Alaska Department of Transportation & Public Facilities
Alaska University Transportation Center

New 2012 Precipitation Frequency Estimation Analysis for Alaska: Musings on Data Used and the Final Product

Prepared By:
Douglas L. Kane, Ph.D
Svetlana Stuefer, Ph.D
Water and Environmental Research Center
Institute of Northern Engineering
University of Alaska Fairbanks

June 2013

Prepared By:

Alaska University Transportation Center
Duckering Building Room 245
P.O. Box 755900
Fairbanks, AK 99775-5900

Alaska Department of Transportation
Research, Development, and Technology Transfer
2301 Peger Road
Fairbanks, AK 99709-5399

INE/AUTC 13.11

FHWA-AK-RD-13-04

REPORT DOCUMENTATION PAGE

Form approved OMB No.

1. AGENCY USE ONLY (LEAVE BLANK) FHWA-AK-RD-13-04	2. REPORT DATE June 2013	3. REPORT TYPE AND DATES COVERED Final Report (07/01/08-08/31/2013)

4. TITLE AND SUBTITLE
New 2012 Precipitation Frequency Estimation Analysis for Alaska: Musings on Data Used and the Final Product

5. FUNDING NUMBERS
T2-08-15
AUTC #207119
DTRT06-G-0011

6. AUTHOR(S)
Douglas Kane, Ph.D.
Svetlana Stuefer, Ph.D

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Alaska University Transportation Center
P.O. Box 755900
Fairbanks, AK 99775-5900

8. PERFORMING ORGANIZATION REPORT NUMBER
INE/AUTC 13.11

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Research and Innovative Technology Administration (RITA) (USDOT)
1200 New Jersey Ave, SE, Washington DC 20590
Alaska Department of Transportation: Research, Development, and Technology Transfer
2301 Peger Rd., Fairbanks, AK 99709-5399

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
FHWA-AK-RD-13-04

11. SUPPLENMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
No restrictions

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The major product of this study was a precipitation frequency atlas for the entire state of Alaska; this atlas is available at http://dipper.nws.noaa.gov/hdsc/pfds/. The process of contributing to this study provided an opportunity to (1) evaluate the complete precipitation data-collection program for Alaska and (2) compare the new precipitation frequency estimates with those published in 1963. It has been known for some time that the precipitation data-collection program in Alaska has many limitations and challenges. This present report summarizes the limitations of the data collection program identified during the study and includes a comparison of the 1963 and 2012 results for selected stations at major population centers. The authors hope that this report will lead to improvements in data collection so that better precipitation frequency estimates can be made in the future.

14- KEYWORDS: Precipitation (Meteorology) (Jbmbkmp), Analysis of variance (Usa), Statistical sampling (Usw)

15. NUMBER OF PAGES

16. PRICE CODE
N/A

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT N/A

NSN 7540-01-280-5500

STANDARD FORM 298 (Rev. 2-98)
Prescribed by ANSI Std. 239-18 298-1

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The major product of this study was a precipitation frequency atlas for the entire state of Alaska; this atlas is available at http://dipper.nws.noaa.gov/hdsc/pfds/. The process of contributing to this study provided an opportunity to (1) evaluate the complete precipitation data-collection program for Alaska and (2) compare the new precipitation frequency estimates with those published in 1963. It has been known for some time that the precipitation data-collection program in Alaska has many limitations and challenges. This present report summarizes the limitations of the data collection program identified during the study and includes a comparison of the 1963 and 2012 results for selected stations at major population centers. The authors hope that this report will lead to improvements in data collection so that better precipitation frequency estimates can be made in the future.

INTRODUCTION

Estimates of intensity-duration-frequency (IDF) or depth-duration-frequency (DDF) made from records of continuously measured precipitation are used in numerous engineering applications. These estimates were first made for the state of Alaska in 1963 (Miller 1963, 1965, Technical Papers 47 and 52) and repeated recently (Perica et al. 2012). Historically, precipitation stations in Alaska have been sparse. A closer look at the station locations reveals that a majority of the stations are still at low elevations along the coast or on major tributaries. Alaska is a very large state (1,480,000 km^2; 570,000 mi^2); it spans approximately 20° latitude (~51° N to 70° N) and 57° longitude (~130° W to 173° E), an expanse almost equivalent to the Lower 48. This geographic size results in five to seven regional climates that range from arctic to maritime, depending on the criteria used (Arctic, Interior, West Coastal, Southwest Islands, Bristol Bay/Cook Inlet, and South/Southeast Coast). The warm season, when rainfall is possible, varies from 12 months in the southern coastal areas (SW Islands and SE Panhandle) to 4½ months in the Arctic. Annual precipitation over the state varies by over 120 in. (3,050 mm), with the driest regions (less than 10 in.; 254 mm) being the lowlands in Interior Alaska and the coastal plain on the Arctic North Slope, and the wettest regions (120 in.; 3,040 mm) being the mountainous southern/southeastern coast. At higher ungauged areas, annual precipitation can be substantially greater than the figures just given. Permafrost is continuous in the Arctic, discontinuous in the Interior, and completely absent in the southern coastal areas (with the possible exception of some alpine permafrost).

In the Miller (1963) report, 234 daily stations, 9 hourly stations, 18 6-hour stations and 33 Canadian stations were used to estimate precipitation frequency. For the latest precipitation frequency estimation (Perica et al. 2012), data were potentially available from 1,689 stations: 913 daily stations, 667 hourly stations, 73 15-minute stations, and 36 *n*-minute stations. Sixty daily stations and 10 hourly stations in Canada, along its boundary with Alaska, were used. In the final 2012 analyses, 396 daily stations and 121 hourly Alaska stations were used.

When the 1963 study was performed, computers and computer analyses were in their infancy, and calculations made for IDF analyses were done by hand. For this reason, the amount and depth of the analyses were limited. Further, the presentation of the results was limited to hand drawing of contours on maps for each set of durations and frequencies. Hand drawing of these maps for areas with extensive relief was quite challenging considering that there were very few precipitation stations at high latitudes. This difficulty explains why the precipitation contours in Technical Papers 47 and 52 do not clearly reflect the presence of the Alaska Range and the Brooks Range (though it is evident that there are mountains along the coast).

Fifty years later, with the completion of the most recent precipitation frequency estimates for Alaska (Perica et al. 2012), computers were used extensively in all steps of the process. The use of computers allows for much more sophisticated analyses, such as determining the spatial distribution of precipitation frequency estimates in mountainous terrain. While researchers were in a better position to make precipitation frequency estimates in 2012 than in the early 1960s, they still encountered many impediments when performing precipitation frequency estimation. The following is a discussion of some of the major issues faced by the research team in completing the 2012 precipitation frequency analyses for Alaska. The research team was composed of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service (NOAA/NWS), and the University of Alaska Fairbanks, Water and Environmental Research Center (UAF/WERC).

The new 2012 "Precipitation Frequency Atlas" for Alaska can be found online (NOAA Precipitation Frequency Data Server) at http://dipper.nws.noaa.gov/hdsc/pfds/. The citation for this publication is as follows:

> Perica, S., D. Kane, S. Dietz, K. Maitaria, D. Martin, S. Pavlovic, I. Roy, S. Stuefer, A. Tidwell, C. Trypaluk, D. Unruh, M. Yekta, E. Betts, G. Bonnin, S. Heim, L. Hiner, E. Lilly, J. Narayanan, F. Yan, and T. Zhao. 2012. NOAA Atlas 14, Volume 7, Version 2.0, Precipitation Frequency Atlas of the United States, Alaska. NOAA, National Weather Service, Silver Spring, MD.

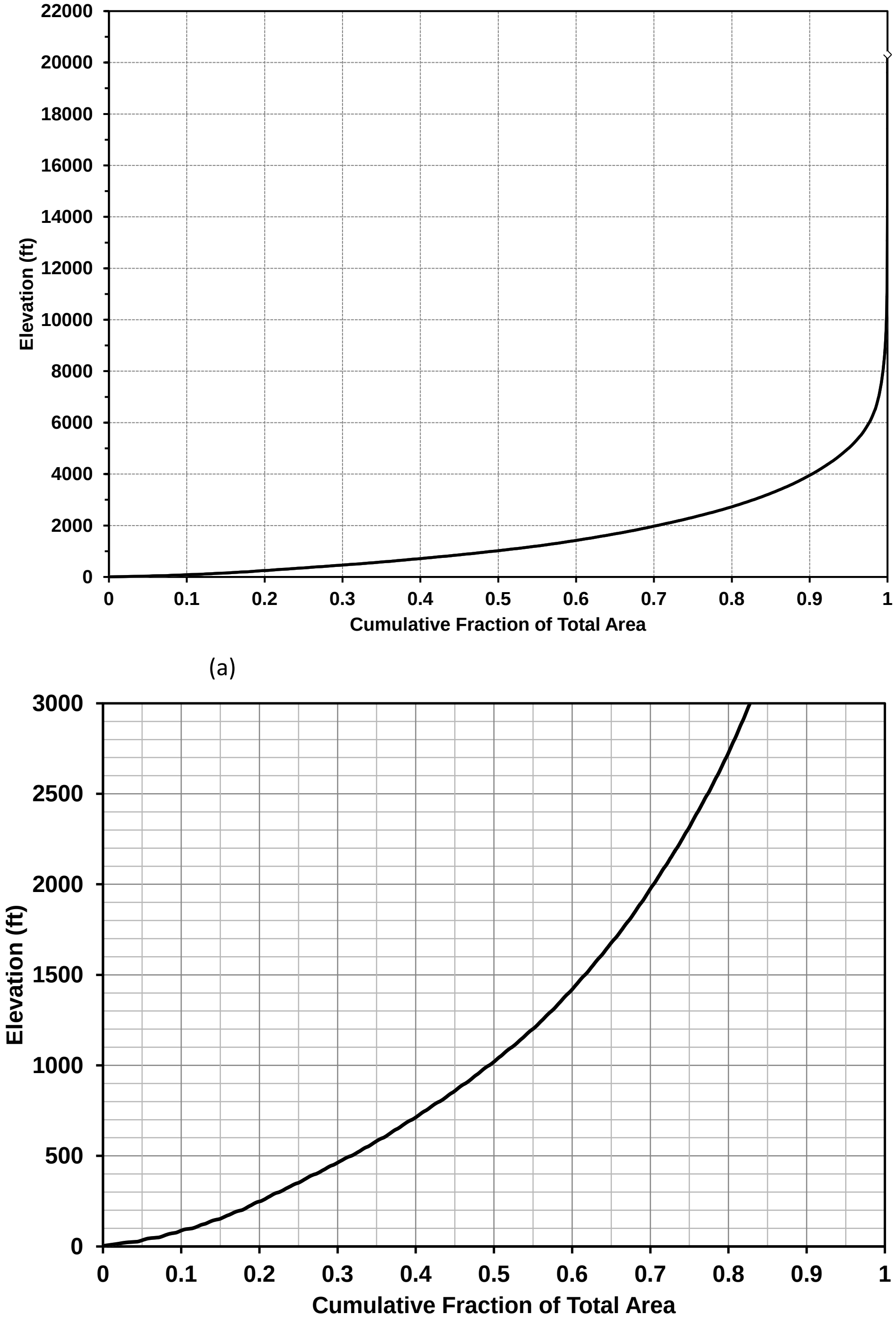
SETTING

Because Alaska is such a large state, it has a wide range of climates, from arctic to maritime. Permafrost is continuous in Arctic Alaska and totally lacking in the southern coastal areas. Alaska's populated centers are generally located along the coast or on major drainages. The collection of meteorological and hydrological data has been sporadic, sparse, and usually confined to low elevations where cities and villages exist. Over 50% of the land area of Alaska is above 1,000 ft (~305 m) in elevation, and 30% is above 2,000 ft (~610 m) in elevation (Figure 1a, b). In the 1963 precipitation frequency analysis, there was approximately one station for every 10,000 mi^2 (28,500 km^2) above 1,000 ft (~305 m); in the 2012 analysis, this statistic had improved by about a factor of 5: one station every 2,100 mi^2 (5,500 km^2).

