NOAA Atlas 14

Precipitation-Frequency Atlas of the United States

Volume 5 Version 2.0: Selected Pacific Islands

Sanja Perica, Bingzhang Lin, Deborah Martin, Fenglin Yan, Daniel Brewer, Carl Trypaluk, Michael Yekta, Lillian Hiner, Sarah Heim, Sarah Dietz, Tye Parzybok, Li-Chuan Chen, Kazungu Maitaria, Ruiming Chen, Ishani Roy, Dale Unruh, Tan Zhao, John Yarchoan, Geoffrey M. Bonnin

U.S. Department of Commerce

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Table of Contents

1. Abstract

NOAA Atlas 14 contains precipitation frequency estimates for the United States and U.S. affiliated territories with associated 90% confidence intervals and supplementary information on temporal distribution of heavy precipitation, analysis of seasonality, analysis of trends in annual maximum series data, etc. It includes pertinent information on development methodologies and intermediate results. The results are published through the Precipitation Frequency Data Server (http://hdsc.nws.noaa.gov/hdsc/pfds).

The Atlas is divided into volumes based on geographic sections of the country. The Atlas is intended as the U.S. Government source of precipitation frequency estimates and associated information for the United States.

2. Preface to Volume 5

NOAA Atlas 14 Volume 5 contains precipitation frequency estimates for selected durations and frequencies with 90% confidence intervals and supplementary information on temporal distribution of heavy precipitation, analysis of seasonality, analysis of trends in annual maximum series data, etc., for selected Pacific Islands. The results are published through the Precipitation Frequency Data Server (http://hdsc.nws.noaa.gov/hdsc/pfds).

NOAA Atlas 14 Volume 5 was developed by the Hydrometeorological Design Studies Center within the Office of Hydrologic Development of the National Oceanic and Atmospheric Administration's National Weather Service. Any use of trade names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Citation and version history. This documentation and associated artifacts such as maps, grids, and point-and-click results from the PFDS are part of a whole with a single version number and can be referenced as:

Sanja Perica, Bingzhang Lin, Deborah Martin, Fenglin Yan, Daniel Brewer, Carl Trypaluk, Michael Yekta, Lillian Hiner, Sarah Heim, Sarah Dietz, Tye Parzybok, Li-Chuan Chen, Kazungu Maitaria, Ruiming Chen, Ishani Roy, Dale Unruh, Tan Zhao, John Yarchoan, Geoffrey M. Bonnin (2009).
NOAA Atlas 14, Volume 5, Version 2.0: *Precipitation-Frequency Atlas of the United States, Selected Pacific Islands*. NOAA, National Weather Service, Silver Spring, MD.

The version number has the format P.S where P is a primary version number representing a number of successive releases of primary information. Primary information is essentially the data. S is a secondary version number representing successive releases of secondary information. Secondary information includes documentation and metadata. S reverts to zero (or nothing; i.e., Version 2 and Version 2.0 are equivalent) when P is incremented. When new information is completed and added (such as draft documentation) without changing any prior information, the version number is not incremented.

The primary version number is stamped on the artifact or is included as part of the filename where the format does not allow for a version stamp (for example, files with gridded precipitation frequency estimates). All location-specific output from the PFDS is stamped with the version number and date of download.

Table 2.1 lists the version history associated with the NOAA Atlas 14 Volume 5 precipitation frequency project and indicates the nature of changes made. If major discrepancies are observed or identified by users, a new release may be warranted.

Table 2.1. Version history of NOAA Atlas 14, Volume 5.

Version no.	**Date**	**Notes**
Version 1.0	July 2009	Draft data used in peer review
Version 2.0	December 2009	Final data and documentation released

3. Introduction

3.1. Objective

NOAA Atlas 14 Volume 5 provides precipitation frequency estimates for selected islands and atolls in the Pacific Ocean that are part of the following seven countries or territories: the Commonwealth of Northern Mariana Islands, the Territory of Guam, the Republic of Palau, the Federated States of Micronesia, the Republic of the Marshall Islands, Wake Island and the Territory of American Samoa.

The Atlas provides precipitation frequency estimates for 5-minute through 60-day durations at average recurrence intervals of 1-year through 1,000-year. The estimates were computed using an L-moment based regional frequency analysis of annual maximum series and then converted to partial duration series results. The results are provided at high spatial resolution and include confidence limits for the estimates. The Atlas also includes information on temporal distributions of heavy precipitation (Appendix A.1) and seasonal information for annual maxima (Appendix A.2). In addition, the potential effects of climate change as trends in historic annual maxima were examined (Appendix A.3).

3.2. Approach and deliverables

The approach used in this project for calculating precipitation frequency estimates largely follows the index-flood regional frequency analysis approach based on L-moment statistics described in Hosking and Wallis (1997). This section provides an overview of the approach; greater detail is provided in Section 4.

The annual maximum series used in the precipitation frequency analysis were extracted from precipitation measurements recorded at daily, hourly and n-minute time intervals from various sources. The data were carefully screened for erroneous measurements. The 1-day annual maximum series were also analyzed for potential trends (Appendix A.3).

To support the regional frequency analysis approach, homogeneous regions with respect to heavy precipitation characteristics were delineated. Adjustments were made in the definition of regions based on statistical tests and underlying climatology.

A variety of probability distribution functions were examined for each region and duration and the most suitable distribution was selected based on the results of goodness-of-fit tests. Precipitation frequency estimates for a selected distribution were determined at each station based on the mean of the annual maximum series at the station and the regionally determined higher order L-moment ratios for each duration. A Monte-Carlo simulation approach was used to produce upper and lower bounds of the 90% confidence intervals for the precipitation frequency estimates. Due to the small number of stations recording data at less than 1-hour intervals, precipitation frequency estimates and confidence intervals for durations below 1-hour (n-minute durations) were computed using an average ratio between the n-minute and 1-hour frequency estimates as determined based on available data.

Gridded estimates of precipitation frequency estimates and 90% confidence intervals were determined based on the mean annual maxima grids and the regionally determined higher order L-moment ratios. The mean annual maxima grids for the 1-day duration were derived from mean annual precipitation grids or through direct spatial interpolation of at-station mean annual maxima for regions where no relationship between mean annual maxima and mean annual precipitation was found. The 1-day mean annual maxima grids were then used to estimate mean annual maxima grids at other durations. Higher order L-moments were smoothed across durations to ensure consistency in estimates. Both spatially interpolated and point estimates were subject to external peer reviews (see Section 6 and Appendix A.5).

Temporal distributions of heavy precipitation in the project area for selected durations were calculated; they are shown in Appendix A.1. Graphs showing seasonality of heavy precipitation were developed for each precipitation frequency region by tabulating the number of precipitation amounts exceeding precipitation frequency estimates for several selected annual exceedance probabilities and durations (Appendix A.2).

NOAA Atlas 14 Volume 5 precipitation frequency estimates for any location in the project area are available for download in a variety of formats through the Precipitation Frequency Data Server (PFDS) at http://hdsc.nws.noaa.gov/hdsc/pfds (via a point-and-click interface). The additional types of results and information found there include:

- ArcInfo ASCII grids of partial duration series-based and annual maximum series-based precipitation frequency estimates and associated confidence intervals for a range of durations and frequencies;
- cartographic maps of partial duration series-based precipitation frequency estimates for selected frequencies and durations;
- annual maximum series used in the analysis;
- temporal distributions of heavy precipitation for selected durations;
- seasonal exceedance graphs for selected frequencies and durations;
- associated Federal Geographic Data Committee-compliant metadata.

Cartographic maps were created to serve as visual aids and are not recommended for estimating precipitation frequency estimates. Users are advised to take advantage of the Precipitation Frequency Data Server or the underlying ArcInfo ASCII grids for obtaining point frequency estimates.

4. Precipitation frequency analysis

4.1. Project area description

The project area, shown in Figure 4.1.1, includes selected islands and atolls in the Pacific Ocean that are part of the following territories or states: the Commonwealth of Northern Mariana Islands, the Territory of Guam, the Republic of Palau, the Federated States of Micronesia, the Republic of the Marshall Islands, Wake Island and the Territory of American Samoa. Listed below are all islands and atolls for which precipitation frequency estimates are available; these islands or atolls had at least one precipitation recording station that passed all screening criteria (described in subsequent sections):

- Commonwealth of the Northern Mariana Islands: Rota, Saipan, Tinian
- Territory of Guam: Guam
- Republic of Palau: Angaur, Babelthuap, Koror
- Federated States of Micronesia, State of Yap: Yap Islands (Gagil-Tamil, Maap, Rumung, Yap), Ulithi, Woleai
- Federated States of Micronesia, State of Chuuk: Lukunor, Weno
- Federated States of Micronesia, State of Pohnpei: Nukuoro, Pingelap, Pohnpei
- Federated States of Micronesia, State of Kosrae: Kosrae
- Republic of Marshall Islands: Ailinglapalap, Enewetak, Jaluit, Kwajalein, Majuro, Mili, Utirik, Wotje
- Wake Island
- Territory of American Samoa: Tutuila.

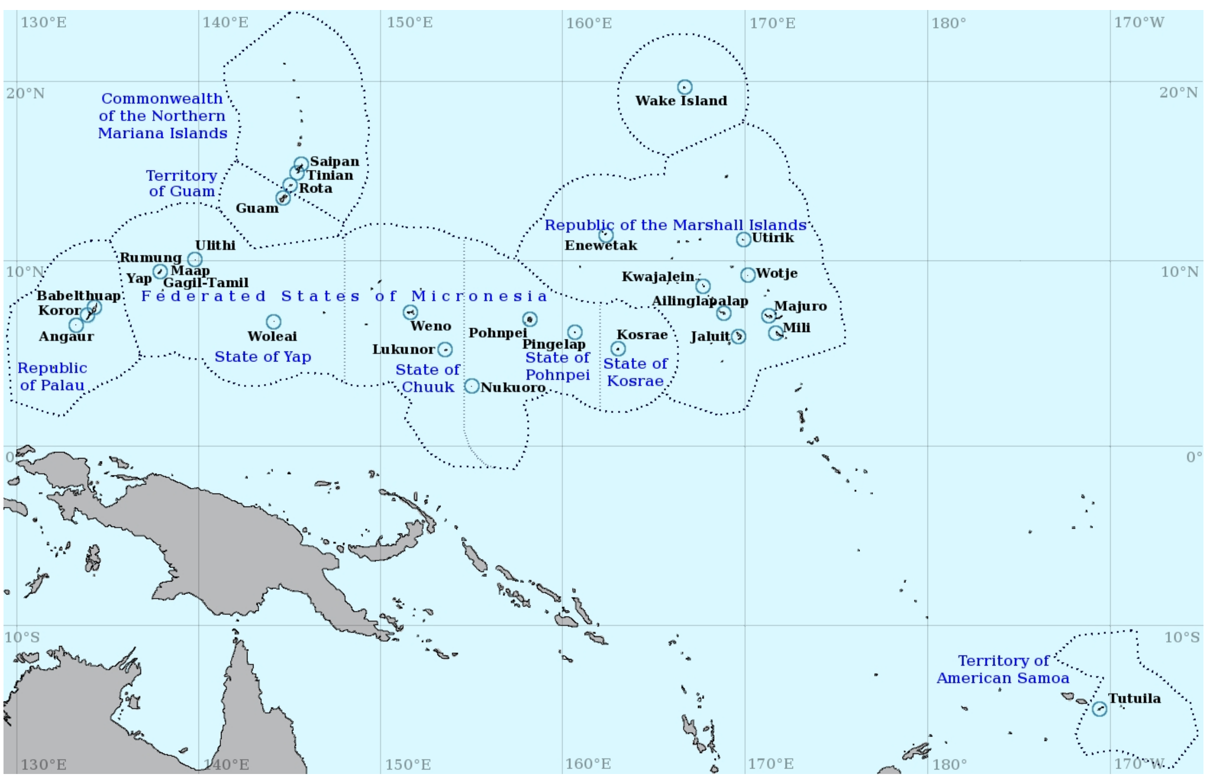


Figure 4.1.1. Project area for NOAA Atlas 14 Volume 5. Only islands or atolls with at least one recording station used in the precipitation frequency analysis are labeled.

Climatology of heavy precipitation. The selected Pacific Islands are located in the tropical region where temperatures remain moderate throughout the year and the weather pattern is dominated by northeast trade winds in the northern hemisphere and southeast trade winds in the southern hemisphere (American Samoa). The wet season typically lasts from November through April for American Samoa islands and from July through December for the other islands, although heavy precipitation events occur throughout the year. Heavy precipitation mechanisms include tropical disturbances, tropical depressions, tropical storms, and typhoons. These are collectively referred to as tropical cyclones. The rainfall from these events can be further enhanced by orographic effects such as on Pohnpei, Kosrae, and Tutuila. Islands closer to the equator see more heavy precipitation, especially during the wet season, due to their proximity to the Intertropical Convergence Zone (ITCZ). The ITCZ moves throughout the year, shifting north during the northern hemisphere summer and south during the northern hemisphere winter. In this zone, the northeast and southeast trade winds converge, producing areas of strong convection known as the trade wind trough. Farther west, the easterly trade winds clash with westerly (more equatorial) monsoon winds to produce the monsoon trough.

Thunderstorms associated with the monsoon trough can produce large amounts of precipitation over short durations. Sometimes these storms become more organized and a thunderstorm complex develops known as a tropical disturbance, which may last a day or more. These disturbances can develop cyclonic surface circulations and further strengthen into typhoons (hurricanes east of the Date Line, cyclones in the southern hemisphere), which can also be a major influence on heavy precipitation. Although typhoons are more prevalent during the wet season, they can form any time of year in the warm waters of the western North Pacific.

To portray the seasonality of heavy precipitation throughout the project area, precipitation amounts that exceeded selected annual exceedance probabilities for chosen durations were examined for each region delineated in the frequency analysis (see Appendix A.2 and Section 4.5.2). Graphs showing the seasonality of heavy precipitation for any location in the project area are provided via the Precipitation Frequency Data Server.

4.2. Data

4.2.1. Data sources

The annual maximum series used in the precipitation frequency analysis were extracted from precipitation measurements recorded at 1-day, 1-hour, 15-minute and various n-minute time intervals from several sources. The National Weather Service (NWS) Cooperative Observer Program's stations obtained from National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) were the primary data source. Table 4.2.1 shows all potential data sources we were able to identify, grouped based on the data reporting intervals (data type), with links to web sites from which the data were downloaded when applicable. Additional data for recent years were also received from the National Weather Service Forecast Office in Guam and were used to extend records at several NCDC stations. The table shows the total number of stations obtained from each source and the number of stations that passed all screening criteria and were used in the frequency analysis (numbers shown in this table are before some stations were merged; see Section 4.2.2).

Table 4.2.1. Data sources with dataset names grouped by reporting interval and links to web sites from which the data were downloaded when applicable (web links as of May 2009). Also shown are total number of stations and number of stations used in frequency analysis per source.

Data reporting interval	**Source of data and dataset name**	**Number of stations**	
		total	**used**
1-day	NCDC: TD3200 and TD 3206 datasets updated with data obtained from NWS Forecast Office in Guam (http://cdo.ncdc.noaa.gov/CDO/dataproduct)	113	59
	USGS Pacific Islands Water Science Center: online database and paper records (http://hi.water.usgs.gov/studies/project_waterdata.htm)	17	7
	Environmental Verification and Analysis Center: Pacific Rainfall Data Base (PACRAIN) dataset (http://pacrain.evac.ou.edu/)	114	0
1-hour	NCDC: TD3240 dataset (http://cdo.ncdc.noaa.gov/CDO/dataproduct)	38	7
	USGS Pacific Islands Water Science Center database (http://hi.water.usgs.gov/studies/project_waterdata.htm)	14	3
15-min	NCDC: TD 3260 dataset (http://cdo.ncdc.noaa.gov/CDO/dataproduct)	11	11
n-min	NCDC: TD9649 dataset (5-min to 180-min monthly maxima for 1973-1997) and Automated Surface Observing System (ASOS) dataset (1-min data beginning in 1998)	10	7
	NASA: Tropical Rainfall Measuring Mission (TRMM) dataset (http://rmm-fc.gsfc.nasa.gov/trmm_gv)	27	0
TOTAL		**344**	**94**

4.2.2. Initial data screening

Initial data screening included the following steps: a) examination of geospatial data, b) screening for duplicate stations, c) screening for duplicate records at co-located daily, hourly, and/or 15-minute stations, d) extending records using data from co-located stations, e) merging data from two or more nearby stations. Further data screening for sufficient number of years with usable data and data quality control were done on annual maximum series extracted from precipitation records for a range of durations (see Section 4.4). Table 4.2.2 shows how many stations per duration were available for each island/atoll in the study area after all screenings were done. Only islands and atolls with at least one station used in frequency analysis are listed in the table.

Locations of stations used in the project are shown in Figure 4.2.1. More detailed information on each station used in the frequency analysis is given in Appendix A.6. The table in the appendix includes station sources, names, identification numbers and data reporting intervals, as well as their latitudes, longitudes, elevations, period of records and regional assignment (used in regional frequency analysis described in Section 4.5.2). Stations in the table are grouped by state/territory and by island. There was more than one version of name for several islands and atolls in the project area; names were adjusted to match one of currently accepted island/atoll names. Identification numbers shown in the table were assigned internally and, except for NCDC stations, do not match identification numbers assigned by agencies that provided the data.

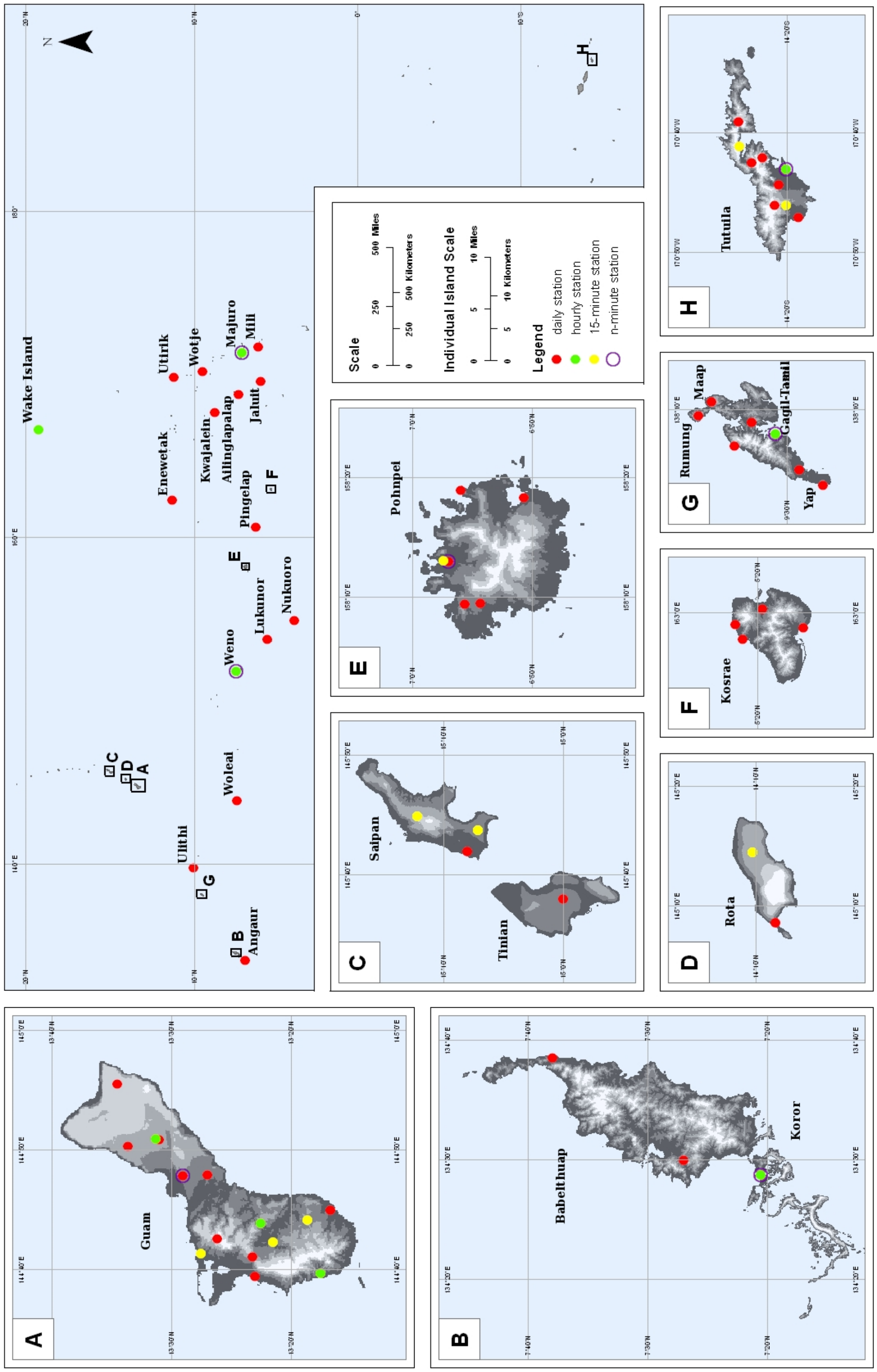


Figure 4.2.1. Map of stations recording at 1-day, 1-hour, 15-minute and various n-minute durations used in frequency analysis.

Table 4.2.2. Number of stations used in frequency analysis at various durations per island/atoll in each territory/state.

Abbr.	Territory/state		Island/atoll	Number of stations per duration			
				≥1 day	≥1hr	≥15min	<15min
CNMI	Commonwealth of the Northern Mariana Islands		Rota	2	1	1	0
			Saipan	3	2	2	0
			Tinian	1	0	0	0
GU	Territory of Guam		Guam	15	6	3	1
PW	Republic of Palau		Angaur	1	0	0	0
			Babelthuap	2	0	0	0
			Koror	1	1	0	1
FSM	Federated States of Micronesia	State of Chuuk	Lukunor	1	0	0	0
			Weno	1	1	0	1
		State of Kosrae	Kosrae	4	0	0	0
		State of Pohnpei	Nukuoro	1	0	0	0
			Pingelap	1	0	0	0
			Pohnpei	6	1	1	1
		State of Yap	Gagil-Tamil	1	0	0	0
			Maap	1	0	0	0
			Rumung	1	0	0	0
			Ulithi	1	0	0	0
			Woleai	1	0	0	0
			Yap	4	1	0	1
RMI	Republic of Marshall Islands		Ailinglapalap	1	0	0	0
			Enewetak	1	0	0	0
			Jaluit	1	0	0	0
			Kwajalein	1	0	0	0
			Majuro	1	1	0	1
			Mili	1	0	0	0
			Utirik	1	0	0	0
			Wotje	1	0	0	0
WAKE			Wake Island	1	1	0	0
AS	Territory of American Samoa		Tutuila	9	3	2	1
TOTAL				**66**	**18**	**9**	**7**

Geospatial data. Latitude, longitude and elevation data for all stations used in the project were screened for errors. Several stations had to be re-located because they plotted in the ocean or were clearly misplaced based on inspection of satellite images and maps. Misplacement was typically the result of no seconds recorded in latitude and longitude data. There were also several stations with no elevation data; for those stations, elevation was estimated from high resolution DEM grids. All adjusted geospatial data are shown in bold letters in the table in Appendix A.6.

Duplicate stations. In some instances, the same station was reported by more than one source (station identification numbers were often different). For example, a majority of NCDC stations were also included in the PACRAIN dataset. Duplicate stations were screened from the final dataset.

Co-located stations. Co-located stations are defined as stations that have the same metadata (primarily geospatial data but may also have the same identification numbers as in the case of NCDC stations), but report data at different time intervals. Screening of co-located stations was done as follows:

- If co-located 15-minute and hourly stations provided data for the same period and there were no differences in annual maximum series for constrained 1-hour maxima (15-minute data aggregated based on the clock hour), only the 15-minute station was retained and used to extract AMS for all longer durations. The majority of NCDC's 1-hour co-located stations in this project were deleted because they reported aggregated data from co-located 15-minute stations.
- If 15-minute or hourly station provided data for the same period as a co-located daily station and there were no differences in annual maximum series for constrained 1-day maxima (15-minute or 1-hour data aggregated from 0 to 24 hours), only the 15-minute or hourly station was retained and used to extract AMS for all longer durations.
- If periods of record at co-located stations were consistent but did not completely overlap, aggregated data from the station with the shorter reporting interval were used to extend datasets of the station with the longer reporting interval.
- If the station with the longer reporting interval had a longer period of record, then it was retained in the dataset in addition to the co-located station with the shorter reporting interval.

Data consistency across durations was ensured in later quality control procedures (see Section 4.4.3).

Nearby stations. For this project, nearby stations were defined as stations located within 1-mile distance and no more than 200-feet difference in elevation. They were considered for merging to increase record lengths. Double-mass curve analysis and *t*-tests at the 90% confidence level were used to ensure that the annual maximum series of stations considered for merging were from the same population. Table 4.2.3 shows basic information on stations that were merged. The metadata from first station in the group was retained in the dataset.

Table 4.2.3. Groups of stations that were merged to increase record lengths.

Group	Island/atoll	Station name	Source	Station type	Station ID	Latitude	Longitude	Elev. (ft)	Period of record	
									before	after
1	TUTUILA	VAIPITO	NCDC	15MIN	91-4902	-14.2678	-170.6847	265	2000-2007	1979-2007
	TUTUILA	ATUU	NCDC	15MIN	91-4060	-14.2667	-170.6833	265	1979-2000	
2	SAIPAN	CAPITOL HILL1	NCDC	15MIN	91-4080	15.2032	145.7485	827	1986-2007	1980-2007
	SAIPAN	CAPITOL HILL	NCDC	15MIN	91-4075	15.2167	145.7500	672	1980-1986	
3	WENO	CHUUK WSO	NCDC	HLY	91-4111	7.4552	151.8376	5	1993-2008	1984-2008
	WENO	TRUK WSO AP	NCDC	HLY	91-4851	7.4552	151.8376	5	1984-1993	
4	GUAM	UMATAC	USGS	DLY	93-3766	13.2918	144.6622	5	1988-2008	1978-2008
	GUAM	UMATAC	NCDC	DLY	91-4885	13.2833	144.6667	190	1978-1988	
5	WENO	CHUUK WSO	NCDC	DLY	91-4111	7.4552	151.8376	5	1990-2008	1914-2008
	WENO	TRUK WSO AP	NCDC	DLY	91-4851	7.4552	151.8376	5	1956-1990	
	WENO	TRUK WB AP	NCDC	DLY	91-4551	7.4552	151.8376	8	1914-1955	
6	LUKUNOR	LUKUNOR	NCDC	DLY	91-4419	5.5135	153.8167	5	1986-2005	1962-2005
	SATOWAN	SATOWAN	NCDC	DLY	91-4814	5.3333	153.7333	9	1969-1976	
	SATOWAN	SATOWAN	NCDC	DLY	91-4811	4.3000	152.7000	4	1962-1968	
7	ULITHI	ULITHI	NCDC	DLY	91-4892	10.0204	139.7916	6	1989-2008	1954-2008
	ULITHI	ULITHI	NCDC	DLY	91-4185	10.0333	139.8000	6	1954-1989	

Group	Island/atoll	Station name	Source	Station type	Station ID	Latitude	Longitude	Elev. (ft)	Period of record	
									before	after
8	JALUIT	JALUIT	NCDC	DLY	91-4304	5.9167	169.6432	6	1985-2005	1956-2005
	JALUIT	JABOR	NCDC	DLY	91-4300	5.9167	169.6432	0	1956-1962	
9	TUTUILA	LEONE	NCDC	DLY	91-4397	-14.3500	-170.7833	20	1967-1978	1955-1978
	TUTUILA	TAPUTIMU	NCDC	DLY	91-4873	-14.3500	-170.7667	49	1955-1967	
10	TUTUILA	PAGO PAGO	NCDC	DLY	91-4690	-14.3333	-170.7167	12	1966-2008	1956-2008
	TUTUILA	TAFUNA AP	NCDC	DLY	91-4869	-14.3333	-170.7167	10	1956-1966	

4.3. Annual maximum series extraction

4.3.1. Series selection

Precipitation frequency estimates can be obtained by analyzing annual maximum series (AMS) or partial duration series (PDS). AMS are constructed by extracting the highest precipitation amount for a particular duration in each successive year of record, whether the year is defined as a calendar or water year. Water year, starting on October 1 of the previous calendar year and ending on September 30, was used in this project. AMS inherently exclude other heavy precipitation cases that occur in the same year, regardless of whether they exceed maxima of other years. PDS include all amounts for a specified duration at a given station above a pre-defined threshold regardless of year and can include more than one event from any particular year. Differences in magnitudes of corresponding frequency estimates from the two series are negligible for average recurrence intervals greater than about 15 years, but notable at smaller average recurrence intervals (see Section 4.5.1 for more details). These differences may be important depending on the application. Because PDS can include more than one event in any particular year, the results from a PDS-based analysis are regarded as more suitable for designs based on more frequent events.

