Rainfall Climatology for Saipan: Distribution, Return-periods, El Nino, Tropical Cyclones, and Long-term Variations

By

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OF THE WESTERN PACIFIC
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Technical Report No. 103
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THE WATER RESOURCES RESEARCH INSTITUTE PROGRAM OF THE US GEOLOGICAL SURVEY, AWARD NO. 01HQPA0010, SUPPORTED THE WORK REPORTED HERE.

Abstract

The long-term variations of rainfall on Saipan are very similar to those on Guam. As on Guam, the distribution of rainfall on the island is affected by the topography, and the mean annual rainfall totals among recording stations on Saipan differ by as much as 15 inches (380 mm), or approximately 20%. 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 causes of extreme rainfall events on Saipan are typhoons, monsoon squall lines, and other so-called mesoscale weather systems. Unlike the spatial distribution of mean annual rainfall, the spatial distribution of short-period extreme rainfall is independent of the island topography. The highest-intensity 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 (i.e., without typhoons, the return-periods for daily rainfall in excess of 10 inches would be much longer).

More rainfall on Saipan occurs in the 12-hour span between midnight and noon than in the 12-hour span between noon and midnight; with an absolute minimum in the evening. This is the typical rainfall distribution over the open ocean undisturbed by the effects of island topography and land-surface heating, and is caused by diurnally varying radiative processes in the tropical oceanic atmosphere. Unlike larger or more mountainous islands, Saipan is too small to appreciably alter the over-water diurnal rainfall pattern.

Once thought to be largely random, rainfall in the tropics was found to have a strong month-to-month variation caused by a phenomenon known as the Madden-Julian Oscillation (MJO). The rainfall on Saipan is probably affected by the MJO. The manifestation of the MJO signal at Saipan is to produce several weeks of wet weather broken by a week or two of hot dry weather. The signal is not always very strong, but during some years (such as during the rainy season of 2004), it is particularly strong.

Inter-annual variations of Saipan's rainfall are closely linked to the El Niño/Southern Oscillation (ENSO) phenomenon. Saipan is 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. Large inter-decadal variations in rainfall and also in the distribution of typhoons are noted. The causes of these remain unknown.

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1. Introduction

Saipan is one of fourteen main islands of the Northern Mariana Group stretching northward from Guam (Fig. 1). Guam, the southernmost of the Mariana Islands, is a territory of the United

States; whereas all of the Mariana islands to the north of Guam are part on the Commonwealth of the Northern Mariana Islands (CNMI). The islands of Guam, Rota, Tinian, and the tiny uninhabited Aguijan lie to the south of Saipan. To the immediate north of Saipan one finds the small island of Farallon de Mendenilla, the tall Anatahan (currently in active volcanic eruption), and, further to the north, several other high islands of volcanic origin (one of which – Pagan – had a major volcanic eruption in 1981). The island of Saipan (Fig. 2) is quite small (80 km^2) and its tallest mountain rises to modest height of 471 m.

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 extreme rainfall events. Unfortunately, Saipan does not have a daily rainfall database that is anywhere close to 30 years for any location. Statistics for Saipan's rainfall had to be constructed from a concatenation of existing data on Saipan and from similarities to the properties of the rainfall on Guam. Among other general statistics of Saipan's rainfall, Section 2 investigates the effects of the island topography on the distribution of rainfall, the short- and long-term variations of rainfall, and the return periods of rainfall extremes.

Saipan is affected by many weather systems (large and small) of the tropical atmosphere: typhoons; the east Asian Monsoon; the Pacific trade winds; the Inter-tropical Convergence zone (ITCZ); El Niño and La Niña; and, deep convection on scales ranging from individual towering cumulus clouds to mesoscale convective systems (Maddox 1980). With the retreat of the ITCZ to the south in the late fall through spring, Saipan spends much of the year in trade winds. From July through October, the ITCZ (manifested across much of the western North Pacific as a monsoon trough) episodically migrates to the vicinity of Saipan causing widespread heavy rains from tropical deep convection. Because of the occurrence of typhoons, Saipan is subjected to very high-magnitude rainfall events — well above those expected from other tropical rain-producing weather systems.

Inter-annual variations of Saipan's rainfall are closely linked to the El Niño/Southern Oscillation (ENSO) phenomenon. The long-term variations of rainfall on Saipan are very similar to those on Guam. The CNMI and Guam are in an ENSO core region that features very dry conditions in the year following El Niño (Ropelewski and Halpert 1987), and an increase in the level of threat from typhoons during an El Niño year.

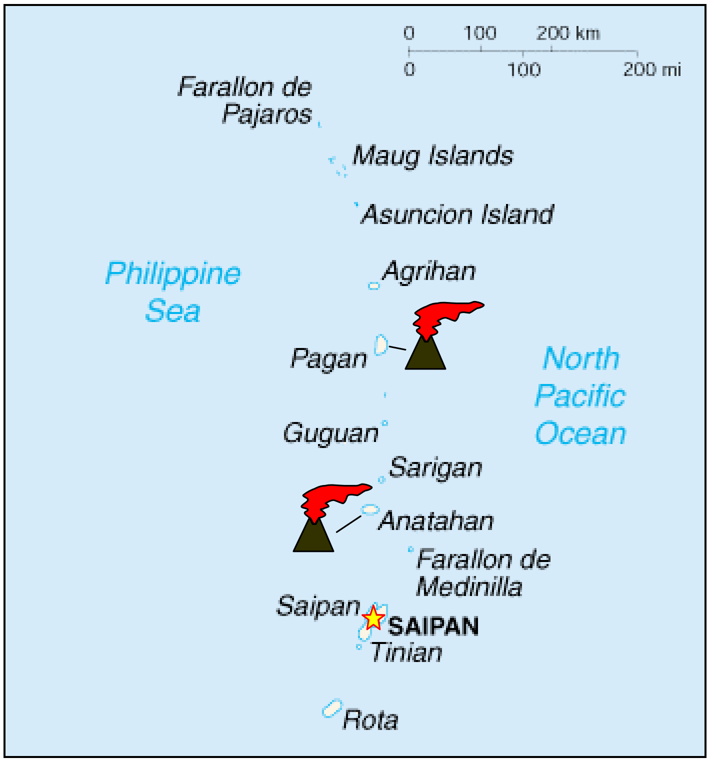
This technical report presents a description of the weather and climate of Saipan to include: general rainfall statistics, a summary of the annual distribution of rainfall, and an examination of the return periods of short-term high-intensity rainfall events (Section 2); the effects of ENSO on the climate and weather of Saipan (Section 3); a summary of tropical cyclones affecting the island (Section 4); and, an examination of inter-annual and inter-decadal variations in mean annual rainfall (Section 5). A summary of the principal findings is found in Section 6.

(a)

Figure 1. Saipan locator maps showing (a) world setting, (b) aerial photo of the Saipan International Airport (looking NE), and (c) regional map of the northern Mariana Islands (Pagan and Anatahan have experienced recent volcanic eruptions).

(b)

(c)



2. Saipan’s Rainfall

a. Data

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. Saipan's rainfall databases are extremely piecemeal. Table 1 shows the name, elevation, location, length of record, and the percent completeness of the record for the existing post-war rainfall records for various sites on the island, and for some rainfall readings acquired by the Japanese during the period 1924-37. Lander and Guard (2004) constructed 46-year rainfall records for Saipan from existing data on Saipan and from similarities to the properties of the rainfall on Guam (Appendix A). The site selected for this construction was the Saipan International Airport (SIA).

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 Isley Tower (manned)	215	15°7'N-145°43'E	11/88-present	100%
Saipan International Airport Fischer-Porter Rain Guage	215	15°7'N-145°43'E	9/79-present	~80%
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%
Commonwealth Utilities Corporation (CUC) Lab	~100	15°13'N-145°44'E	01/99-present	100%
Capitol Hill Fischer-Porter Rain Gauge	825	15°13'N-145°45'E	08/80-07/86 01/87-present	~60% ~75%
Mt. Tagpochau (EMO Tower)	1602	15°13'N-145°45'E	01/99-present	100%
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%
Susupe (Private)	~20	15°09'N-145°44'E	08/85-12/90	100%
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)	679 ft (206.3 m)	15°14'N-145°46'E	01/32-12/37	100%

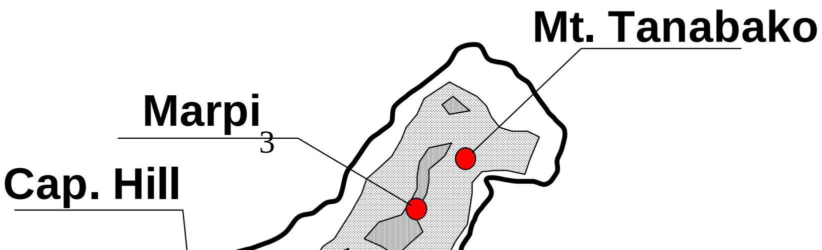


Figure 2. Stations on the island of Saipan where there are historical records of rainfall. Half-tone shading indicates elevation: light gray ≥ 50 m; dark gray ≥ 200 m.

Hourly rainfall data from Fischer-Porter type recording rain gauges is available for Saipan at only two locations: the SIA and Capitol Hill. These gauges record rainfall at .10 inch increments. They are somewhat difficult to maintain, so the records from these gauges are often piecemeal. They are, however, the only sources of data for estimates of return-periods of short-term (e.g., hourly and 3-hourly) rainfall events. Approximately 20 years of hourly rainfall data is available from the SIA and Capitol Hill gages, with the SIA record 80% complete, and the Capitol Hill record only 60% complete (Table 1).

The possible length of the Lander and Guard (2004) manufactured monthly rainfall database for the SIA was determined to be 46 years (Appendix A). They used several techniques to create this database including the close correlation between 11 years of SIA data with 11 years of concurrent smoothed Guam rainfall data (Fig. 3). Because of the large spatial scale of the western Pacific monsoon and El Niño 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 both raw and smoothed SIA data and Guam data from 1989-1999 (Figs. 3 and 4). 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 (or more) of the total annual rainfall. The short period of record overlap between SIA and Capitol Hill was used to assess relationships during lighter rainfall (e.g., trade-wind and thunderstorm regimes). The longer record of the Coast Guard Loran Station was used considerably in the construction of the SIA manufactured long-term record. Fortunately, the rainfall characteristics of the Loran Station location and the SIA location were found to be similar, although the SIA is approximately 5 percent drier.

The annual rainfall for the derived 46-year SIA database is 73.48 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 inch (annual average)
1960’s	88.19 inch (annual average)
1970’s	68.11 inch (annual average)
1980’s	80.04 inch (annual average)
1990’s	66.48 inch (annual average)

(See Section 5, page 44, for more discussion of the inter-decadal variation of rainfall on Saipan.)

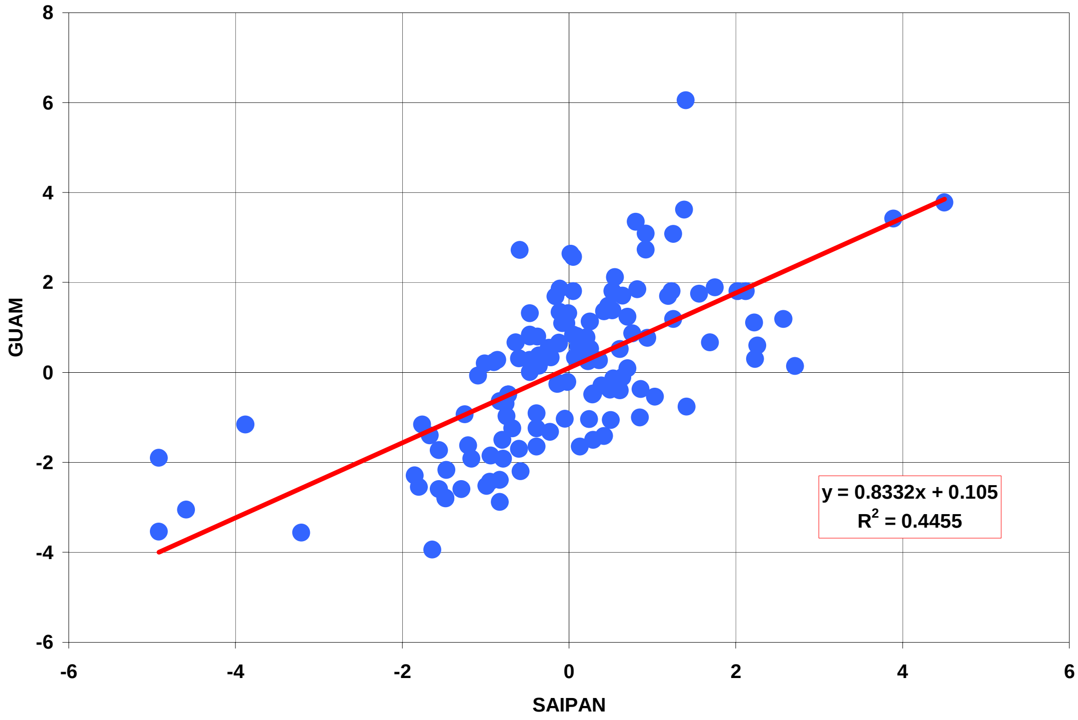


Figure 3. A comparison of the raw monthly rainfall anomalies at the Guam and Saipan International Airports for the period 01/89 to 09/99.

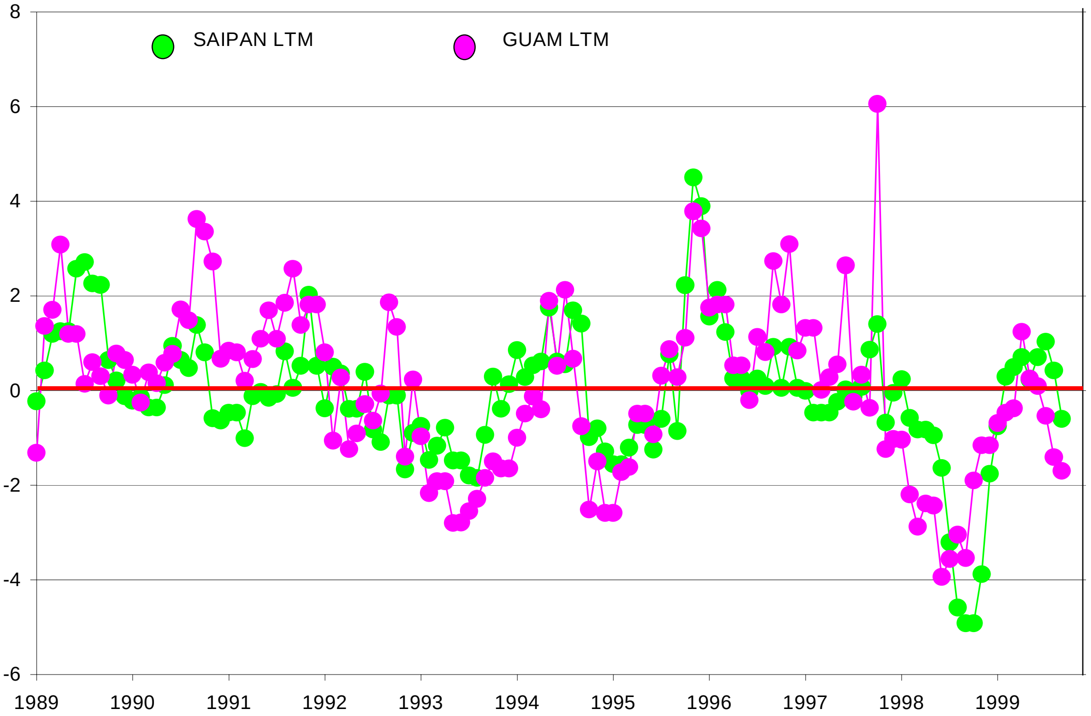


Figure 4. A five-month moving average of the monthly rainfall anomalies at Saipan (green dots) and at Guam (purple dots). The strong coherence between the rain on Guam and Saipan is largely a function of both locations reacting similarly to the status of ENSO, and receiving heavy rainfall from the same 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.

b. Rain-producing weather systems

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 southwest 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 SW 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. Guard and Lander (1997) determined the frequency distribution of strong, moderate, and weak monsoon surges affecting Guam from 1954 to1995. 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.

Much of Saipan's wet-season rainfall is derived from cloud clusters and tropical cyclones that form in or near the monsoon trough. The general properties of the monsoon trough of the western North Pacific (WNP) follow:

(1) It is elongated east-west,
(2) It is a nearly linear shear zone between easterly and southwesterly wind currents,
(3) It possesses a nearly linear east-west oriented cloud band with most of the cloudiness and deep convective elements located to the south of the trough axis, and
(4) It is the genesis site of most of the tropical cyclones of the WNP.

The monsoon trough generally becomes firmly established in the WNP basin in July, and it is usually during July that the trough makes its first migration to the north of Saipan bringing the first episode of SW monsoon winds. Throughout the summer, the monsoon trough undergoes substantial migrations and major changes to its shape and orientation. Tropical cyclones further complicate the flow pattern. A very vigorous monsoon trough established to the north of Saipan can bring strong southwest winds, cloudy wet weather, and rough seas on the western shores. Intense squalls with gales and white-out conditions in heavy rain often accompany the southwest monsoon flow (these can easily be mistaken by residents for tropical cyclones). A strong monsoon trough and tropical cyclone formation go hand-in-hand.

At the arrival of the boreal winter, the monsoon trough of the Northern Hemisphere disappears as northerly winds cross the equator and follow a curved path to become the northwesterly flow of the Australian Northwest Monsoon. By early January, the monsoon trough axis of the Southern Hemisphere becomes firmly anchored across northern Australia eastward into the Solomon Islands. At the same time, trade wind flow becomes firmly established over Saipan, and the character of the cloudiness and rainfall on the island (apart from relatively rare off-season tropical cyclones) becomes that of a trade wind regime.

Wet season weather systems

During the wet season, the atmosphere over Saipan becomes deeply moist and less resistant to vertical ascent of low-level air into towering convective clouds. Large billowing thunderheads (deep convective clouds) can grow vertically to great heights (55,000 ft or more) and produce very heavy rainfall. The origin of most of the wet season rainfall can be attributed to deep convective clouds in various stages of organization and/or life cycle. Deep convection can be in the form of an isolated towering cloud column (which may produce a heavy downpour over only a very small area (e.g., a square kilometer). Individual large convective clouds may coalesce into larger clusters known as Mesoscale Convective Systems (MCSs) (Maddox 1980). An MCS may cover 10,000 to 50,000 square kilometers and produce steady moderate to heavy rainfall over a similar large area. Prolonged island-wide downpours are often attributable to the formation (or passage) over Saipan of an MCS. Two other important organized forms of convective clouds are the tropical cyclone (with its core convection and peripheral rainbands) and monsoon squall lines.

In summary, wet-season precipitation is predominantly of convective origin. Much of the wet-season precipitation falls as heavy downpours from individual active convective clouds although some wet-season rain derives from stratiform (i.e., “flat,” or “layered”) clouds which are the decaying remnants of a prior MCS. Heavy downpours from isolated convective clouds may cover only small portions of the island at a given time. Larger-scale heavy rain events may result from the formation or passage over Saipan of an MCS. The passages of tropical cyclones over or near the island have produced the largest historical 24-hour rainfall values, and the most widely distributed heavy rain possible. The passage of the eye wall cloud of a typhoon over the island is the likely cause of all extreme rain events at all time periods (e.g., 15-minute, 1-hour, 3-hour and 24-hour). In order of the spatial scale (small to large) of the heavy precipitation, the causes of wet-season heavy rain events are:

(1) Individual isolated thunderstorm cells,
(2) Formation, or passage, of an MCS over the island,
(3) Squall lines in strong southwesterly monsoon flow,
(4) Convective cloud bands in the peripheral flow of a tropical cyclone, and
(5) Direct passage over the island of the eye wall of a typhoon.

Extreme gradients of rainfall are seen in the rainy season. Twenty-four hour storm-total rainfall gradients on the order of 100 mm per kilometer are common. Even weather systems with large spatial scales (e.g., tropical storms and typhoons, and monsoon squall lines) may produce substantial rainfall over the whole island with, but with surprisingly large spatial gradients. On Guam, the NEXRAD Doppler weather radar has proven to be a valuable tool to determine the amounts and gradients of rainfall over that island and surrounding ocean. The Guam NEXRAD was sited at a location from which the view of Saipan is partially blocked by hills on Guam; and, at Saipan’s distance from the radar, data can’t be obtained below 20,000 ft. Properties of the rainfall as seen by NEXRAD near Guam, however, are likely to be similar to those on Saipan.

Dry season weather systems

The dry season on Saipan is dominated by trade winds. In a trade wind regime the air is subsiding, clouds lack vertical development, and rainfall comes in the form of sporadic trade wind showers. Although the rainfall in trade wind showers may be locally heavy, its normal character is brief spates of light to moderate rainfall. Daily rainfall totals rarely exceed .25 inches. The trade wind flow is usually peppered with a random distribution of clusters of trade wind showers. Thus, even during the dry season, a few light showers are experienced on most days, but the accumulated amounts are usually very small. On rare occasions, clusters of showers in the trade wind flow may produce daily rainfall totals of up to one inch. Another rarely occurring cause of substantial rainfall in the dry season is the northward spread of clusters of thunderstorms (that remain common south of 10°N during the dry season) to Saipan’s latitude that bring a heavy rainfall event of convective origin.

Two types of large-scale weather systems can bring substantial (an inch or more in a day) rainfall to Saipan during the dry season: an off-season tropical cyclone, and a “shear line” (Fig. 4). During the period 1960-1990, the Joint Typhoon Warning Center (JTWC) (on Guam until its move to Hawaii in 1999) recorded an average of 5.5 tropical cyclones in the WNP basin during the dry season (JTWC 1990) with a monthly distribution as follows:

January – 0.6
February – 0.2
March – 0.5
April – 0.7
May – 1.3
June – 2.2

During the period 1970-1999, only ten tropical cyclones passed within 180 n mi of Saipan during the dry season (an average of about one such tropical cyclone every three years). However, one of Saipan's most destructive typhoons, Typhoon Olive, occurred at the end of April 1963.