The wettest month of the year varies across the state. For example, in the Arctic, the wet season lasts from June to September, with August usually the wettest month; in the South/Southeast Coast, the wet season is August to January, with October usually the wettest month.

In general, the annual maximum precipitation event occurs as rain, but it is possible that some of these annual maximum precipitation events occur as solid precipitation. Using solid precipitation measurements in frequency estimation is misleading. The runoff mechanism for solid precipitation is completely different from that of liquid precipitation. Runoff after liquid precipitation can begin immediately, while runoff after solid precipitation occurs only after melting takes place. Also, the amount of solid precipitation can (and usually does) further accumulate before snowmelt occurs. The amount of runoff then depends on the ablation rate.

The biggest advantage of the 2012 analysis in comparison with the 1963 results is the additional 50 years of collected data. In the 1963 study, the maximum record length was about 50 years, while in the 2012 study, itthe maximum record length was over 100 years. The average record length for the 2012 study (Perica et al. 2012) was 32 years for daily stations (*n* = 396) and 18 years for durations between 1 hour and 24 hours. In the 1963 study, stations with 5 years of data were included, while in the 2012 study, all stations with 15 years of data were retained (including some with as few as 9 to 10 years in remote areas). Because of copious stations in the Lower 48 and their longer duration (stations were established earlier relative to Alaska), NOAA/NWS uses the minimum criteria of 30 data years for precipitation frequency estimation in the contiguous states.



(a)

(b)

Figure 1: Hypsometric curve for Alaska; (a) shows the full range of the elevations from sea level to 20,320 ft (6,194 m), illustrated by a diamond on the right vertical axis; (b) shows the same curve in more detail below 3,000 ft (914 m).

PRECIPITATION STATIONS

Some of the shortfalls of the effort to measure precipitation in Alaska—sparse network and poor distribution—were mentioned in the Introduction. The density of precipitation stations in Alaska is at least an order of magnitude less than in the contiguous states, mainly because of the comparatively few populated centers, rugged terrain, extreme climates, and vast size of the state. For example, in California (also a recent location for IDF/DDF analysis), there is approximately one precipitation gauge for every 50 km^2, while in Alaska there is one precipitation gauge for every 880 km^2. Thus, the California density is approximately 18 times greater. There were almost 1,700 potential precipitation stations for use in the recent precipitation frequency estimation for Alaska (Perica et al. 2012); however, only 396 daily and 121 hourly stations were used (one station every 2,860 km^2). The distributions of these daily and hourly (including sub-hourly) stations in Alaska and western Canada are shown in Figures 4.4.2 and 4.4.3 in Perica et al. (2012).

For most of the U.S., there are enough NOAA/NWS stations to do an adequate job of IDF/DDF analyses. However, because of the sparseness of stations in Alaska, data from any source (assuming it passed quality checks) were considered for use in the state's precipitation frequency analyses. Data from the following sources were collected: Alaska Dept. of Transportation and Public Facilities; Environment Canada; USDC Midwestern Region Climate Center; USDC National Climate Data Center; National Interagency Fire Center; USDC Western Region Climate Center; USDA National Resource Conservation Service; USDI Geological Survey; and University of Alaska Fairbanks. Data from Environment Canada were collected along Alaska's eastern boundary; all other boundaries (southern, western, and northern) of Alaska are open water.

Only about one-third of the historical stations that were used for collecting rainfall data were used in the most recent analysis. The reasons why are as follows:

- The period of data collection was too short for frequency analysis. As a rule of thumb, in other regions of the U.S., NOAA now requires the station record to be at least 30 years in length. Using this criterion in the recent Alaska analysis would have resulted in a further reduction in the number of stations used in the analysis by two-thirds. In the Miller (1963) report, 184 daily stations were used in the frequency analysis, where stations with 5 or more years of data were used. Because of the sparse data network in Alaska, the number of years of record needed to be lowered, otherwise there would be even fewer stations used. In the Alaska precipitation dataset, there are ~220 (combined hourly and daily) precipitation stations with 11 to 20 years of record and ~110 stations with 21 to 30 years of record. In the final analysis, a handful of stations (~20) with approximately 10 (9 or 10) years of record were used. The justification for using these stations was that they were in isolated regions of the state, where station density is extremely low (mainly in northern Alaska). Many of these stations with short periods of record are located at research sites where the station is terminated when the research funding expires.
- Often at unstaffed remote sites, the warm season precipitation is measured (either hourly or daily), but the cold season precipitation is not measured. In several of these cases, cold season

precipitation is measured on the ground (snow depth, density, and water equivalent) at winter's end. In the Alaska Arctic, this practice results in about two-thirds of the annual (hourly or daily) data missing for that location; the record includes almost all of the liquid precipitation but none of the solid precipitation, generating the issue of solid versus liquid precipitation and the runoff response of each. Solid precipitation must melt before runoff occurs, while liquid precipitation can result in immediate runoff. NOAA has criteria for how much data can be missing from a station before it is deemed unusable. In the case of Alaska, NOAA eased its criteria, especially for remote areas where data are limited.

- In remote, unpopulated areas, unstaffed sites are often only visited once or twice per year. These sites are subjected to a harsh environment and to interested wildlife. If something happens at these sites, data can be lost for extended periods. Also at many of these sites, precipitation data are only collected during the warm season. Having sufficient power to operate remote, unstaffed sites is always a challenge. Preventing snow from collecting on the orifice entrance of the standard NWS 8 in. (20.32 cm) orifice gauge is a continuous problem when minimal power is available for melting the snow. Numerous sites have considerable missing data during the year, especially in winter, because of this problem.
- Some stations that are located in proximity (within 5 miles; ~7.8 km) to other stations were considered for merging. Elevation was also a factor in deciding whether to merge stations or not (some stations are close to each other but at substantially different elevations). These stations were considered for merging mainly to increase the record length. Before merging, the datasets from both locations were examined to determine whether they came from the same population. In most cases, the reason for stations being located near each other was that the station was moved at some point in time. There is often overlap between the two stations.

It is clear that the density of the precipitation data network in Alaska is far lower than what is preferred. The criteria were relaxed on station duration and percent of missing data to increase the number of stations that could be used in the analysis. Also, use was made of data collected by any agency as long as the data met the minimum criteria.

DATA QUALITY

One of the major issues addressed in the frequency estimation was the quality of the precipitation data. Although there were over 1,600 potential stations, only slightly more than 500 (or about one-third) were actually used in the precipitation frequency analysis. Clearly, it is a challenge to measure precipitation, especially solid, in this environment. Sevruk and Klemm (1989) compiled a catalog of national precipitation gauges used around the world. Each of these gauges has its own distinct catch efficiency. It is well-documented (Goodison et al. 1998) that all gauges undercatch true precipitation by an amount that increases as the wind speed increases during an event. One would expect the data collected at first-order stations operated by the NWS to be the best quality. These stations (approximately 20 in Alaska), which collect hourly or sub-hourly data, are maintained by trained technicians. Many cooperative stations (over 600 past and present) are scattered around the state; at these stations, unpaid and moderately trained observers collect daily data. A third class of stations is those that are unstaffed. The quality of data at these stations can range significantly, as can the amount of missing data. These stations are often associated with research projects, but some, like the Remote Automated Weather System (RAWS), are operational networks used to monitor wildfire conditions.

It was our intention to make bias corrections for gauge undercatch (including wetting losses and trace amounts of precipitation), following the recommendations of Goodison et al. (1998), Yang et al. (1998), Yang et al. (1999), and Yang et al. (2000). Unfortunately, after considerable effort, we were unable to document when wind shields (Alter shields in this case) were added at each station. We were hoping that all standard NWS 8 in. (~20 cm) orifice gauges would have been upgraded within a relatively narrow time frame, but from the skimpy data we could find, this did not appear to be the case. The predominant gauge used is the NWS 8 in. orifice gauge in a variety of forms (tipping bucket, weighing, manual, etc.). Although a few other types of gauges (4 in. plastic gauge, 12 in. diameter gauge, Wyoming gauge, etc.) are being used in Alaska to collect precipitation data, only the 8 in. NWS orifice gauge and the Wyoming gauge being used in the contiguous U.S. were tested by the World Meteorological Organization (WMO) and reported in the publications just cited. Thus, we would only have been able to make bias corrections for undercatch to those two types of gauges when used.

The Annette Weather Service Office at the airport in the extreme southeast of Alaska is an example of complications faced in trying to identify when a shield was added to a precipitation gauge. There is conflicting evidence about whether the station started in 1941 or 1947. A note was added to the file by the station manager that the weighing precipitation gauge (there were two gauges at this site) was shielded in 1954. The interesting aspect of this note is that it was dated March 13, 1991, approximately 46 years after the wind shield was added. If we knew when wind shields were added to gauges, we would then need wind speed (which often is not available) to make the corrections suggested by the WMO report of Goodison et al. (1998) and Yang et al. (1998, 2000). In these publications, only corrections for daily precipitation are included, not for other durations, such as hourly.

COMPARISON OF 1963 AND 2012 RESULTS

There was an expectation that the intensities of precipitation for all durations and return periods had increased since the Miller (1963) report. This expectation was based on the idea that, at around the time of the report's publication, Alter shields were beginning to be added to gauges. After 1960, therefore, the gauge catch for the NOAA/NWS standard 8 in. (~20 cm) orifice gauge would have increased, assuming that all gauges were upgraded with wind shields. To demonstrate the magnitude of the gauge undercatch for a shielded gauge, we selected the annual maximum precipitation event for Annette Island (extreme southeastern Alaska, where it can rain on any day) for the years 1984 to 2008. We applied the WMO-derived equations (Yang et al. 1998) for correcting the undercatch. To make this adjustment, we needed to know the type of gauge (some precipitation gauges still used today were not tested in the WMO study), if it was shielded or not shielded (different corrections for each), and the wind speed. For the standard 8 in. orifice gauge with an Alter shield at Annette Island, the corrections to the annual maximum 24-hour precipitation amounts are shown in Table 1. The magnitude of this increase averages around 15%. The amount of undercatch increases even more for solid precipitation and for those gauges without a wind shield.

