US Army Corps
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Weather and Climate Extremes

Dr. Paul F. Krause
Kathleen L. Flood

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TEC-0099

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September, 1997

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U.S. Army Corps of Engineers
Topographic Engineering Center
7701 Telegraph Road
Alexandria, Virginia 22315-3864

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Engineering Center

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1997

3. REPORT TYPE AND DATES COVERED
Technical Oct. 1995 - Dec. 1996

4. TITLE AND SUBTITLE
Weather and Climate Extremes

5. FUNDING NUMBERS
DA Program 001TZN
WU QG6855M602

6. AUTHOR(S)
Paul F. Krause
Kathleen L. Flood

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Topographic Engineering Center
7701 Telegraph Road
Alexandria, VA 22315-3864

8. PERFORMING ORGANIZATION REPORT NUMBER
TEC-0099

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

MONITORING

19980611 102

11. SUPPLEMENTARY NOTES
Additional copies of this report, and separate maps, may be purchased by contacting:
Department of Commerce, National Technical Information Service,
5285 Port Royal Road, Springfield, VA 22161

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report consists of world weather and climate extremes that have been extracted from various sources. The report contains discussions covering the measurement of various meteorological elements, measurement practices, and instrumentation. All extremes are presented in terms of their location and date and, where supportive information is available in the professional literature, detailed discussions of the extreme event are provided. The elements covered in this report include surface air temperature, precipitation (rainfall, snowfall and hail), wind, thunderstorms, air pressure, solar radiation, dew point temperature and fog. The report contains five maps. There is one each for the worldwide extremes of temperature, precipitation, and other elements. The remaining two maps show U.S. state extremes for monthly temperature (absolute maximum and absolute minimum) and precipitation (maximum monthly and maximum 24-hour).

14. SUBJECT TERMS

Extremes	Weather	Climate	Temperature	Precipitation
Rainfall	Snowfall	Hail	Air Pressure	Thunderstorms
Wind	Fog	Dew Point	Solar Radiation	

15. NUMBER OF PAGES
94

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

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PREFACE

This is the fourth revision of this report. In 1955, a map titled "World Weather Extremes" was prepared by the U.S. Army Quartermaster Research and Engineering Center, Natick, MA, as a handout to visitors and other interested parties. In 1970, the map was updated and explanatory notes were added. In addition, a technical report titled "Weather Extremes Around the World" was prepared.[1] In 1974, the maps and text were again updated.[2] In 1985, the third revision of the report was published.[3] The goal of each revision was to assist designers of military equipment with information about the extremes of the natural environment. However, the technical report and accompanying maps also have been useful teaching and research aids. The maps themselves have appeared in a number of military and civilian publications.

In the 1985 revision, changes in format and content made the report and maps more comprehensive and readable. In this new revision, worldwide extremes are now portrayed on three maps, one each for temperature, precipitation, and for various other weather/climate elements (Maps 1, 2, 3). The North American map that appeared in the 1985 version has been eliminated, with its extremes being merged onto the three world maps. In addition, two new maps have been included. The first map presents U.S. temperature extremes for the 50 states (Map 4). The second one presents precipitation extremes for the 50 states (Map 5). The title of the report now includes the term "climate," inasmuch as a number of the extremes appearing in this report are climatological averages. The text format is more structured, with each well-documented extreme appearing as a separate entity. All references cited in the discussion appear in a bibliographic section at the end of the report. Several rounding errors in the 1985 version also have been corrected. Geographic coordinates (latitude and longitude) have now been included for most stations. Although these coordinates were extracted from atlases, they are probably not the exact coordinates of the meteorological stations at which the extreme values were measured. They do, however, provide the reader with a general point of geographic reference. All extremes are expressed in both English units and their metric equivalents.

This report was prepared under DA Program 001TZN, Work Unit QG6855M602, "Terrain/Climate Interactions."

This document was prepared by Dr. Paul F. Krause and Ms. Kathleen L. Flood, Remote Sensing Technology Division, U.S. Army Topographic Engineering Center (TEC). The work was performed under the supervision of Ms. Betty Mandel, Chief, Remote Sensing Technology Division; and, Mr. Joseph E. Swistak, Director, Topographic Technology Laboratory/Acting Associate Director, Technology Directorate.

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[1] Pauline Riordan, Weather Extremes Around the World. U.S. Army Natick Laboratories. TR-70-45-ES, 1970. AD 707 920

[2] Pauline Riordan, Weather Extremes Around the World. U.S. Army Engineer Topographic Laboratories. ETL-TR-74-5, 1974. AD A000 082

[3] Pauline Riordan and Paul G. Bourget, World Weather Extremes. U.S. Army Engineer Topographic Laboratories. ETL-0416, 1985. AD-A170 138

Dr. William E. Roper was Acting Director and COL Robert F. Kirby was Commander of the U.S. Army Topographic Engineering Center at the time of report publication.

ACKNOWLEDGMENTS

Appreciation is hereby given to a number of individuals who contributed their time, effort and/or materials during the preparation of this report. Messrs. Kevin R. Slocum and William Z. Clark, Jr., TEC, for their review of this document and for their constructive comments; Mr. John Neander, TEC, for his work on gathering the correct geographic coordinates for many of the U.S. state extremes, providing photographs of extreme weather events, and for information on El Niño; Messrs. Cedric Key and Herman Hamn, Automated Cartography Division, TEC, for their assistance in producing the color map separates; Mr. William E. Diego, Science and Technology Corporation, who provided guidance and direction on the Arc/Info rendering of the U.S. state extreme maps; and, Mr. Matthew P. Harden, TEC, for his cartographic advice provided during the preparation of the world maps. A special thank you is extended to Mr. Doyle Rice, Managing Editor, Weatherwise, for providing photographs of extreme weather events, and also to the individual photographers who graciously gave us their permission to use their photographs: Mr. Michael Changery, National Climate Data Center, Asheville, NC, for assistance in validating the U.S. state extremes; Mr. Grant Goodge, National Climate Data Center, Asheville, NC, for providing photographs of extreme weather events and for his assistance in validating several extremes; Dr. Thomas W. Schmidlin, Chairman, Department of Geography, Kent State University, for providing information on several extreme events. Gratitude is extended to Dr. Jon M. Wraith, State Climatologist for Montana, and Dr. Dwight D. Pollard, State Climatologist for Alaska, for their timely assistance in providing geographic coordinates for various state extremes. Appreciation also is given to the many meteorological organizations worldwide that responded to our inquiries for weather extreme updates. A special thank you goes out to the many other interested individuals who have kept in contact with us over the years and urged us to update this document. And finally, appreciation also goes to the many teachers and educators who have requested copies of the report and the accompanying maps for use in the classroom and for research purposes.

Individuals who become aware of new extremes or have additional information about existing extremes are encouraged to contact the authors at:

Director
U.S. Army Topographic Engineering Center
ATTN: CETEC-TD-T (Weather Extremes)
7701 Telegraph Road
Alexandria, VA 22315-3864

WEATHER AND CLIMATE EXTREMES

I. INTRODUCTION

"...weather-lovers are part scientist, part poet. They rejoice in the forms and colors that glorify the weather. They delight in extremes."

T. Morris Longstreth (1886-1975)

Extremes have always held a certain fascination for people. Individuals such as P.T. Barnum and Robert Ripley presented or documented things that were the fastest and slowest, biggest and smallest, tallest and shortest, to mention but a few. The continued popularity of the Guinness Book of World Records further attests to the natural interest of individuals in extreme and unusual phenomena. Extremes of weather and climate also hold an enchantment all their own. There is something intriguing about locations that are the hottest, coldest, wettest, driest, windiest, foggiest, and so forth. Many locales have even erected markers, signs, or plaques to commemorate some past extreme meteorological or climatological event. This document is not just intended to provide readers with snippets of curious meteorological and climatological oddities, but rather to make the reader aware of the range of many of the weather and climate elements and the overall diversity and variability of the environment in which we live.[1]

This report presents documented meteorological and climatological extremes that date from 1861 through January 1997. The bulk of the extremes appearing in this report are for surface air temperature and precipitation – these are the most commonly measured elements around the world. Many of these extremes carry the label "official." A meteorological organization has thoroughly researched the extreme event and has sanctioned it as an accepted measurement. In the United States (U.S.), elements of the National Oceanic and Atmospheric Administration (NOAA) are responsible for archiving and disseminating climate data and assessing the legitimacy of extreme value claims. "Official" extremes normally have numerous background references in the professional literature that discuss all aspects of the extreme, such as the measuring instrument and its calibration, type of exposure, and the meteorological conditions at time of occurrence. Unfortunately, many of the extremes appearing in this document have very limited or practically no supportive documentation as to whether they are "official" or have been the subject of some form of investigation. The extreme can be traced to a particular reference in which the location, date and the extreme value are identified, but little or no other background information is provided.

[1] The Appendix, appearing at the end of this report, contains a brief list of selected books, periodicals and resources that may prove to be beneficial to individuals who have an interest in weather and climate. A list of advanced meteorology and climatology texts is not included. These texts can be obtained at most college and university libraries.

II. WEATHER AND CLIMATE RECORDS

To ensure standardization in meteorological observations, institutions such as the World Meteorological Organization (WMO) have prescribed regulations covering meteorological instruments, their siting, and also proper observing practices. Hence, observations taken in accordance with these regulations and quality control practices would be accepted by the national meteorological agencies. Many of the extremes appearing in this volume, however, predate the establishment of official observation practices and standardized instrumentation. And, even after official acceptance, the validity of many extremes is still sometimes questioned. A number of extremes appearing in this volume are still viewed with some skepticism by meteorologists and climatologists.

It also must be remembered that it is quite probable the extremes presented in this report have been exceeded at some time and at some place. In earlier versions of this report, M.A. Arkin of the Environmental Science Services Administration, stated that "... record extremes must be taken with a grain of salt ..." (M.A. Arkin, personal communication, 1969). He explained that news of extreme weather events is not always widely disseminated, meteorological records at many locations are relatively short, stations are very few, and "... even the densest network of stations provides only a very small sample of the weather ...." For example, in areas such as mountains, deserts and the Arctic regions where many extremes occur and where the environment may be very diverse over short distances, reporting stations are, for the most part, few and far between. Within these regions, there are areas covering many thousands or even tens of thousands of square miles in which there may be no reporting stations at all. Hence, extremes can occur in these areas, but they are never measured. There have been a number of claims for even more extravagant extreme values than those appearing in this document. When information about these claims is available, it is discussed.

Some of the extremes appearing in this report were obtained from stations possessing very short periods-of-record (POR). In some instances the records were from scientific research sites that existed for just a scant, few years. The appropriate POR required so that the data are representative of typical climatic conditions depends on, among other factors, the element itself, its natural variability, and climatic area. As a general rule, a station should possess a continuous record of 30 years of data. This is referred to as a climatic "normal" period. However, some researchers have suggested that a location should have at least a continuous 10-year POR before they can call an extreme reading a record (Burroughs, 1996).

The authors of this report also had some difficulty in tracking down the exact source(s) of a number of extremes. Some extremes appear in the literature with absolutely no references at all. It also was quite common to find different extreme values for the same extreme event. In some cases, it was simply the result of a value being rounded to whole units of measure. In other instances, the values were radically different. This was especially evident when the extreme value was a climatological average. Depending on the POR used and the element being measured, the extreme averages varied greatly in different references.

III. TEMPERATURE

A. The Temperature Environment. Temperature is one of the most pervasive of all elements that comprise our weather and climate system. It affects practically everything, both natural and artificial. Temperature impacts the type of clothes we wear, the heating and cooling requirements of our homes, the types of vegetation indigenous to our area, the varieties of commercial crops that will flourish (Griffiths and Driscoll, 1982), and the design of our equipment, to mention but a few examples. Also, when combined with other elements, temperature can have a profound effect on our lives. High temperatures and high humidity produce heat stress, thus lowering human stamina and performance (Russell and Hay, 1957). High temperatures and solar radiation loads can degrade equipment so exposed (Krause, 1978). Low temperatures and wind can produce harmful wind chill. Low temperatures and precipitation may manifest itself with copious amounts of snow, freezing rain and sleet.

The natural surface air temperature environment of the earth ranges from approximately -129°F to +136°F (-89.4°C to +57.8°C), a span of 265 Fahrenheit degrees (~147 Celsius degrees). This full range does not occur at any one point. There are some locations, however, that are highly continental and experience large ranges in their absolute extremes that are greater than 180 Fahrenheit degrees (100 Celsius degrees). Conversely, many tropical locations show very little change in their month-to-month temperature environment. The following sections discuss temperature in terms of its measurement and also the conditions required for extremes to occur.

B. Temperature Measurement. Surface air temperature is measured with various types of thermometers. A common type is the liquid-in-glass thermometer. The liquid resides in a graduated, vacuum-filled tube. The liquid expands or contracts with changes in the temperature. Normally, mercury is used as the liquid. Since mercury freezes at -38°F (-38.89°C), thermometers used at locations that experience severe cold temperatures are filled with alcohol, which has a freezing point of -179.14°F (-117.3°C).

The most common thermometers used to measure extremes are the "maximum" and "minimum" thermometers. The maximum thermometer has a constriction just above the mercury bulb. As the air temperature rises, the mercury expands and is forced past this constriction. The constriction prevents the mercury from returning to the bulb when the air temperature cools. Hence, the temperature appearing on the maximum thermometer is the highest temperature reached since the thermometer was last reset. The minimum thermometer is an alcohol thermometer with a dumbbell-shaped rod, called an "index," in the alcohol column. As air temperature decreases, the surface tension at the top of the alcohol column drags the index down, leaving it at the minimum temperature. When the temperature rises, the alcohol flows freely around the index.

There are many other types of thermometers in use. Some rely on bimetallic strips made of metals with different coefficients of expansion. A bimetallic strip often is used in a thermograph. This type of device records a continuous trace of temperature through the use of an ink pen on a paper chart mounted on a revolving drum. Some thermometers measure a metal's changing electrical resistance with changes in temperature. There are others that measure current flow through a thermoelectric circuit composed of two dissimilar metals (thermocouples). As a general rule, most college-level meteorological and climatological texts generally present good discussions of the various types of thermometers.

In measuring surface air temperature, the thermometers are usually located in a standard instrument shelter. This is essentially a white, louvered box mounted on legs, situated over a flat, close cut, grassy surface. The exposure site should be representative of the surrounding landscape. The base of the shelter is normally between 4 to 6.6 ft (1.2 to 2.0 m) (Linacre, 1992). The box is louvered to permit the free flow of air over the instruments. The door of the box faces poleward so that direct sunlight does not impinge upon the thermometers while they are being read. In the tropical regions, where the sun is both north and south of the observer during various portions of the year, both the northward and southward faces of the box are hinged. The instruments are located in the shelter at approximately 4.5 to 6.0 ft (1.4 to 1.8 m) above the ground. In many areas outside the U.S., the standard instrument shelter is commonly referred to as a Stevenson screen. Air temperature measurements taken from instruments in this shelter may be referred to in the literature as screen temperatures. Linacre (1992) discusses the history of the standard instrument shelter.

A standard complement of instruments found in a typical instrument shelter would normally include a maximum and minimum thermometer, a thermograph, and a psychrometer. A psychrometer consists of a pair of standard thermometers, one of which has a cloth wick covering its bulb. When the wick is wetted and ventilated, water evaporates from the wick and lowers its temperature below the free-air temperature. This "wet-bulb" temperature along with the free-air temperature, or "dry-bulb," allows the computation of relative humidity and dew point temperature.

C. Temperature Extremes. This section presents discussions of extreme temperature events. Detailed summaries are provided for the extremes for which there exists sufficient information in the professional literature. Extremes with little or no available supportive information are presented in a concise format: extreme, location, date and reference. Extremes are organized by high temperature, low temperature, and temperature variability. Map 1 displays the temperature extremes.

1. High Temperature Extremes

Among the factors that contribute to the occurrence of extremely high temperatures are: strong heating of the surface, especially desert sand and rock, during times of high sun and very clear atmosphere; an extensive period of time that the air has passed or remained over an extremely warm surface; the inhibition of vertical convection or local circulation by subsidence; advection of air from places where it was already heated; and passage of air over mountains, especially when latent heat absorbed during condensation or rainfall on the ascent is released into the descending air (Lamb, 1958).

The highest frequency of maximum temperatures, >120°F (48.9°C) occurs in the northern and western Sahara Desert; Death Valley, CA; low-lying desert areas abutting the Persian Gulf; a small part of western Pakistan; and east-central portions of Australia (Hoffman, 1963).

WORLD'S HIGHEST TEMPERATURE
136°F (57.8°C)

Location: El Azizia, Libya [32°32'N, 13°01'E, elevation: 367 ft (112 m)]

Date: 13 September 1922

Discussion: Although this record has gained general acceptance as the world's highest temperature recorded under standard conditions, the validity of the extreme has been questioned. Fántoli (1954, 1958) examined the extreme in some detail. He researched the exposure, the instrument shelter and the instruments themselves, and also examined the prevailing weather conditions within the general vicinity of El Azizia at the time that this extreme was recorded. A discussion, in English, of Fántoli's 1954 work appears in Gentilli, 1955. Fántoli generally concluded that the probable extreme maximum should have been only 132.8°F (56°C).

Meteorological/Climatological Factors: Lamb (1958) discusses the meteorological conditions just before this extreme event. The extreme occurred just prior to the passage of a cold front. The region around El Azizia had been experiencing hot, southerly winds for two days prior to the event. Also, latent heat may have been added to the air mass by rainfall that occurred as the air mass passed over mountains to the south of El Azizia. Lamb also describes conditions that are favorable to the development of very high surface air temperatures. Some of the factors include: strong heating of the ground surface; high sun periods; clear atmosphere; air moving over a warm surface for long periods of time; inhibition of vertical convection or local circulation by subsidence; and descending (subsiding air).

Further Reading: Further discussions of the El Azizia high temperature extreme appear in Seamon and Bartlett (1956), and the U.S. Environmental Science Services Administration (1967). It is interesting to note that claims for even higher air temperature extremes have been made. For example, it's claimed that 140°F (60°C) was reached at Delta in Baja California [32°22'N, 115°12'W] and also at Riito [~32°15'N, 115°W] in Sonora, Mexico (International Boundary and Water Commission, 1964). However, these extreme temperatures have never been validated. Several works also have proposed theoretical limits for high surface air temperatures. An early work is that of famed geographer Mark Jefferson (1926), and more recently by Hoffman (1963). Hoffman concludes that the highest possible surface air temperature would be slightly over 131°F -- a full 5°F lower than the El Azizia record.

WESTERN HEMISPHERE'S HIGHEST TEMPERATURE 134°F (56.7°C)

Location: Greenland Ranch, CA, U.S. [36°28'N, 116°51'W, elevation: -178 ft (-54 m)]

Date: 10 July 1913

Discussion: This temperature occurred in Death Valley, CA. This area is a low elevation desert flanked by mountains. It has the hottest summers in the Western Hemisphere and the highest mean annual temperature in the U.S. -- 78°F (25.6°C). This record was officially accepted by the U.S. Weather Bureau.

Court (1949) examined this high temperature record in detail. His research included examinations of the surrounding environment, the meteorological equipment, the procedures used in taking the observation, and the temperature frequencies at Greenland Ranch for the period 1911 to 1947. Aside from the record, which occurred in July 1913, Court found only two instances during the 1911-1947 period in which temperatures of 127°F (52.8°C) had been recorded. Court determined that the record temperature of 134°F (56.7°C) has an expectancy of only once in every 650 years, thus, he concludes that "... no future official observation will exceed the present high temperature record for North America now held by Death Valley." (Court, 1949).

Meteorological/Climatological Factors: On the day this record temperature occurred, winds were strong and sandstorm conditions prevailed. The region had been undergoing a heat spell for 8 consecutive days. Maximum temperatures of 127°F (52.8°C) or higher were being measured (Williams, 1971). Court (1949) also noted at the time this extreme had occurred, there were comparatively low maximum temperatures at other stations in the area. There have been some assertions that this extreme might be an induced value. The sandstorm, occurring at the time the extreme was measured, may have lifted hot sand and dust from the desert surface. These super-heated surface materials then impinged upon the thermometer inside the shelter, thus giving an artificially high reading. Neiburger, Edinger and Bonner (1973) totally dismiss the Greenland Ranch extreme as well as the El Azizia world record. They state that "... analysis has shown them to be unreliable." They put forth a world record high temperature of 129°F (53.9°C) occurring at Furnace Creek, Death Valley, CA [36°28'N, 116°52'W] – the date of this extreme is not stated.

Further Reading: See Tattelman, Sissenwine and Lenhard (1969) for a general discussion and maps concerning the worldwide frequencies of high temperatures. Harrington (1892) provides an early narrative about the geography, climate and meteorology of Death Valley. He mentions that a temperature of 137°F (58.3°C) was once reported to have occurred.

HIGHEST ANNUAL MEAN TEMPERATURE
94°F (34.4°C)
(Possibly a World's Record)

Location: Dallol, Ethiopia [14°19'N, 40°11'E, elevation: -258 ft (-79 m)]

Date: Period of Record: October 1960 through November 1966

Discussion: Although not an official record, Dallol's annual mean air temperature is worthy of note. This is especially true when one considers that the highest annual mean temperature within the U.S. is 78°F. Dallol is located on the edge of the Danakil Depression, a salt desert. The temperatures were obtained from readings taken at a climatological station maintained at the base camp of an American prospecting company over a period of 6 years (October 1960 through November 1966). During the measurement period, the average mean daily maximum temperature was 106°F (41.1°C) and the average mean daily minimum temperature was 83°F (28.3°C). These values, averaged together, produce the extreme of ~94°F (34.4°C). Although the POR is quite small by meteorological standards (only 6 years), it is believed that the differences between these available 6-year values and longer-term means would be insignificant. At nearby Khormaksar, a location exhibiting similar temperature trends to Dallol's, the greatest difference between the means of daily maximum temperatures for the years 1961 through 1966, and those for 1947 through 1966, was only 0.54°F (0.3°C).