In this project, only AMS were directly extracted from the data. AMS-based precipitation frequency estimates where then converted to PDS-based frequency estimates using Langbein's empirical formula (see Sections 4.5.1 and 4.5.4). The AMS were extracted for a range of durations varying from 5-minute to 60-day. AMS for the 1-day through 60-day durations were compiled from daily, hourly, or 15-minute records. Hourly and 15-minute data were aggregated to constrained 1-day (0 to 24 hour) values before extracting 1-day and longer duration annual maxima. Hourly and 15-minute data were also used to compile AMS for 1-hour through 12-hour durations. Again, 15-minute data were aggregated to constrained 1-hour (0 to 60 minute) values before extracting AMS. 15-minute data were used to compile AMS for 15-minute and 30-minute durations and n-minute data were used to compile AMS for durations from 5-minute to 60-minute.

4.3.2. Criteria for extraction

The procedure for developing an AMS from a precipitation dataset used specific criteria designed to extract only reasonable maxima if a year was incomplete or had accumulated data. Accumulated data occurred in some records where observations were not taken regularly, so recorded numbers represent accumulated amounts over extended periods of time. Since the precipitation distribution over the period is unknown, the total amount was distributed uniformly across the whole period. All annual maxima that resulted from accumulated data were flagged and went through additional screening to ensure that the incomplete data did not result in erroneously low maxima (see Section 4.4.2).

The criteria for AMS extraction was designed to exclude maxima if there were too many missing or accumulated data during the year and more specifically during critical months when rainfall maxima were most likely to occur ("wet season"). The wet seasons for extraction purposes were assigned by inspecting histograms of annual maxima for the 1-day and 1-hour durations and by assessing the periods in which two-thirds of annual maxima occurred at each station. Although the wet season typically lasts from November through April for American Samoa islands and from July through December for the other islands, histograms of AMS show that heavy precipitation events occur throughout the year. Based on these assessments, a wet season that comprises the whole year was assigned to the entire project area for all durations for the extraction process. The flowchart below (Figure 4.3.1 with Table 4.3.1) depicts the AMS extraction criteria for all durations. Various thresholds for acceptable amounts of missing or accumulated data were applied to the year and wet season based on duration.

For example, regarding accumulations for the 10-day duration, if a year had more than 66% of days with accumulated data, then the maxima for that year for 10-day duration was (conditionally) rejected. If the year had between 33% and 66% of days with accumulated data, then it was further screened by assessing the lengths of the accumulated periods. If more than 66% of the accumulated data came from accumulation periods of 7 days or more, a maximum for that year was rejected. If the year had less than 33% of accumulated data, the extracted maximum was passed to another set of criteria for accumulations during its wet season, etc.

The extracted maximum amount for a given year had to pass through all of the criteria in Figure 4.3.1 to be accepted. All rejected maxima were compared with the accepted maxima; if they were higher than 95% of the maxima at that station, then they were kept in the record. Also, if a 1-day observation was higher than any other accumulated amount in a year, then it was retained. For the 1-day duration, annual maxima can also be extracted from datasets that contain records of only 1-day monthly maxima (although there were no such records in this project). Data quality flags were assigned to accepted and rejected maxima to assist in further quality control of AMS described in Section 4.4.

Table 4.3.1. Specific parameters applied during annual maxima extraction for different durations (as shown in Figure 4.3.1).

Parameter	**Duration**															
	Minutes		**Hours**					**Days**								
	15	**30**	**1**	**2**	**3**	**6**	**12**	**1**	**2**	**4**	**7**	**10**	**20**	**30**	**45**	**60**
X_1, X_2 (%)	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
X_3 (%)	0	66	0	66	66	66	66	0	66	66	66	66	66	66	66	66
X_4 (%)	0	33	0	33	33	33	33	0	33	33	33	33	33	33	33	33
X_5 (%)	0	15	0	15	15	15	15	0	15	15	15	15	15	15	15	15
X_6, X_7 (%)	0	66	0	66	66	66	66	0	66	66	66	66	66	66	66	66
X_8 (%)	33	33	33	33	33	33	33	20	20	20	20	20	20	20	20	20
D (min/hr/days)	15	15	1	2	3	5	8	1	2	4	6	7	12	15	18	18

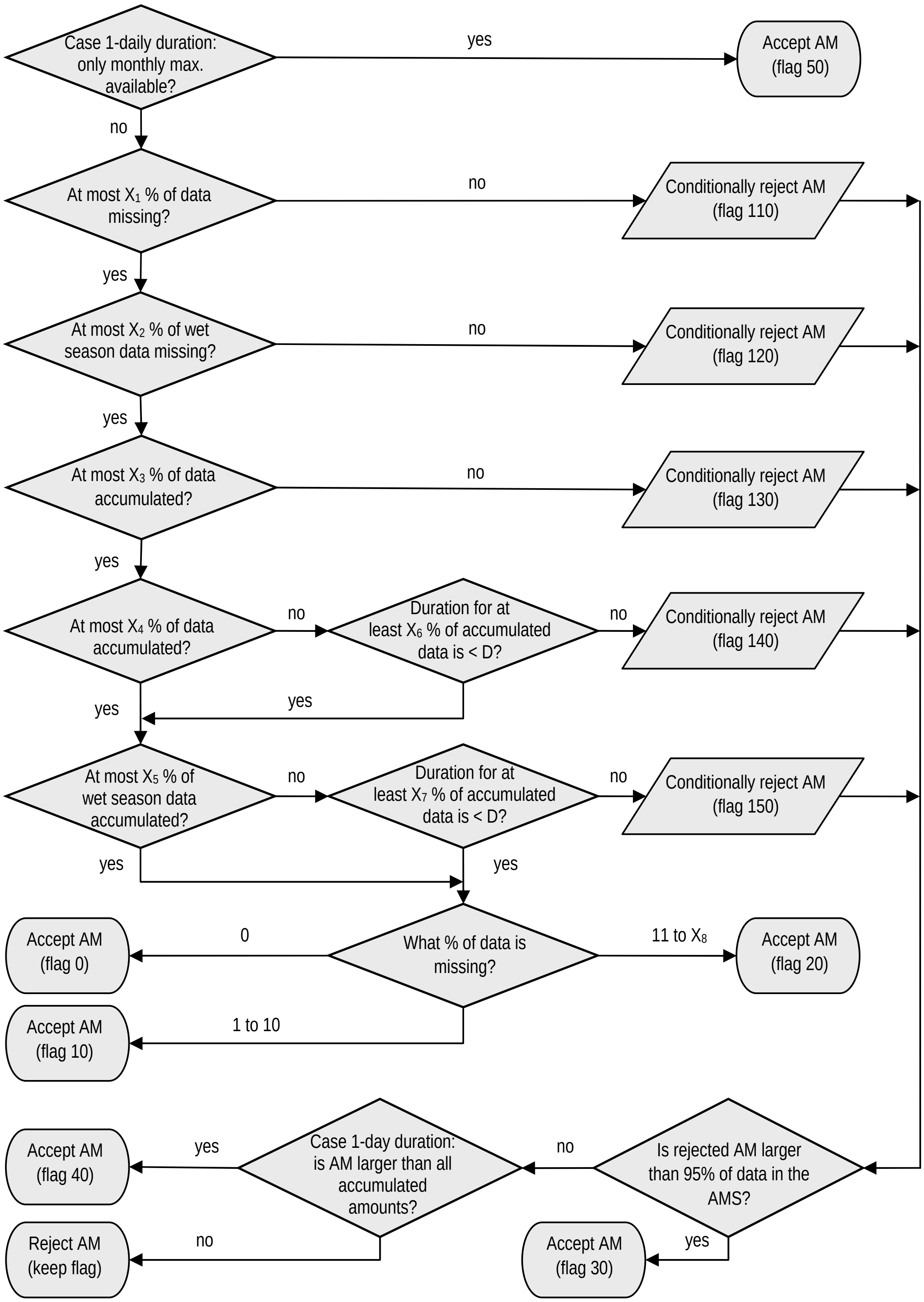


Figure 4.3.1. Flowchart depicting the criteria used to extract annual maxima. Data quality flags were assigned based on acceptance and rejection. Table 4.3.1 shows the parameter values (X_i and D) for each criterion and duration.

4.4. AMS screening and quality control

4.4.1. Record length

In NOAA Atlas 14, record length is characterized by the number of years for which annual maxima could be extracted (and is termed data years) rather than the entire period of record. Generally, only stations with at least 20 data years are used in precipitation frequency analysis. Because for this project area there were so few stations and many were extremely remote, this criterion was relaxed. Stations with at least 10 data years and no nearby stations with longer records were also considered for the precipitation frequency analysis. The average and median record lengths for 5-minute, 15-minute, 1-hour and 1-day durations, as well as corresponding ranges in record lengths are given in Table 4.4.1. The number of data years for other hourly and daily durations may vary slightly due to accumulated data and corresponding extraction rules. Figure 4.4.1 shows histograms for the number of stations within given ranges of data years for selected durations. Where available, the records extended through the end of 2008.

Table 4.4.1. Record length statistics for stations used in the analysis for different durations.

Duration	Number of stations	Record length (data years)		
		average	median	range
1-day	66	27	23	10 - 58
1-hour	18	20	21	12 - 28
15-minute	9	23	25	16 - 28
5-minute	7	17	18	11 - 19

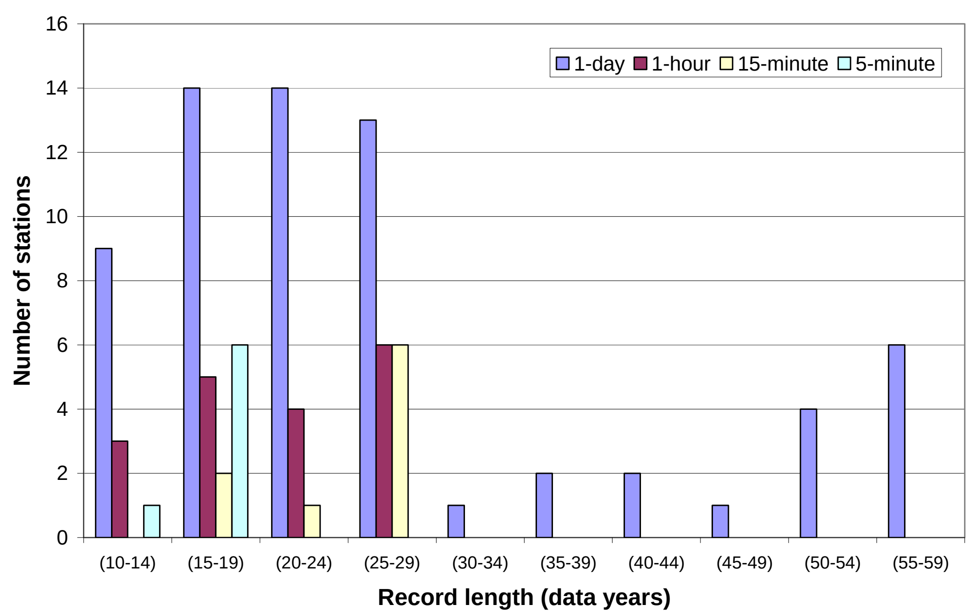


Figure 4.4.1. Number of stations used for precipitation frequency analysis grouped by record length for 1-day, 1-hour, 15-minute, and 5-minute durations.

4.4.2. Outliers

For this project, outliers are defined as annual maxima which depart significantly from the trend of the remaining maxima at a given station for a given duration. Since data at both high and low extremities can considerably affect precipitation frequency estimates, they have to be carefully investigated and either corrected or removed from the AMS if due to measurement errors. The Grubbs-Beck (G-B) statistical test for outliers (Interagency Advisory Committee on Water Data, 1982) and the median +/- two standard deviations thresholds were used to identify low and high outliers for all durations (see an example of outlier examination in Figure 4.4.2).

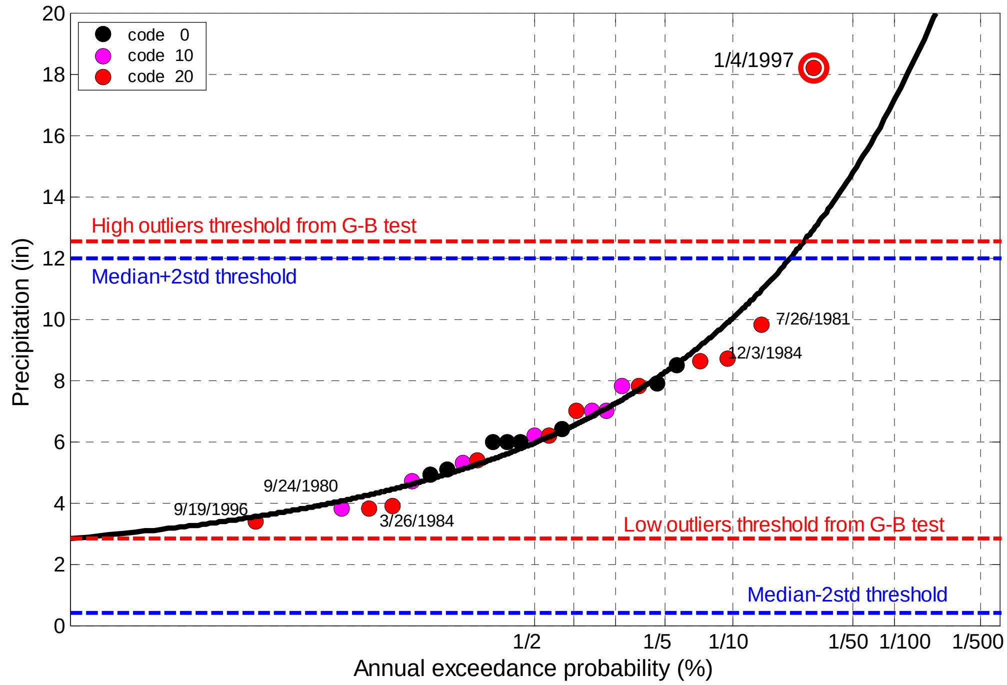


Figure 4.4.2. Outlier examination of 1-day AMS at station 91-4594 (Tutuila, AS).

Examination of low outliers indicated that almost all of them were from years with a significant percent of missing and/or accumulated data. They were presumed untrue maxima and were removed from the datasets. All values identified as high outliers were mapped with concurrent measurements taken at nearby stations. Values that were recommended for further investigation were then checked against original records, climatological bulletins, and/or local expertise at the National Weather Service Forecast Office in Guam. Depending on the outcomes of investigation, values were kept in the dataset, corrected and kept, or removed from the datasets. For example, the 1-day amount recorded on January 14, 1997 at station 91-4594, identified as a high outlier (as shown in Figure 4.4.2), was confirmed and kept in the dataset.

4.4.3. Inconsistencies in AMS across durations

Annual maxima were compared across durations for each year. If station data had a significant number of missing and/or accumulated data, cases could exist where extracted shorter duration annual maxima were greater than corresponding longer duration annual maxima. In those cases, shorter duration precipitation amounts were used to replace annual maxima extracted for longer durations.

Co-located stations. 1-hour AMS at co-located hourly and 15-minute stations were compared for overlapping periods of record. Similarly, 1-day AMS at co-located daily, hourly and 15-minute stations were compared for overlapping periods of record. Where corresponding AMS were significantly different, efforts were made to identify source of error and to correct erroneous observations across all durations that may be affected.

4.4.4. AMS correction factors for constrained observations

Daily durations. The majority of daily AMS data used in this study came from daily stations at which readings were taken once every day at fixed times (constrained observations). Due to the fixed beginning and ending of observation times at daily stations, it is likely that extracted (constrained) annual maxima were lower than the true (unconstrained) maxima. To account for the likely failure of capturing the true-interval 24-hour maxima, correction factors were applied to constrained AMS extracted from data recorded at daily stations or aggregated from hourly and 15-minute station data. Slope coefficients of zero-intercept regression models of concurrent (occurring within +/- 1 day) unconstrained and constrained annual maxima for a given duration at co-located stations were used to estimate correction factors. Correction factors for all daily durations are given in Table 4.4.2. As can be seen from the table, the effects of constrained observations were negligible for durations of 4 days or more.

Table 4.4.2. Correction factors applied to constrained daily AMS data.

Duration (days)	Correction factor
1	1.10
2	1.05
4 or more	1.00

Hourly durations. Similar adjustment was needed on hourly AMS data extracted from hourly or aggregated 15-minute stations to account for the effects of constrained 'clock hour' to unconstrained 60-minute observations. Correction factors applied to hourly AMS are given in Table 4.4.3. Correction factors for durations of 3 hours or longer were approximately 1.0.

Table 4.4.3. Correction factors applied to constrained hourly AMS data.

Duration (hours)	Correction factor
1	1.10
2	1.05
3 or more	1.00

N-minute durations. No correction factors were applied to 15-minute and 30-minute durations. 5-minute and 10-minute data were provided as unconstrained observations.

4.4.5. AMS trend analysis

Precipitation frequency analysis methods used in NOAA Atlas 14 volumes are based on the assumption of a stationary climate over the period of observation (and application). Statistical tests for trends in AMS and the main findings for this project area are described in more detail in Appendix A.3. Briefly, the stationarity assumption was tested by applying a parametric *t*-test and non-parametric Mann-Kendal test for trends in the annual maximum series data at 5% significance level.

Statistical tests were performed on stations with at least 30 years of data. Only 16 daily stations satisfied this requirement. The 1-day AMS at those stations were tested for trends. Statistical tests did not detect trends at most stations; the Mann-Kendall test identified a positive trend at one location, and the *t*-test identified a negative trend at one location. The relative magnitude of any trend in AMS for the project area as a whole (excluding American Samoa in southern hemisphere) was also assessed by linear regression techniques. AMS were rescaled by corresponding mean values and then regressed against time. The regression results were tested as a set against a null hypothesis of zero serial correlation. The null hypothesis of no trends in AMS data could not be rejected at 5% significance level. Because all tests indicated no trends in the data, the assumption of stationary climate was accepted for this project area and no adjustment of AMS was recommended.

4.5. Precipitation frequency estimates with confidence intervals at stations

4.5.1. Overview of methodology and related terminology

Precipitation magnitude-frequency relationships at individual stations have been computed using an index-flood regional frequency analysis approach based on L-moment statistics, as outlined by Hosking and Wallis (1997). Frequency analyses were carried out on annual maximum series (AMS) for the following n-minute durations: 5-minute, 10-minute, 15-minute, and 30-minute, for the following hourly durations: 1-hour, 2-hour, 3-hour, 6-hour, and 12-hour, and for the following daily durations: 1-day, 2-day, 4-day, 7-day, 10-day, 20-day, 30-day, 45-day and 60-day. AMS-based precipitation frequency estimates were converted to partial duration series (PDS) based frequency estimates using an empirical formula that allows for conversion between AMS and PDS frequencies. To allow for assessment of uncertainty in estimates, 90% confidence intervals were constructed on AMS and PDS frequency curves using a simulation-based procedure described in Hosking and Wallis (1997).

Frequency analysis involves mathematically fitting an assumed distribution function to the data. Distribution functions commonly used to fit precipitation data include 3-parameter distributions such as Generalized Extreme Value (GEV), Generalized Normal (GNO), Generalized Pareto (GPA), Generalized Logistic (GLO) and Pearson Type III (PE3), the 4-parameter Kappa (KAP) distribution, and the 5-parameter Wakeby (WAK) distribution. When fitting a distribution to a precipitation annual maximum series extracted at a given location (and selected duration), the result is a frequency distribution relating precipitation magnitude to its annual exceedance probability (AEP). The inverse of the AEP is frequently referred to as the average recurrence interval (ARI), also known as return period. When used with the AMS-based frequency analysis, ARI does not represent the "true" average period between exceedances of a given precipitation magnitude, but the average period between years in which a given precipitation magnitude is exceeded at least once. Those two average periods can be considerably different for more frequent events. The "true" average recurrence interval (ARI) between cases of a particular magnitude can be obtained through frequency analysis of PDS.

Differences in magnitudes of corresponding frequency estimates (i.e., quantiles) from the two series are negligible for ARIs greater than about 15 years, but notable at smaller ARIs (especially for ARI $\leq$ 5 years). Because the PDS can include more than one event in any particular year, the results from a PDS analysis are generally considered to be more reliable for designs based on frequent events (e.g., Laurenson, 1987). To avoid confusion, we use the term AEP with AMS frequency analysis and ARI with PDS frequency analysis. The term 'frequency' is interchangeably used to specify the ARI and AEP.

L-moments provide an alternative way of describing frequency distributions to traditional product moments (conventional moments) or maximum likelihood moments. They are well suited for analysis of precipitation data that exhibit significant skewness. Because sample estimators of L-moments are linear combinations of ranked observations, they are less subject to bias in estimation and are less susceptible to the presence of outliers in the data than conventional moments. Furthermore, it has been shown that L-moment estimators of GEV distribution parameters (which is the distribution found to be most representative in this project; see Section 4.5.3) compare favorably with parameter estimators obtained from either conventional moments or maximum likelihood moments, especially for small to moderate sized samples (Hosking and Wallis, 1997). L-moments that are typically used to describe various frequency distributions include 1st and 2nd order L-moments: L-location (λ_1) and L-scale (λ_2), and the following L-moment ratios: L-CV (τ), L-skewness (τ_3), and L-kurtosis (τ_4). L-CV, which stands for "coefficient of L-variation", is calculated as the ratio of L-scale to L-location (λ_2/λ_1). L-skewness and L-kurtosis are calculated as ratios of the 3rd order (λ_3) and 4th order (λ_4) L-moments to the 2nd order (λ_2) L-moment, respectively, and are therefore independent of scale.

One of the primary problems in frequency analysis is the need to provide frequency estimates for average recurrence intervals that are significantly longer than available records. The regional approach, which uses data from all stations that form a homogeneous region to obtain quantiles at a single station, has been shown to yield more accurate estimates of extreme quantiles than other approaches that use data from only a single station. The regional approach of choice for this project is the <u>index-flood regional frequency analysis approach</u>. The term 'index-flood' comes from its first applications in flood frequency analysis (Dalrymple, 1960), but the method is applicable to precipitation or any other type of data. The underlying assumption of the index-flood approach is that all stations in a homogeneous region have a common magnitude-frequency curve (<u>regional growth curve</u>) that becomes station-specific after applying a station-specific scaling factor (<u>index-flood</u>).

This underlying assumption is validated by testing discordancy and heterogeneity for each region (see below). The scaling factor is typically the mean of the data at a given location. Accordingly, the mean of the annual maximum series extracted from the precipitation record for a given station and selected duration was the scaling factor in this project. Station-specific estimates of L-location and regional estimates of L-CV, L-skewness and L-kurtosis are used to calculate distribution parameters and quantiles. Regional values of L-moment ratios are obtained from station-specific L-moment ratios weighted by record lengths. They are used to calculate quantiles of a regional dimensionless distribution, called <u>regional growth factors (RGFs)</u>, for selected AEPs. Because the distribution parameters are constant for each region, there is a single set of RGFs for each region for a specified duration. The RGFs are then multiplied by the corresponding station-specific scaling factors to produce the quantiles at each frequency and duration for each station.

4.5.2. Delineation of homogeneous regions

Initial delineation of regions. The K-mean nonhierarchical clustering method was used to initially group stations into homogenous regions. A single set of regions applicable to all durations was constructed. Regional groups obtained through cluster analysis were improved based on an analysis of selected statistical measures and the consideration of climatology of heavy events.

Nonhierarchical clustering algorithms start with predefined clusters that can be formed randomly. Cluster membership is reassigned based on the similarity between stations that is measured by the Euclidian distance in terms of the selected attribute variables (Everitt et al., 2001). Attribute variables selected for this project area were: latitude, longitude, mean annual precipitation and mean annual maximum precipitation at 1-hour and 1-day durations. Because cluster analysis is sensitive to differences in attribute variables' ranges, all variables were standardized to make their ranges comparable. After several iterations, eight clusters (regions) were determined to be the optimal number of clusters for this project area.

Refinement of regions. Homogeneity of eight regions delineated by the clustering procedure was further investigated using discordancy and heterogeneity measures (Hosking and Wallis, 1997), and by inspection of the evolution of station-specific L-location, L-CV and L-skewness moments with duration (see Section 4.6).

Discordancy measure (D) is used to determine if a station has been inappropriately assigned to a region. The measure is calculated for each station in a region and for each duration as the distance of a point in a 3-dimensional space represented by at-station estimates of three duration-specific L-moment ratios (L-CV, L-skewness and L-kurtosis) from the cluster center. The cluster center is defined using the un-weighted average of the three L-moment ratios from all stations within the region. The discordancy measure is most helpful for regions with at least 7 stations and cannot be used for regions with less than 5 stations. For that reason, it had a limited value for this project where several regions had only 1 to 4 stations.

Heterogeneity measures can be used to judge the relative homogeneity/heterogeneity of a proposed region as a whole based on L-moment ratios. Heterogeneity measures compare the variability of sample estimates of L-moment ratios in a region relative to their expected variability. Expected variability of L-moments is obtained through simulations using the Kappa distribution as the underlying population distribution. The Kappa distribution includes several 3-parameter distributions as special cases, so its results are less affected by the choice of distribution. The heterogeneity measure, H1 that examines the variability of sample estimators of L-CV was used in this project to judge the relative heterogeneity in the proposed regions. H1 is generally accepted to be the most reliable among potential heterogeneity measures in discriminating between homogeneous and heterogeneous regions. A region is generally considered homogenous if H1 is less than 2.0.

Regional homogeneity was further tested by inspection of changes in station-specific L-moment statistics across durations with corresponding changes in regional estimates. Stations with changes in statistics that were significantly different from the rest of the stations in the region were considered for reassignment to different regions. This investigation resulted in some interesting findings on evolution of L-moment statistics with duration, which was heavily used later in the adjustment of inconsistencies across durations for at-station frequency curves and in the construction of precipitation frequency grids (see Sections 4.5.3 and 4.6 for more details).

Based on combined results of all statistical tests and consideration of the climatology of heavy precipitation events, several stations were reassigned to different regions and two regions were divided in sub-regions, ending in a total of 10 homogeneous regions. Figure 4.5.1 shows final regional groupings that were applied to all durations. Appendices A.7 and A.8 list the regionally-averaged L-CV, L-skewness, and L-kurtosis statistics and H1 values, respectively, for all regions and durations.