Table 1: The estimated magnitude of the undercatch correction for the annual maximum 24-hour storm at Annette Island, Alaska, 1984–2008.

Annette Island (Station 50-0352) AMS Date	Measured Wind Speed (m/s)	Gauge Catch Ratio (%)	Adjusted Shielded Precipitation (in.)	Measured Shielded Precipitation (in.)	Increase in Precipitation with Bias Correction (%)
10/3/84	3.31	91.14	3.58	3.26	9.72
1/15/85	9.12	82.89	2.47	2.05	20.64
9/22/86	7.82	84.48	3.36	2.84	18.38
9/22/87	2.73	92.21	3.52	3.25	8.45
9/23/87	2.77	92.13	3.77	3.47	8.55
9/24/87	2.82	92.04	3.31	3.05	8.65
9/25/87	2.86	91.96	2.94	2.70	8.75
9/26/87	2.91	91.87	3.73	3.43	8.85
9/27/87	2.95	91.79	3.32	3.05	8.94
2/26/93	11.53	80.19	4.74	3.80	24.70
10/16/94	7.38	85.05	2.41	2.05	17.58
10/1/95	7.47	84.93	2.64	2.24	17.74
2/12/96	7.51	84.88	2.52	2.14	17.82
12/12/97	10.64	81.16	4.94	4.01	23.21
8/28/98	7.51	84.88	3.26	2.77	17.82
10/21/99	6.04	86.86	3.48	3.02	15.13
8/21/00	7.38	85.05	3.86	3.28	17.58
9/21/01	7.69	84.65	3.04	2.57	18.14
11/20/02	5.77	87.24	2.72	2.37	14.63
10/25/03	5.99	86.92	6.30	5.48	15.05
12/2/04	4.83	88.63	2.47	2.19	12.83
11/8/05	8.81	83.27	3.28	2.73	20.10
4/7/06	5.68	87.37	3.50	3.06	14.46
10/23/07	6.84	85.75	3.96	3.40	16.61
8/23/08	5.54	87.56	3.73	3.27	14.20
AVERAGES	6.15	87.00	3.47	3.02	15.14

The new estimates (Perica et al. 2012) did not produce precipitation frequency estimates that were substantially different from those reported by Miller (1963). Comparisons between the old and new estimates were made in two ways: (1) The 1963 maps were scanned and then compared with the spatial estimates of 2012 for both 1-hour and 24-hour durations at the 100-year return period (Perica et al. 2012); and (2) for seven selected first-order stations spatially distributed around the state (Anchorage, Barrow, Cold Bay, Fairbanks, Juneau, Ketchikan, and Nome), the new 2012 results were compared with the old 1963 results for recurrence periods from 1 to 100 years and the following durations: 30 minutes, 1, 2, 3, 6, 12, and 24 hours (Figures 2 through 8).

Perica et al. (2012) summarized the results of the first exercise, (1) described in the paragraph above. For the 1-hour duration and the 100-year recurrence interval, there was an average point increase of 0.21 in. (0.53 cm) and a range of -0.72 to 1.26 in. (-1.83 to 3.20 cm). The hourly 100-year estimates over the state range from 0.38 to 2.4 in. (0.96 to 6.10 cm). For the 24-hour duration 100-year recurrence interval, the average precipitation frequency values changed very little (0.18 in.; 0.46 cm), while the differences ranged from -9.27 to 11.17 in. (-23.56 to 28.37 cm). For the 24-hour duration 100-year frequency, the estimates ranged from 1.33 to 23.01 in. (3.38 to 58.44 cm). The larger discrepancies between the two studies are found in southeastern Alaska, where the amounts of precipitation are high, the terrain is rugged, and the precipitation gauges at higher elevations are few.

Some of the discrepancy between the 1963 values and the 2012 values can probably be attributed to the methods available for presenting the 1963 results (hand-plotted maps). Both the original plotting and the later scanning of the 1963 maps, especially in steep mountainous terrain, are quite challenging. The 2012 electronic presentation of the precipitation frequency estimates should be far superior to those results shown in the earlier hand-drawn maps, especially in areas of rugged terrain.

In the second exercise (2), we compared the 1963 and 2012 results to look at specific stations (specific locations). This comparison was done graphically for seven stations (Figures 2 to 8) scattered around Alaska for the range of durations and recurrence intervals (frequencies) mentioned above. The stations selected were first-order stations, where observers are present 24 hours per day and hourly data are collected; this precipitation data are expected to be the best available. The first example (Figure 2) is the Anchorage International Airport (southcentral coast). For the short durations (30 min and 1 hr), the 2012 estimates are slightly higher, especially at the higher recurrence intervals. For the 2-hour duration estimates, there is a transition to higher 1963 results. For durations greater than 2 hours, the 1963 results are higher for all return periods.

For Barrow (northwestern coast) (Figure 3), the 2012 estimates are generally higher across the board. It can be seen that the 1963 curves are not very smooth; this is due to the lack of contour lines near Barrow and the sparseness of stations on the North Slope. For Cold Bay (Figure 4) at the eastern end of the Aleutian Islands, the 2012 estimates are usually slightly higher than 1963; exceptions are the estimates for the 12-hour duration and all of the recurrence intervals from 2 to 100 years, which are almost identical. All of the 2012 estimates for Fairbanks (Interior Alaska) (Figure 5) are lower than the earlier estimates. Juneau in southeastern Alaska (Figure 6) had higher estimates in 1963 except for the durations up to 2 hours, where the results were quite similar to those for 2012. The 2012 estimates for Ketchikan (extreme southeastern Alaska) (Figure 7) are all higher than the 1963 estimates, with the exception of the 6-hour duration, where the values are quite comparable at all recurrence intervals. The last station, Nome (western Alaska) (Figure 8) had higher 1963 estimates for all durations and frequencies. In summary, the 2012 estimates produce higher estimates for Barrow, Cold Bay, and Ketchikan, with a few exceptions. For the other four stations (Anchorage, Fairbanks, Juneau, and Nome), the 1963 estimates are higher. There is no clear and explainable pattern for these results.

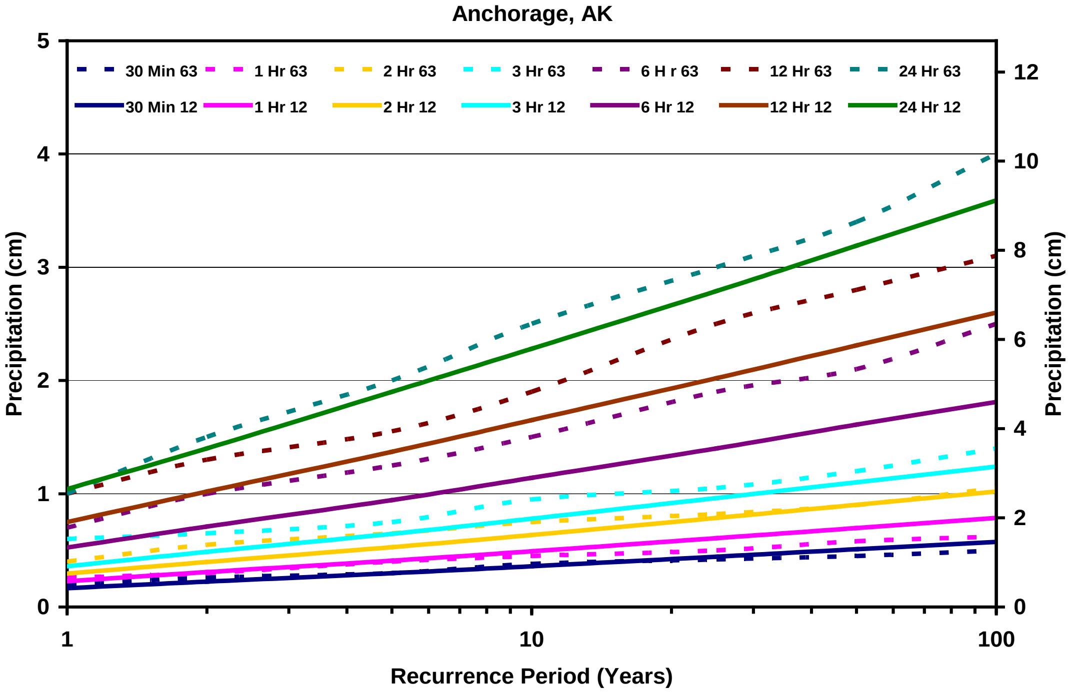


Figure 2: Comparison of 1963 and 2012 precipitation frequency estimates for Anchorage International Airport (50-0280) for durations of 30 min to 24 hr.

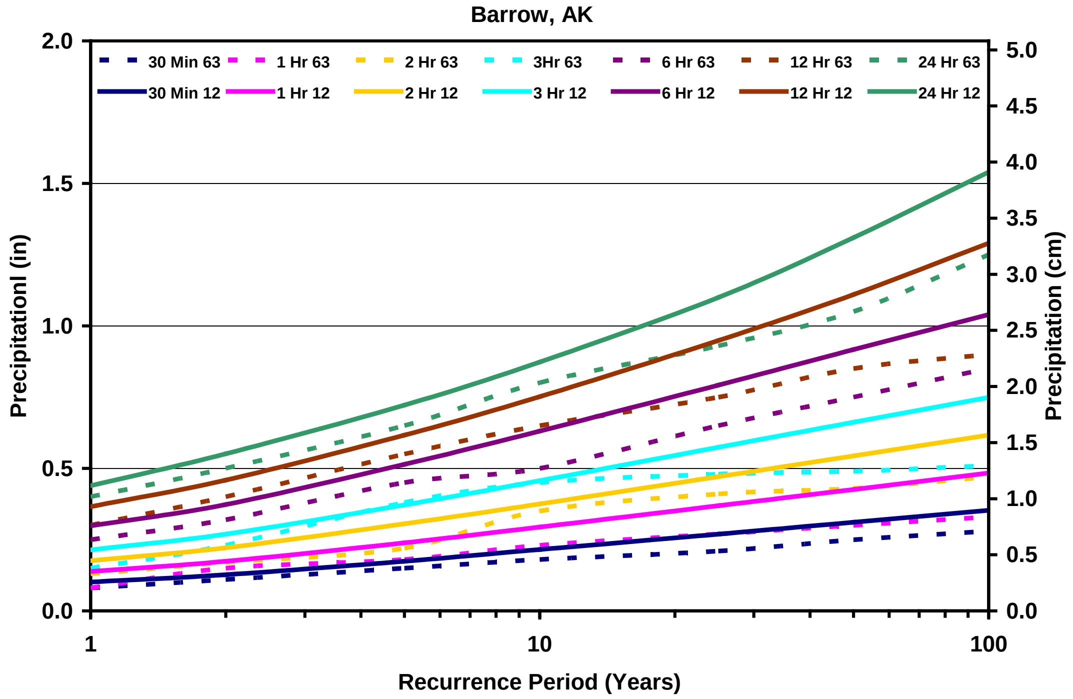


Figure 3: Comparison of 1963 and 2012 precipitation frequency estimates for Barrow Post–Rodgers Airport (50-0546) for durations of 30 min to 24 hr.

