Report for 2003GU19B: Development of Annual Rainfall Distribution Map for Island of Pohnpei State, Federated State of Micronesia

- Water Resources Research Institute Reports:
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Report Follows

PROJECT SYNOPSIS REPORT

Project Title: A rainfall climatology for Pohnpei Island

Problem and Research Objectives

Pohnpei Island is a "high" volcanic island, having a rugged, mountainous interior with some peaks as high as 2600 feet. It measures about thirteen miles across and is roughly circular in shape. It is the largest and tallest island in the FSM. The interior peaks get plenty of rainfall annually and this creates more than 40 rivers that feed the lush upper rain forest. A coral reef surrounds the island, forming a protected lagoon. There are few beaches on Pohnpei — the coast is surrounded by mangrove swamps. Several smaller islets and atolls, many of them inhabited, lie nearby and are included in the State of Pohnpei. The world-famous Nan Madol islet complex is located on the southeast coast of Madolenihmw municipality on Pohnpei Island (Fig. 1). The ruins at Nan Madol consist of 92 man-made islets covering an area of approximately 200 acres. The most spectacular of the islets have remains of sea walls, tombs and other structures built of large columnar basalt stones, brought to Nan Madol from other parts of Pohnpei.

The island of Pohnpei (6.9N 158.2E) lies about halfway between Hawaii and the Philippines in the recently formed country of the Federated States of Micronesia (FSM) (fig. 2). Pohnpei State is made up of one large volcanic island and six inhabited atolls, with most of its 133 square miles on Pohnpei Island. Its population is 34,486 (census 2000). Pohnpei State is the national capital of the FSM and site of the Community College of Micronesia. Pohnpei is a beautiful and fertile island with much local agriculture and a growing tourism industry. The main town on the island is Kolonia, on the north side.

The mountainous islands of the Pacific are seeing increased activity in development and agriculture. In addition, surface water is being increasingly tapped as a source of potable water and for hydroelectric generation. The soils of these islands are for the most part extremely thin and very easily eroded. Episodes of high rainfall events make the islands very susceptible to erosion and slope failures (such as the slope failure at Sokehs in 1997 that killed 30 people, and the slope failures at Chuuk during tropical cyclone Chata'an in 2002). The United States Department of Agriculture Natural Resources Conservation Service (USDA/NRCS) has implemented several programs to help manage and reduce erosion on the islands. These programs require accurate estimates of annual erosion, which is calculated using the Revised Universal Soil Loss Equation (RUSLE). The Universal Soil Loss Equation (USLE) and its updated revision the Revised Universal Soil Loss Equation (RUSLE) are the equations used most commonly to predict soil erosion rates and soil losses in the tropical pacific. In tropical environments, climate or specifically the volume and intensity of rainfall is most significant cause of high soil erosion rates (Foster et al., 1982). This factor is identified in the USLE and RUSLE as the R factor, or rainfall erosivity factor. It is important to have an accurate rainfall record with resolved 15-minute duration (or lower) for calculating the R factor.

Annual rainfall maps for most of the islands of Micronesia are incomplete, inaccurate, and/or non-existent for many areas. Estimated annual rainfall for Pohnpei prepared by the Spatial Climate Analysis Service, Oregon State University using the Precipitation-elevation Regression Independent Slopes Model (PRISM) analysis (Daly, et al. 1994) (Fig. 2) depicts rain in the central highlands that is estimated to be nearly twice that of the rain along the coast. This project will measure the influence of elevation on rainfall at Pohnpei Island.

Some problems that the local and Federal agencies face are:

(1) The USDA/NRCS requires the adaptation of RUSLE to selected Pacific Islands, which include: Guam, CNMI (Saipan, Tinian, Rota), Palau (Babeldaob), American Samoa (Tuitula), and Pohnpei. Success depends on the calculation of accurate R-factors, which depends directly on the accuracy of the values of annual rainfall for specific locations.
(2) USDA/NRCS needs an accurate annual rainfall maps for the indicated islands.
(3) Local water managers need accurate rainfall maps for purposes of development of infrastructure for storage and distribution of surface water.
(4) Disaster managers need accurate rainfall maps to better understand the processes that lead to slope failure, and local stream flooding.
(5) The optimal design of hydroelectric power plants requires an accurate knowledge of the annual and short-term distribution of rainfall.

This research project yielded a description of the weather and climate of Pohnpei to include: general rainfall statistics, a summary of the annual distribution of rainfall; an examination of the return periods of short-term high-intensity rainfall events; the effects of ENSO on the climate and weather of Pohnpei; a summary of tropical cyclones affecting the island; and, an examination of inter-annual and inter-decadal variations in mean annual rainfall.

Figure 1. The crowning achievement of Nan Madol is the royal mortuary islet of Nandauwas. Here, walls of 18 to 25 feet high surround a central tomb enclosure within the main courtyard. An impressive portal (shown here) marks the entry into the mortuary enclosure of Nandauwas. The second entryway in Nandauwas leads to the inner courtyard and central tomb, where the remains of the deceased *saudeleur* and, later, the *nahnmwarki* were interred.

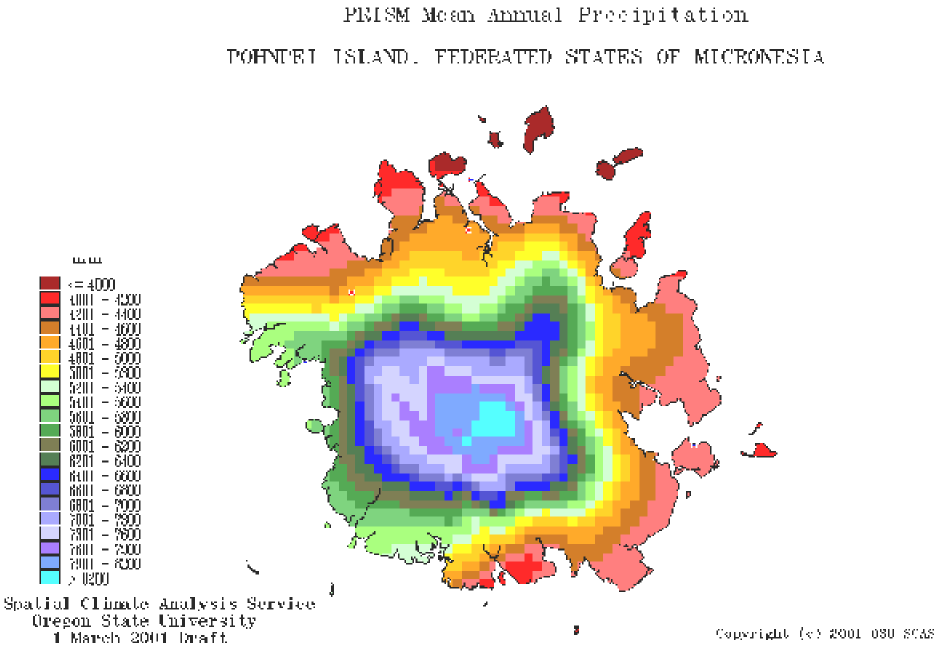


Figure 2. Estimated annual rainfall for Pohnpei prepared by the Spatial Climate Analysis Service, Oregon State University using the Precipitation-elevation Regression Independent Slopes Model (PRISM) analysis (Daly, et al. 1994). Note that the rain in the central highlands is estimated to be nearly twice that of the rain along the coast.

Methodology

There are very few locations on Pohnpei 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. Monthly data for the WSO exists for the period 1954 to present. Hourly rainfall data from Fischer-Porter type recording rain gauges is available for Pohnpei at two locations: the WSO and the Hospital (near the current WSO). 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. Monthly rainfall is available from several locations during the Japanese period of record (1926-1937).

All of the historical rainfall readings acquired on Pohnpei are from stations located along the coastal perimeter of the island. No sites have ever been located in the rain forests of the mountainous interior of the island. There are meteorological reasons why the interior highlands should receive more rain than the coastal perimeter of the island including the ascent of moist air over the mountains (the typical mechanism for the distribution of heavy rainfall in the higher elevations of the Hawaiian Islands), and inland convection driven by daytime heating of the island. Also, there is evidence that the western side of the island is wetter than the eastern side of the island. Personal observation confirms that, as on Guam and other tropical islands, daytime convection forms and/or advects downwind of the island in the form of an island could plume. On Guam this manifests in a concentration of thunderstorm activity offshore to the west of the island in east wind conditions, and to the northeast of the island when the southwest monsoonal winds are blowing. Lightning observed after sunset on Pohnpei during travels there by the project investigators has a strong preference for the western side or offshore of the western side of the island in conditions of easterly wind flow. Winds on Pohnpei can become westerly, especially during El Niño, but the project investigators have not been on Pohnpei during such times.

The methodology used in the Precipitation-elevation Regression Independent Slopes Model (PRISM) analysis (Daly, et al. 1994) for Pohnpei Island predicts that the interior highlands receive much more rain than the coastal perimeter (Fig. 2). The PRISM model indicates that the annual rainfall in the mountainous center of Pohnpei is over twice that of the coastal perimeter. This is an enormous amount of rainfall (~300 inches per year) for the interior, and represents tremendous gradients of mean annual rainfall on this relatively small – 12-mile diameter – roughly circular island.