Station independence check. One of the assumptions in the index-flood method is that annual maxima extracted at different stations inside a homogeneous region are independent. Precipitation events, especially at longer durations, typically affect an area large enough to contain more than one station. Daily AMS data were investigated in each region for cross correlation between stations to assess inter-station dependence. Stations within a region were analyzed using a *t*-test at the 90% confidence level for correlation coefficients. Cross correlation between stations in the project area was not found to be statistically significant for most cases analyzed, so it was assumed that the impact of potential station dependence on the precipitation quantiles is minimal.

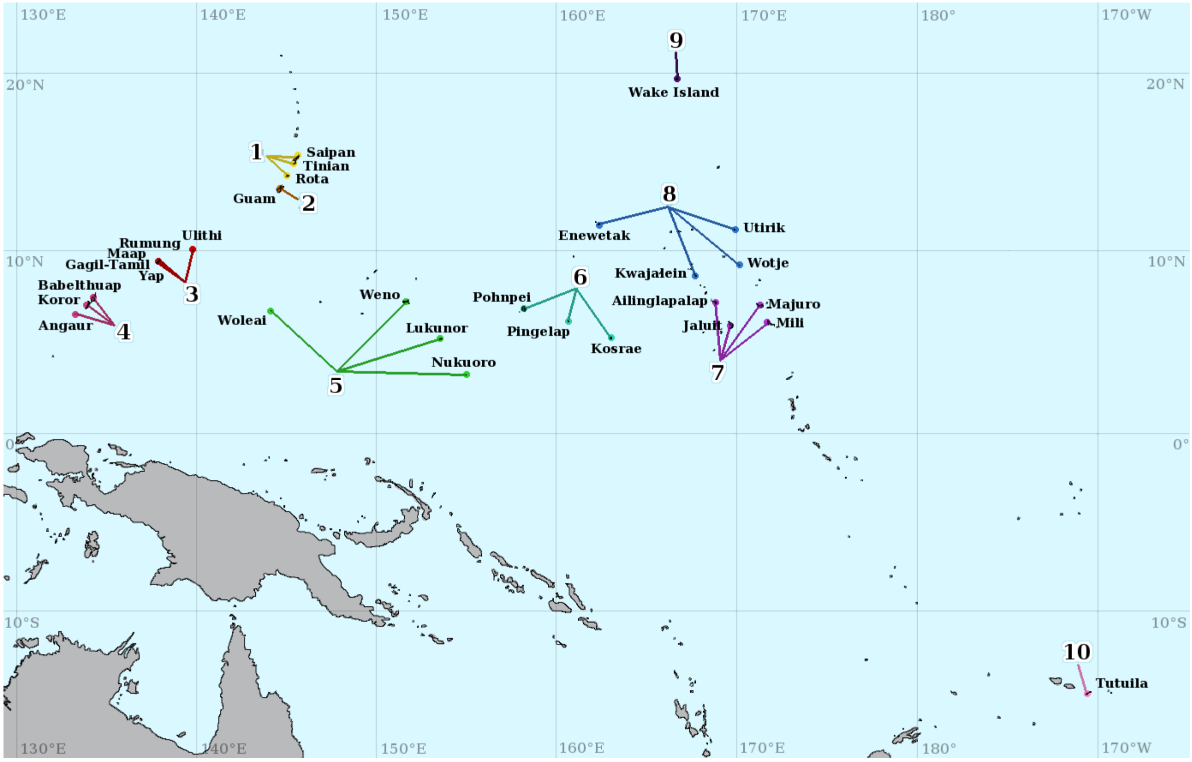


Figure 4.5.1. Station groupings for regional frequency analysis applied to all durations.

4.5.3. AMS-based frequency estimates

Choice of distribution. Although it is not required to use the same type of distribution across all regions and durations, changes in distribution type for different durations (and/or regions) may lead to inconsistencies among frequency estimates across durations (and/or nearby stations). Therefore, it was decided to identify and use a single distribution that will provide an acceptable fit to the AMS data across all regions and durations. The relatively small number of stations in the project area allowed us to visually inspect and compare several distributions (GEV, GNO, GLO, GPA, PE3, KAP, WAK) on probability plots for every station (see an example of a probability plot for station 91-4594 on Tutuila in Figure 4.5.2). A goodness-of-fit test based on L-moment statistics for 3-parameter distributions, as suggested by Hosking and Wallis (1997), was also used to assess which of the 3-parameter distributions provide acceptable fit to the AMS data. The GEV distribution tested as an acceptable distribution for the vast majority of cases. Also, on probability plots, the GEV curve was typically very close to 4-parameter Kappa and 5-parameter Wakeby distribution curves, meaning that precipitation frequency estimates from all three distributions were comparable even for very rare events. Since the GEV distribution is a distribution frequently used to describe precipitation data, the decision was made to adopt the GEV distribution for all regions and for all durations.

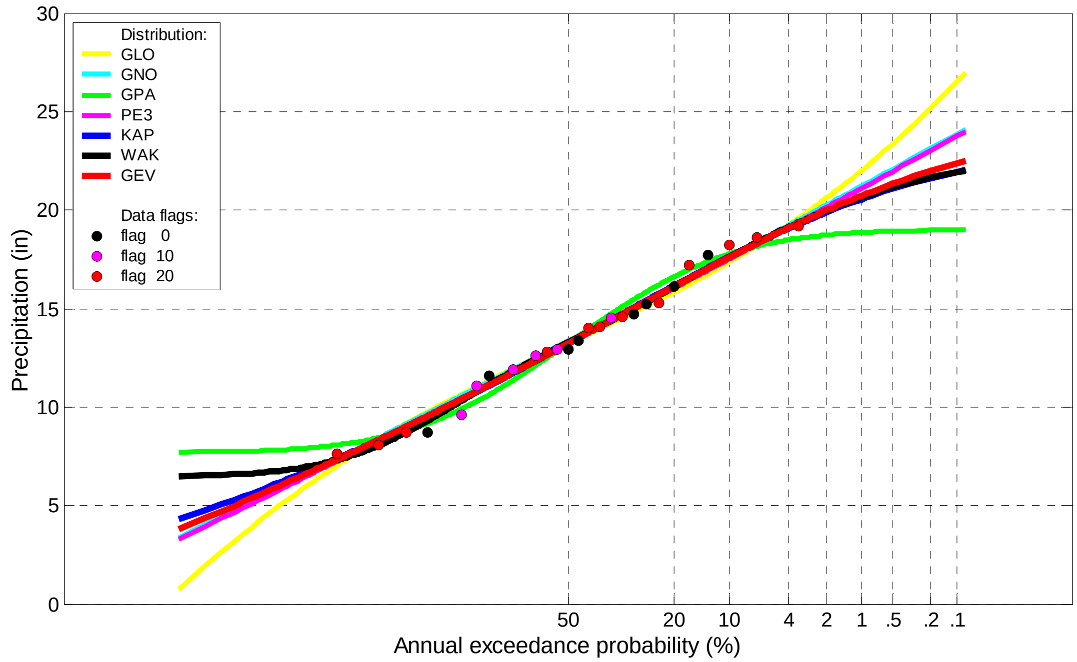


Figure 4.5.2. Probability plots for selected distributions for 7-day AMS at station 91-4594 (Tutuila, AS). Data quality flags were assigned to all annual maxima during the extraction process to assist in data quality control described in Section 4.3.2.

Frequency estimates for daily and hourly durations. For a given duration, regional estimates of L-CV, L-skewness and L-kurtosis for each of the 10 regions were obtained from corresponding station-specific estimates weighted by record lengths. Regional L-moment statistics were used to calculate parameters of a regional dimensionless GEV distribution following formulas given in Hosking and Wallis (1997) and regional growth factors for selected AEPs (1/2, 1/5, 1/10, 1/25, 1/50, 1/100, 1/200, 1/500 and 1/1000). The RGFs were then multiplied by station-specific mean annual maximum values to produce quantiles for each selected frequency and duration for all stations in the region. This calculation was repeated for all regions and for all durations. Appendix A.9 lists the RGFs for all regions and durations.

Consistency in frequency estimates across durations. All precipitation quantiles were inspected for inconsistencies across durations. Since quantiles at a given station were calculated independently for each duration, there were cases when for a given AEP, the quantile estimate for a shorter duration was higher than the quantile estimate at the next longer duration (see dotted precipitation-frequency curves shown in an example in Figure 4.5.3). The majority of anomalous cases were caused by random variation in L-moments across durations caused by data sampling variability. This showed particularly in transition from 12-hours to 24-hours at co-located stations because record lengths at hourly durations were typically shorter than record lengths at daily durations. When selected regional L-moments and L-moment ratios (particularly L-skewness) were smoothed across durations (see more details on this in Section 4.6), irrational estimates were removed. Figure 4.5.3 illustrates precipitation depth-duration-frequency curves before and after smoothing.

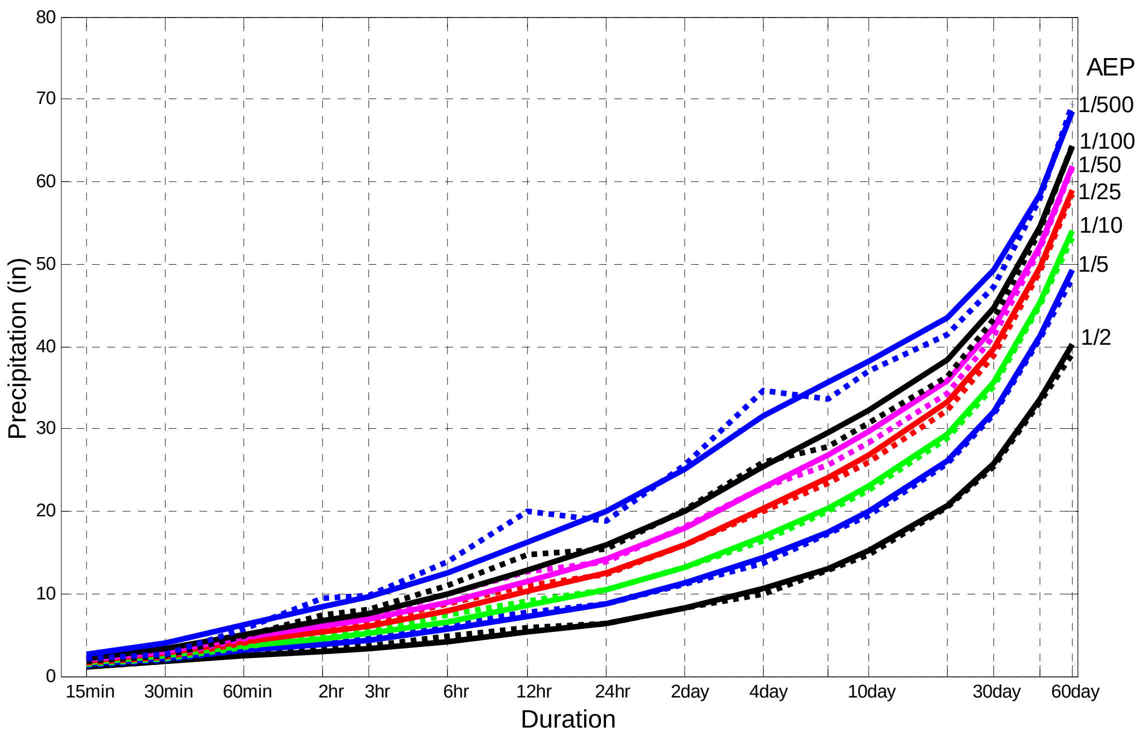


Figure 4.5.3. Precipitation frequency estimates for a range of durations for selected AEPs for station 91-4594 (Tutuila, AS). Dotted lines represent original estimates; full lines represent estimates obtained after L-moments were smoothed across durations.

Frequency estimates for n-minute durations. Because n-minute stations were not found in all regions, n-minute precipitation frequencies were first estimated through extrapolation of curves showing relationships between selected regional L-moment statistics and duration (see Figures 4.6.3 and 4.6.4 in Section 4.6.1). Precipitation frequency estimates at 5- and 10-minute durations showed sensitivity to small changes in curves' slopes, so instead, n-minute scaling factors from unconstrained 1-hour data, as used in previous NOAA Atlas 14 volumes, were developed to estimate precipitation frequencies at 5- to 30-minute durations. Seven n-minute stations that had at least 10 years of data were analyzed as one region. The same regional frequency algorithm as for daily and hourly durations was used for n-minute durations. The GEV distribution was, similarly, the distribution of choice. The n-minute scaling factors were calculated as the averages of ratios of n-minute quantiles and corresponding unconstrained 1-hour quantiles for AEPs between 1/2 and 1/100. These scaling factors were applied to all unconstrained 1-hour quantiles to estimate quantiles at n-minute durations. Table 4.5.1 shows the n-minute scaling factors used in this project.

Table 4.5.1. Scaling factors applied to unconstrained 1-hour quantiles to estimate quantiles for n-minute durations.

Duration (minutes)	5	10	15	30
Scaling factor	0.29	0.38	0.48	0.69

4.5.4. PDS-based frequency estimates

As mentioned in Section 4.3, partial duration series were not extracted from the precipitation datasets in this project. Instead, PDS-based quantiles were estimated indirectly using the Langbein's empirical formula (Langbein, 1949) that transforms PDS-based average recurrence intervals (ARIs) to annual exceedance probabilities (AEPs):

$$\mathrm{AEP} = 1 - \exp\left(-\frac{1}{\mathrm{ARI}}\right).$$

PDS-based frequency estimates were calculated for the same durations as AMS-based estimates. For a given daily or hourly duration, PDS-based quantiles were calculated for 1-, 2-, 5-, 10-, 25-, 50-, 100-, 200-, 500- and 1,000-year ARIs. Selected ARIs were first converted to AEPs using the above formula and then used to calculate regional growth factors following the same regional approach and using the same L-moments that were used in the AMS analysis (analysis was done simultaneously for both time series). The RGFs were finally rescaled by the station-specific mean annual maxima to produce the PDS-based quantiles for each station. Calculations were repeated for all selected durations between 1-hour and 60-day. N-minute estimates were obtained using the scaling factors calculated for AMS-based quantiles.

4.5.5. 90% confidence intervals on AMS and PDS frequency curves

A frequency curve that is calculated from sample data represents some average estimate of the population frequency curve, but there is a high probability that the true value actually lies above or below the sample estimate. Confidence limits determine values between which one would expect the true value to lie with certain confidence. They provide an estimate of the magnitude of uncertainty or potential error associated the precipitation frequency estimates. The interval between the confidence limits is the confidence interval. The width of a confidence interval is affected by a number of factors, such as the degree of confidence, sample size, exceedance probability, distribution selection, and so on. Simulation-based procedures are typically used to estimate confidence intervals on frequency curves.

In this project, a Monte Carlo simulation procedure, as described in Hosking and Wallis (1997), was used to construct 90% confidence intervals (i.e., 5% and 95% confidence limits) on both AMS-based and PDS-based precipitation frequency curves. For each region and for each hourly and daily duration, 1,000 simulated datasets were generated using the same number of stations and associated record lengths as in actual regions. They were used to generate 1,000 frequency estimates at each station using the same distribution that was fitted to original data. Generated frequency estimates were sorted from smallest to largest and the 50th value was selected as the lower confidence limit and the 950th value was selected as the upper confidence limit.

Confidence limits were independently derived for each duration through simulation and so varied from duration to duration. However, when confidence limits were standardized (i.e., divided by corresponding MAMs), very little variation was found across daily durations and across hourly durations. Standardized confidence limits did, however, vary between hourly and daily durations primarily due to differences in number of stations and cumulative number of data years per region. Therefore, two sets of lower and upper standardized confidence limits were created for each station: one applicable for daily durations and one for hourly durations. Standardized confidence limits were multiplied by corresponding MAMs to derive upper and lower bounds of 90% confidence interval. Confidence limits for n-minute durations were calculated from unconstrained 1-hour confidence limits using the same n-minute scaling factors that were used to estimate n-minute frequency estimates.

4.6. Spatially interpolated precipitation frequency estimates with confidence intervals

4.6.1. Derivation of precipitation frequency estimates grids

As discussed in Section 4.5.1, for a given duration, at-station mean annual maximum (MAM) values serve as scaling factors to generate station-specific AMS- and PDS-based precipitation frequency estimates from duration-specific regional growth factors. Similarly, duration-specific grids of AMS- and PDS-based precipitation frequency estimates can be created by re-scaling duration-specific regional growth factors by corresponding gridded MAM estimates.

There is a significant difference in the way at-station MAMs were spatially interpolated to produce MAM grids for selected durations in this NOAA Atlas 14 volume relative to previous volumes. In previous volumes, a hybrid statistical-geographic approach for mapping climate data, Parameter-elevation Regressions on Independent Slopes Model (PRISM) developed by Oregon State University's PRISM Climate Group (Daly and Neilson, 1992; Daly et al., 2002) was used to create MAM grids for all hourly and daily durations. The resulting high-resolution (typically 15- or 30-arc-seconds) MAM grids then served as the basis for deriving gridded precipitation frequency estimates for different AEPs using the Cascade, Residual Add-Back (CRAB) spatial interpolation procedure (described in Section 4.6.2 of documentation accompanying previous volumes). Since no funding was available for this project to support the PRISM work and the project area was unique in many ways relative to previous volumes, particularly with respect to the lack of adjacent precipitation frequency region boundaries, alternative interpolation techniques were applied.

Interpolation was first completed on 1-day MAMs. In regions where PRISM mean annual precipitation (MAP) grids were available and where reliable relationships were found between at-station 1-day MAMs and MAPs), regression equations were used to create MAM grids from MAP grids. For regions where no relationships between MAM and MAP existed (for those regions no relationships were found between MAM and elevation either), at-station MAM estimates were directly interpolated. On several small, low-elevation islands and atolls, no interpolation was needed. The 1-day MAM grids were used to derive MAM grids for other durations using relationships in MAM ratios across durations. The MAM grids were then used to derive grids of precipitation frequency estimates by rescaling with corresponding regional growth factors. The series of steps used to derive precipitation frequency grids with accompanying confidence limits across all durations are described in more detail below.

Step 1: Development of mean annual maximum grids at 1-day duration.

Prior to using at-station 1-day MAM estimates for the development of 1-day MAM grids, at-station MAMs were investigated for spatial inconsistencies. Several locations were identified where differences in MAMs at close stations could be attributed to differences in record lengths and/or different periods of record. Linear regression was used on annual maxima from overlapping periods (when such data existed) to adjust MAMs at stations with shorter periods of record.

For all precipitation frequency regions (shown in Figure 4.5.1), relationships were explored between at-station mean annual maxima for a range of durations and MAP, because if such relationships exist, high resolution grids of MAP created in November 2006 by the PRISM Climate Group (available for download from http://www.prism.oregonstate.edu/products/pacisl.phtml) could be used to derive MAM grids. This approach is consistent with methods used in prior volumes of NOAA Atlas 14 (Bonnin et al., 2004a; Bonnin et al., 2004b; Bonnin et al., 2006; Perica et al., 2009). For this project area, if a relationship between MAM and MAP existed in a region for one duration, it existed for all durations (however, relationships were not linear for all durations). Strong linear relationships (with correlation coefficients greater than 0.9) between 1-day MAM and MAP were found only in regions 6 and 10 (see an example for region 10 in Figure 4.6.1). For those two regions, locally developed linear regression equations between MAP and 1-day MAM were used to derive high resolution (9-arc-seconds) 1-day MAM grids. Figure 4.6.2 shows an example of a resulting 1-day MAM grid for region 10 (Tutuila, AS).

For regions 1, 2, 3 and 4, no relationships between MAM (at any duration) and MAP or between MAM and elevation were established. For those four regions, direct interpolation on at-station 1-day MAM estimates was applied. Interpolation presented a significant challenge for this project due to a limited number of stations per island and because of island boundaries. Various interpolation techniques (nearest-neighbor, inverse-distance weighting, spline, etc.) were considered to interpolate at-station MAMs. MAM isohyets resulting from the various interpolation methods were compared and checked for reasonableness. In the end, MATLAB's v4 griddata function, based on biharmonic spline interpolation (Sandwell, 1987), was selected to derive MAM grids in regions 1 to 4.

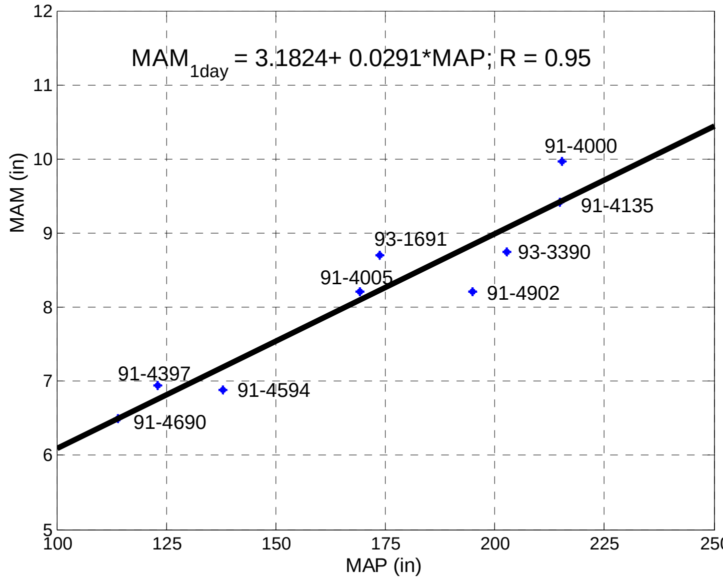


Figure 4.6.1 Relationship between 1-day MAM and MAP for region 10 (Tutuila, AS).

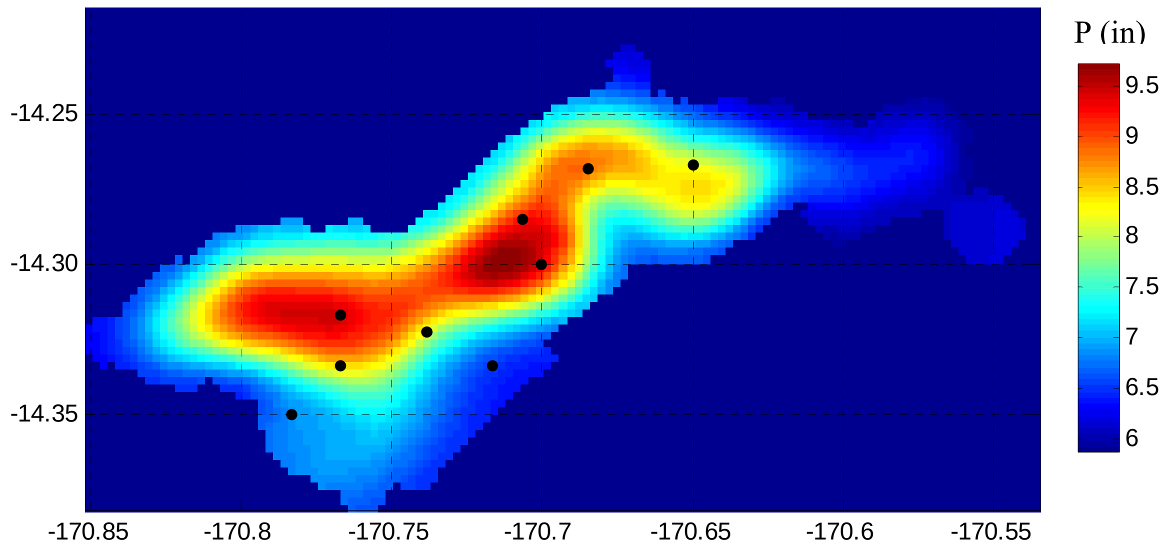


Figure 4.6.2. 1-day MAM grid for region 10 (Tutuila, AS).

No MAP grids were available for region 5. Because islands in this region are small and scattered with only a single station at an elevation less than 10 feet on each, no relationship between MAM and elevation could be investigated either. Therefore, MAMs were not interpolated in region 5. Because of the lack of precipitation data in higher elevations, any potential orographic influences on these islands are unclear. This may be a factor only for Weno Island where elevation reaches 1,214 feet (370 meters) and the MAM value estimated at a single station at 5-feet elevation may or may not be appropriate for the whole island.

For islands/atolls in regions 7, 8 and 9, as well as for several small islands/atolls in other regions, no interpolation was needed because of their size and the fact that highest elevations on those islands/atolls are well below 100 feet.

Table 4.6.1 lists various methods that were implemented in the project area to create 1-day MAM grids.

Table 4.6.1. List of methods used to create 1-day MAM grids.

Abbr.	**Territory or state**		**Island/atoll**	**Region**	**Method**
CNMI	Commonwealth of the Northern Mariana Islands		Rota	1	direct interpolation
			Saipan	1	direct interpolation
			Tinian	1	direct interpolation
GU	Territory of Guam		Guam	2	direct interpolation
PW	Republic of Palau		Angaur	4	no interpolation needed
			Babelthuap	4	direct interpolation
			Koror	4	direct interpolation
FSM	Federated States of Micronesia	State of Chuuk	Lukunor	5	no interpolation needed
			Weno	5	none
		State of Kosrae	Kosrae	6	regression with MAP
		State of Pohnpei	Nukuoro	5	no interpolation needed
			Pingelap	6	no interpolation needed
			Pohnpei	6	regression with MAP
		State of Yap	Gagil-Tamil	3	direct interpolation
			Maap	3	direct interpolation
			Rumung	3	direct interpolation
			Ulithi	3	no interpolation needed
			Woleai	5	no interpolation needed
			Yap	3	direct interpolation
RMI	Republic of Marshall Islands		Ailinglapalap	7	no interpolation needed
			Enewetak	8	no interpolation needed
			Jaluit	7	no interpolation needed
			Kwajalein	8	no interpolation needed
			Majuro	7	no interpolation needed
			Mili	7	no interpolation needed
			Utirik	8	no interpolation needed
			Wotje	8	no interpolation needed
WAKE			Wake Island	9	no interpolation needed
AS	Territory of American Samoa		Tutuila	10	regression with MAP

Step 2: Development of precipitation frequency grids for 1-day duration.
Gridded MAM estimates and regional estimates of L-CV and L-skewness (obtained through analysis of station data; as described in Section 4.5) were used to calculate GEV-distribution quantiles for selected AEPs and ARIs for each grid cell. PDS- and AMS-based precipitation frequency grids were created simultaneously (ARIs selected for PDS-based analysis were first converted to AEPs using Langbein's formula and then added to a set of AEPs selected for AMS-based frequency analysis).

Step 3: Development of MAM grids for other hourly and daily durations.
In contrast to previous volumes where MAM grids were created independently for each hourly and daily duration using PRISM techniques, in this volume MAM grids at hourly and daily durations were derived from 1-day MAM grids by taking advantage of simple relationships that were established for each region between at-station MAM ratios and durations, where MAM ratio is a ratio of at-station MAM for any given duration and corresponding 1-day MAM. As shown in the upper panel of Figure 4.6.3, changes in MAM with duration are different from station to station within a given region (in this example, region 10 stations are shown). However, when at-station MAM ratios are plotted against durations, inter-station variability significantly decreases (lower panel in Figure 4.6.3). An average of all at-station MAM ratios (regional MAM ratio; shown as thick solid line in bottom panel) was applied as a scaling factor on 1-day MAM grids to develop MAM grids at other hourly and daily durations for a region. The 2[nd] order polynomial function was used to smooth average regional MAM ratios across durations, but adjustment was typically minor.