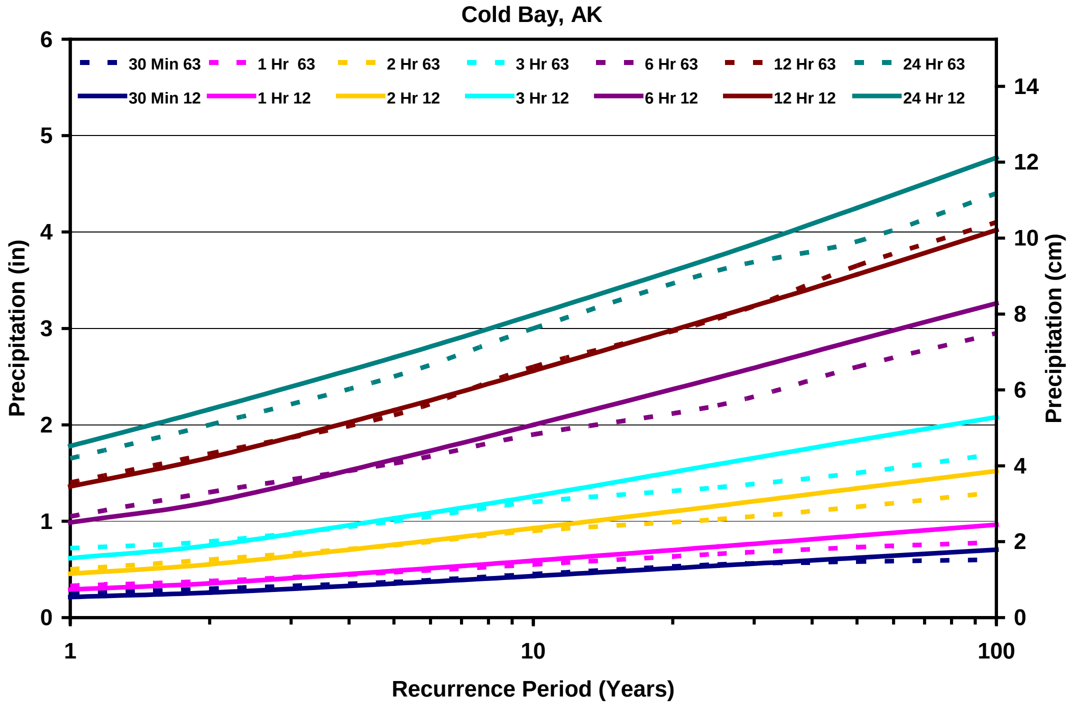


Figure 4: Comparison of 1963 and 2012 precipitation frequency estimates for Cold Bay Airport (50-2102) for durations of 30 min to 24 hr.

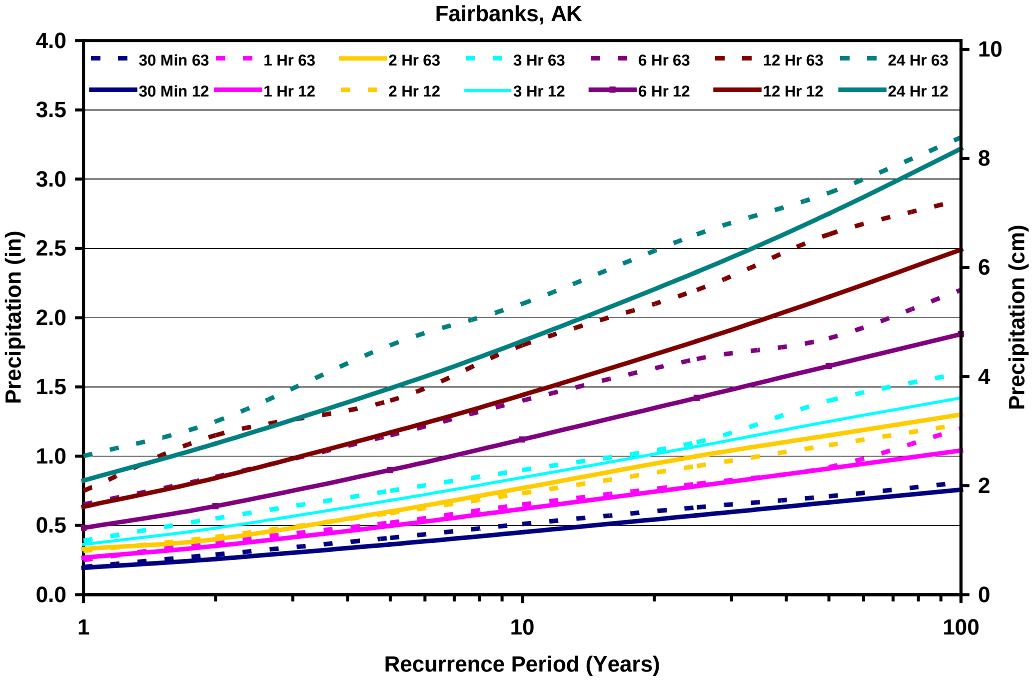


Figure 5: Comparison of 1963 and 2012 precipitation frequency estimates for Fairbanks International Airport (50-2968) for durations of 30 min to 24 hr.

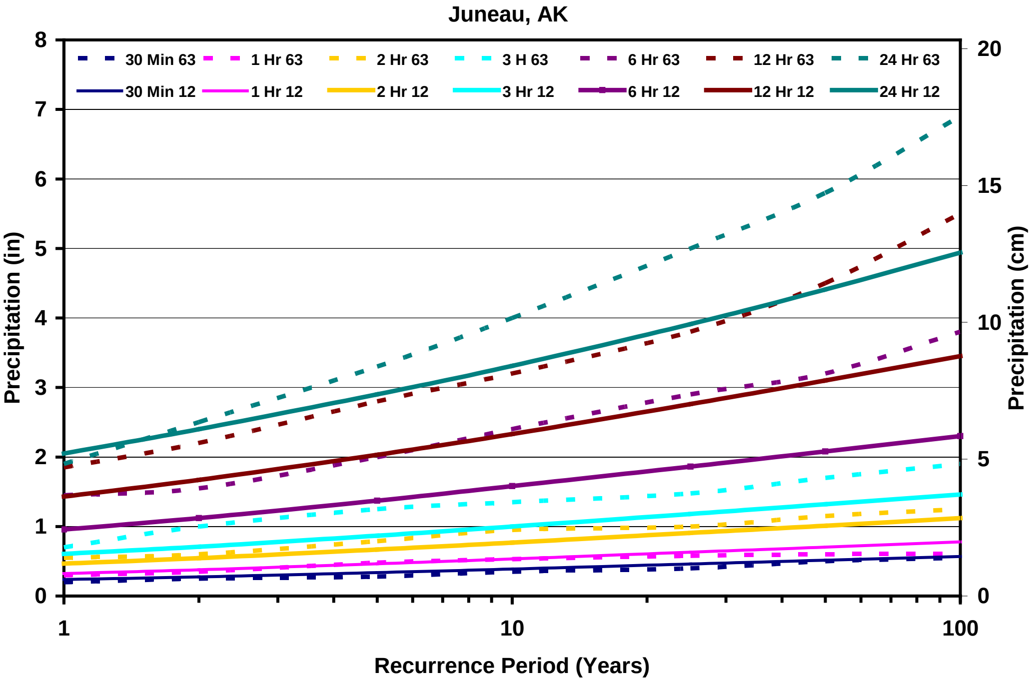


Figure 6: Comparison of 1963 and 2012 precipitation frequency estimates for Juneau International Airport (50-4100) for durations of 30 min to 24 hr.

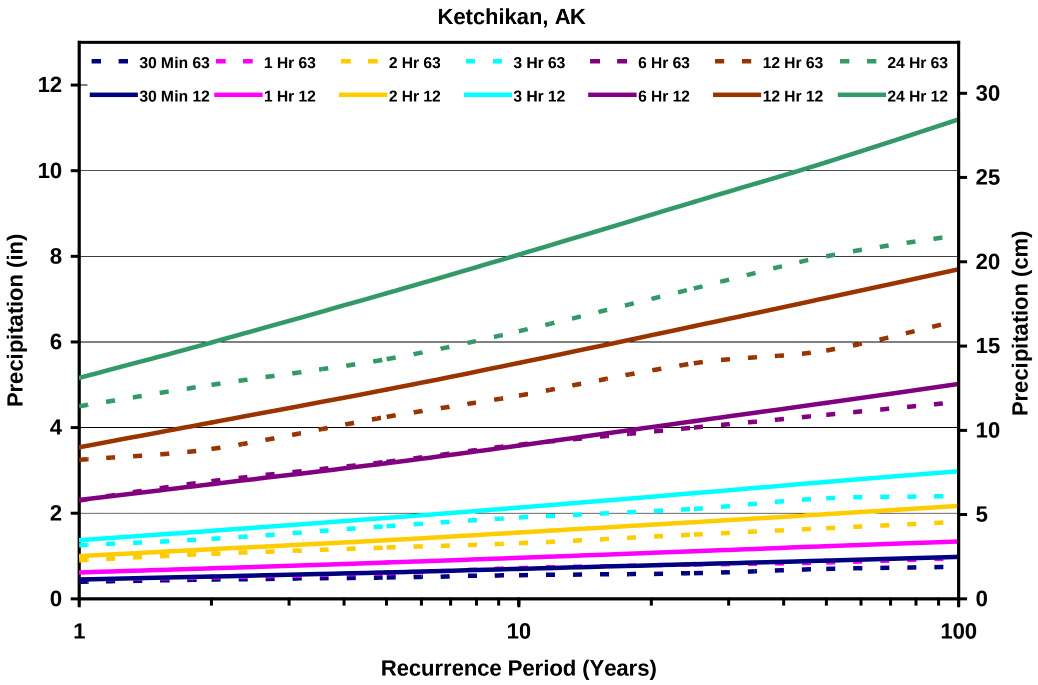


Figure 7: Comparison of 1963 and 2012 precipitation frequency estimates for Ketchikan International Airport (50-4590) for durations of 30 min to 24 hr.