Meteorological/Climatological Factors: Locations that are hot in summer and warm in winter have high annual means of daily maximum temperature. The highest occur at low elevations, away from coasts, and within the latitude belt between 12° and 20°N across Africa and possibly in the southwestern Arabian peninsula (Pedgley, 1967). Pedgley investigated this temperature extreme, including the instrumentation and instrument siting. He also examined the records of nearby locations that might possess average daily maximums equal to or exceeding Dallol's. He concluded that in the lowest part of the Danakil depression (situated about 20 mi. south of Dallol and at an elevation about 390 ft (119 m) below sea level), annual mean daily maximum temperatures might be a "fraction of a degree greater" than at Dallol (Pedgley, 1967).

Further Reading: Extremes close to those in Dallol are found in the report "Temperature Extremes," published by the U.S. Environmental Science Services Administration (1967), and in data tables produced by Great Britain's Air Ministry (1941).

ANTARCTICA'S HIGHEST TEMPERATURE
59°F (15°C)
(Possibly a Record)

Location: Vanda Station, Antarctica [77°32'S, 161°40'E].

Date: 5 January 1974

Discussion: This possible record occurred at a New Zealand research station located on the shore of Lake Vanda. It was the highest temperature recorded since the station was established in 1970. Although the observation was officially accepted by the New Zealand Antarctic Society, they hesitate to claim it as Antarctica's highest (New Zealand Antarctic Society, 1974). This extreme exceeded the record of 58°F (14.4°C) that occurred on 20 October 1956 at Esperanza [~63°24'S, 57°00'W], an Argentinean research station on the Antarctic Peninsula (U.S. Environmental Science Services Administration, 1968). Esperanza (also known as Bahia Esperanza, Hope Bay) was in operation from 1945 through the early 1960s.

Meteorological/Climatological Factors: This extreme occurred during a period of record high temperatures in the McMurdo Sound and dry valley regions of the continent (New Zealand Antarctic Society, 1974).

Other High Temperature Extremes

ANTARCTICA: The **highest measured temperature** at the South Pole is 7.5°F (-13.6°C) recorded on 27 December 1978 and the highest measured temperature at Vostok, Antarctica [77°32'S, 161°40'E; elevation: 11,220 ft (3,420 m)] is 4°F (-15.7°C) (M.W. Sinclair, 1981).

ASIA: Asia's **highest measured temperature** is 129°F (53.9°C) and was recorded at Tirat Tsvi (Tirat Zevi), Israel [32°25'N, 35°32'E] on 21 June 1942 (U.S. Environmental Science Services Administration, 1968).

AUSTRALIA: Australia's **highest measured temperature** is 128°F (53.3°C) and was recorded at Cloncurry, Queensland [20°42'S,140°30'E] on 16 January 1889 (U.S. Environmental Science Services Administration, 1968).

AUSTRALIA: Marble Bar, Western Australia [21°12'S, 119°44'E] **experienced temperatures at or above 100°F** (37.8°C) on 162 consecutive days, from 30 October 1923 to 7 April 1924 (Ashton and Mayer, 1960).

CANADA: Canada's **highest measured temperature** is 113°F (45°C) and was recorded at two Saskatchewan locations -- Midale [49°22'N, 103°27'W] and Yellow Grass [49°49'N, 104°08'W] on 5 July 1937 (Manning, 1983). [Because of their proximity, these sites are shown as one location on Map 1.]

EUROPE: Europe's **highest measured temperature** is 122°F (50°C) and was recorded at Seville, Spain [37°23'N, 5°59'W] on 4 August 1881 (U.S. Environmental Science Services Administration, 1968).

PERSIAN GULF: The Persian Gulf had a **sea-surface temperature** of 96°F (35.6°C) recorded on 5 August 1924 by the SS Frankenfels (U.S. Environmental Science Services Administration, 1967). The exact geographic coordinates where the extreme was measured are unknown. This may not be the highest, however, because published values have indicated occurrences of Persian Gulf sea-surface temperatures as high as 98°F (36.7°C) (Great Britain Air Ministry, 1941). Average water temperatures in the Persian Gulf are very high during the summer -- 88°F (31.1°C) during July and August (U.S. Environmental Science Services Administration, 1967).

SOUTH AMERICA: South America's **highest measured temperature** is 120°F (48.9°C) and was recorded at Rivadavia, Argentina [24°11'S, 62°53'W] on 11 December 1905 (U.S. Environmental Science Services Administration, 1968).

UNITED STATES: The **warmest winters** in the U.S. averaged 73°F (22.8°C) at Honolulu, HI [21°19'N, 157°52'W] during the period 1941-1970 (Environmental Data and Information Service, 1979).

UNITED STATES: A **ground surface temperature** of 201°F (93.9°C) was recorded at Furnace Creek, Death Valley, CA [36°28'N, 116°52'W], on 15 July 1972. The air temperature at that time was 128°F (53.3°C). This information was obtained from a climate summary sheet prepared by the National Park Service, Death Valley National Monument, a National Weather Service Cooperative Station (P. Kubecka, personal communication, September 29, 1992). [Not mapped.]

WESTERN HEMISPHERE: The **hottest summers** in the Western Hemisphere averaged 98°F (37°C) in Death Valley, CA during the period 1941-1970 (Environmental Data and Information Service, 1979).

2. Low Temperature Extremes

Extreme low temperatures result from the simultaneous occurrence of an optimum combination of several meteorological elements; the absence of solar radiation, clear skies, and calm air are the most essential requirements (McCormick, 1958). During such conditions, there is a minimum of mixing in the vertical air layers. As the ground surface loses heat through terrestrial radiation, the nearest air layers become cooled and, consequently, heavier than the air layers above them. Extremely cold temperatures occur in interior, high latitude localities, under clear skies, and with topographic features that afford protection from sources of any modifying influences.

Geographic areas that experience high frequencies of extreme low temperatures are: the Antarctic Continent, especially the eastern Antarctic Plateau; the central portions of the Greenland ice cap; east-central portions of Siberia; and, the Yukon River basin of northwestern Canada and eastern Alaska.

WORLD'S LOWEST TEMPERATURE
-129°F (-89.4°C)

Location: Vostok, Antarctica [77°32'S, 161°40'E; elevation: 11,220 ft (3,420 m]

Date: 21 July 1983

Discussion: This record was confirmed by the Arctic and Antarctic Research Institute at Leningrad, Russia. This record exceeds the previous record, also at Vostok, of -126.9°F (-88.3°C) that occurred 24 August 1960.

Meteorological/Climatological Factors: Extremes of cold temperature result from "... the simultaneous occurrence of an optimum combination of several meteorological elements; absence of solar radiation, clear skies, and calm air are the most essential requirements, with the ultimate temperature dependent upon the duration of these conditions ..." (McCormick, 1958). During such conditions, there is a minimum mixing of the vertical air layers. As the ground surface loses heat through terrestrial radiation, the nearest air layers become cooler and, subsequently, heavier than the layers above them. Extremely cold temperatures occur in interior high latitude localities with clear skies, which are conducive to maximum terrestrial radiation, and with topographic features that afford protection from the wind. The Antarctic Continent, especially the eastern Antarctic Plateau, with elevations of 9,000 to 12,000 ft (2,750 to 3,700 m), is one of these geographic areas.

Further Reading: An account of this record reportedly appears in the Information Bulletin of the Soviet Antarctic Expedition, Number 105. A discussion of the theoretical minimum temperature limit can be found in Shliakhov (1958) and in McCormick (1958).

NORTHERN HEMISPHERE'S LOWEST TEMPERATURE
-90°F (-67.8°C)

Location: Verkhoyansk, Russia [67°34'N,133°51'E: elevation: 350 ft (107 m)] and at Oimekon, Russia [63°28'N, 142°49'E; elevation: 2,625 ft (806 m)].

Date: Verkhoyansk on 5 and 7 February 1892; Oimekon on 6 February 1933

Discussion: Very low winter temperatures occur in the Verkhoyansk-Oimekon cold zone, between approximately 63° and 68°N, and 125° and 150°E in the East Siberian taiga (northern coniferous forest). Claims of lower temperatures ranging from -95°F (-70.6°C) to -108°F (-77.8°C) have been made (Stepanova, 1958; Seamon and Bartlett, 1956; Finn, 1967, Neuberger and Stephens, 1948). Considerable controversy has arisen about the record low temperature extremes at Verkhoyansk because of instrument corrections and about the records at both locations because of misleading references to incorrect values found in the literature (Stepanova, 1958; Rubinshtein, 1959; Rubinshtein, 1968).

Meteorological/Climatological Factors: Sometimes referred to as the Northern Hemisphere's 'Cold Pole', this region of Siberia is one of extreme continentality. It is located near the eastern end of the world's largest land mass (Asia) and blocked off by mountain ranges from moderating oceanic influences. During the winter months, the high air pressures from the Asiatic anticyclone create clear weather and calm winds, which promotes strong radiational cooling over the snow surface during the long nights.

Further Reading: A discussion of Russia's 'Cold Pole' can be found in Borisov (1965).

GREENLAND'S LOWEST TEMPERATURE
-87°F (-66.1°C)

Location: Northice, Greenland [78°04'N,38°29'W; elevation: 7,687 ft (2,341 m)]

Date: 9 January 1954

Discussion: This record temperature was recorded at Northice, a station established by the British North Greenland Expedition (Hamilton and Rollitt, 1957). Although the POR for Northice is extremely short (November 1952 through June 1954), temperatures below -75°F (-59.4°C) occurred 16 times during that period (Quiroz, 1958).

Meteorological/Climatological Factors: Practically all of interior Greenland is covered with a permanent ice cap. Extreme low temperatures are the result of the loss of heat through radiation and evaporative cooling from the snow and ice surface (Hogue, 1964).

Further Reading: A detailed discussion of the temperature regime on the Greenland ice cap appears in P. Putnins (1970).

NORTH AMERICA'S LOWEST TEMPERATURE (excluding Greenland) -81.4°F (-63°C)

Location: Snag, Yukon Territory, Canada [62°23'N,140°23'W; elevation: 2,120 ft (646 m)]

Date: 3 February 1947

Discussion: The extreme occurred at the Snag Aerodome, which was in operation from 1943 to 1966. At the time this extreme occurred, the lowest gradation on the minimum thermometer that recorded it was -80°F. A pencil mark had been made at about 4 degrees below -80°F (Court and Samela, 1963). However, subsequent laboratory calibration of the thermometer indicated that the instrument had an error of approximately 3.0 degrees, and so the value of -81.4°F (-63°C) was officially set by the Canadian Meteorological Service (Court and Salmela, 1963; Thomson, 1958). At Snag, on the preceding day, 2 February, the corrected minimum was set at -80.1°F (-62.3°C). On the same day the record low temperature occurred at Snag, a value of -80°F (-62.2°C) was reported at Mayo [63°35'N, 135°54'W], a location on the Stewart River about 150 mi. to the northeast (Thomas, 1963). This low temperature record surpassed the old record of -78°F (-61.1°C) which was set at Fort Vermilion, Alberta, Canada [58°24'N, 116°00'W] on 11 January 1911 (Manning, 1983). An even lower value, -85°F (-65°C), was recorded at Fort Selkirk, Yukon Territory [62°45'N, 137°22'W], on 3 February 1947. The thermometer, however, was exposed on the side of the building instead of in a standard instrument shelter. Hence, the value was never considered official (Court, Sissenwine and Mitchell, 1949).

On 7 January 1982, temperatures of -96°F (-71.1°C) and -92°F (-68.9°C) were reported at two weather stations that had been established near Fort Nelson, British Columbia [58°49'N, 122°39'W), in connection with a permafrost study. To date, these temperatures have not been accepted by Canada's Atmospheric Environment Service. A discussion of these extremes appears in Harris (1982).

Meteorological/Climatological Factors: This record low temperature occurred during a prolonged cold spell caused by an influx of cold Arctic air accompanied by clear and calm weather, which is discussed in some detail by Wexler (1948).

Further Reading: See the chapter "The Climate of Canada and Alaska," by K.F. Hare and J.E. Hay (1974), and also "Canada's Cold Environments," by French and Slaymaker (1993).

UNITED STATES LOWEST TEMPERATURE
-79.8°F (-62.1°C)

Location: Prospect Creek, AK, U.S. [66°48'N,150°40'W; elevation: 1,100 ft (335 m)]

Date: 23 January 1971

Discussion: This extreme was recorded at a camp along the Alaska pipeline in the Endicott Mountains southeast of Bettles, AK. The official value of -79.8°F (-62.1°C) was established "... after subsequent recalibration of the thermometer at the Bureau of Standards in Washington ..." (Ludlum, 1971a). It replaced the previous official U.S. low of -76°F (-60°C) recorded in January 1886 at Tanana, AK [65°10'N, 152°05'W], in the Yukon Valley (Seamon and Bartlett, 1956).

During the month this record extreme occurred, extreme cold temperatures prevailed throughout the region. Fairbanks, AK [64°51'N,147°43'W] experienced its coldest month in 41 years – its January mean temperature was -31.7°F (-35.4°C). In Canada's Yukon Territory, the town of Mayo [63°35'N, 135°54'W] experienced a low temperature of -73°F (-58.3°C) and the mean temperature at Dawson, Yukon Territory [64°04'N, 139°25'W] was -44°F (-42.2°C) – some 26°F below normal (Ludlum, 1971a).

As an interesting aside, a minimum thermometer left for 19 years on Mount McKinley at an elevation of 15,000 ft (4,572 m) indicated that a temperature of -100°F (-73°C) had occurred sometime during its exposure (U.S. Army Natick Laboratories, 1969).

Meteorological/Climatological Factors: As with the other low temperature extremes, high pressure dominated this region, especially during the last half of the month.

Further Reading: See the chapter "The Climate of Canada and Alaska," by K.F. Hare and J.E. Hay (1974).

LOWEST AVERAGE TEMPERATURE FOR A MONTH
-99.8°F (-73.2°C)
(Possible Extreme)

Location: Plateau Station, Antarctica [79°15'S,40°30'E; elevation: 11,890 ft (3,625 m)]

Date: July 1968

Discussion: This extreme occurred at Plateau Station, Antarctica, a U.S. research site that was in operation from December 1964 through January 1969 (Schwerdtfeger, 1970). This extreme exceeded a mean monthly average temperature of -97.2°F (-71.8°C) recorded during August 1958 at Sovietskaya, Antarctica, a Russian station [78°24'S, 87°35'E; elevation: 11,713 ft (3,570 m)] (Alt, 1960). The Plateau Station extreme is believed to be a new world record (P.C. Dalrymple, personnal communication, 1985). During the winter season when the extreme occurred, Plateau Station experienced 100 days with temperatures below -100°F (-73.3°C) and on 20 July, the temperature dropped to -123.1°F (-86.2°C). This is approximately 6°F (3.3°C) less than the world's low temperature record that occurred at Vostok, Antarctica.

Meteorological/Climatological Factors: Plateau Station was located near the coldest part of Antarctica, which is believed to be close to the ridge line in East Antarctica (Lamb, 1958).

Further Reading: See the chapter titled "The Climate of the Antarctic," by W. Schwerdtfeger (1970).

Other Low Temperature Extremes

AFRICA: Africa's **coldest measured temperature** is -11°F (-23.9°C) and occurred at Ifrane, Morocco [33°30'N, 51°00'W] on 11 February 1935 (U.S. Environmental Science Services Administration, 1968).

ANTARCTICA: An **annual mean temperature** of -71°F (-57.2°C) was recorded at the Russian research station Sovietskaya, Antarctica [78°24'S, 87°35'E] in 1957 and 1958 (Stepanova, 1958). This is 1.0°F colder than the mean annual temperature reported at Plateau Station, Antarctica for the period 1966 to 1969.

AUSTRALIA: Australia's **coldest measured temperature** is -9.4°F (-23°C) and occurred at Charlotte Pass, New South Wales [~36°31'S, 148°19'E; elevation: 5758 ft (1755 m)] on 29 June 1994 (Buckley, 1995).

CANADA: Canada's **lowest annual mean temperature** is -3°F (-19.4°C) recorded at Eureka, Northwest Territories [79°59'N, 85°49'W] during the period 1947 to 1980 (Phillips and Ashton, 1980).

EUROPE: Europe's **coldest measured temperature** is -67°F (-55°C) and was reported at Ust 'Shchugor, Russia [~57°45'E, 64°15'N] during a 15-year period (exact years unknown) (U.S. Environmental Science Services Administration, 1968).

NORTH AMERICA: North America's **lowest mean temperature** for a month is -54°F

(-47.8°C) recorded at Eureka, Northwest Territories, Canada [79°59'N, 85°49'W] and occurred February 1979 (Phillips and Ashton, 1980).

SOUTH AMERICA: South America's **coldest measured temperature** is -27°F (-32.8°C) and occurred at Sarmiento, Argentina [45°35'S, 65°05'W] on 1 June 1907 (U.S. Environmental Science Services Administration, 1968).

UNITED STATES: The **coldest winters** in the U.S. averaged -16°F (-26.7°C) during the period 1941 to 1970 at Barter Island, AK [70°08'N, 143°35'W] (National Oceanic and Atmospheric Administration, 1979).

UNITES STATES: The **coolest summers** in the U.S. averaged 36°F (2.2°C) during the period 1941 to 1970 at Barrow, AK [71°18'N, 156°47'W] (National Oceanic and Atmospheric Administration, 1979).

UNITED STATES: The U.S. **low temperature record extreme** (excluding Alaska) is -69.7°F (-56.5°C) and was recorded at Rogers Pass, MT on 20 January 1954 (Ludlum, 1954). Rogers Pass is located on the Continental Divide, on Highway 200, about 40 mi. northwest of Helena, MT. Its approximate coordinates are 47°00'N, 112°24'W (J.Wraith, personal communication, 24 September 1996).

UNITED STATES: The U.S. **lowest annual mean temperature** is 9°F (-12.8°C) recorded at Barrow, AK [71°18'N, 156°47'W] during the period 1941 to 1971 (National Oceanic and Atmospheric Administration, 1979).

UPPER AIR: An **ozonospheric temperature** of -143°F (-97.2°C) was measured at about 78,740 ft (~24,000 m) above Halley Bay, Antarctica [75°31'S, 26°36'W; elevation 98 ft (~30 m)], on 9 August 1959 (George, 1961). [Not mapped.]

UPPER AIR: The **lowest temperature recorded in the Earth's atmosphere** is -243°F (-152.8°C) at 58 mi. (~93.3 km) above Point Barrow, AK (located approximately 10 mi. northeast of Barrow, AK) in June 1956 (Faust, 1969). [Not mapped.]

3. Temperature Variability Extremes

Large differences in temperature can occur seasonally, diurnally (daily), and in response to certain weather conditions. Seasonally, interior, continental areas, far from the modifying influence of water bodies, can experience very large differences between summer high temperatures and winter low temperatures. Sites in areas such as Siberia and Canada's Yukon Territory routinely have differences in the course of a year of over 150F° (~83C°). Diurnal temperature differences are greatest in areas where the air is dry and skies are clear. Arid areas at high elevations are prime candidates for having high daily ranges in temperature – one can swelter during the day and experience below freezing temperatures at night. Weather conditions, such as the passage of strong cold fronts and regional phenomena, such as warming *chinook* winds to the lee of mountain ranges, can cause rapid changes in temperature over very short periods of time.

UNITED STATES LARGEST 2-MINUTE TEMPERATURE RISE
49F° (27.2C°)

Location: Spearfish, SD, U.S. [44°30'N,104°00'W; elevation: 3,637 ft (1,108 m)]

Date: 22 January 1943

Discussion: Spearfish, SD, is located in the Black Hills, a large sedimentary dome mass culminating in peaks of over 7,200 ft (3,195 m) in elevation. The effects of this topography on winds from the west can cause rapid temperature fluctuations to occur quite frequently. During this extreme, 2-minute event, temperatures rose from -4°F at 7:30 a.m. to 45°F at 7:32 a.m. (Cameron, 1948). They then fell to 16°F at 12:15 p.m. and subsequently rose to 56°F at 12:40 p.m. (Hamann, 1943). These changes were so rapid that buildings were experiencing winter on one side and spring around the corner. Plate glass windows were said to have cracked due to the thermal action (Cameron, 1948).

On the same day, the temperatures at Rapid City, SD (44°05'N, 103°14'W), about 40 mi. (25 km) to the southeast of Spearfish, experienced a similar, wild roller coaster ride. Between 9:20 a.m. and 12:40 p.m. (a span of 3 hours and 20 minutes), the temperature rose from 5°F to 54°F in 20 minutes, followed by a drop to 11°F in 50 minutes, followed by a rise to 55°F in 15 minutes, followed by a drop to 10°F in 45 minutes, followed by a rise to 34°F in 20 minutes, followed by a drop to 16°F in 25 minutes, and culminating in a rise to 56°F in 25 minutes (Hamann, 1943). At the same time, this phenomena caused sharp temperature contrasts over quite small distances. For example, while the temperature at Lead, SD [44°21'N, 103°46'W] was 52°F (11°C), the temperature 3 mi (4.8 km) away at Deadwood, SD [44°23'N, 103°44'W], was -16°F (-27°C) – a difference of 68F° (~38 C°) (Hamann, 1943). During the event, small changes in elevation could mean up to 50F° difference in the air temperature. As automobiles passed from the cold air to the warm air, they instantly frosted over (Cameron, 1948).

Meteorological/Climatological Factors: Hamann (1943) attributed this phenomenon as being "... essentially the result of the wavering motion of a pronounced quasistationary front separating Continental Arctic air from Maritime Polar air...." Local *chinook* effects probably contributed to the unusual conditions. *Chinook* is a term given to a wind descending a mountain side and warming in the process by dynamic compression. The term *chinook* also is commonly called *foehn*, but may have other local names.

Further Reading: A detailed narrative of this event can be found in Cameron (1948). Ludlum (1971b) discusses similar events in Canada. Barry (1992) presents an excellent overview of mountain wind systems. See Strahler and Strahler (1987) for a treatment of the Black Hills Dome.