In order to investigate the rainfall differences between the highlands and the coastal regions of Pohnpei (that are currently depicted to differ by a factor of two for annual rainfall), a transect of manual and electronic rain gages was set up extending from the coast to the highlands of the island. Figure 4 shows the location of WERI and WSO rain gages. Since rainfall is so heavy on Pohnpei (nearly 20 inches per month), simple manual rain gauges that consist of a 56-inch tall 6-inch diameter PVC cylinder capped by a funnel with a debris screen were constructed (Fig. 5a). These are cheap, easy to install and to maintain. Although not highly accurate, these crude manual gauges may be able to accurately measure the differences between rainfall among the sites. One of the manual rain gauges was collocated with existing accurate recording stations at the WSO Pohnpei. Tipping bucket rain gauges with data loggers were set up at three of the transect sites (Madolenimw Mayor's Office, Nihpit, and Nahna Laud) (Fig. 5b). These allowed a calibration and validation of the rain collected by the manual gages. Two of the manual rain gauges were collocated with WERI/CSP electronic rain gauges at the College of the FSM, and on top of Nahna Laud. Additional electronic rain gauges were placed at the Airport and the College. Manual rain gauges were also placed at the Airport, the College, at a site (Mahnd) along the mountain transect between the Mayor's Office and Nihpit.

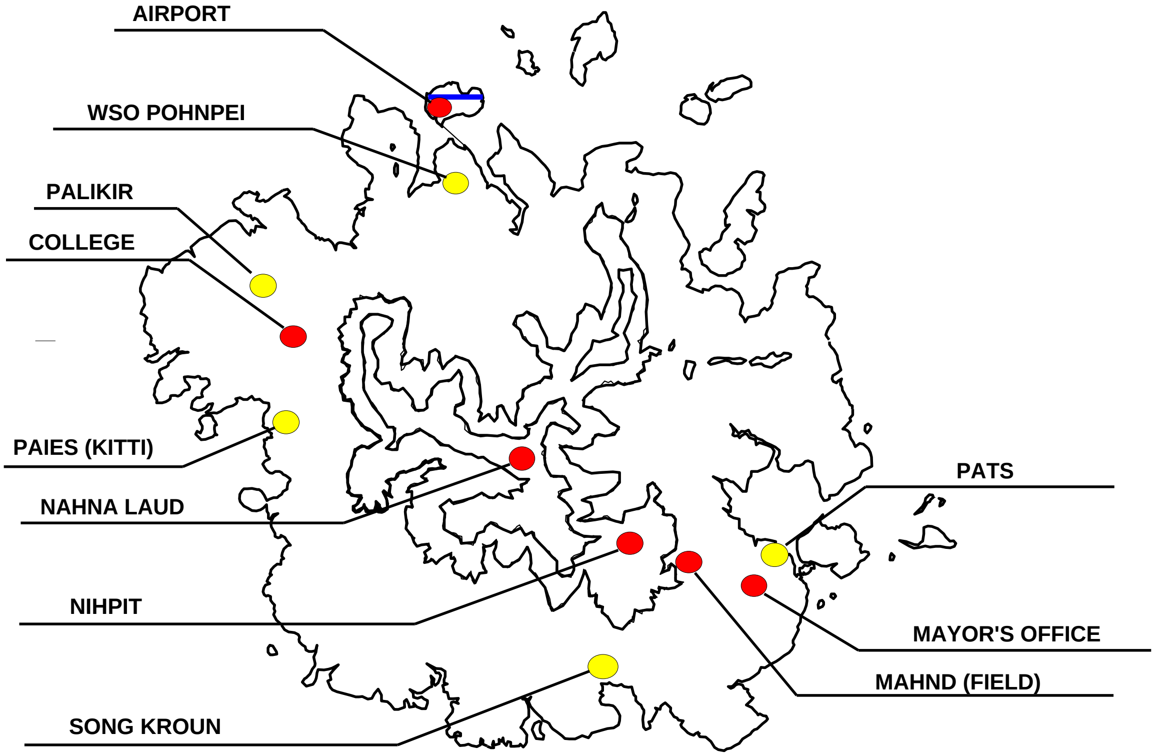


Figure 4. Stations on the island of Pohnpei where there are records of rainfall. Red dots are WERI Network installed in June 2003. Yellow dots are National Weather Service rain gauges. Half-tone shading indicates elevation: light gray ≥ 250 m; dark gray ≥ 500 m.

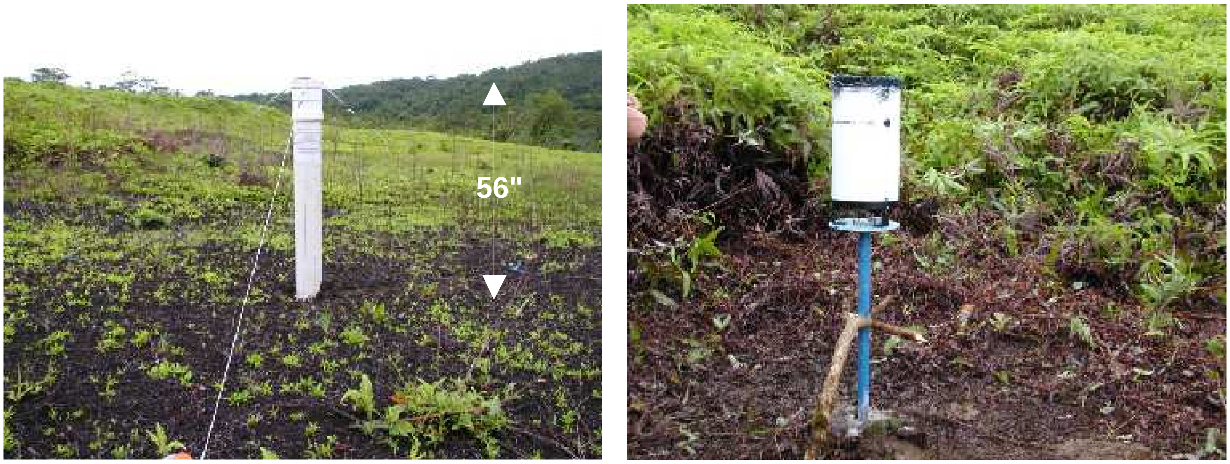


Figure 5. (a) A view of the specially designed 56-inch PVC pipe rain gage assembled in the field at the Mahnd site on Pohpei Island. (b) A view of the recording tipping bucket rain gage assembled in the field at the Nihpit site on Pohnpei Island.

The top of Nahna Laud was the selected site in the central highlands where two rain gages were set up near one another – one in an open area, and another under the canopy of the rainforest – to assess the impact of fog drip on the water budget of the island. The central highlands of Pohnpei are of sufficient height (~2,000 – 2,600 ft) to often be enshrouded in fog. Deposition of cloud droplets onto leaves, and subsequent coalescence and drip, may enhance the total water budget substantially. This so-called fog-drip is responsible for a substantial portion of the water budget on portions of the islands of Hawaii. An electronic gage is required at this site to determine the times when it is actually raining at the open-area location. The percent of time the highlands are enshrouded in cloud is itself an unknown. A project currently funded by the USGS is attempting to quantify the importance of fog drip to ecosystem hydrology and water resources in tropical mountain cloud forests on East Maui, Hawaii, where there is evidence that fog drip is substantial (Juvik, J.O. and P.C. Ekern, 1978). The investigators on the Maui project are measuring the amounts of water input from fog by analyzing for stable isotope composition. Previous work (Ingraham and Matthews, 1995) has shown that rain and fog have unique isotopic signatures, so that stable isotopes of water can be used to track the fog water through the hydrologic cycle.

The WERI project investigators traveled to Pohnpei at least once every three months to perform maintenance on the gages and to collect the data. Personnel at the Pohnpei CSP were contracted to perform readings of the rain gauges and routine maintenance. An estimate of the contribution of fog-drip to the water budget of the highlands will be obtained from a careful analysis of the data from the dual open-area/canopy site. Satellite imagery will be monitored, and observations from the WSO archived, to help determine the precipitation event type, and the presence or absence of cloud cover over the highlands (probably only during daylight hours).

Before field installation, all rain gage equipment was evaluated by setting up a test site at the UOG campus where there already exists a dense network of manual and electronic rain gages: several 4-inch plastic manual gages, two Qualimetrics tipping bucket rain gages with data logger, a National Weather Service (NWS) HANDAR station that contains a tipping bucket rain gage, and a NWS standard 8-inch brass manual rain gage.

Principal Findings and Significance

This research project yielded a description of the weather and climate of Pohnpei to include: general rainfall statistics, a summary of the annual distribution of rainfall, an examination of the return periods of short-term high-intensity rainfall events; the effects of ENSO on the climate and weather of Pohnpei; a summary of tropical cyclones affecting the island; and, an examination of inter-annual and inter-decadal variations in mean annual rainfall.

Unlike the islands of Guam, Saipan, Kwajalein and other islands further to the north, the island of Pohnpei does not experience a pronounced wet season and a dry season. The driest months are January and February and the wettest months are April and May. Pohnpei's mean monthly rainfall is nearly uniform at 16-17 inches per month from May through December, then drops to its lowest value of just over 10 inches in February and rises to its peak value of nearly 20 inches in May. For most of the year the, the *mean* wind is from an easterly direction. Pohnpei is in the doldrums; that is, along the axis of the intertropical convergence zone (ITCZ). Winds are generally light, but can become fairly brisk trade winds in the winter and spring. During the spring through fall months, Pohnpei can experience episodes of brisk monsoonal winds from a westerly direction (the more-so in El Niño years).

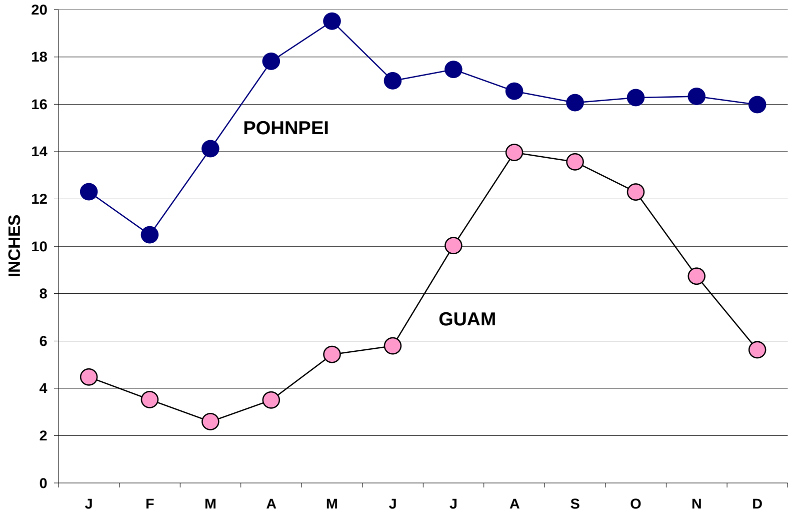


Figure 6. Monthly mean rainfall at WSO Pohnpei and at Guam's Andersen Air Force Base (in inches). Note that Pohnpei receives much more rainfall than at Guam in every month of the year, and has only two months (January and February) of relatively drier conditions, compared to the sharpy drier and prolonged "Dry Season" on Guam

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).