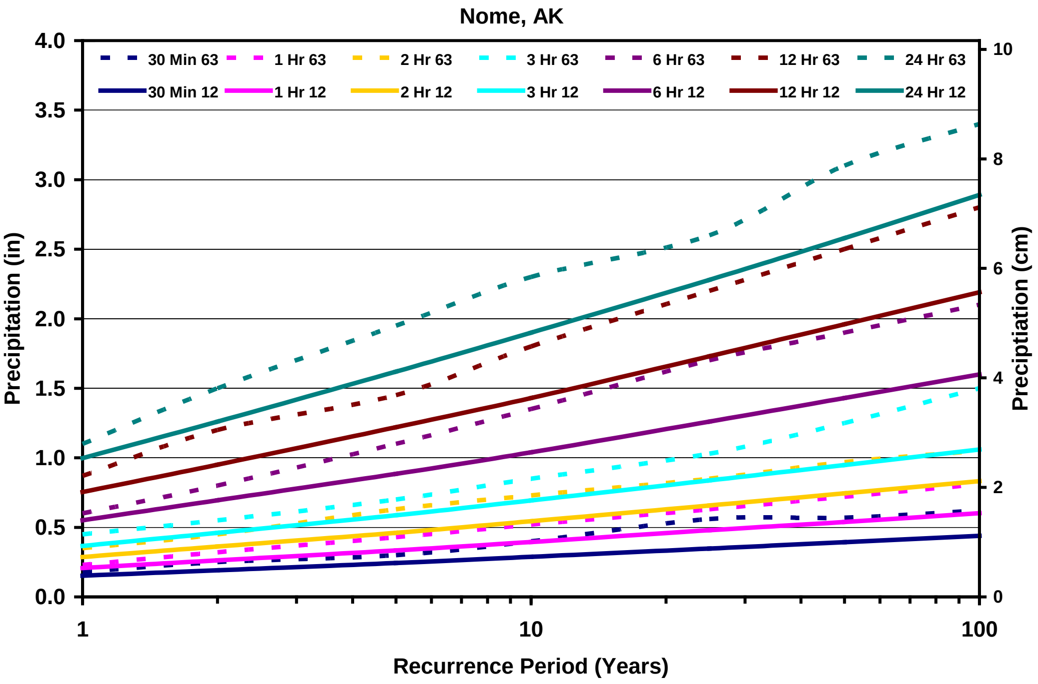


Figure 8: Comparison of 1963 and 2012 precipitation frequency estimates for Nome Municipal Airport (50-0546) for durations of 30 min to 24 hr.

In light of IDF data not being updated for an extended period, the Municipality of Anchorage (MOA) developed its own updated IDF criteria based on data from Anchorage International Airport and a map of orographic corrections for the city and its surroundings (personal communication with Janie Dusel, HDL; MOA 2007). The NOAA Atlas 14 results differ from the MOA guidelines in two ways. At the Anchorage International Airport, the Atlas 14 estimate for the 10-year 24-hour event is slightly higher (2.28 in.) when compared with the MOA value of 1.77 in. Note that the 2012 estimates are lower than the 1963 estimates. In addition, the NOAA Atlas 14 reports precipitation frequency estimates with confidence intervals; for this example, the 90% confidence interval is 1.74–3.02 in. It is not surprising that the MOA values do not match the NOAA Atlas 14 results. In the NOAA Atlas 14, precipitation frequency estimates are of the entire state; the MOA is addressing the same problem in a relatively small area.

Girdwood (a community south of Anchorage in the mountains) uses MOA criteria for most water-conveyance systems. The NOAA Atlas 14 (Perica et al. 2012) gives significantly higher precipitation frequency values for the Girdwood area. For example, at Girdwood Airport (elevation 101 ft.), NOAA Atlas 14 reports 5.40 in. for the 10-year 24-hour event. This value changes with elevation and aspect in this mountainous area.

Precipitation Trends

Precipitation frequency analysis is based on the assumption of stationarity, meaning no change in climate over time; for example, a variable such as precipitation retains the same mean and variance over time. In stochastic processes such as annual precipitation, natural year-to-year variation occurs, but the question is, Is there a long-term change or trend in the data? Perica et al. (2012) found that for the annual maximum series (AMS) of stations with at least 40 years of data, there were significant (5% significance level) positive trends in 8% of the station data, significant negative trends in 7% of the station data, and no significant trends in 85% of the station data.

There are several ways that a time series like the AMS can have trend-like qualities. A station could be moved (for example, away from buildings or large vegetation), or the instrumentation could change (for example, wind shields could be added to the rain gauge). A more recent possibility is climate change (for example, either more or less precipitation).

If a rain gauge has had a wind shield added to it, we would expect the gauge catch to increase and thus the slope of the cumulative annual precipitation (plotted versus time in years) to increase. We hoped that by plotting cumulative curves of annual precipitation (Figures 9–15), we could determine when wind shields were added to the precipitation gauges; unfortunately, this approach does not appear to be that simple. For example, of the seven stations that we looked at in detail, four of them—Anchorage (Figure 9), Cold Bay (Figure 11), Juneau (Figure 13), and Nome (Figure 15)—show an increase in annual precipitation around 1976. This increase, however, coincides with observations reported by Ebbesmeyer et al. (1991) when they examined 40 time series of multidisciplinary environmental variables from the Pacific Ocean and the Americas, collected in 1968 to 1984, that exhibited a major climate-related step-like change in 1976. It seems unlikely that wind shields would be added to these first-order precipitation gauges so late in the record. We have only limited documentation on wind shield additions, but the gauge at the Annette Island Airport received a wind shield in 1954.

From the seven graphs of cumulative precipitation, it is not possible to draw any significant conclusions. The stations at Fairbanks and Ketchikan (Figures 12 and 14) show very little variation from a straight line connecting the values for the first year and last year. Cumulative annual precipitation for Anchorage (Figure 9) decreased from 1972 to 1980, but then increased from 1980 to 1990; otherwise, it did not vary much from the straight line. The Barrow data (Figure 10) showed two periods (1923 to 1936 and 1960 to 1980) when the rate of precipitation increased, immediately followed by a decrease, with the remaining years having a consistent slope. Cold Bay (Figure 11) deviated substantially from the straight line from 1960 to 1978 and then recovered in two spurts (1978 to 1982 and 1998 to 2005). Juneau (Figure 13) had a 25-year period (1966 to 1991) when the rate of precipitation deviated below the straight line and then a 17-year period (1991 to 2008) when it returned to the straight line. Nome (Figure 15) had a few years in the 1920s with increased precipitation, then a period of missing data (1930 to 1952), followed by a few years of lower precipitation rates. For the last 40 years, the slope for Nome has been very constant.

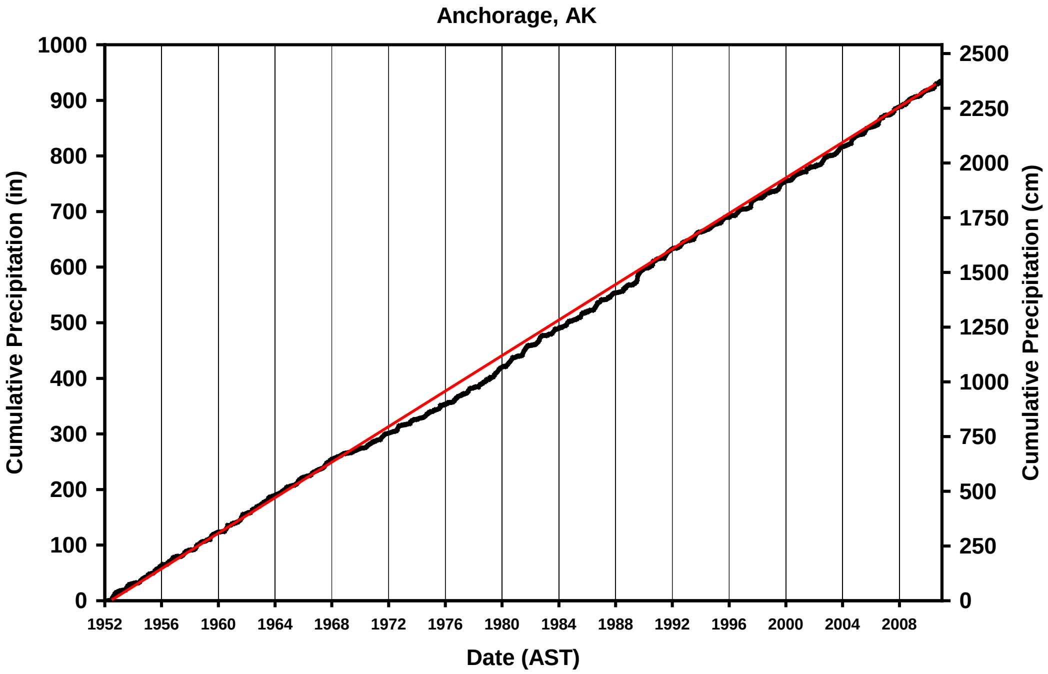


Figure 9: Cumulative curve for annual precipitation at the Anchorage International Airport (50-0280) for the period of record. Note the decline in measured annual precipitation in the late 1960s and the recovery in the late 1970s and 1980s.

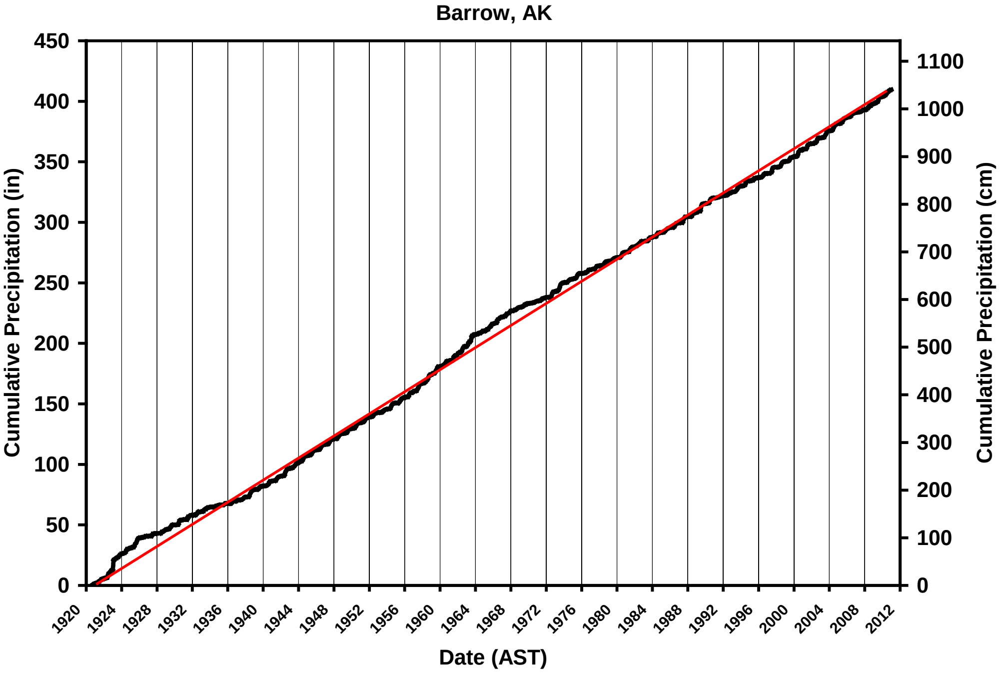


Figure 10: Cumulative curve for annual precipitation at the Barrow Post–Rodgers Airport (50-0546) for the period of record. Note that there are three periods when the annual precipitation deviates from a constant slope: early 1920s to mid-1940s, late 1950s to 1980, and finally 1996 to present.