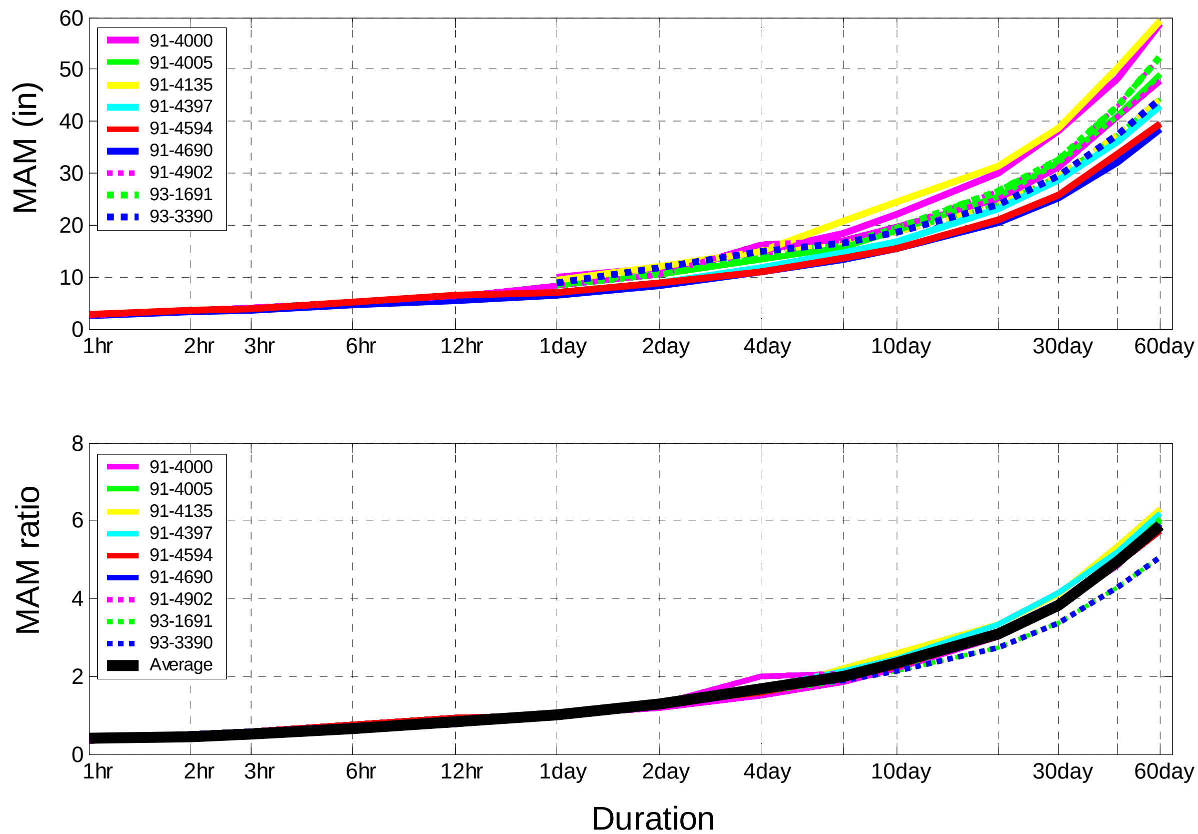


Figure 4.6.3. At-station MAMs versus duration (upper panel) and at-station MAM ratios versus duration (lower panel) for stations in region 10 (Tutuila, AS).

Step 4: Development of precipitation frequency grids for other hourly and daily durations.
A comparison of precipitation quantiles (discussed in Section 4.5.3) indicated that the majority of inconsistencies that occurred occasionally in depth-duration-frequency (DDF) curves were caused by random variation of L-moments across durations. Smoothing of regional L-moment ratios across durations (see an example for region 10 in Figure 4.6.4) improved at-station DDF curves (see results for station 91-4594 from region 10 in Figure 4.5.3). For a given duration, gridded MAM estimates and regional estimates of L-CV and L-skewness, obtained through regional analysis of station data and smoothed across durations, were used to calculate GEV-distribution quantiles for selected AEPs and ARIs for each grid cell. PDS- and AMS-based precipitation frequency grids were created simultaneously.

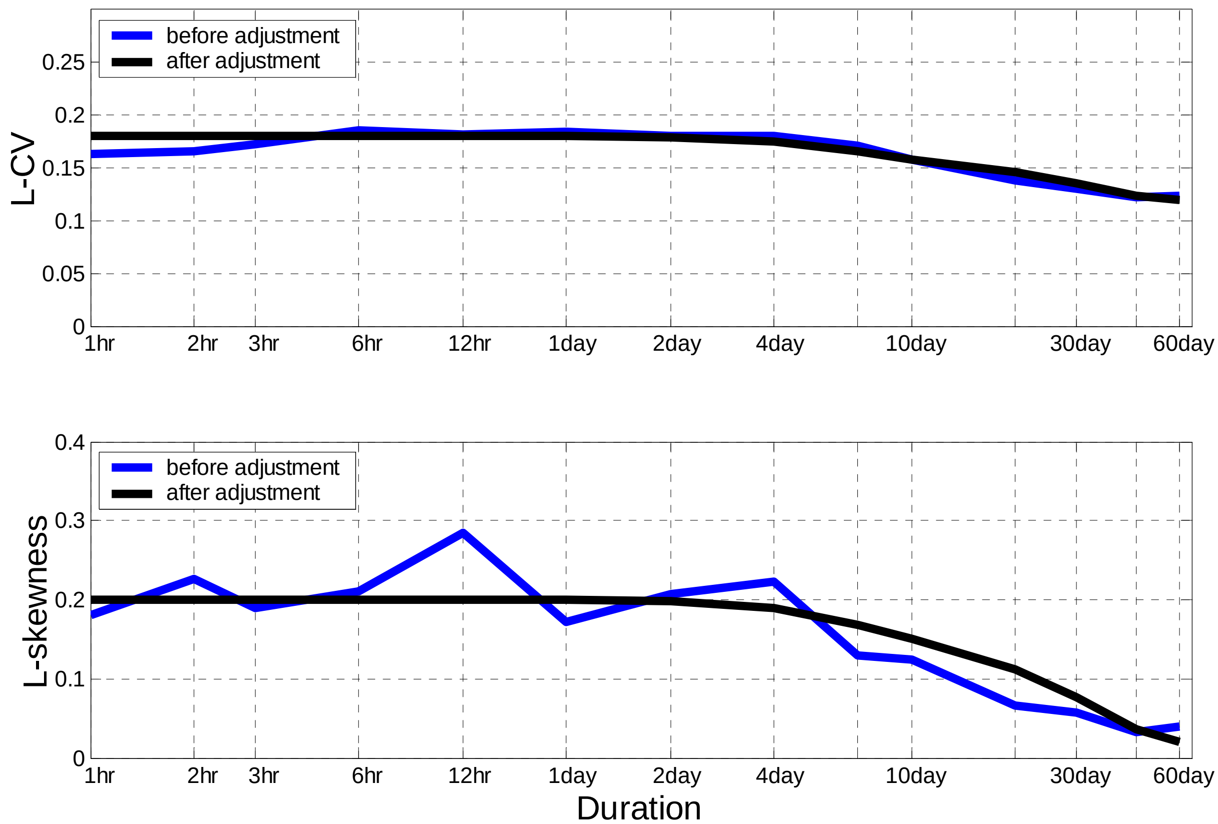


Figure 4.6.4. Regional L-moment ratios before and after adjustments across durations for region 10. Upper panel shows L-CV and lower panel shows L-skewness.

Step 5: Derivation of confidence limits grids for hourly and daily durations.
At-station upper and lower confidence limits (Section 4.5.5) for daily (hourly) durations were standardized by dividing them by corresponding MAMs and then interpolated using biharmonic spline interpolation method. For a given daily (hourly) duration, standardized upper and lower confidence limits grids were then rescaled by related MAM grids to obtain grids of upper and lower confidence limits at all daily (hourly) durations.

Step 6: Development of n-minute precipitation frequency and confidence limits grids.
Grids of n-minute precipitation frequency estimates for all AEPs and ARIs were calculated by applying n-minute scaling factors from Table 4.5.1 (in Section 4.5.3) to corresponding grids of unconstrained 1-hour precipitation frequency estimates. Similarly, grids of n-minute upper (lower) confidence limits for all AEPs and ARIs were calculated by applying n-minute scaling factors from Table 4.5.1 to corresponding unconstrained 1-hour upper (lower) confidence limits grids.

4.6.2. Creation of cartographic maps

Isohyetal files for precipitation frequency estimates were created from the grids of PDS-based estimates for selected durations and ARIs and used to create color cartographic maps. The choice of contour intervals was determined to accommodate the range of values taking place on all islands for a given duration and ARI. The number of individual contour intervals was typically between 10 and 20.

The maps were created using Environmental Systems Research Institute, ArcGIS 9.1 software, in particular ArcMap (ESRI, 2003). The cartographic maps are provided in an Adobe Portable Document (PDF) format for easy viewing and printing. When printed in their native size, 11” x 17” (ANSI B), the scale of the maps is 1:22,000,000 for the general area and 1:50,000 for individual islands; however the maps can be printed at any size. The color cartographic maps were created to serve as visual aids and are not recommended for interpolating precipitation frequency estimates. Users are urged to take advantage of the Precipitation Frequency Data Server graphical user interface for accessing estimates (see Section 5).

5. Precipitation Frequency Data Server (PFDS)

5.1. Introduction

NWS precipitation frequency estimates have traditionally been delivered in the form of Weather Bureau Technical Papers and Memoranda as well as NOAA Atlases. These were hard copy (i.e., paper) documents.

NOAA Atlas 14 precipitation frequency estimates are now delivered entirely in digital form in order to make the estimates more widely available and to provide them in various formats. The Precipitation Frequency Data Server (http://hdsc.nws.noaa.gov/hdsc/pfds/) is a point-and-click interface developed as the primary web portal for precipitation frequency estimates and associated information (Durrans and Brown, 2002; Parzybok and Yekta, 2003).

5.2. Underlying data

The PFDS operates from a set of ASCII grids of precipitation frequency estimates and lower and upper bounds of the 90% confidence interval. The same grids can be downloaded from the website and imported into a Geographical Information System (GIS). Table 5.2.1 shows the complete set of average recurrence intervals (1-year to 1,000-year) and durations (5-minute to 60-day) for which PDS-based frequency estimates are available from the PFDS for any particular location in the project area. Similarly, Table 5.2.2 shows the complete set of annual exceedance probabilities (1/2 to 1/1000) and durations (5-minute to 60-day) for which AMS-based frequency estimates with confidence limits are available from the PFDS for any particular location.

Table 5.2.1. Average recurrence intervals and durations for which PDS-based precipitation frequency estimates with 95% confidence limits are available from the PFDS.

Duration	**Average recurrence interval (ARI)**									
	1-yr	**2-yr**	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**	**200-yr**	**500-yr**	**1,000-yr**
5-minute	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
10-minute	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
15-minute	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
30-minute	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
60-minute	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2-hour	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3-hour	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6-hour	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
12-hour	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
24-hour	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2-day	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4-day	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
7-day	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
10-day	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
20-day	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
30-day	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
45-day	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
60-day	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 5.2.2. Annual exceedance probabilities and durations for which AMS-based precipitation frequency estimates with 95% confidence limits are available from the PFDS.

Duration	**Annual exceedance probability (AEP)**								
	1/2	**1/5**	**1/10**	**1/25**	**1/50**	**1/100**	**1/200**	**1/500**	**1/1000**
5-minute	✓	✓	✓	✓	✓	✓	✓	✓	✓
10-minute	✓	✓	✓	✓	✓	✓	✓	✓	✓
15-minute	✓	✓	✓	✓	✓	✓	✓	✓	✓
30-minute	✓	✓	✓	✓	✓	✓	✓	✓	✓
60-minute	✓	✓	✓	✓	✓	✓	✓	✓	✓
2-hour	✓	✓	✓	✓	✓	✓	✓	✓	✓
3-hour	✓	✓	✓	✓	✓	✓	✓	✓	✓
6-hour	✓	✓	✓	✓	✓	✓	✓	✓	✓
12-hour	✓	✓	✓	✓	✓	✓	✓	✓	✓
24-hour	✓	✓	✓	✓	✓	✓	✓	✓	✓
2-day	✓	✓	✓	✓	✓	✓	✓	✓	✓
4-day	✓	✓	✓	✓	✓	✓	✓	✓	✓
7-day	✓	✓	✓	✓	✓	✓	✓	✓	✓
10-day	✓	✓	✓	✓	✓	✓	✓	✓	✓
20-day	✓	✓	✓	✓	✓	✓	✓	✓	✓
30-day	✓	✓	✓	✓	✓	✓	✓	✓	✓
45-day	✓	✓	✓	✓	✓	✓	✓	✓	✓
60-day	✓	✓	✓	✓	✓	✓	✓	✓	✓

To accommodate the vast size of the project area, it was broken up in 14 geographic regions, as shown in Table 5.2.3. All applicable files for a region start with a two-letter abbreviation assigned to each region, as shown in column 2 (for example, all files for Rota, Saipan and Tinian in CNMI start with "nm"). For more information on file download, see http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_gis.html.

Table 5.2.3. Regional groupings for file download.

Group	**Abbr.**	**State/territory**	**Islands/atolls in the group**
1	nm	CNMI	Rota, Saipan and Tinian
2	gu	GU	Guam
3	yp	FSM/Yap	Yap islands (Gagil-Tamil, Maap, Rumung, Yap)
4	pl	PW	Angaur, Babelthuap, Koror
5	ul	FSM/Yap	Ulithi
6	ch	FSM/Chuuk	Lukunor, Weno
7	wl	FSM/Yap	Woleai
8	nk	FSM/Pohnpei	Nukuoro
9	pp	FSM/Pohnpei	Pohnpei
10	pg	FSM/Pohnpei	Pingelap
11	ko	FSM/Kosrae	Kosrae
12	rm	RMI	Ailinglapalap, Enewetak, Jaluit, Kwajalein, Majuro, Mili, Utirik, Wotje
13	wi	WAKE	Wake Island
14	as	AS	Tutuila

Grid resolution depends primarily on the group's areal coverage. The ASCII grids, which represent the official estimates, have the following pertinent metadata:

- Resolution: 9-seconds for all groups in Table 5.2.3 except for groups 6 and 12, which were mapped at 0.1 degree resolution;
- Units: inches*1000 (integer);
- Projection: geographic (longitude/latitude);
- Datum: WGS 84;
- No data value: -9999.

The PFDS operates with conventional web-tools, including cgi-bin (Perl) scripts, JAVAScript and a C program. The main cgi-bin script is activated when a user selects a location, either by manually entering latitude and longitude coordinates, selecting a station, or clicking a location on the state map. The cgi-bin script develops a comprehensive output web page on the fly.

5.3. Methods

Since the PFDS is not an Internet Map Server, a so-called "information" function had to be coded so that when provided latitude and longitude coordinates, the PFDS could return the appropriate precipitation frequency and confidence limit estimates. "Getcell," a C-compiled program, was written to accomplish this function. "Getcell" uses the header information provided in the ArcInfo ASCII Grid and the supplied latitude and longitude coordinates to calculate location of the desired grid cell within the grid matrix. Using the PFDS, a location can be selected by:

- Clicking on the map;
- Manually entering latitude and longitude coordinates in decimal degrees (negative numbers should be entered for southern hemisphere latitudes and for western hemisphere longitudes);
- Selecting a station from a pull-down list.

5.4. Output

After the location is selected, all precipitation frequency and confidence limit estimates from the underlying grids are extracted, and the output web page is built and displayed on-the-fly. There are two basic types of output: depth-duration-frequency (DDF) and the intensity-duration-frequency (IDF) graphs. The PFDS provides DDF graphs in two different formats (see examples in Figures 5.4.1 and 5.4.2). An example of the classic IDF graph, which is widely used in engineering applications, is shown in Figure 5.4.3. Both, DDF and IDF graphs can be built from either AMS or PDS data. The graphs are produced using gnuplot (http://www.gnuplot.info) as portable network graphics (*.png), while the remainder of the page is basic HTML.

Precipitation quantiles from this Atlas are estimates for a point location, and are not directly applicable for an area. The conversion of a point to an areal estimate is typically done by applying an areal reduction factor to the point estimate. If areal estimate is needed, it can be computed using precipitation frequency estimates from this Atlas by obtaining an average of the point estimates within the subject area and then multiplying that average by the appropriate areal reduction factor. Areal reduction factors have been published, for example, in the following publications: NOAA Technical Report NWS 24 (Meyers and Zehr, 1980), NOAA Technical Memorandum NWS HYDRO-40 (Zehr and Meyers, 1984), and NOAA Atlas 2 (Miller et al., 1973).

The output page also has data tables of the precipitation frequency depths (or intensities) and tables of the lower and upper bounds of the 90% confidence interval. These can also be downloaded as text via a button on the output page. The links provided in the header of the precipitation frequency table display precipitation magnitude-frequency curves with upper and lower confidence limits for the selected duration (see example in Figure 5.4.4). In addition, location maps and helpful links are provided on the output page, when available. Embedded maps are provided by a hyperlink to the U.S. Census Bureau Mapping and Cartographic Resources Tiger Map Server (http://tiger.census.gov/cgi-bin/mapbrowse-tbl).

Additionally, seasonal exceedance graphs are provided via a button on the top of the output page. Exceedance graphs indicate the percentages of precipitation amounts exceeding precipitation frequency estimates for selected annual exceedance probabilities for the specified duration (see Figure 5.4.5 for an example and Appendix A.2 for more information). The purpose of the graphs is to portray the monthly seasonality of heavy precipitation. The percentages are based on regional statistics and the seasonal graphs are unique for each precipitation frequency region. Durations include: 60-minute, 24-hour, 48-hour, and 10-day.

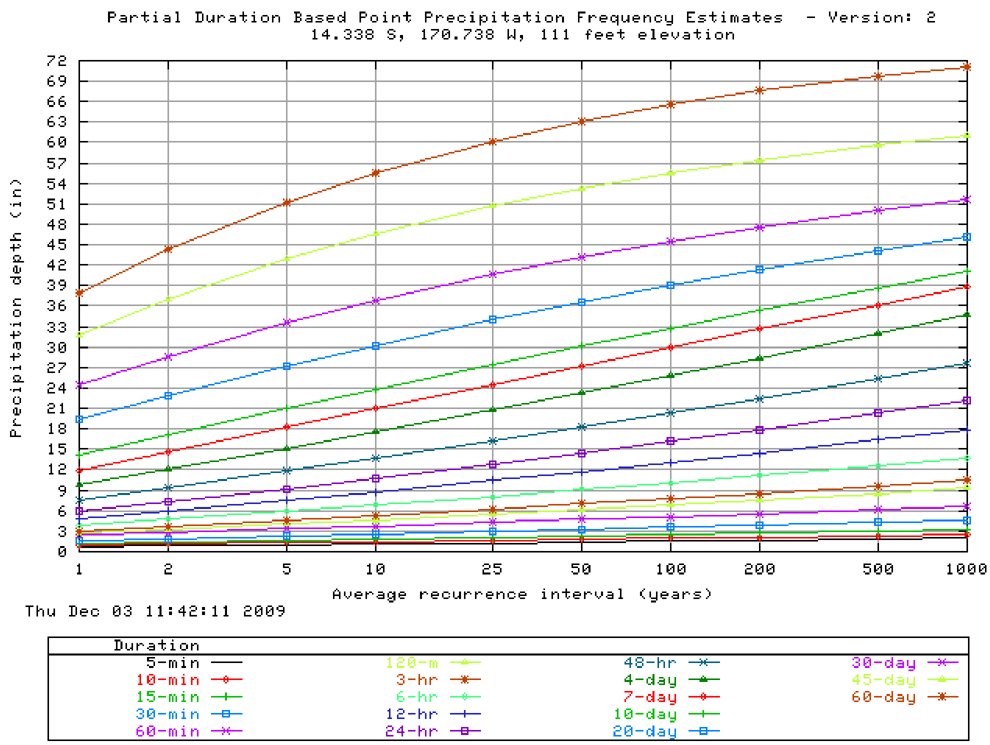


Figure 5.4.1. Sample depth-duration-frequency plot built from the PDS data with average recurrence interval on the x-axis.

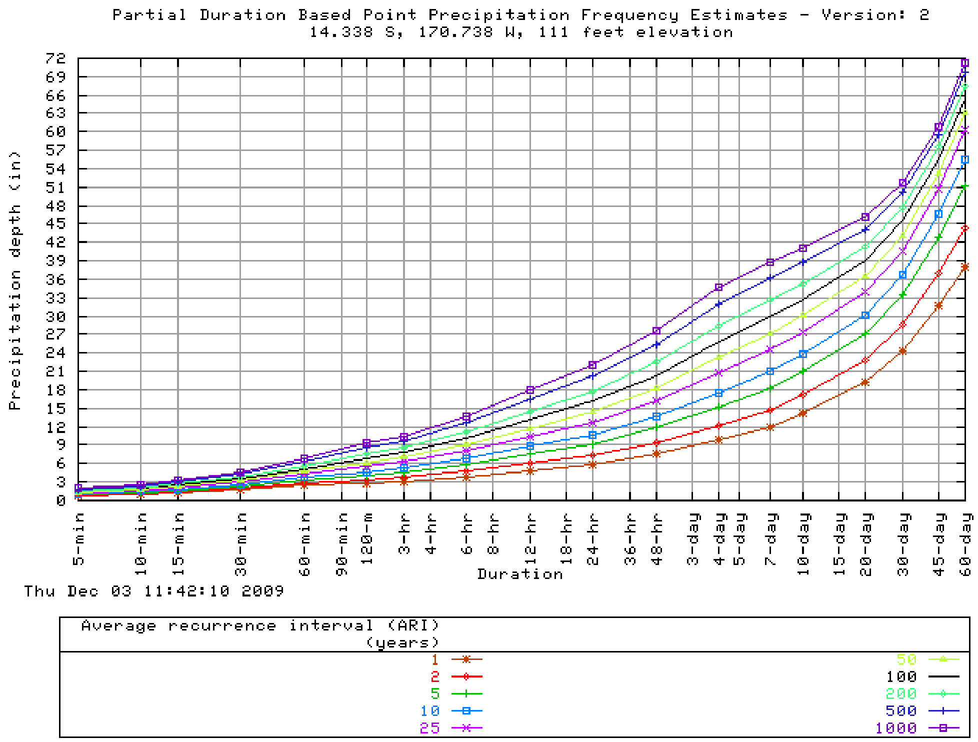


Figure 5.4.2. Sample depth-duration-frequency plot built from the PDS data with duration on the x-axis.

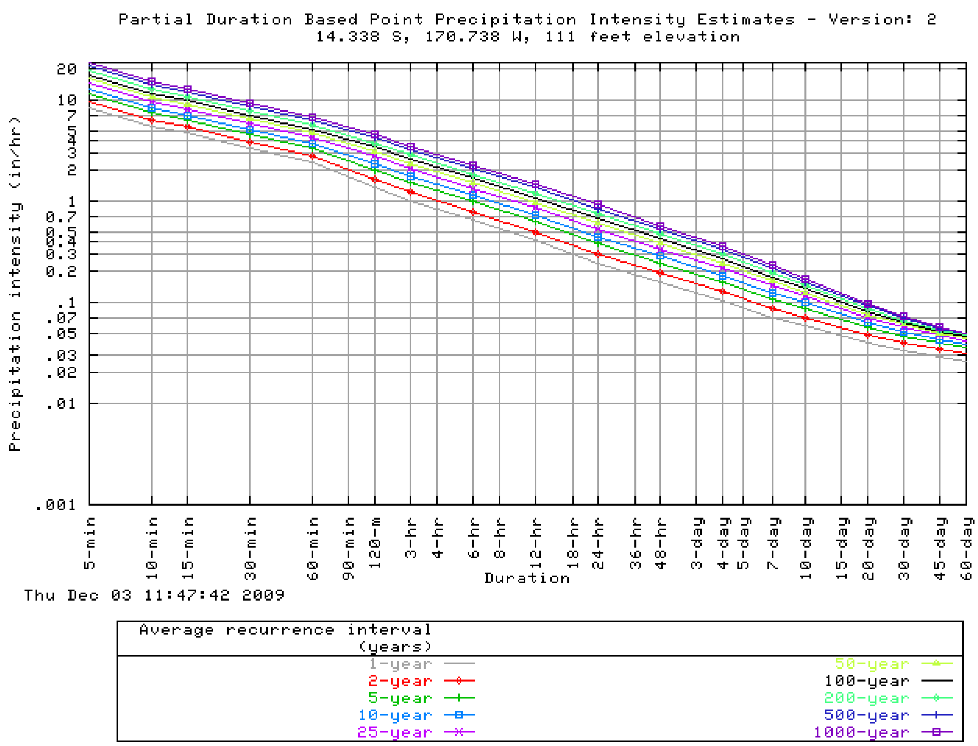


Figure 5.4.3. Sample intensity-duration-frequency (IDF) graph.

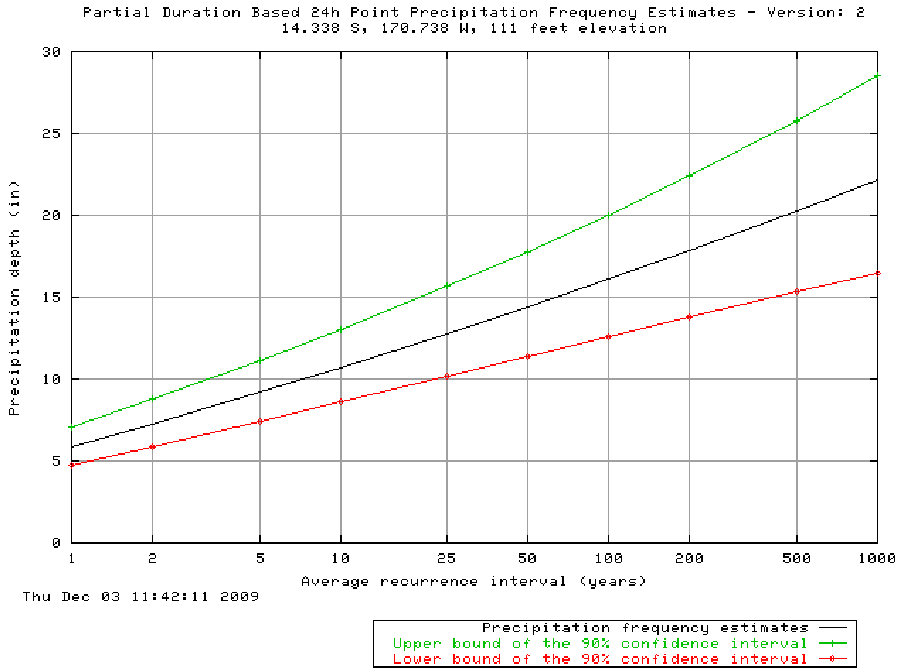


Figure 5.4.4. Sample plot of precipitation frequency estimates with the upper and lower bounds of the 90% confidence interval for the 24-hour duration.

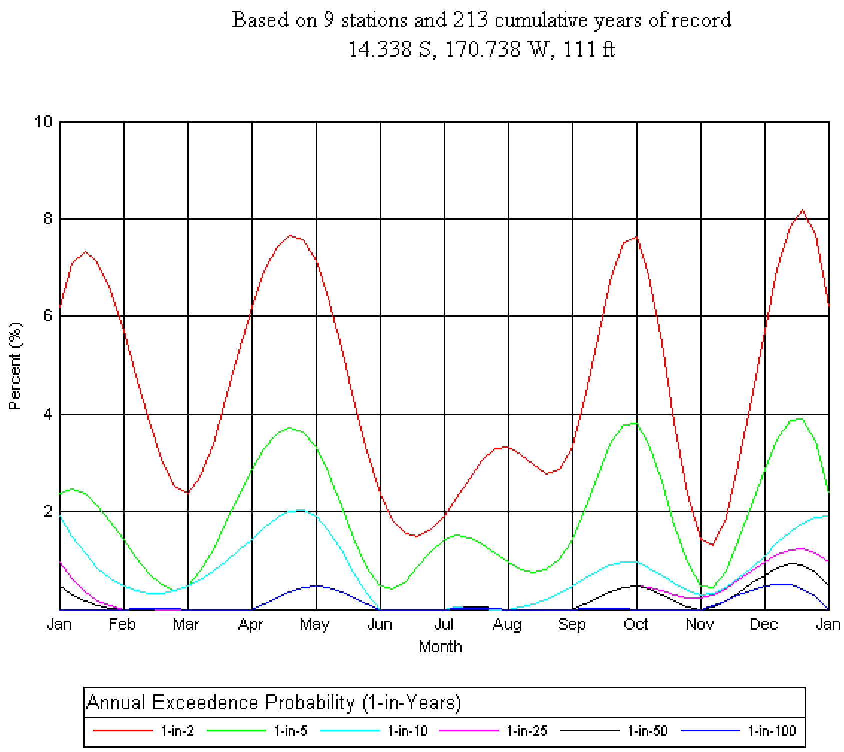


Figure 5.4.5. Sample 24-hour seasonal exceedance graph.