The other important rain-producing large-scale weather system of the dry season is the "shear line." A "shear line" accompanies (or can be said to be) the band of clouds and showers which are the extension into the tropics of the cloud band associated with the cold fronts of the large extra-tropical storm systems which traverse the mid-latitudes of the North Pacific. Rather than the abrupt and relatively large directional shift of the wind experienced with the passage of a cold front in the mid-latitudes, a "shear line" passage in the tropics or subtropics often brings a dramatic strengthening—but little change in direction—of the prevailing trade wind flow. The character of the rain on Saipan produced by a shear line is typically a prolonged period of episodic light to moderate showers and periods of misty drizzle. At times there are embedded heavier showers, and occasionally there is even an outbreak of deeper convective rain clouds along the leading edge of a shear line. Rainfall totals of .50 inch to over one inch are common during the one-to-two day passage of a strong shear line cloud band over Saipan.

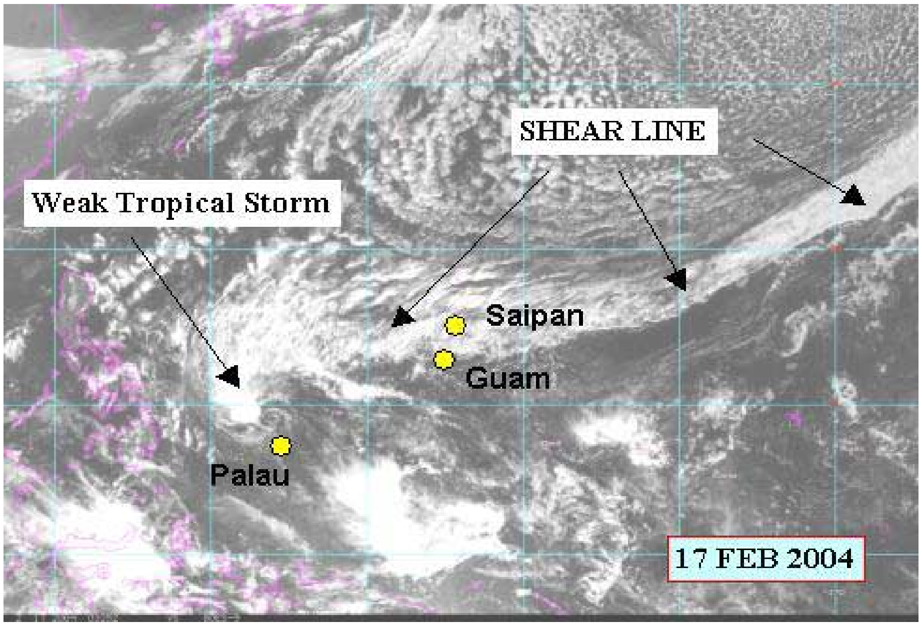


Figure 5. Weather satellite imagery for February 17, 2004 shows a shear line moving southward to cover Guam and Saipan with a period of showers and gusty northeasterly wind. A tropical cyclone (Tropical Storm 01W) is seen to the northwest of Palau. February is the quietest month for tropical cyclones in the western North Pacific; but, as seen in this image, they still can occur.

c. Total rainfall

Inhabitants of Saipan recognize two major divisions of the year based on the local climate—the wet season and the dry season. The dry season generally comprises the first half of the calendar year (January through June), and the wet season typically occurs from July through December. Saipan's mean monthly rainfall follows a roughly sinusoidal curve that falls to a minimum of about 2.5 inches in March and rises to a maximum of 12 inches in August (Fig. 6). The comfort level of the dry season is accentuated by persistent east-northeast trade winds averaging 15-20 mph. During the summer, the *mean* wind becomes almost calm — the result of long periods of light winds from the east interspersed with shorter episodes of brisk monsoonal winds from the southwest.

An average of roughly 80 inches (2000 mm) of rain falls on Saipan during the calendar year. The island is quite small (80 km^2) and its mountains are relatively low (471 m or less), however, the distribution of rainfall on the island is affected by the topography, and the mean annual rainfall totals among recording stations on Saipan differ by as much as 15 inches (380 mm) (20%). The region in the vicinity of Saipan's international airport (SIA) receives the lowest annual total of about 75 inches (1900 mm). The highest measured mean annual total of approximately 90 inches (2300 mm) occurs at Capitol Hill, and extends along the high ground from Marpi to Mount Tagpochau.

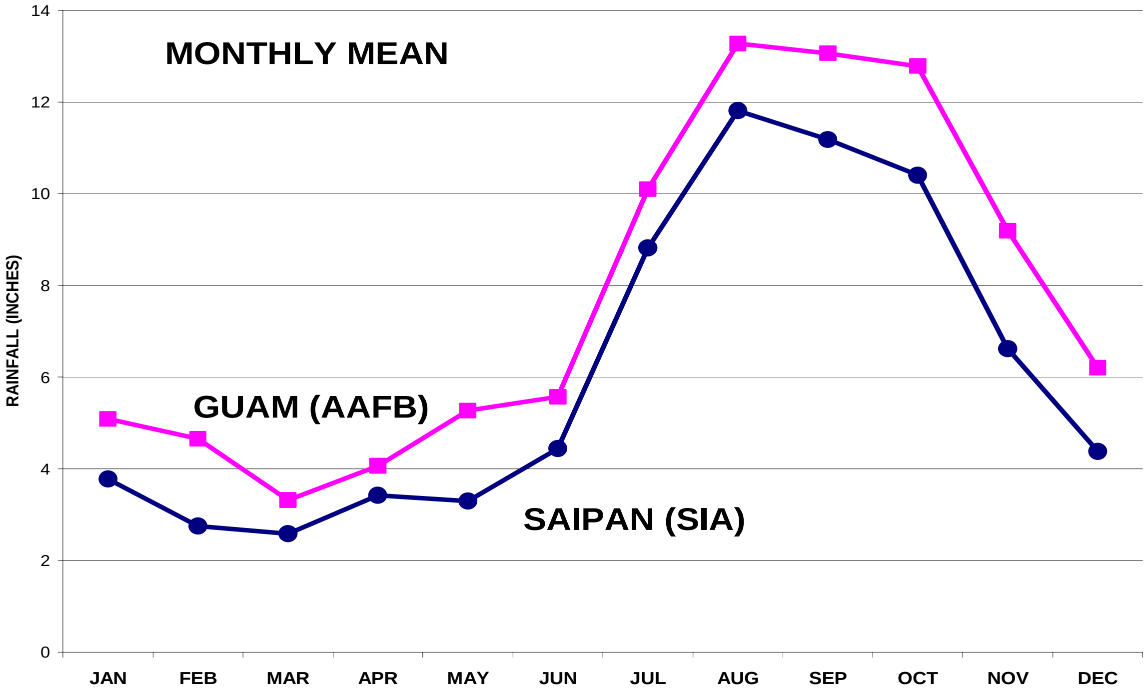


Figure 6. Monthly mean rainfall at Saipan International Airport and at Guam's Andersen Air Force Base (in inches). Note that in every month of the year, Guam (located further south) gets about 2 inches more rain than Saipan.

On the large scale, there is an east-west zone of maximum annual rainfall from 4-8°N across Micronesia. The amounts drop off steadily as one progresses northward (where the dry season becomes more prolonged). The islands of Kosrae and Pohnpei experience at least 160 inches of rain annually, with no appreciable wet or dry seasons. A bit further north at Chuuk and at Palau, the over-water annual rainfall is approximately 140 inches; falling to 120 inches at Yap, 100 inches at Guam, and to 80 inches at Saipan. North and east from Saipan, the region is dominated by the mid-Pacific subtropical high pressure area and its accompanying trade winds, and the annual rain decreases to values around 40 inches (Fig. 7).

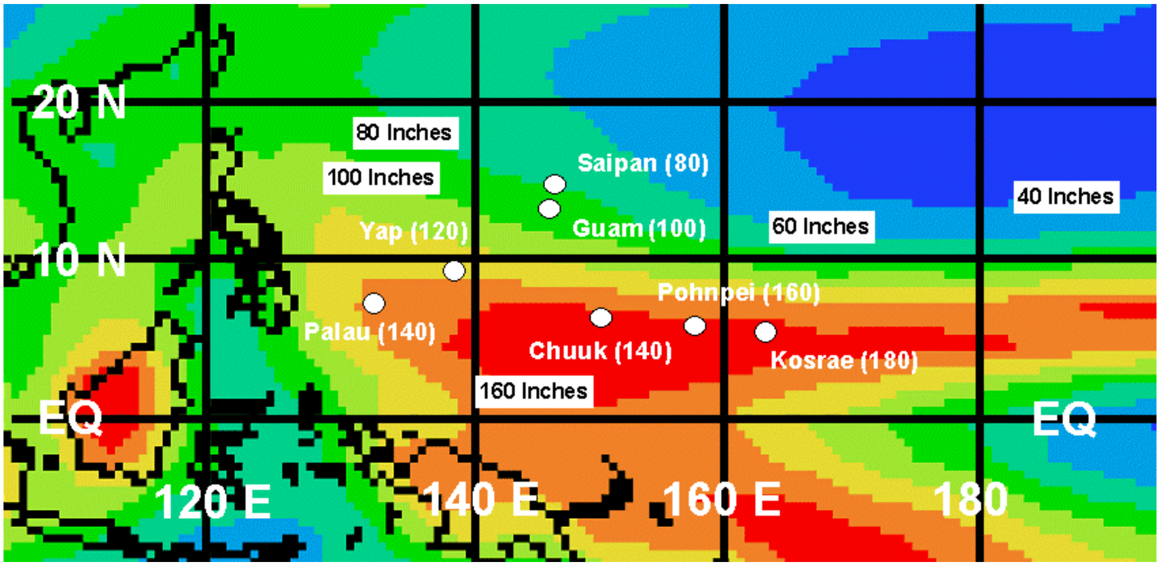


Figure 7. Mean annual over-water rainfall in Micronesia. Colors indicate rainfall pattern (amounts as labeled: red ≥ 160 inches per year, orange ≥ 140, yellow ≥ 120, light green ≥ 100, dark green ≥ 80, teal ≥ 60, blue ≥ 40, and within the dark blue region there is less than 40 inches of annual rainfall). Mean annual over-water rainfall at selected islands is indicated. Image adapted from figure on website URL http://orbit35i.nesdis.noaa.gov/arad/gpcp/

d. Temporal variability

In the vicinity of the SIA, the mean annual rainfall during the period 1954-99 was 73.48 inches with a standard deviation of 16.42 inches (Lander and Guard 2004). The mean dry-season (January through June) rainfall was 20.26 inches with a standard deviation of 7.90 inches; the mean wet-season (July through December) rainfall was 53.21 inches with a standard deviation of 12.84 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 35.65 inches recorded in 1998. The second driest year was 1983 with 51.26 inches of rain. The wettest annual total in the time series is the 115.17 inches recorded during 1968 followed by 112.47 inches in 1986. The wettest dry season (40.83 inches) occurred in 1985, and the driest dry season (9.38 inches) occurred in 1998. The wettest wet season (85.92 inches) occurred in 1960, and the driest wet season (26.27 inches) occurred in 1998. Nearly all extremely dry years on Saipan occur during the year following an El Niño event (see Section 3b).

The lowest mean (2.58 inches) monthly rainfall occurs in March. The highest mean monthly rainfall (11.81 inches) occurs in August. Monthly rainfall values below one inch have occurred in February through June. Monthly rainfall values above 20 inches have occurred in August, September, October, November, and December. The lowest value of the monthly time series of the rainfall at the SIA is the reading of 0.19 inches during March 1995. The highest monthly value is the 28.94 inches recorded during August 1960, which was recently surpassed by an enormous monthly total of 35 inches during August 2004.

A study of the distribution of the daily rainfall values within each month shows that nearly half of a given month's total rainfall is typically accrued during the wettest 3 days of the month. There is quite a bit of scatter about the generic curve shown in Fig. 8; for example, during some months with typhoons, the highest one-day rainfall may comprise 50-75% (or more) of the monthly total, and during other months the curve is not as skewed. Using the generic curve of Fig. 9, the following may be said of a month with 10 inches of rain:

(1) the rainfall exceeded 2 inches in 24 hours on one day,
(2) the rainfall equaled or exceeded one inch in 24 hours on three of the days,
(3) the rainfall equaled or exceeded 0.50 inches in 24 hours on 7 days,
(4) the rainfall was less than 0.10 inches in 24 hours on 13 days.

For a month with only three inches of rain:

(1) the rainfall exceeded 0.5 inches in 24 hours on one day,
(2) the rainfall equaled or exceeded 0.3 inches in 24 hours on three of the days,
(3) the rainfall equaled or exceeded .15 inches in 24 hours on 7 days, and
(4) the rainfall was less than 0.10 inch in 24 hours on 20 days.

There is a tendency for the curves to be more highly skewed in the dry season. The daily rainfall distribution given by the generic curve (Fig. 8) needs to be altered slightly for such months so that higher daily rainfall amounts are squeezed into fewer days, and lower daily rainfall rates occur more often.

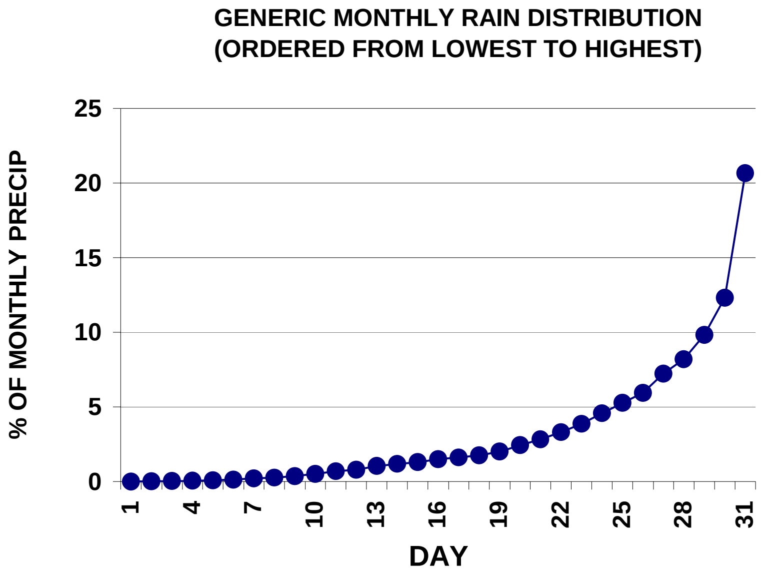
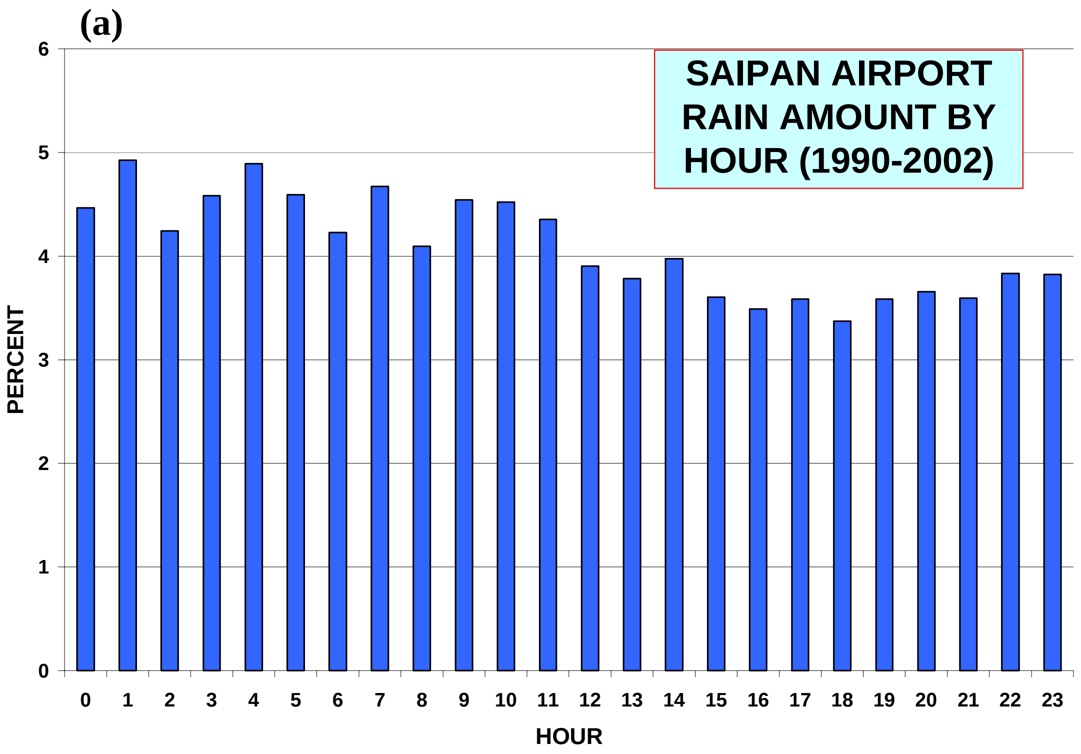


Figure 8. Daily rainfall (as a percent of the monthly total) arranged in order of the lowest to the highest. This curve is an average of the daily rainfall during six August's and six July's at the SIA. Dry season months are typically more accentuated, and individual months may vary markedly from this curve, especially if there is a major typhoon event.

e. Hourly Distribution of daily rainfall

Throughout much of the tropical Pacific there is a tendency for more rainfall to occur in the morning hours. Ruprecht and Gray (1976) analyzed 13 years of cloud clusters over the tropical western Pacific and found that over twice as much rain fell on small islands from morning (0700 to 1200L) clusters as from evening (1900 to 2400L) clusters. The heaviest rain fell when it was part of an organized weather system and when diurnal variation was most pronounced. Fu et al. (1990) used satellite infrared images over the tropical Pacific to confirm and refine these findings. Deep convective cloudiness was greatest around 0700L and least around 1900L. The morning rainfall maximum associated with western Pacific cloud clusters and the early morning instability in the trade winds both originate from the nocturnal radiational cooling of cloud tops. An analysis of the fraction of the rainfall accumulated during each hour of the day shows that there is a tendency for most rainfall to occur between local midnight and sunrise than during other hours, with an absolute minimum in net long-term accumulations contributed during the evening hours. This is true for Saipan (Fig. 9 a,b) and other small islands and atolls of Micronesia such as Majuro and Chuuk (Fig. 9 c-e), but becomes more complicated at larger islands (Fig. 9 f-i) such as Guam (where the diurnal variation is not as pronounced), and mountainous islands such as Pohnpei and on the Hawaiian islands where large diurnal variations in rainfall (not necessarily synchronous with typical open-ocean variations) are driven by mountain- and sea-breeze circulations. At the SIA, the total amount of rain accumulated during the first half of the day (0000L-1200L) is 122% of the total amount of rain accumulated during the latter half of the day (1200L-2400L); at Capitol Hill, this statistic is 132%.



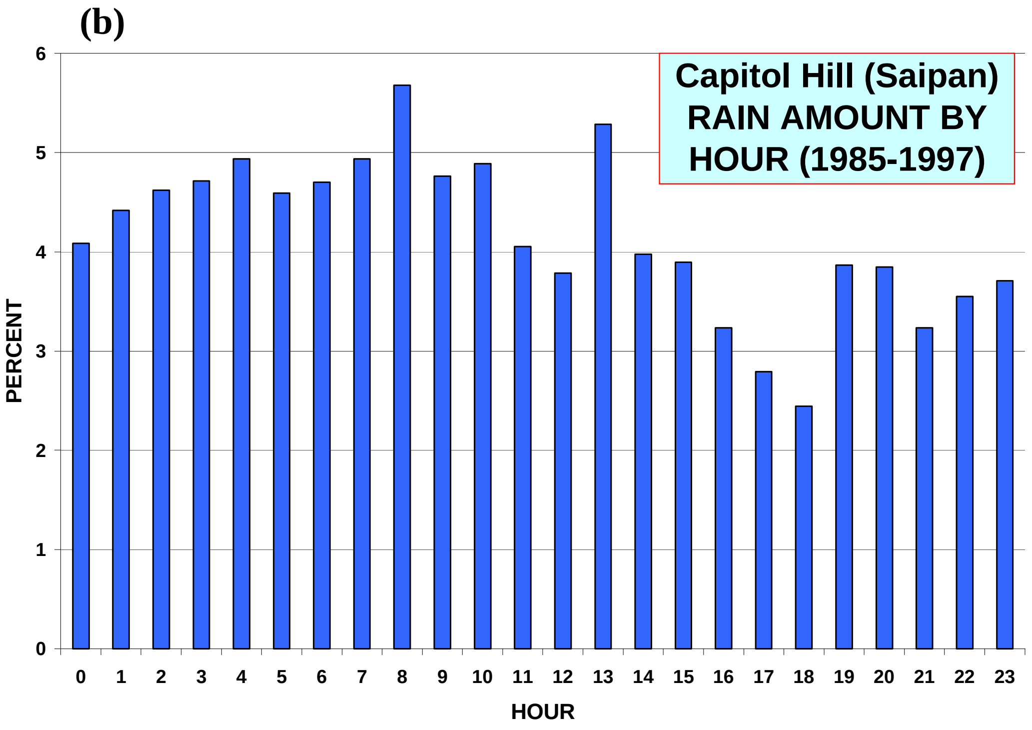
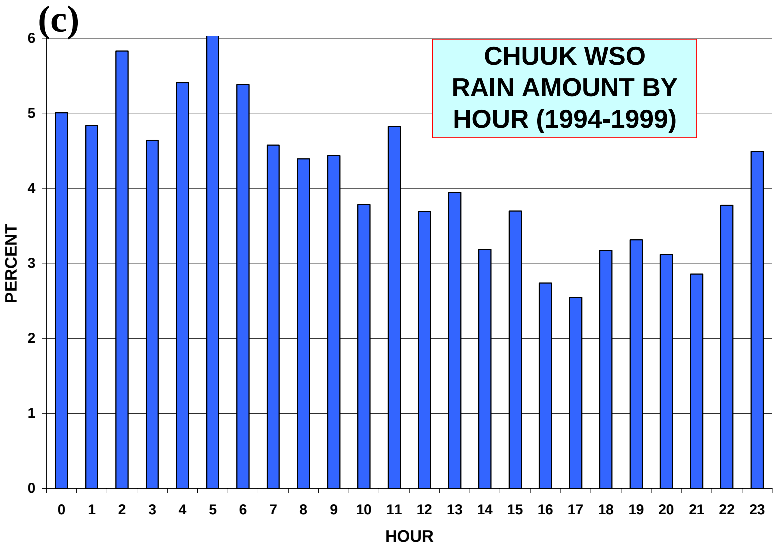
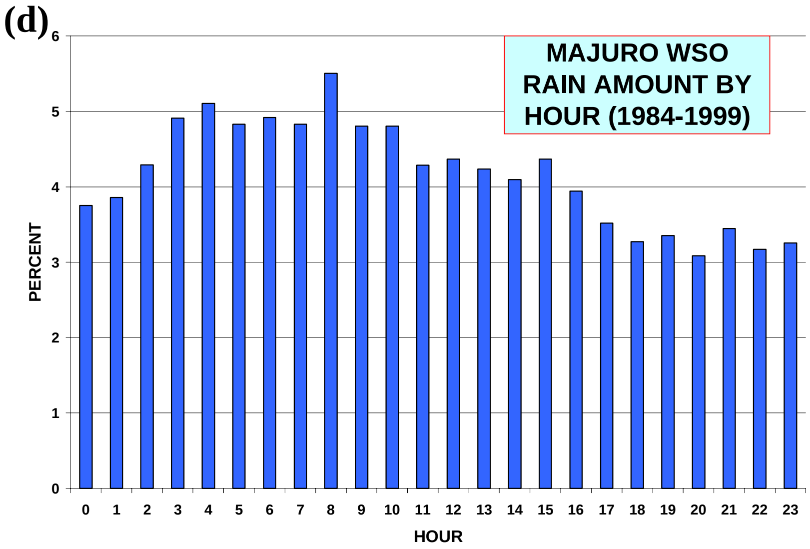


Figure 9 a,b. Rainfall amount (in percent by hour) of the grand total of all rainfall at (a) the SIA and at (b) Capitol Hill. There is a tendency for most of the rainfall on Saipan to occur in the morning hours with a pronounced minimum at sunset (18L). The ratio of the amount of rain from midnight to noon versus the rain from noon to midnight is 1.22 at SIA and 1.32 at Capitol Hill.