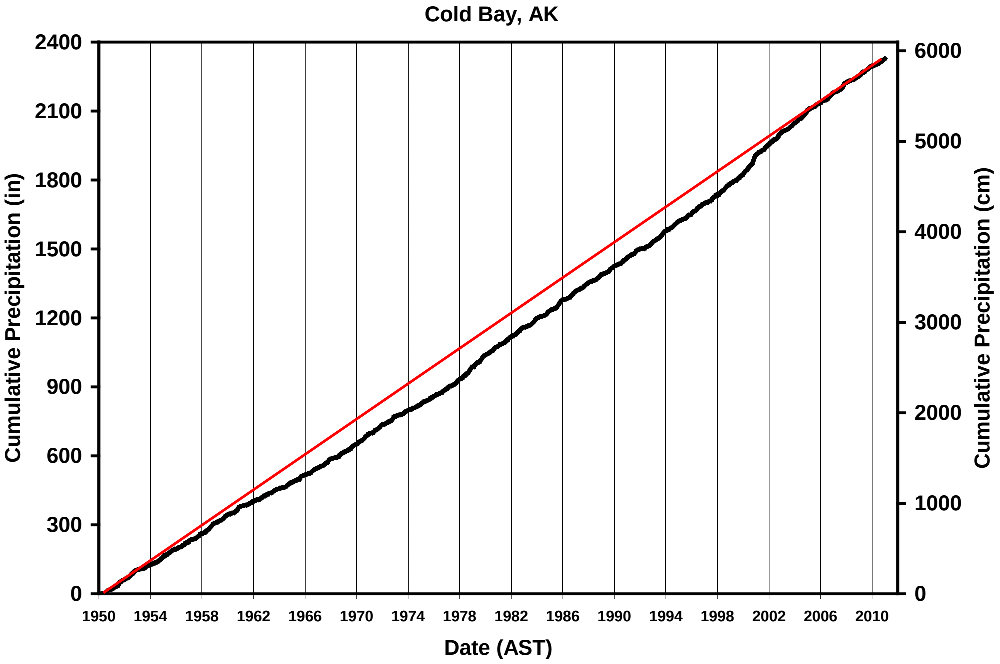


Figure 11: Cumulative curve for annual precipitation at the Cold Bay Airport (50-2102) for the period of record. The cumulative curve deviated below the constant slope early in the record and only returned to the constant slope recently.

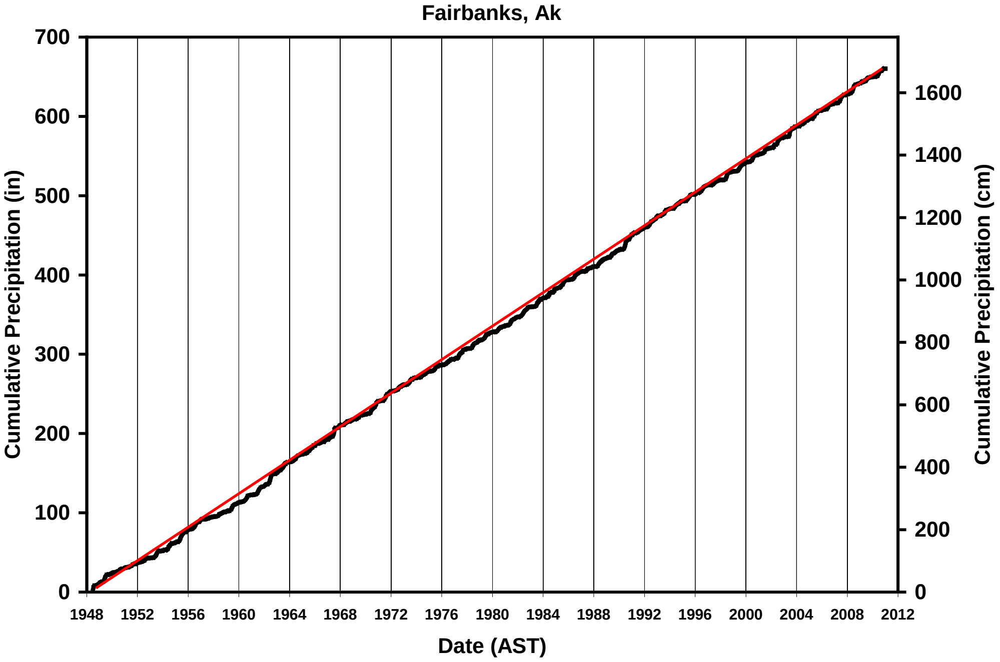


Figure 12: Cumulative curve for annual precipitation at the Fairbanks International Airport (50-2968) for the period of record. There are only small, short deviations from the constant slope.

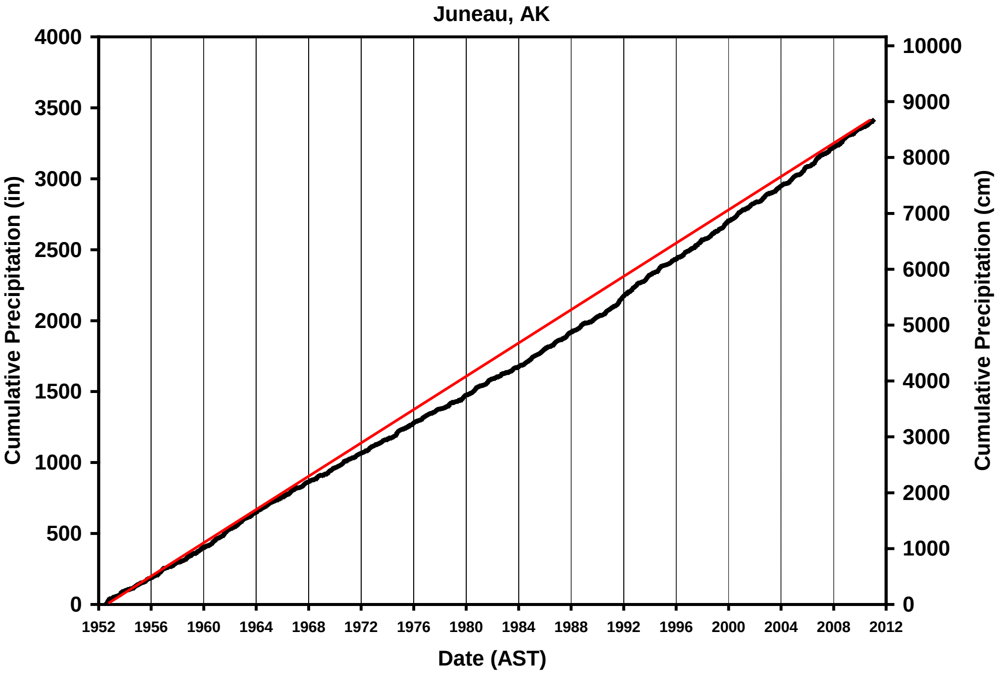


Figure 13: Cumulative curve for annual precipitation at the Juneau International Airport (50-4100) for the period of record. The pattern is quite similar to that of Cold Bay (Figure 11).

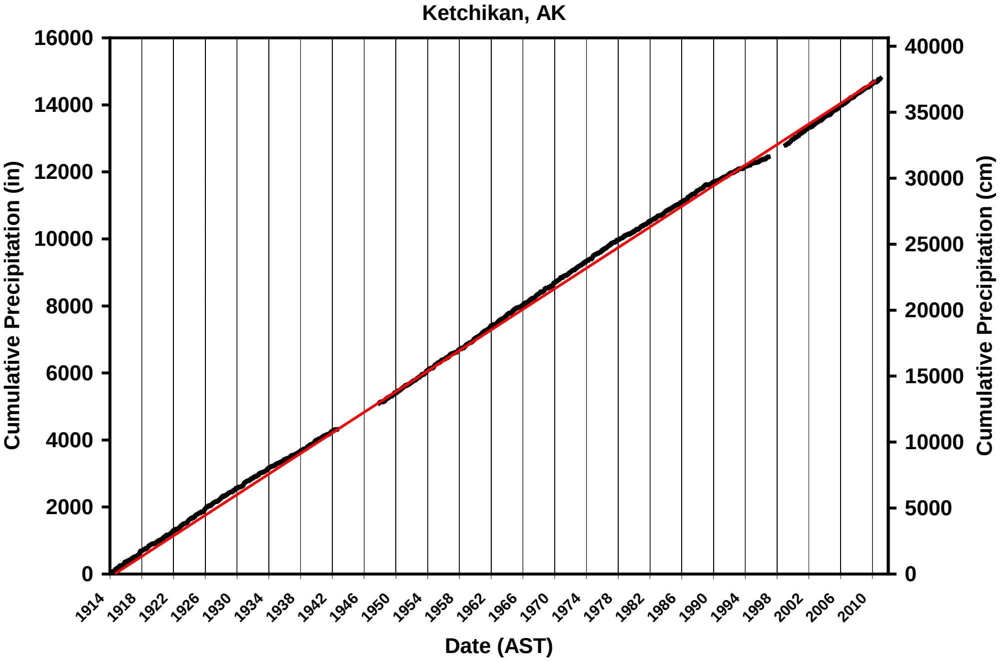


Figure 14: Cumulative curve for annual precipitation at the Ketchikan International Airport (50-4590) for the period of record. Note the two gaps in the data; however, the slope of the cumulative curve is fairly constant.