5.5. Using the Precipitation Frequency Data Server

The PFDS homepage (http://hdsc.nws.noaa.gov/hdsc/pfds/) has a clickable map of the United States. States/territories with available precipitation frequency updates are indicated in blue. Upon clicking on a state/territory, a state-specific web page appears. From this page the user selects the desired location, units, and output via a web form.

The PFDS is also the portal for all NOAA Atlas 14 data formats, including:

- **Annual maximum series (AMS) dataset**
  Annual maximum series datasets used in the preparation of NOAA Atlas 14 Volume 5 are available at http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_series.html. Information regarding extraction and quality control of AMS can be found in Sections 4.3 and 4.4 of this document.
- **ArcInfo ASCII grids of precipitation frequency estimates**
  Grids are available for PDS- and AMS-based estimates for all combinations of durations and annual recurrence intervals or annual exceedance probabilities (as shown in Tables 5.2.1 and 5.2.2).
- **Cartographic maps**
  Cartographic maps show contour lines created from gridded PDS-based precipitation frequency estimates for selected durations and average recurrence intervals. They were created to serve as visual aids and are not recommended for interpolating precipitation frequency estimates. It is strongly recommended to retrieve point precipitation frequency values from the PFDS interface which accesses the gridded data directly. Figure 5.5.1 shows an excerpt from a cartographic map.

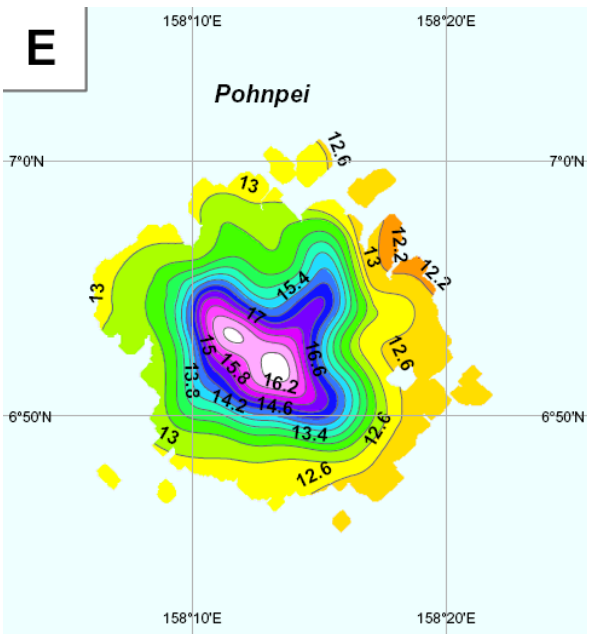


Figure 5.5.1. An excerpt of the 100-year 24-hour cartographic map for Pohnpei. Precipitation frequency estimates are given in inches.

- **Temporal distributions of heavy precipitation**
  Temporal distributions of heavy precipitation for 6-, 12-, 24- and 96-hour durations for the project area are available from http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_temporal.html.

- **Documentation**
  The complete NOAA Atlas 14 Volume 5 documentation is available at
  http://www.nws.noaa.gov/ohd/hdsc/currentpf.htm.

It is strongly advised that users review the Federal Geographic Data Committee (FGDC) compliant metadata before using any of the GIS datasets. On-line help and frequently asked questions (FAQ) are also available via links on the PFDS web site.

Questions regarding the use of the PFDS or its data can be addressed by emailing HDSC.Questions@noaa.gov.

6. Peer review

A peer review of selected preliminary results was carried out during the four week period starting on July 21, 2009. 646 users who were members of the HDSC list-server, and other interested parties were contacted via email for the review. Potential reviewers were asked to evaluate the reasonableness of point precipitation frequency estimates as well as their spatial patterns. The review included the following items:

a. at-station depth-duration-frequency curves built from annual maximum series data for a range of durations for which data were available;
b. isohyethal maps of mean annual maximum precipitation amounts for 60-minute, 24-hour, and 10-day durations;
c. isohyethal maps of precipitation frequency estimates for 1/2 and 1/100 annual exceedance probabilities and 60-minute, 24-hour, and 10-day durations;
d. map showing regional groupings of stations used in frequency analysis.

The reviews provided useful feedback that HDSC used to create a better product. Details regarding reviewer comments and HDSC responses can be found in Appendix A.5.

7. Comparison with previous NWS studies (n/a)

To be consistent with documentation of previous volumes of NOAA Atlas 14, this section was retained. However, NOAA Atlas 14 Volume 5 is the first NWS publication that covers Pacific Islands. Therefore, no comparison is offered with previous studies.

Appendix A.1 Temporal distributions of heavy precipitation

1. Introduction

Temporal distributions of heavy precipitation are provided for use with precipitation frequency estimates from NOAA Atlas 14 Volume 5 for 6-hour, 12-hour, 24-hour, and 96-hour durations. The temporal distributions are expressed in probability terms as cumulative percentages of precipitation totals at various time steps. The precipitation cases used to derive the temporal distributions were defined in the similar fashion as those for estimating precipitation frequencies for consistency. To provide detailed information on the varying temporal distributions, separate temporal distributions were derived for four precipitation cases defined by the duration quartile in which the greatest percentage of the total precipitation occurred.

2. Methodology and results

The methodology used to produce the temporal distributions is similar to the one developed by Huff (1967) except in the definition of precipitation cases. Because of that, temporal distribution curves may be different from corresponding temporal distribution curves obtained from the analysis of single storms. In accordance with the way a precipitation case ("event") was defined for the precipitation frequency analysis, a precipitation case for temporal distribution analysis was computed as the total accumulation over a specific duration (6-, 12-, 24-, or 96-hours). As a result, the accumulation may contain parts of one or more storms. Also, a precipitation case was defined to start with precipitation but not necessarily to end with precipitation resulting in potentially more front-loaded cases when compared with distributions derived from the single storm approach. To eliminate potential biases, a constraint was imposed to exclude cases with a continuous dry period that lasted for more than 20% of the duration. This restriction produced a less variant sample. Table A.1.1 shows the number of precipitation cases used to derive the temporal distributions for each duration. By imposing the restriction on continuous dry periods, the number of cases available for temporal distribution analysis decreased with duration because long, continuous precipitation events occurred less frequently than continuous short-duration events.

For each precipitation case, precipitation accumulation was converted into a percentage of the total precipitation amount at one hour time increments. All cases for a specific duration were then combined and probabilities of occurrence of precipitation totals were computed at each hour. The temporal distribution curves for nine deciles (10% to 90%) were smoothed using linear programming method (Bonta and Rao, 1988) and plotted in the same graph. Figure A.1.1 shows temporal distribution curves for the four selected durations; time steps were converted into percentages of durations for easier comparison.

The cases were further divided into four categories by the quartile in which the greatest percentage of the total precipitation occurred. Table A.1.1 shows the numbers and proportion of precipitation cases used to derive the temporal distributions in each quartile. Unlike the cases of 12-, 24-, and 96-hour durations in which the number of data points can be equally divided by four, the cases of 6-hour duration contain only six data points and they cannot be evenly distributed into four quartiles. Therefore, in this analysis, for 6-hour duration, the first quartile contains precipitation cases where the most precipitation occurred in the first hour, the second quartile contains precipitation cases where the most precipitation occurred in the second and third hours, the third quartile contains precipitation cases where the most precipitation occurred in the fourth hour, and the fourth quartile contains precipitation cases where the most precipitation occurred in the fifth and sixth hours. This uneven distribution affects the number of cases contained in each quartile for the 6-hour duration. Figures A.1.2 through A.1.5 show the temporal distribution curves for four quartile cases for 6-hour, 12-hour, 24-hour and 96-hour durations, respectively.

Table A.1.1. Number of all precipitation cases and number (and percent) of cases in each quartile for selected durations.

Duration (hours)	All cases	First-quartile cases	Second-quartile cases	Third-quartile cases	Fourth-quartile cases
6	363	25 (7%)	179 (49%)	45 (12%)	114 (32%)
12	298	60 (20%)	70 (24%)	111 (37%)	57 (19%)
24	205	31 (15%)	57 (28%)	71 (35%)	46 (22%)
96	176	39 (22%)	38 (22%)	43 (24%)	56 (32%)

Temporal distribution data are also available in a tabular form at PFDS web page (http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_temporal.html). For 6-hour, 12-hour and 24-hour durations, temporal distribution data are provided in 0.5-hour increments and for 96-hour duration in hourly increments.

3. Interpretation

Figure A.1.1 shows the temporal distribution curves of all precipitation cases for the 6-, 12-, 24-, and 96-hour durations for the project area. Time steps were converted into percentages of total durations for easier comparison. Figures A.1.2 through A.1.5 show temporal distribution curves for first-, second-, third-, and fourth-quartile cases for 6-hour, 12-hour, 24-hour and 96-hour durations, respectively. First-quartile plots show temporal distribution curves for cases where the greatest percentage of the total precipitation fell during the first quarter of the duration (e.g., the first 3 hours of a 12-hour duration). The second, third, and fourth quartile plots are similarly for cases where the most precipitation fell in the second, third, or fourth quarter of the duration.

The temporal distribution curves represent the averages of many cases and illustrate the temporal distribution patterns with 10% to 90% occurrence probabilities in 10% increments. For example, the 10% curve in any figure indicates that 10% of the corresponding precipitation cases had distributions that fell above and to the left of the curve. Similarly, 10% of the cases had temporal distribution falling to the right and below the 90% curve. The 50% curve represents the median temporal distribution.

The following is an example of how to interpret the results using the figure (a) in the upper left panel of Figure A.1.4 and information from Table A.1.1 for 24-hour first-quartile cases.

- Of the total of 205 24-hour cases, 31 (15%) of them were first-quartile.
- In 10% of the first-quartile cases, 50% of the total precipitation fell by 4.8 hours and 90% of the total precipitation fell by 15.5 hours.
- A median case of this type will drop half of the precipitation (50% on the y-axis) in approximately 8 hours.
- In 90% of the cases, 50% of the total precipitation fell by 12.5 hours and 90% of precipitation fell by 22.8 hours.

Temporal distribution curves are presented in order to show the range of possibilities. Care should be taken in the interpretation and use of temporal distribution curves. For example, the use of different temporal distribution data in hydrologic models may result in very different peak flow estimates. Therefore, they should be selected and used in a way to reflect users' objectives.

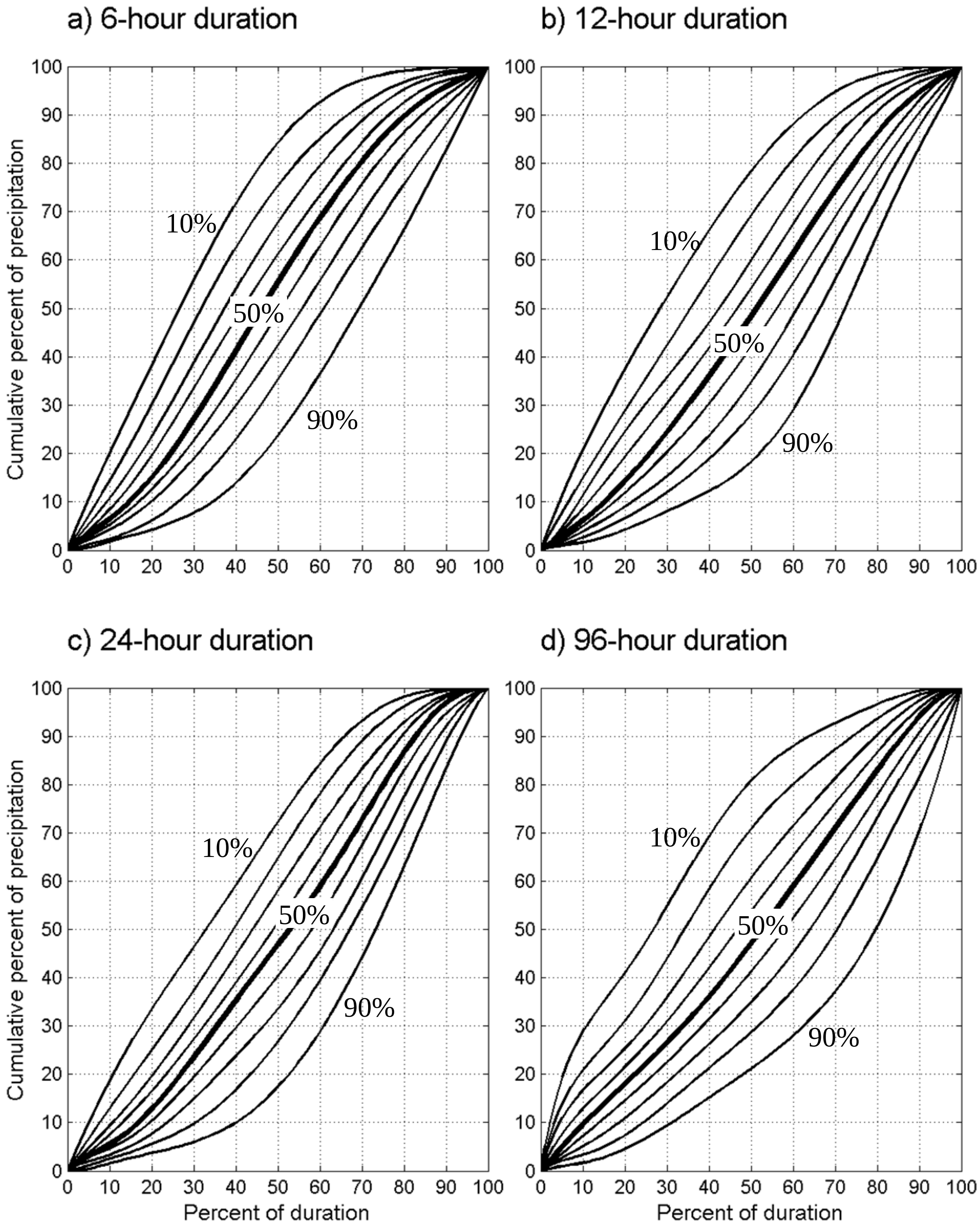


Figure A.1.1. Temporal distribution curves for all cases for: a) 6-hour, b) 12-hour, c) 24-hour, and d) 96-hour durations.

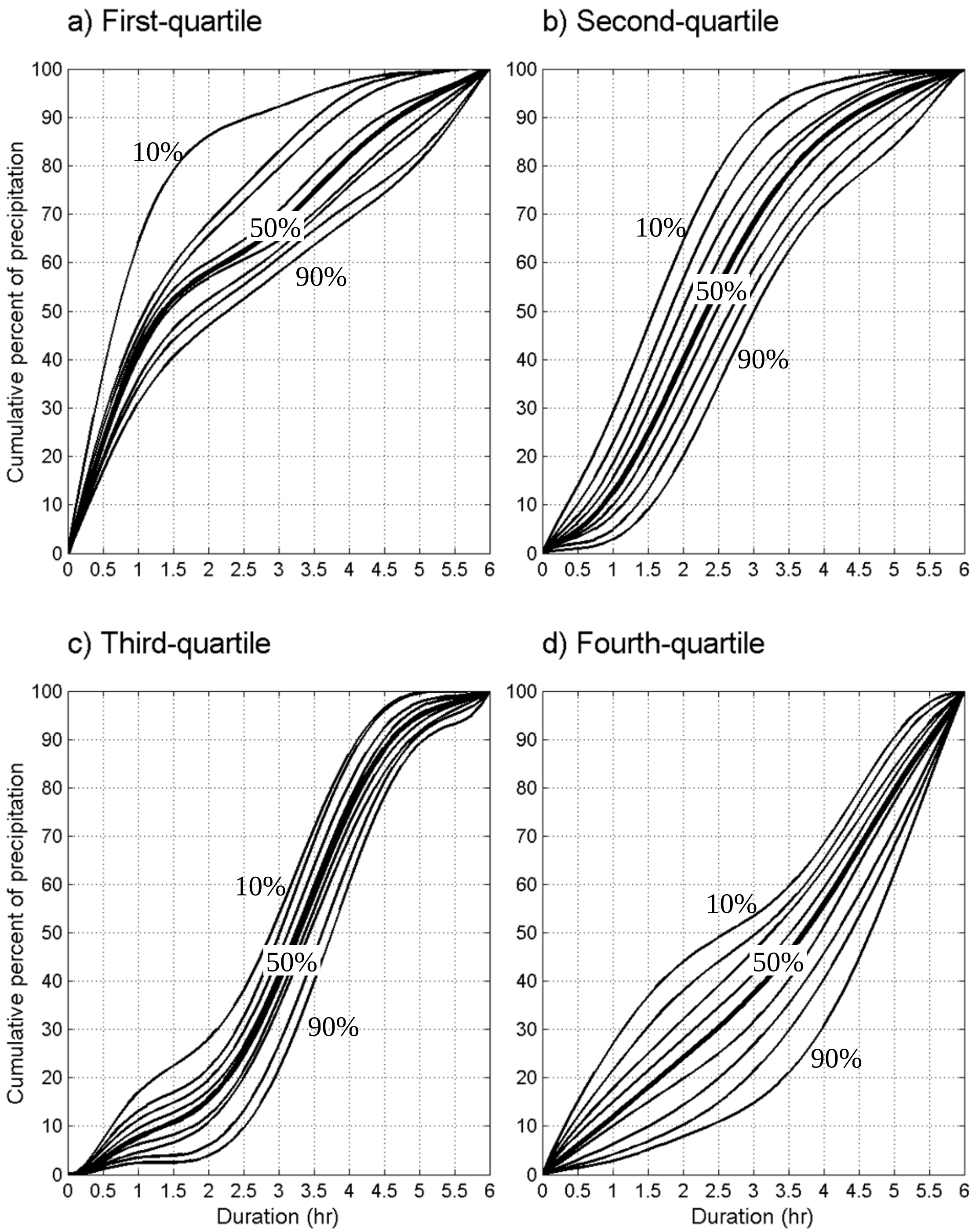


Figure A.1.2. 6-hour temporal distribution curves for: a) first-quartile, b) second-quartile, c) third-quartile, and d) fourth-quartile cases.

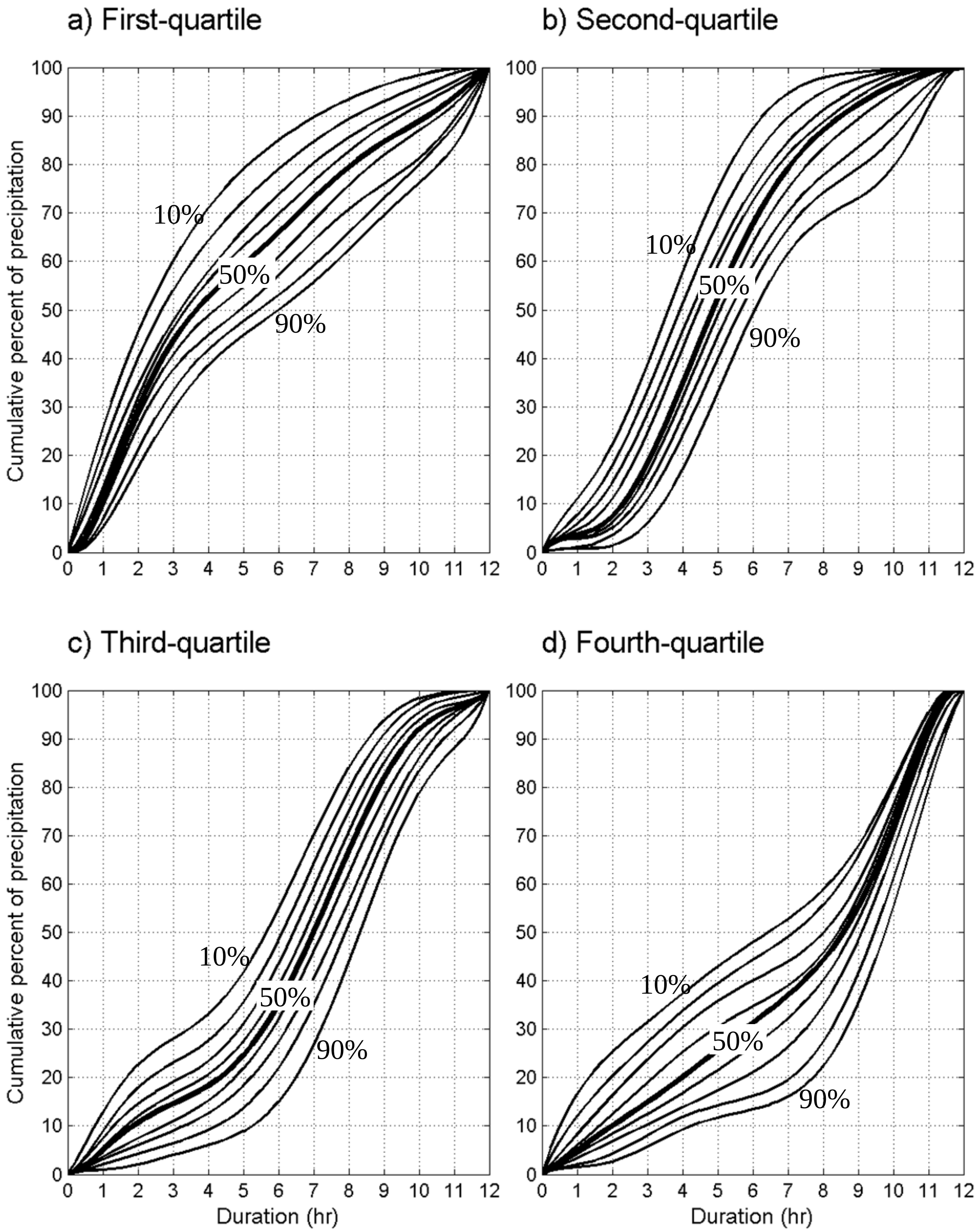


Figure A.1.3. 12-hour temporal distribution curves for: a) first-quartile, b) second-quartile, c) third-quartile, and d) fourth-quartile cases.

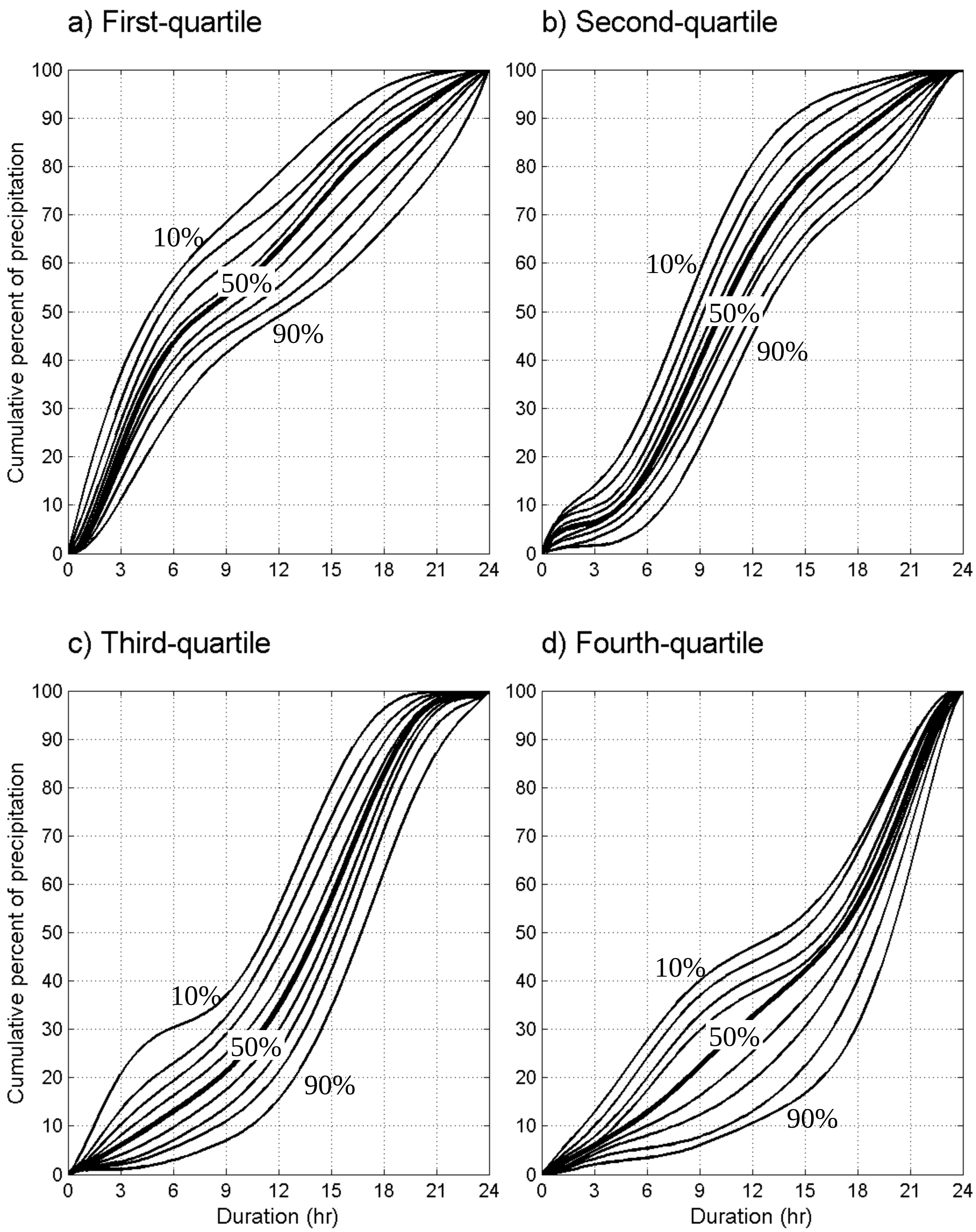


Figure A.1.4. 24-hour temporal distribution curves for: a) first-quartile, b) second-quartile, c) third-quartile, and d) fourth-quartile cases.