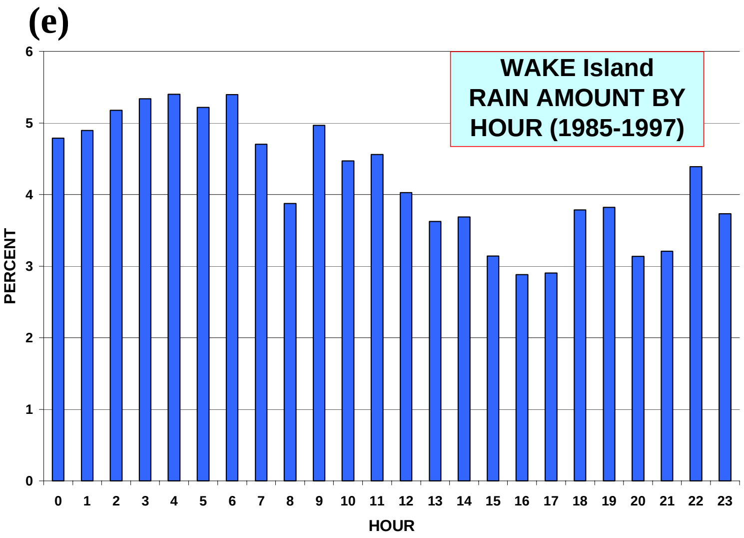


Figure 9 c-e. Rainfall amount (in percent by hour) of the grand total of all rainfall at (c) Chuuk, (d) Majuro, and (e) Wake Island. The rainfall at these islands reflects the typical open-ocean rainfall distribution found for the tropics of the western Pacific. There is more rain in the morning hours and a pronounced minimum in the evening (18-20L). The ratio of the amount of rain from midnight to noon versus the rain from noon to midnight is 1.47 at Chuuk, 1.32 at Majuro, and 1.39 at Wake Island.

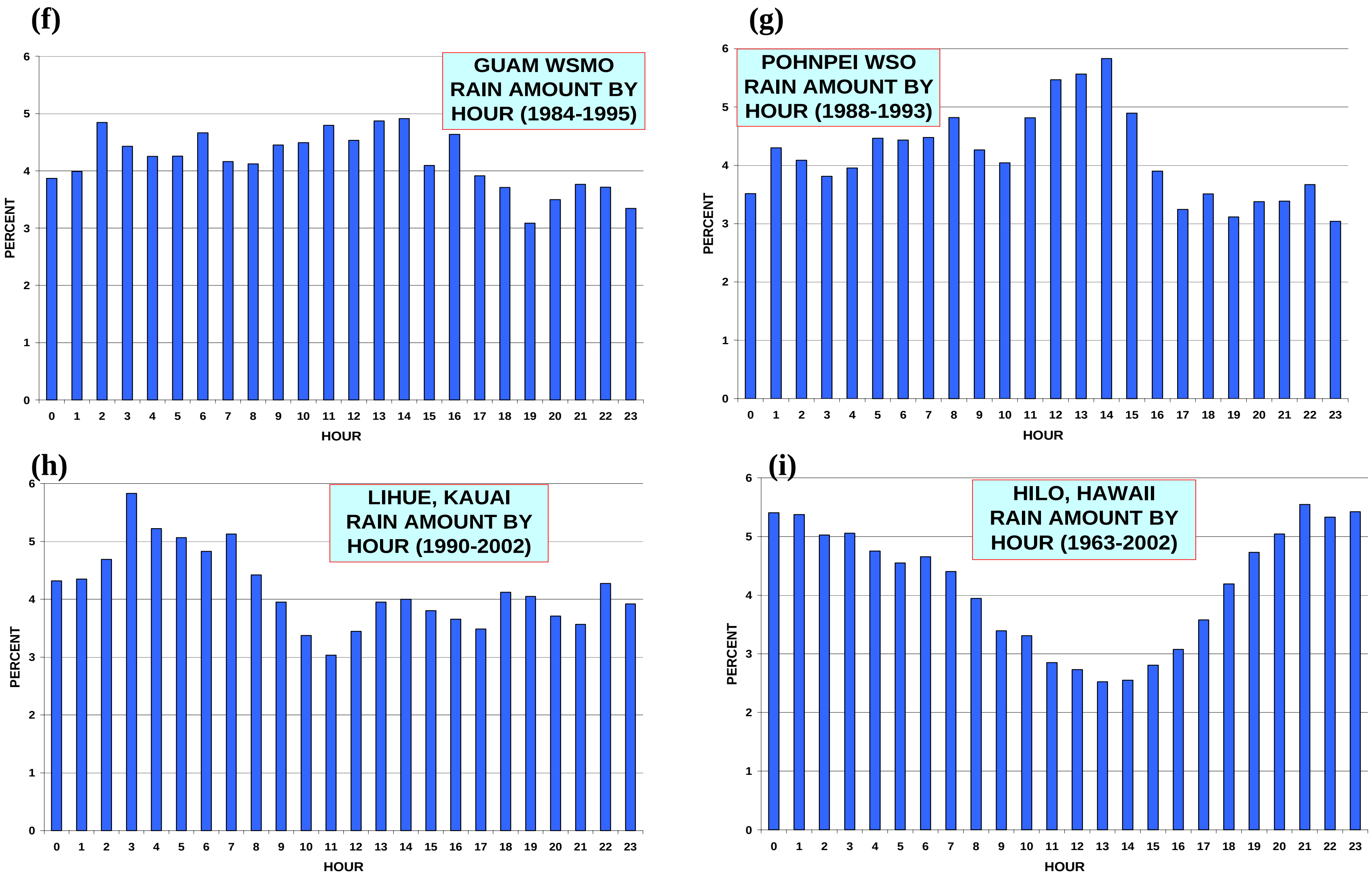


Figure 9 f-i. Rainfall amount (in percent by hour) of the grand total of all rainfall at (f) Guam, (g) Pophnpei, (h) Lihue, and (i) Hilo. The hourly distribution of the rainfall on these larger and/or mountainous islands is quite different from the open-ocean distribution. Diurnal heating and cooling of the land and mountain areas may substantially affect the hourly distribution of rainfall.

g. Spatial Distribution of annual rainfall

The distribution of rainfall on the island of Saipan is affected by the topography, and the mean annual rainfall totals among recording stations on Saipan differ by as much as 15 inches (380 mm) (20%). The region in the vicinity of Saipan's international airport (Fig. 1) 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. In order to arrive at an annual rainfall distribution chart for Saipan, the rainfall at recording stations was first compared to simultaneous readings at Capitol Hill — the wettest among all of Saipan's rain recording sites. Normalizing the stations to Capitol Hill (where Capitol Hill = 1.00) resulted in the distribution of Fig. 10.

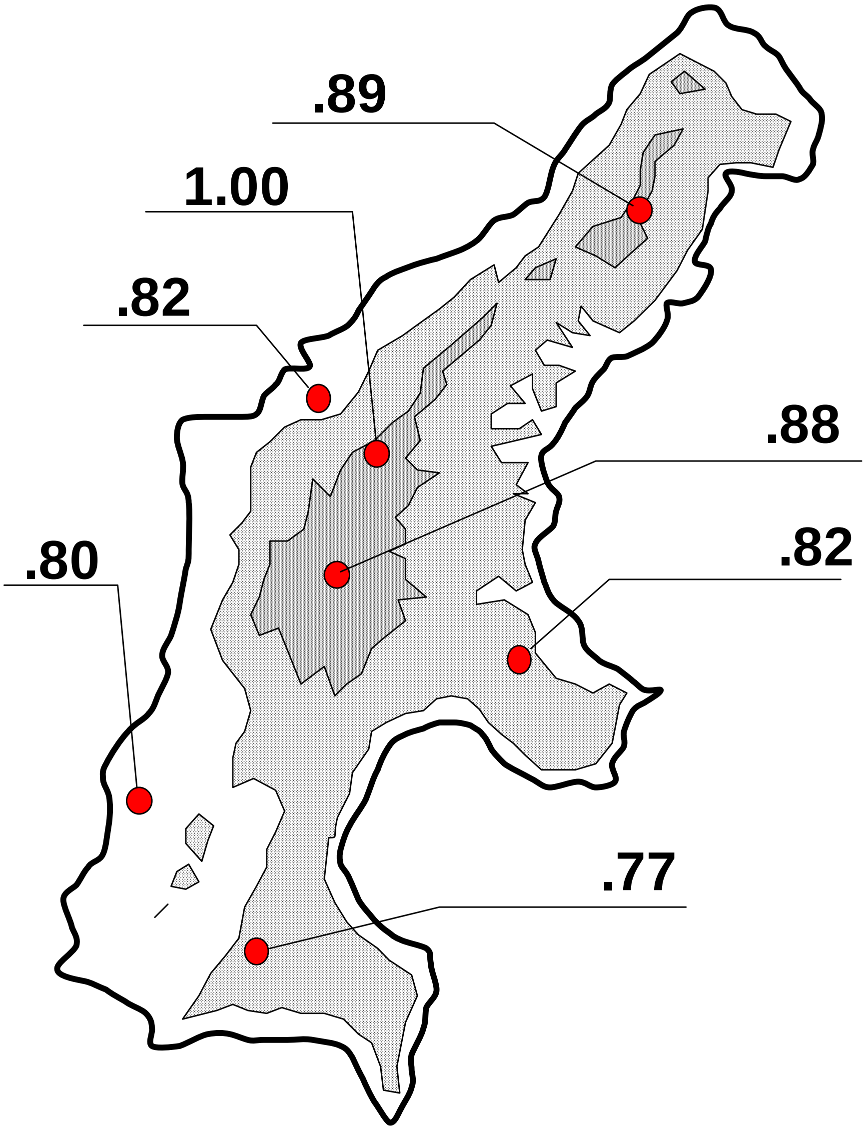


Figure 10. Rainfall at several sites on Saipan normalized to the rainfall at Capitol Hill, where the mean annual rainfall at Capital Hill is arbitrarily set to equal 1.00.

The next step was to convert the percentages in Fig. 10 to rainfall in inches per year. The sites in Fig. 10 are based on the post-war rain records, and some other stations have been added based on inter-comparisons of stations during the Japanese record of 1924-37. This process resulted in the mean annual rainfall map shown in Fig. 11. Contours are drawn using this data to arrive at the presentation in Fig. 12.

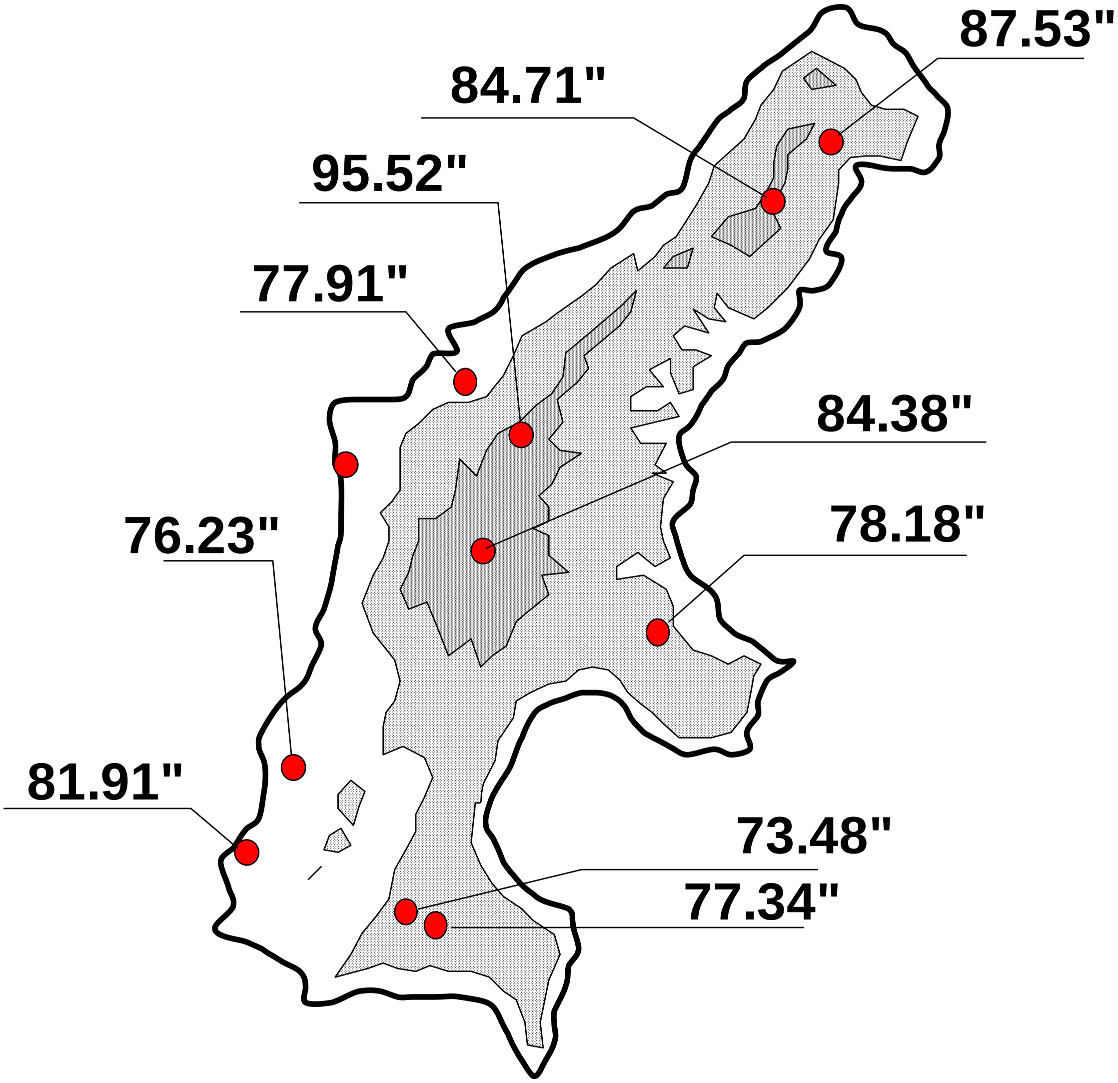


Figure 11. Mean annual rainfall at selected sites on the island of Saipan.

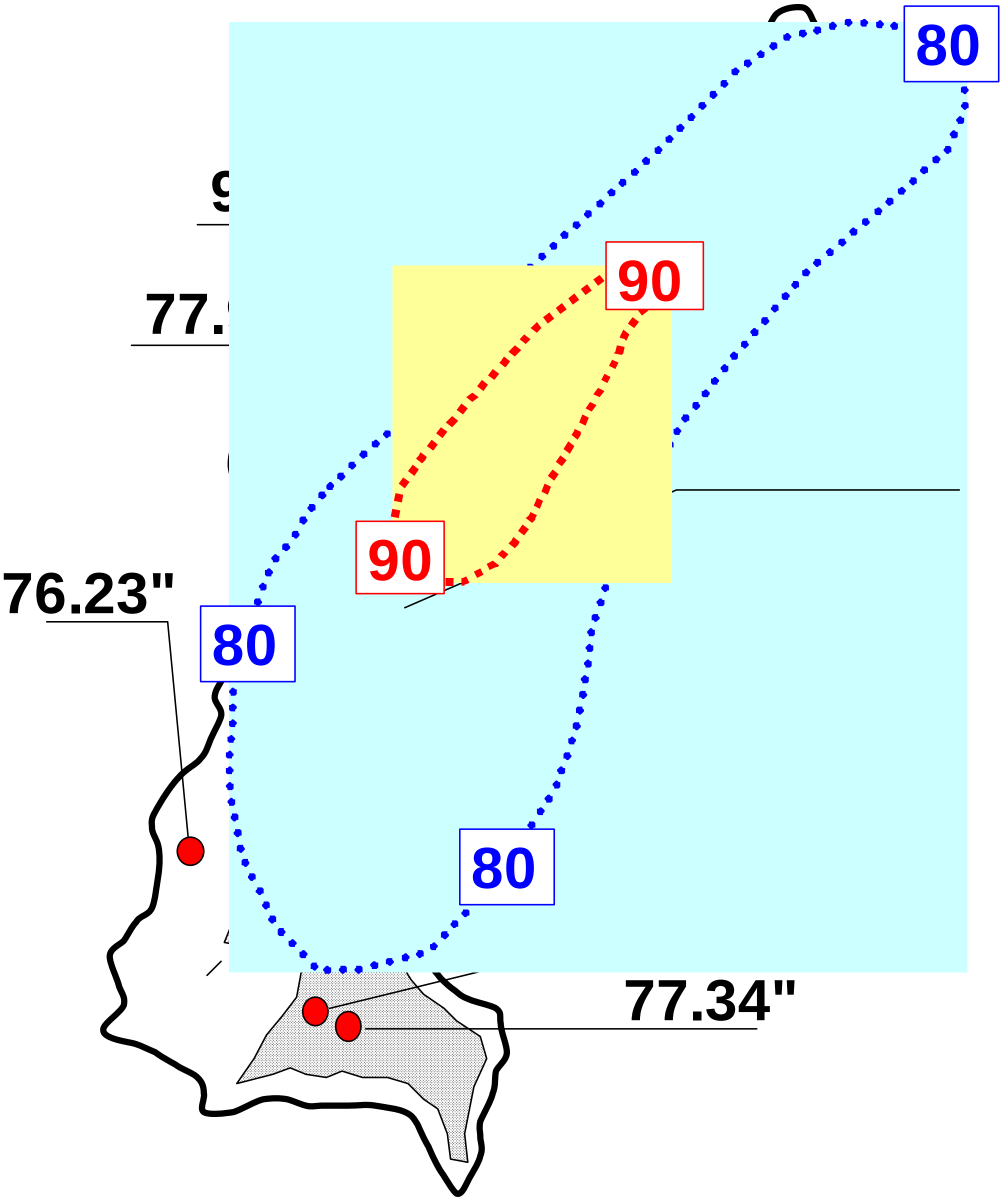


Figure 12. Contours of mean annual rainfall based on the rainfall at selected sites on the island of Saipan.

h. 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 mean annual rainfall drops steadily with latitude (Fig. 7), and Saipan's annual rainfall is about 20 inches less than that of Guam. Return-period calculations for Guam's peak annual 24-hour rainfall (Fig. 13) yield a mixed distribution, with typhoons causing all daily rainfall events in excess of 10 inches.