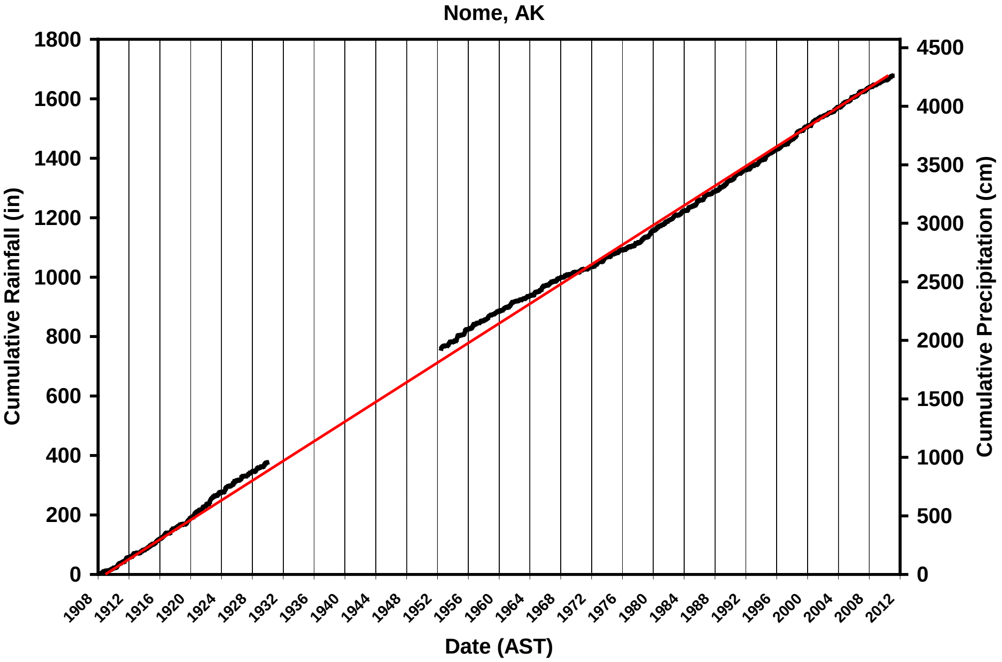


Figure 15: Cumulative curve for annual precipitation at the Nome Municipal Airport (50-0546) for the period of record. The ~22 yr gap in data makes it difficult to draw any conclusions.

For the seven stations examined, we looked at the average annual precipitation for two periods (Table 2), an approximate period of 25 years (roughly from 1950 to 1975), and a period of 34 years (from 1976 to 2010). Five of the stations showed increases in average annual precipitation, and two showed deceases ranging from 6.6 to 26.9%. Both Cold Bay and Nome show fairly large increases of around 26 to 27%. Barrow and Ketchikan showed a decrease of about 11%. The other three stations had positive increases of approximately 7 to 14%. Since we do not know when wind shields were added to the station gauges, we cannot explain the reason why changes have occurred at these stations.

Table 2: Comparison of annual precipitation for roughly the period from 1950 to 1975 against the period from 1976 to 2010 for seven first-order stations in Alaska.

Station	Analysis Period (years)	Average Annual Precipitation (inches/year)	Analysis Period (years)	Average Annual Precipitation (inches/year)	Precipitation Change (%)	Precipitation Change (inches/year)
Anchorage	1953-1976 (24 years)	14.62	1977-2010 (34 years)	16.68	14.0	2.06
Barrow	1953-1976 (24 years)	4.92	1977-2010 (34 years)	4.37	-11.0	-0.55
Cold Bay	1951-1976 (26 years)	33.45	1977-2010 (34 years)	42.21	26.2	8.76
Fairbanks	1949-1976 (28 years)	10.11	1977-2010 (34 years)	10.78	6.6	0.67
Juneau	1953-1976 (24 years)	53.67	1977-2010 (34 years)	61.02	13.7	7.35
Ketchikan	1950-1976 (27 years)	163.45	1977-2010 (34 years)	145.60	-10.9	-17.85
Nome	1952-1976 (25 years)	13.32	1977-2010 (34 years)	16.90	26.9	3.58

Liquid versus Solid Precipitation

In northern Alaska, it can snow any day of the year, and in southeastern Alaska, it can rain any day of the year. Liquid and solid precipitations have different runoff mechanisms; liquid depends upon the intensity of the storm, while solid depends upon the rate of melt sometime after the precipitation event. Solid precipitation can also accumulate for periods ranging to several months before it ablates and generates runoff. On the other hand, liquid precipitation can produce almost immediate runoff. In cold environments with solid precipitation, it is possible for the annual maximum to be a solid precipitation event; generally though the annual maximum is liquid precipitation (the warmer the atmosphere the more precipitation it can hold). Considerable time was spent examining the role of solid and liquid precipitation in the frequency analysis. We used only two datasets (NWS first-order stations and Environment Canada), both of which indicated the form of precipitation. It is obvious that if raw collected precipitation records are examined in detail, numerous errors in converting snow depth to snow water equivalent will be found. To gain insight into the magnitude of the role of solid precipitation frequency estimates, we used simple algorithms to estimate the form of precipitation at other stations where it was not indicated.

Where snow depth was recorded, a simple conversion to snow water equivalent was made by assuming snow density to be 10% of water density. While this average density of snow is a good approximation, the value can easily range from 0.05 to 0.15 Kg/m^3 for dry to wet snow. We also examined the threshold temperature where there was a greater likelihood of snow or rain for each of the climatic regions used in this study. This transition in Alaska occurred at warmer temperatures (as high as 36°F) for southern coastal climatic regions and cooler temperatures (as low as 32°F) for northern Arctic regions. The transition temperature, in general, increased from north to south (Table 3). These air temperatures would generally occur in the two seasonal transitions between the rainy warm season and the cooler winter season.

Two examples (Figures 16 and 17) are shown of where the daily threshold temperature was determined for the Interior and Cook Inlet/Bristol Bay. In each climatic zone, stations were identified where the form of the precipitation was recorded. In Interior Alaska, seven such stations were identified. In the first panel of Figure 16, the number of rain events at or below 32°F (0°C) is plotted along with all of the snow events above 32°F (0°C). The last bar in each grouping is the average of all of the stations. Note that on average there are more snow events at 32°F (0°C) than rain events. However, the next panel shows that there are slightly more rain events at 33°F (0.55°C) than snow events. The next two panels show that rain events are dominant at 34°F (1.11C) and 36°F (2.22°C). Thus we concluded that the threshold value of 33°F (0.55°C) would be used for the Interior region of the state. Precipitation events at or above 33°F (0.55°C) are liquid precipitation, and those below this temperature are solid precipitation.

For the Cook Inlet/Bristol Bay climatic region (with four stations having the prerequisite data), the daily threshold temperature (Figure 17) was determined to be 34°F (1.11°C). At and above 34°F (1.11°C), the event was liquid precipitation, and below this temperature, the event was solid precipitation.

The daily threshold values (Table 3) in the other climatic regions are as follows: Arctic 32°F (0°C), West Coastal 33°F (0.55°C), Southwest Islands 35°F (1.66°C), and South/Southeast Coast 36°F (2.22°C). Where precipitation frequency comparisons between rainfall and all precipitation could be made, Perica et al. (2012) found that the precipitation estimates were quite similar, especially for shorter durations. For longer durations (20 to 60 days), the likelihood of having a mixed contribution of solid and liquid precipitation increases. This likelihood increases with latitude (the warm season becomes shorter).

SUMMARY

During the 50 years between the original precipitation frequency analysis (Miller 1963, 1965) and the recent analysis (Perica et al. 2012), some positive changes have occurred in precipitation data collection and analyses:

1. Computers have allowed much more detailed and sophisticated analyses of precipitation data. For example, numerous distributions can be tested for goodness-of-fit, although in the 2012 study, there was not one distribution that performed better than another did, so the generalized extreme value (GEV) distribution was used.

Table 3: Daily mean air temperature threshold for each climate region.

Code	Region	Warm Season	Cold Season	Rainfall
1	Arctic	April 15–September 30	October 1–April 14	Daily mean $T_{air} \geq 32°F$ (0°C)
2	Interior	April 1–October 31	November 1–March 31	Daily mean $T_{air} \geq 33°F$ (0.55°C)
3	West Coastal	April 1–October 31	November 1–March 31	Daily mean $T_{air} \geq 33°F$ (0.55°C)
4	SW Islands	January 1–December 31	Not applied	Daily mean $T_{air} \geq 35°F$ (1.66°C)
5	Bristol Bay/ Cook Inlet	March 1–November 30	December 1–February 28	Daily mean $T_{air} \geq 34°F$ (1.11°C)
6	SE Panhandle	January 1–December 31	Not applied	Daily mean $T_{air} \geq 36°F$ (2.22°C)
7	Other (Canada)	April 1–October 31	November 1–March 31	Not applied*

**direct rainfall records are available from Environment Canada.*

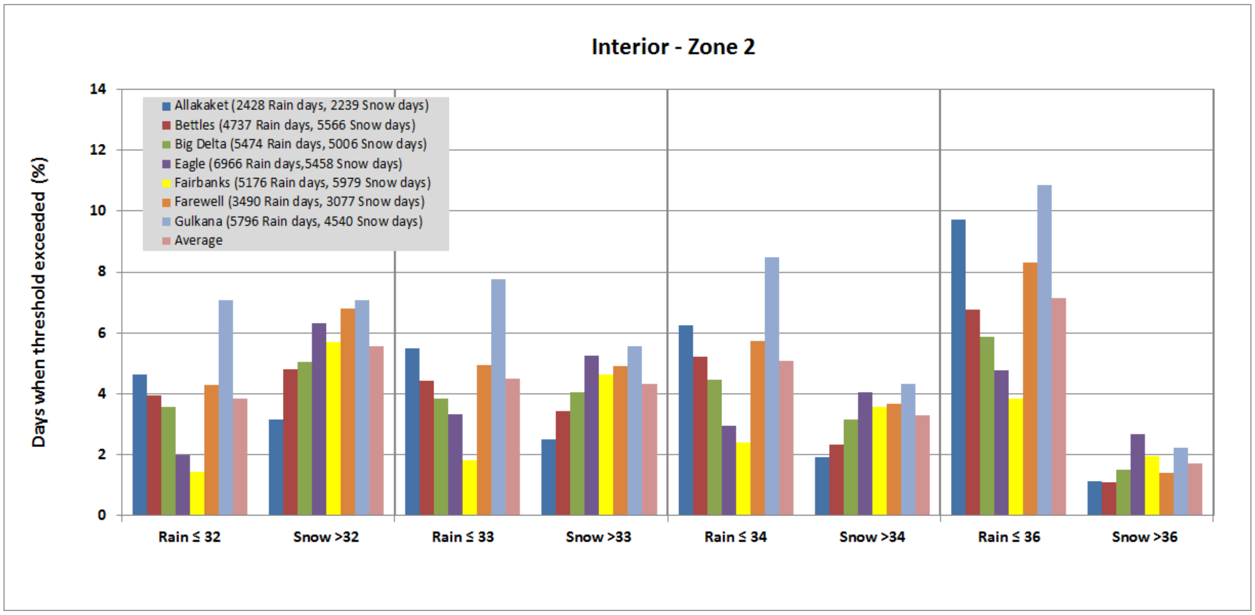


Figure 16: Days with rain and snow events when certain daily air temperature thresholds are exceeded. The daily air temperature threshold is shown on the horizontal axis. The selected daily air temperature threshold for rainfall segregation is 33°F (0.55°C) for the Interior Alaska climatic zone (see the last bar on the right in each panel for the average of all stations).

