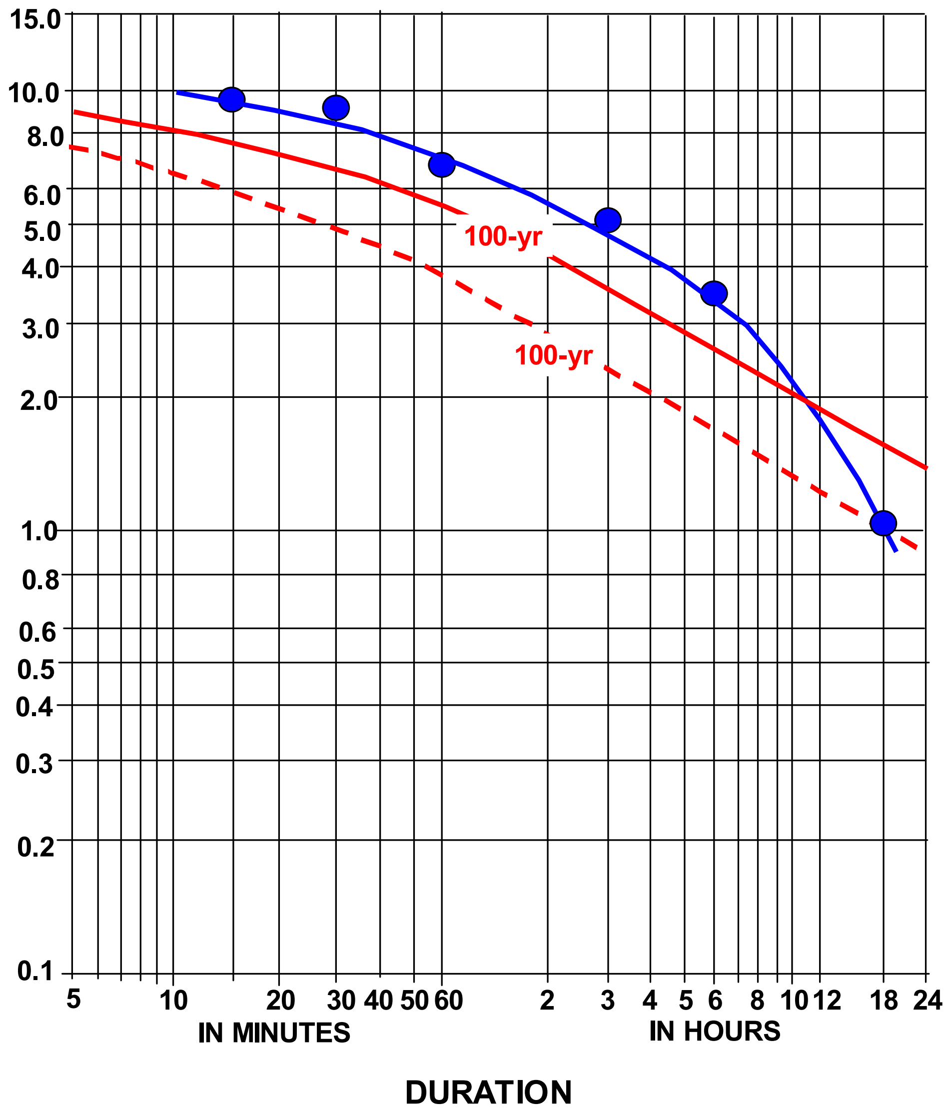

Figure 12. Peak short-term rain rates (blue dots) in Typhoon Pongsona over Guam. Note that the rates generally greatly exceed the existing values for the 100-year return period as found in the Guam Storm Drainage Manual.