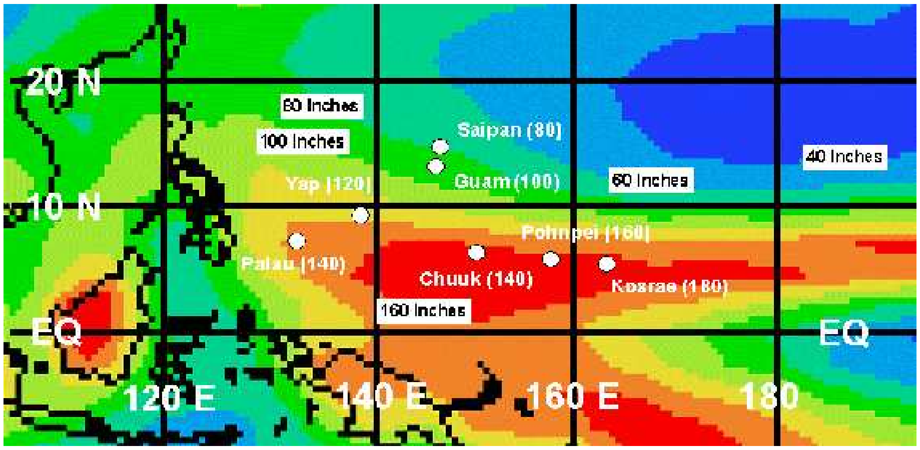


Figure 7. Mean annual over-water rainfall in Micronesia. Colors indicate rainfall pattern (amounts as labeled: red = 160 inches per year, orange = 140, yellow = 120, light green = 100, dark green = 80, teal = 60, light blue = 40, and within the blue there is a bit less than 40 inches of annual rainfall).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

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 at the Pohnpei rain gage at the Hospital site for only the winter months and year-round at other small islands and atolls of Micronesia such as Majuro and Chuuk. During the summer at the Pohnpei Hospital most of the rain tends to fall in the early afternoon. The hourly rainfall distribution is more complicated on the larger islands such as Pohnpei, Hawaii, and Guam. On mountainous islands such as Pohnpei and on the Hawaiian Islands, the large diurnal variations in rainfall (not necessarily synchronous with typical open-ocean variations) are driven by mountain- and sea-breeze circulations. Indeed, from personal experience, during the summer months when the winds are light, there is a strong tendency for heavy showers to develop over the mountains by noon (Fig. 8). These rain-out and die by evening. At almost all islands, there is an evening minimum of rainfall. ***Pohnpei's extreme amount of rain in the interior appears to derive from day-time convection over the mountains, and not from orographically enhanced rainfall as winds pass over the high terrain (as on many of the Hawaiian Islands).***

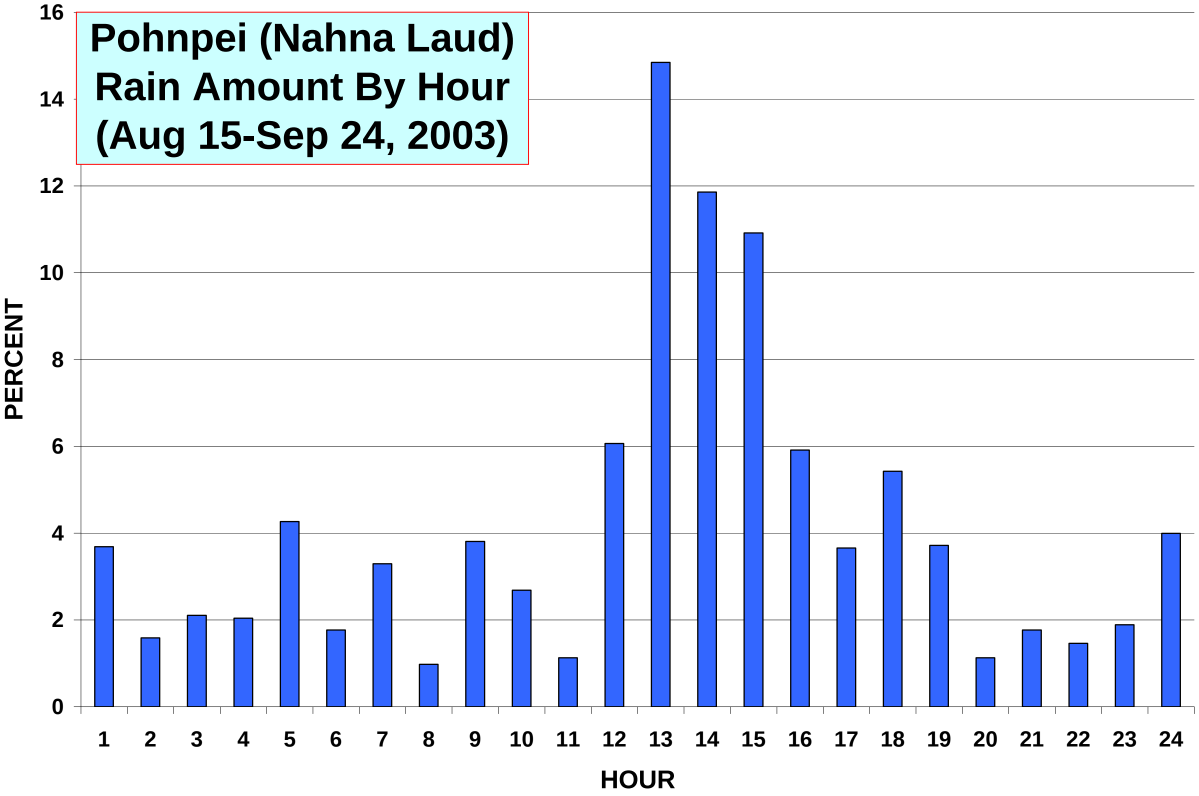


Figure 8. Preliminary data from the Nahna Laud site shows a sharp concentration of rain fall in the three hours from local noon to 3 PM in the afternoon. Convection induced by daily heating in light wind conditions allows for the build-up of thunderstorms nearly every day in Pohnpei's interior.

Historical records suggest that the annual mean rainfall on Pohnpei differs substantially across the island, and is heaviest in the interior of the island. While no rainfall measurements have ever been obtained in the interior highlands of the island (until the WERI transect was set-up in June 2003), the distribution of rainfall at existing locations on the perimeter of the island suggested that existence of sharp rainfall gradients as one ascended into the interior. The PRISM analysis using the historical rain fall records from Pohnpei yielded estimates of rainfall in the interior that were over twice the value of the rainfall along the north coast. The first 9-months of rain readings from the WERI-CSP network have revealed that this estimate is quite realistic.

The distribution of rainfall on the island of Pohnpei is affected by the topography, and the mean annual rainfall totals among recording stations on Pohnpei may differ by more than 100 inches! The region in the vicinity of Pohnpei's international airport receives the lowest annual total of about 120 inches. The highest annual average of approximately 300 inches (2300 mm) probably occurs in the central highlands. The western side of the island is wetter than its eastern side.

In order to arrive at an annual rainfall distribution chart for Pohnpei, the rainfall at recording stations was first compared to simultaneous readings at Nahna Laud – the wettest among all of Pohnpei's rain recording sites. Normalizing the stations to Nahna Laud (where Nahna Laud = 1.00) resulted in the distribution of Fig. 9.