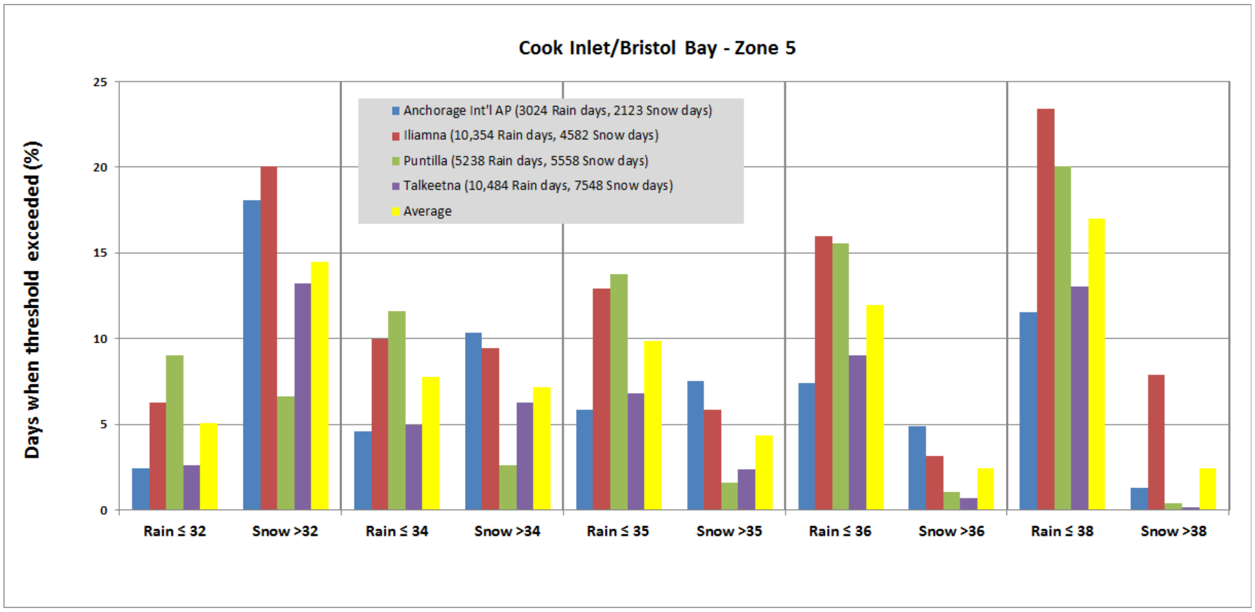


Figure 17: Days with rain and snow events when certain daily air temperature thresholds are exceeded. The daily air temperature threshold is shown on the horizontal axis. The selected daily air temperature threshold for rainfall segregation is 34°F (1.11°C) for the Cook Inlet/Bristol Bay climatic zone (see the last bar on the right in each panel for the average of all stations).

2. Computers have allowed much more detailed and sophisticated analyses of precipitation data. For example, numerous distributions can be tested for goodness-of-fit, although in the 2012 study, there was not one distribution that performed better than another did, so the GEV distribution was used.

3. The precipitation frequency estimates from this study are presented in an electronic form that is much simpler to use. In the original report, Technical Paper 47 (Miller 1963), the form used to present precipitation frequency estimates was a printed state of Alaska map with contours, and the user needed to interpolate between contour lines to get a value for analysis. In locations with steep terrain, this task is challenging because the contour lines are crowded together. Also, in the Arctic, there were very few contours because of the lack of stations.

4. Although still not ideal, the number of precipitation stations has increased since 1963. Unfortunately, the duration of many of the new stations was still too short to use in the analysis. In the 1963 report, only 1 station had a record longer than 50 years; 61 stations had a record longer than 20 years. In the recent report by Perica et al. (2012), approximately 80 stations had a record length exceeding 50 years. Several of the new stations have been installed by organizations other than the National Weather Service. It appears that the 1963 study only used data from the National Weather Service (plus some Canadian stations on Alaska's eastern boundary); in the 2012 study, data from all collecting organizations were used if the data passed quality checks.

5. In the past 50 years, the density (area/station) of precipitation stations in Alaska has improved (the area per station has decreased) slightly. However, in large areas of the state—like the Arctic and Southwestern regions—the number of precipitation stations is still quite sparse. The northern part of the state (230,000 km^2 or ~89,000 mi^2) has improved slightly from 7 to 17 daily stations, with a few additional hourly stations.

6. Establishing precipitation stations at higher elevations remains a challenge in Alaska. In the 1963 report, data from 184 precipitation gauges were used in the analyses, with only 26 gauges above 1,000 ft (~300 m). In the recent analyses by Perica et al. (2012), data from 396 daily stations were used, with 134 gauges above 1,000 ft (~300 m) and 10 gauges above 3,000 ft (~900 m). With the extensive land area that is covered with mountains—50% of the state is above 1,300 ft (~400 m) and 20% is above 3,000 ft (~915 m)—and the fact that considerable runoff is generated in the higher headwater areas of the watersheds, it is imperative that more gauges are placed at higher elevations to improve precipitation frequency estimates in Alaska. The problem is that few communities are located at higher elevations. The only alternative is to install unstaffed stations, which can lead to various problems.

RECOMMENDATIONS

It is clear that we need to do a better job of collecting meteorological data, particularly precipitation data; this includes improving the quality of the data we presently collect. There has long been an awareness of the need for more and better-quality precipitation data, but the problem of needing to do better persists. The following are recommendations generated during this precipitation frequency-estimation effort:

1. Additional precipitation stations are needed. It is abundantly clear that we will never have the density of stations that exist in the contiguous states. However, some stations strategically placed in extremely remote areas and at higher elevations would dramatically improve Alaska's precipitation frequency estimates. At higher elevations, stations are needed on both the windward and leeward sides of mountain ranges.

2. In this study, precipitation data from numerous stations (roughly two-thirds of the stations) were not used because of the issue of data quality and other factors. The people collecting this data range from having minimal training in data collection to being highly trained. One very common problem in the datasets was that of readings at daily stations not having been logged for one or more days. Then, when daily precipitation recordings resumed, the first reading was of that day plus any cumulative precipitation during the period without readings, resulting in a higher daily precipitation value than actually occurred. Another common problem was the recording of snowfall precipitation, where the depth of snow was converted 1:1 directly to the snow water equivalent. Many of the problems related to quality issues at stations occur when cooperators leave the site (vacation or for some other reason), and data collection is turned over to someone with minimal training or no training at all.

3. Better equipment is needed both to measure precipitation, especially solid precipitation, and for use in remote, unstaffed areas. Power for data collection and transmission are two hurdles faced at remote, unstaffed sites. We know that all gauges undercatch and that some gauges perform better than others do. In this study, we were unable to ascertain when wind shields were added to precipitation gauges (resulting in increased gauge catch). It is possible that gauges are still being used without wind shields. Surely, a majority of the data used in the 1963 report was collected from gauges without wind shields. It is not clear why no record was made of when wind shields were added to gauges, whereas there appears to be a good record of when gauges were moved or instruments replaced.

4. It would be ideal if all of the agencies collecting precipitation data could get together at a workshop in a cooperative atmosphere to improve both the quality of the data and the spatial coverage. Realistically, most agencies are not going to make big changes in the instrumentation they use. However, an organization like the Interagency Hydrology Committee for Alaska (IHCA) may be able to generate improvements, as the organization has representatives from a majority of the agencies collecting precipitation data. The problem of data collection is a very challenging one, since it requires a long-term commitment by the agencies. With climate change on the horizon, it is even more important that we make an effort to collect better quality precipitation data.

REFERENCES

Ebbesmeyer, C.C., D.R. Cayan, D.R. McLain, F.H. Nichols, D.H. Peterson, and K.T. Redmond. 1991. 1976 Step in the Pacific Climate: Forty Environmental Changes Between 1968–1975 and 1977–1984. Proceedings of the Seventh Annual Pacific Climate (PACLIM) Workshop (J.L. Betancourt and V.L. Sharp, Eds., April 1990), California Department of Water Resources, Interagency Ecological Studies Program, Technical Report 26, pp. 115–126.

Goodison, B.E., P.Y.T. Louie, and D. Yang. 1998. WMO Solid Precipitation Measurement Intercomparison. World Meteorological Organization, Instrument and Observing Methods Report No. 67, WMO/TD Report No. 872, 212 pp.

Miller, J.F. 1963. Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska for Areas to 400 Square Miles, Durations to 24 Hours, Return Periods from 1 to 100 Years. Technical Paper No. 47, U.S. Dept. of Commerce, Weather Bureau, U.S. Government Printing Office, Washington, DC, 69 pp.

Miller, J.F. 1965. Two- to Ten-Day Precipitation for Return Periods of 2 to 100 Years in Alaska. Technical Paper No. 52, U.S. Dept. of Commerce, Weather Bureau, U.S. Government Printing Office, Washington, DC, 30 pp.

MOA (Municipality of Anchorage). 2007. Drainage Design Guidelines. Document Number WMP CPg09001, ver. 4.09. Project Management and Engineering Department.

Perica, S., D. Kane, S. Dietz, K. Maitaria, D. Martin, S. Pavlovic, I. Roy, S. Stuefer, A. Tidwell, C. Trypaluk, D. Unruh, M. Yekta, E. Betts, G. Bonnin, S. Heim, L. Hiner, E. Lilly, J. Narayanan, F. Yan, and T. Zhao. 2012. *NOAA Atlas 14*, Volume 7, Version 2.0, Precipitation Frequency Atlas of the United States, Alaska. NOAA, National Weather Service, Silver Spring, MD.

Sevruk, B., and S. Klemm. 1989. Catalogue of National Standard Precipitation Gauges. World Meteorological Organization, Instrument and Observing Methods Report No. 39, WMO/TD-No. 313, 50 pp.

Yang, D., B.E. Goodison, J.R. Metcalfe, V.S. Golubev, R. Bates, T. Pangburn, and C.L. Hanson. 1998. Accuracy of NWS 8” standard nonrecording precipitation gauge: Results and application of WMO intercomparison. *Journal of Atmospheric and Oceanic Technology*, 15: 54–68.

Yang, D., B.E. Goodison, J.R. Metcalfe, P. Louie, G. Leavesley, D. Emerson, C.L. Hanson, V.S. Golubev, E. Elomaa, T. Gunther, T. Pangburn, E. Kang, and J. Milkovic. 1999. Quantification of precipitation measurement continuity induced by wind shields on national gauges. *Water Resources Research*, 35(2): 491–508.

Yang, D., D.L. Kane, L.D. Hinzman, B.E. Goodison, J.R. Metcalfe, P.Y.T. Louie, G. Leavesley, D.G. Emerson, and C.L. Hanson. 2000. An evaluation of the Wyoming gauge system for snowfall measurement. *Water Resources Research*, 36(9): 2665–2677.