Other Temperature Variability Extremes

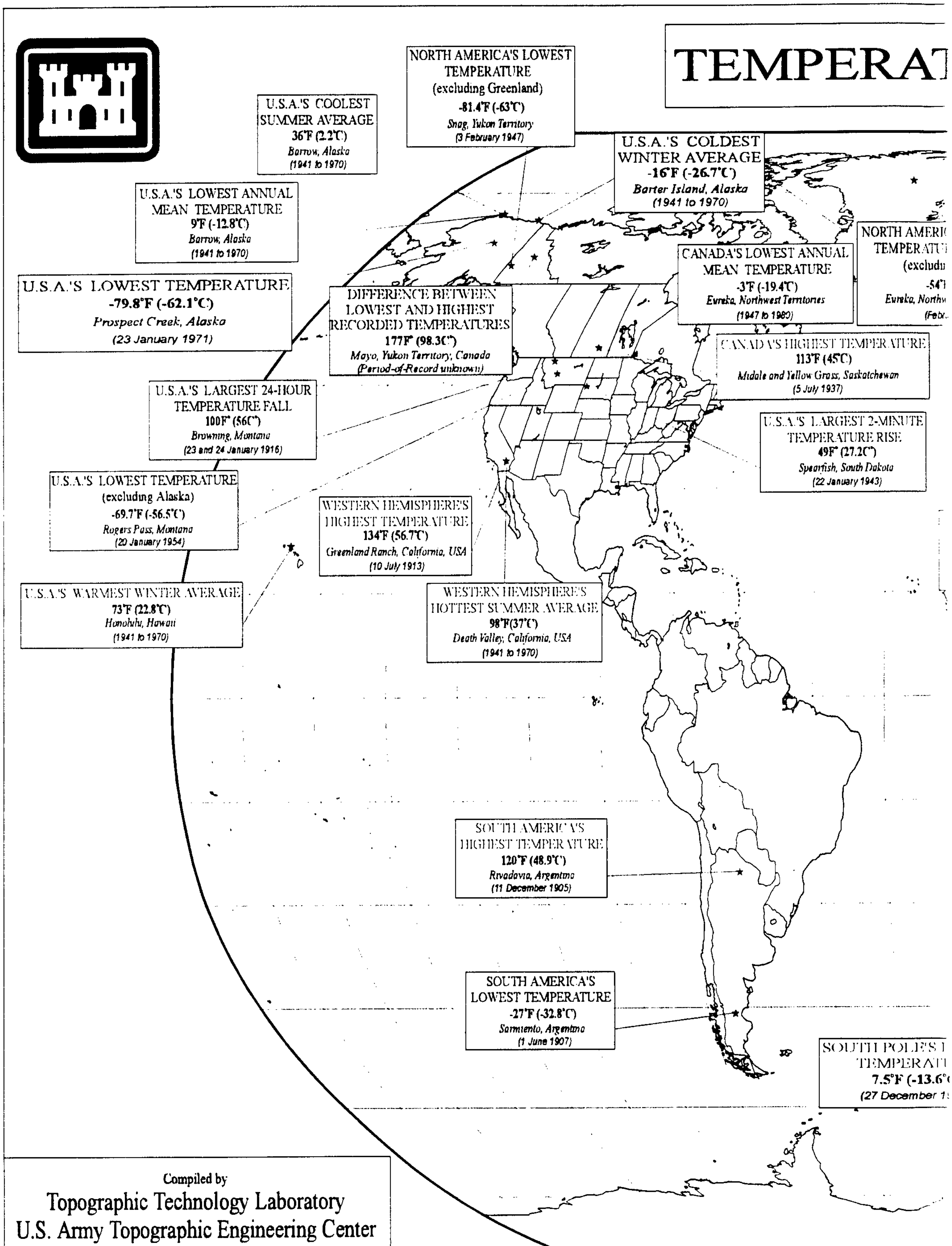
CANADA: During a 2-hour period on 6 January 1966, the temperature at Pincher Creek, Alberta [49°29'N, 113°57'W] rose 45F° from -12°F to 33°F and then fell from 33°F to 7°F. Several hours later it again rose 46F° from -10°F to 36°F within one hour (Ludlum, 1971b).

CANADA: Mayo, Yukon Territory [63°35'N, 135°54'W] recorded Canada's greatest difference between a location's absolute maximum and minimum temperature. The value is 177F° (98.3C°) [maximum = 97.0°F (36.1°C) and minimum = -80.0°F (-62.2°C)] (Newark, 1984).

RUSSIA: The Eastern Sayan Region of Russia [~52°45N, 96°E] has a mean annual temperature range of 146.4F° (81.3C°) [from 93.2°F (34.0°C) to -53.2°F (-47.3°C)] (Newark, 1984).

RUSSIA: Verkhoyansk, Russia [67°34'N, 133°51'E: elevation: 350 ft (107 m)] has a difference between its absolute maximum and minimum temperature of 183.2F° (101.8 C°) [maximum = 93.5°F (34.2°C) and minimum = -89.7°F (-67.6°C)] (Suslov, 1961).

UNITED STATES: The largest 24-hour temperature fall in the U.S. was 100F° (55.6C°) [from 44°F (6.7°C) to -56°F (-48.9°C)] and occurred at Browning, MT [48°34'N, 113°01'W] on 23-24 January 1916 (Environmental Data and Information Service, 1979).



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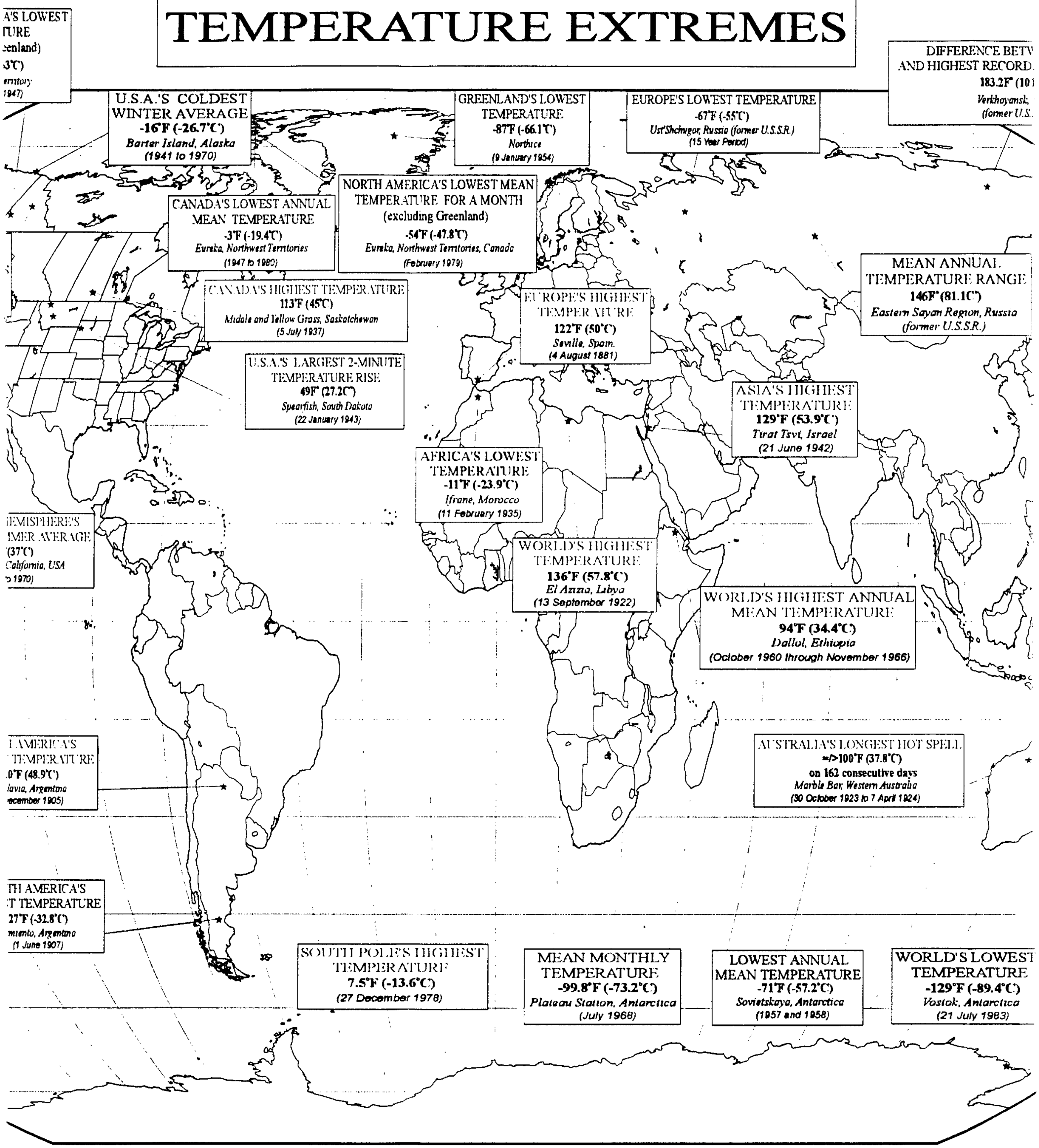
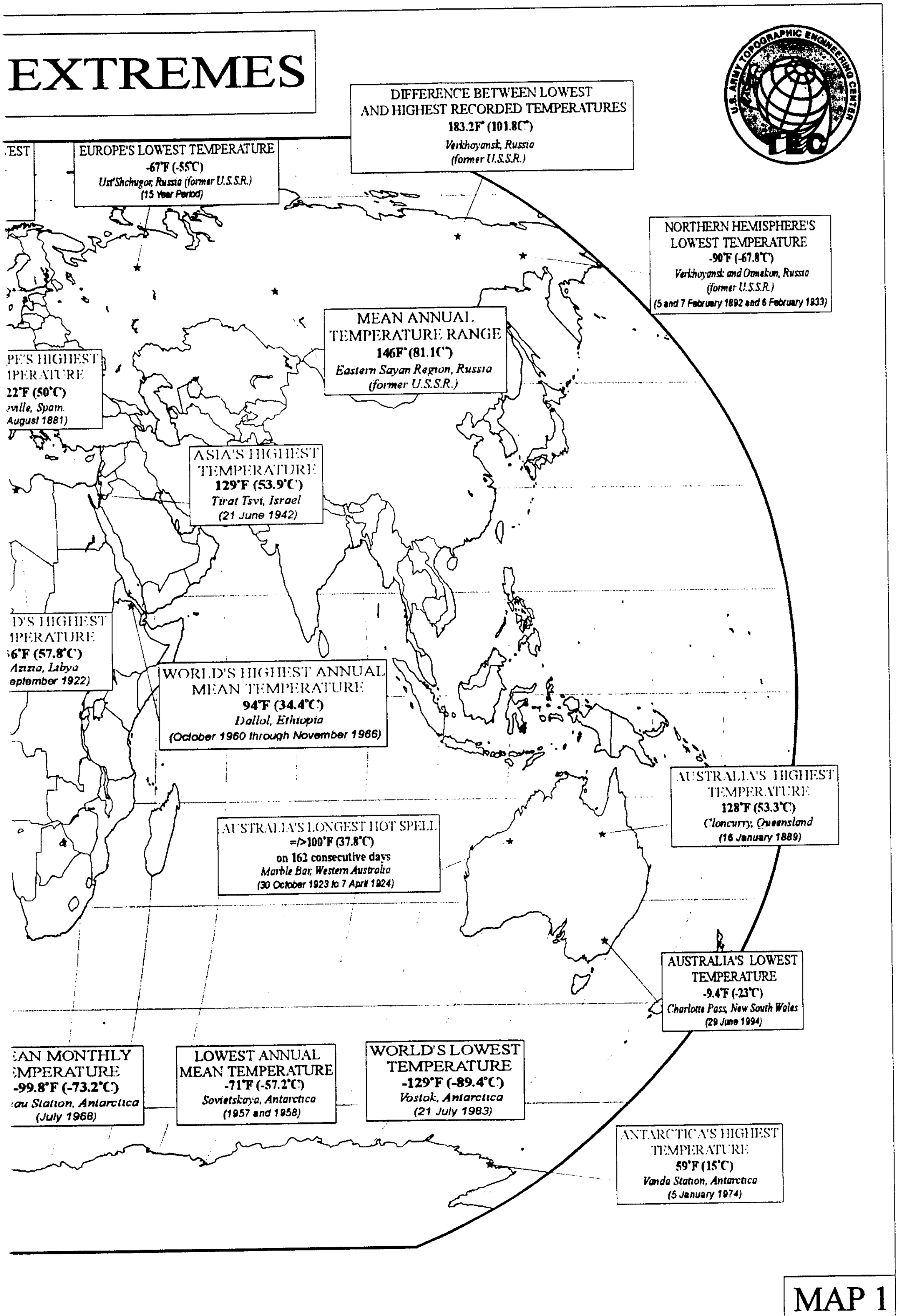
Alexandria, Virginia
22315-3864
for *"Weather and Climate Extremes"*, 1997

TEMPERATURE EXTREMES




EXTREMES
EST
EUROPE'S LOWEST TEMPERATURE
-67°F (-55°C)
Ust'Shchugor, Russia (former U.S.S.R.)
(15 Year Period)
DIFFERENCE BETWEEN LOWEST AND HIGHEST RECORDED TEMPERATURES
183.2F (101.8C)
Verkhoyansk, Russia
(former U.S.S.R.)
U.S. ARMY TOPOGRAPHIC ENGINEERING CENTER
TEC
NORTHERN HEMISPHERE'S LOWEST TEMPERATURE
-90°F (-67.8°C)
Verkhoyansk and Oimekon, Russia
(former U.S.S.R.)
(5 and 7 February 1892 and 6 February 1933)
MEAN ANNUAL TEMPERATURE RANGE
146F (81.1C)
Eastern Sayan Region, Russia
(former U.S.S.R.)
PE'S HIGHEST
IPERATURE
22°F (50°C)
eville, Spain
August 1881)
ASIA'S HIGHEST TEMPERATURE
129°F (53.9°C)
Tirat Tsvi, Israel
(21 June 1942)
D'S HIGHEST
IPERATURE
36°F (57.8°C)
Azizia, Libya
eptember 1922)
WORLD'S HIGHEST ANNUAL MEAN TEMPERATURE
94°F (34.4°C)
Dallol, Ethiopia
(October 1960 through November 1966)
AUSTRALIA'S HIGHEST TEMPERATURE
128°F (53.3°C)
Cloncurry, Queensland
(16 January 1889)
AUSTRALIA'S LONGEST HOT SPELL
=/>100°F (37.8°C)
on 162 consecutive days
Marble Bar, Western Australia
(30 October 1923 to 7 April 1924)
AUSTRALIA'S LOWEST TEMPERATURE
-9.4°F (-23°C)
Charlotte Pass, New South Wales
(29 June 1994)
EAN MONTHLY
EMPERATURE
-99.8°F (-73.2°C)
au Station, Antarctica
(July 1968)
LOWEST ANNUAL MEAN TEMPERATURE
-71°F (-57.2°C)
Sovietskaya, Antarctica
(1957 and 1958)
WORLD'S LOWEST TEMPERATURE
-129°F (-89.4°C)
Vostok, Antarctica
(21 July 1983)
ANTARCTICA'S HIGHEST TEMPERATURE
59°F (15°C)
Vanda Station, Antarctica
(5 January 1974)
MAP 1

IV. PRECIPITATION

A. The Precipitation Environment. Precipitation, like temperature, is a dominant element in our weather/climate system. And, like temperature, precipitation affects practically everything. It supports life on our planet and also helps shape our physical surroundings. Precipitation impacts the types of clothes we wear and the types of vegetation that grows where we live. Precipitation, both solid and liquid, affects the design requirements of various types of equipment, buildings and structures. An overabundance of precipitation can cause severe localized flooding and erosion, as well as making off-road mobility difficult if not impossible. As snowfall, it can paralyze our transportation systems, while conversely creating a medium for winter recreation and providing a source of beneficial irrigation waters during spring snow melt. However, a lack of precipitation can decimate crops and, if severe enough, cause famine and starvation.

The precipitation environment on earth ranges from desert locations that have received no precipitation for more than a decade, to a site in India that once received almost 87 ft (26 m) of rain in the course of a 12-month period. There are locations that exhibit month-to-month uniformity of precipitation, and locations that have distinct wet and dry seasons.

B. Types of Precipitation. There are many types of liquid and solid (frozen) precipitation. The main liquid types are mist, drizzle and rain. When the liquid form falls and freezes upon impact with the ground or objects it is termed freezing precipitation (freezing mist, freezing drizzle and freezing rain). Solid (frozen) types include snow, hail, snow pellets (graupel) and ice pellets (sleet). Many of these liquid and solid types are further sub-classified by scientists based on rate of accumulation, prevailing visibility during the event, and other characteristics. The Glossary of Meteorology (Huschke, 1959) provides a detailed explanation of all possible types.

The follow sections discuss precipitation in terms of its measurement and the atmospheric mechanisms that produce precipitation.

C. Precipitation Measurement. A standard rain gauge is commonly used to measure rainfall. It consists of a funnel-shaped collector normally 8 inches (in) [20.3 centimeters(cm)] in diameter attached to a 20-in (51-cm) long collection tube. The cross-sectional area of this collector is ten times that of the tube. Hence, rain falling into the collector is amplified tenfold in the tube, permitting measurements of great precision. A calibrated wooden scale is then inserted into the tube and withdrawn. The wet portion of the scale indicates the depth of the water. Accuracy can be obtained to approximately 0.01 in (0.025 cm). Any amount less than this is termed a trace (Ahrens, 1991).

Other common types of rain gauges include the tipping bucket and the weighing types. These types are recording gauges and have the advantage that they need not be tended to on a daily basis. Precipitation amounts are recorded either on a paper chart attached to a revolving, clock-driven drum, or they may be sent as a signal to an electronic recording device or computer. All of the above means of measurement have advantages and disadvantages. A good discussion of the pros and cons of various rain gauges appears in Linacre (1992).

The amount of snowfall is determined by measuring its depth at a number of representative locations and then averaging the measurements, although it is sometimes measured within the rain gauge itself. Ahrens (1991) states that three or more measurements should be taken to account for the spatial variability of the snowfall. Linacre (1992) increases the number of measurements to "... 10-20 points about 20 m (~66 ft) apart..." in order to provide a representative sample. Very often a snow board is used. It is a white, 16-inch square, waterproof board. It is set upon the ground or upon a board laid upon previously fallen snow. New snowfall is then measured with a graduated stick. The liquid equivalent of the fallen snow as well as its depth also can be measured using a graduated tube. The tube of a given volume is used to cut a cylinder of snow. The snow is allowed to melt and is then poured into a gauge for measurement. Also, the snowfall could be weighed to find the equivalent depth of water. As a general rule, in a fresh snowpack, about 10 units of snow will melt down to 1 unit of water, giving a ratio of 10:1 (e.g., 10 in of snow = 1 in of water). Dry, powdery snow may have a ratio as high as 30:1. Very wet snow may have a typical ratio on the order of 4:1. Older, partially melted snow can have a ratio as low as 2:1.

Discussion of other measurement methods, as well as the inherent problems in snowfall measurement, can be found in a number of sources (Doesken and Judson, (1996), Linacre (1992), Barry (1992), Critchfield (1983), and most meteorology and climatology texts). Official measurement techniques and reporting practices for observers are published by the National Weather Service. They can be obtained from the Office of Meteorology, National Weather Service, NOAA. The latest update of these rules was published in 1996.

D. Precipitation Producing Mechanisms. In general, the process of precipitation consists of a moist body of air rising, cooling, becoming saturated, condensing to form a cloud, and subsequently releasing the moisture as some form of precipitation. Four main types of mechanisms responsible for precipitation are recognized in the literature. They are: convection, frontal or cyclonic, orographic, and convergence.

Convection is the process whereby moist air at the surface is heated, becomes less dense than the surrounding air, and rises. Convective showers tend to be frequent in warm areas and seasons, and are responsible for many short-period rainfalls. Frontal (or cyclonic) precipitation results from the meeting of dissimilar air masses. These air masses do not mix readily. Rather a zone of discontinuity called a "front" is established between them. The warmer air inevitably rises over the cooler air. As the warmer air rises, it may be cooled to its dew point with resulting clouds and precipitation. In the more severe cyclonic storms, such as hurricanes and typhoons, very heavy and prolonged rainfall can occur. These storms are responsible for extreme amounts occurring over several hours or days. Orographic precipitation results from the forced upward deflection of an air mass as it strikes a topographic barrier. If the ascending air is cooled to its dew point then precipitation can occur. If occurring in conjunction with the convective and frontal types, large increases in precipitation may occur. Highlands in the path of moisture-carrying winds from warm seas have abundant and frequent precipitation. Such areas may experience extreme annual rainfall amounts. Convergence occurs when air comes together. When air converges, it results in a general uplift because of the crowding. This results in enhanced instability, and will likely produce showery precipitation. A large-scale example of this is the convergence of the Northern Hemisphere's northeast trade winds and the Southern Hemisphere's southeast trade winds. The area of convergence is commonly termed the "intertropical convergence zone" (ITCZ).

E. Precipitation Extremes. This section presents discussions of extreme precipitation events. Detailed summaries are provided for the extremes for which there exists sufficient information in the professional literature. Extremes with little or no available supportive information are presented in a concise format: extreme, location, and date. Extremes are organized by greatest precipitation, least precipitation, and precipitation variability. Map 2 displays the precipitation extremes.

1. Greatest Rainfall Extremes

WORLD'S GREATEST 1-MINUTE RAINFALL
1.23 in (3.12 cm)

Location: Unionville, MD [38°48'N, 76°08'W, elevation: 499 ft (152.13 m)]

Date: 4 July 1956

Discussion: At Unionville, the total precipitation during the storm was 3.60 in (9.1 cm), of which 2.84 in (7.2 cm) fell during a 50-minute period from 2:50 to 3:40 p.m. Rainfall was measured with a recording rain gauge located in satisfactory exposure. Some 13 points pertaining to functioning of the gauge were considered in evaluating this record by H.H. Engelbrecht, then State Climatologist for Maryland, and T.E. Hostrander, who was Substation Inspector. An enlarged photograph of the recording rain gauge chart revealed that at chart time 3:23+ the pen was at 2.47 in on the chart scale and at chart time 3:23- it was at 3.70 in. It was concluded that "... 1.23 in of precipitation occurred in an estimated period of one-minute or less..." (Engelbrecht and Brancato, 1959). This exceeded the previous world record l-minute rainfall of 0.69 in. (1.75 cm) at Jefferson, IA [42°01'N, 94°22'W], which in turn had exceeded the earlier record of 0.65 in (1.65 cm) at Opid's Camp, CA.