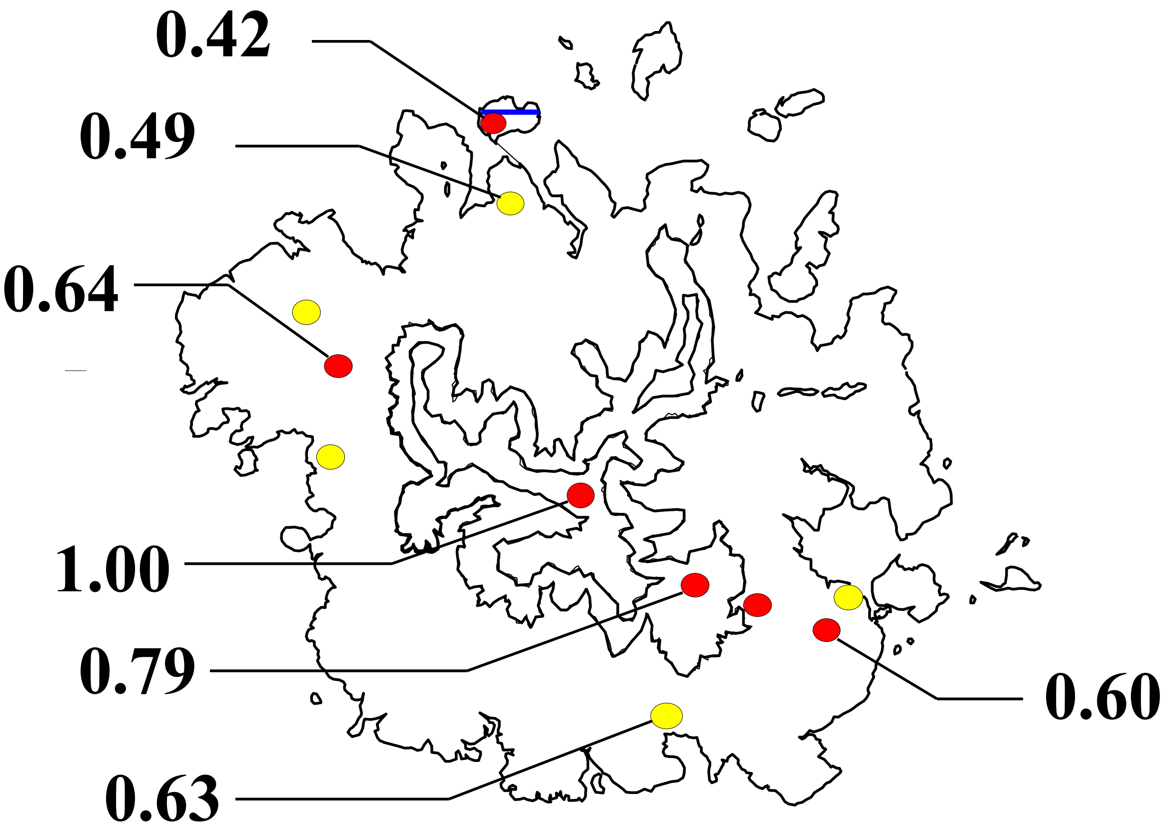


Figure 9. Rainfall at several sites on Pohnpei normalized to the rainfall at Nahna Laud, where the annual rainfall at Nahna Laud = 1.00.

The next step was to convert the percentages in Fig. 9 to rainfall in inches per year. This process resulted in the annual rainfall map shown in Fig. 10.

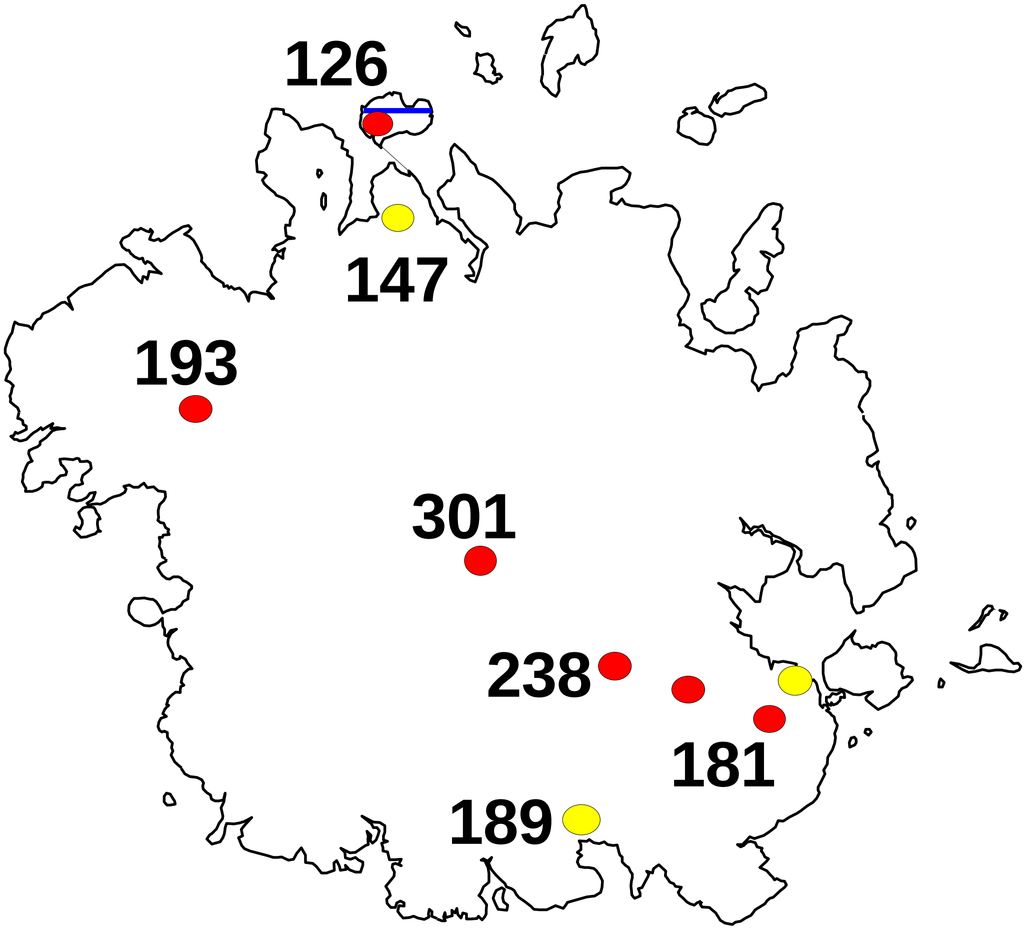


Figure 10. Mean annual rainfall at selected sites on the island of Pohnpei.

The extrapolated mean-annual rainfall from the 9-month inter-comparison of the WERI/CSP network (Fig. 10) compares favorably with the PRISM estimates of mean annual rainfall (Figs. 11 and 12).

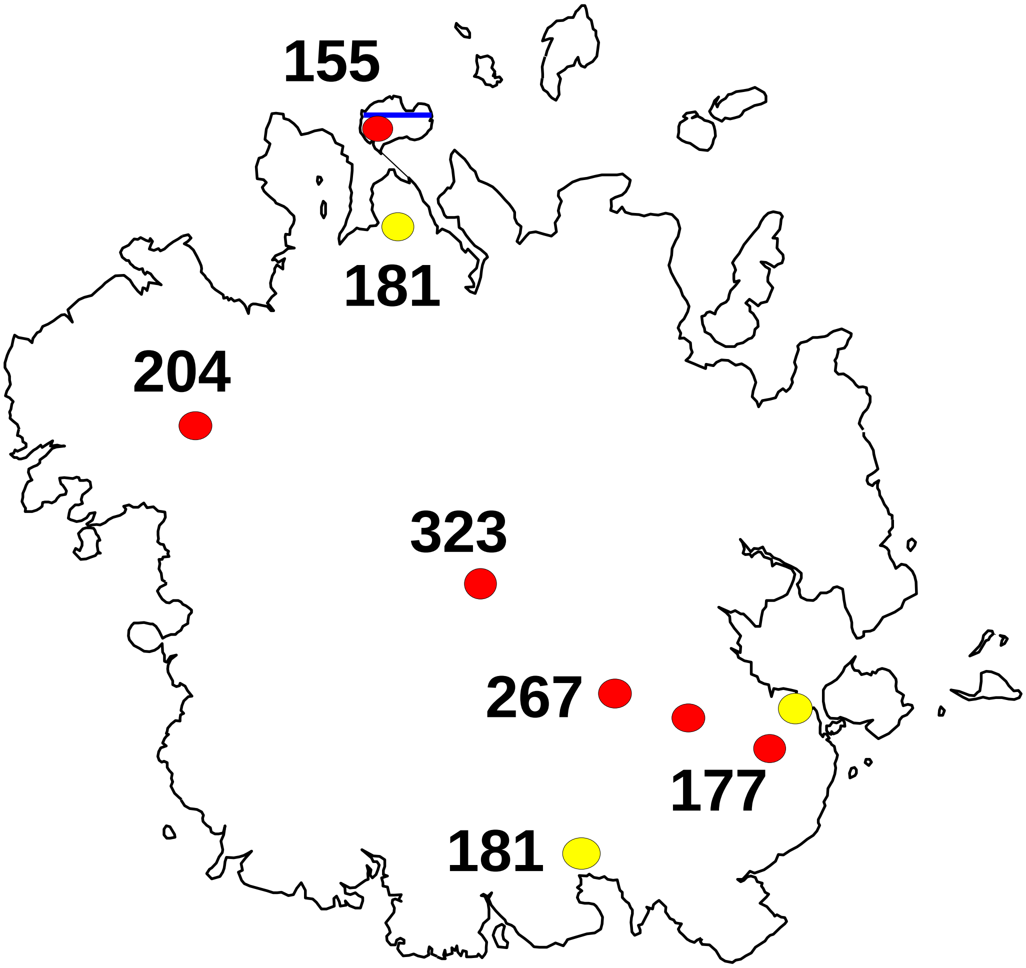


Figure 11. Contours of mean annual rainfall based on the PRISM analysis at selected sites on the island of Pohnpei.

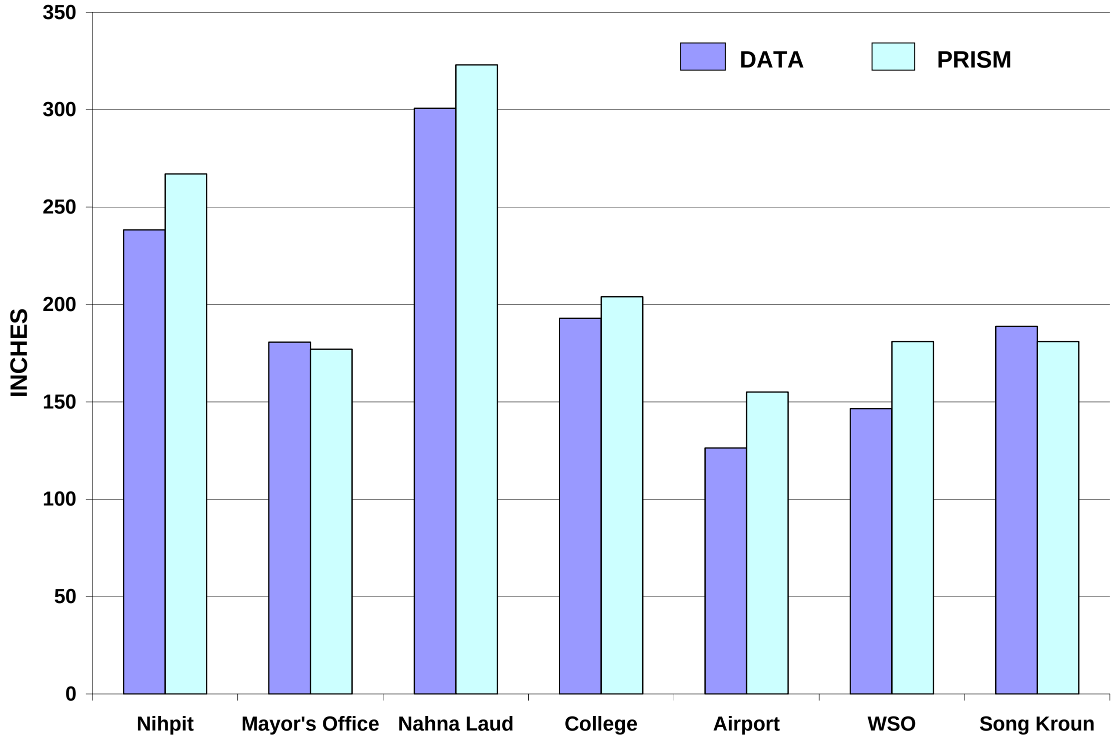


Figure 12. Comparison of measured mean annual rainfall those obtained from the PRISM analysis at selected sites on the island of Pohnpei.