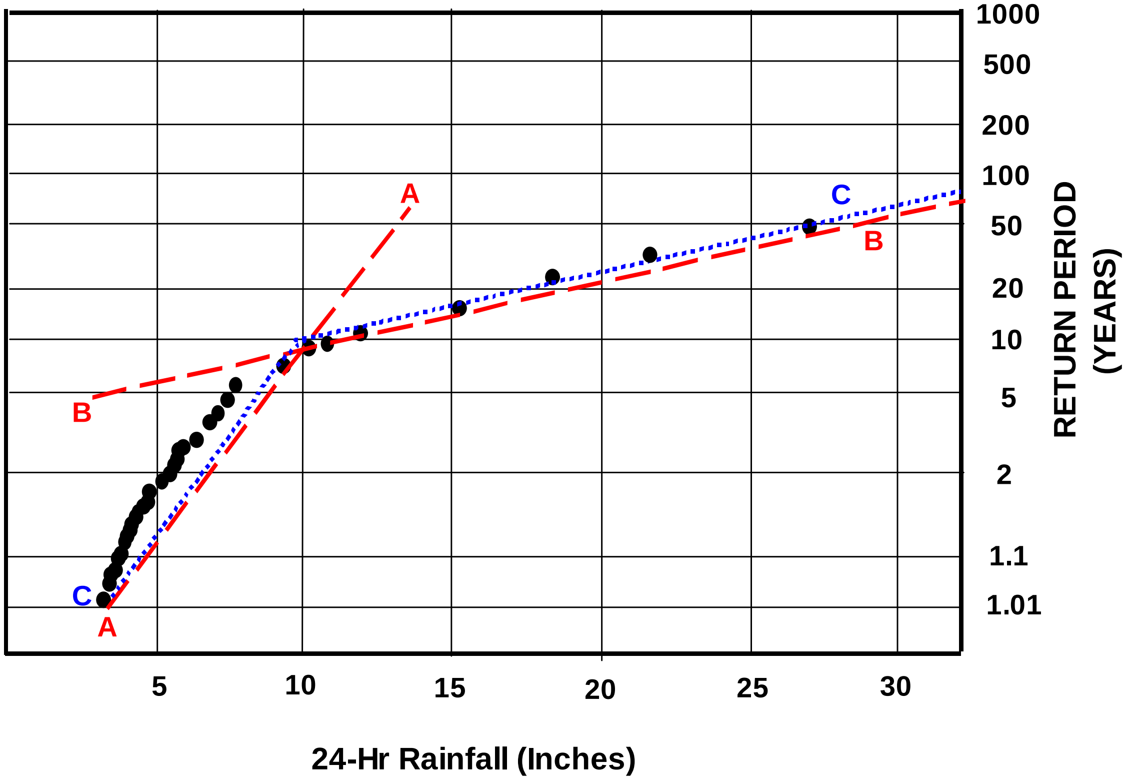


Figure 13. Return period for 24-hour rainfall totals computed for Guam. The change of slope of the lines that fit the individual realizations indicates that there is a mixed distribution of rainfall causes. This is indeed the case, as all rainfall totals in excess of 10 inches on this chart were caused 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. 14) yields a very wide range of possible values that center on the results for Guam.

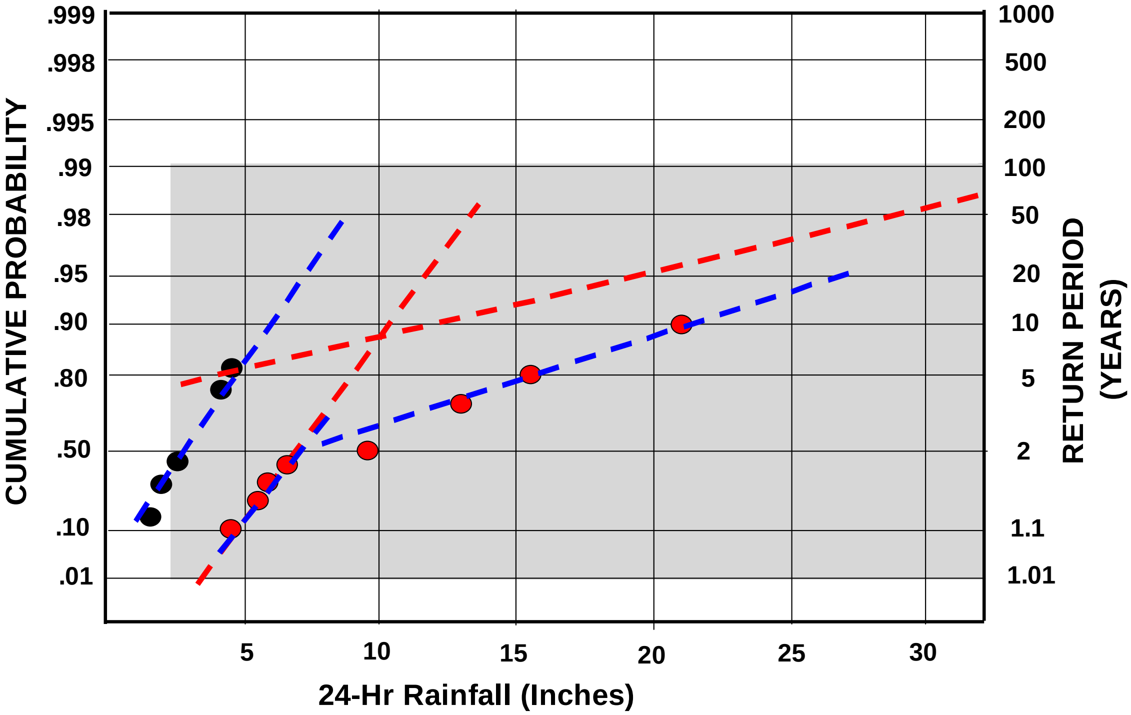


Figure 14. Method-of-moments (ranking method) computations of 24-hour return period extreme rainfall events using Saipan data. Black dots are from the record at Susupe, and red dots are from the record at Capitol Hill. The Capitol Hill record contains an unusual number of typhoon-associated rainfall events that occurred in the 1990's. Guam's 24-hour return period curve is shown by the dashed red line.

Previous studies have shown 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 (e.g., Fig. 15) and on Guam show no systematic topographical variations.

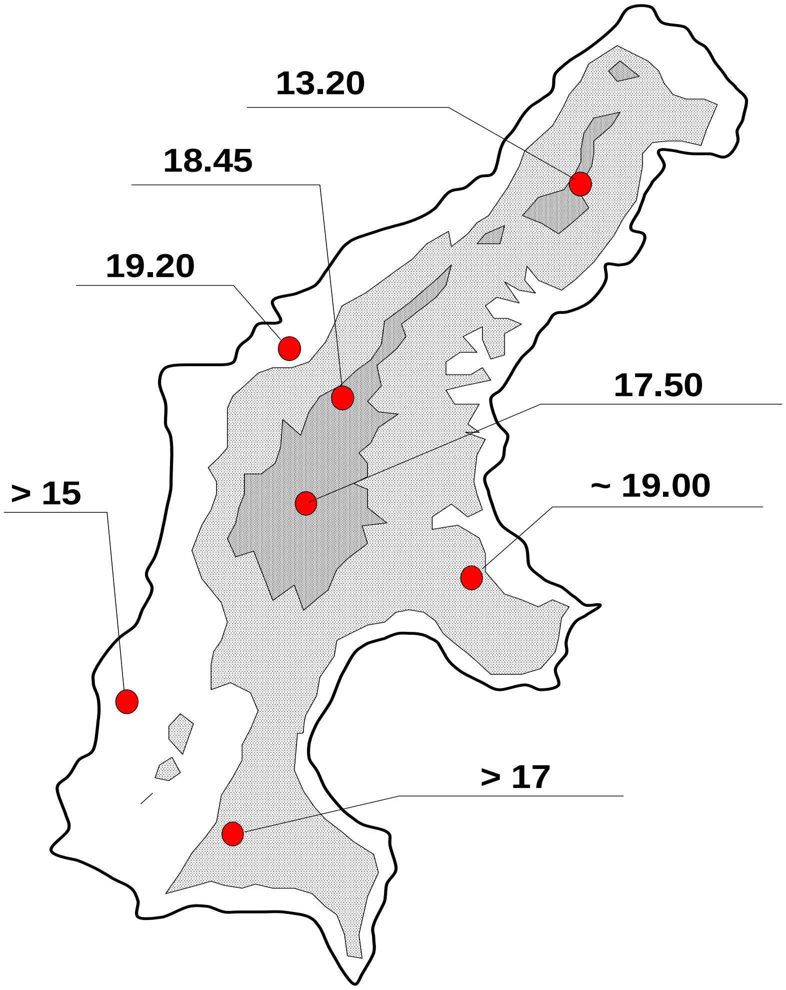


Figure 15. Twenty-four hour rainfall during Typhoon Steve, August 08, 1993. Note that the extreme rainfall totals are not a function of elevation. A similar distribution of extreme 24-hour rainfall was experienced on Saipan just one year later (not shown) during the passage of Typhoon Wilda.

In both typhoons Chataan (July 2002) and Pongsona (December 2002) on Guam, the rains recorded by newly installed electronic gages exceeded the extant 100-year event (Fig. 16). The 100-year event was exceeded at all intervals up to the 12-hour rainfall. It is thus likely 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 (See discussion of typhoons in Section 4); although during the 1990's Guam has experienced an unusual spate of typhoon strikes!

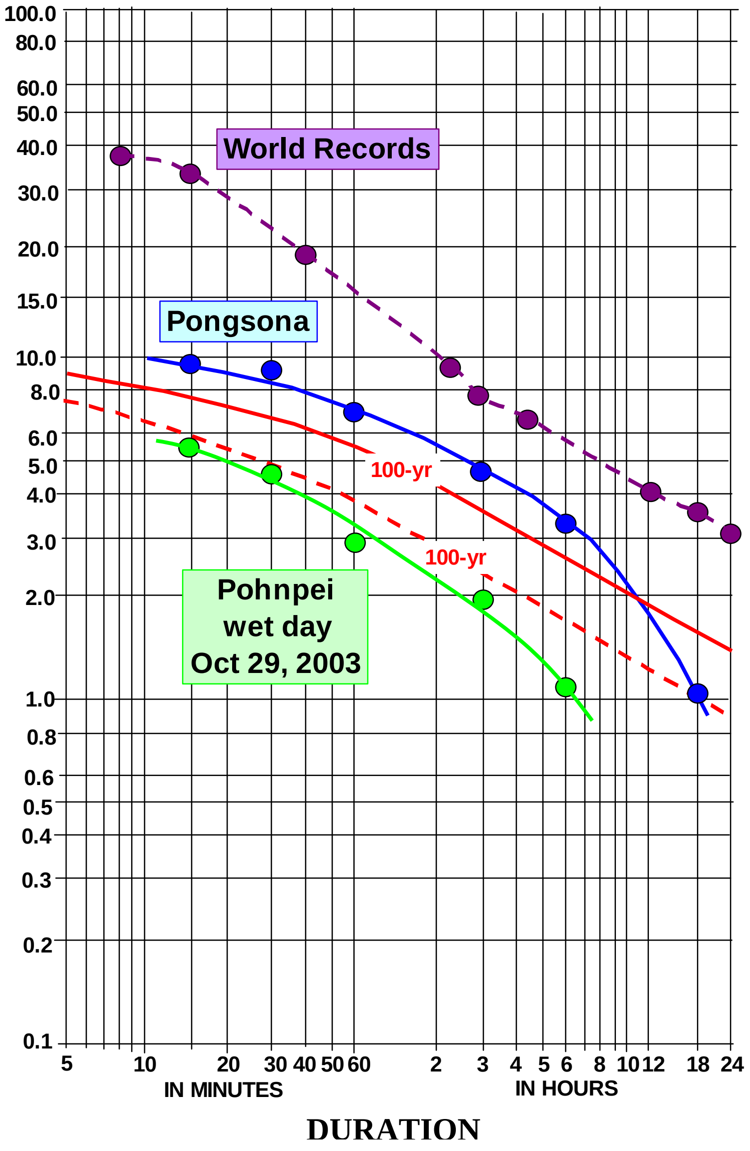


Figure 16. Peak short-term rain rates (blue dots) in Typhoon Pongsona over Guam. World records (Ramage 1995) are shown in purple, and amounts from a recent wet day on Pohnpei during 2003 are shown in green. Note that the rates in Typhoon Pongsona exceed the existing values for the 100-year return period as found in the Guam Storm Drainage Manual.

Because of Saipan's short rainfall records, it is very difficult to assess the return periods of extreme rainfall events. From a consideration of longer records on Guam, and the recent capture of typhoon rain rates by newly installed electronic rain gauges there, it appears that the eyewall of a typhoon produces the extreme rainfall rates at all time intervals from 15-minutes to 24-hours. Historically, typhoon rainfall has not been accurately measured (or even measured at all, due to instrument failure!). If one were to consider only non-typhoon rainfall, the computation of return periods of extreme rainfall for Guam and Saipan would yield numbers that are far too low. The rainfall is so heavy, and the rainfall gradients are so sharp under the eyewall of a typhoon (e.g., Fig. 17), that they act to create a mixed distribution on plots of return periods (Fig. 18a-f). Thus, the extreme rainfall from typhoons does not conform to the statistical properties extrapolated from rainfall from all other sources. In order to directly compute the return period of extreme rain events in such cases, one must have a much longer time-series with which to work. Even with a long time series, the mixed distribution would probably still be apparent. To overcome this, one may group the extreme rainfall amounts into longer intervals, say the extreme amounts by 5-year blocks, then graph the results and analytically derive the annual extremes. In order to derive a working chart of return-periods of extreme Saipan rainfall at 15-minute to 24-hour durations (Fig. 19), properties of the Saipan time series (SIA and Capitol Hill) (Fig. 18 a-f) were used for the shorter return periods (5- to 20-year), and the properties of typhoon rainfall recorded on Guam (and the capture of Typhoon Steve in the Saipan record) were used to assess the longer (50- to 100-year) return periods. NOTE: ***Because of the spatial scale of typhoons, the return periods of extreme rain events are not dependent upon elevation, and may be considered the same at all locations.***

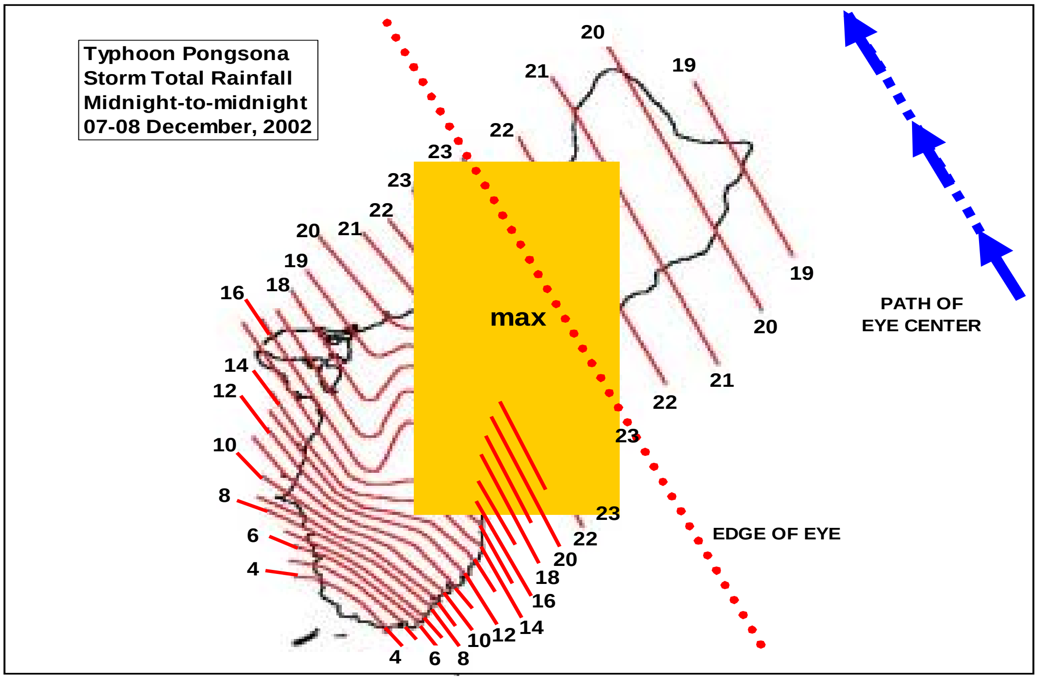


Figure 17. Twenty-four hour rain amounts on Guam during the passage of Typhoon Pongsona over the island. Note the extreme amounts of rainfall and the sharp gradients of rainfall that are a function of the geometry of the eye wall. The maximum rainfall occurs in those regions that pass through the inner edge of the eye wall ring, but do not go into the rain-free eye.

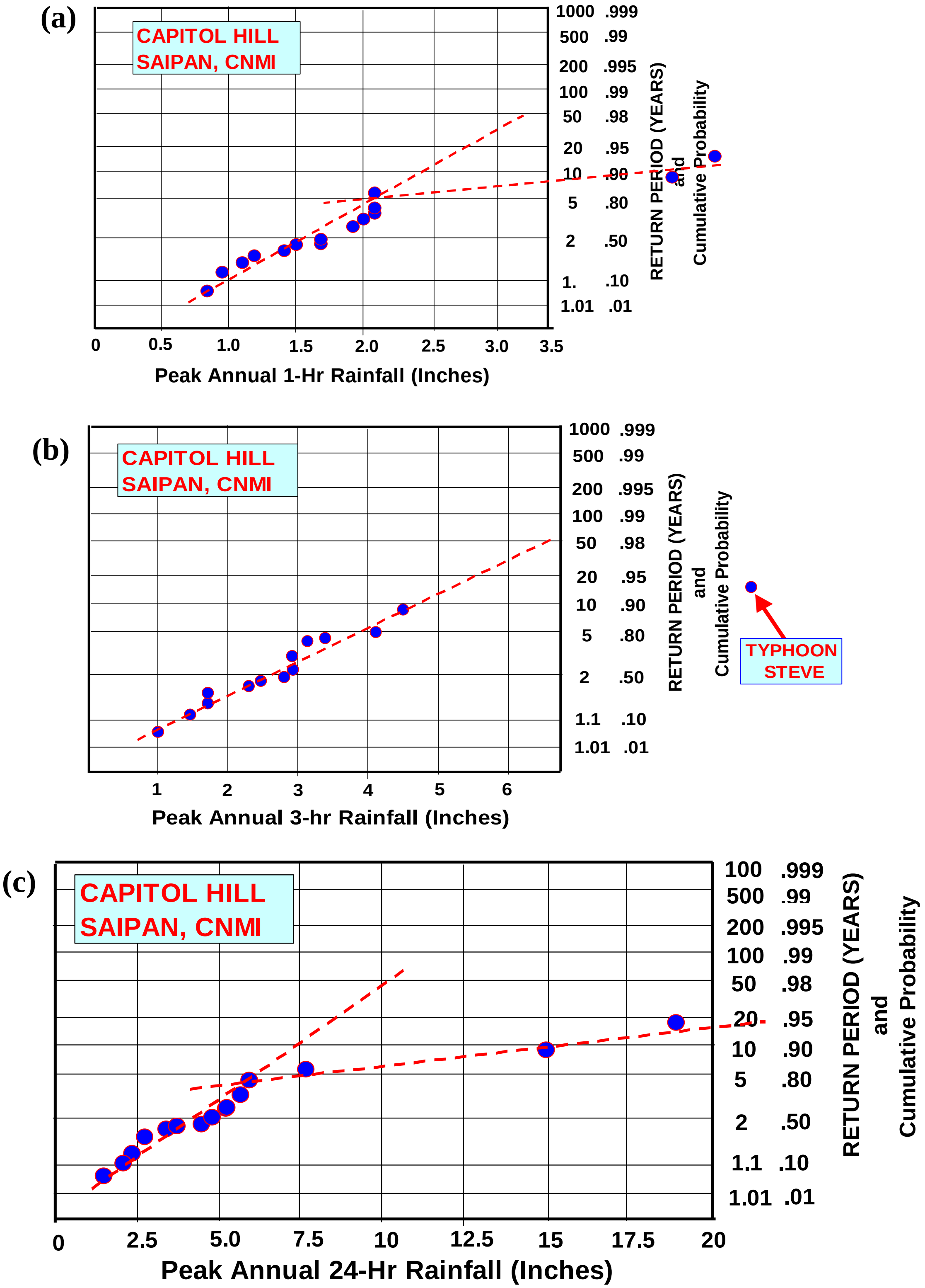


Figure 18 a-c. Peak annual (a) 1-hour, (b) 3-hour, and (c) 24-hour rainfall at Capitol Hill. Note the evidence of a mixed distribution caused by the extreme rainfall during typhoon events. Without typhoons, the return-period line would extrapolate to far too low longer-period extremes.

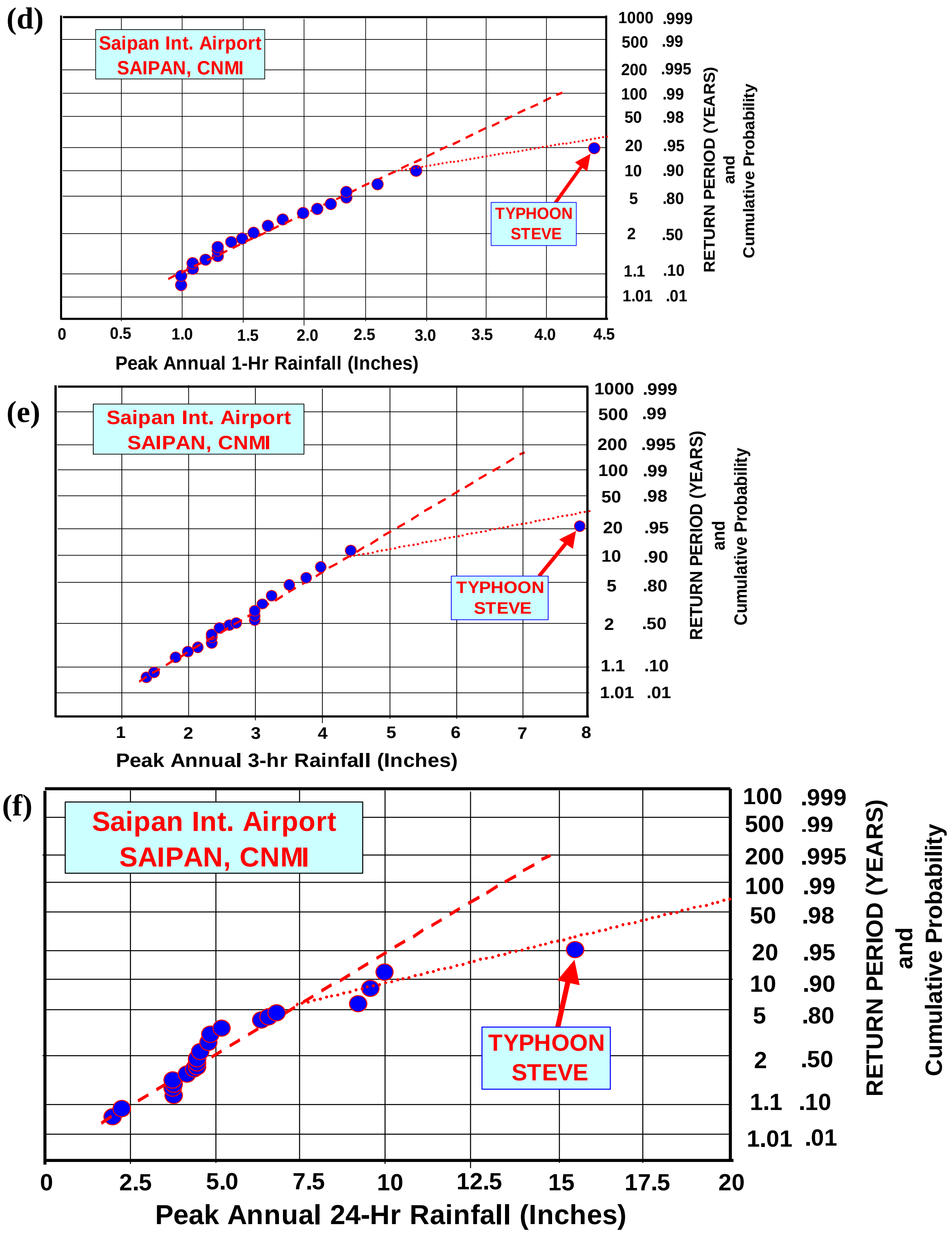


Figure 18 d-f. Peak annual (a) 1-hour, (b) 3-hour, and (c) 24-hour rainfall at SIA. Note the evidence of a mixed distribution caused by the extreme rainfall during typhoon events. Without typhoons, the return-period line would extrapolate to far too low longer-period extremes.