Meteorological/Climatological Factors: The extreme fall occurred during an afternoon of intense thunderstorms in the foothills of northern Virginia and adjacent north-central Maryland.

Further Reading: The U.S. Weather Bureau's investigation of this record is described by H.H. Engelbrecht and G.N. Brancato (1959).

POSSIBLY WORLD'S GREATEST 1-MINUTE RAINFALL
1.5 in (3.12 cm)

Location: Barot, Guadeloupe, West Indies [exact coordinates unknown]

Date: 26 November 1970

Discussion: This extreme appears in Schlatter (1991), and also in Williams (1992). Both of these sources cite only the extreme and date of occurrence. Neither of these authors discuss any details of the event. Schlatter cites the source of the extreme as the World Meteorological Organization's "Manual for Estimation of Probable Maximum Precipitation," WMO No.332, Operational Hydrology Project No. 1, World Meteorological Organization, Geneva, Switzerland, 1986.

Authors' Note: Barot could not be located on any map or in any gazetteer. Additionally, the National Imagery and Mapping Agency [NIMA] (formerly the Defense Mapping Agency [DMA]) searched its hard copy and automated databases and could not find the site in question. Since its location could not be determined and there was no detailed information about the extreme, it is presented as merely a possible record.

WORLD'S GREATEST 42-MINUTE RAINFALL
12 in (30.5 cm)

Location: Holt, MO [39°27'N, 94°20'W, elevation: 863 ft (263.11 m)]

Date: 22 June 1947

Discussion: The storm was reported by seven volunteer observers, two of whom noted the 12-in occurrence in 42 minutes (U.S. Weather Bureau, 1947). Many roads and bridges were washed out in the area surrounding this small Missouri town.

Meteorological/Climatological Factors: G.A. Lott (1954) has examined the meteorological data available for this storm and considered the factors responsible for its remarkable intensity. According to Lott, the storm occurred "... as a local intensification in a long, narrow, warm sector convective system (the leading edge of which may be interpreted as an instability line) a short distance ahead of a surface cold front ...." He further states that "... a unique factor was the tightening of the pressure gradient north of an instability-line Low, causing an extraordinarily strong low-level flow of unstable air into the pre-existing convective system ...." Schlatter (1991) notes that the storm producing the extreme has a very strong inflow (approximately 48 mi/h) of very moist air (dew point 73-74°F).

WORLD'S GREATEST 60-MINUTE RAINFALL
12.0 in (30.5 cm)

Location: Holt, MO [39°27'N, 94°20'W, elevation: 863 ft (263.11 m)] and
Kilauea Sugar Plantation, Kauai, HI [coordinates and elevation unknown]

Date: Kilauea Sugar Plantation: 24-25 January 1956; Holt, MO: 22 June 1947

Discussion: The world's greatest precipitation in 60 minutes is listed as occurring both at Holt, MO, and at Kilauea Sugar Plantation, Kauai, HI (Schmidli, 1983). The amount, 12 in (30.5 cm), is the same for each. The rainfall at Kilauea occurred during the storm on 24 and 25 January 1956, in which over 38 in (96.5 cm) fell within a 24-hour period, 6 in (15 cm) during a 30-minute period, and about 12 in (30.5 cm) in 1 hour. "The 38-in value for 24 hours is conservatively low, because the gauge was already overflowing when it was emptied for the first time. The 12-in value for one hour is an estimate only - again because of overflow - and may be in error by as much as an inch." (National Climatic Data Center, 1978). [Not mapped.]

Meteorological/Climatological Factors: None provided for Kilauea Sugar Plantation. See text for "World's Greatest 42-Minute Rainfall" for a summary of the Holt, MO, event.

Authors' Note: Schlatter (1991) cites a record 60-minute rainfall of 15.78 in (41.1 cm) which supposedly occurred at Muduocaidang, Nei Monggol, China, on 1 August 1977. On the same day this 60-minute extreme was set, records for the greatest 6-hour (33.07 in) and 10-hour rainfalls (55.12 in) also were set at the same location (Schlatter, 1991). Schlatter cites the source of the extreme as the WMO's "Manual for Estimation of Probable Maximum Precipitation," WMO No.332, Operational Hydrology Project No. 1, WMO, Geneva, Switzerland, 1986. Unfortunately, this extreme does not appear in this WMO document (see Annex 2, Tables A.2.1 and A.2.2). No other reference could be located that mentions or discusses this extreme. Also, this site could not be located on any map or in any gazetteer. As an additional check, the Names Division of NIMA was gracious enough to search their hard copy and automated databases for this location They could not find the site in question. Since its location could not be determined, and there was no detailed information about the extreme, it is presented here as merely a possible record.

WORLD'S GREATEST 12-HOUR RAINFALL
46 in (117 cm)

Location: Grand Ilet, La R'eunion Island [21°00'S, 55°30'E]

Date: 26 January 1980

WORLD'S GREATEST 24-HOUR RAINFALL
72 in (182.5 cm)

Location: Foc-Foc, La R'eunion Island [21°00'S, 55°30'E]

Date: 7-8 January 1966

WORLD'S GREATEST 5-DAY RAINFALL
169.3 in (430 cm)

Location: Commerson, La R'eunion Island [21°00'S, 55°30'E]

Date: 23-28 January 1980

Discussion: The heavy rainfall that produced the world's greatest 12-hour and 5-day rainfall amounts was attributable to tropical cyclone Hyacinthe, which meandered near La R'eunion Island for 15 days during January 1980 (Chaggar, 1984). Record rainfalls were set all over La R'eunion during this period. The 7-day total at Commerson broke the 15-day total held by Cherrapunji, India. The 12-hour extreme amount at Grand Ilet is less than the 53 in (135 cm) for Belouve that appeared in the 1985 version of this report. Correspondence from the National Meteorological Service of France warned that the Belouve value is suspect and should not be used (G. Dhonneur, personal correspondence, 23 April 1993). Rainfall amounts at La R'eunion Island approach some of the estimates of the greatest amounts that could possibly occur. According to the formula of Paulhus, the greatest amount for 12 hours would be 54 in (137 cm); for 24 hours, 75 in (191 cm); and for 1 hour, 16.6 in (42 cm). According to Marx's formula, the greatest amount for 12 hours would be 53 in (135.5 cm) and for 1 hour, 15 in (39 cm).

Meteorological/Climatological Factors: La R'eunion Island is located approximately 400 mi. east of Madagascar in the Indian Ocean and holds all of the greatest observed point rainfall records for the periods from 9-hours to 8-days (Chagger, 1984). The island is about 30 by 40 mi. (48 by 64 km) in extent, and very mountainous, with steep slopes up to 10,000 ft (3,300 m), and narrow valleys, where winds are funneled to increase the orographic effects. This orography greatly intensifies the heavy rainfalls associated with tropical storms. Sea surface temperature is highest during the tropical cyclone season, reaching 81°F (27°C) in March.

Further Reading: On the basis of the La R'eunion records, formulas to compute the greatest amounts possible for various durations have been developed by Paulhus (1965), and also by Marx (1969). Jennings (1950) plotted extreme precipitation amounts versus time on log-log paper (the plotted points form a straight line).

NORTHERN HEMISPHERE'S GREATEST 24-HOUR RAINFALL
49 in (125 cm)

Location: Paishih, Taiwan [24°33'N, 121°13'E, elevation: 5,358 ft (1,636 m)]

Date: 10-11 September 1963

Discussion: Paishih is located on the island of Taiwan. The record rainfall, 49.13 in (124.79 cm), occurred during typhoon Gloria, and was measured in a recording gauge, thus adding to the reliability of the observation (Paulhus, 1965). Rain of similar intensity fell at nearby stations during the same storm. At one of these locations, Paling, total rainfall during the typhoon was greater than at Paishih, and, for some durations, intensity might have been greater. However, no further information on Paling is available.

Meteorological/Climatological Factors: Taiwan, like La R'eunion, is very mountainous and is surrounded by warm ocean water, 82°F (28°C) in August and September during the tropical storm season.

UNITED STATES GREATEST 24-HOUR RAINFALL
43 in (109 cm)

Location: Alvin, TX [29°25'N, 91°15'W; elevation: 51 ft (15.6 m)]

Date: 25-26 July 1979

Discussion: The 43 in (109 cm) of rainfall was measured 25 July through noon on 26 July, and 26 in (66 cm) fell in the 10-hour period between 9 p.m. on the 25th and 7 a.m. on the 26th. Although this is not an official record, it is one of the few "well-accepted unofficial extremes" included by Schmidli (1983), as was the previous 24-hour record of 39 in (99 cm) for North America at Yankeetown, FL [29°02'N, 82°43'W]. It exceeds the 39 in (99 cm) at Dharampuri, India [12°08N, 78°10'E], which had been included on the 1970 and 1974 maps of this report as possibly the world's greatest on flat terrain.

Meteorological/Climatological Factors: Alvin is located on the flat coastal plain about 25 mi. south of Houston, TX. The extreme rainfall there occurred in connection with tropical storm Claudette. According to Hill (1980) when this storm moved into southeastern Texas, weak stirring currents allowed it to "... drift for about 30 hours in a region of very high residual moisture while its circulation continued to bring large amounts of moisture onshore from the nearby Gulf."

AUSTRALIA'S GREATEST 24-HOUR RAINFALL
44 in (114 cm)

Location: Bellenden Ker (Top Station), Queensland [(17°16'S, 145°51'E, elevation: 5,102 ft (1,555 m)]

Date: 4 January 1979

Discussion: This new record has been officially accepted by the Australian Bureau of Meteorology. It replaces the previous record of 3 February 1893, of 36 in (91 cm) at Crohamhurst, Queensland (J. de la Lande, personal correspondence, 5 July 1985).

Meteorological/Climatological Factors: The rainfall occurred during a cyclonic storm in which comparable heavy rain fell at nearby stations.

UNITED STATES GREATEST 12-MONTH RAINFALL
739 in (1878 cm)

Location: Kukui, Maui, HI [20°54'N, 156°36'W, elevation: 5,788 ft (1,764 m)]

Date: December 1981 to December 1982

Discussion: The 1981-1982 rainfall at Kukui, HI, 624 in (1,585 cm), surpassed the previous U.S. record for 12 months, July 1947-July 1948, at Mount Waialeale, HI. Kukui also had the greatest precipitation in the U.S. during a calendar year, 704.83 in (1,790 cm) in 1982.

Meteorological/Climatological Factors: Kukui is located in a mountainous area on the windward side of the island of Maui. The moisture-laden northeast trade winds impact this area, and when combined with the local orographic lifting, produce copious amounts of rain.

Further Reading: See the "Atlas of Hawaii" by Armstrong (1973) for a good discussion of the precipitation environment of the Hawaiian islands.

[Authors' Note: The following discussions concern the location possessing the greatest average annual precipitation – also termed "the World's Wettest Place" in the literature. Four locations with this possible distinction appear in the published literature: Mount Waialeale, HI, U.S.; Mawsynram and Cherrapunjii, India; and Lloro, Colombia, South America. Each of these extremes is discussed in some detail. The discussion should provide the reader with an appreciation concerning the effect of the length of a station's POR on average annual precipitation values. Average precipitation values for the same station can vary wildly in the literature depending on what POR is used by the author. The reader also should gain an understanding of the inherent difficulty in assigning the title "World's Wettest Place" to any of the candidate stations.]

UNITED STATES GREATEST AVERAGE YEARLY PRECIPITATION AND POSSIBLY WORLD'S GREATEST AVERAGE YEARLY PRECIPITATION 460 in (1,168 cm)

Location: Mount Waialeale, Kauai, HI [(22°03'N, 159°30'W, elevation: 5,148 ft (1,569.5 m)]

Date: 1931 - 1960

Discussion: The value of 460 in (1,168 cm) is based on data for the period from 1931 through 1960 (U.S. Environmental Science Services Administration, 1968). Higher averages are cited for other PORs, e.g. 472 in (1,199 cm) for 1912 through 1949 and 486 in (1,234 cm) for a more recent period beginning (presumably) in 1941.

Meteorological/Climatological Factors: Conditions pertinent to the record rainfall are described by Henning (1967). According to him, the storage rain gauge is at an elevation of 5,075.5 ft (1,547 m), and measurements are usually made at 1- to 3-month intervals.

Further Reading: See the "Atlas of Hawaii" by Armstrong (1973) for a good discussion of the precipitation environments of the Hawaiian Islands.

ASIA'S GREATEST AVERAGE YEARLY PRECIPITATION AND POSSIBLY WORLD'S GREATEST AVERAGE YEARLY PRECIPITATION 467.4 in (1,187.3 cm)

Location: Mawsynram, India [25°18'N, 91°35'E]

Date: 1941-1979

Discussion: This extreme is discussed in some detail by Thapliyal and Kulshrestra (1992). Looking at similar PORs, they compared the annual average rainfall amounts at Mawsynram, Cherrapunji, and Mount Waialeale. They believe that Mawsynram should hold the title of the world's wettest location with an average annual amount of 467.4 in (1,187.3 cm) for a 38-year period. Cherrapunji would be the second wettest with an average annual amount of 463 in (1176.3 cm) during a recent 36 year period. Mount Waialeale would be the third wettest with 460 in (1,168 cm) during a recent 32-year period.

If all available records are considered, Mawsynram would still be the wettest with an annual average of 467.4 in (1187.3 cm) for the period 1941-1979. Mount Waialeale would be second with an annual average of 450.3 in (1143.8 cm) and Cherrapunji would be the third wettest with an annual average of 445.4 in (1131.4 cm) for the period 1852-1989 (Thapliyal and Kulshrestra, 1992).

During the period 1948-57, rainfall at Mawsynram averaged a sizable 550 in (1,397.8 cm). India's greatest 24-hour rainfall also occurred at Mawsynram. It was 38.96 in (98.96 cm) on 9-10 July 1952 (Thapliyal and Kulshrestra, 1992).

Meteorological/Climatological Factors: When the summer monsoon depressions (moderately vigorous, warm-cored cyclonic disturbances accompanied by heavy rain) from the Bay of Bengal reach the Himalayas, the rainfall is further increased by orographic lifting (Walker, 1972). As a result of these monsoon disturbances, which are still not fully understood, the eastern Himalayan foothills are very wet regions (both Cherrapunji and Mawsynram are located in this geographic area). Thapliyal and Kulshrestra (1992) point out that higher rainfall rates at Mawsynram than at Cherrapunji can be attributed to the fact that "... [Mawsynram] has a higher elevation and is located the crest of a hill range on the edge of a narrow valley... an orographic position more favorable to higher rain." Also see Riabchikov (1970) for a comparison of the rainfall at Cherrapunji and Mawsynram.

In addition, Cherrapunji holds records for the world's greatest rainfalls for various duration of from 15 days to 2 years (Paulhus, 1965). The greatest amount for a calendar year at Cherrapunji is 905.1 in (2,298.95 cm) and the least, 282.6 in (717.8 cm).

POSSIBLY WORLD'S GREATEST AVERAGE YEARLY PRECIPITATION
523.6 in (1,330 cm)
(amount was estimated)

Location: Lloro, Colombia [5°31'N, 76°33'W]

Date: 1932-1960

Discussion: Lloro is located on the Atrato River about 20 mi. from Quibdo. The annual precipitation values for the period 1932-1960 were reduced based on very reliable data from a nearby location (Snow, 1976). An annual value for 1953 of 726.3 in (1,844.9 cm) was reported to have occurred.

Meteorological/Climatological Factors: See the same section of the following extreme for a discussion of this geographic region.

SOUTH AMERICA'S GREATEST AVERAGE YEARLY PRECIPITATION 354 in (899 cm)

Location: Quibdo, Colombia [5°41'N, 76°40'W, elevation: 120 ft (37 m)]

Discussion: The value of 354 in shown on the current map was obtained from the Environmental Data Service (Arkin, 1969). A rainfall average of 413 in (1,049 cm) at Quibdo, based on data from 1931 through 1946 taken from Colombian sources, was cited on the 1964 revision of the world weather extremes map. Earlier maps cited a value of 342 in (869 cm) at Buena Vista, Colombia (Seamon and Bartlett, 1956). Trewartha (1970) discusses some early precipitation statistics at Quibdo, Colombia. During a 5.5-year period, average annual precipitation was 430 in (1092 cm), and in one year, 1937, 536 in (1361 cm) were recorded. Snow (1976) reports that in 1936, an astonishing 781 in (1,984 cm) fell at Quibdo; however, Snow could not corroborate this value in other sources.

Meteorological/Climatological Factors: Trewartha (1970) discusses the rainfall environments of the Pacific lowlands of Colombia. He notes that this area has an extraordinary amount of annual precipitation that represents the "... heaviest rainfall in all of the Americas, and possibly the greatest for any equatorial region of the earth." He points to the circulation in the area as being from the west and consequently onshore. In addition to this orographic component, he discusses the precipitation enhancement caused by the position of the intertropical convergence zone (ITCZ) in relation to coastal Colombia (Trewartha, 1970).

NORTH AMERICA'S GREATEST AVERAGE YEARLY PRECIPITATION 256 in (650 cm)

Location: Henderson Lake, British Columbia [49°88'N, 125°08'W, elevation: 12 ft (3.66 m)]

Discussion: This station was at a fish hatchery (no longer in operation) at the head of Henderson Lake on the west coast of Vancouver Island. A nearby station, Ucluelet Brynnor Mines, had the greatest l-day precipitation in Canada, 19.26 in (48.92 cm) (Potter, 1968).

Meteorological/Climatological Factors: The local topography contributes to extreme rainfall through orographic lifting reinforced by convergence (Potter, 1968). Mountains to the north and northwest of the station are at right angles to the main inflows of moist air. A direct onshore flow of moist air may be deflected by the mountains and converge in the Henderson Lake area. During these conditions, it also is likely that the outflow in the lowest level from Juan de Fuca Strait adds to the convergence.

Further Reading: Henderson Lake also had the second greatest 1-day amount, 16.61 in (42.19 cm), as well as Canada's greatest annual precipitation, 319.78 in (812.24 cm), which occurred in 1931 (Manning, 1983).

AUSTRALIA'S GREATEST AVERAGE YEARLY PRECIPITATION 340 in (864 cm)

Location: Bellenden Ker (Top Station), Queensland [(17°16'S, 145°51'E, elevation: 5,102 ft (1,555 m)]

Discussion: This value was obtained over a 9-year POR (J. de la Lande, personal correspondence, 5 July 1985). According to de la Lande, Bellenden Ker (Top Station) is "... the wettest place in Australia." This record replaces the value of 179 in (455 cm) which occurred at Tully, Queensland, and appeared in the previous version of this report.

Meteorological/Climatological Factors: Bellenden Ker (Top Station) is located in the mountains along Australia's northeastern coast. It is wet throughout the year with the bulk of precipitation falling from January through April. Its wettest month, February, averages approximately 56 in of rainfall (142 cm). Its driest month, September, averages 13.8 in (35.1 cm).

Other Greatest Rainfall Extremes

AFRICA: Africa's **greatest average yearly rainfall** is 405 in (1,029 cm) and occurred at Debundscha, Cameroon [4°01'N, 9°01'E, elevation: 30 ft (9.15 m)] during a 32-year period (U.S. Environmental Science Services Administration, 1968).

CANADA: Canada's **greatest measured 24-hour rainfall** is 19 in (49 cm) and occurred at Ucluelet Brynnor Mines, British Columbia [48°57'N, 125°32'W] on 6 October 1967 (Manning, 1983; Newark, 1984).

CANADA: Canada's **highest frequency of days with precipitation** averages 242 per year, and occurs at Langara, Queen Charlotte Islands, British Columbia [54°12'N, 133°2'W] (Newark, 1984). [Not mapped.]

CHILE: Bahia Felix, Chile [53°22'S, 69°25'W] averages **325 days per year with rain** (Seamon and Bartlett, 1956).

EUROPE: Europe's **greatest average yearly rainfall** is 183 in (465 cm) and occurred at Crkvice, former Yugoslavia [exact location unknown] during a 22-year period (U.S. Environmental Science Services Administration, 1968).

WORLD: The world's **greatest measured 20-minute rainfall** is 8.10 in (20.5 cm) and occurred at Curtea-de-Arges, Romania [45°8'N, 24°42'E] on 7 July 1889 (Paulhus, 1965).

WORLD: The world's **greatest measured 1-month rainfall** is 366 in (930 cm) and occurred at Cherrapunji, India [25°02'N, 91°08'E, elevation: 4,309 ft (1,313 m)] in July 1861 (Paulhus, 1965; Jennings, 1950).

WORLD: The world's **greatest measured 12-month rainfall** is 1,042 in (2,647 cm) and occurred at Cherrapunji, India [25°02'N, 91°08'E; elevation: 4,309 ft (1,313 m)] from August 1860 to August 1861 (Paulhus, 1965; Jennings, 1950).

2. Greatest Snowfall Extremes

NORTH AMERICA'S GREATEST 24-HOUR SNOWFALL 76 in (192.5 cm)

Location: Silver Lake, CO [40°00'N, 105°40'W, elevation: 10,220 ft (3,115 m)]

Date: 14-15 April 1921

Discussion: Silver Lake is located in the Colorado Rockies. The snowfall in April 1921 established several records: 75.8 in (192.5 cm) in 24 hours, prorated from a measured fall of 87 in (221 cm) in 27.5 hours; 95 in (241 cm) in 32.5 hours; 98 in (249 cm) in 72 hours; and 100 in (254 cm) in 85 hours (Paulhus, 1953). According to Paulhus, the measurement was examined thoroughly before being accepted by the U.S. Weather Bureau. Paulhus stated that "... there was no evidence to indicate that the measurement was any less reliable than that of other heavy snowfalls, and it appears that a snowfall of this magnitude is meteorologically possible ..." (Paulhus, 1953).