The top of Nahna Laud was the selected site in the central highlands where two rain gages were set up near one another – one in an open area, and another under the canopy of the rainforest – to assess the impact of fog drip on the water budget of the island. The central highlands of Pohnpei are of sufficient height (~2,000 – 2,600 ft) to often be enshrouded in fog. Deposition of cloud droplets onto leaves, and subsequent coalescence and drip, may enhance the total water budget substantially. This so-called fog-drip is responsible for a substantial portion of the water budget on portions of the islands of Hawaii. An electronic rain gauge in the open area determines the times when it is actually raining. The rain gauge under the forest canopy continues to receive water from residual drip, and/or cloud-droplet deposition onto leaves. One of the problems with the site is the dwarf nature of the rain forest at high elevation. There are lots of shrubs and low trees across much of the summit area. Nevertheless, a rain gage was placed under the forest canopy at a site approximately 300 ft away from the gauge in the clearing in a small crater at the top of Nahna Laud. Analysis of the data is inconclusive. There are times, such as in Fig. 14, when it is clear that the rain gauge under the forest canopy continues to receive water for hours after the rain ceases in the clearing. Assuming the first hour or so to be residual drip, one can see from Fig. 13 that approximately .01 inches of rain accumulates every two hours. There is no way to know what portion of this is from the deposition of cloud liquid water onto the leaves. If this rate were continuous, there would be an accumulation of .12 inches of rain per day from this source which amounts to 14% of the net accumulation at the clearing.

A 14% increase over the open-area rainfall may therefore be considered an upper limit for fog drip accumulation, but this result in not trusted. In order to get a better picture of the contribution of fog drip at this site, the WERI/CSP team has proposed to set up a special fog-drip collector designed by Juvik.

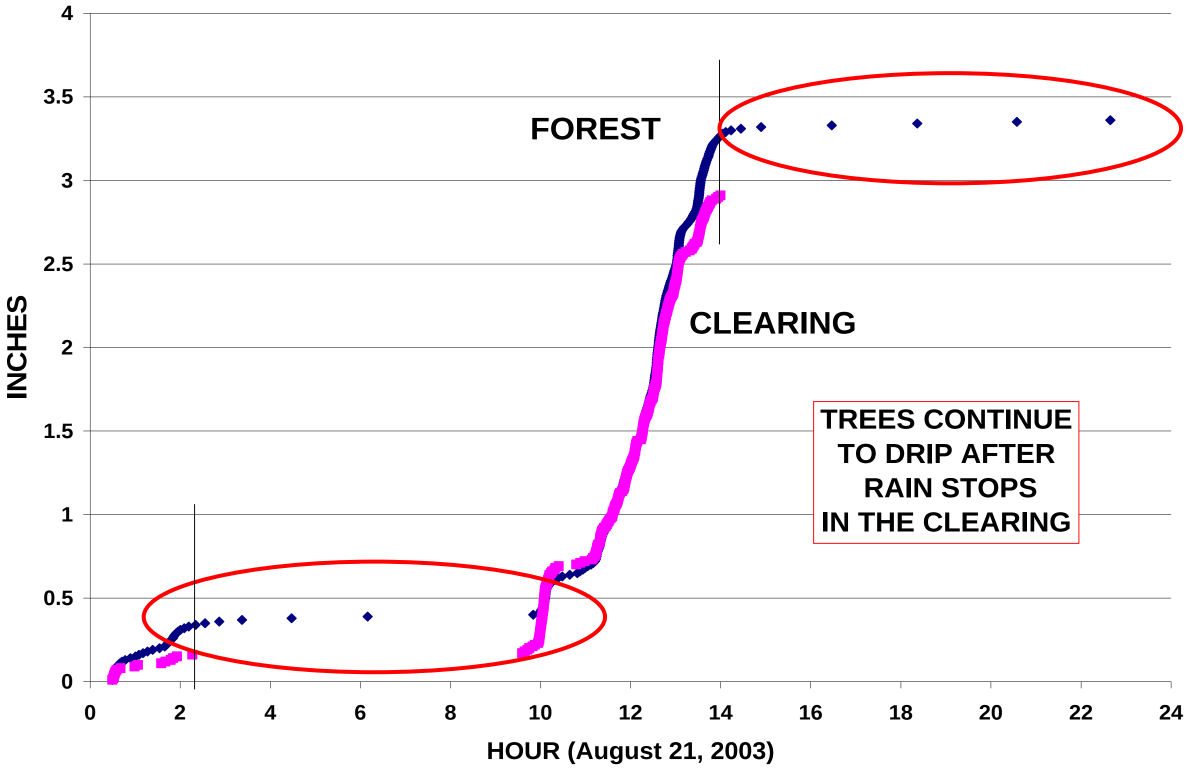


Figure 13. Rainfall on August 21, 2003 at two sites on Nahna Laud: one in a clearing, and the other under the canopy of the rainforest at a site located about 300 feet from the clearing. Each dot indicates an increment of .01 inch of rain. Note the continuation of rain accumulation at the canopy site after the rain stops in the clearing.

Since the rainfall records on Pohnpei are so short and/or incomplete, calculations of return periods of extreme rain events may only be crudely estimated. A similar return-period analysis of the extreme 24-hour rain rates using Pohnpei's shorter and more incomplete record (Fig. 14a,b), and extreme 1-hour rain rates (Fig 15 a,b). A chart of rainfall intensity-duration-frequency was constructed (Fig. 16).

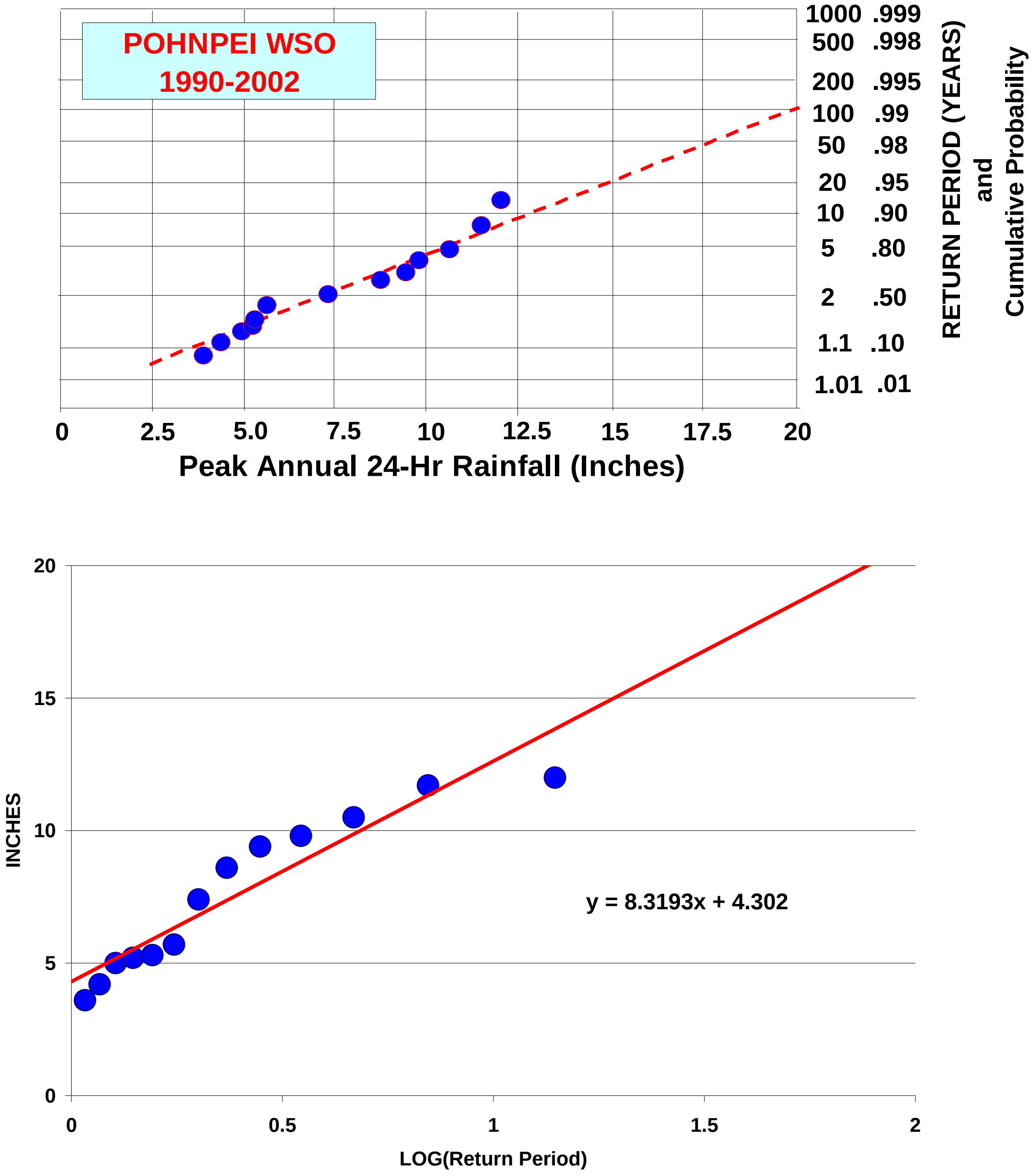


Figure 14. **(a)** Method-of-moments (ranking method) computations of 24-hour return period extreme rainfall events using Pohnpei WSO data. **(b)** Peak annual 24-hour rainfall at Pohnpei WSO versus the log of the estimated return period from the ranking method.