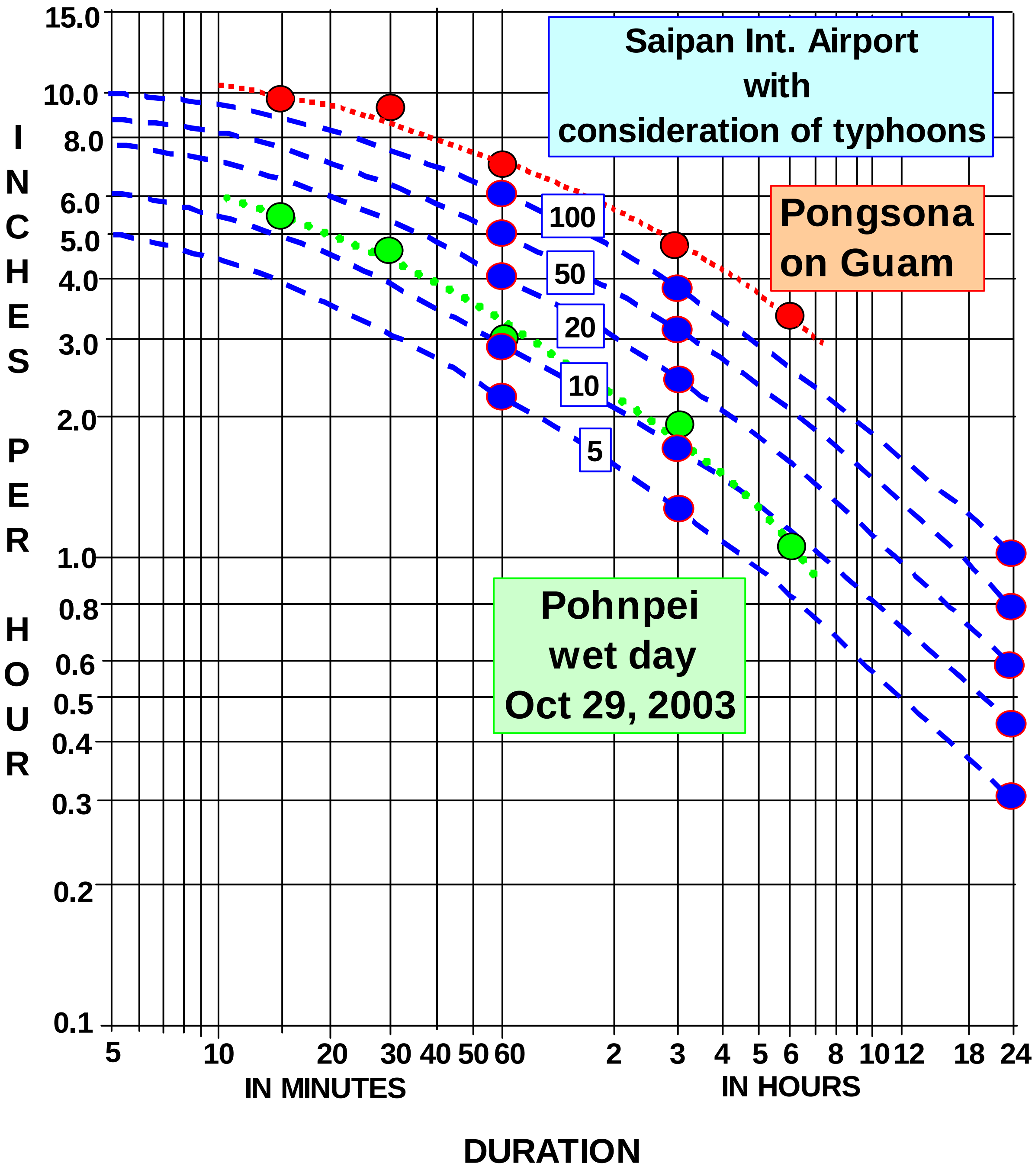


Figure 19. Intensity-Duration chart of selected return periods at the SIA (blue dots connected by blue dashed lines). Because the cause of the extreme events is typhoons, this curve may be considered applicable for all of Saipan. For comparison, the intensity-duration values measured during Typhoon Pongsona on Guam (red dots connected by red dotted line) are shown. Also, the highest Intensity-duration values measured within the past 9 months by a newly installed rain gauge network on Pohnpei have been plotted (green dots connected by green dotted line). The Pohnpei event was a fairly typical afternoon thunderstorm. Without typhoons, the return-periods at all durations would be much lower.

TABLE 2. Charts of Saipan Rainfall Intensity-Duration-Frequency (IDF). U.S. Army Corps of Engineers SIA (2003) recommended for all of Saipan values in black. UOG study values in red. Yellow-shaded cells indicate UOG higher.

Return Period	RAINFALL (Inches)								
	15 Minutes	30 Minutes	45 Minutes	60 Minutes (1 Hour)	120 Minutes (2 hrs)	180 Minutes (3 hrs)	360 Minutes (6 Hrs)	720 Minutes (12 Hrs)	1440 Minutes (24 Hrs)
X_{100}	2.65 ***2.20***	3.36 ***3.85***	3.91 ***4.80***	4.48 ***6.10***	6.77 ***9.40***	7.54 ***11.70***	10.90 ***16.20***	14.36 ***20.40***	16.80 ***26.40***
X_{50}	2.37 ***1.95***	3.03 ***3.10***	3.54 ***4.27***	4.06 ***5.00***	6.05 ***7.60***	6.74 ***9.30***	9.65 ***12.60***	12.69 ***16.80***	14.87 ***19.20***
X_{25}	2.08 ***1.68***	2.69 ***2.80***	3.16 ***3.60***	3.64 ***4.30***	5.32 ***6.40***	5.93 ***7.80***	8.40 ***10.80***	11.00 ***13.20***	12.94 ***14.88***
X_{10}	1.70 ***1.25***	2.24 ***1.95***	2.66 ***2.48***	3.06 ***2.90***	4.35 ***4.20***	4.83 ***5.40***	6.70 ***7.20***	8.74 ***8.40***	10.33 ***10.32***
X_{5}	1.39 ***1.00***	1.88 ***1.50***	2.26 ***2.02***	2.61 ***2.20***	3.57 ***3.40***	3.97 ***3.90***	5.36 ***4.92***	6.94 ***6.60***	8.26 ***7.68***

Return Period	RAINFALL INTENSITY (Inches/Hour)								
	15 Minutes	30 Minutes	45 Minutes	60 Minutes (1 Hour)	120 Minutes (2 hrs)	180 Minutes (3 hrs)	360 Minutes (6 Hrs)	720 Minutes (12 Hrs)	1440 Minutes (24 Hrs)
X_{100}	10.60 ***8.80***	6.71 ***7.60***	5.21 ***6.40***	4.48 ***6.10***	3.39 ***4.70***	2.51 ***3.90***	1.82 ***2.70***	1.20 ***1.70***	0.70 ***1.10***
X_{50}	9.47 ***7.80***	6.05 ***6.20***	4.72 ***5.70***	4.06 ***5.00***	3.03 ***3.80***	2.25 ***3.10***	1.61 ***2.10***	1.06 ***1.40***	0.62 ***0.80***
X_{25}	8.32 ***6.70***	5.38 ***5.60***	4.22 ***4.80***	3.64 ***4.30***	2.66 ***3.20***	1.98 ***2.60***	1.40 ***1.80***	0.92 ***1.10***	0.54 ***0.62***
X_{10}	6.78 ***5.00***	4.48 ***3.90***	3.54 ***3.30***	3.06 ***2.90***	2.17 ***2.10***	1.61 ***1.80***	1.12 ***1.20***	0.73 ***0.70***	0.43 ***0.43***
X_{5}	5.56 ***4.00***	3.76 ***3.00***	3.01 ***2.70***	2.61 ***2.20***	1.79 ***1.70***	1.32 ***1.30***	0.89 ***0.82***	0.58 ***0.55***	0.34 ***0.32***

3. El Niño and the Southern Oscillation

a. Description of El Niño, La Niña and the Southern Oscillation

Interannual variations of Saipan's rainfall are closely linked to the El Niño/Southern Oscillation (ENSO) phenomenon. The CNMI and Guam are in an ENSO core region that features very dry conditions in the year following El Niño (Ropelewski and Halpert 1987), and an increase in the level of threat from typhoons during an El Niño year (Fig. 20).

Ramage (1981 and 1986) describes the El Niño phenomenon as follows:

> *"For more than a century, the name El Niño, the Spanish term for the Christ child, has been applied by fisherman to the annual appearance at Christmas time of warm water off the coast of Ecuador and northern Peru.*
>
> *For most of the year, the ocean surface waters off Peru and Ecuador are cool. The combined actions of southerly winds blowing parallel to the South American coast and the earth's rotation, forces cool, nutrient-rich water to "upwell" to the surface. In the sunlit upper layers phytoplankton grow in profusion and are grazed by zooplankton. These in turn are eaten by anchovies which comprise the world's largest single fishery resource.*
>
> *Every year, around Christmas a warm current moves south off Ecuador, displacing the cool surface waters – the phenomenon known as El Niño. Fishing is slightly disrupted but the effect is short-lived. Occasionally, however (in 1891, 1925, 1941, 1957-58, 1965, 1972-73, and 1976* [subsequently also: 1982-83, 1987, 1991-93, 1997, and 2002], *El Niño is much more intense and prolonged. Sea-surface temperatures rise along the coast of Peru, and in the equatorial eastern Pacific, and may stay high for more than a year. The anchovy fishery is disrupted, and unusually heavy rain may fall over western tropical South America. In recent years its original meaning has lapsed; now to oceanographers and meteorologists "El Niño" signifies the major phenomenon. There is now general agreement on the broad features of El Niño. In the tropical eastern Pacific beyond the immediate South American coastal waters, El Niño is associated with South Pacific trade winds relatively weaker than North Pacific trade winds, the north Pacific near equatorial convergence zone* [which is synonymous with the east-west oriented band of heavy rain clouds of the eastern and central north Pacific commonly referred to as the Inter-Tropical Convergence Zone] *nearer than normal to the equator, and development of equatorial westerlies and bad weather up to 20° of longitude east of the dateline. Sea surface temperatures are generally well above normal along the equator off South America, and positive anomalies may extend beyond 10ºN and 10º S.*
>
> *El Niño generally sets in around March or April and may last a year or more*."

The atmospheric component tied to El Niño is termed the Southern Oscillation. The intense warmings of the eastern equatorial Pacific (the oceanographic El Niños) are known to be closely linked with the behavior of the Southern Oscillation (a massive seesawing of atmospheric pressure between the southeastern and the tropical western Pacific). Many indices of the Southern Oscillation have been proposed and used. The warm-water episodes of El Niño coincide with negative anomalies of indices of the Southern Oscillation. The cold episodes, known as "La Niña", are seen to coincide with positive anomalies of indices of the Southern Oscillation.

Quoting again from Ramage (1986):

> *"The first major step toward understanding El Niño was taken in 1966 by Jacob Bjerknes of the University of California at Los Angeles, who noted that the anomalous warming of the sea is associated with the Southern Oscillation. The Southern Oscillation, first observed in 1924 by Sir Gilbert Walker, is a transpacific linkage of atmospheric pressure systems. When pressure rises in the high-pressure system centered on Easter Island, it falls in the low-pressure system over Indonesia and northern Australia, and vice versa. To quantify the phenomenon Walker defined the Southern Oscillation index (SOI) which is calculated by subtracting pressure in the western Pacific from pressure in the eastern Pacific. The index is positive when the difference between east and west is higher than normal and negative when the difference is lower than normal."*

The close link of the major warning of the sea surface temperature of the eastern equatorial Pacific during El Niño with negative anomalies of the SOI has prompted scientists to call the phenomenon of El Niño, "ENSO" (an acronym derived from El Niño/Southern Oscillation). Several methods for calculating the SOI are in use. In this report the monthly values of the SOI as defined and computed by the U.S. Climate Prediction Center (formerly the U.S. Climate Analysis Center) are used.

Definitions of El Niño developed in the early 1980s were contingent on persistent SST anomalies of at least +1ºC along the tropical Pacific coast of South America. A Scientific Committee for Ocean Research working group, SCOR WG 55, was set up to define El Niño (SCOR 1983) and came up with the following:

> "El Niño is the appearance of anomalously warm water along the coast of Ecuador and Peru as far south as Lima (12°S). This means a normalized Sea surface temperature (SST) anomaly exceeding one standard deviation [approximately 1°C] for at least four (4) consecutive months. This normalized SST anomaly should occur at least at three (3) of five (5) Peruvian coastal stations."

More recent definitions of El Niño have focused on substantial and persistent SST anomalies in the central equatorial Pacific. The Japan Meteorological Agency (JMA) working definition of El Niño required that the 5-month running mean of the monthly SST anomaly in the area 4°N-4°S and 90°-150°W (essentially the region known as "Niño 3") be +0.5°C or more for at least six consecutive months. Kiladis and Van Loon (1988) suggested that an atmospheric index (i.e., the SOI) be combined with an SST anomaly index in a definition of El Niño. For them, a "warm event (i.e., El Niño) required that the SST anomaly index for the eastern tropical Pacific (within 4° of the equator from 160°W to the South American coast) had to be positive for at least three seasons and be at least 0.5°C above the mean, while the SOI had to remain negative and below -1.0 for the same duration. The "cold events" (i.e., La Niña) required the inverse of the conditions for El Niño. From observations and numerical simulations of coupled atmosphere-ocean interactions in ENSO, Trenberth (1997) argues for a definition of El Niño that is based upon SST anomalies in a region a bit farther west than "Niño 3". Since April 1996, the Climate Prediction Center (CPC) of NOAA's National Centers for Environmental Prediction introduced a new SST index called Niño 3.4 for the region 5°N-5°S and 120°-170°W. Trenberth (1997) proposed that El Niño and La Niña be defined by the JMA definition modified to apply to SST's in the Niño 3.4 region and with a threshold exceeding ± 0.4°C. During the summer of 2003, the CPC adopted a slightly modified version of Trenberth's proposed definitions of El Niño and La Niña that require the value of the SST anomaly thresholds in the Niño 3.4 region to be ± 0.5°C, instead of ± 0.4°C.

El Niño and La Niña events can be weak, moderate or strong. Since 1980 there have been two major El Niño events (1982 and 1997), and 5 weak-to- moderate events, including the moderate El Niño of 2002. In the same time frame, there were four periods of La Niña, with the years 1998-2001 comprising a prolonged strong La Niña event. **The effects of El Niño and La Niña on Saipan and the rest of Micronesia include:**

(1) Changes in the rainfall distribution;
(2) Changes in the typhoon distribution; and,
(3) Changes in the sea level.

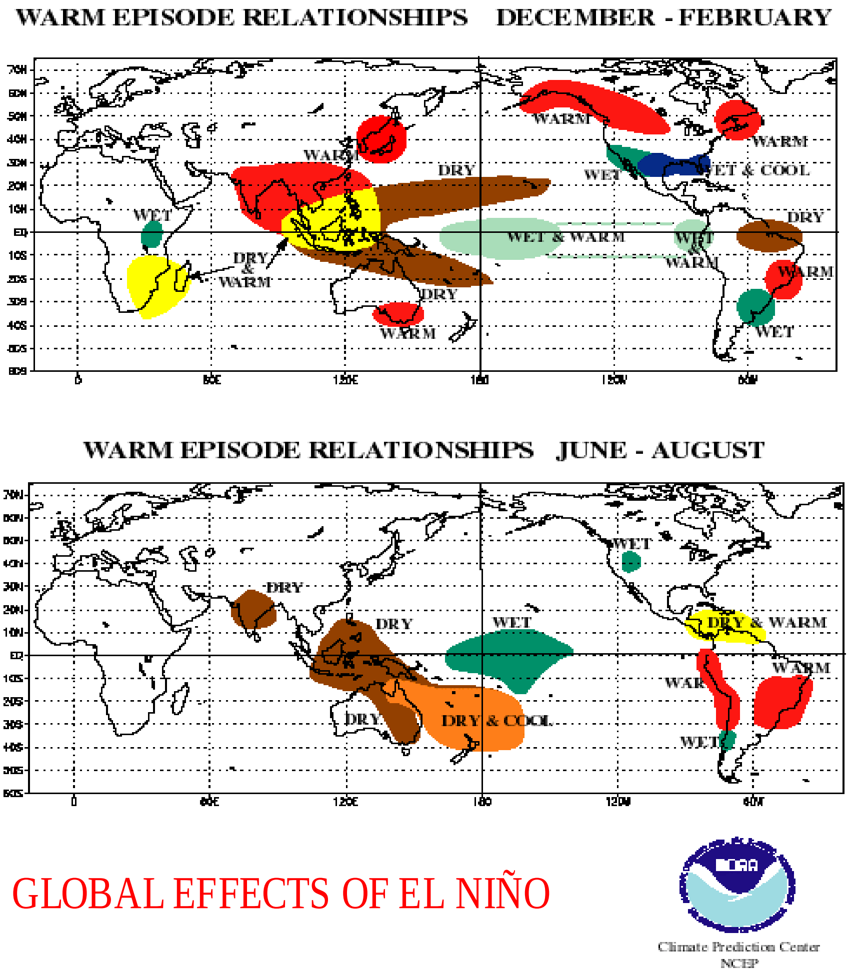


Figure 20. The effects of El Niño on global rainfall and temperature patterns. Note the large "boomerang"-shaped area of drought encompassing most of Micronesia in the months following El Niño, and the progression of drought during the El Niño year from Australia and Indonesia northward into Micronesia.

b. Effects of El Niño and La Niña on the weather and climate of Saipan

1) RAINFALL

Nearly all extremely dry years on Saipan occur during the year following an El Niño event (Figs. 21 and 22). The driest year on record in Saipan and throughout most of Micronesia occurred in 1998 (the follow-on year to the major El Niño of 1997). Some El Niño years are very wet depending upon the behavior of typhoons and the monsoon trough. Most La Niña years and non-ENSO years are near normal to slightly above normal (unless they are the year following an El Niño, in which case, they are dry).

On Saipan and Guam, persistent dryness tends to become established in the fall of the El Niño year (Fig. 22) (unless a late-season typhoon makes a direct strike – for example, the direct passage of Typhoon Paka over Guam in December 1997). Deleterious effects of drought (e.g., desiccation of grasslands and forests, draw-down of streamflow and well-heads, and wildfires) are exacerbated by extreme dryness in the normal "dry season", and extension of drier than normal conditions into the "wet season". Figure 22 is somewhat deceptive in that 50% of rainfall in March (when the normal is 2 inches) does not represent the same loss of rainfall as say, receiving 75% of the rainfall in August or September when the normal is approximately 10 inches.

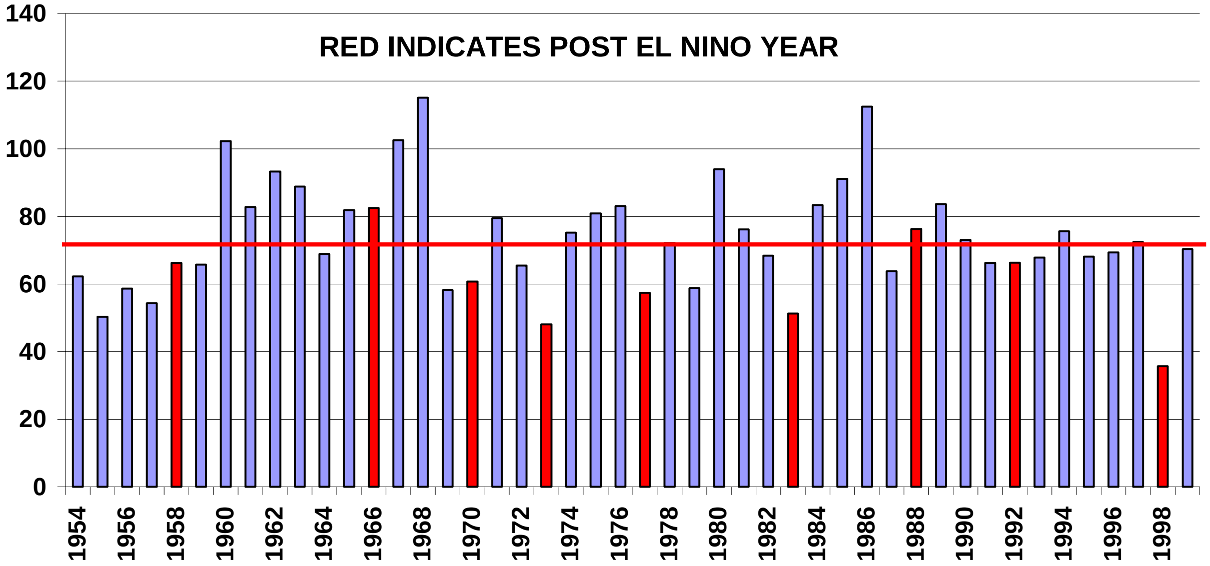


Figure 21. Annual rainfall at the Saipan International Airport (1954-1999). Years that follow an El Niño are indicated in red. Such years tend to be drier than others.