In addition to the record at Silver Lake, a fall of 62 in (157.5 cm) in 22 hours was reported at Fry's Ranch, CO. Both of these exceeded the previous U.S. record of 60 in (152 cm) in 24 hours at Giant Forest, CA, in January 1933 (Paulhus, 1953). The maximum amount of snow that can fall in 24 hours has been estimated as approximately 72 in (183 cm) for snow with a density of 0.10 under normal packing conditions and correspondingly greater for lesser density (Brooks, 1938). The density of the snow at Silver Lake was 0.06 (Paulhus, 1953).

Meteorological/Climatological Factors: During the storm, thunder occurred in various parts of the region, indicating widespread convective activity, and the combined convective and orographic influences produced excessive amounts of snow at several places.

EXTREME 24-HOUR SNOWFALL
77 in (195.6 cm)
[*NOT AN OFFICIAL RECORD*]

Location: Montague Township, NY [~43°43'N, 76°43'W]

Date: 11-12 January 1997

Discussion: This 24-hour snowfall occurred in Montague Township, Lewis County, NY. This is a sparsely populated location to the east of Lake Ontario. Between 1:30 p.m. on the 11^{th} and 1:30 p.m. on the 12^{th}, a total of 77 in of snow was reported by Mr. Bill Ottoshavett, the local cooperative observer. During the entire weekend, a total of 95 in fell at this site. There were some reports that indicated that snow was falling at the rate of 5 to 6 in per hour (G. Goodge, personal communication, 3 March 1997). Montague Township sits atop the Tug Hill Plateau, an area notorious for heavy lake-effect snow blowing in from Lake Ontario.

Although this amount exceeded the record snowfall at Silver Lake, CO, NOAA has stated that this amount "... not be recognized as an official climatological snowfall amount for that 24-hour period ..." (Leffler, et.al., 1997). A committee of NOAA scientists and State Climatologists visited the site and thoroughly reviewed the evidence. The Committee was led by Robert J. Leffler, National Weather Service (NWS) Headquarters, and consisted of: Grant W. Goodge, National Climatic Data Center (NCDC); Nolan Doesken, Assistant Colorado State Climatologist, Colorado Climate Center, Ft Collins, CO; Dr. David Robinson, Rutgers University and State Climatologist for New Jersey; Keith L. Eggleston, State Climatologist for New York, Cornell University; and Raymond Downs, NWS Headquarters.

The Committee recognized the observations taken at Montague to be "... valid individual snow measurements, that when used in real-time by the Weather Service Forecast Office, Buffalo, provided meaningful support for operational National Weather Service programs." They further stated, however, that "... too frequent, inflationary snowfall measurement intervals used to derive the 24-hour snowfall total ..." was the primary reason why NOAA rejected the claim that this event should be considered official (Leffler, et.al., 1997).

Meteorological/Climatological Conditions: During the event, a deep low pressure system moved northeastward from Ontario and produced a persistent west-southwest to westerly wind flow across both Lake Erie and Lake Ontario (G. Goodge, personal communication, 13 March 1997). This situation produced copious amounts of lake-effect snow in this region during the weekend in question. Several locations within 10 mi. of this site reported 90 in (228.6 cm) for storm totals. This extreme snow event brought the season's total in Montague Township to approximately 250 in – just 40 in below the average for the entire winter season.

Further Reading: See Eichenlaub (1979) and Muller (1966) for discussions of lake-effect snow in the Great Lakes region. Phillips and McCulloch (1972) present a detailed look at the climatology of the Great Lakes region.

RECORD SNOWFALL OF
68 in (172 cm) in 19 hours

Location: Bessans, France [45°19'N, 7°00'E, elevation: 5,610 ft (1,710 m)

Date: 5-6 April 1959

Discussion: Bessans is located in the French Alps near the Italian border. Parts of Norway also have very high 24-hour snowfalls, as do parts of northeastern Japan and some other world areas. In this connection it should be mentioned that the predominance of North American records on the world weather extremes map is because of their availability rather than to greater amounts of snowfall on this continent.

Meteorological/Climatological Factors: Very intense snowstorms occur in this area as the result of a southeast wind, known locally as "*la lombarde*." These storms, of which the one at Bessans is a good example, also are very localized. The meteorological and environmental conditions contributing toward them are examined by Jail (1969).

Other Snowfall Extremes

CANADA: Canada's **greatest measured snowfall in a climatological day** is 46 in (118 cm) and occurred at Lakelse Lake, British Columbia [54°25'N, 128°30'W] on 17 January 1974 (Manning, 1983). [Not mapped.]

CANADA: Canada's **greatest measured snowfall in one season** is 964 in (2446.5 cm) and occurred at Revelstoke Mount Copeland, British Columbia [50°58'N, 118°10'W], 1971-1972 (Manning, 1983).

CANADA: Canada's **highest frequency of days with snow**, 142 per year average, occurs at Old Glory Mountain, British Columbia [exact coordinates unknown] (Newark, 1984). [Not mapped.]

CANADA: Canada's **greatest depth of snow on the ground** is 305 in (775 cm) and occurred at Loch Lomond, British Columbia [45°45'N, 60°35'W] (Newark, 1984). [Not mapped.]

NORTH AMERICA: North America's **greatest measured snowfall in one storm** is 189 in (480 cm) and occurred at Mount Shasta Ski Bowl, CA [41°18'N, 122°18'W, elevation: 3,554 ft (1,083.54 m)] on 13-19 February 1959 (Schmidli, 1983).

NORTH AMERICA: North America's **greatest measured snowfall in one season** is 1,122 in (2,850 cm) and occurred at Rainier Paradise Ranger Station, WA [46°51'N, 121°45'W, elevation: 14,410 ft (4,393.29 m)], 1971-1972 (Ludlum, 1972).

NORTH AMERICA: North America's **greatest depth of snow on the ground** is 451 in (1,145.5 cm) and occurred at Tamarack, CA, [~38°27'N, ~120°04'W] on 11 March 1911 (Schmidli, 1983).

3. Hail Extremes

The different characteristics of hail (e.g. frequency, intensity, season of occurrence, hailstone size) vary with latitude and location in regard to landforms, water bodies, and urban areas. Generally, hail occurs most often in the interiors of continents at middle latitudes. In North America, the principal hail area is "... along and to the lee of the eastern Rocky Mountains and from New Mexico to Alberta. This area averages more hail days, more hailstorms, more and bigger hailstones, and thus, a greater hail intensity than any other area in the continent" (Changnon, 1977a). See Ahrens (1991) for a discussion of hail formation. A more technical discourse on hail appears in F.H. Ludlam (1958). The monetary impacts of hail storms and hail suppression techniques are discussed in detail by Changnon (1977b).

Outside of the U.S. and Canada, less information is available about hail and hailstones; however, claims have been made of large hailstones in many places. One hailstone weighing 2.14 lbs [972 grams (g.)] was weighed and photographed in Strasbourg, France, near the German border on 11 August 1958, and a heavier one of 4.18 lbs [1.9 kilograms (kg)] was weighed up in Kazakhstan, U.S.S.R., in 1959 (Verdou, 1972). Other areas where very large, heavy hailstones occur are Hungary (Bognar, 1971) (Rethly, 1971) China, and northern India (Ludlum, 1961). In this last area, a very high frequency of large hailstones occurs as a result of the very tall thunderstorms that develop in the pre-monsoon squall lines (Changnon, 1971). Large hailstones and intense falls of hail are said to have killed people and animals and destroyed villages (Ludlum, 1961; Field, 1933-34). Williams (1992) notes that large hailstones can fall at the rate of 90 mi/h (144.8 km/h) and the last known hail fatality in the U.S. was that of an infant killed in Fort Collins, CO in 1979.

UNITED STATES LARGEST HAILSTONE
17.5 in (44.5 cm) CIRCUMFERENCE

Location: Coffeyville, KS [37°02'N, 95°37'W]

Date: 3 September 1970

Discussion: The hailstone at Coffeyville is the largest officially recorded in the U.S., and according to a British publication, it is "... the world's heaviest fully authenticated hailstone ..." (Meaden, 1977). It weighed 1.67 lbs (758 g.) (Ludlum, 1971c) and measured about 5.6 in (14 cm) in diameter (Gringorten, 1971). It fell during a severe storm with hundreds of other large stones in southeast Kansas and was preserved and sent to the National Center for Atmospheric Research where it was photographed. The photograph shows that it was irregular in shape and had five alternating layers made up of either clear or milky-appearing ice. The previous official hailstone record in the U.S., which appeared on earlier maps of weather extremes, was for a hailstone that weighed 1.5 lbs (680 g.) and measured 17 in (43 cm) in circumference. It was recorded at Potter, NE [41°13'N, 103°19'W], on 6 July 1928.

Meteorological/Climatological Factors: Hailstones are pieces of ice that precipitate either separately as spheres or cones, or agglomerated into irregular lumps. They originate in convective clouds of the cumulonimbus type and are usually associated with thunderstorms.

Further Reading: Pictures of the Coffeyville hailstones can be seen in Weatherwise, Volume 24, Number 2, 1970; Ahrens (1991), and, in many other meteorology and climatology texts.

CANADA'S HEAVIEST HAILSTONE
10.23 oz. (290 g.)

Location: Cedoux, Saskatchewan, Canada [49°54'N, 103°54'W]

Date: 27 August 1973

Discussion: This record is discussed by L. Wojtiw and E. P. Lozowski (1975). According to them, the man who picked up the hailstone stated that it had spiky lobes and "... a half inch of ice had melted in his hands..." during the half hour required to get it to a freezer. From this information, the authors estimate "... its mass on falling could therefore have been as high as 450 g." The hailstone fell during a series of storms in southeastern Saskatchewan, accompanied by a great deal of larger than golf ball-sized hail and high winds. It measured 4 in (10.2 cm) in diameter; but hailstones as large as or larger than that have fallen in Canada (Newark, 1984). Among these is one with a diameter of 5 in (12.7 cm) that fell at Windigo Lake, Ontario [52°40'N, 91°35'W], on August 23, 1948. This record, however, has not been verified.

Meteorological/Climatological Factors: "Sizes of hailstones appear to be largely dependent on the vertical extent (depth) of the storm, the amount of shear and/or the distance between cloud base and the surface (amount of evaporation and melting)" (Changnon, 1971).

Other Hail Extremes

CANADA: Canada's **highest frequency of days with hail** is 7 and occurs at Edson [53°35'N, 116°26'W] and Red Deer [52°16'N, 113°48'W], Alberta (Newark, 1984). [Not mapped.]

UNITED STATES: The U.S. **highest frequency of days of hail** is 9.4 and occurs at Cheyenne, Wyoming [41°08'N, 104°49'W], based on a 40-year POR (Gringorton, 1971).

WORLD: The world's **heaviest hailstone** is 2.25 lbs (1.02 kg.) and fell on 14 April 1986 in the Gopalganj district, Bangladesh [~23°01'N, 89°50'E] (Burroughs, 1996).

4. Least Precipitation Extremes

Generally, areas of low precipitation occur in continental interiors, on lee sides of high mountains, on coasts adjacent to cool currents, in zones of higher atmospheric pressure where the air is subsiding, and in high latitudes. Arid areas are found in east Africa and adjacent southwest Asia between 15° and 35°N, western South America between 5° and 30°S, eastern South America between 35° and 50°S, western Africa between 15° and 35°S, western and interior Australia, interior Asia, parts of western North America between 25° and 40°N, and in the polar regions. As with records of high average precipitation, those of low average precipitation vary according to the years on which they are based, and they tend to be more reliable for a longer period. In some very dry areas, e.g. Chile and Sudan, it is not unusual for several years to pass with no recorded precipitation.

CANADA: Canada's **least precipitation during a calendar year** is 0.05 in (0.127 cm) at Arctic Bay, Northwest Territories [73°05'N, 85°20'W] in 1949 (Newark, 1984). [Not mapped.]

CANADA: Canada's **lowest frequency of days with precipitation** is 8 per year average at Rea Point, Northwest Territories [exact coordinates unknown] (Newark, 1984). [Not mapped.]

CHILE: Arica, Chile [18°32'S, 70°22'W], recorded **no rain for more than 14 consecutive years**, October 1903 to January 1918 (Schmidli, 1983). See Trewartha (1970) for a good account of the factors that contribute to the extremely low precipitation amounts in Chile's Atacama Desert.

UNITED STATES: The U.S. **longest dry period** is 767 days from 3 October 1912 to 8 November 1914, at Bagdad, CA [34°34'N, 115°52'W, elevation: 788 ft (240.24 m)] (Seamon and Bartlett, 1956).

Lowest Average Yearly Precipitation Extremes

AFRICA: Africa's **lowest average yearly precipitation** is <0.1 in (<0.25 cm) during a 39-year period at Wadi Halfa, Sudan [21°56'N, 31°20'E] (U.S. Environmental Science Services Administration, 1968).

ASIA: Asia's **lowest average yearly precipitation** during a 50-year period is 1.8 in (4.6 cm) at Aden, South Yemen [12°45'N, 45°4'E] (U.S. Environmental Science Services Administration, 1968).

AUSTRALIA: Australia's **lowest average yearly precipitation** during a 42-year period is 4.05 in (10 cm) at Troudaninna, South Australia [exact coordinates unknown] (U.S. Environmental Science Services Administration, 1968; J. de la Lande, personal communication, 5 July 1985).

EUROPE: Europe's **lowest average yearly precipitation** during a 25-year period is 6.4 in (16 cm) at Astrakhan, Russia [46°22'N, 48°6'E] (U.S. Environmental Science Services Administration, 1968).

NORTH AMERICA: North America's **lowest average yearly precipitation** is 1.2 in (3.0 cm) during a 14-year period at Bataques, Mexico [32°34'N, 115°02'W] (U.S. Environmental Science Services Administration, 1968).

UNITED STATES: The U.S. **lowest average yearly precipitation** during a 42-year period is 1.63 in (4.1 cm) at Death Valley, CA [36°27'N, 116°52'W, elevation: 276 ft (84.15 m)] (M.A. Arkin, personal communication, 6 Oct 1969); U.S. Weather Bureau (1953).

WORLD: The world's **lowest average yearly precipitation** is 0.03 in (0.08 cm) during a 59-year period at Arica, Chile [18°32'S, 70°22'W] (U.S. Environmental Science Services Administration, 1968).

5. Precipitation Variability Extremes

Variations in precipitation can be downward, i.e., occurrence of below-average amounts or even drought; or upward, i.e., occurrence of above-average amounts. One of the factors causing a location to experience extreme variations in precipitation is differences in strength of the monsoonal circulation from year to year. Differences in strength of monsoonal circulation is most pronounced along the borders of areas covered by these seasonal winds. During years of a weak monsoon, less territory is covered by the rain-bearing winds, thus less rain is deposited by them.

The other factor is displacement of ocean currents. Coasts adjacent to cold currents are generally dry, but if the current deviates even slightly, making room for warmer water, relatively abundant rainfall can occur, as in the coastal areas of Chile and Peru. Disastrous droughts in northeast Brazil might be caused by the opposite occurrence, the invasion of cold currents into warmer water.

One very important event that enhances precipitation variability over large portions of the globe is El Niño. The term El Niño (Spanish for "the Christ Child") was originally used by fishermen along the coasts of Ecuador and Peru to refer to a warm ocean current that typically appears around Christmas time and lasts for several months. Over the years, the term "El Niño" has come to be reserved for these exceptionally strong, warm intervals that not only disrupt the normal lives of the fishermen, but also bring heavy rains. El Niño is second only to the march of the seasons in its impact on world climate, and is a much greater challenge to predict.

During an El Niño year, the change in ocean currents and temperatures is reflected in the atmosphere above to the extent that mid- and high-level wind patterns also change their characteristic wind speed and direction averages. This results in a wind field that is not conducive to hurricane formation (either in the Gulf of Mexico or in the central or southern North Atlantic ocean). As various storm wave patterns come off the western African coastline, the natural tendency to form tropical waves, storms, and finally, hurricanes, over the warm summer waters (thus getting rid of the unequal heating effects of the summer sun) is severely diminished. Thus, very few tropical storms or hurricanes will form during an El Niño year.

The hurricane season of 1983 (an El Niño year), with a total of four named cyclones, was the least active season since 1930. Three hurricanes that did occur were rather short lived. A total number of only five hurricane days made this season the least in number of hurricane days since 1931. For comparative purposes, the average number of hurricane days per season, based on a 30-year period, is 26. Also, 1983 became the first year since 1871 that no storms or hurricanes formed south of latitude 25°N. Finally, the 1982 and 1983 seasons became the first consecutive years since 1871 that no tropical storms or hurricanes formed in the Caribbean.

By comparison, 1995, a non-El Niño year, was the second most active tropical Atlantic season on record since 1933 with 11 hurricanes, 8 tropical storms and 2 tropical depressions. However, it is not considered a "typical" non-El Niño year.

AVERAGE VARIABILITY OF ANNUAL PRECIPITATION 75 in (191 cm)

Location: Debundscha, Cameroon [4°01'N, 9°01'E; elevation 30 ft (9 m)]

Discussion: The places with the greatest average variability (the average of the differences between mean value and individual yearly value for a given number of years) are Debundscha, Cameroon, and Cherrapunji, India, with 75.28 and 66.02 in (191 and 168 cm), respectively. Debundscha has the greatest average yearly precipitation in Africa, 405 in (1,029 cm). Cherrapunji has the greatest average yearly precipitation in Asia, 450 in (1,143 cm) (U.S. Environmental Science Services Administration, 1968). In addition to having a very high average variability of annual precipitation, Cherrapunji may hold the record for the highest actual amount of variability. The difference between the greatest amount of precipitation there during a calendar year, 905.1 in (2,298.95 cm), and the least amount, 282.6 in (717.8 cm), is over 600 in (1,581 cm).

Meteorological/Climatological Factors: Because the rainfall amounts at these places are so high, the average differences from year to year can be correspondingly high without being extreme in proportion to the mean.

Further Reading: The average and relative variability of annual precipitation at 384 places throughout the world were tabulated by E. Biel (1929) and examined statistically by V. Conrad (1941).

94 PERCENT RELATIVE VARIABILITY OF ANNUAL PRECIPITATION

Location: Themed, Israel [~29°40'N, 34°17'E]

Date: 1921-1947

Discussion: Themed (Thamad) is a desert station on the Sinai Peninsula. Its relative variability record is based on the ratio of the mean deviation from the arithmetic mean of annual precipitation for a period of years beginning in 1921, and ending in 1947, divided by the arithmetic mean for those years (Katsnelson and Kotz, 1957). Other places with high values based on this same measure of variability are Walvis Bay, at 22°53'S, 14°26'E, in Southwest Africa with 87 percent (Katsnelson and Kotz, 1957), and Malden Island in the Line Islands of the equatorial Pacific with 71 percent (Biel, 1929). Walvis Bay, like Themed, is a very dry area, and because rainfall amounts at these places are so low, a small variation in actual amount can become a large percentage of the mean value. Malden Island's average variability of 20.24 in (51.41 cm) from its mean annual precipitation of 28.6 in (72.6 cm) is thought to be caused by displacement of ocean currents (Katsnelson and Kotz, 1957). The relative variability of monthly rainfall can have even higher values than that of annual rainfall. A value of 193 percent for September has been cited at Beersheba, Israel [31°14'N, 34°47'E], where rain fell in only 1 of 30 Septembers from 1921 through 1950 (Katsnelson and Kotz, 1957). This almost reaches the theoretical upper limit of 200 percent determined analytically by Schumann and Mostert (1949).

Further Reading: For a good discussion of the precipitation environment of Israel, see Rosenan (1970).

108 PERCENT RELATIVE VARIABILITY OF ANNUAL PRECIPITATION

Location: Lhasa, Tibet [29°40'N, 91° 07'E, elevation 12,090 ft (3,685 m)]

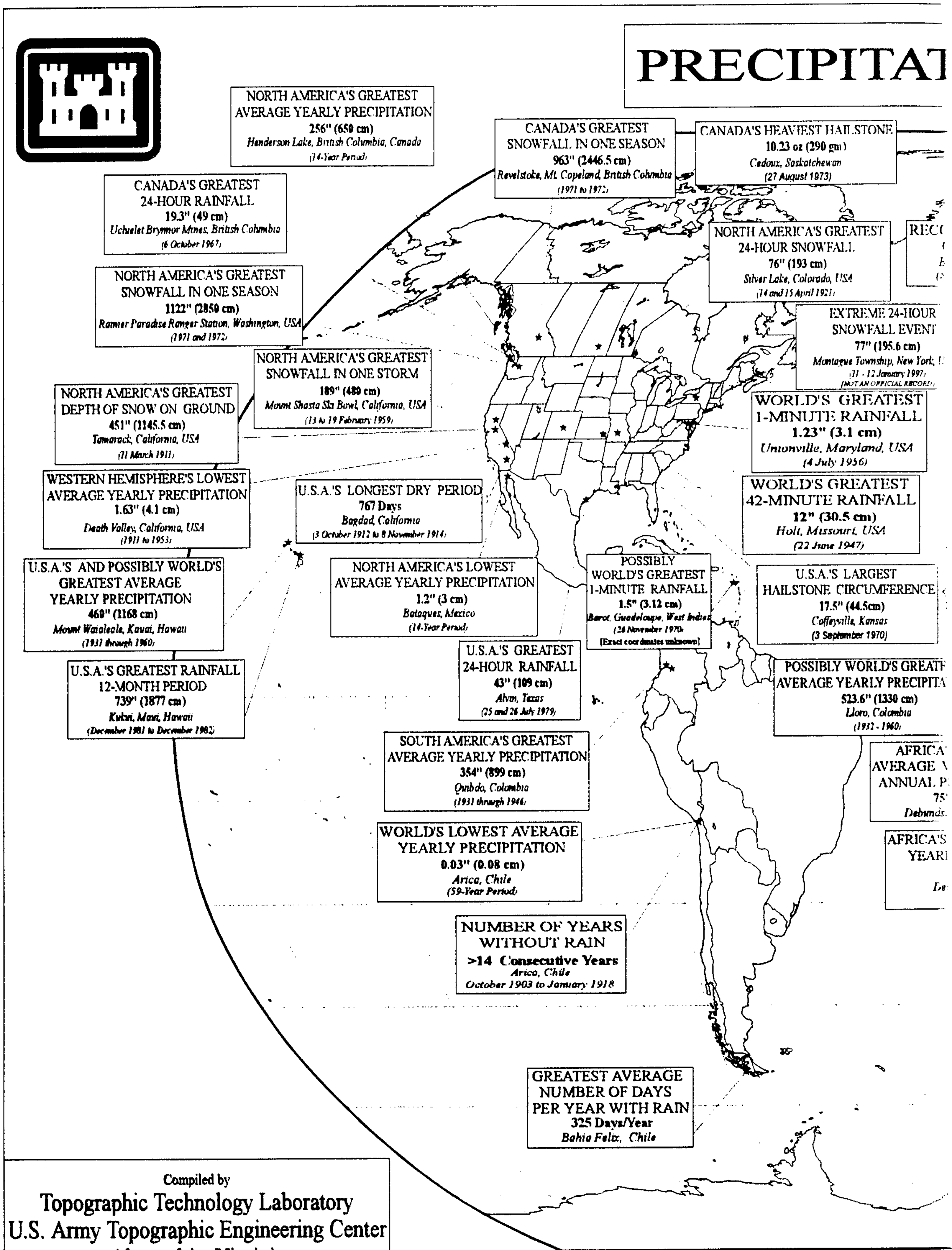
Date: 1935 to 1939

Discussion: In 1936, the annual precipitation reported for Lhasa, 198.3 in (503.7 cm), was more than 10 times greater than the average amount. However, there is some doubt as to the authenticity of the amount of precipitation recorded for 1936. Flohn considers the value questionable and attributes it to "... a possible misplacement of a decimal point by a partly educated weather observer" (Flohn, 1958). On the basis of Lu's data and for most of the years from 1941 to 1955, Flohn found no amount that even approached that of 1936. The highest was 22.9 in (58.1 cm). The frequency of precipitation, as indicated by the number of rainy days during 1936, was not unusual. Furthermore, Gyantse, in the same climatic region as Lhasa at 28°56'N, 89°36'E, elevation 10,486 ft (3,196 m), had no similar extreme variation in a 38-year period. In 1936, Gyantse had only 13 in (33 cm) more than the average precipitation.