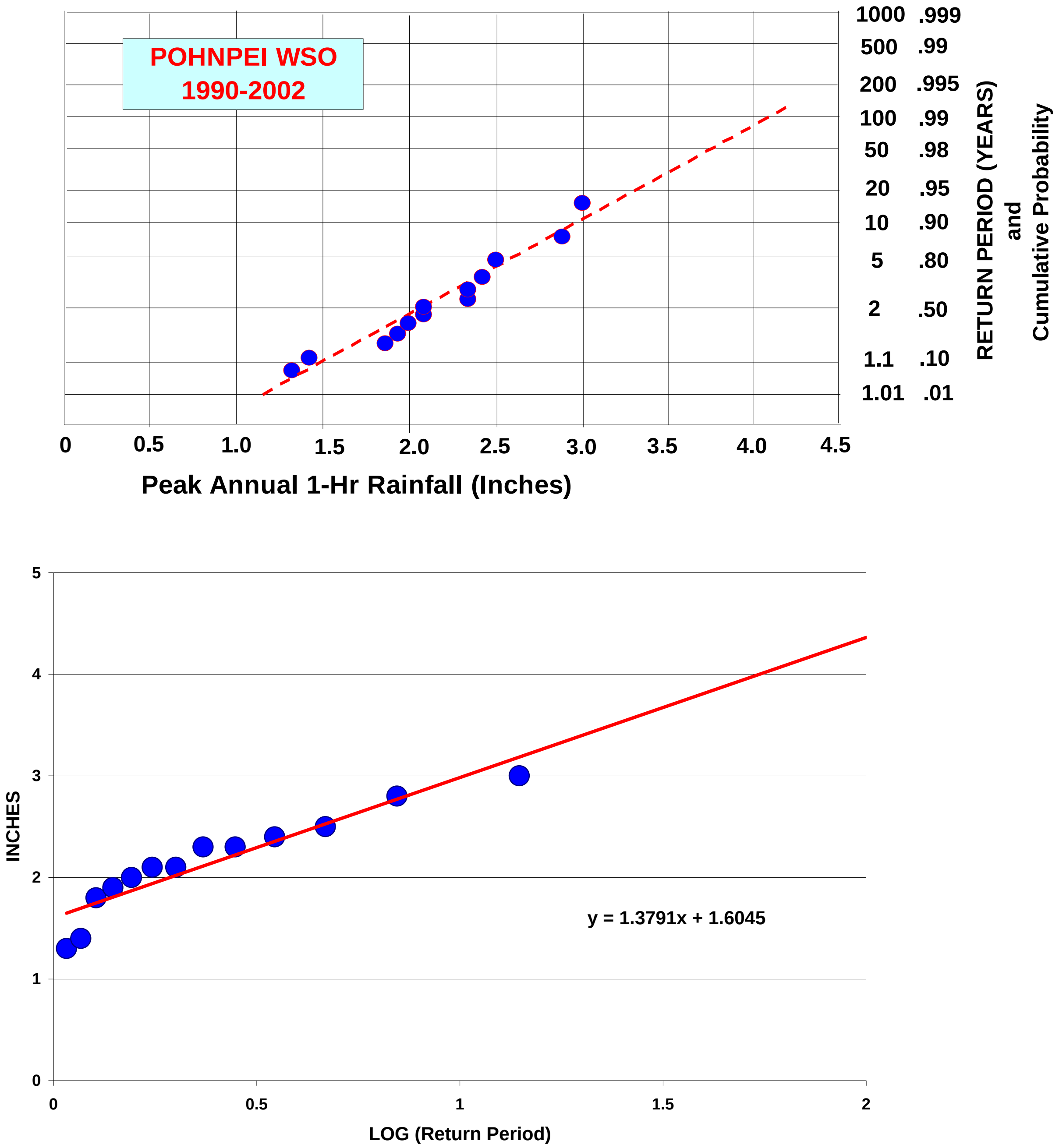


Figure 15. **(a)** Method-of-moments (ranking method) computations of 1-hour return period extreme rainfall events using Pohnpei WSO data. **(b)** Peak annual 1-hour rainfall at Pohnpei WSO versus the log of the estimated return period from the ranking method.

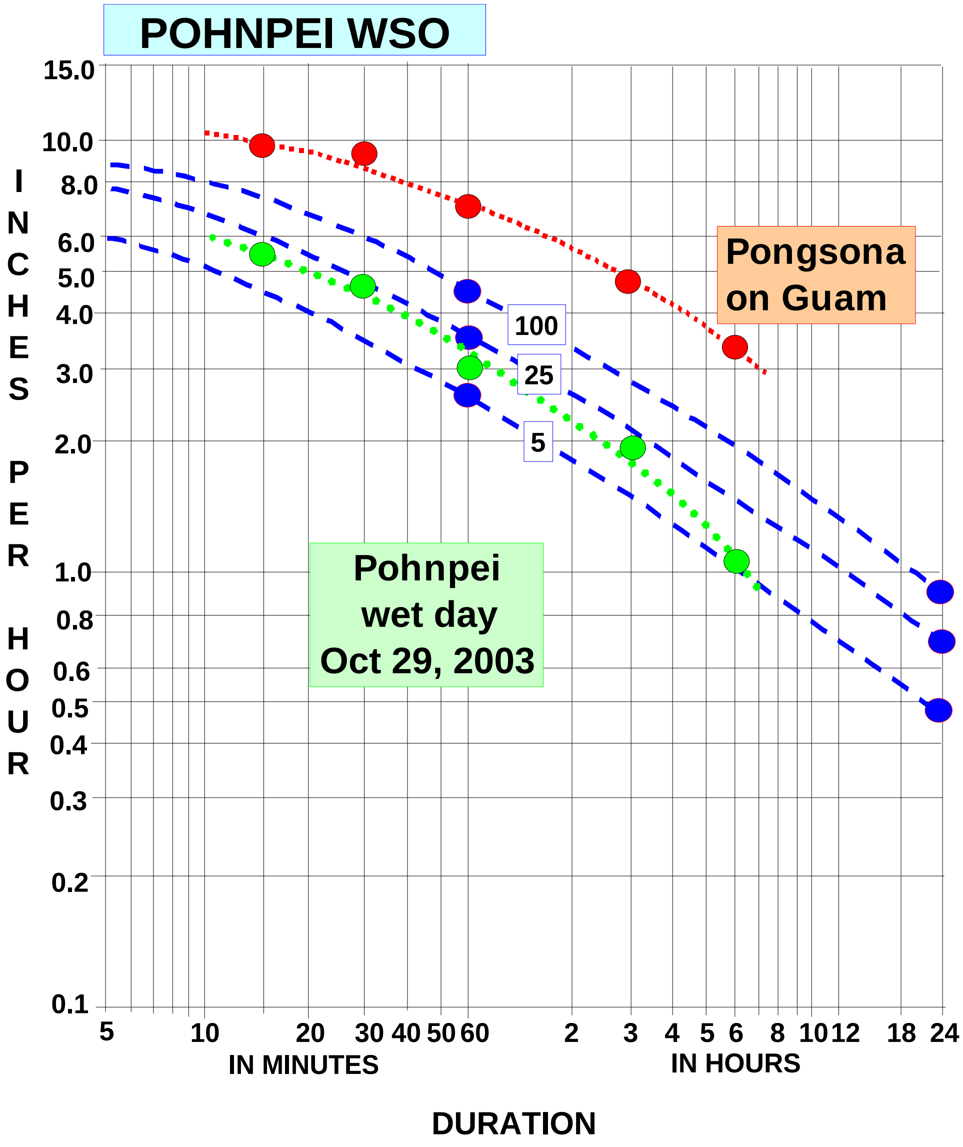
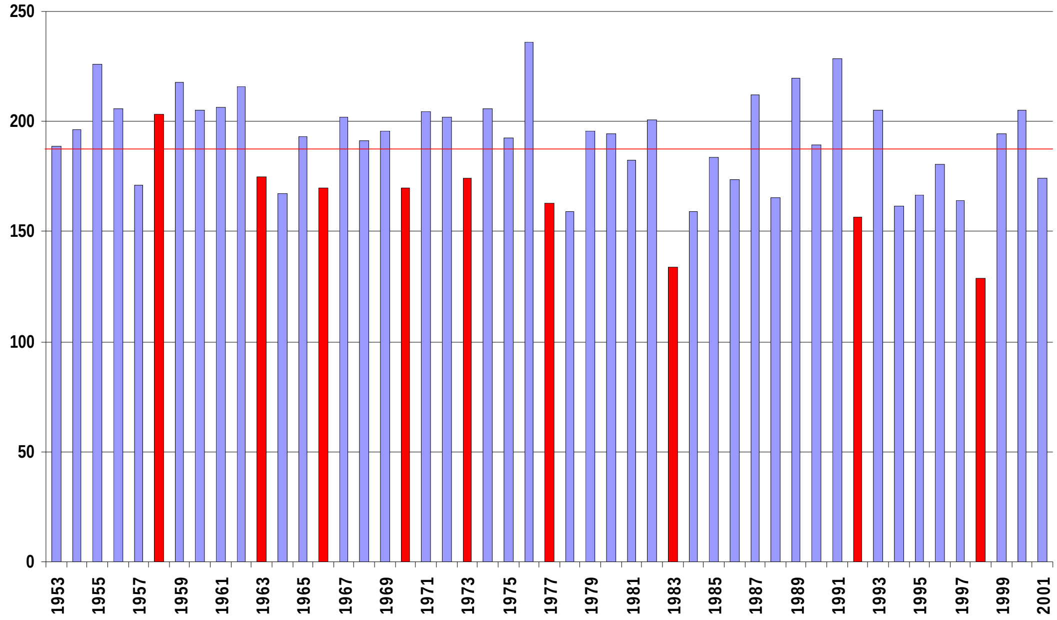


Figure 16. Intensity-Duration-Frequency (IDF) chart of selected return periods at the Pohnpei WSO (blue dots connected by blue dashed lines). For comparison, the IDF values measured during Typhoon Pongsona on Guam (red dots connected by red dotted line) are shown. Also, the highest IDF values measured within the past 9 months by the newly installed WERI/CSP rain gauge network on Pohnpei have been plotted (green dots connected by green dotted line). The Pohnpei event was a fairly typical afternoon thunderstorms.