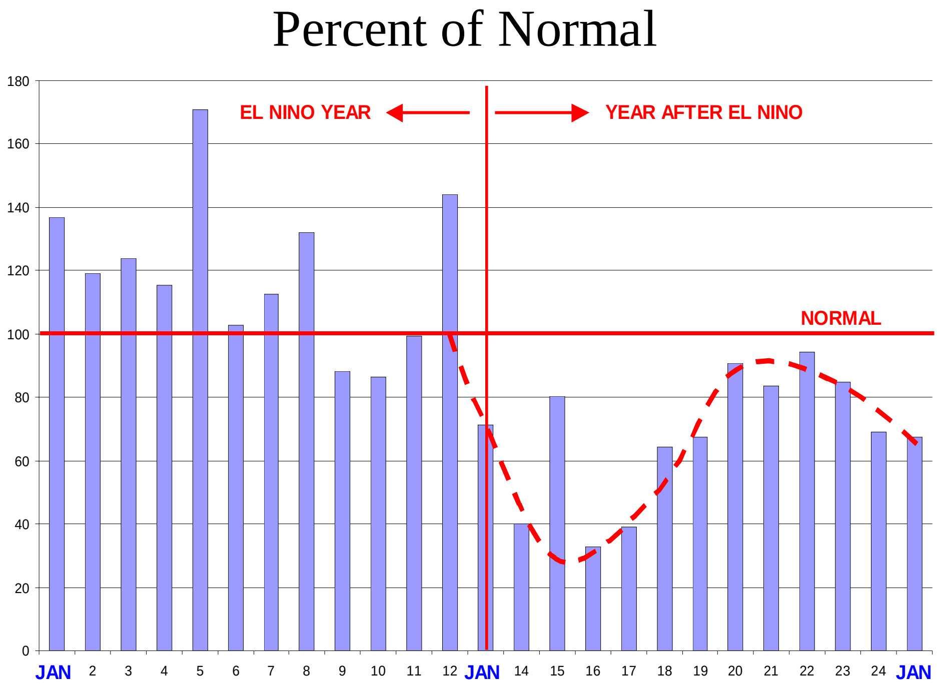


Figure 22. Average rainfall (in terms of percent of normal) during an El Niño year and during the year following El Niño.

2) SEA LEVEL

During an El Niño year, the mean sea level drops across most of Micronesia. Typically, the sea level in the region of Guam, Yap, and Saipan falls to its lowest value in December of the El Niño year, and then quickly recovers by the spring of the year following El Niño (Fig. 23). During La Niña, the sea level is elevated above its normal value. During the major El Niño of 1997, the sea level fell approximately 0.5 foot below its baseline average, and during the La Niña years that followed (1998-2001), the sea level rose to levels nearly 1 foot above its baseline average. The net difference of the sea level between the El Niño minimum in December 1997 and the La Niña high stands of the sea level during the summers of 1999, 2000, and 2001 was approximately 1.5 feet. This is substantial, considering that the normal range between the daily high and low astronomical tides is on the order of only 2 feet! On the question of long-term sea-level rise due to global warming, it must be pointed out that the long-term rise of sea level due to large-scale global climate change is estimated to be on the order of 4 or 5 inches per century. The ENSO changes in sea level of 1.5 feet over the course of a year or two are enormous compared to this, and make it difficult to retrieve the long-term signal.

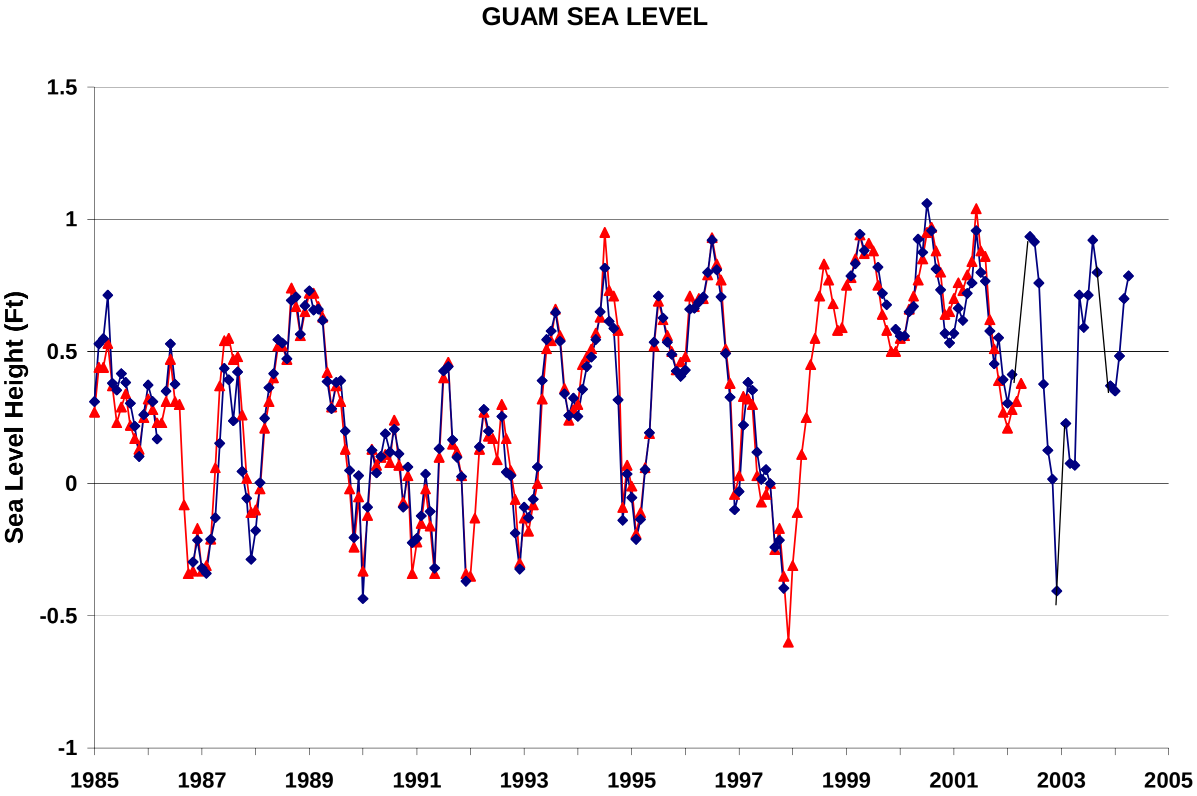


Figure 23. The record of monthly mean sea level at Guam for the period 1985-2004. These changes in sea level are highly coherent across the area from Yap to Guam and Saipan. Note the low sea level at the end of El Niño years (1987, 1991, 1997, and 2002) and the high sea level in the summers of La Niña years (1988, 1994, 1996, and 1998-2001). Periods of missing data from the NOAA tide gage at the Sumay Cove Marina have been filled-in by cross-correlation prediction (red line) from the USGS tide gage at the Agaña Boat Basin.

3) TROPICAL CYCLONES

The ENSO cycle has a profound effect on the distribution of tropical cyclones in the western North Pacific basin. The total number of tropical cyclones in the basin is not so much affected as is the formation region of the tropical cyclones. During El Niño, the formation region of tropical cyclones extends eastward into the eastern Caroline Islands and the Marshall Islands (see Fig. 24). During the year following an El Niño year, the formation region of tropical cyclones retracts to the west. This results in an increased risk of a typhoon for Guam and Saipan during El Niño years, and a decreased risk during the year following El Niño. On Guam, the risk of having typhoon force winds of 65 kt or greater is 1 year in 3 for El Niño years, and approximately 1 year in 10 for non-El Niño years. The long-term statistical typhoon risk is approximately the same for Guam and Saipan, although during the period 1990-2002, Guam has been affected by an inordinate number of typhoons, which skews the return period calculations for a typhoon strike on Guam to a higher value than at Saipan. Saipan has not had a direct strike by a major typhoon (100 kt sustained wind or higher) since Super Typhoon Kim in 1986 (an El Niño year, by the way). Guam has been struck by three major typhoons since 1990: Omar (1992), Paka (1997), and Pongsona (2002). The years 1997 and 2002 were El Niño.

INCREASED Threat for Marshalls, Guam, and CNMI

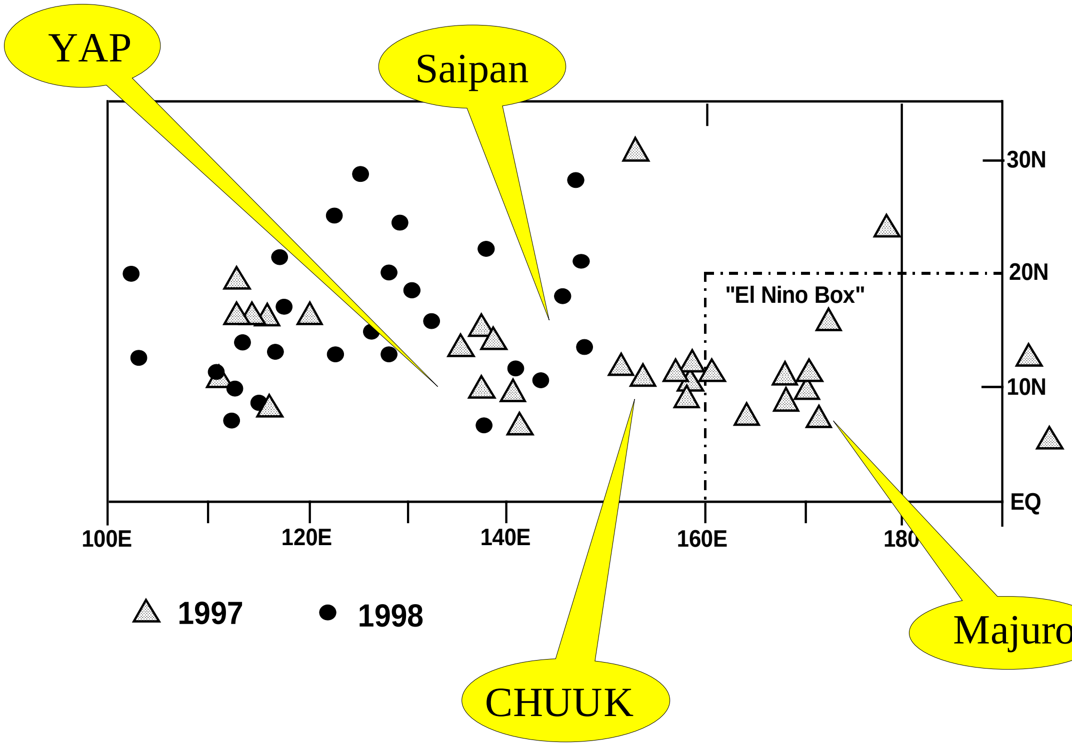


Figure 24. The formation locations for all western Pacific basin tropical cyclones during the El Niño year of 1997 (black dots) and the El Niño follow-on year of 1998 (gray triangles). Note the enormous difference in the formation region (especially in the area designated as the, "El Niño box"). Formation is defined as that point along the JTWC best-track that the tropical cyclone attained an intensity of 25 kt.

4. Tropical Cyclones affecting Saipan

a. Tropical cyclone definitions

Saipan, one of the largest of the Mariana Island group, lies within the breeding ground for tropical cyclones, and thus may be threatened on a year-round basis by the passage of a developing tropical cyclone, and on occasion by a typhoon. This report attempts to initiate for Saipan a foundation document similar to the Joint Typhoon Warning Center's, "Tropical Cyclones Affecting Guam" (JTWC 1990). In this section, tropical-cyclone behavior, frequency, and extremes, as well as individual chronicles of those tropical cyclones that adversely affected Saipan are found.

Tropical cyclone is a generic term for atmospheric cyclonic circulations that originate over the tropical oceans. As opposed to cyclones in the mid-latitudes, tropical cyclones usually develop a relatively narrow band of maximum winds encircling a calm center, or, for tropical cyclones that reach typhoon intensity, an eye. Tropical cyclones also develop spiral cloud bands that produce torrential rain and high winds, often causing structural damage, floods and sea inundation. Some definitions follow:

TROPICAL DISTURBANCE – A discrete system of apparently organized convection, generally100 to 300 nautical miles (n mi) in diameter, originating in the tropics or subtropics, having a non-frontal, migratory character and having maintained its identity for 12- to 24-hours. The system may or may not be associated with a detectable perturbation of the low-level wind or pressure field. It is the basic generic designation which, in successive stages of development, may be classified as a tropical depression, tropical storm, typhoon or super typhoon.

TROPICAL DEPRESSION – A tropical cyclone with maximum sustained 1-minute winds that do not exceed gale force (i.e., less than 34 knots).

TROPICAL STORM – A tropical cyclone with maximum sustained 1-minute mean surface winds in the range of 34-63 knots (39-73 mph).

TYPHOON – A tropical cyclone with maximum sustained 1-minute winds of 64 knots (74 mph) or higher.

SUPER TYPHOON – A typhoon with maximum sustained winds of 130 knots (150 mph) or higher.

MONSOON DEPRESSION – A tropical cyclonic vortex characterized by: (1) its large size, the outermost closed isobar may have a diameter on the order of 600 n mi; (2) a large loosely organized grouping of deep convective cloud elements; (3) a low-level wind distribution that features a 100 n mi diameter light wind core which may be partially surrounded by a band of gales; and, (4) a lack of a distinct cloud system center. Note: most monsoon depressions that form in the western north Pacific eventually acquire persistent central convection and accelerated core winds marking its transition into a conventional tropical cyclone.

INTENSITY – The maximum sustained wind averaged over a period of 1 minute, typically located within 60 n mi of the center of a tropical cyclone, and in the case of a typhoon, occurring in the eye wall. Other tropical cyclone advisory agencies, such as the Japan Meteorological Agency (JMA), use a 10-minute averaging interval to describe their sustained winds. The 1-minute average is approximately 15% higher than the 10-minute average, and is one reason why warnings from the Joint Typhoon Warning Center may differ in wind speed from other international agencies. Peak gusts over water tend to be 20-25% higher than the sustained 1-minute wind.

Minimum sea level pressure at the center of a tropical cyclone is also used as a measure of its intensity. There are several wind-pressure relationships for tropical cyclones that are often used to obtain an estimate of the peak wind speeds from the minimum central sea-level pressure.

SIZE – The areal extent of a tropical cyclone, usually measured radially outward from the center to the outermost closed isobar, or to some other parameter such as the boundary of the 30-kt wind. Based on an average radius of the outer-most closed isobar, size categories in degrees of latitude (1 degree of latitude = 60 n mi) are: < 2º = very small (midget), 2º to 3º = small, 3º to 6º = medium (average), 6º to 8º = large, and 8º or greater = very large (giant) (Brand 1972, and a modification of Merrill 1982). The eye, the typhoon-force winds, and the area of gales of a midget typhoon could nearly fit over Saipan. Although it possessed a small 8 n mi eye, one of the largest typhoons ever observed, Typhoon Tip (1979), had a radius of gales of 600 n mi that nearly filled the western North Pacific basin from the equator to Japan and from the Philippines to Guam and the CNMI.

The term **knot** (abbreviated kt) is a unit of speed (one knot = one nautical mile per hour) that is used extensively in tropical meteorology as a unit of measure for wind speed or forward speed of motion. Knot has the built-in meaning of "per hour"; therefore the wind is properly said to be blowing 10 knots (not at ten *knots per hour*). To convert kt to mph, multiply by 1.1538. For example, a tropical cyclone reaches tropical-storm intensity when its sustained winds reach 34 kt or approximately 39 mph. Other tropical cyclone thresholds include typhoon intensity at 64 kt (74 mph), and super typhoon intensity at 130 kt (150 mph).

Local time on Saipan is Universal Time Coordinated (**UTC**) or Greenwich Mean Time (GMT or Z) plus 10 hours. Guam and the CNMI are in the same time zone, and remain in the standard time for their time zone year-round. Because of greater seasonal changes in the amount of daylight hours, the U.S mainland shifts from standard time to daylight savings time from April to October. During the period of daylight savings time, each time zone adds one hour to its local time. Thus, Eastern Standard Time is 15 hours behind Guam and CNMI local time, and Eastern Daylight Time is 14 hours behind Guam and CNMI local time. The difference in the length of sunlight hours on Saipan differs by 2 hours from December to June. During late June, the sunrise on Saipan is at approximately 5:45 AM and sunset at 6:45 PM; during late December, the sunrise on Saipan is at approximately 6:35 AM and the sunset at 5:50 PM. Sunrise and sunset times for Saipan can be found at the website of the U.S. Naval Observatory (www.usno.navy.mil). Other astronomical and oceanographic information (such as tide tables and times of moonrise/moonset) can be found there or at the NOAA National Ocean Service site: www.co-ops.noaa.gov/tpred2.html#PI.

Tropical cyclone advisories for the western North Pacific are issued by the Joint Typhoon Warning Center (JTWC), now at Pearl Harbor, HI (web site: https://www.npmoc.navy.mil/jtwc.html). The JTWC tropical cyclone advisories contain information on the location and intensity of each active tropical cyclone, and the forecasts of the track and intensity out to 72 hours. Beginning in 2003, the advisories contain track and intensity forecasts out through five days. They are prepared every six hours valid at 0000, 0600, 1200, and 1800 UTC (10 AM, 4 PM, 10 PM and 4 AM local time) and are released to the public at a three-hour lag from the valid time of the current position and intensity; thus, the 0000, 0600, 1200 and 1800 UTC advisories are released at 0300, 0900, 1500, and 2100 UTC (1 PM, 7 PM, 1 AM, and 7 AM local time) respectively. Positions of tropical cyclones may be made on a more frequent basis when they threaten Guam or Saipan. The National Weather Service Forecast Offoce (NWSFO), Tiyan, Guam, may release positions of typhoons on an hourly basis when such positions are made available from the U.S. Air Force using the NEXRAD weather radar on Guam. For a list of products issued by the NWSFO during times of typhoon threats to Guam and the CNMI, contact the Warning Coordination Meteorologist at the NWSFO, Tiyan:

National Weather Service
Forecast Office, Guam
3232 Hueneme Road
Barrigada, Guam 96913

Phone: 671-472-0900
FAX: 671-472-7405
http://www.prh.noaa.gov/pr/guam/.

OTHER USEFUL URL's

Naval Research Lab Monterey CA (Typhoon tracks and pics)
http://www.nrlmry.navy.mil/tc_pages/tc_home

Joint Typhoon Warning Center
https://metoc.npmoc.navy.mil//jtwc.html

Navy Fleet Numerical (Weather Forecast Maps)
https://www.fnmoc.navy.mil/

Climate Prediction Center
http://www.cpc.ncep.noaa.gov/products/monitoring_and_data/

The naming authority for tropical cyclones in the western North Pacific passed from the JTWC to the Japan Meteorological agency (JMA) starting in the year 2000. The JTWC numbers their tropical cyclones independently of the JMA, but uses the JMA name when it is available. It is possible (and has already occurred) that the JTWC may be issuing advisories on a numbered, but unnamed tropical storm, or that the JMA may have named a tropical storm that the JTWC has only as a numbered tropical depression.

The NWSFO, Guam, is responsible for issuing tropical storm and typhoon *watches* and *warnings* for Guam, the CNMI, the FSM, the Republic of Palau, and the Republic of the Marshall Islands. Watches and warnings are issued for 37 specific locations (islands) in Micronesia. The National Presidents, local Governors, and military commanders are responsible for placing their respective nations, states, and military units into *Tropical Cyclone Conditions of Readiness.*

TROPICAL CYCLONE WATCHES AND WARNINGS

The tropical cyclone watches and warnings issued by the Tiyan NWSFO follow:

Tropical Storm Watch: A tropical cyclone (tropical depression, tropical storm or typhoon) poses a threat. The onset of damaging wind associated with the tropical cyclone is possible within the watch area within 48 hours. The winds are not expected to increase to typhoon force (64 kt /74 mph or higher). NOTE: Damaging winds are defined as a sustained 1-minute wind of at least 34 kt (39 mph).

Tropical Storm Warning: A tropical cyclone (tropical depression, tropical storm or typhoon) poses a threat. Damaging winds associated with the tropical cyclone are expected in the warning area within 24 hours, or are already occurring. The winds are not expected to increase to typhoon force (64 kt or higher).

Tropical Storm Warning/Typhoon Watch: A tropical cyclone (tropical depression, tropical storm or typhoon) poses a threat. Damaging winds associated with the tropical cyclone are expected in the warning area within 24 hours, or are already occurring. Typhoon force winds (64 kt/74 mph or higher) are not anticipated, but a change in track or intensity could require elevation to a typhoon warning.

Typhoon Watch: A tropical cyclone (tropical depression, tropical storm or typhoon) poses a threat. If the tropical cyclone is not already a typhoon, it is expected to become one as it nears the watch area. Damaging winds associated with the tropical cyclone are possible within 48 hours. The winds in the watch area may increase to typhoon force after the onset of damaging winds.

Typhoon Warning: A tropical cyclone (tropical depression, tropical storm or typhoon) poses a threat. If the tropical cyclone is not already a typhoon, it is expected to become one as it nears the warning area. Damaging winds associated with the tropical cyclone are expected in the warning area within 24 hours, or are already occurring. Also, the winds are expected to increase to typhoon force after the onset of damaging wind, or typhoon force winds are already occurring.

NOTE: The generic typhoon warning specifies only that winds of at least 64 kt/74 mph are expected. Information regarding the peak wind expected for a particular typhoon will be provided by the NWSFO Tiyan on a case-by-case basis.