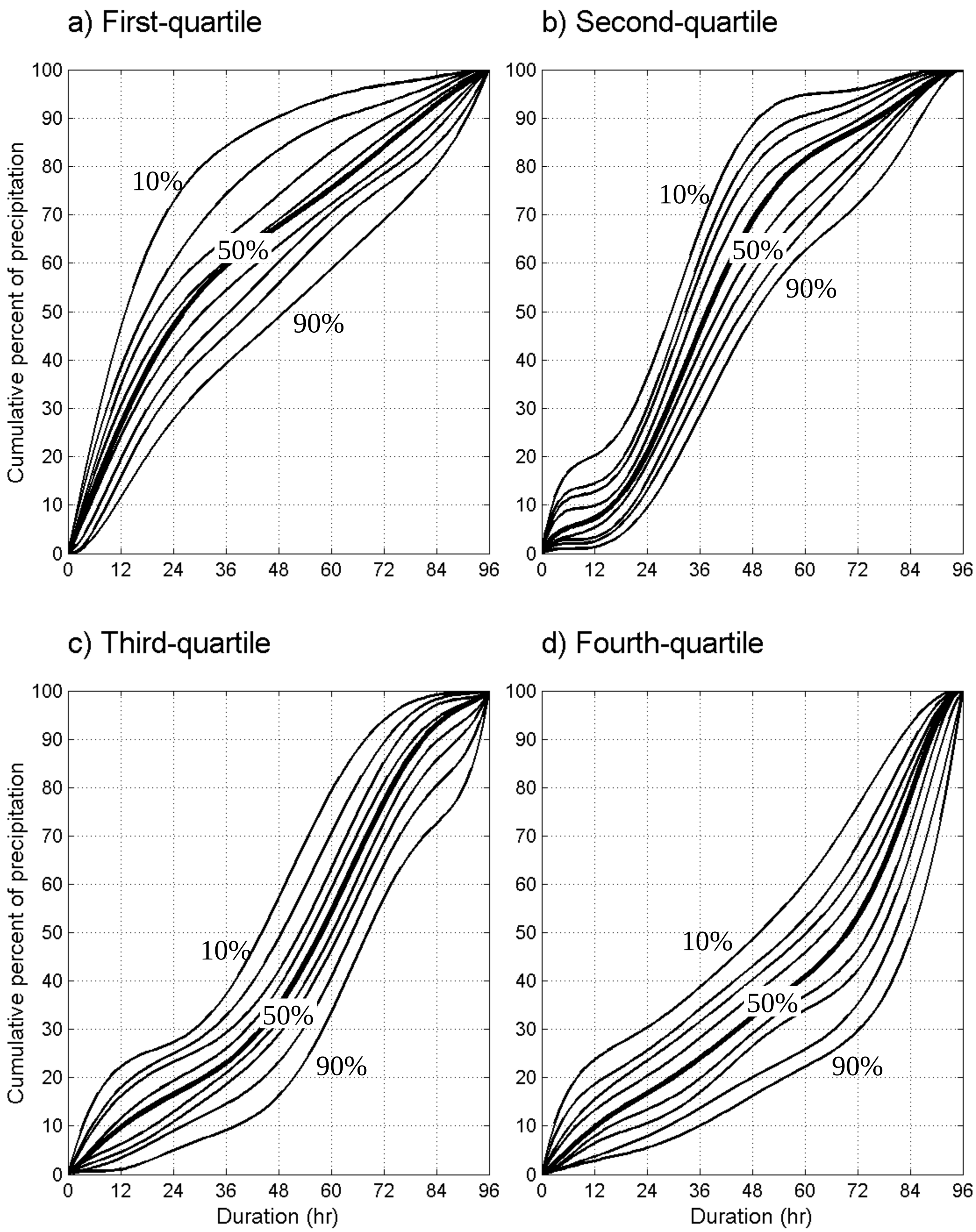


Figure A.1.5. 96-hour temporal distribution curves for: a) first-quartile, b) second-quartile, c) third-quartile, and d) fourth-quartile cases.

Appendix A.2 Seasonality

1. Introduction

To portray the seasonality of extreme precipitation throughout the project area, precipitation amounts that exceeded precipitation frequency estimates (quantiles) with selected annual exceedance probabilities (AEPs) for chosen durations were examined for each region delineated for frequency analysis (shown in Figure 4.5.1). Graphs showing the monthly variation of the exceedances for a region are provided for each location in the project area via the Precipitation Frequency Data Server (PFDS) at http://hdsc.nws.noaa.gov/hdsc/pfds/. Seasonal exceedance graphs can be viewed by clicking the "Seasonality" button from the output page when a point (or station) in the project area is selected.

2. Method

Exceedance graphs show the percentage of precipitation totals for a given duration that exceeded the precipitation frequency estimate for the duration and selected AEPs in each month for each region. The precipitation frequency estimates were derived from annual maximum series at each station in the region (as described in Section 4.5). Results are provided for unconstrained 60-minute, 24-hour, 2-day, and 10-day durations and for annual exceedance probabilities of 1/2 (or 1-in-2), 1/5, 1/10, 1/25, 1/50, and 1/100.

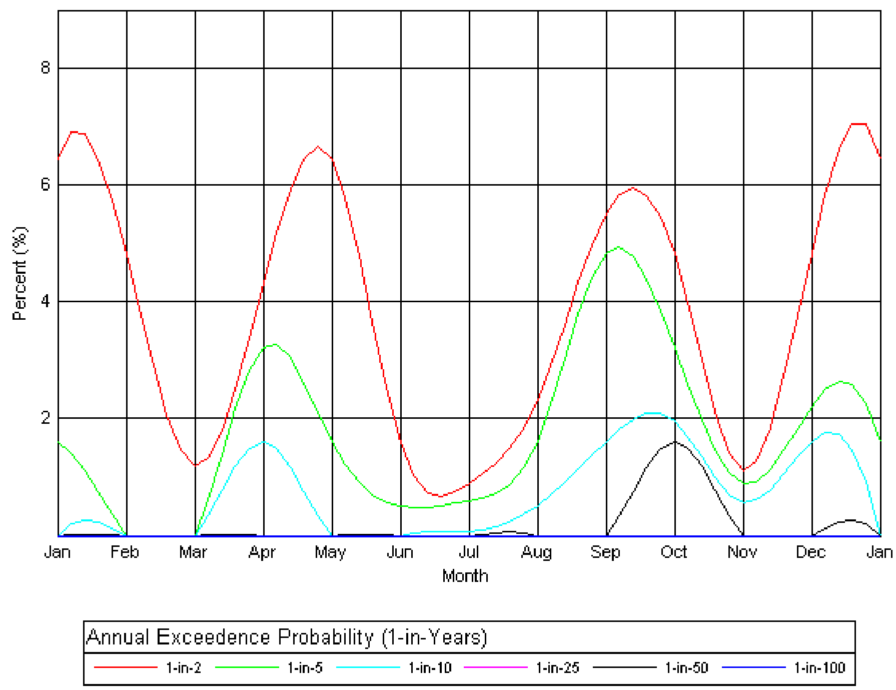
To prepare the graphs, first, the number of precipitation totals exceeding the precipitation frequency estimate at a station for a given AEP for each selected duration was tabulated. Those numbers were then combined for all stations in a given region, sorted by month, normalized by the total number of data years in the region, and finally plotted via the PFDS.

3. Results

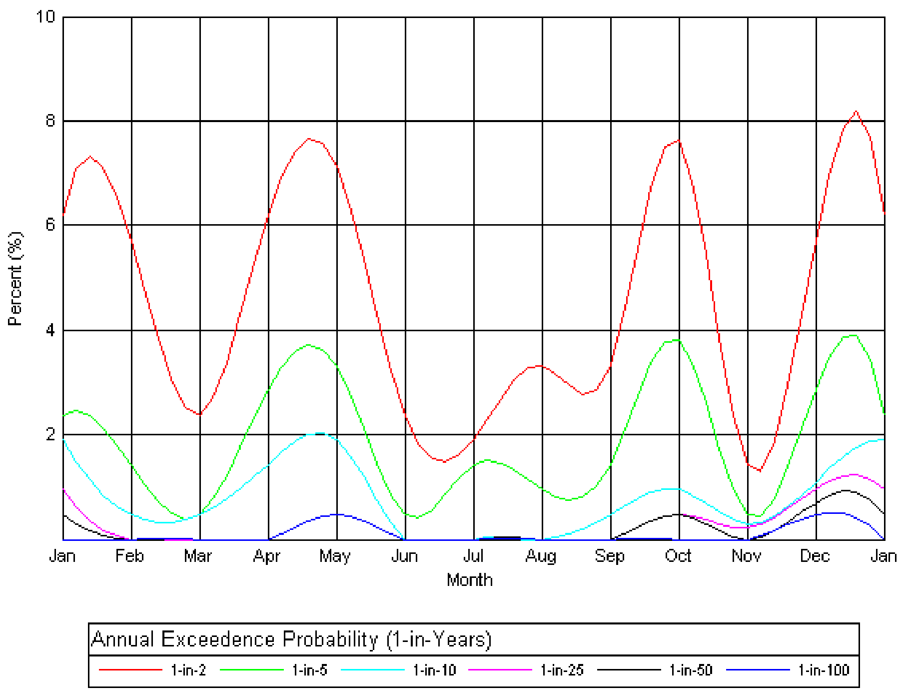
The exceedance graphs for a selected location (see an example for a location in region 10 in Figure A.2.1) indicate percent of precipitation totals exceeding the quantiles with selected AEPs for various durations. The percentages are based on regional statistics. On average, 50% of precipitation totals for a given duration in a year (i.e., the sum of percentages of all twelve months) would exceed the 1/2 (1-in-2) AEP quantile, 4% would exceed the 1/25 AEP quantile, and only 1% would exceed the quantile with the 1/100 AEP.

Note that seasonality graphs should not be used to derive seasonal precipitation frequency estimates.

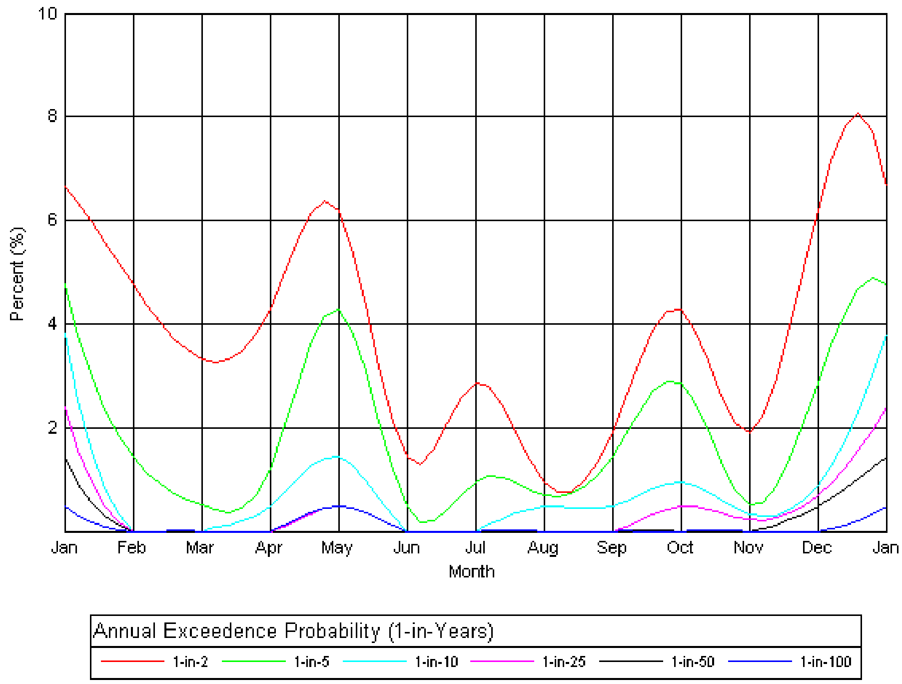
a) 60-minute duration



b) 24-hour duration



c) 2-day duration



d) 10-day duration

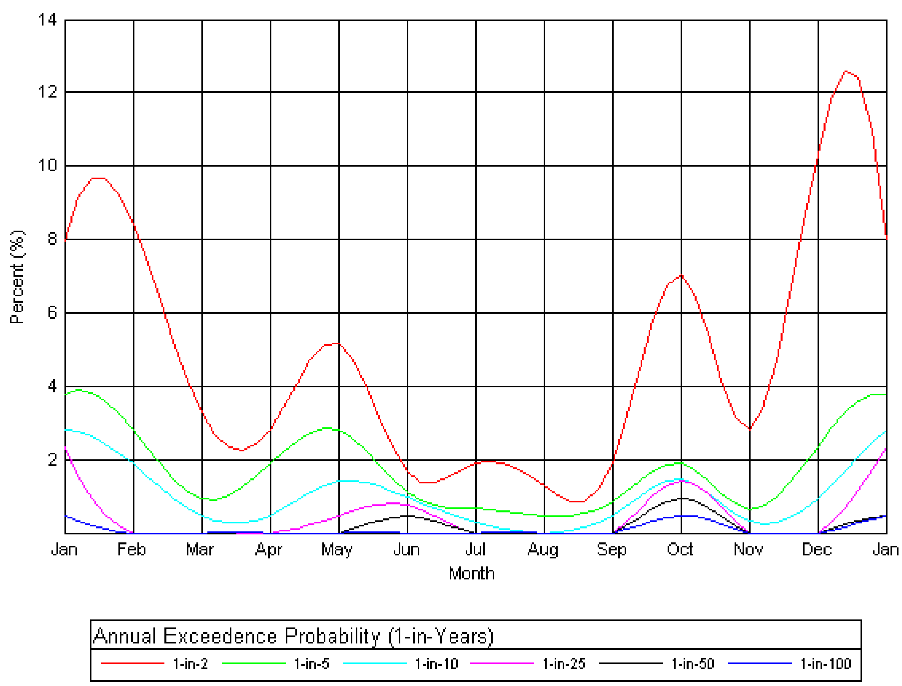


Figure A.2.1. Example of seasonal exceedance graphs for region 10 (Tutuila, AS) for the: a) 60-minute, b) 24-hour, c) 2-day, and d) 10-day durations.

Appendix A.3 Annual maximum series trend analysis

1. Selection of statistical tests for detection of trends in AMS

Precipitation frequency analysis methods used in NOAA Atlas 14 volumes are based on the assumption of stationary climate over the period of observation (and application). To meet the stationarity criterion, the annual maximum series data must be free from trends during the observation period. A number of parametric and non-parametric statistical tests are available for the detection and/or quantification of trends. Selection of an appropriate statistical test requires consideration of the data tested and the limitations of the test.

Annual maximum series (AMS) were first graphed for each station in the project area to examine the time series and to observe general types of trends in the data. Visual inspection of time series plots indicated that there were no abrupt changes or apparent cycles in the AMS, but suggested the possibility of slight trends at some locations. Changes appeared to be gradual and approximately linear, and mostly decreasing trends were observed in these data.

The null hypothesis that there are no trends in annual maximum series was tested on AMS data at each station in the project area with at least 30 years of data. Since there were no hourly stations that satisfied that requirement, testing was done on 1-day AMS only. The hypothesis was tested at each station separately and for the region as a whole (American Samoa was excluded because of its distance from other islands) at the level of significance $\alpha = 5\%$. At-station trends were inspected using the parametric *t*-test for trend and non-parametric Mann-Kendall test (Maidment, 1993). Both tests are extensively used in environmental sciences and are appropriate for records that have undergone a gradual change. The tests are fairly robust, readily available, and easy to use and interpret. Since each test is based on different assumptions and different test statistics, the rationale was that if both tests have similar outcomes there can be more confidence about the results. If the outcomes were different, it would provide an opportunity to investigate reasons for discrepancies.

Parametric tests in general have been shown to be more powerful than non-parametric tests when the data are approximately normally distributed and when the assumption of homoscedasticity (homogeneous variance) holds (Hirsch et al., 1991), but are less reliable when those assumptions do not hold. The parametric *t*-test for trend detection is based on linear regression, and therefore checks only for a linear trend in data. However, requiring a linear trend assumption seemed sufficient, since, as mentioned above, time series plots indicated monotonic changes in AMS. The Pearson correlation coefficient (r) was used as a measure of linear association for the *t*-test. The hypothesis that the data are not dependent on time (and also that they are independent and normally distributed numbers) was tested using the test statistic t that follows Student's distribution and is defined as:

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

where n is the record length of the AMS. The hypothesis is rejected when the absolute value of the computed *t*-statistic is greater than the critical value obtained from Student's distribution with (n - 2) degrees of freedom and exceedance probability of $\alpha/2\%$, where α is the significance level. The sign of the *t*-statistic defines the direction of the trend, positive or negative.

Non-parametric tests have advantages over parametric tests since they make no assumption of probability distribution and are performed without specifying whether trend is linear or nonlinear. They are also more resilient to outliers in data because they do not operate on data directly. One of the disadvantages of non-parametric tests is that they do not account for the magnitude of the data. The Mann-Kendall test was selected among various non-parametric tests because it can accommodate missing values in a time series, which was a common occurrence in the AMS data. The Mann-Kendall test compares the relative magnitudes of annual maximum data. If annual maximum values are indexed based on time, and x_i is the annual maximum value that corresponds to year t_i, then the Mann-Kendall statistic is given by:

$$S = \sum_{k=1}^{n-1} \sum_{i=k+1}^{n} sign(x_i - x_k)$$

The test statistic *Z* is then computed using a normal approximation and standardization of the statistic *S*. The null hypothesis that there is no trend in the data is rejected at significance level α if the computed *Z* value is greater, in absolute terms, than the critical value obtained from standard normal distribution that has probability of exceedance of α/2%. The sign of the statistic defines the direction of the trend, positive or negative.

In addition to an at-station trend analysis, the relative magnitude of any trend in AMS for the region as a whole (excluding American Samoa) was assessed by linear regression techniques. Station-specific AMS were rescaled by corresponding mean annual maximum values and then regressed against time, where time was defined as year of occurrence minus 1900. The regression results from all stations were tested against a null hypothesis of zero serial correlation (zero regression slopes).

2. Trend analysis

The null hypothesis that there are no trends in annual maximum series was tested on 1-day AMS data at each station in the project area with at least 30 years of data. 16 daily stations (and no hourly or 15-minute stations) satisfied the record length criterion. The *t*-test and Mann-Kendall test for trends were applied to test the hypothesis. As can be seen from Table A.3.1, results from both tests were essentially the same for the 1-day AMS. Both tests indicated no statistically-significant trends in 14 of 16 stations tested. The Mann-Kendal test detected a positive trend in 1-day AMS data in one location in Pohnpei, and the *t*-test identified a negative trend in one location on Guam. Spatial distribution of trend analysis results for 1-day AMS is shown in Figure A.3.1.

Table A.3.1. Trend analysis results based on *t*-test and Mann-Kendall test for 1-day AMS data.

	***t*-test**	**Mann-Kendall test**
Number of stations with no trend	15	15
Number of stations with positive trend	0	1
Number of stations with negative trend	1	0
Total number of stations tested	16	16

Results from the regional trend analysis also indicated that the null hypothesis (no trends in AMS in the project area) could not be rejected at 5% significance level. Because all tests indicated no statistically-significant trends in the data, the assumption of stationary climate was accepted for this project area and no adjustment to AMS data was recommended.

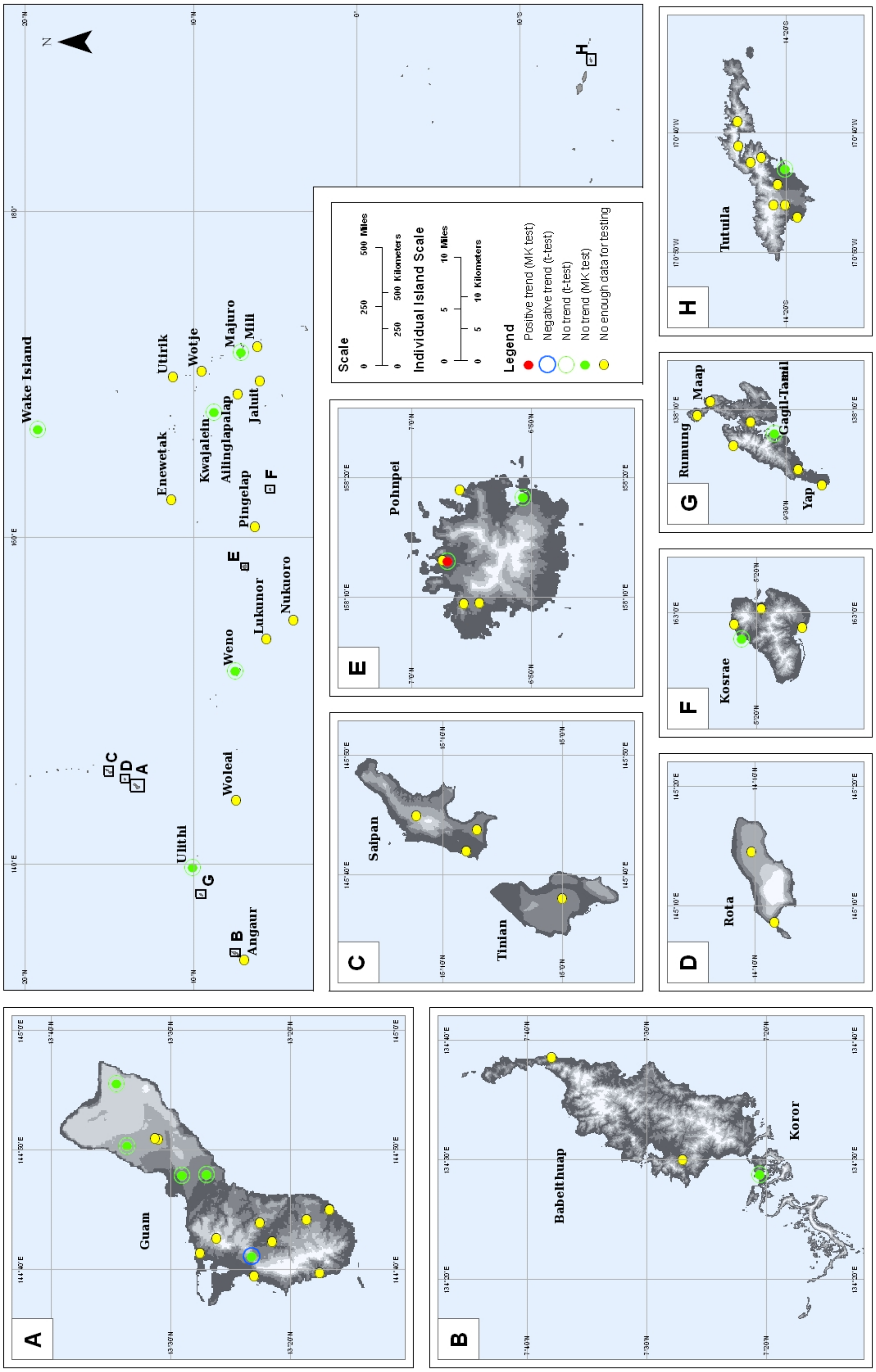


Figure A.3.1. Spatial distribution of trend results for 1-day AMS.

Appendix A.4 PRISM report (n/a)

For previous NOAA Atlas 14 volumes, mean annual maxima (MAM) grids at various durations were developed by the PRISM Climate Group of Oregon State University. Those grids were used to spatially interpolate at-station precipitation frequency estimates (e.g., Perica et al., 2009). However, for the Pacific Islands, lack of funding precluded development of PRISM-based grids of mean annual maxima, so alternative approaches were used to derive MAM and precipitation frequency grids (see Section 4.6). This appendix was retained for consistency with the documentation for other volumes.

Appendix A.5 Peer review comments and responses

The Hydrometeorological Design Studies Center (HDSC) conducted a peer review of the Selected Pacific Islands precipitation frequency project during the period July 21, 2009 to August 15, 2009. The review included the following items:

1. depth-duration-frequency curves at stations derived from annual maximum series data;
2. maps of spatially-interpolated mean annual maximum precipitation amounts for 60-minute, 24-hour, and 10-day durations;
3. isohyetal maps of precipitation frequency estimates for 1/2 and 1/100 annual exceedance probabilities and for 60-minute, 24-hour, and 10-day durations;
4. map showing regional groupings of stations used in frequency analysis.

646 users who were members of the HDSC list-server and other interested parties were contacted via email for the review. We received written responses from two colleagues. This document addresses the comments received. Issues/comments are paraphrased and are accompanied by an HDSC response. The comments and their respective HDSC responses have been divided into three categories:

1. comments pertaining to mean annual maximum precipitation and precipitation frequency estimates at stations;
2. comments pertaining to isohyetal maps;
3. general questions and comments.

1. Comments pertaining to mean annual maximum precipitation and precipitation frequency estimates at stations

1.1 *How are differences in periods of record handled with respect to co-located daily, hourly and 15-minute stations or with nearby stations?*

HDSC response: We extensively quality controlled any differences in annual maxima and in mean annual maxima (MAM) at co-located daily, hourly and 15-minute stations. Also, where possible, data records were extended at stations by aggregating and appending data from a co-located station with a shorter reporting interval and/or by merging data from nearby stations. Furthermore, at-station MAMs were investigated for spatial inconsistencies and compared to assess the impact of different periods of record. Several locations were identified where differences in MAMs at nearby stations were significant and caused primarily by differences in record lengths and/or different periods of record. Whenever possible, linear regression was used on annual maxima from overlapping periods to adjust MAMs at stations with shorter periods of record. Finally, it should not be forgotten that the regional approach accommodates sampling differences by joining station data into a homogenous group (i.e., region) leading to a more robust estimation of precipitation frequency estimates.

2. Comments pertaining to isohyetal maps

2.1 *Were the mean annual precipitation maps from PRISM used to generate gridded values for Guam and Pohnpei? This approach was used in Volume 4, Hawaiian Islands. Pohnpei has a significant orographic effect whereas Guam does not, as illustrated when Typhoon Pongsona, December 2002 struck Guam. The precipitation isohyets were related to the direction and path of the eye instead of according to topography. These types of issues should be addressed.*

HDSC response: No funds were available for this project to support the PRISM work to create MAM grids at selected hourly and daily durations, so alternative interpolation techniques were applied. They will be described in detail in Section 4.6 of this volume's documentation. In short, for each island in the project area, we selected the best approach to derive precipitation frequency grids. In regions where reliable relationships were found between MAM and mean annual precipitation (MAP) and where PRISM MAP grids were available, regression equations were used to create MAM grids from MAP grids. For regions where no relationships between MAM and MAP existed (for those regions no relationships were found between MAM and elevation either), at-station MAM estimates were interpolated using biharmonic spline interpolation method. On several small, low-elevation islands and atolls, no interpolation was needed. So for instance, regression with MAP (which is highly correlated with elevation) was used to create MAM grids at Pohnpei, and at-station estimates were interpolated to create MAM grids on Guam.

2.2 *The color scheme on the contour maps was difficult to read. How will these data be provided in the final product?*

HDSC response: The color scheme in the final product will be different from the one used for the peer review. The cartographic maps for this NOAA Atlas 14 volume will look similar to those for previous volumes. Upon clicking on Pacific Islands web page, users will be able to retrieve precipitation frequency estimates and their confidence limits for a desired location. The PFDS is the portal for all NOAA Atlas 14 data formats, including: annual maximum series dataset, GIS data, cartographic maps, temporal distributions of heavy precipitation, etc.

2.3 *On your maps: The Republic of Palau, the Federated States of Micronesia and the Republic of the Marshall Islands are all countries. Should not the all be in the same types of letters?*

HDSC response: They should. We will make changes accordingly in the final product.

2.4 *I reviewed your maps and they look reasonable particularly based on the data you have.*

HDSC response: Thank you.

3 General questions and comments

3.1 *The scope of the peer review is limited. Will other judgments such as not considering a certain gauge or the computation of sub-hourly precipitation frequency estimates be subject to peer review? What about other relatively subjective decisions?*

HDSC response: Generally, precipitation frequency estimates provided for peer review are not final estimates and may change as a result of comments received and further evaluation. The purpose of the peer review is to check reasonableness in at-station depth-duration-frequency curves and spatial patterns in the estimates for selected durations and annual exceedance probabilities (AEPs) which we felt were the more important ones and indicative of patterns in subsequent durations and AEPs. The detailed description of methodology and decisions made will be provided in final documentation and the level of detail provided will be similar to previous volumes. The final data set, including metadata, used for the analysis will also be provided as part of the on-line publication so that the results of all decisions are apparent.

3.2 *How will the limited sub-hour data be used in developing estimates of sub-hourly precipitation frequencies?*

HDSC response: For sub-hourly durations, we apply n-minute scaling factors on 1-hour precipitation frequency estimates. For more information on development of 5- to 30-minute precipitation frequency estimates, please see Section 4.5.3 of any NOAA Atlas 14 volume documentation.