However, Hsu was at Lhasa in 1936, presumably as the station observer or supervisor, and he wrote about the unusually heavy rain and its causes (Hsu, 1941) and informed Lu (Lu, 1939) of the difference between the rainfall in 1936 and in other years. Normally, rainfall at Lhasa comes from thundershowers, but in 1936 only 23 percent was of this type, and 69 percent was from nighttime rain, possibly caused by interaction between a strong southwest monsoon and cold air masses from the north (Lu, 1939).

In another paper, Lu described a similar extreme variation at Omei Shan, China, to the east of Lhasa, at ~29°30'N, 103°30'E, elevation 10,023 ft (3,055 m) (Lu, 1947). The annual mean there is 73 in (185 cm); but during the Second Polar Year from August 1932 to August 1933, Omei Shan had 319 in (810 cm), "... the largest amount ever recorded in China in a 13-month period ..." (Lu, 1947). This difference of 246 in (625 cm) between the annual mean and the August 1932 to August 1933 value is even greater than the difference between Lhasa's annual mean and its 1936 precipitation. Flohn's paper also mentioned Omei Shan, but his figures differ somewhat from Lu's with a 25-in (63.5-cm) annual mean and 300 in (762 cm) in the Second Polar Year, making a difference of 275 in (698.5 cm) (Flohn, 1958).

Meteorological/Climatological Factors: Lhasa is located on the Tibetan plateau. It is in an approximately east-west valley flanked on both sides by mountains of 15,000 to 16,000 ft (4,572 to 4,877 m). Its climate has been described by Ginn-Tze Hsu (1941), who established a meteorological station there in 1934, and also by A. Lu (1939) and H. Flohn (1958). Data for 1935 through 1938 from Lu's paper (1939) were calculated by Conrad's methods (1941) to obtain the average variability of 67.7 in (171.9 cm) and a relative variability of 108 percent.



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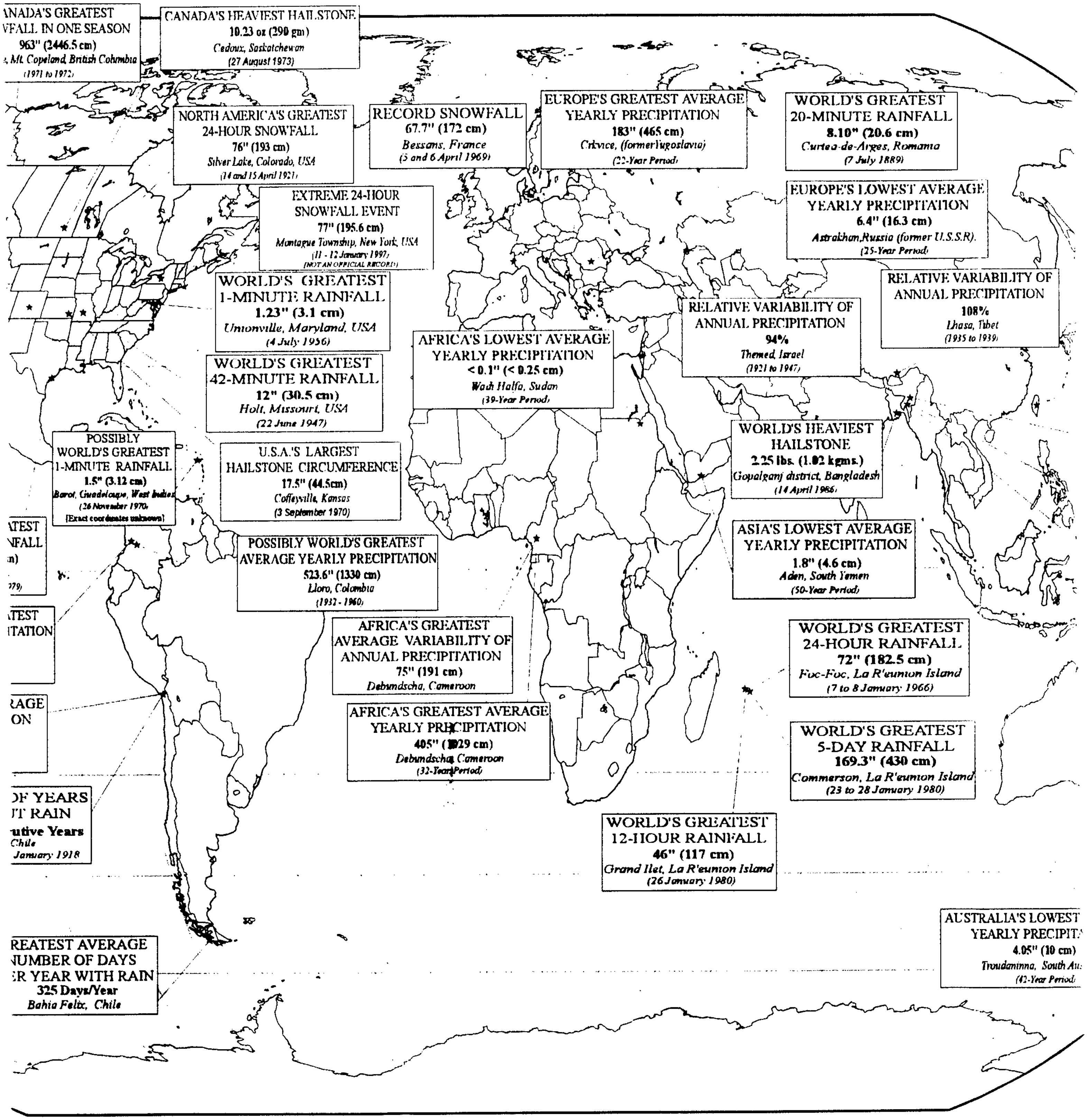
U.S. Army Topographic Engineering Center
Alexandria, Virginia
22315-3864
for *"Weather and Climate Extremes"*, 1997

PRECIPITATION EXTREMES



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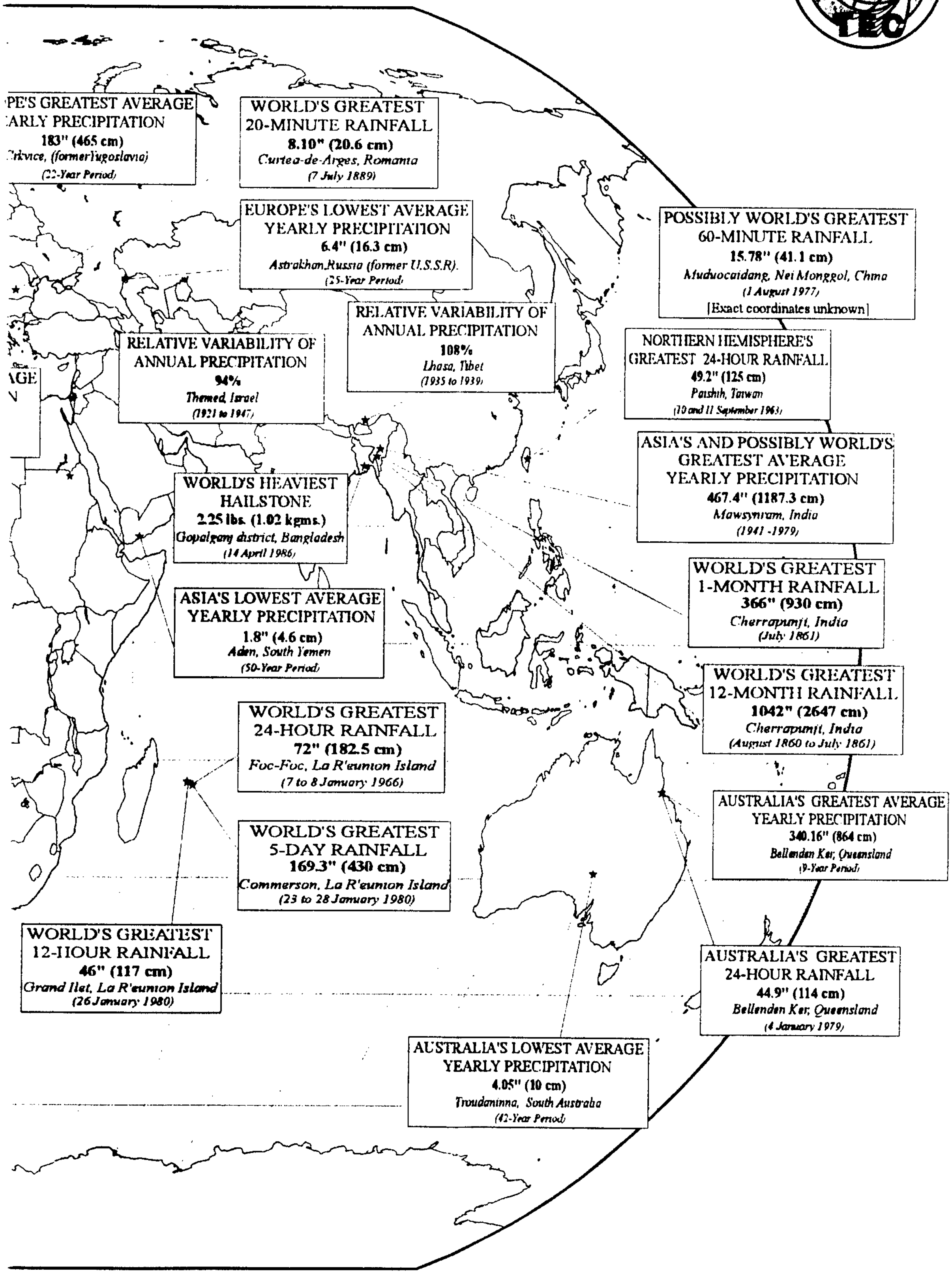


MAP 2

V. OTHER WEATHER/CLIMATE EXTREMES

This section discusses other meteorological and climatological extremes. For each of these, the most extreme occurrences have their own particular set of causes, limits, and distributions in time and space; and for each there are problems in obtaining accurate measurements. In evaluating reliability of the records, all of these factors should be taken into consideration.

This section presents discussions of extreme events of other various weather and climate elements. Detailed summaries are provided for the extremes for which there exists sufficient information in the professional literature. Extremes with little or no available supportive information are presented in a concise format: extreme, location, and date. Map 3 displays these extremes.

A. Thunderstorm Extremes.

A thunderstorm is a local storm defined as "... one or more sudden electrical discharges, manifested by a flash of light (lightning) and a sharp or rumbling sound (thunder)." Thunderstorms are associated with convective clouds and are most often accompanied by precipitation which, when it reaches the ground, is in the form of a shower of rain, snow, snow pellets, ice pellets or hail (World Meteorological Organization, 1975). Thunderstorms seldom last more than 2 hours. Criteria for recording thunderstorms can vary from storms actually occurring at a station, to merely thunder heard or lightning seen from the reporting station.

Thunderstorms are most prevalent in warm weather and, in some places, during the rainy season. However, although thunderstorms frequently produce heavy rainfall, there are places where seasons of rainfall and thunderstorm maxima do not coincide. In addition, some very rainy places have few thunderstorms, while places with very frequent thunderstorms can have relatively small amounts of rainfall (Portig and Gerhardt, 1962). Also, there are some places, e.g. in polar regions, where thunderstorms rarely occur.

KAMPALA, UGANDA, AVERAGES
242 THUNDERSTORM DAYS PER YEAR

Location: Kampala, Uganda [0°20'N, 32°36'E, elevation: 4,304 ft (1,312 m)]

Discussion: Kampala is located to the north of Lake Victoria. It has the highest number of thunderstorm days of any place listed in the World Distribution of Thunderstorm Days (World Meteorological Organization, 1953). The record for Kampala is based on a period of 10 years, but the exact calendar dates are not given.

Meteorological/Climatological Factors: Because diurnal variations of air temperature are very small over Lake Victoria and large over the surrounding area, land and lake breezes develop and conditions become favorable for thunderstorms. "Land-breeze convergence over the Lake during the night releases the latent instability of the moist lower layers of air over the Lake which participate in the land breeze circulation, resulting in the development of cumulonimbus clouds and these thunderstorms over the Lake on most nights of the year" (Lumb, 1970). When these storms are close enough for thunder to be heard at Kampala, they are counted as thunderstorms there, even though they do not actually reach the town (W.H. Portig, personal correspondence, 23 November 1970). In addition to these night storms, others develop over land at certain times of the year from afternoon convection at the lake breeze front (Lumb, 1970). Thus, the Kampala area is subject to frequent thunderstorm activity, and nearby stations, such as Entebbe and Kisumu, also average very high numbers of thunderstorm days per year (Lumb, 1970).

BOGOR, INDONESIA, AVERAGED
322 THUNDERSTORM DAYS PER YEAR
(1916 to 1920)
(this extreme is highly debatable)

Location: Bogor, Indonesia [6°30'S, 106°48'E]

Date: 1916 to 1920

Discussion: Bogor, formerly Buitenzorg, is located on the island of Java. The mean annual number of thunderstorm days recorded there changed from 151 in the years 1841 through 1857 to 322 from 1916 through 1919; it ranged from 4 to 41 for the years 1953 through 1962 (Arabadzhi, 1966). These differences might reflect changes in the criteria for recording thunderstorms. For instance, "... during a certain period ... " Bogor recorded lightning seen, in addition to thunder heard, and the actual thunderstorm occurring at the station (W.H. Portig, personal correspondence, 23 November 1970). Also, the interpretation of 322 in the Bogor record is doubted by W. H. Portig, and others, who consider that it represents the "... mean number of occurring thunderstorms and not the mean number of days on which thunder was heard ... " (Portig, 1963). According to Portig, the absolute occurring maximum is "... approximately 250 or 260 thunderstorm days annually, although such a location has not as yet been found ..." (Portig, 1963).

Other Thunderstorm Extremes

CANADA: Canada's highest **average annual frequency of thunderstorms** is 34 and occurs at Windsor, Ontario [42°18'N, 83°01W] (Newark, 1984).

NORTH AMERICA: The **highest average annual number of thunderstorm days** (days on which thunder is heard) is 100 and occurs at Tampa International Airport, FL, U.S. [27°58'N, 82°32'W; elevation: 19 ft (5.8 m)] (Clary, 1985).

B. Air Pressure Extremes

The pressure value for a given unit area of surface very nearly represents the actual weight of a vertical column of air of the same unit area extending upward from that surface to the top of the atmosphere. Pressure is expressed in a number of different units of measure. Standard sea level pressure can be expressed as 29.92 in of mercury; 1013.25 millibars (mbars); or 14.7 lbs per in^2. In this report, barometric pressures are given in inches of mercury (in) and millibars (mbars). Another unit of measure for barometric pressure that is being used in more recent meteorology texts is the hectopascal (hPa). A hectopascal is equivalent to a millibar. Surface barometric pressure decreases with altitude from an average of 31.3 in (1060 mbars) in the earth's deepest depression (1,300 ft (396 m) below sea level), to less than half that amount, about 14.9 in or ~500 mbars at 18,000 ft (5,486 m). At the top of the world's highest mountain, 29,028-foot (8,848-meter) Mount Everest, it would be approximately 9 in of mercury (~305 mbars).

Air pressure is usually measured by mercurial or aneroid barometers. The mercurial barometer balances pressure of the atmosphere against the weight of column of mercury. The aneroid type contains a hollow metal chamber, partly emptied of air and sealed, that expands and contracts as the pressure changes. Mercurial barometers are generally more accurate, but the aneroid types are smaller, more portable, and less expensive. Because mercury is affected by temperature and gravity, adjustments must be made in the readings of mercurial barometers to allow for these factors. Also, in order to standardize readings of any kind of barometer when made at different times and places, adjustments are required to compensate for errors in the individual instrument used (index error) and for difference in altitude. For the altitude adjustment, the station pressure readings are usually equated to sea level pressure and the resulting values (which are lower for elevations below sea level, and higher for elevations above sea level) and are recorded. There are possible sources of error peculiar to each type of barometer, as well as errors that could occur from making the various types of adjustments. For example, different values can be obtained when different methods are used for equating station pressures to their sea level equivalents.

1. High Pressure Extremes

The highest station pressures occur at the lowest elevations, i.e. in depressions below sea level, as in Death Valley, CA, where the lowest point is -280 ft (-85 m); the Qattara depression in northwestern Egypt, with a minimum elevation of -436 ft (-133 m); and the shores of the Dead Sea between Israel and Jordan, at -1,286 ft (-392 m). In the Dead Sea area, a station pressure of 31.91 in (1080.6 mbars) was reported at Sedom (the biblical Sodom) [31°04'N, 35°23'E] on 21 February 1961 (Court, 1969). Another depression, the Turfan in central Asia, at approximately 45°N, 90°E, is thought to have station pressures similar to, or even higher than, those of the Dead

Sea area (Loewe, 1969). At or near sea level, high pressures occur along Arctic coasts. A value of 31.43 in (1063.6 mbars) was recorded at Barrow, AK, on 3 January 1970 (Schmidli, 1983). This is the record high pressure for the U.S.

WORLD'S HIGHEST SEA LEVEL AIR PRESSURE
32.01 in (1083.3 mbars)

Location: Agata, Russia [66°53'N, 93°28'E, elevation: 855 ft (261 m)]

Date: 31 December 1968

Discussion: Agata is located in Siberia where the highest recorded pressures occur during winter. The high pressure record there was the culmination of an intense anticyclone that originated in east Siberia on 22 December 1968 and continued until 2 January 1969, when it declined somewhat as it moved south and west into European Russia (Giles, 1970). On 31 December, seven stations in north-central Siberia had air pressures greater than 31.565 in (1068.9 mbars).

Meteorological/Climatological Factors: The weather was clear and calm with temperatures between -40°F and -58°F (-40°C and -50°C). At 1200 hours GMT, the pressure in the center of the anticyclone "reached 1083.3 mbars" according to M.V. Burkova and V. A. Dzhordzhio (1973), who analyzed the meteorological and environmental conditions contributing to the extreme high pressure. This record has been authenticated. However, a previous world record of "1079 mbars at Barnaul," Siberia, was found to be "exaggerated" (M.V. Burkova and V. A. Dzhordzhio, 1973). The 31.75 in (1075.2 mbars) recorded in 1893 at Irkutsk, Siberia [52°16'N, 104°20'E] might remain the second highest world record.

Other High Pressure Extremes

NORTH AMERICA: North America's highest sea level pressure is 31.85 in (1078.6 mbars) and was recorded at Northway, AK [62°59'N, 141°43'W] on 31 January 1989 (Ludlum, 1989; LeComte, 1990). Ludlum notes that during January 1989, a massive Siberian high pressure system brought record cold temperatures to over 20 stations in Alaska. Temperatures dipped to -76°F (-60°C) at Tanana and -75°F (-59.4°C) at McGrath, and Nome had its coldest month since records began in 1906. This record high pressure surpassed the old record of 31.53 in (1067.7 mbars) that occurred at Mayo, Yukon Territory, Canada on 1 January 1974 (Schmidli, 1983), and appeared in the 1985 version of "World Weather Extremes."

2. Low Pressure Extremes

The lowest station pressures occur at the highest altitudes, e.g. in the Himalayas of Asia, the Andes in South America, and the Rockies in western North America. Beginning at about 4,000 ft (1,219 m), the average station pressures are lower than the most extreme low pressures that occur at sea level. At the approximate upper limit of weather stations, 15,000 ft (4572 m), standard pressure is 16.90 in (572.3 mbars), and the extreme lowest is estimated at about 14.76 in (499.8 mbars) (Court and Salmela, 1963). At sea level the lowest pressures and most rapid falls in pressure occur during tornadoes. "Accurate pressure measurements by a recorder directly in the center of a tornado have never been made ..." (Ludlum, 1983), but various estimates are available. Among these are Court and Salmela's "... a reduction of no more than one-fourth of the pre-existing pressure ..." which could occur "... within 15 seconds ..." (1963). Fujita's estimate calls for a drop of 1.5 lbs in^2 (~103 mbars or ~3 in) and a time change of 0.5 psi (34 mbars or 1 in) per second in pressure of tornadoes with 200-mi/h winds (Fujita, 1970).