Nearly all extremely dry years on Pohnpei occur during the year following an El Niño event (Fig. 17). The driest year on record in Pohnpei 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; then, they are dry).

On Pohnpei, persistent dryness tends to become established in the fall of the El Niño year (unless a late-season tropical cyclone makes affects the island. 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 and extension of drier than normal conditions for several months.



POHNPEI ANNUAL RAIN

NOTE: POST-EL NINO YEARS IN RED

Fig. 17. Time series of annual rainfall at the Pohnpei Weather Service Observatory (WSO). Most post-El Niño years (red bars) are dry.

During an El Niño year, the mean sea level drops across most of Micronesia. Typically, the sea level in the region of Pohnpei falls to its lowest value in December of the El Niño year, then quickly recovers by the spring of the year following El Niño (Fig. 18). During La Niña, the sea level is elevated above its normal value. During the major El Niño of 1997, the sea level fell approximately 1 foot below its long-term average, and during the La Niña years that followed (1998-2001), the sea level rose to levels nearly 1 foot above its long-term 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 2 feet. This is substantial, considering that the normal range between the daily high and low astronomical tide is on the order of 4 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 2 feet over the course of a year or two are enormous compared to this, and make it difficult to retrieve the long-term signal.

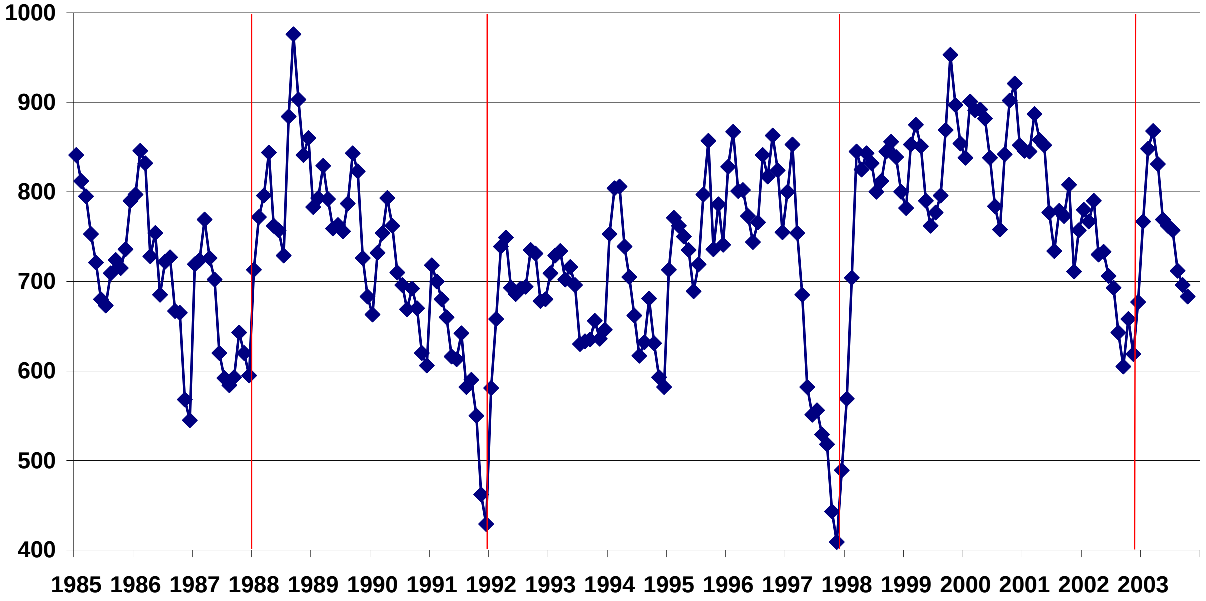


Figure 18. The record of monthly mean sea level at Pohnpei for the period 1985-2004. These changes in sea level are highly coherent across the region from Yap to Guam, Chuuk, Pohnpei, and Kosrae. Note the low sea level at the end of El Niño years (1987, 1991, 1997, and 2002) and the high sea level in the summers of La Niña years (1988, 1994, 1996, and 1998-2001).

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. 19). 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 Pohnpei during El Niño years, and a decreased risk during the year following El Niño and during La Niña years. On Pohnpei, the risk of having typhoon force winds of 65 kt or greater is 1 year in 10 for El Niño years, and approximately 1 year in 50 for non-El Niño years. Pohnpei has not had a strike by a typhoon (65 kt wind on island) since Typhoon Lola in 1986 (an El Niño year, by the way).

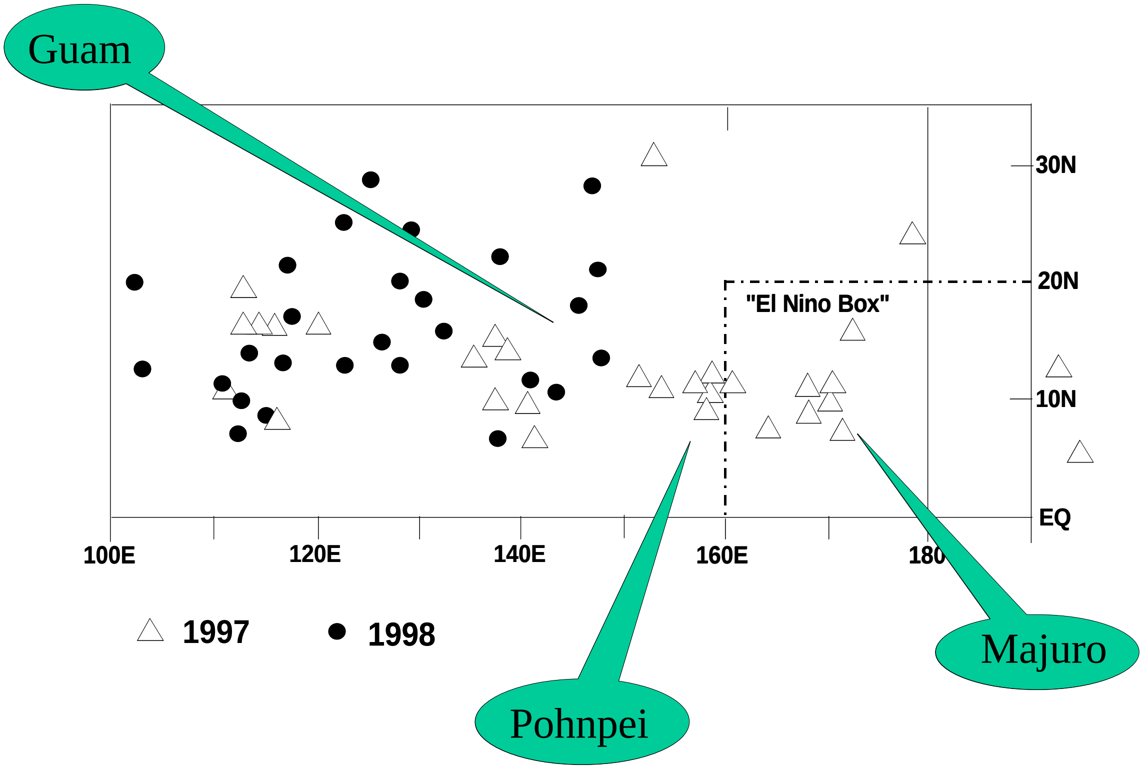


Figure 19. The formation locations for all western Pacific basin tropical cyclones during the El Niño year of 1997 (black dots) and the El Niño follow-on year of 1998 (gray triangles). Note the enormous difference in the formation region (especially in the area designated as the, “El Niño box”). Formation is defined as that point along the JTWC best-track that the tropical cyclone attained an intensity of 25 kt.

Typhoons rarely hit Pohnpei; more often they are spawned in central and eastern Micronesia and sent north-westward towards Guam. Every several years or so on average, a mildly damaging tropical storm or depression will affect Pohnpei island. 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 (Fig. 20) 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 Pohnpei, the frequency of tropical cyclones of tropical storm intensity or higher is less than one per 5-degree latitude-longitude square per year. The frequency of tropical cyclones passing Pohnpei is less than one every three years within 75 n mi. (Fig. 21), with a sharp gradient that features almost no tropical storms south of 5° N to over 1 tropical storm or typhoon passing within 75 n mi of locations several hundred miles to the north and west of Pohnpei. The distribution of tropical cyclone tracks passing Pohnpei appears to be random (Fig. 22) with a very sharp north-south gradient.