Appendix A.6 List of stations used to prepare precipitation frequency estimates

Table A.6.1. List of stations used in the analysis showing state/territory name, island and station names, station ID, source of data, latitude, longitude, elevation, regional affiliation, data reporting interval (station type) and period of record. Bold font indicates information that has been adjusted from original value. NCDC* indicates NCDC stations for which records were extended using data provided by the NWS Weather Forecast Office in Guam.

Territory/ state	Island/atoll	Station name	Station ID	Source of data	Latitude	Longitude	Elevation (ft)	Region	Type	Period of record
CNMI	ROTA	ROTA	91-4800	NCDC	**14.1397**	**145.1442**	47	1	DLY	1956-1982
		ROTA AP	91-4801	NCDC	14.1717	145.2428	588	1	15MIN	1982-2007
	SAIPAN	CAPITOL HILL 1	91-4080	NCDC	**15.2032**	**145.7485**	827	1	15MIN	1980-2007
		SAIPAN INTL AP	91-4855	NCDC	15.1189	145.7294	215	1	15MIN	1979-2007
		SAIPAN LORAN	91-4860	NCDC	15.1333	145.7000	10	1	DLY	1954-1978
	TINIAN	TINIAN	91-4874	NCDC*	15.0000	145.6333	268	1	DLY	1987-2008
GU	GUAM	AGAT	91-4001	NCDC	**13.3840**	144.6575	10	2	DLY	1978-2008
		ANDERSEN AFB	91-4025	NCDC*	**13.5759**	**144.9259**	624	2	DLY	1953-2002
		DEDEDO	91-4156	NCDC	13.5171	**144.8479**	350	2	DLY	1978-2008
		DEDEDO	93-4966	USGS	13.5223	144.8493	**398**	2	DLY HLY	1988-2008 1992-2008
		FENA FILTER PLANT	93-5766	USGS	**13.3867**	**144.6845**	398	2	DLY	1951-1983
		FENA LAKE	91-4200	NCDC	**13.3589**	**144.7056**	60	2	15MIN	1980-2007
		GUAM NWSO TIYAN	91-4226	NCDC	**13.4843**	**144.7979**	254	2	DLY NMIN	1945-2008 1984-2007
		GUAM WSMO	91-4229	NCDC*	**13.5600**	**144.8389**	361	2	DLY	1957-1998
		INARAJAN AG STN	91-4275	NCDC	**13.2785**	**144.7504**	30	2	DLY	1978-2008
		INARAJAN-NASA	91-4278	NCDC	**13.3100**	**144.7366**	280	2	15MIN	1979-2007
		MANGILAO	91-4468	NCDC	**13.4499**	**144.7995**	60	2	DLY	1970-2008
		MOUNT CHACHAO NEAR PITI	93-3366	USGS	**13.4365**	**144.7105**	**803**	2	DLY	1988-2008
		PITI	91-4670	NCDC	**13.4589**	**144.6899**	10	2	15MIN	1978-2007
		UMATAC	93-3766	USGS	13.2918	144.6622	**253**	2	DLY HLY	1978-2008 1992-2008
		WINDWARD HILLS NEAR TALOFOFO	93-1966	USGS	13.3761	144.7316	**305**	2	DLY HLY	1974-2008 1991-2007

Territory/ state	Island/atoll	Station name	Station ID	Source of data	Latitude	Longitude	Elevation (ft)	Region	Type	Period of record
PW	ANGAUR	ANGAUR	91-4030	NCDC*	**6.9046**	**134.1387**	20	4	DLY	1955-1977
	BABELTHUAP	NEKKEN FORESTRY	91-4519	NCDC*	7.4500	134.5000	102	4	DLY	1983-2004
		NGASANG	91-4580	NCDC*	7.6333	**134.6429**	10	4	DLY	1955-1979
	KOROR	KOROR WSO	91-4351	NCDC*	**7.3430**	**134.4785**	94	4	DLY HLY NMIN	1951-2008 1984-2008 1973-1997
FSM/CHUUK	LUKUNOR	LUKUNOR	91-4419	NCDC*	**5.5135**	**153.8167**	5	5	DLY	1962-2005
	WENO	CHUUK WSO AP	91-4111	NCDC*	7.4552	151.8376	5	5	DLY HLY NMIN	1914-2008 1984-2008 1973-1997
FSM/KOSRAE	KOSRAE	KOSRAE	91-4395	NCDC*	**5.3544**	**162.9533**	7	6	DLY	1954-2008
		TAFUNSAK	91-4825	NCDC*	5.3646	**162.9840**	14	6	DLY	1991-2003
		TOFOL	91-4843	NCDC*	5.3264	163.0050	49	6	DLY	1987-2008
		UTWA	91-4898	NCDC*	5.2701	**162.9792**	13	6	DLY	1990-2008
FSM/POHNPEI	NUKUORO	NUKUORO	91-4590	NCDC*	3.8500	**154.9730**	8	5	DLY	1985-2008
	PINGELAP	PINGELAP	91-4720	NCDC*	**6.2107**	**160.7039**	8	6	DLY	1985-2008
	POHNPEI	METALANIM	91-4482	NCDC*	6.8456	158.3064	30	6	DLY	1967-2005
		OA	91-4665	NCDC*	6.9333	158.3167	79	6	DLY	1956-1966
		PAIES-KITTI	91-4705	NCDC*	6.9053	158.1586	150	6	DLY	1981-2002
		PALIKIR	91-4710	NCDC*	6.9269	158.1572	280	6	DLY	1991-2008
		POHNPEI HOSPITAL	91-4745	NCDC	6.9569	158.2178	30	6	15MIN	1980-2007
		POHNPEI WSO	91-4751	NCDC	**6.9500**	158.2167	120	6	DLY NMIN	1951-2008 1973-1997
FSM/YAP	GAGIL-TAMIL	TAMIL	91-4831	NCDC*	9.5500	138.1500	70	3	DLY	1991-2008
	MAAP	MAAP	91-4446	NCDC*	9.6053	138.1786	49	3	DLY	1991-2008
	RUMUNG	RUMUNG	91-4808	NCDC*	9.6244	138.1592	65	3	DLY	1993-2008
	ULITHI	ULITHI	91-4892	NCDC*	**10.0204**	**139.7916**	6	3	DLY	1954-2008
	WOLEAI	WOLEAI ATOLL	91-4911	NCDC*	**7.3797**	**143.9113**	7	5	DLY	1968-2008
	YAP	GILMAN	91-4213	NCDC*	9.4508	**138.0619**	50	3	DLY	1997-2008
		LUWEECH	91-4429	NCDC*	**9.4833**	**138.0833**	33	3	DLY	1987-2008

Territory/ state	Island/atoll	Station name	Station ID	Source of data	Latitude	Longitude	Elevation (ft)	Region	Type	Period of record
		NORTH FANIF	91-4585	NCDC*	**9.5742**	**138.1108**	10	3	DLY	1993-2008
		YAP ISLAND WSO AP	91-4951	NCDC	**9.5167**	**138.1333**	44	3	DLY HLY NMIN	1951-2008 1985-2008 1973-1997
RMI	AILINGLAPALAP	AILINGLAPALAP	91-3915	NCDC*	**7.2755**	**168.8246**	6	7	DLY	1985-2006
	ENEWETAK	ENEWETAK WSO	91-4165	NCDC	**11.3500**	**162.3406**	10	8	DLY	1953-1978
	JALUIT	JALUIT	91-4304	NCDC*	5.9167	**169.6432**	6	7	DLY	1956-2005
	KWAJALEIN	KWAJALEIN MISSLE RANGE	91-4375	NCDC*	**8.7279**	**167.7374**	7	8	DLY	1952-2008
	MAJURO	MAJURO WBAS AP	91-4460	NCDC*	**7.0906**	171.3833	10	7	DLY HLY NMIN	1954-2008 1984-2008 1973-1997
	MILI	MILI	91-4487	NCDC*	6.0833	171.7333	10	7	DLY	1985-2006
	UTIRIK	UTIRIK	91-4895	NCDC*	**11.2300**	**169.8500**	6	8	DLY	1985-2006
	WOTJE	WOTJE	91-4903	NCDC*	9.4667	**170.2341**	6	8	DLY	1985-2006
WAKE	WAKE	WAKE ISLAND	91-4901	NCDC	19.2833	166.6500	12	9	DLY HLY	1953-2004 1985-2004
AS	TUTUILA	AASUFOU	91-4000	NCDC	-14.3167	-170.7667	1340	10	DLY	1980-2008
		AFONO	91-4005	NCDC	-14.2667	-170.6500	600	10	DLY	1980-1998
		FAGA ALU RSVR	91-4135	NCDC	-14.3000	-170.7000	820	10	DLY	1963-1976
		LEONE	91-4397	NCDC	**-14.3500**	-170.7833	20	10	DLY	1955-1978
		MALAELOA	91-4594	NCDC	-14.3333	-170.7667	139	10	15MIN	1980-2007
		MALAEIMI NR MAPUSAGA	93-1691	USGS	**-14.3225**	**-170.7381**	140	10	DLY	1990-2008
		PAGO PAGO WSO AP	91-4690	NCDC	**-14.3333**	**-170.7167**	12	10	DLY HLY NMIN	1956-2008 1984-2008 1984-1997
		VAIPITO	91-4902	NCDC	**-14.2678**	**-170.6847**	265	10	DLY 15MIN	1958-2007 1979-2007
		VAIPITO RES RG AT PAGO PAGO	93-3390	USGS	**-14.2847**	**-170.7067**	305	10	DLY	1989-2008

Appendix A.7 Regional L-moment ratios

Table A.7.1. Number of stations, total number of data years, sample estimates of regional L-moment ratios: coefficient of L-variation (L-CV), L-skewness and L-kurtosis for each region and duration.

Region	Duration	Number of stations	Number of data years	L-CV	L-skewness	L-kurtosis
1	1-hour	3	62	0.193	0.228	0.209
	2-hour	3	61	0.203	0.233	0.194
	3-hour	3	64	0.213	0.175	0.205
	6-hour	3	65	0.245	0.223	0.225
	12-hour	3	65	0.255	0.253	0.190
	1-day	6	114	0.267	0.291	0.235
	2-day	6	112	0.265	0.248	0.146
	4-day	6	110	0.233	0.199	0.135
	7-day	6	113	0.224	0.189	0.130
	10-day	6	113	0.218	0.196	0.120
	20-day	6	113	0.200	0.176	0.141
	30-day	6	112	0.185	0.130	0.123
	45-day	6	114	0.176	0.103	0.103
	60-day	6	112	0.168	0.098	0.070
2	1-hour	6	121	0.166	0.186	0.175
	2-hour	6	122	0.196	0.238	0.117
	3-hour	6	123	0.208	0.251	0.180
	6-hour	6	123	0.220	0.248	0.202
	12-hour	6	123	0.223	0.223	0.179
	1-day	15	462	0.266	0.306	0.197
	2-day	15	457	0.245	0.301	0.215
	4-day	15	473	0.218	0.275	0.228
	7-day	15	473	0.203	0.262	0.219
	10-day	15	471	0.188	0.244	0.209
	20-day	15	474	0.175	0.200	0.178
	30-day	15	474	0.160	0.162	0.175
	45-day	15	474	0.146	0.082	0.162
	60-day	15	466	0.143	0.091	0.166
3	1-hour	1	21	0.277	-0.113	-0.069
	2-hour	1	21	0.299	-0.042	-0.036
	3-hour	1	21	0.307	-0.056	-0.031
	6-hour	1	21	0.314	-0.049	0.005
	12-hour	1	21	0.344	-0.002	-0.007
	1-day	8	196	0.189	0.177	0.178
	2-day	8	196	0.193	0.201	0.167
	4-day	8	196	0.179	0.239	0.222

Region	Duration	Number of stations	Number of data years	L-CV	L-skewness	L-kurtosis
	7-day	8	195	0.170	0.212	0.235
	10-day	8	193	0.159	0.227	0.258
	20-day	8	197	0.144	0.116	0.216
	30-day	8	195	0.136	0.096	0.185
	45-day	8	196	0.122	0.095	0.199
	60-day	8	196	0.116	0.083	0.160
4	1-hour	1	23	0.148	0.242	0.229
	2-hour	1	23	0.182	0.216	0.120
	3-hour	1	23	0.165	0.072	0.094
	6-hour	1	23	0.131	0.008	0.213
	12-hour	1	23	0.174	0.238	0.239
	1-day	4	119	0.207	0.25	0.185
	2-day	4	117	0.207	0.307	0.176
	4-day	4	117	0.180	0.213	0.177
	7-day	4	118	0.153	0.154	0.168
	10-day	4	118	0.148	0.186	0.157
	20-day	4	118	0.124	0.179	0.178
	30-day	4	118	0.122	0.156	0.147
	45-day	4	119	0.118	0.112	0.121
	60-day	4	118	0.116	0.128	0.152
5	1-hour	1	16	0.181	0.299	0.15
	2-hour	1	16	0.213	0.308	0.275
	3-hour	1	16	0.216	0.354	0.295
	6-hour	1	16	0.200	0.393	0.360
	12-hour	1	16	0.256	0.503	0.559
	1-day	4	133	0.18	0.246	0.225
	2-day	4	134	0.186	0.264	0.222
	4-day	4	134	0.182	0.253	0.213
	7-day	4	133	0.175	0.246	0.218
	10-day	4	132	0.157	0.247	0.208
	20-day	4	133	0.134	0.159	0.282
	30-day	4	132	0.118	0.147	0.261
	45-day	4	133	0.114	0.137	0.205
	60-day	4	131	0.107	0.125	0.172
6	1-hour	1	27	0.156	0.18	0.178
	2-hour	1	27	0.168	0.124	0.098
	3-hour	1	27	0.155	0.084	0.093
	6-hour	1	27	0.169	0.163	0.075
	12-hour	1	27	0.213	0.36	0.165

Region	Duration	Number of stations	Number of data years	L-CV	L-skewness	L-kurtosis
	1-day	11	275	0.187	0.270	0.213
	2-day	11	275	0.180	0.273	0.167
	4-day	11	279	0.164	0.249	0.195
	7-day	11	279	0.142	0.240	0.177
	10-day	11	279	0.137	0.218	0.144
	20-day	11	279	0.120	0.189	0.131
	30-day	11	279	0.115	0.18	0.156
	45-day	11	279	0.114	0.164	0.164
	60-day	11	279	0.108	0.151	0.139
7	1-hour	1	21	0.090	-0.071	-0.016
	2-hour	1	21	0.109	0.126	0.044
	3-hour	1	21	0.111	0.159	0.070
	6-hour	1	22	0.169	0.252	0.179
	12-hour	1	22	0.195	0.437	0.348
	1-day	4	109	0.188	0.229	0.147
	2-day	4	109	0.179	0.267	0.245
	4-day	4	109	0.173	0.194	0.180
	7-day	4	109	0.153	0.168	0.220
	10-day	4	106	0.132	0.155	0.162
	20-day	4	108	0.117	0.060	0.139
	30-day	4	108	0.117	0.042	0.145
	45-day	4	109	0.119	0.049	0.109
	60-day	4	107	0.111	0.083	0.151
8	1-hour	0	-	-	-	-
	2-hour	0	-	-	-	-
	3-hour	0	-	-	-	-
	6-hour	0	-	-	-	-
	12-hour	0	-	-	-	-
	1-day	4	109	0.202	0.295	0.211
	2-day	4	110	0.220	0.268	0.219
	4-day	4	110	0.215	0.290	0.237
	7-day	4	110	0.203	0.267	0.255
	10-day	4	109	0.182	0.269	0.248
	20-day	4	110	0.173	0.161	0.174
	30-day	4	110	0.170	0.18	0.216
	45-day	4	110	0.161	0.101	0.179
	60-day	4	108	0.149	0.12	0.153
9	1-hour	1	12	0.148	0.284	0.330
	2-hour	1	12	0.226	0.274	0.124

Region	Duration	Number of stations	Number of data years	L-CV	L-skewness	L-kurtosis
	3-hour	1	12	0.238	0.260	-0.021
	6-hour	1	12	0.280	0.262	-0.007
	12-hour	1	12	0.279	0.337	0.014
	1-day	1	52	0.238	0.284	0.121
	2-day	1	52	0.258	0.298	0.152
	4-day	1	52	0.271	0.350	0.210
	7-day	1	52	0.281	0.384	0.242
	10-day	1	52	0.275	0.360	0.220
	20-day	1	52	0.249	0.286	0.211
	30-day	1	52	0.218	0.282	0.303
	45-day	1	52	0.213	0.222	0.264
	60-day	1	52	0.224	0.237	0.256
10	1-hour	3	62	0.138	0.180	0.088
	2-hour	3	62	0.166	0.227	0.116
	3-hour	3	62	0.173	0.189	0.162
	6-hour	3	62	0.186	0.211	0.193
	12-hour	3	62	0.182	0.284	0.289
	1-day	9	210	0.184	0.172	0.120
	2-day	9	210	0.180	0.207	0.140
	4-day	9	192	0.181	0.224	0.158
	7-day	9	213	0.172	0.130	0.172
	10-day	9	213	0.158	0.124	0.155
	20-day	9	213	0.138	0.066	0.098
	30-day	9	214	0.130	0.057	0.110
	45-day	9	211	0.123	0.033	0.092
	60-day	9	211	0.123	0.039	0.122

Appendix A.8 Regional heterogeneity measures

Table A.8.1. Regional heterogeneity measure H1 for 1-hour through 60-day durations. H1 was calculated only for regions/durations with at least 2 stations.

Duration	Region									
	1	2	3	4	5	6	7	8	9	10
1-hour	1.20	1.30		-0.30						0.07
2-hour	0.62	1.48		-0.47						-1.51
3-hour	0.31	0.91		-0.40						-0.45
6-hour	-0.68	-0.64		-0.39						0.51
12-hour	-0.34	-0.29		-0.39						-0.11
1-day	-0.65	-0.38	-1.24	-1.15	1.10	1.33	-1.34	1.40		1.56
2-day	-0.31	-0.18	0.85	-0.42	1.00	-0.58	0.13	0.64		0.32
4-day	-0.42	0.50	0.78	0.49	-0.26	-0.09	-0.18	2.08		0.04
7-day	1.18	-0.92	0.81	1.28	-0.99	-0.99	-0.29	1.57		0.03
10-day	0.30	-0.99	0.45	1.23	0.30	-1.21	-0.96	2.13		1.63
20-day	-0.34	-0.72	1.85	0.41	0.47	-0.55	0.23	2.50		0.12
30-day	-0.97	1.48	1.10	1.78	2.16	1.01	0.72	1.55		0.39
45-day	-0.27	2.58	1.61	2.67	1.76	0.46	1.17	3.05		-0.27
60-day	0.15	2.59	0.34	1.82	2.37	0.83	-0.72	2.32		0.57

Appendix A.9 Regional growth factors for selected ARIs and AEPs

Table A.9.1. Regional growth factors (RGF) used to calculate precipitation frequency estimates based on partial duration series for selected durations and average reccurence intervals.

Region	Duration	Average reccurence interval (years)									
		1	**2**	**5**	**10**	**25**	**50**	**100**	**200**	**500**	**1000**
1	1-hour	0.83	1.01	1.27	1.47	1.76	1.99	2.23	2.49	2.85	3.14
	2-hour	0.81	1.02	1.31	1.55	1.88	2.15	2.43	2.73	3.15	3.49
	3-hour	0.80	1.02	1.32	1.57	1.91	2.19	2.48	2.79	3.22	3.57
	6-hour	0.79	1.02	1.34	1.59	1.95	2.24	2.54	2.87	3.32	3.68
	12-hour	0.76	1.02	1.38	1.68	2.09	2.42	2.77	3.14	3.66	4.08
	1-day	0.76	1.02	1.39	1.68	2.09	2.42	2.77	3.14	3.66	4.08
	2-day	0.78	1.02	1.35	1.62	1.99	2.30	2.61	2.95	3.42	3.80
	4-day	0.79	1.02	1.34	1.60	1.95	2.24	2.54	2.86	3.30	3.66
	7-day	0.81	1.02	1.31	1.55	1.87	2.12	2.39	2.67	3.06	3.37
	10-day	0.82	1.02	1.30	1.52	1.82	2.06	2.30	2.56	2.92	3.20
	20-day	0.84	1.03	1.28	1.48	1.74	1.95	2.16	2.37	2.66	2.89
	30-day	0.85	1.03	1.27	1.45	1.69	1.87	2.05	2.23	2.47	2.66
	45-day	0.86	1.04	1.26	1.42	1.63	1.78	1.93	2.08	2.26	2.40
	60-day	0.87	1.04	1.26	1.41	1.60	1.73	1.86	1.98	2.13	2.23
2	1-hour	0.85	1.02	1.24	1.42	1.66	1.86	2.05	2.26	2.54	2.75
	2-hour	0.85	1.02	1.25	1.43	1.68	1.87	2.07	2.28	2.56	2.78
	3-hour	0.85	1.02	1.26	1.45	1.70	1.90	2.11	2.33	2.62	2.85
	6-hour	0.82	1.02	1.31	1.53	1.83	2.07	2.32	2.57	2.92	3.20
	12-hour	0.77	1.03	1.38	1.66	2.03	2.33	2.64	2.95	3.39	3.73
	1-day	0.77	1.03	1.39	1.67	2.06	2.36	2.67	3.00	3.44	3.79
	2-day	0.79	1.03	1.36	1.62	1.97	2.25	2.54	2.83	3.24	3.56
	4-day	0.79	1.03	1.35	1.60	1.94	2.21	2.49	2.77	3.17	3.48
	7-day	0.81	1.02	1.31	1.54	1.85	2.09	2.34	2.60	2.96	3.24
	10-day	0.83	1.02	1.29	1.50	1.79	2.02	2.25	2.49	2.83	3.09
	20-day	0.84	1.02	1.26	1.45	1.71	1.92	2.13	2.35	2.65	2.88
	30-day	0.85	1.02	1.25	1.43	1.68	1.87	2.07	2.27	2.56	2.78
	45-day	0.86	1.02	1.23	1.39	1.62	1.79	1.97	2.16	2.42	2.63
	60-day	0.88	1.02	1.20	1.35	1.54	1.70	1.86	2.03	2.26	2.44
3	1-hour	0.82	1.03	1.31	1.52	1.81	2.03	2.26	2.49	2.80	3.04
	2-hour	0.83	1.03	1.29	1.50	1.78	1.99	2.21	2.43	2.73	2.97
	3-hour	0.83	1.03	1.29	1.49	1.76	1.97	2.18	2.39	2.69	2.91
	6-hour	0.84	1.03	1.27	1.46	1.72	1.92	2.12	2.32	2.60	2.81
	12-hour	0.85	1.02	1.26	1.44	1.68	1.87	2.06	2.25	2.51	2.72
	1-day	0.86	1.02	1.24	1.41	1.64	1.82	2.00	2.18	2.43	2.63
	2-day	0.86	1.02	1.23	1.40	1.62	1.79	1.96	2.14	2.38	2.57

	4-day	0.86	1.02	1.23	1.40	1.62	1.79	1.96	2.14	2.38	2.57
	7-day	0.87	1.02	1.22	1.38	1.60	1.76	1.93	2.10	2.33	2.51
	10-day	0.87	1.02	1.22	1.37	1.58	1.74	1.90	2.07	2.29	2.47
	20-day	0.88	1.02	1.21	1.35	1.55	1.70	1.86	2.01	2.23	2.40
	30-day	0.88	1.02	1.20	1.34	1.53	1.68	1.83	1.99	2.20	2.36
	45-day	0.89	1.02	1.19	1.32	1.51	1.65	1.79	1.94	2.14	2.29
	60-day	0.90	1.02	1.18	1.30	1.47	1.60	1.74	1.88	2.06	2.21
4	1-hour	0.87	1.01	1.21	1.36	1.58	1.76	1.94	2.14	2.41	2.63
	2-hour	0.87	1.01	1.21	1.36	1.58	1.76	1.94	2.14	2.41	2.63
	3-hour	0.87	1.01	1.21	1.36	1.58	1.76	1.94	2.14	2.41	2.63
	6-hour	0.87	1.01	1.21	1.36	1.58	1.76	1.94	2.14	2.41	2.63
	12-hour	0.87	1.01	1.21	1.36	1.58	1.76	1.94	2.14	2.41	2.63
	1-day	0.87	1.01	1.20	1.36	1.57	1.75	1.93	2.12	2.39	2.60
	2-day	0.88	1.01	1.20	1.35	1.56	1.72	1.90	2.08	2.34	2.55
	4-day	0.88	1.01	1.20	1.34	1.55	1.71	1.88	2.05	2.30	2.49
	7-day	0.89	1.02	1.19	1.33	1.52	1.67	1.83	1.99	2.20	2.38
	10-day	0.89	1.02	1.19	1.33	1.51	1.65	1.80	1.95	2.15	2.31
	20-day	0.89	1.02	1.19	1.32	1.49	1.63	1.77	1.91	2.10	2.25
	30-day	0.89	1.02	1.19	1.31	1.49	1.62	1.75	1.89	2.07	2.21
	45-day	0.90	1.02	1.18	1.31	1.47	1.60	1.73	1.86	2.03	2.17
	60-day	0.90	1.02	1.18	1.30	1.46	1.58	1.71	1.83	2.00	2.13
5	1-hour	0.88	1.01	1.20	1.35	1.56	1.74	1.92	2.12	2.41	2.64
	2-hour	0.88	1.01	1.19	1.34	1.55	1.72	1.90	2.09	2.36	2.59
	3-hour	0.88	1.01	1.19	1.34	1.55	1.71	1.89	2.08	2.36	2.58
	6-hour	0.88	1.01	1.20	1.35	1.57	1.74	1.93	2.12	2.41	2.64
	12-hour	0.87	1.01	1.21	1.37	1.60	1.78	1.98	2.19	2.49	2.73
	1-day	0.87	1.01	1.21	1.37	1.59	1.77	1.96	2.16	2.44	2.68
	2-day	0.88	1.01	1.20	1.35	1.57	1.74	1.92	2.11	2.37	2.59
	4-day	0.88	1.01	1.20	1.35	1.56	1.73	1.90	2.08	2.34	2.54
	7-day	0.88	1.01	1.20	1.34	1.54	1.70	1.86	2.04	2.28	2.46
	10-day	0.88	1.01	1.19	1.33	1.53	1.68	1.84	2.00	2.23	2.41
	20-day	0.89	1.02	1.19	1.32	1.50	1.64	1.78	1.93	2.14	2.29
	30-day	0.89	1.02	1.18	1.31	1.49	1.62	1.76	1.90	2.09	2.24
	45-day	0.90	1.02	1.18	1.30	1.47	1.60	1.73	1.87	2.05	2.19
	60-day	0.90	1.02	1.17	1.29	1.46	1.58	1.71	1.84	2.01	2.15
6	1-hour	0.86	1.02	1.23	1.40	1.63	1.81	1.99	2.18	2.44	2.65
	2-hour	0.86	1.02	1.24	1.41	1.65	1.83	2.02	2.21	2.47	2.68
	3-hour	0.86	1.02	1.24	1.42	1.66	1.84	2.03	2.23	2.50	2.70
	6-hour	0.85	1.02	1.25	1.43	1.67	1.86	2.06	2.26	2.54	2.75
	12-hour	0.85	1.02	1.26	1.44	1.69	1.89	2.09	2.29	2.57	2.79