WORLD'S LOWEST AIR PRESSURE AT SEA LEVEL
(EXCLUDING TORNADOES)
25.69 in (870 mbars)

Location: Estimated by Dropsonde in Eye of Typhoon Tip [16°44'N, 137°46'E]

Date: 12 October 1979

Discussion: This record, which occurred 520 mi. northwest of Guam, was based on a dropsonde observation made from a reconnaissance aircraft of the U.S. Air Weather Service. As the plane approached the center of the eye of the storm, "... flight level pressures fell rapidly until the absolute altimeter read 6,590 ft and the pressure altimeter, 10,040 ft! These readings produced a 700 mbar height of only 1,900 m" (National Weather Association, 1980) and a new world record. Although a major source of error in this type of measurement would be in the aircraft altimetry, calibration checks are a routine part of each flight on reconnaissance aircraft

The low pressure record of typhoon Ida, which was included on previous maps of world weather extremes, was obtained by the same method, as was the record of typhoon June, which surpassed Ida's on 19 November 1975. The lowest pressure during Ida was 25.90 in (877 mbars) and during typhoon June, 25.87 in (876 mbars) (Schmidli, 1983). Typhoon June was distinguished by the abruptness of the fall in pressure. Most of it, 1.5 in (~58 mbars), fell in 11 hours (Holliday, 1976). Pressures remained below 26.5 in (~897 mbars) over a very long period (36 hours) (Rodewald, 1977a).

The lowest pressure that has actually been measured at sea level was 26.185 in (886.7 mbars) on the vessel Sapoerea at 460 mi. (740 km) east of Luzon, Philippine Islands, on 18

August 1927 (Schmidli, 1971). All of the records of extreme low pressure during the tropical cyclones mentioned above have occurred in the Philippine Sea area of the western North Pacific Ocean (Rodewald, 1977b). This area also has a very high frequency of intense tropical cyclones equal to or greater than 34 kn (39 mi/h or 63 km/h) (Rodewald, 1977b). Luzon, in the Philippine Islands, experiences an average of five of these storms a year. Manila, most probably, holds the frequency record among the world's large urban areas.

Other Low Pressure Extremes

NORTH AMERICA: North America's lowest sea level pressure is 26.35 in (892.3 mbars) and occurred at Matecumbe Key, FL, U.S. [~24°56N, 80°37'W], on 2 September 1935 (Schmidli, 1983).

C. Solar Radiation Extremes.

Measurements of the flux of solar radiation penetrating to the lower layers of the atmosphere can be subdivided into several main classes. Values considered here are for global solar radiation received on a horizontal surface. This includes both radiation received directly from the solid angle of the sun's disc, and also radiation that has been scattered or diffusely reflected in traversing the atmosphere. Such measurements are usually made with pyranometers, and as in all radiation measurements, considerable care and attention to detail is required to ensure accuracy.

AVERAGE DAILY INSOLATION IN DECEMBER
955 LANGLEYS (463 W/M^2)

Location: Amundsen-Scott Station, South Pole at 90°S, elevation: 9,186 ft (2,800 m)

Date: Decembers 1958 through 1965

Discussion: Solar radiation values vary with time and place according to factors such as latitude and atmospheric clarity. The world's highest daily amounts of solar radiation are received on the Antarctic Plateau during summer, when there are 24 hours of continuous daylight (Hanson, 1961). The North Polar area also has continuous daylight during its summer, but at that time of the year the earth is about 3 million mi. further from the sun. Consequently, about 7 percent less solar radiation impinges on the top of the Arctic's atmosphere during midsummer (Hanson, 1961). The South Pole record was obtained by averaging daily values of hemispheric global solar radiation, which were available from Amundsen-Scott Station at 90°S, elevation 9,186 ft (2,800 m) for Decembers 1958 through 1965 (U.S. Environmental Science Services Administration, 1962 and

1968). The resultant value was 954.6 langleys, equivalent to 463 W/m^2 or 954.6 g-cal cm^{-2} day^{-1}. However, the average daily insolation could be even greater at other stations on the Antarctic Plateau. In contrast to these high daily values, the polar areas do not have high annual and hourly solar radiation values because of the continuous darkness during winter months and the increased obliqueness of the sun's angle at higher latitudes.

Some very high hourly values have been reported from western Africa south of the equator. Malange, Angola, had a value of 113 langleys (1,314 W/m^2) in one hour on 7 November 1961 (World Meteorological Organization, 1961), and Windhoek, Southwest Africa, had 112 langleys (1,303 W/m^2) in 1 hour on 20 December 1956 (World Meteorological Organization, 1957). Malange is located at 9°33'S, 16°22'E, altitude 3,710 ft (1,131 m), and Windhoek is at 22°34'S, 17°16'E, altitude 5,640 ft (1,728 m).

Meteorological/Climatological Factors: The highest annual values of solar radiation are observed in desert areas of northeastern Africa (Budyko, 1958), where there is very little cloud cover and the sun's rays are never very oblique. High hourly values of solar radiation can be expected at relatively low latitudes during the hours of the day and times of the year when the sun's angle is most nearly vertical, when cloud cover is absent, and when the air is as clear as possible from dust and other impurities. Other conditions being equal, high hourly values would tend to occur at the higher elevations.

D. Wind Speed Extremes.

Of all the elements, wind is most variable. To compare wind speeds reported form various places and times, information should be known about the height and exposure of the measuring instrument (anemometer), the type of instrument, and the time interval covered by the measurement. Wind speed is usually measured by either rotating or pressure anemometers. In the former type, wind passage is measured by the rate of motion imparted to a freely rotating mechanism. A timing mechanism is usually combined with the anemometer to indicate the rate of passage. Pressure anemometers measure the instantaneous speeds (averages for about 1 second) by means of pressure effects, i.e. force applied to a surface or surfaces. The time intervals of wind observations differ between countries and even between stations. In the U.S., the values tabulated, as of 1981, include "peak wind, the greatest 5-second average wind speed during the previous hour that exceeded 35 kn or 17 ms" (U.S. National Oceanic and Atmospheric Administration, 1981) and, "fastest mile, the fastest wind speed in miles per hour (mi/h) of any 'mile' of wind over the 24-hour observation day" (Huschke, 1959). Converting to units used in this publication, peak wind would exceed 40.3 mi/h (64.9 km/h). In addition, wind gusts (sudden brief increases in the speed of the wind) (Huschke, 1959), and gust spread between peak and lull also are included. For many years, prior to the use of more sophisticated instruments, the standard observation was the number of miles of wind passing the anemometer in five minutes, multiplied by 12 to obtain the miles per hour (Sissenwine and Cormier, 1974).

Winds are strongest at the times and places of maximum temperature and pressure gradients. They increase with altitude and during thunderstorms, hurricanes, and tornadoes. A tornado is defined as "a violently rotating column of air from a cumulonimbus cloud (Huschke, 1959). It is believed that the most extreme wind speeds that occur on the earth are those found in the suction vortices that orbit around the centers of tornadoes. However, according to T. T. Fujita, as of 1981, it was not yet possible to measure these speeds accurately (Fujita, 1981). Measuring instruments would be unable to withstand the impact. Ways of estimating extreme wind speeds by various means, such as photogrammetry, engineering, minimum pressure, funnel shape, etc., have been devised. An example is Fujita's scale of wind speed/damage relationships that range from "light" damage at 40-72 mi/h (64-116 km/h), to "incredible" damage at 261-318 mi/h (420-512 km/h), and "inconceivable" damage above these values (Fujita, 1981). Since some tornadoes have caused "incredible" damage, wind speeds of at least 261 mi/h (420 km/h) would have occurred. Worldwide, tornadoes occur most often in the U.S., where they are most prevalent in states like Kansas, Oklahoma, and Texas, which are near the eastern foot of the Rocky Mountains. These areas also have a high incidence of severe hailstorms.

WORLD'S HIGHEST SURFACE WIND
(EXCLUDING TORNADOES)
231 mi/h (372 km/h),
PEAK GUST
188 mi/h (303 km/h),
5-min wind speed

Location: Mount Washington, NH [44°16'N, 71°18'W, elevation: 6,288 ft (1,916 m)]

Date: 12 April 1934

Discussion: The speed of the peak gust was measured by a heated rotation anemometer but, in such strong winds, airflow speed can only be recorded approximately, and actual velocity may be in error by 10 to 40 mi/h (16 to 64 km/h) (Brooks, 1940; Mount Washington Observatory News Bulletin, 1953). The 231 mi/h (372 km/h) value is documented in the official records (NCDC, 1982). A value of 225 mi/h, after anemometer calibration, is given in some sources (Court, 1953) and was cited in earlier editions of the world weather extremes map. Direction of the wind during the gust was from the direction in which the most severe storms in the Mount Washington area usually arrive. Its force, caused by the reduced air density on the mountain top, was equal to that of about a 180 mi/h wind at sea level (Court, 1953). The 24-hour period during which the gust was recorded had a mean wind speed of 128 mi/h (206 km/h) and a speed of 173 mi/h (278 km/h) during the fastest hour (Pagliuca, 1934). Next to the world record peak gust, the second highest gust that has occurred on Mount Washington is apparently the 189 mi/h (304 km/h) estimated during the hurricane of 21 September 1938 (Brooks, 1940). The annual mean wind speed recorded on Mt. Washington, which varies with the period of observation, was 35.1 mi/h (56 km/h) for the 48-year period through 1982 (NCDC, 1982).

Meteorological/Climatological Factors: Winds are stronger at the summit of this mountain than they are at the same elevation in the free air some distance away. "... This is probably due to 'uplift' over the slope, or to the Bernoulli effect introduced by the surrounding mountains. Wind speeds of 100 mi/h (161 km/h) are not uncommon..." (NOAA, 1983).

PEAK GUST OF 207 mi/h (333 km/h)

Location: Thule, Greenland [76°31'N, 68°19'W; elevation: 990 ft (302 m)]

Date: 8 March 1972

Discussion: This peak wind speed of 180 kn was recorded at 9:55 p.m. at an off-base survival shelter (Stansfield, 1972). It was observed by two site dispatchers on an anemometer capable of registering winds of up to 276 mi/h (444 km/h). It occurred at a considerably lower elevation than the peak gust on Mount Washington, and consequently could have exceeded it in force. Similar, though somewhat lesser, speeds were observed throughout the area. The U.S. Air Base at Thule had a speed of 110 mi/h (177 km/h).

Meteorological/Climatological Factors: The gust was observed during a severe Arctic storm in which the site experienced winds of 146 mi/h (235 km/h) or greater for 4 hours (Stansfield, 1972). High winds are common in this northwest Greenland area because of intense winter storms and local topographic conditions. Winds blowing down from the dome-shaped Greenland ice cap are accelerated by gravity, and by compression and funneling, as a result of the local orientation of mountains and valleys.

Further Reading: See Putnins (1970) for a discussion of the climate of Greenland.

PEAK GUST OF 190 mi/h (306 km/h)

Location: Miyakojima Island, Ryukyu Island [24°47'N, 17°00'E]

Date: 5 September 1966

Discussion: A peak gust of 85.3 meters per second (190 mi/h or 306 km/h) and a maximum wind of 60.8 meters per second (136 mi/h or 219 km/h) were observed at the weather station on Miyakojima Island, Ryukyu Island, and officially reported by the Ryukyu Meteorological Agency (Mitsuta and Yoshizumi, 1968).

Meteorological/Climatological Factors: Hurricanes, called typhoons in the Pacific area, are defined on the basis of their wind speed as tropical cyclones, with winds of 65 kn (74 mi/h, 119 km/h) or higher or as tropical cyclones with wind Beaufort force equal to 12 or more (Huschke, 1959). Hurricane winds can sometimes be measured, however, in the most severe storms, the anemometers usually fail before the peak values are reached. As with tornadoes, various methods are used for estimating the hurricane wind speeds, and a scale, the Saffir/Simpson scale, has been developed for rating the severity of the storms (Hebert and Taylor, 1979). Those in the highest category of the scale have air pressure less than 27.17 in (920 mbars) and winds over 155 mi/h (249 km/h), and they cause "catastrophic" damage. Because pressure gradients "have a reasonably close relationship to the wind speeds since the two quantities are related physically" (Gentry, 1974), they are often used to estimate hurricane winds. Surface winds during typhoon Tip, which had the world's lowest sea-level air pressure, were estimated by the Joint Typhoon Warning Center of the U.S. Navy, and U.S. Air Force, to be 160 kn (184 mi/h or 296.5 km/h) with gusts to 195 kn (225 mi/h or 361 km/h) (National Weather Association, 1980). Maximum winds in the two U.S. hurricanes with lowest pressures, at Matecumbe Key, FL in 1935, and on the coast of Louisiana and Mississippi in 1969 (hurricane Camille) have been estimated at about 200 mi/h (322 km/h) (Gentry, 1974).

The western North Pacific Ocean has the world's largest, most intense, and frequent, tropical cyclones. Each year about 18 typhoons occur there, according to the U.S. Navy's Mariners Worldwide Climatic Guide to Tropical Storms at Sea, by Crutcher and Quayle; and each year, one or two of the storms equals the one at Miyakojima in severity (Mitsuta and Yoshizumi, 1968). The U.S. averages about two hurricanes per year, with Florida most often impacted (Hebert and Taylor, 1979).

MEAN WIND SPEED FOR 24 HOURS OF
108 mi/h (174 km/h)
21-22 MARCH 1951
AND MEAN WIND SPEED FOR 1 MONTH OF
65 mi/h (105 km/h)

Location: Port Martin, Antarctica [66°49'S, 141°24'E]

Date: March 1951

Discussion: These wind speeds were recorded at a station maintained by the *Expeditions Polaires Francaises* on the coast of Adelie Land from February 1950 to January 1952 (Loewe, 1972). The wind-measuring installations did not fully comply with international standards, being somewhat sheltered by snowdrifts, or the values would have been slightly higher. Winds of hurricane force equal to, or greater than, 74 mi/h (119 km/h), were recorded at the station on 10 consecutive days in March 1951, and on 122 days during 1951. The hurricane force winds are extremely steady both in their direction, south-southeast, and in their strength, which varies very little and appears lacking in normal gustiness. However, they can drop within a minute from full hurricane strength to near-calm, and just as suddenly return. Extreme winds also were reported by Mawson's expeditions at nearby Cape Denison [67°01'S, 142°41'E] in 1912 and 1913 (Loewe, 1972).

Meteorological/Climatological Factors: Various explanations of the causes of strong winds in this part of Antarctica have been advanced (Mather and Miller, 1967), but, as yet, the reasons for them are not definitely established (Loewe, 1972). Burroughs (1996) cites a wind speed value of 200 mi/h (322 km/h) at nearby Commonwealth Bay, George V Coast, Antarctica [~67°S, 143°E]. The date of this occurrence was not provided by Burroughs.

Other Wind Speed Extremes

CANADA: Canada's **highest average annual wind speed** is 22 mi/h (35 km/h) and occurs at Cape Warwick, Resolution Islands, Northwest Territories [~61°30'N, 65°W] during the period 1962 to 1973 (Georgiades, 1977).

CANADA: Canada's **highest maximum hourly wind speed** is 125 mi/h (201 km/h) and occurred 18 November 1931 at Cape Hopes Advance, Quebec [~58°30'N, 60°W] (Newark, 1984).

UNITED STATES: Mount Washington, NH [44°16'N, 71°18'W, elevation: 6,288 ft (1,916 m)] had a **mean wind speed for 24 hours** of 128 mi/h (206 km/h) on 11-12 April 1934 (Pagliuca, 1934).

UNITED STATES: Mount Washington, NH [44°16'N, 71°18'W, elevation: 6,288 ft (1,916 m)] had a **mean wind speed for a month** of 70 mi/h (112 km/h) during February 1939 (Mount Washington Observatory News Bulletin, 1943).

UNITED STATES: The U.S. **highest average annual wind speed** is 35 mi/h (56 km/h) at Mount Washington, NH [44°16'N, 71°18'W, elevation: 6,288 ft (1,916 m)] for the period 1934 to 1983 (National Climate Data Center, 1967, 1983).

E. Dew Point (Humidity) Extremes.

Dew point is "... the temperature to which a given parcel of air must be cooled at constant pressure and constant water vapor content in order for saturation to occur ..." (Huschke, 1959). This is the temperature at which the vapor returns to liquid water. Huschke (1959) describes six different types of dew point measuring devices, or hygrometers. High dew point values occur in proximity to water bodies with high surface temperatures, such as parts of the Gulf of California, the Red Sea, the Persian Gulf and, possibly, in some tropical swamplands.

AVERAGE AFTERNOON DEW POINT OF 84°F (29°C)

Location: Assab, Ethiopia [13°00'N, 42°42'E]

Date: June

Discussion: The dew point value for Assab was taken from a footnote in a report by A.V. Dodd. "... recently available data furnished by the National Weather Records Center indicates that very high dew points also occur in the Red Sea littoral. Assab and nearby Ras Andahglie on the Red Sea coast of Eritrea (Ethiopia) had average afternoon dew points higher than 84°F ..." (Dodd, 1969). This value was for the most extreme month which, according to the author, is June.

Other Dew Point Extremes

SAUDI ARABIA: One of the highest dew points ever recorded is 93.2°F (34°C) at Sharjah, Saudi Arabia [25°20'N, 55°31'E] on the western shore of the Persian Gulf (Salmela and Grantham, 1972). See Grantham and Sissenwine (1970) for a discussion of the frequencies of occurrence of high dew points.

F. Fog Extremes.

Fog is a "suspension of minute water droplets which are based on the earth's surface and extend vertically to at least 20 ft (6 m) and reduces horizontal and vertical visibility" (NOAA, 1981). It can occur, if there are sufficient condensation nuclei present, whenever the air is cooled to its dew point, or the dew point is raised by the addition of moisture to the air. Ahrens (1991) describes the many types of fog (e.g., advection, radiation (ground), upslope, evaporation and frontal). Fog occurs most often on mountains, where the surface of the earth is high enough to be in the clouds, and on coasts, where land and water temperatures differ and moisture is present. Mountain stations with very frequent occurrences of fog are Mt. Washington, NH, averaging 308 days a year on which there is some fog, and Stampede Pass at 3,958 ft (1206 m) in Washington, which averages 252 days a year (Ludlum, 1971b).

UNITED STATES WEST COAST FOGGIEST PLACE 2,552 HOURS PER YEAR AVERAGE FREQUENCY

Location: Cape Disappointment, WA [~46°15'N, 124°05'W]

UNITED STATES EAST COAST FOGGIEST PLACE 1,580 HOURS PER YEAR AVERAGE FREQUENCY

Location: Moose Peak Lighthouse, Mistake Island, ME [~44°28.5'N, 67°32'W]

Discussion: The records for Cape Disappointment, at the mouth of the Columbia River in Washington, and Moose Peak Lighthouse, off the northern coast of Maine, are based on fog signal operation and on low visibility operation of radio beacons at light stations, lightships, and other Coast Guard units during a period of 10 years or longer. They were obtained from M.A. Arkin, then of the U.S. Environmental Data Service. Arkin also provided an extreme for Willapa on the coast of Washington. At this place, the average was 3,863 hours of fog per year for a 4-year period; and for one of those years, there was a total of 7,613 hours of fog (M.A. Arkin, personal communication, 10 September 1969).

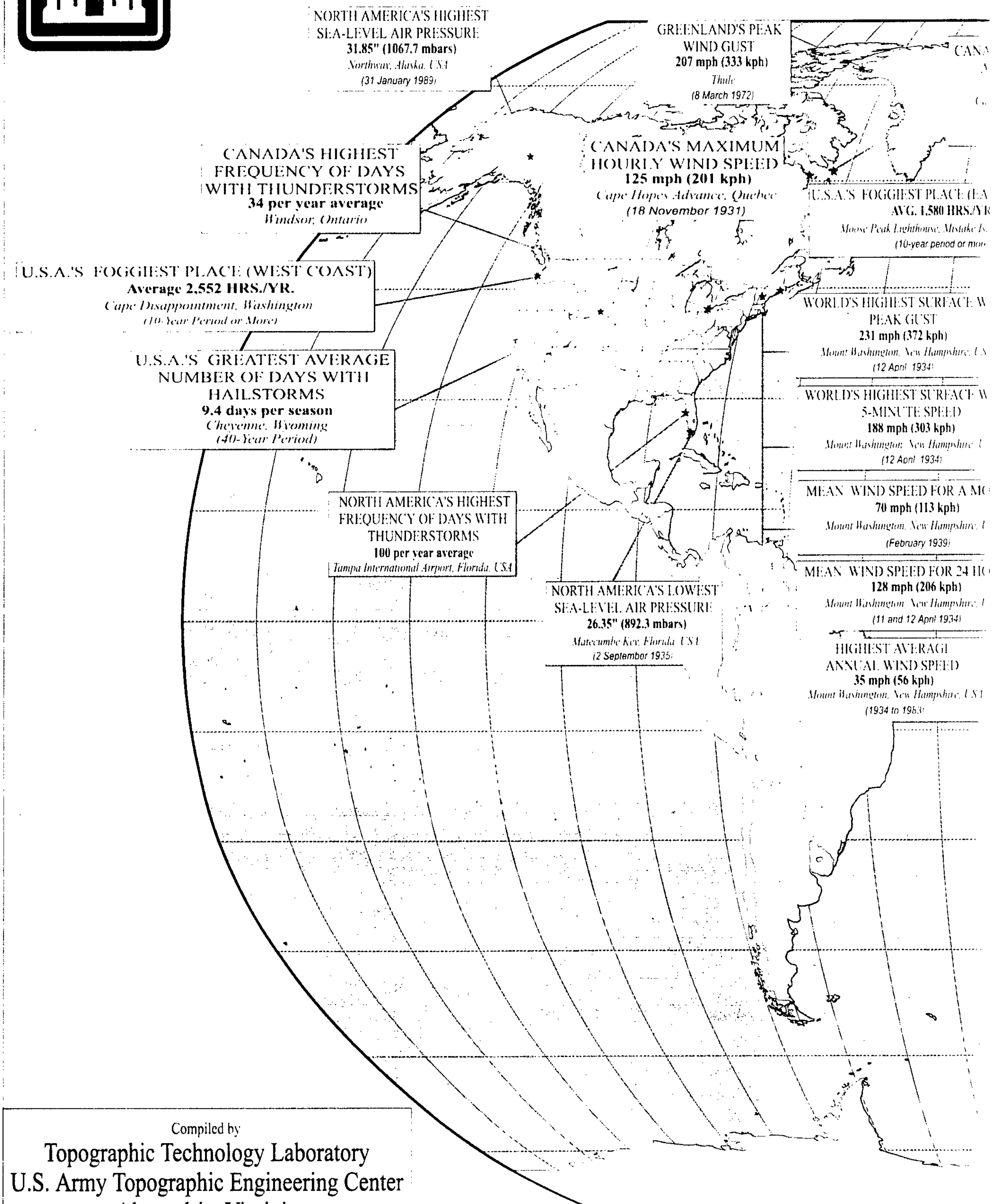
Meteorological/Climatological Factors: On the west coast of the U.S., fog is produced by the orographic lift provided by the mountains to the moist air of the Pacific Ocean. Also, the cold California current reacts with the warmer air off the Pacific Ocean to produce fog. Along the coast of Maine is found the cold Labrador current and the much warmer Gulf Stream – an ideal combination for fog production.