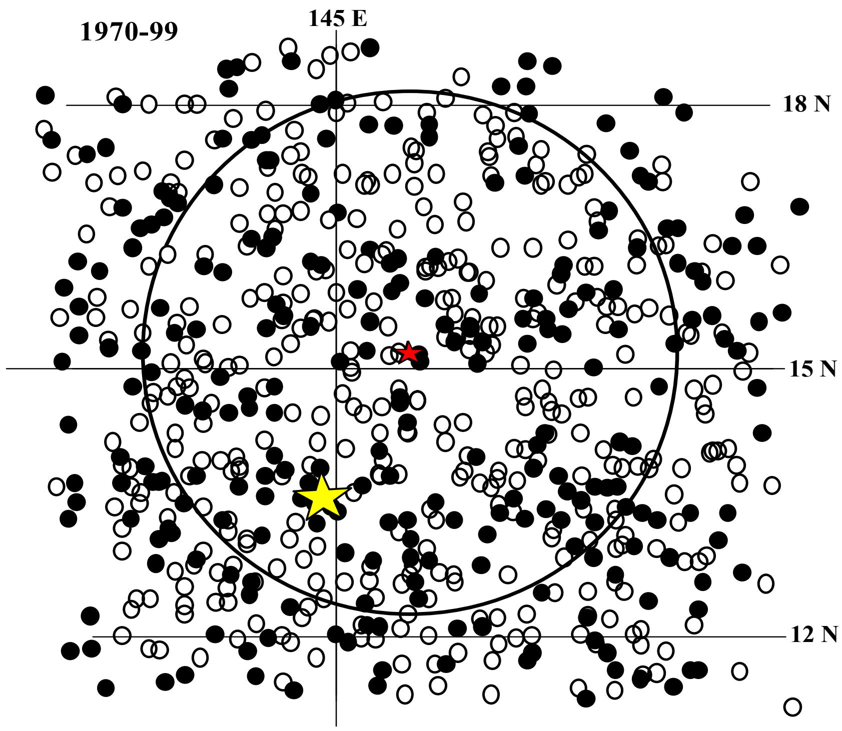

Figure 13. Six-hourly positions of all tropical storms (open dots) and typhoons (black dots) centered on Saipan (red star) for the period 1970-99. Despite Guam's recent spate of typhoon strikes in the 1990's, it appears that the typhoon distribution at Guam (yellow star) and at Saipan are roughly the same.

Inter-annual and inter-decadal variation

Saipan is located in a region of the world characterized by large-scale seasonal weather changes associated with the monsoons of the Eastern Hemisphere. For most of the year, the winds on Saipan are from the east, but during the summer and early autumn, the winds can become west to southwest for periods lasting up to one month. Generally, the swing of wind to the southwesterly is episodic and occurs in 3- to 10-day periods during which the winds may approach gale force. The number, strength and duration of episodes of southwest winds on Saipan is highly variable from year to year. The wind may become southwesterly on Saipan at any time of the year when a tropical cyclone passes to the north of the island. A monsoon index, and a wind rose chart have been prepared from the long-term records of the wind on Guam. Guam and Saipan share much of the same large-scale weather features such as episodes of the southwest monsoon, shear-line passages, hazardous surf events, and El Niño-related droughts. The behavior of the southwest monsoon (and the wind climate in general) on Saipan may have some slight differences that will be revealed when a study of the Saipan wind records are examined and compared with those of Guam. A monsoon index has not yet been prepared for Saipan because of the shorter length and fragmentary nature of its historical records of wind and rain.

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 inter-decadal variations in Guam's rainfall. The 1950s was a very dry decade, as indicated by the sharp downward slope of the running accumulations of rainfall anomalies shown in Fig. 14. 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. 14. 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), and at SIA. 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.