Tropical Cyclone hazards

There are several hazards associated with tropical cyclones. These are: (1) destructive winds and wind-blown debris; (2) coastal inundation; (3) torrential rains and flooding; (4) wind shear and mechanical turbulence; (5) rough seas and hazardous surf; (6) tornadoes; (7) sea salt deposition; (8) erosion and slope failures. Saipan, to one extent or another, is susceptible to most typhoon-related hazards. Tornadoes probably do not occur in association with typhoons on Saipan. The three primary hazards are destructive winds, coastal inundation, and flooding. On Saipan, high surf (even from distant typhoons) is an often over-looked risk. Slope failure is a larger risk in areas of surface-exposed, steep-gradient, highly weathered volcanic rock formations. Chuuk and Pohnpei have recently experienced deadly slope failures.

b. The historical record of tropical cyclones on Saipan

The western North Pacific is the most active tropical cyclone basin in the world. On average, 28 tropical storms and typhoons occur annually (this compares to about 10 for the North Atlantic Basin). Of the annual average of 28 tropical cyclones of tropical storm intensity or higher, 18 become typhoons, and 4 become super typhoons. Another distinguishing feature of the western North Pacific basin is that tropical cyclones, although most common in late summer and autumn, can occur at any time of the year, whereas over other basins, off-season occurrences are rare. The main TC season for the western North Pacific extends from mid-May through mid-December. For the basin as a whole, tropical cyclones are least likely during the month of February.

The highest frequency of occurrence of typhoons in the western North Pacific is in an area just to the northeast of Luzon in the Philippine Sea (Figure 25) where there are, on average, five passages of a tropical storm or typhoon per 5-degree latitude-longitude square per year. In the region of Saipan, the frequency of tropical cyclones of tropical storm intensity or higher is three per 5-degree latitude-longitude square per year. The frequency of tropical cyclones passing Saipan is approximately equal to the number passing Guam, with some evidence of a track split: there appears to be a relative maximum of typhoons passing to the south of Guam on a west-northwest heading, and another relative maximum of typhoons moving northwest into the Northern Mariana islands north of Saipan (figure 26). The distribution of tropical cyclone tracks passing Saipan and Guam appears to be random (Fig. 27a-d). The small islands of Guam and Saipan also have no noticeable affects on the intensity of tropical cyclones. There is some evidence in Figure 27a-d that there were fewer tropical cyclones passing near Saipan during the 1970’s than in the later decades of the 80’s and 90’s. Appendix B is a list of all the tropical cyclones shown in Figure 27 with a description of any known adverse affects on Saipan.

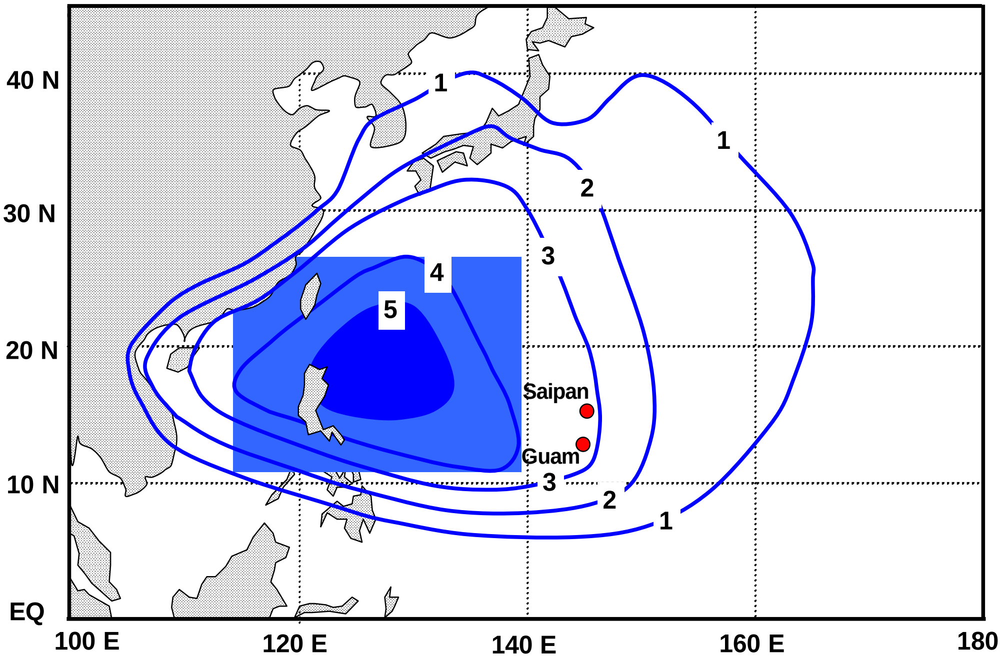


Figure 25. Mean annual number of tropical storms and typhoons traversing 5-degreee latitude by 5-degree longitude squares (adapted from Crutcher and Quayle 1974). Note that on the large scale, Guam and Saipan have roughly the same statistical risk of being affected by a tropical storm or a typhoon.

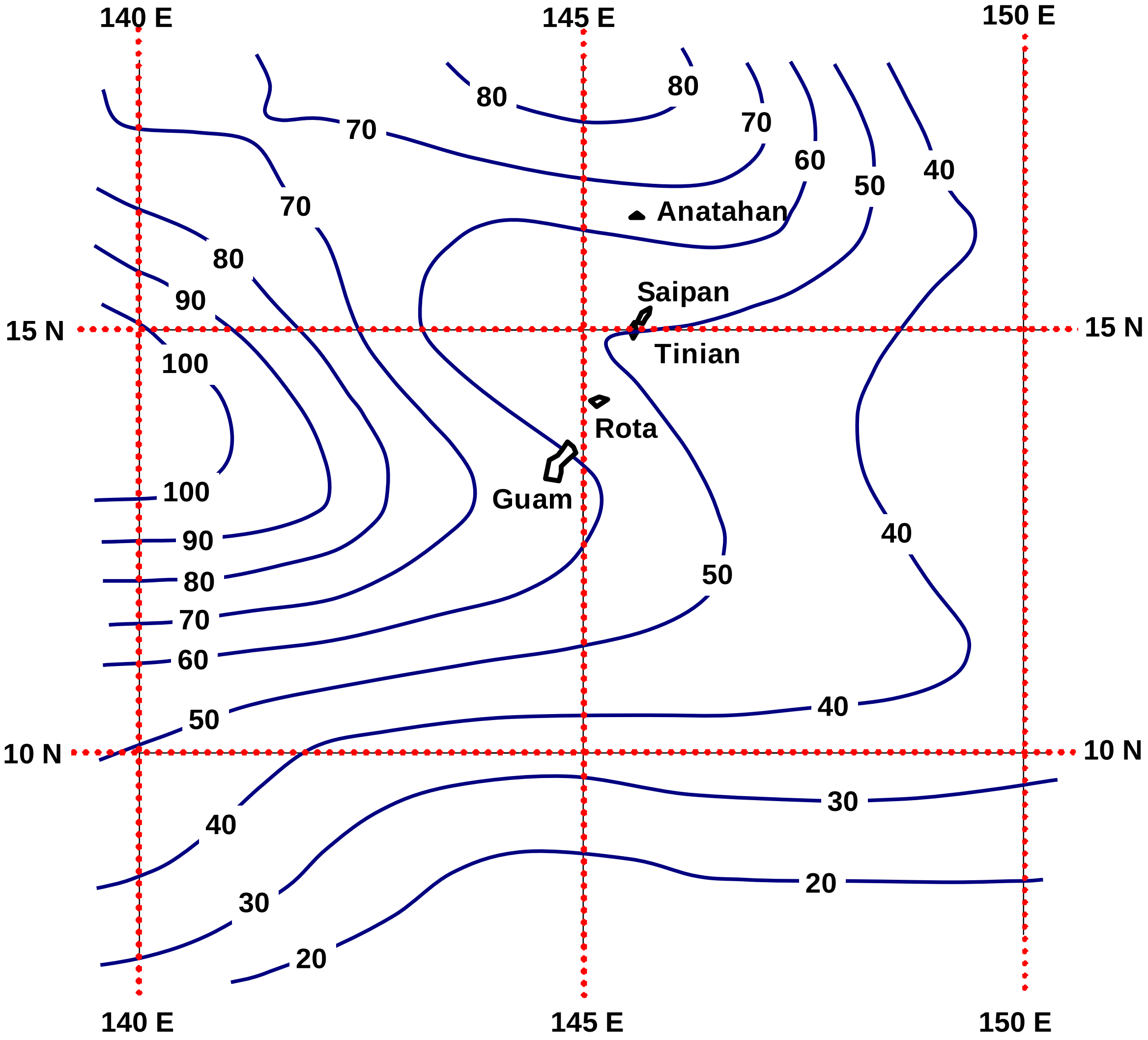
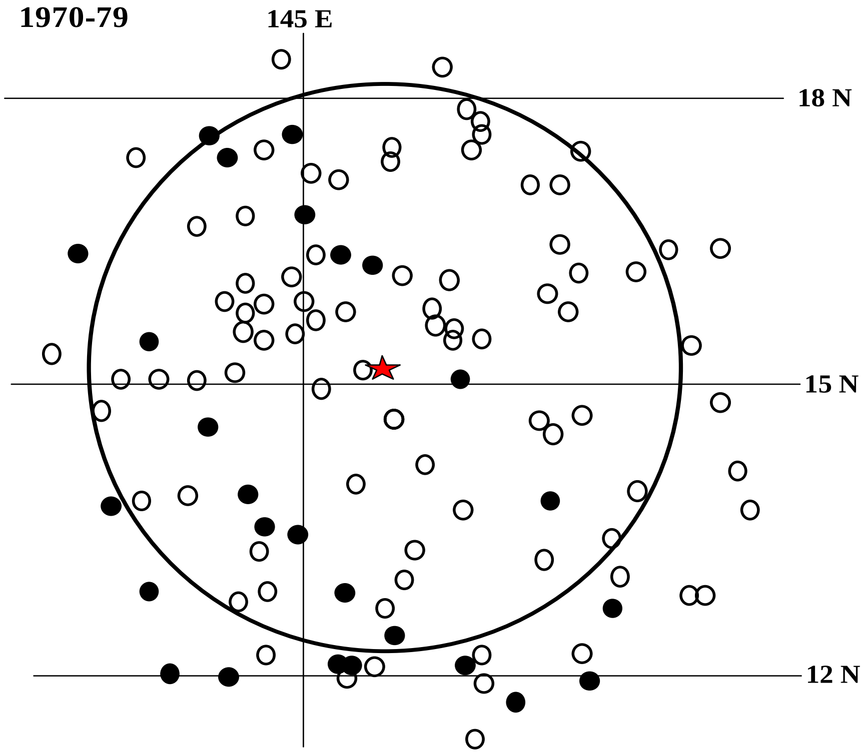


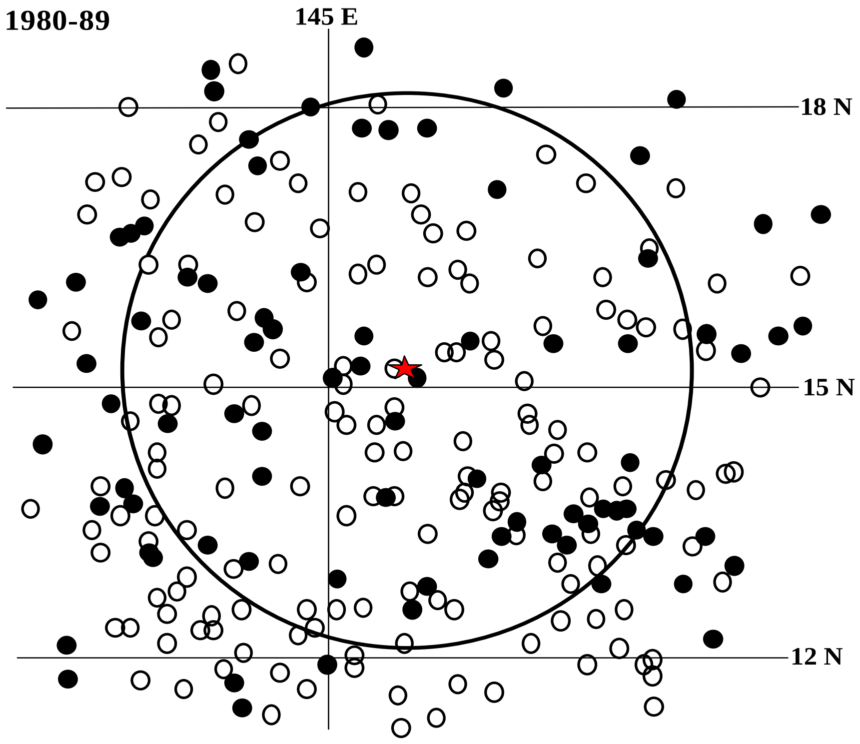
Figure 26. Contours (at intervals of 10) show the number of tropical storms and typhoons per 100-years expected to pass within 75 nautical miles from any map location. Analysis is based on the years 1945-97. Chart adapted from Guard, et al. (1999). Note that on this fine scale, Guam appears to have a slightly higher risk of a tropical storm or a typhoon than Saipan (60 per 100-years, versus 50 per 100-years).

(Fig. 27 a)



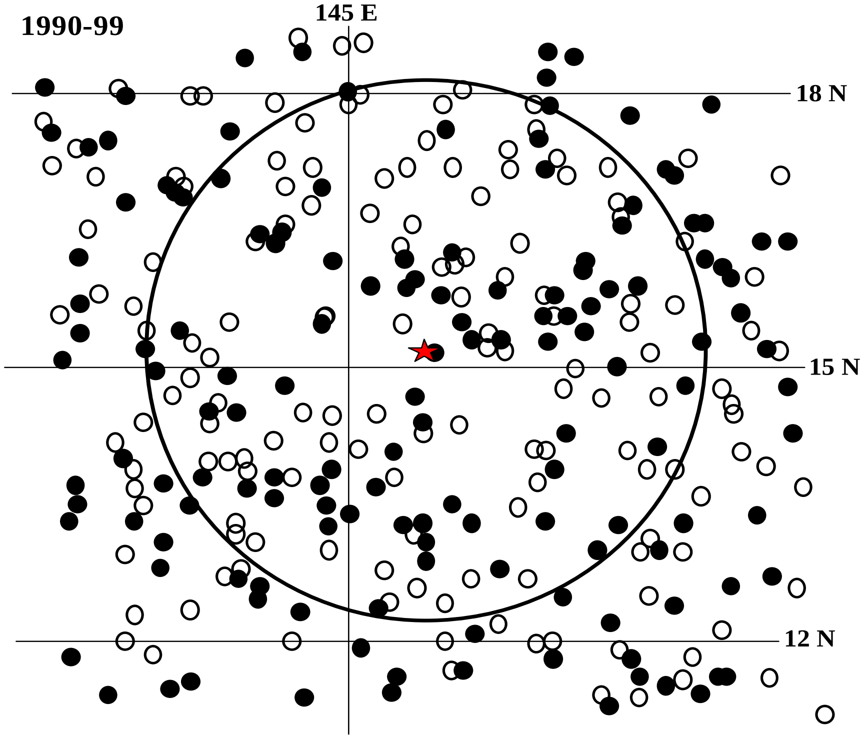
1970-79

(Fig. 27 b)



1980-89

(Fig. 27 c)



(Fig. 27 d)

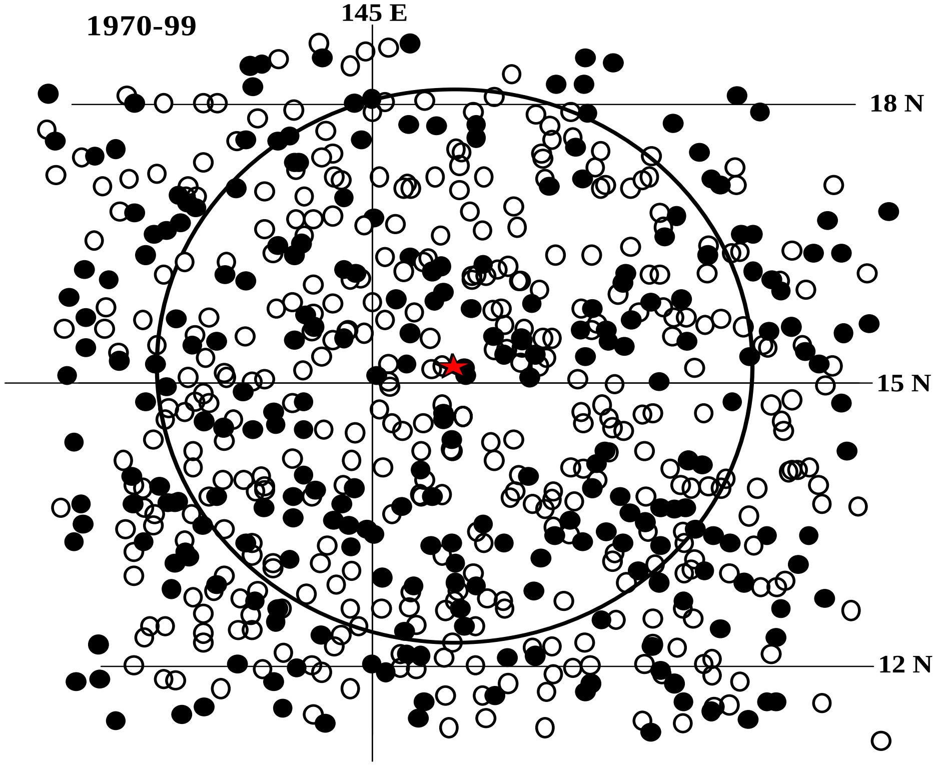


Figure 27. Tropical cyclone positions at six-hour intervals from the JTWC best-track archive: (a) the 1970’s, (b), the 1980’s, (c) the 1990’s, and (d) the period 1970-1999. Open circles indicate tropical storm intensity, black dots indicate typhoon positions, star is the location of Saipan and the large circle has a radius of 180 n mi from Saipan.

5. Month-to-month, inter-annual, and inter-decadal variation

a. Month-to-month variation: The Madden-Julian Oscillation (MJO)

In 1971 Roland Madden and Paul Julian (1971) stumbled upon a 40-50 day oscillation when analyzing wind anomalies in the tropical Pacific. They used ten years of pressure records at Canton (at 2.8° S in the Pacific) and upper level winds at Singapore. The oscillation of surface and upper-level winds was remarkably clear in Singapore. Until the early 1980's little attention was paid to this oscillation, which became known as the *Madden and Julian Oscillation* (MJO), and some scientists questioned its global significance. Since the 1982-83 El Niño event, low-frequency variations in the tropics, both on intra-annual (less than a year) and inter-annual (more than a year) timescales, have received much more attention.

The MJO, also referred to as the 30-60 day or 40-50 day oscillation, turns out to be the main intra-annual fluctuation that explains weather variations in the tropics. The MJO affects the entire tropical troposphere but is most evident in the Indian and western Pacific Oceans. The MJO involves variations in wind, sea surface temperature (SST), cloudiness, and rainfall. Because most tropical rainfall is convective, and convective cloud tops are very cold (emitting little longwave radiation), the MJO is most obvious in the variation of outgoing longwave radiation (OLR), as measured by an infrared sensor on a satellite.

Associated with the propagation of convective anomalies, the MJO involves variations in the global circulation. The MJO affects the intensity and break periods of the Asian and Australian monsoons and interacts with El Niño. Wet spells in the Australian monsoon occur about 40 days apart. Fairly weak correlations with the mid-latitude rainfall patterns and jet stream characteristics have also been found. The rainfall on Saipan is probably affected by the MJO. The manifestation of the MJO signal at Saipan is to produce several weeks of wet weather broken by a week or two of hot dry weather. The signal is not always very strong, but during the rainy season of 2004, it seemed to be particularly strong (Fig. 28).

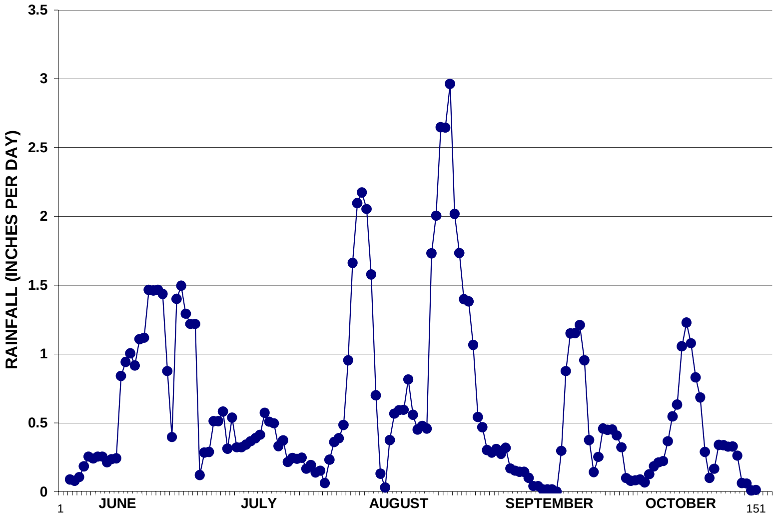


Figure 28. A plot of a 5-day moving average of the rainfall on Guam from June 1, 2004 through October 31, 2004. Large fluctuations of rainfall are evident with episodes of very wet weather occurring at intervals of 25 to over 40 days apart. Day 1 = June 1.

b. Inter-annual variation

One of the strongest inter-annual variations of the global climate is the ENSO cycle (See previous discussion of ENSO in Section 3). On the basis of sea surface temperature in the El Nino 3.4 region (5 deg N.,-5 deg. S.,120-170 deg. W.) during the interval of 1950-1997, Kevin Trenberth (1997) previously has identified some 16 El Niño's and 10 La Niña's, these 26 events representing the extremes of the quasi-periodic El Nino-Southern Oscillation (ENSO) cycle. The duration, recurrence period, and sequencing of these extremes vary randomly. Hence, even the decade of the 1990's, with its abundance of weak, moderate and one very strong El Niño (i.e., 1997), is not significantly different from that of previous decadal epochs, at least, on the basis of the frequency of onsets of ENSO extremes. Additionally, the distribution of duration for both El Niño and La Niña looks strikingly bimodal, each consisting of two preferred modes, about 8- and 16-months long for El Niño and about 9- and 18-months long for La Niña, as does the distribution of the recurrence period for El Niño, consisting of two preferred modes about 21- and 50-months long (Wilson 2000). The effects of El Niño on the weather, typhoons, and sea level in the region of Saipan were discussed in Section 3.

c. Inter-decadal variation and climate change

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 (Walker 1924). 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 substantial 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. 29. 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. 29. 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.