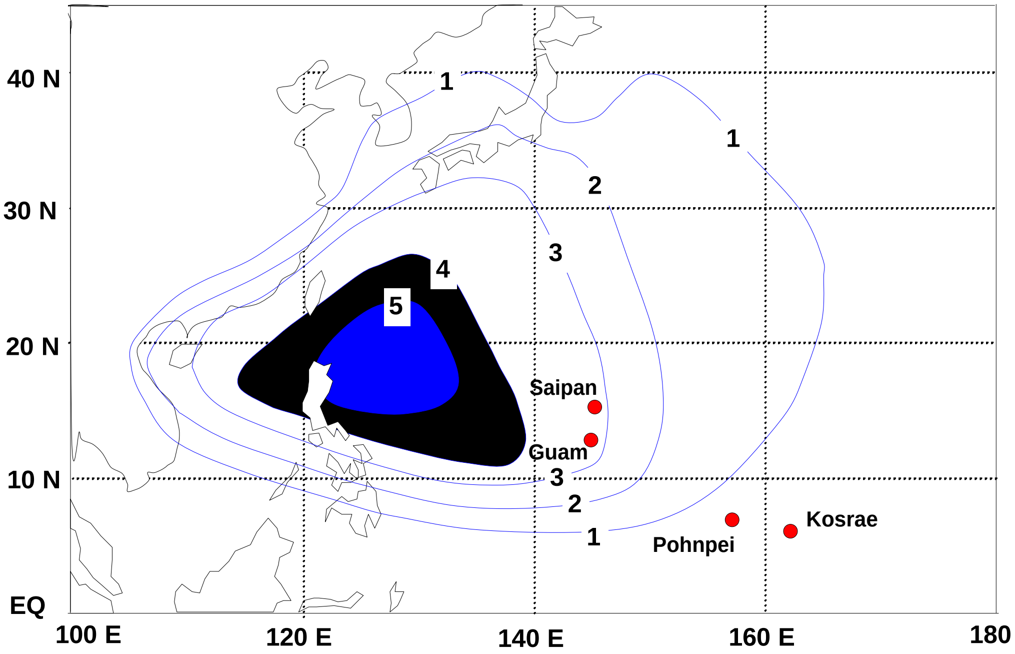


Figure 20. Mean annual number of tropical storms and typhoons traversing 5-degreee latitude by 5-degree longitude squares (adapted from Crutcher and Quayle 1974).

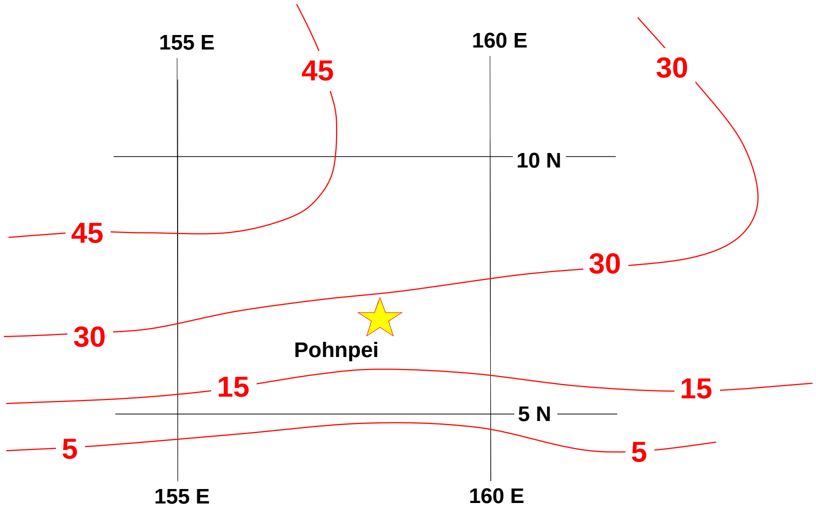


Figure 21. Number of tropical storms and typhoons per 100 years passing within 75 n mi of any map location. (Created from JTWC best-track data 1970-99.)

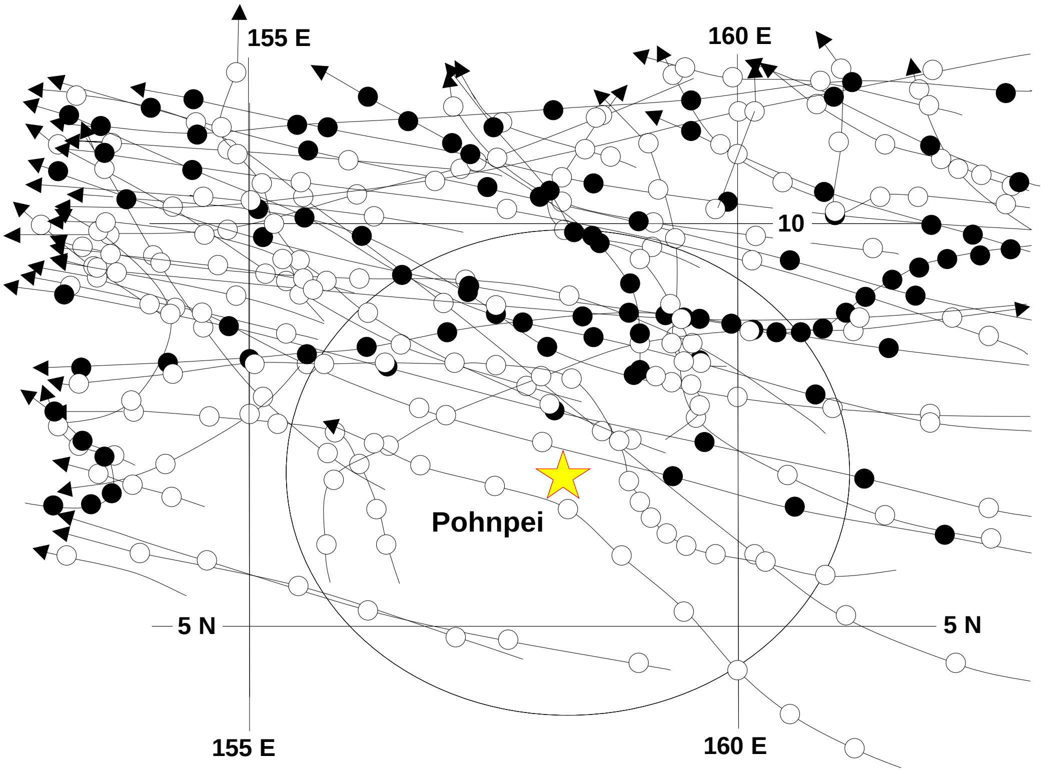


Figure 22. All tropical cyclone positions at six-hour intervals from the JTWC best-track archive. (a) The 1970's, (b), the 1980's, (c) the 1990's , and (d) the period 1970-1999. Open circles indicate tropical storm intensity, black dots indicate typhoon positions, star is the location of Pohnpei and the circle has a radius of 180 n mi from Pohnpei.

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

The 50-year record allowed some assessment of inter-decadal variations in Pohnpei'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. 23. The late 1960s to the mid-1970s were slightly drier than the long-term average, while the 1980s through the early 1990s were drier 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. 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.

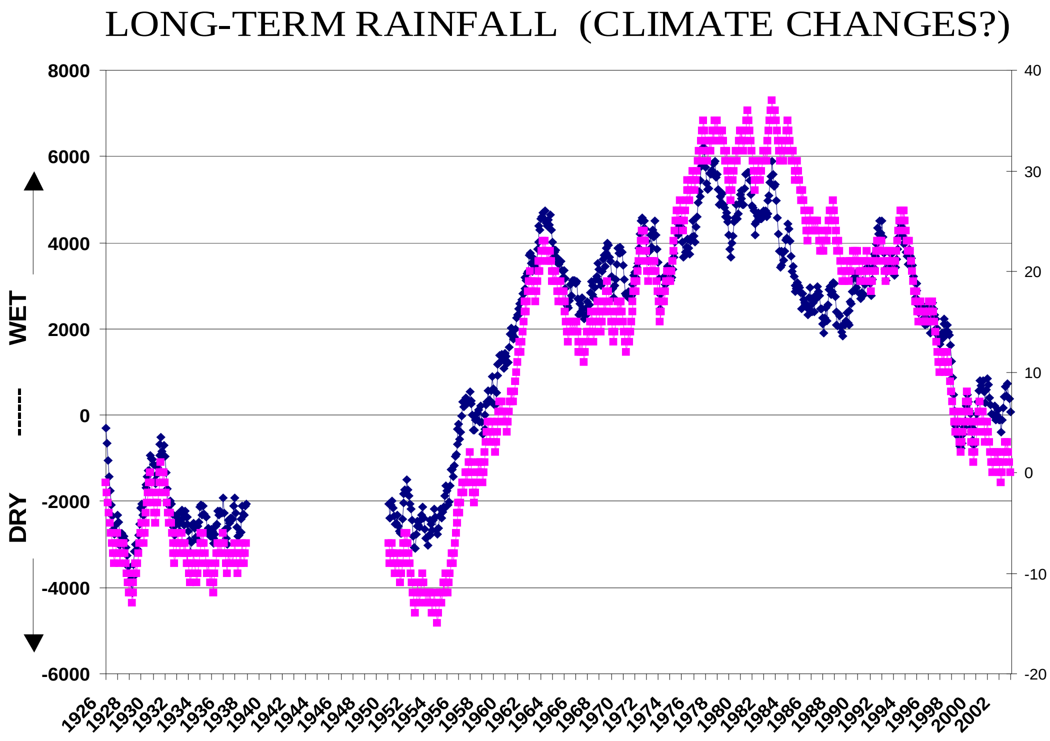


Figure 23. Running accumulations of the rank (lowest month = -305, highest month = +306) of each month's rainfall for the period 1954 to 2000 (annual cycle not removed). Complete records were available from Andersen AFB, Guam, and the constructed time series of the SIA. Prominent features include the 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

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