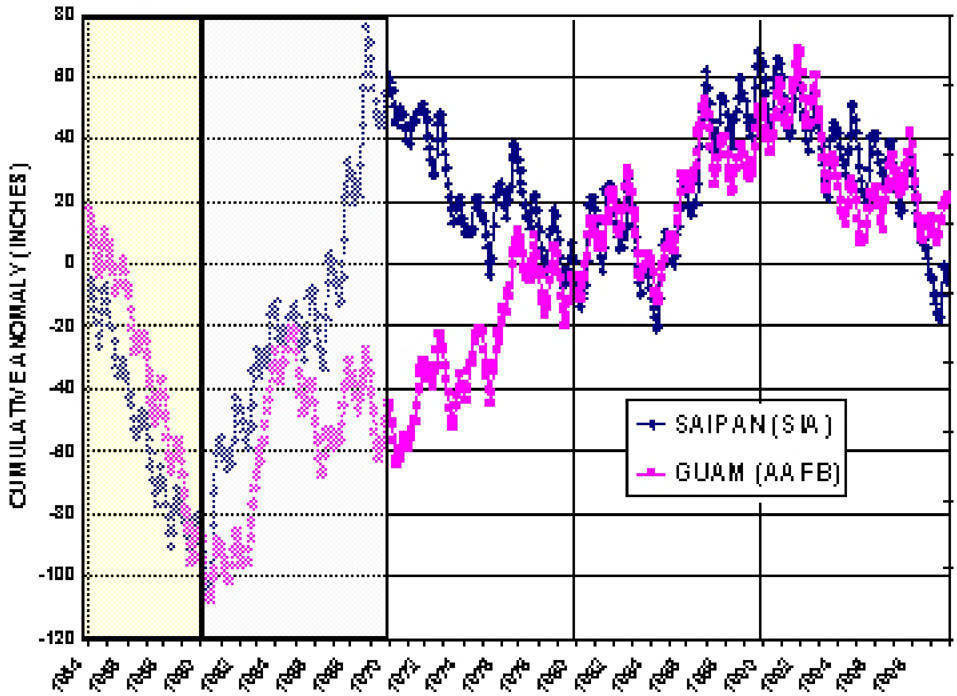

Figure 14. Running accumulations of the rank (lowest month = -305, highest month = +306) of each month's rainfall for the period 1954 to 2000 (annual cycle not removed). Complete records were available from Andersen AFB, Guam, and the constructed time series of the SIA. Prominent features include the extreme dryness of the 1950's (orange half-tone), a very wet period in the 1960's (light-blue half-tone), and recent overall dryness in the 1990's. Recent short-term prominent rainfall fluctuations include relative dryness from late 1992 through 1995, and a wet period during 1996 and 1997, followed by the driest year of record: 1998. These short-term fluctuations are related to El Niño

Principal Findings and Significance

The distribution of rainfall on Saipan is affected (to some degree) by the topography, and the mean annual rainfall totals among recording stations on Saipan differ by as much as 15 inches (380 mm). The region in the vicinity of Saipan's international airport receives the lowest annual total of about 75 inches (1900 mm). The highest measured annual average of approximately 90 inches (2300 mm) occurs at Capitol Hill, and extends along the high ground from Marpi to Mount Tagpochau.

The Saipan rain record is too short to develop accurate return periods of extreme rainfall events. The 24-hour extreme rainfall curve for Guam may be used as a proxy for the 24-hour extreme rain total on Saipan. Recent accurate measurement of rainfall in typhoons on Guam show extraordinary magnitudes that exceed existing 100-year values at all short-term intervals from 15 minutes to 12 hours. More rain records need to be collected in typhoons to produce reliable tables of return periods for short-term extreme rain events. In any case, it is suggested that the extant tables for Guam extreme rains be used at both Guam and Saipan (albeit with the provisos that typhoons may cause higher rain rates than previously thought, and that the frequency of direct typhoon strikes on Guam has recently been much higher than that on Saipan). The return periods of extreme rain rates should be considered uniform across the topography.

Inter-annual variations of Saipan's rainfall are closely linked to the El Niño/Southern Oscillation (ENSO) phenomenon. To some extent, the occurrence of typhoons in Guam and in the CNMI is also linked to ENSO. Large inter-decadal variations in rainfall (and also in the distribution of typhoons) are noted. The causes of these remain a mystery.