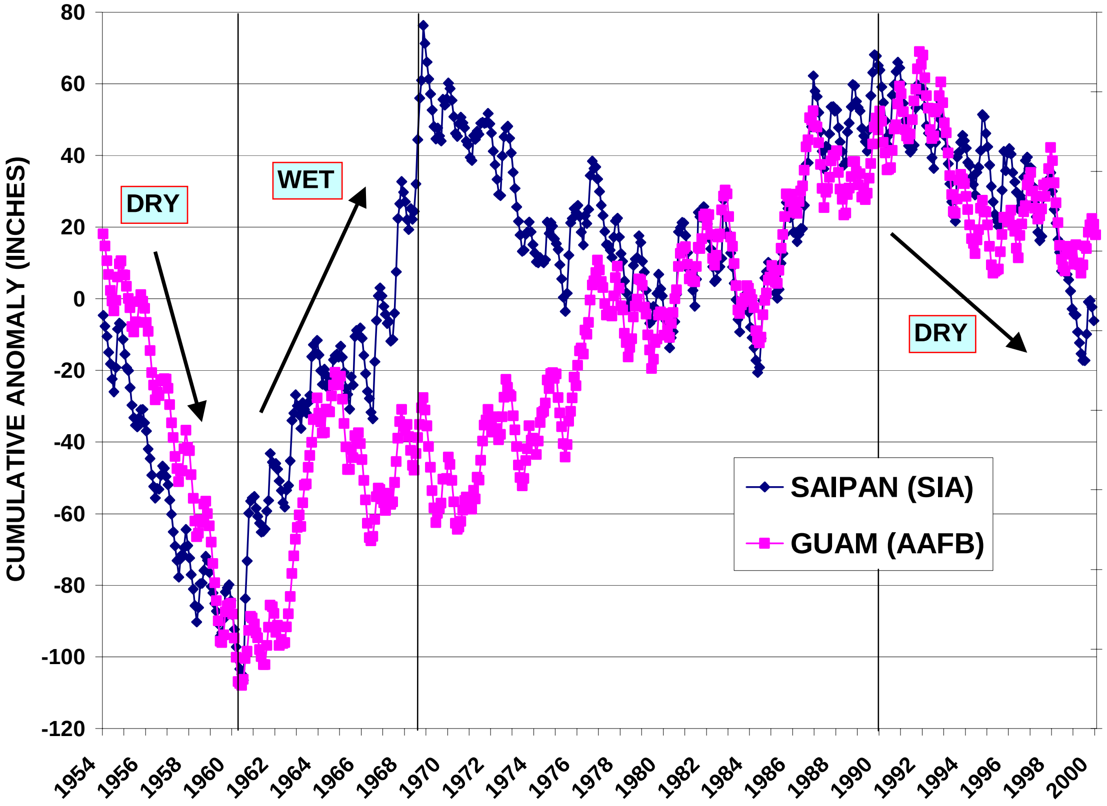


Figure 29. Running accumulations of the rank (lowest month = -305, highest month = +306) of each month's rainfall for the period 1954 to 2000 (annual cycle not removed). Complete records were available from Andersen AFB, Guam, and the constructed time series of the SIA. Prominent features include the extreme dryness of the 1950's, a very wet period in the 1960's, 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 sharp short-term fluctuations are related to El Niño.

6. Principal findings

This technical report presents a description of the rainfall climate of Saipan. Principal findings are:

(1) The distribution of mean annual rainfall on Saipan is affected by the topography, and the mean annual rainfall totals among recording stations on Saipan differ by as much as 15 inches (380 mm).

(2) The region in the vicinity of Saipan's International Airport receives the lowest annual total of about 75 inches (1900 mm). The highest mean annual rainfall of approximately 90 inches (2300 mm) occurs at Capitol Hill, and extends along the high ground from Marpi to Mount Tagpochau. .

(3) Intensity-duration-frequency (IDF) tables were generated using the short Saipan rainfall data sets, and with consideration of rainfall properties of typhoons. The intensity values at most durations and frequencies are higher than others have reported.

(4) It is likely that typhoons are the cause of the highest rainfall intensities at all durations (from 15 minutes to 24 hours). Typhoon rainfall is negligibly affected by the topography of the island. Therefore, ***the return periods of extreme rain rates should be considered uniform across the whole island***.

(5) More rainfall on Saipan occurs in the 12-hour span between midnight and sunrise than in the 12-hour span between noon and midnight; with an absolute minimum in the evening. This is the typical rainfall distribution over the open ocean undisturbed by the effects of island heating, and is caused by diurnally varying radiative processes in the tropical oceanic atmosphere.

(6) Month-to-month fluctuations of rainfall on Saipan are influenced by the Madden-Julian Oscillation (MJO).

(7) 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 Saipan is also linked to ENSO.

(8) Large inter-decadal variations in rainfall (and also in the distribution of typhoons) are noted. The causes of these remain unknown. Inter-decadal variations of rainfall and other hydro-meteorological phenomena render the search for signals of long-term climate change very difficult.

The Saipan rain record is too short to develop accurate return periods of extreme rainfall events (although attempts have been made in this report and by others that may be refined as more data is gathered). The extreme rainfall curves for Guam may be used as proxies for the extreme rain events on Saipan (but they are probably slightly higher than the true Saipan curves because of the marginally higher frequency of typhoons on Guam). 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, intensity-duration-frequency tables have been generated with the short Saipan rainfall data sets.

ACKNOWLEDGMENTS

The author would like to thank the U.S. Geological Survey (USGS) for their support of this project. In addition, this project benefited from the help of the personnel from the Saipan Field Office of the USGS, the Saipan Department of Environmental Quality, the National Resources Conservation Service (NRCS), and the local forecast office of the National Weather Service. Several people deserve recognition.

From the Saipan Field Office of the USGS:

Rob Carruth

From the Saipan Department of Environmental Quality:

Brian Beardon

From the NRCS (Portland Oregon)

Greg Johnson

From the NWSFO, Guam

Charles P. "Chip" Guard

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APPENDIX A. Constructed monthly time series of rainfall at SIA (Lander and Guard 2004).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1954	1.51	3.11	3.32	1.69	2.85	1.92	2.53	12.91	16.88	7.82	5.66	2.05
1955	2.01	2.35	5.37	1.36	1.26	2.65	4.00	5.67	8.67	8.39	6.27	2.34
1956	3.87	1.07	3.51	1.51	2.92	2.92	8.84	5.86	10.02	8.81	5.46	3.84
1957	3.82	1.85	2.19	1.21	2.24	2.04	1.48	11.27	7.43	7.93	11.23	1.59
1958	2.73	1.47	2.08	1.58	1.51	10.19	12.76	6.35	9.68	10.02	5.06	2.73
1959	2.19	4.34	3.14	4.02	2.63	2.76	7.11	9.85	13.68	7.34	7.04	1.67
1960	2.16	2.06	1.22	2.52	3.58	4.78	4.38	28.94	16.61	19.50	9.45	7.04
1961	6.52	2.83	3.89	4.23	3.66	6.36	6.80	11.10	9.11	19.29	3.64	5.27
1962	6.65	4.55	2.87	3.45	2.74	4.84	10.91	7.44	12.99	17.45	8.14	11.29
1963	3.06	3.54	2.40	13.31	4.33	5.05	9.06	8.14	16.99	9.40	3.87	9.69
1964	2.02	1.74	2.29	10.38	4.56	2.49	8.05	7.09	11.07	7.30	6.64	5.25
1965	9.20	3.00	1.98	1.68	4.41	2.03	15.17	3.80	19.71	7.82	4.88	8.14
1966	3.18	1.37	1.01	1.23	4.14	2.27	4.35	22.03	17.63	13.04	8.39	3.87
1967	3.17	3.98	3.55	6.62	0.74	6.57	13.47	17.69	21.02	10.20	12.35	3.14
1968	3.55	1.12	3.31	11.99	3.16	8.41	13.74	18.53	17.73	11.10	21.44	1.10
1969	0.99	1.36	1.96	1.63	1.57	2.65	9.20	3.90	4.79	17.68	4.57	7.87
1970	10.57	4.61	2.84	1.56	1.41	5.36	9.68	7.89	4.59	4.75	2.42	5.11
1971	2.64	5.23	13.10	5.10	8.44	5.22	9.22	6.46	5.84	6.33	8.67	3.23
1972	3.56	1.04	2.38	2.02	1.94	5.82	17.20	11.48	8.60	6.60	2.81	2.02
1973	0.72	1.66	0.97	2.09	2.33	1.55	6.50	10.52	6.86	8.89	3.36	2.60
1974	3.84	3.59	5.93	7.53	5.04	5.76	6.97	16.68	2.96	9.13	5.16	2.62
1975	4.76	4.52	1.85	2.18	1.01	2.19	11.22	16.71	15.20	7.32	8.90	4.96
1976	8.22	3.08	1.74	2.57	14.30	3.90	10.12	15.62	10.15	4.03	6.58	2.77
1977	2.66	2.30	3.25	1.70	2.48	5.87	4.82	4.10	11.83	10.63	6.95	0.85
1978	1.47	3.98	0.67	2.77	1.97	7.40	7.13	15.77	7.89	6.54	12.26	4.25
1979	0.89	3.13	1.01	1.82	1.29	6.91	9.99	5.72	10.20	11.50	2.10	4.18
1980	1.10	4.17	1.52	3.20	8.97	7.88	8.86	13.81	23.58	7.30	7.60	6.00
1981	2.56	1.43	1.14	5.84	0.86	1.71	13.68	24.80	4.85	5.99	9.12	4.18
1982	3.33	2.19	3.06	1.14	2.00	6.72	9.10	6.72	8.55	22.33	2.01	1.33
1983	4.83	1.64	2.21	1.61	1.50	0.65	2.68	13.28	6.04	9.41	5.16	2.25
1984	1.99	3.18	3.36	2.60	2.69	7.61	14.23	16.71	12.42	7.90	8.77	1.81
1985	8.07	2.57	3.47	4.67	8.65	13.41	8.87	11.44	15.09	4.40	3.63	6.83
1986	1.33	5.97	3.67	8.15	7.79	6.07	12.70	17.54	6.57	17.96	4.42	20.31
1987	1.86	4.63	1.72	0.89	0.57	1.19	12.38	5.85	9.91	13.71	6.18	4.90
1988	6.48	1.20	2.11	3.44	2.37	6.99	14.50	8.67	10.64	12.36	5.75	1.79
1989	4.44	5.20	1.20	4.07	4.49	3.54	12.11	15.65	12.60	11.06	5.78	3.52
1990	4.82	1.46	1.75	1.04	1.65	3.56	10.05	16.41	9.14	9.75	8.77	4.60
1991	1.61	0.70	1.25	3.49	1.85	4.32	6.94	7.28	16.52	12.59	5.06	4.65
1992	7.57	1.05	0.87	4.05	3.12	2.36	3.14	13.39	8.54	10.38	10.83	1.03
1993	1.68	2.60	1.89	0.56	1.07	2.30	4.57	24.07	7.47	8.95	8.09	4.56
1994	4.08	2.19	5.27	2.78	4.16	3.25	12.41	7.60	10.76	16.18	5.45	1.51
1995	2.45	1.01	0.19	1.83	2.64	4.37	4.55	7.60	14.69	17.02	0.74	11.03
1996	7.42	4.61	0.98	3.49	3.24	1.58	9.73	5.00	12.44	10.79	7.12	2.96
1997	6.36	0.95	1.61	2.10	1.84	3.78	7.36	17.03	6.41	10.45	9.21	5.27
1998	0.99	1.11	2.30	1.51	2.56	0.91	7.08	5.46	4.89	4.68	2.95	1.21
1999	4.77	5.71	1.48	3.07	3.08	4.32	6.08	13.47	15.12	6.54	4.32	2.32

APPENDIX B. Tropical cyclones affecting Saipan (1970-1999)

Year	Tropical Cyclone	CPA to Saipan (n mi)	CPA Date	CPA Intensity	Remarks
1970	None				
1971	TY Faye	10 N	6-Oct	TS 55 kt	
1972	TY Betty	40 NE	10-Aug	TS 60 kt	Wind 30 G 50 kt on Saipan
	TY Ida	200 NE	21-Sep	TY 90 kt	
	TY Marie	205 NE	9-Oct	TY 110 kt	45 G 55 kt on Saipan, Pagan, Agrihan, Alamagan: Extensive damage
	TY Olga	188 NNE	27-Oct	TY 116 kt	Gusty SW Winds
1973	None				
1974	Polly	50 NE	26-Sep	40 kt	Gusty SW Winds
	Mary		13-14-Aug		Gales in gyre, crops hard hit with wind and rain Tininan: MV Mariants aground
1975	Ida	170 NE	7-Nov	TS 45 kt	West winds, Gusts 30-40 kt
	June	310 SW	19-Nov	STY 160 kt	Well SW, High seas, SE Gales
1976	Nancy	40 NNW	1-May	TS 35 kt	
	Pamela	110 SW	21-May	120 kt	G 55 kt, 10" rain
	Therese	30 NE	14-Jul	STY 130 kt	Minor damage, 75-100 kt
	Billie	10 NSW	4-Aug	TS 40 kt	3.86" rain
	Georgia	170 S	12-Sep	TS 40 kt	
	Fran	140 SW	5-Sep	TS 50 kt	Sea gusts to gales
1977	Ivy	120 NNW	22-Oct	TS 45 kt	
	Kim	110 SSW	8-Nov	TS 55 kt	Gusty E wind
	Mary	240 SSE	29-Dec	TS 55 kt	Gusty E wind
1978	Carmen	80 NW	11-Aug	TS 40 kt	
	Faye	35 WSW	28-Aug	TS 35 kt	65 homes on Pagan destroyed Merchant V aground
	Rina	185 S	23-Oct	STY 150 kt	Small compact STY- no effects on Guam and CNMI
	Tess	110 WNW	2-Nov	TD 30 kt	
	Winnie	110 ENE	28-Nov	TS 35 kt	
1979	Alice	185 S	9-Jan	TY 75 kt	
	Judy	130 SSW	17-Jul	TS 35 kt	Passed over Guam, G 51 kts
1980	Orchid	42 W	9-Sep	TD 30 kt	
	Wynne	55 SW	7-Oct	TS 50 kt	
	Betty	145 SSW	31-Oct	TY 70 kt	Damage to Guam
	Dinah	0	23-Nov	TY100 kt	Extensive damage to vegetation on Tinian and Saipan, No power for several days; $7 million damage
1981	Gerald	60 E	19-Apr	TD 30 kt	Dissipating TS LLCC
	Gay	30 NE	15-Oct	TS 40 kt	
	Hazen	0	15-Nov	TY 65 kt	North Tip 35G62, Airport minor structure damage, Many trees and power lines down
	Irma	85 S	20-Nov	TS 40 kt	Gales
	Jeff	85 SSE	23-Nov	TS 35 kt	
	Kit	175 SSW	13-Dec	TS 55 kt	
1982	Ruby	145 W	23-Jun	TS 45 kt	
	Andy	205 SW	24-Jul	TY 65 kt	Huge waves west side of Guam
	Bess	>180 NE	28-Aug	TY100 kt	
	Judy	160 SSW	6-Sep	TD 30 kt	
	Mac	150 SSW	3-Oct	TY 65 kt	Southern Guam crop damage
	Owen	100 NNE	17-Oct	TS 50 kt	
	Pamela	190 S	1-Dec	TS 45 kt	40 kt Gust on Guam
1983	NONE				
1984	Ike	220 SW	28-Aug	TS 60 kt	
	Roy	185 SW	11-Oct	TS 35 kt	Dissipated W as LLCC
	Thad	55 NE	20-Oct	TS 50 kt	
	Vanessa	230 SW	25-Oct	TY 80 kt	Gust 59 kt on Guam

	Bill	145 S	13-Nov	TY 85 kt	Crop damage: >$7 million on Guam Gust 86 kt
1985	NONE				
1986	Peggy	40 SSW	4-Jul	TS 55 kt	Gales from E, damage to crops
	Abby	170 SW	13-Sep	TS 35 kt	
	Ben	155 NNE	23-Sep	TS 60 kt	
	Carmen	55 SW	4-Oct	TS 50 kt	G 41 kt, Heavy rain
	Forrest	190 NNE	17-Oct	TY 80 kt	Agrihan slammed, one building left standing
	Kim	18 N	3-Dec	STY 135 kt	Substantial damage, 1/3 all power poles are down, hundreds are homeless, 14 injured, 1 fatality $15 million damage
	Norris	215 SSW	27-Dec	TS 55 kt	Guam 50 kt, a rain event
1987	Thelma	40 SW	9-Jul	TS 35 kt	
	Wynne	125 NE	26-Jul	TY 115	Extensive damage Alamagan, Agrihan
	Ed	170 ENE	27-Aug	TS 35 kt	Died passing 50 n mi NNE
	Freda	170 SW	5-Sep	TS 35 kt	
	Ian	60 N	24-Sep	TS 40 kt	
	Lynn	35 SW	19-Oct	TY 80 kt	G 65 kts, Airport closed, power out
1988	Roy	85 SW	12-Jan	TY 110 kt	N. Guam damage, Rota heavy damage, G104 95% poles down
	Warren	185 SSW	13-Jul	TS 35 kt	
	Hal	270 N	12-Sep	TY 105 kt	SW Gales, power outages, minor damage
1989	Winona	5 N	19-Jan	TS 55 kt	Airport 25 G 35
	Andy	130 SE	21-Apr	STY 140 kt	G 68 kts, Guam crop damage, power outages, minor damage, heavy rains
	Coleen	70 ENE	4-Oct	TS 55 kt	Heavy rains
	Forrest	35 SW	24-Oct	TS 60 kt	G 50 kt; power out; trees, limbs and power lines down; flooding
	Jack	160 SE	22-Dec	125	Rapid death SW of Island
1990	Koryn	0	15-Jan	TY 75 kt	Typhoon Force Gusts; Airport closed; 32 kts sustained 981 mb; minor damage
	Zola	130 NW	17-Aug	TS 35 kt	SW monsoon gales
	Flo	75 SW	13-Sep	TS 35 kt	SE Gales
	Hattie	60 NNE	2-Oct	TS 40 kt	
	Kyle	40 NE	17-Oct	TS 40 kt	
	Page	260 SW	22-Nov	TS 40 kt	
	Russ	175 SSW	21-Oct	TY 120 kt	Major TY on Guam, E Gales on Saipan
1991	Walt	265 SW	10-May	TY 105 kt	
	Ivy	115 ENE	5-Sep	TY 65 kt	
	Mirrelle	20 N	19-Nov	TY 80 kt	70-80% crop damage, uprooted trees, flooding
	Seth	20 NE	4-Nov	TY 120 kt	Significant property damage, $2 million damage to public facilities, widespread flooding, ~10" rain
	Verne	145 NE	9-Nov	TS 55 kt	
	Yuri	205 SW	28-Nov	STY 150 kt	Major Guam Typhoon, Rota damage
1992	Janis	205 SW	4-Aug	TS 40 kt	
	Omar	115 SW	28-Aug	TY 110 kt	Major Guam Typhoon
	Ryan	145 NE	2-Sep	TS 60 kt	Gusty SW winds
	Brian	125 SW	22-Oct	TY 70 kt	Typhoon over Guam
	Elsie	195 SW	3-Nov	TY 95 kt	
	Hunt	100 SW	18-Nov	TY 65 kt	
	Gay	105 SSW	23-Nov	TY 85 kt	Over Guam
1993	Nathan	65 NE	21-Jul	TS 45 kt	
	Steve	20 NNE	8-Aug	TS 50 kt	15-20" rain, 45 G 60
	Cecil	155 NE	25-Sep	TS 55 kt	
	Ed	110 SSW	1-Oct	TS 40 kt	Over Guam
1994	Fred	265 NW	15-Aug	TS 35 kt	
	Nat	50 SSE	16-Sep	TS 40 kt	Approached from W

	Orchid	145 WSW	20-Sep	TS 40 kt	Approached from SW
	Seth	205 SSW	5-Oct	TS 45 kt	
	Verne	55 SSW	19-Oct	TS 45 kt	Gales toppled trees
	Wilda	80 NE	25-Oct	TY 115 kt	Downed trees, power lines and tin roofs; two tugboats sink; flat barge lost; M/V Ronda sank; 15-20" 24-hour rain
	Zelda	35 NE	3-Nov	TY 95 kt	Damage to homes; Anatahan-direct hit; 39 residents evacuated to Saipan
	Bobbie	60 NNE	23-Dec	TS 45 kt	
1995	Eli	145 SW	4-May	TS 40 kt	
	Oscar	150 NE	13-Sep	TS 35 kt	Followed by monsoon surge with lots of rain
	Ward	45 SW	17-Oct	TS 55 kt	Flooding of streets; Tinian loss of pwer to half of island
1996	Ian	135 WSW	28-Jul	TS 35 kt	Northern Half lost power, tree branches, ships failed to put to sea
	Yates	45 NNE	25-Sep	TY 125 kt	Minor damage; a few trees down; minor flooding Anatahan: boats, crops and houses damaged
	Dale	210 S	8-Nov	TY 90 kt	Major high surf for Guam
	Fern	120 N	30-Dec	TS 40 kt	Died to NNE while moving E
1997	Nestor	195 NE	10-Jun	TY 120 kt	High Waves
	Winnie	140 NNE	12-Aug	STY 140 kt	Gales damage crops, salt spray
	Bing	85 SSW	29-Aug	TS 40 kt	
	Ivan	170 SSW	15-Oct	TS 50 kt	
	Joan	35 NNE	18-Oct	STY 135 kt	G 85 kts, some structure damage to homes
	Keith	40 SSW	2-Nov	STY 145	G 95 kts, extensive damage to homes, power poles down
	Paka	95 SSW	16-Dec	TY 125 kt	Major typhoon for Guam and Rota
1998	Alex	70 SSW	11-Oct	TS 50 kt	Over Rota, minor damage to structures, vegetables
1999	NONE				