	1-day	0.85	1.02	1.26	1.44	1.69	1.88	2.07	2.27	2.54	2.75
	2-day	0.86	1.02	1.24	1.41	1.64	1.81	1.98	2.16	2.40	2.59
	4-day	0.87	1.03	1.24	1.40	1.61	1.77	1.93	2.09	2.30	2.46
	7-day	0.88	1.03	1.23	1.38	1.57	1.71	1.85	1.99	2.17	2.31
	10-day	0.88	1.03	1.22	1.35	1.53	1.67	1.79	1.92	2.09	2.22
	20-day	0.90	1.03	1.19	1.31	1.46	1.57	1.69	1.79	1.94	2.04
	30-day	0.90	1.03	1.19	1.30	1.45	1.56	1.66	1.77	1.90	2.00
	45-day	0.91	1.03	1.18	1.30	1.44	1.54	1.65	1.75	1.88	1.97
	60-day	0.91	1.03	1.18	1.29	1.42	1.52	1.62	1.72	1.84	1.93
7	1-hour	0.88	1.02	1.21	1.35	1.56	1.72	1.89	2.08	2.34	2.55
	2-hour	0.88	1.02	1.20	1.35	1.55	1.71	1.88	2.06	2.32	2.52
	3-hour	0.88	1.02	1.20	1.35	1.55	1.71	1.87	2.05	2.30	2.51
	6-hour	0.88	1.02	1.20	1.34	1.54	1.70	1.86	2.03	2.27	2.47
	12-hour	0.88	1.02	1.20	1.34	1.53	1.69	1.84	2.01	2.24	2.43
	1-day	0.88	1.02	1.20	1.34	1.53	1.68	1.83	1.99	2.21	2.39
	2-day	0.88	1.02	1.20	1.34	1.53	1.67	1.82	1.98	2.20	2.37
	4-day	0.88	1.02	1.21	1.35	1.54	1.68	1.83	1.98	2.19	2.35
	7-day	0.89	1.02	1.20	1.33	1.51	1.64	1.78	1.91	2.09	2.23
	10-day	0.89	1.03	1.20	1.33	1.49	1.62	1.74	1.87	2.03	2.15
	20-day	0.90	1.03	1.19	1.31	1.47	1.58	1.69	1.80	1.94	2.04
	30-day	0.90	1.03	1.19	1.30	1.45	1.56	1.66	1.76	1.89	1.99
	45-day	0.91	1.03	1.18	1.29	1.43	1.53	1.63	1.73	1.85	1.94
	60-day	0.91	1.03	1.18	1.29	1.42	1.52	1.62	1.71	1.83	1.92
8	1-hour	0.87	1.02	1.22	1.39	1.61	1.79	1.99	2.19	2.49	2.73
	2-hour	0.87	1.02	1.22	1.38	1.60	1.78	1.97	2.17	2.46	2.70
	3-hour	0.87	1.02	1.22	1.38	1.60	1.77	1.96	2.16	2.44	2.68
	6-hour	0.87	1.02	1.22	1.37	1.59	1.76	1.94	2.13	2.41	2.63
	12-hour	0.87	1.02	1.21	1.37	1.58	1.75	1.92	2.11	2.37	2.58
	1-day	0.88	1.02	1.21	1.36	1.57	1.74	1.91	2.08	2.33	2.54
	2-day	0.87	1.02	1.22	1.37	1.57	1.74	1.90	2.08	2.33	2.52
	4-day	0.87	1.02	1.22	1.38	1.59	1.75	1.92	2.10	2.34	2.54
	7-day	0.87	1.02	1.22	1.37	1.58	1.74	1.90	2.07	2.30	2.48
	10-day	0.88	1.02	1.22	1.36	1.56	1.72	1.87	2.04	2.25	2.43
	20-day	0.88	1.02	1.21	1.35	1.54	1.68	1.83	1.98	2.17	2.33
	30-day	0.89	1.03	1.21	1.34	1.52	1.65	1.78	1.92	2.09	2.22
	45-day	0.89	1.03	1.20	1.33	1.50	1.62	1.74	1.86	2.01	2.12
	60-day	0.90	1.03	1.20	1.33	1.48	1.60	1.71	1.82	1.96	2.06
9	1-hour	0.89	1.03	1.21	1.34	1.52	1.65	1.78	1.92	2.10	2.25
	2-hour	0.89	1.03	1.21	1.34	1.52	1.65	1.78	1.92	2.10	2.25
	3-hour	0.89	1.03	1.21	1.34	1.52	1.65	1.78	1.92	2.10	2.25

	6-hour	0.89	1.03	1.21	1.34	1.52	1.65	1.78	1.92	2.10	2.25
	12-hour	0.89	1.03	1.21	1.34	1.52	1.65	1.78	1.92	2.11	2.25
	1-day	0.89	1.03	1.21	1.34	1.52	1.65	1.78	1.92	2.11	2.25
	2-day	0.89	1.03	1.21	1.34	1.52	1.65	1.78	1.92	2.10	2.25
	4-day	0.89	1.03	1.21	1.34	1.52	1.65	1.79	1.93	2.11	2.26
	7-day	0.89	1.03	1.21	1.34	1.52	1.65	1.79	1.92	2.11	2.25
	10-day	0.89	1.03	1.21	1.34	1.52	1.65	1.78	1.92	2.10	2.25
	20-day	0.89	1.03	1.21	1.34	1.51	1.65	1.78	1.91	2.10	2.24
	30-day	0.89	1.03	1.20	1.34	1.51	1.64	1.77	1.91	2.09	2.23
	45-day	0.89	1.03	1.20	1.33	1.51	1.64	1.76	1.90	2.07	2.21
	60-day	0.89	1.03	1.20	1.33	1.50	1.63	1.76	1.89	2.06	2.20
10	1-hour	0.90	1.02	1.18	1.30	1.47	1.60	1.73	1.87	2.05	2.20
	2-hour	0.88	1.02	1.21	1.36	1.56	1.71	1.87	2.04	2.26	2.44
	3-hour	0.88	1.02	1.21	1.36	1.56	1.72	1.88	2.05	2.28	2.46
	6-hour	0.87	1.02	1.22	1.37	1.58	1.74	1.91	2.08	2.31	2.50
	12-hour	0.87	1.02	1.23	1.38	1.60	1.77	1.94	2.12	2.37	2.56
	1-day	0.86	1.02	1.23	1.40	1.62	1.79	1.97	2.16	2.41	2.61
	2-day	0.87	1.02	1.22	1.37	1.59	1.75	1.92	2.09	2.33	2.51
	4-day	0.87	1.02	1.22	1.38	1.59	1.75	1.91	2.08	2.31	2.49
	7-day	0.88	1.03	1.22	1.37	1.57	1.72	1.87	2.02	2.22	2.37
	10-day	0.88	1.03	1.21	1.35	1.53	1.67	1.80	1.94	2.11	2.24
	20-day	0.90	1.03	1.20	1.32	1.47	1.59	1.69	1.80	1.94	2.04
	30-day	0.90	1.03	1.19	1.31	1.44	1.54	1.64	1.73	1.84	1.93
	45-day	0.91	1.04	1.19	1.29	1.42	1.51	1.59	1.67	1.77	1.84
	60-day	0.91	1.04	1.19	1.29	1.42	1.50	1.58	1.66	1.75	1.82

Table A.9.2. Regional growth factors (RGF) used to calculate precipitation frequency estimates based on annual maximum series for selected durations and annual exceedance probabilities.

Region	**Duration**	**Annual exceedance probability (AEP)**								
		1/2	**1/5**	**1/10**	**1/25**	**1/50**	**1/100**	**1/200**	**1/500**	**1/1000**
1	1-hour	0.93	1.24	1.46	1.75	1.98	2.23	2.49	2.85	3.14
	2-hour	0.92	1.27	1.53	1.87	2.15	2.43	2.73	3.15	3.49
	3-hour	0.91	1.28	1.55	1.90	2.18	2.48	2.79	3.22	3.57
	6-hour	0.91	1.30	1.57	1.94	2.24	2.54	2.87	3.32	3.68
	12-hour	0.90	1.34	1.66	2.08	2.42	2.77	3.14	3.66	4.08
	1-day	0.90	1.34	1.66	2.08	2.42	2.77	3.14	3.66	4.08
	2-day	0.91	1.31	1.60	1.98	2.29	2.61	2.95	3.42	3.80
	4-day	0.91	1.30	1.58	1.95	2.24	2.54	2.86	3.30	3.66
	7-day	0.92	1.28	1.53	1.86	2.12	2.39	2.67	3.06	3.37

	10-day	0.93	1.26	1.50	1.81	2.05	2.30	2.56	2.92	3.20
	20-day	0.94	1.25	1.46	1.74	1.95	2.16	2.37	2.66	2.89
	30-day	0.95	1.24	1.44	1.68	1.87	2.05	2.23	2.47	2.66
	45-day	0.96	1.23	1.41	1.62	1.78	1.93	2.08	2.26	2.40
	60-day	0.96	1.23	1.40	1.59	1.73	1.86	1.98	2.13	2.23
2	1-hour	0.94	1.22	1.41	1.66	1.85	2.05	2.26	2.54	2.75
	2-hour	0.94	1.22	1.41	1.67	1.87	2.07	2.28	2.56	2.78
	3-hour	0.94	1.23	1.43	1.70	1.90	2.11	2.33	2.62	2.85
	6-hour	0.93	1.27	1.51	1.83	2.07	2.32	2.57	2.92	3.20
	12-hour	0.91	1.34	1.64	2.03	2.33	2.64	2.95	3.39	3.73
	1-day	0.91	1.35	1.65	2.05	2.36	2.67	3.00	3.44	3.79
	2-day	0.91	1.32	1.60	1.96	2.25	2.54	2.83	3.24	3.56
	4-day	0.92	1.31	1.58	1.93	2.20	2.49	2.77	3.17	3.48
	7-day	0.92	1.28	1.52	1.84	2.09	2.34	2.60	2.96	3.24
	10-day	0.93	1.26	1.49	1.78	2.02	2.25	2.49	2.83	3.09
	20-day	0.94	1.23	1.44	1.71	1.92	2.13	2.35	2.65	2.88
	30-day	0.94	1.22	1.41	1.67	1.87	2.07	2.27	2.56	2.78
	45-day	0.95	1.20	1.38	1.61	1.79	1.97	2.16	2.42	2.63
	60-day	0.95	1.18	1.33	1.54	1.70	1.86	2.03	2.26	2.44
3	1-hour	0.93	1.27	1.50	1.80	2.03	2.26	2.49	2.80	3.04
	2-hour	0.93	1.26	1.49	1.77	1.99	2.21	2.43	2.73	2.97
	3-hour	0.94	1.26	1.47	1.75	1.96	2.18	2.39	2.69	2.91
	6-hour	0.94	1.24	1.45	1.71	1.91	2.12	2.32	2.60	2.81
	12-hour	0.94	1.23	1.42	1.67	1.86	2.06	2.25	2.51	2.72
	1-day	0.95	1.22	1.40	1.64	1.82	2.00	2.18	2.43	2.63
	2-day	0.95	1.21	1.38	1.61	1.79	1.96	2.14	2.38	2.57
	4-day	0.95	1.21	1.38	1.61	1.79	1.96	2.14	2.38	2.57
	7-day	0.95	1.20	1.37	1.59	1.76	1.93	2.10	2.33	2.51
	10-day	0.95	1.19	1.36	1.57	1.73	1.90	2.07	2.29	2.47
	20-day	0.95	1.18	1.34	1.54	1.70	1.86	2.01	2.23	2.40
	30-day	0.95	1.18	1.33	1.53	1.68	1.83	1.99	2.20	2.36
	45-day	0.96	1.17	1.31	1.50	1.65	1.79	1.94	2.14	2.29
	60-day	0.96	1.16	1.29	1.47	1.60	1.74	1.88	2.06	2.21
4	1-hour	0.95	1.18	1.35	1.58	1.76	1.94	2.14	2.41	2.63
	2-hour	0.95	1.18	1.35	1.58	1.76	1.94	2.14	2.41	2.63
	3-hour	0.95	1.18	1.35	1.58	1.76	1.94	2.14	2.41	2.63
	6-hour	0.95	1.18	1.35	1.58	1.76	1.94	2.14	2.41	2.63
	12-hour	0.95	1.18	1.35	1.58	1.76	1.94	2.14	2.41	2.63
	1-day	0.95	1.18	1.35	1.57	1.74	1.93	2.12	2.39	2.60
	2-day	0.95	1.18	1.34	1.55	1.72	1.90	2.08	2.34	2.55

	4-day	0.95	1.18	1.33	1.54	1.71	1.88	2.05	2.30	2.49
	7-day	0.95	1.17	1.32	1.52	1.67	1.83	1.99	2.20	2.38
	10-day	0.96	1.17	1.31	1.50	1.65	1.80	1.95	2.15	2.31
	20-day	0.96	1.17	1.31	1.49	1.63	1.77	1.91	2.10	2.25
	30-day	0.96	1.17	1.30	1.48	1.62	1.75	1.89	2.07	2.21
	45-day	0.96	1.16	1.30	1.47	1.60	1.73	1.86	2.03	2.17
	60-day	0.96	1.16	1.29	1.45	1.58	1.71	1.83	2.00	2.13
5	1-hour	0.95	1.17	1.34	1.56	1.73	1.92	2.12	2.41	2.64
	2-hour	0.95	1.17	1.33	1.54	1.71	1.90	2.09	2.36	2.59
	3-hour	0.95	1.17	1.33	1.54	1.71	1.89	2.08	2.36	2.58
	6-hour	0.95	1.18	1.34	1.56	1.74	1.93	2.12	2.41	2.64
	12-hour	0.94	1.18	1.36	1.59	1.78	1.98	2.19	2.49	2.73
	1-day	0.94	1.18	1.35	1.58	1.77	1.96	2.16	2.44	2.68
	2-day	0.95	1.18	1.34	1.56	1.74	1.92	2.11	2.37	2.59
	4-day	0.95	1.18	1.34	1.56	1.73	1.90	2.08	2.34	2.54
	7-day	0.95	1.17	1.33	1.54	1.70	1.86	2.04	2.28	2.46
	10-day	0.95	1.17	1.32	1.52	1.68	1.84	2.00	2.23	2.41
	20-day	0.96	1.16	1.31	1.49	1.64	1.78	1.93	2.14	2.29
	30-day	0.96	1.16	1.30	1.48	1.62	1.76	1.90	2.09	2.24
	45-day	0.96	1.16	1.30	1.47	1.60	1.73	1.87	2.05	2.19
	60-day	0.96	1.16	1.29	1.45	1.58	1.71	1.84	2.01	2.15
6	1-hour	0.94	1.21	1.39	1.63	1.81	1.99	2.18	2.44	2.65
	2-hour	0.94	1.21	1.40	1.64	1.83	2.02	2.21	2.47	2.68
	3-hour	0.94	1.22	1.40	1.65	1.84	2.03	2.23	2.50	2.70
	6-hour	0.94	1.22	1.42	1.67	1.86	2.06	2.26	2.54	2.75
	12-hour	0.94	1.23	1.43	1.69	1.89	2.09	2.29	2.57	2.79
	1-day	0.94	1.23	1.43	1.68	1.87	2.07	2.27	2.54	2.75
	2-day	0.95	1.22	1.40	1.63	1.81	1.98	2.16	2.40	2.59
	4-day	0.95	1.22	1.39	1.61	1.77	1.93	2.09	2.30	2.46
	7-day	0.96	1.21	1.37	1.56	1.71	1.85	1.99	2.17	2.31
	10-day	0.96	1.19	1.34	1.53	1.66	1.79	1.92	2.09	2.22
	20-day	0.97	1.17	1.30	1.46	1.57	1.69	1.79	1.94	2.04
	30-day	0.97	1.17	1.29	1.45	1.56	1.66	1.77	1.90	2.00
	45-day	0.97	1.16	1.29	1.44	1.54	1.65	1.75	1.88	1.97
	60-day	0.97	1.16	1.28	1.42	1.52	1.62	1.72	1.84	1.93
7	1-hour	0.95	1.18	1.34	1.56	1.72	1.89	2.08	2.34	2.55
	2-hour	0.95	1.18	1.34	1.55	1.71	1.88	2.06	2.32	2.52
	3-hour	0.95	1.18	1.34	1.54	1.71	1.87	2.05	2.30	2.51
	6-hour	0.95	1.18	1.33	1.54	1.69	1.86	2.03	2.27	2.47
	12-hour	0.95	1.18	1.33	1.53	1.68	1.84	2.01	2.24	2.43

	1-day	0.96	1.18	1.33	1.52	1.67	1.83	1.99	2.21	2.39
	2-day	0.96	1.18	1.33	1.52	1.67	1.82	1.98	2.20	2.37
	4-day	0.96	1.18	1.34	1.53	1.68	1.83	1.98	2.19	2.35
	7-day	0.96	1.18	1.32	1.51	1.64	1.78	1.91	2.09	2.23
	10-day	0.96	1.18	1.32	1.49	1.62	1.74	1.87	2.03	2.15
	20-day	0.97	1.17	1.30	1.46	1.58	1.69	1.80	1.94	2.04
	30-day	0.97	1.17	1.29	1.45	1.55	1.66	1.76	1.89	1.99
	45-day	0.97	1.17	1.29	1.43	1.53	1.63	1.73	1.85	1.94
	60-day	0.97	1.16	1.28	1.42	1.52	1.62	1.71	1.83	1.92
8	1-hour	0.95	1.20	1.37	1.61	1.79	1.99	2.19	2.49	2.73
	2-hour	0.95	1.20	1.37	1.60	1.78	1.97	2.17	2.46	2.70
	3-hour	0.95	1.19	1.36	1.59	1.77	1.96	2.16	2.44	2.68
	6-hour	0.95	1.19	1.36	1.58	1.76	1.94	2.13	2.41	2.63
	12-hour	0.95	1.19	1.36	1.57	1.74	1.92	2.11	2.37	2.58
	1-day	0.95	1.19	1.35	1.57	1.73	1.91	2.08	2.33	2.54
	2-day	0.95	1.19	1.35	1.57	1.73	1.90	2.08	2.33	2.52
	4-day	0.95	1.20	1.36	1.58	1.75	1.92	2.10	2.34	2.54
	7-day	0.95	1.20	1.36	1.57	1.74	1.90	2.07	2.30	2.48
	10-day	0.95	1.19	1.35	1.56	1.72	1.87	2.04	2.25	2.43
	20-day	0.96	1.19	1.34	1.54	1.68	1.83	1.98	2.17	2.33
	30-day	0.96	1.19	1.33	1.52	1.65	1.78	1.92	2.09	2.22
	45-day	0.97	1.18	1.32	1.49	1.62	1.74	1.86	2.01	2.12
	60-day	0.97	1.18	1.32	1.48	1.60	1.71	1.82	1.96	2.06
9	1-hour	0.96	1.18	1.33	1.51	1.65	1.78	1.92	2.10	2.25
	2-hour	0.96	1.18	1.33	1.51	1.65	1.78	1.92	2.10	2.25
	3-hour	0.96	1.18	1.33	1.51	1.65	1.78	1.92	2.10	2.25
	6-hour	0.96	1.18	1.33	1.51	1.65	1.78	1.92	2.10	2.25
	12-hour	0.96	1.18	1.33	1.51	1.65	1.78	1.92	2.11	2.25
	1-day	0.96	1.18	1.33	1.51	1.65	1.78	1.92	2.11	2.25
	2-day	0.96	1.18	1.33	1.51	1.65	1.78	1.92	2.10	2.25
	4-day	0.96	1.19	1.33	1.52	1.65	1.79	1.93	2.11	2.26
	7-day	0.96	1.19	1.33	1.51	1.65	1.79	1.92	2.11	2.25
	10-day	0.96	1.18	1.33	1.51	1.65	1.78	1.92	2.10	2.25
	20-day	0.96	1.18	1.33	1.51	1.64	1.78	1.91	2.10	2.24
	30-day	0.96	1.18	1.33	1.51	1.64	1.77	1.91	2.09	2.23
	45-day	0.96	1.18	1.32	1.50	1.63	1.76	1.90	2.07	2.21
	60-day	0.96	1.18	1.32	1.50	1.63	1.76	1.89	2.06	2.20
10	1-hour	0.96	1.16	1.29	1.46	1.60	1.73	1.87	2.05	2.20
	2-hour	0.95	1.19	1.35	1.55	1.71	1.87	2.04	2.26	2.44
	3-hour	0.95	1.19	1.35	1.56	1.72	1.88	2.05	2.28	2.46

	6-hour	0.95	1.19	1.36	1.57	1.74	1.91	2.08	2.31	2.50
	12-hour	0.95	1.20	1.37	1.60	1.77	1.94	2.12	2.37	2.56
	1-day	0.95	1.21	1.38	1.61	1.79	1.97	2.16	2.41	2.61
	2-day	0.95	1.20	1.36	1.58	1.75	1.92	2.09	2.33	2.51
	4-day	0.95	1.20	1.37	1.58	1.75	1.91	2.08	2.31	2.49
	7-day	0.96	1.20	1.36	1.56	1.72	1.87	2.02	2.22	2.37
	10-day	0.96	1.19	1.34	1.53	1.67	1.80	1.94	2.11	2.24
	20-day	0.97	1.18	1.31	1.47	1.58	1.69	1.80	1.94	2.04
	30-day	0.97	1.17	1.30	1.44	1.54	1.64	1.73	1.84	1.93
	45-day	0.98	1.17	1.29	1.42	1.51	1.59	1.67	1.77	1.84
	60-day	0.98	1.18	1.29	1.41	1.50	1.58	1.66	1.75	1.82

Glossary

(All definitions are given relative to precipitation frequency analyses in NOAA Atlas 14)

ANNUAL EXCEEDANCE PROBABILITY (AEP) – The probability associated with exceeding a given amount in any given year once or more than once; the inverse of AEP provides a measure of the average time between years (and not events) in which a particular value is exceeded at least once; the term is associated with analysis of annual maximum series (see also AVERAGE RECCURENCE INTERVAL).

ANNUAL MAXIMUM SERIES (AMS) – Time series of the largest precipitation amounts in a continuous 12-month period (calendar or water year) for a specified duration at a given station.

ArcInfo ASCII GRID (a.k.a. ESRI ASCII grid) – Grid format with a 6-line header, which provides location and size of the grid and precedes the actual grid data. The grid is written as a series of rows, which contain one ASCII integer or floating point value per column in the grid. The first element of the grid corresponds to the upper-left corner of the grid.

AVERAGE RECURRENCE INTERVAL (ARI; a.k.a. RETURN PERIOD, AVERAGE RETURN PERIOD) – Average time between *cases of a particular precipitation magnitude* for a specified duration and at a given location; the term is associated with the analysis of partial duration series. However, ARI is frequently calculated as the inverse of AEP for the annual maximum series; in this case it represents the average period between years in which a given precipitation magnitude is exceeded at least once.

CASCADE, RESIDUAL ADD-BACK (CRAB) – The HDSC-developed spatial interpolation procedure for deriving grids of precipitation frequency estimates from grids of mean annual maxima and point precipitation frequency estimates for a given duration.

CONSTRAINED OBSERVATION – A precipitation measurement or observation bound by clock hours and occurring in regular intervals. This observation requires conversion to an unconstrained value (see UNCONSTRAINED OBSERVATION) because maximum 60-minute or 24-hour amounts seldom fall within a single hourly or daily observation period.

DATA YEARS – See RECORD LENGTH.

DEPTH-DURATION-FREQUENCY (DDF) CURVE – Graphical depiction of precipitation frequency estimates in terms of depth, duration and frequency (ARI or AEP).

DISCORDANCY MEASURE – Measure used for data quality control and to determine if a station is consistent with other stations in a region. It is calculated for each station in a region as the distance of a point in a 3-dimensional space represented by at-site estimates of three L-moment ratios (L-CV, L-skewness, and L-kurtosis) from the cluster center that is defined using the unweighted average of the three L-moment ratios from all stations within the region.

DISTRIBUTION FUNCTION (CUMULATIVE DISTRIBUTION FUNCTION) – Mathematical description that completely describes frequency distribution of a random variable, here precipitation. Distribution functions commonly used to describe precipitation data include 3-parameter distributions such as Generalized Extreme Value (GEV), Generalized Normal (GNO), Generalized Pareto (GPA), Generalized Logistic (GLO) and Pearson type III (PE3), the 4-parameter Kappa (KAP) distribution, and the 5-parameter Wakeby (WAK) distribution.

FEDERAL GEOGRAPHIC DATA COMMITTEE (FGDC) COMPLIANT METADATA – A document that describes the content, quality, condition, and other characteristics of data and follows the guidelines set forth by the FGDC; metadata is "data about data."

FREQUENCY – General term for specifying the average recurrence interval or annual exceedance probability associated with specific precipitation magnitude for a given duration.

FREQUENCY ANALYSIS – Process of derivation of a mathematical model that represents the relationship between precipitation magnitudes and their frequencies.

FREQUENCY ESTIMATE – Precipitation magnitude associated with specific average recurrence interval or annual exceedance probability for a given duration.

HEAVY PRECIPITATION – Precipitation with an average recurrence interval roughly between 1 year and 1,000 years for a given duration.

HETEROGENEITY MEASURE, H1 – Measure that is used to assess regional homogeneity, or lack thereof. It is based on comparison of the variability of sample estimates of coefficient of L-variation in a region relative to their expected variability obtained through simulations.

INDEX-FLOOD – The mean of the annual maximum series at each observing station.

INDEX-FLOOD REGIONAL FREQUENCY ANALYSIS - Regional frequency analysis approach that assumes that all stations in a homogeneous region have a common regional growth curve that becomes station-specific after scaling by a station-specific index flood value. The name comes from its first applications in flood frequency analysis but the method is applicable to precipitation or any other kind of data.

INTENSITY-DURATION-FREQUENCY (IDF) CURVE – Graphical depiction of precipitation frequency estimates in terms of intensity, duration and frequency.

INTERNAL CONSISTENCY – Term used to describe the required behavior of the precipitation frequency estimates from one duration to the next or from one frequency to the next. For instance, it is required that the 100-year 3-hour precipitation frequency estimates be greater than (or at least equal to) corresponding 100-year 2-hour estimates.

L-MOMENTS – L-moments are summary statistics for probability distributions and data samples. They are analogous to ordinary moments, providing measures of location, dispersion, skewness, kurtosis, and other aspects of the shape of probability distributions or data samples, but are computed from linear combinations of the ordered data values (hence the prefix L).

MEAN ANNUAL PRECIPITATION (MAP) – The average precipitation for a year (usually calendar) based on the whole period of record or for a selected period (usually 30 year period such as 1971-2000).

PARTIAL DURATION SERIES (PDS) – Time series that includes all precipitation amounts for a specified duration at a given station above a pre-defined threshold regardless of year; it can include more than one event in any particular year.

PRECIPITATION FREQUENCY DATA SERVER (PFDS) – The on-line portal for all NOAA Atlas 14 deliverables, documentation, and information; http://hdsc.nws.noaa.gov/hdsc/pfds/.

PARAMETER-ELEVATION REGRESSIONS ON INDEPENDENT SLOPES MODEL (PRISM) – Hybrid statistical-geographic approach to mapping climate data developed by Oregon State University's PRISM Climate Group.

QUANTILE – Generic term to indicate the precipitation frequency estimate associated with either ARI or AEP.

RECORD LENGTH – Number of years in which enough precipitation data existed to extract meaningful annual maxima in a station's period of record (or data years).

REGIONAL GROWTH FACTOR (RGF) – A quantile of a regional dimensionless distribution (regional growth curve) that becomes a location-specific precipitation quantile after scaling by a location-specific index-flood. For a given frequency and duration, there is a single RGF for each region.

UNCONSTRAINED OBSERVATION – A precipitation measurement or observation for a defined duration. However the observation is not made at a specific repeating time, rather the duration is a moveable window through time.

WATER YEAR – Any 12-month period, usually selected to begin and end during a relatively dry season. In NOAA Atlas 14 Volume 5, it is defined as the period from October 1 to September 30.

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