Further Reading: Peace (1969) presents a series of maps showing heavy fog regions in the contiguous Unites States, and Court and Gerston (1966) show frequency maps of fog for the same geographic area.

Other Fog Extremes

CANADA: Canada's **highest average number of days per year** with fog is 158 and occurs at Cape Race, Newfoundland [~46°40'N, 53°W] (Newark, 1984). [Not mapped.]

MISCELLAN



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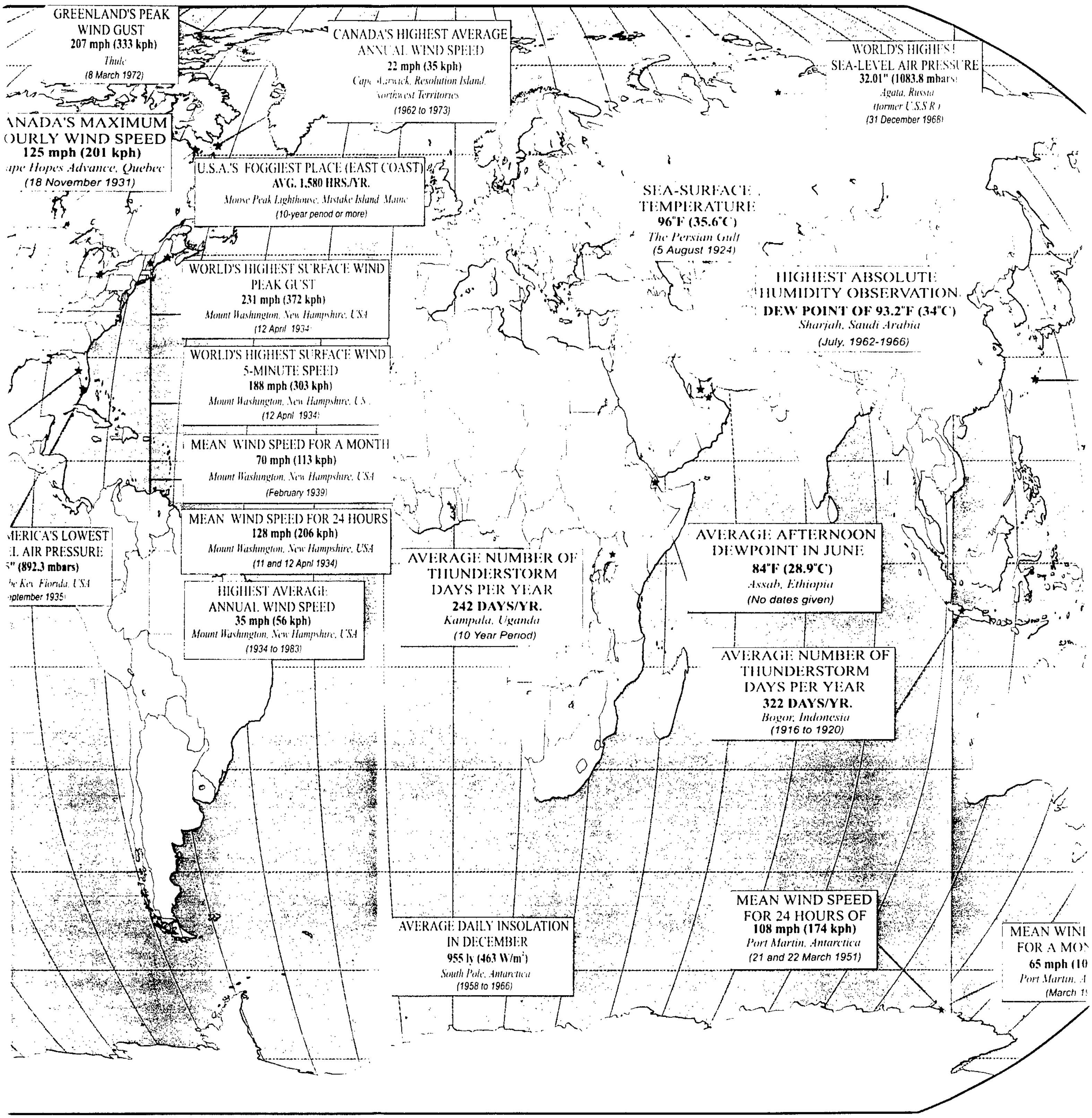
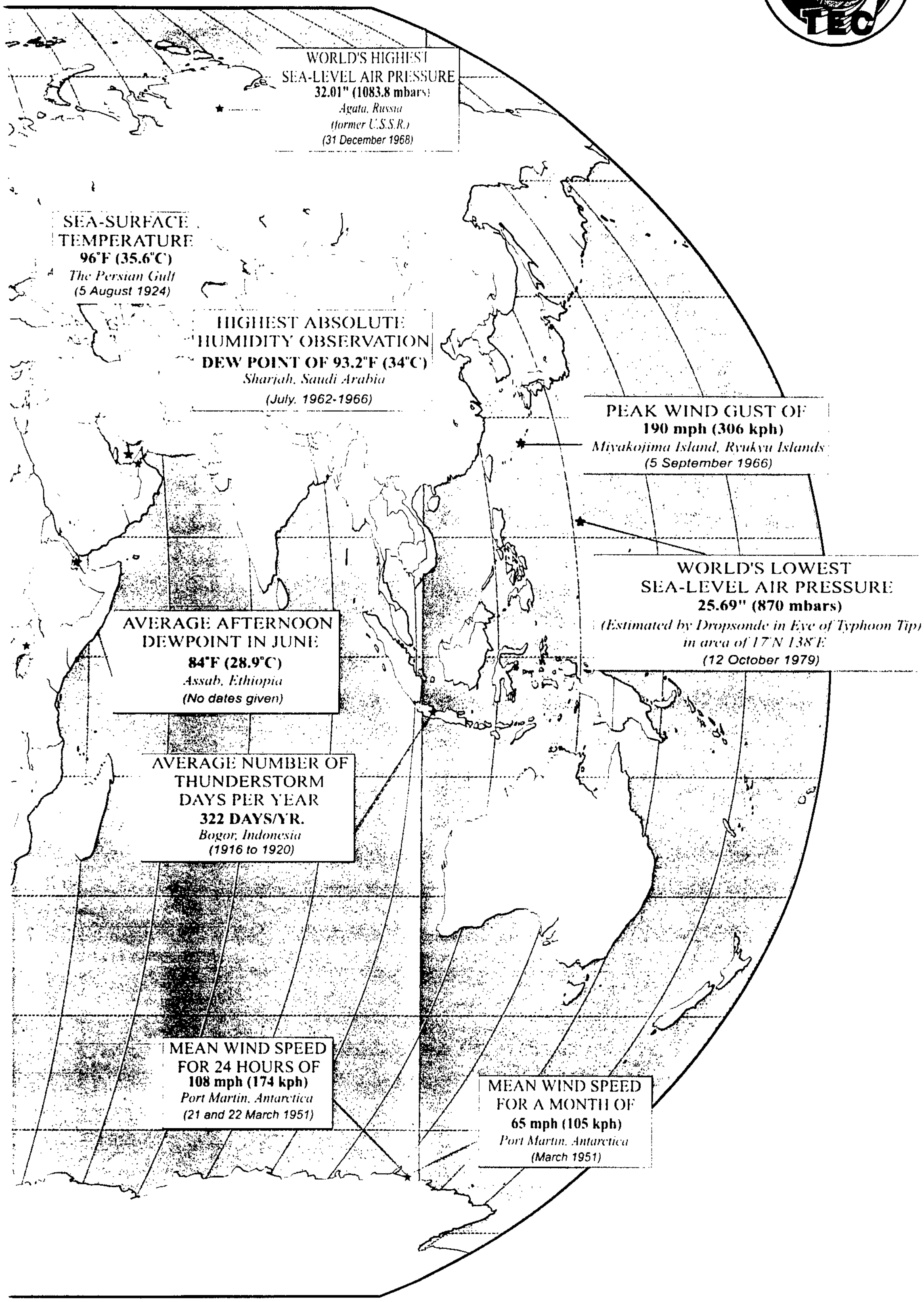
Alexandria, Virginia
22315-3864
for *"Weather and Climate Extremes"*, 1997

MISCELLANEOUS EXTREMES



XTREMES

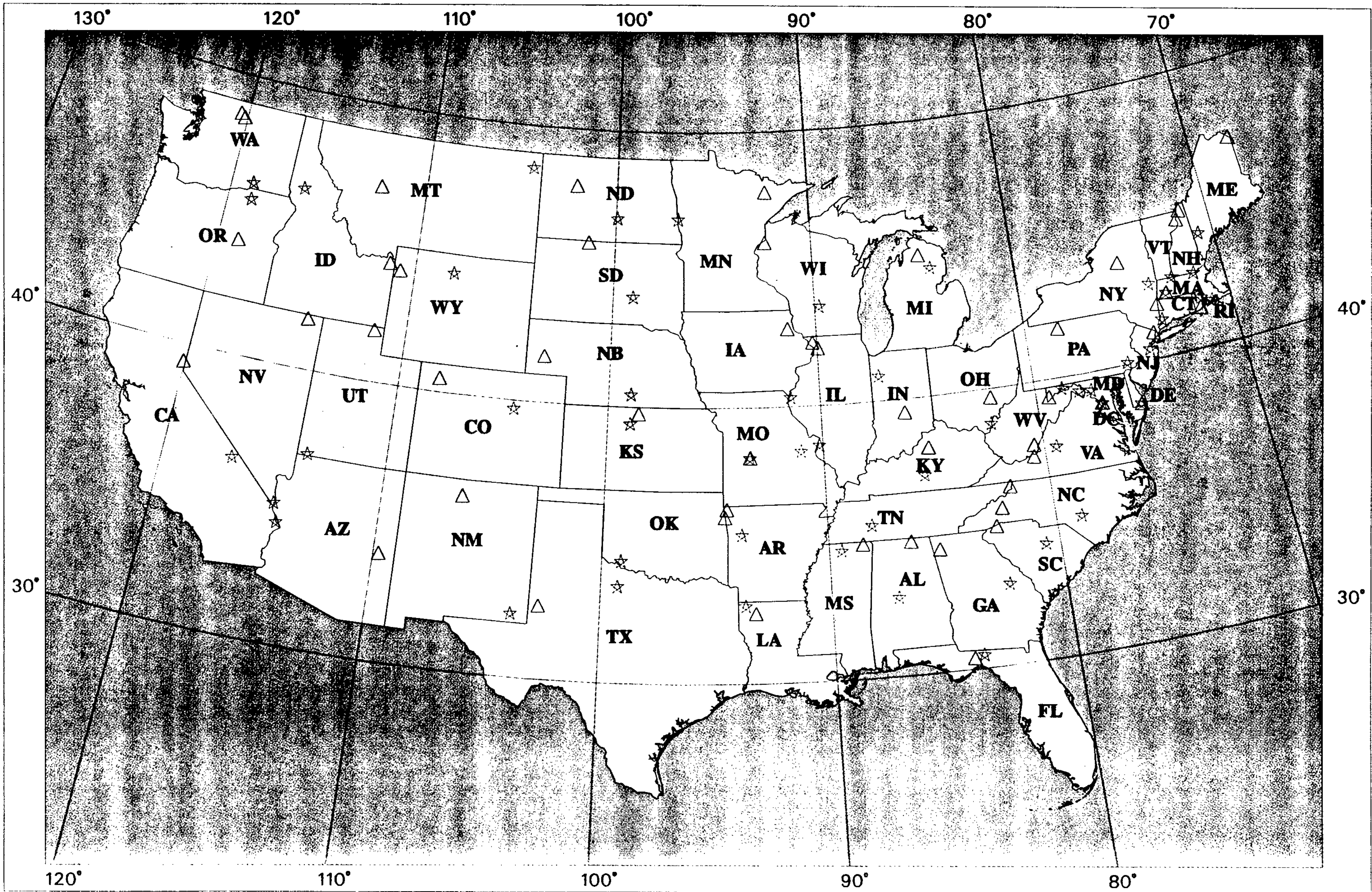


MAP 3

VI. U.S. STATE EXTREMES

Map 4 presents U.S. temperature extremes by state. The high temperature extremes are valid through July 1996, and the low temperature extremes are valid through February 1996. Shown are the absolute maximum and absolute minimum temperatures. **Map 5** presents U.S. precipitation extremes by state. The extremes are valid through July 1996. Shown are the maximum 24-hour precipitation, and maximum monthly precipitation.

U.S. TEMPERATURE EXTREMES BY STATE



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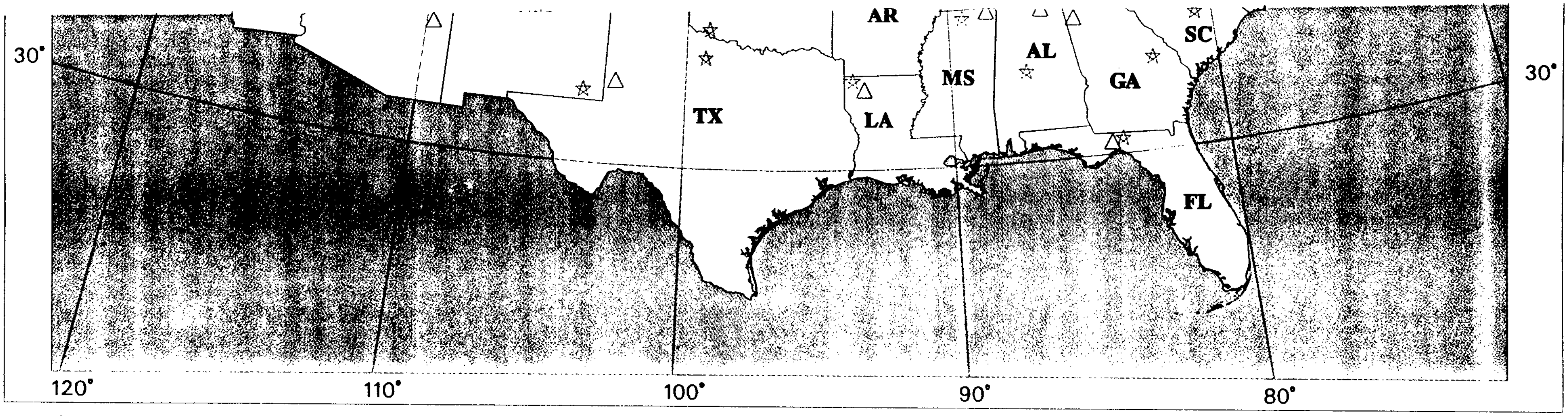
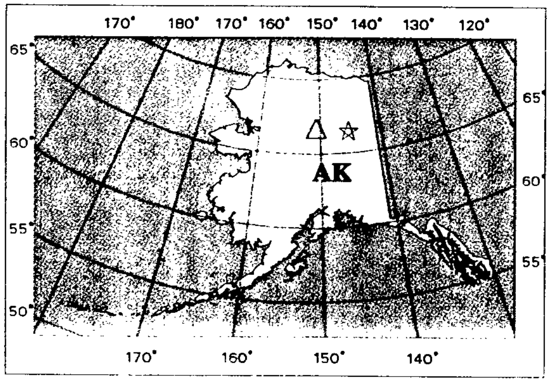
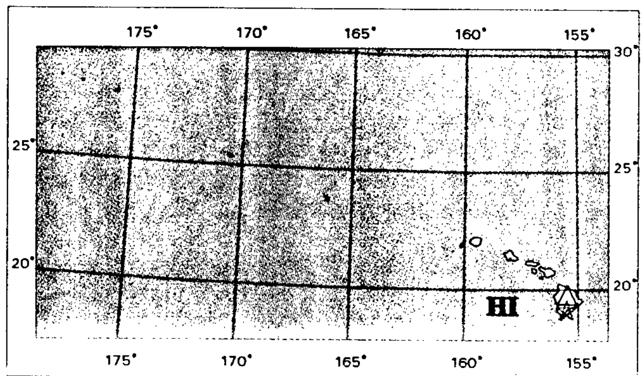


Scale 1:22000000

Data validated through July 1996





Compiled and Produced By:

Topographic Technology Laboratory
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Alexandria, Virginia

For: Weather and Climate Extremes, 1997

MAXIMUM TEMPERATURES ☆

ST	SITE	MAX	DATE	LAT	LONG	ELEV (ft)
AK	FORT YUKON	100	06/27/1915	66°34'N	145°16'W	420
AL	CENTERVILLE	112	09/05/1925	32°57'N	87°08'W	345
AR	OZARK	120	08/10/1936	35°29'N	93°50'W	396
AZ	LAKE HAVASU CITY	128	06/28/1994	34°30'N	114°21'W	505
CA	GREENLAND RANCH	134	07/10/1913	36°27'N	116°52'W	-178
CO	BENNETT	118	07/11/1888	39°46'N	104°26'W	5484
CT	DANBURY	105	07/21/1991	41°24'N	73°28'W	450
DC	WASHINGTON	106	07/20/1930	38°54'N	77°02'W	10
DE	MILLSBORO	110	07/21/1930	38°36'N	75°18'W	20
FL	MONTICELLO	109	06/29/1931	30°33'N	83°52'W	207
GA	LOUISVILLE	112	07/24/1952	33°00'N	82°25'W	132
HI	PAHALA	100	04/27/1931	19°12'N	155°29'W	850
IA	KEOKUK	118	07/20/1934	40°24'N	91°24'W	614
ID	OROFINO	118	07/28/1934	46°29'N	116°15'W	1027
IL	E ST LOUIS	117	07/14/1954	38°37'N	90°09'W	410
IN	COLLEGEVILLE	116	07/14/1936	40°56'N	87°09'W	672
KS	ALTON	121	07/24/1936	39°28'N	98°57'W	1651
KY	GREENSBURG	114	07/28/1930	37°16'N	85°30'W	581
LA	PLAIN DEALING	114	08/10/1936	32°54'N	93°42'W	268
MA	CHESTER	107	08/02/1975	42°17'N	72°59'W	640
MA	NEW BEDFORD	107	08/02/1975	41°38'N	70°56'W	120
MD	CUMBERLAND	109	07/10/1936	39°39'N	78°46'W	623
MD	FREDERICK	109	07/10/1936	39°25'N	77°25'W	325
ME	NORTH BRIDGTON	105	07/10/1911	44°06'N	70°42'W	450
MI	MIO	112	07/13/1936	44°39'N	84°08'W	963
MN	MOORHEAD	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

MINIMUM TEMPERATURES △

ST	SITE	MIN	DATE	LAT	LONG	ELEV (ft)
AK	PROSPECT CREEK	-80	01/23/1971	66°48'N	150°40'W	1100
AL	NEW MARKET	-27	01/30/1966	34°55'N	86°26'W	760
AR	POND	-29	02/13/1905	36°24'N	94°28'W	1250
AZ	HAWLEY LAKE	-40	01/07/1971	33°59'N	109°45'W	8180
CA	BOCA	-45	01/20/1937	39°23'N	120°06'W	5532
CO	MAYBELL	-61	02/01/1985	40°31'N	108°05'W	5920
CT	FALLS VILLAGE	-32	02/16/1943	41°57'N	73°32'W	585
DC	WASHINGTON	-15	02/11/1899	38°54'N	77°02'W	10
DE	MILLSBORO	-17	01/17/1893	38°36'N	75°18'W	20
FL	TALLAHASSEE	-2	02/13/1899	30°27'N	84°17'W	193
GA	CCC CAMP F-16	-17	01/27/1940	34°31'N	85°12'W	1000
HI	MAUNA KEA	12	05/17/1979	19°49'N	155°28'W	13770
IA	ELKADER	-47	02/03/1996	42°51'N	91°24'W	759
ID	ISLAND PARK DAM	-60	01/18/1943	44°24'N	111°19'W	6285
IL	MOUNT CARROLL	-35	01/22/1930	42°06'N	89°59'W	817
IL	ELIZABETH	-35	02/03/1996	42°19'N	90°13'W	792
IN	NEW WHITELAND	-36	01/19/1994	39°33'N	86°06'W	785
KS	LEBANON	-40	02/13/1905	39°49'N	98°33'W	1812
KY	SHELBYVILLE	-37	01/19/1994	38°12'N	85°12'W	730
LA	MINDEN	-16	02/13/1899	32°37'N	93°17'W	194
MA	CHESTER	-35	01/12/1981	42°17'N	72°59'W	640
MD	OAKLAND	-40	01/13/1912	39°25'N	79°24'W	2461
ME	VAN BUREN	-48	01/19/1925	47°10'N	67°57'W	510
MI	VANDERBILT	-51	02/09/1934	45°09'N	84°40'W	785
MN	TOWER	-60	02/02/1996	47°49'N	92°16'W	1350

170° 160° 150° 140° 175° 170° 165° 160° 155°

MAXIMUM TEMPERATURES ☆

ST	SITE	MAX	DATE	LAT	LONG	ELEV (ft)
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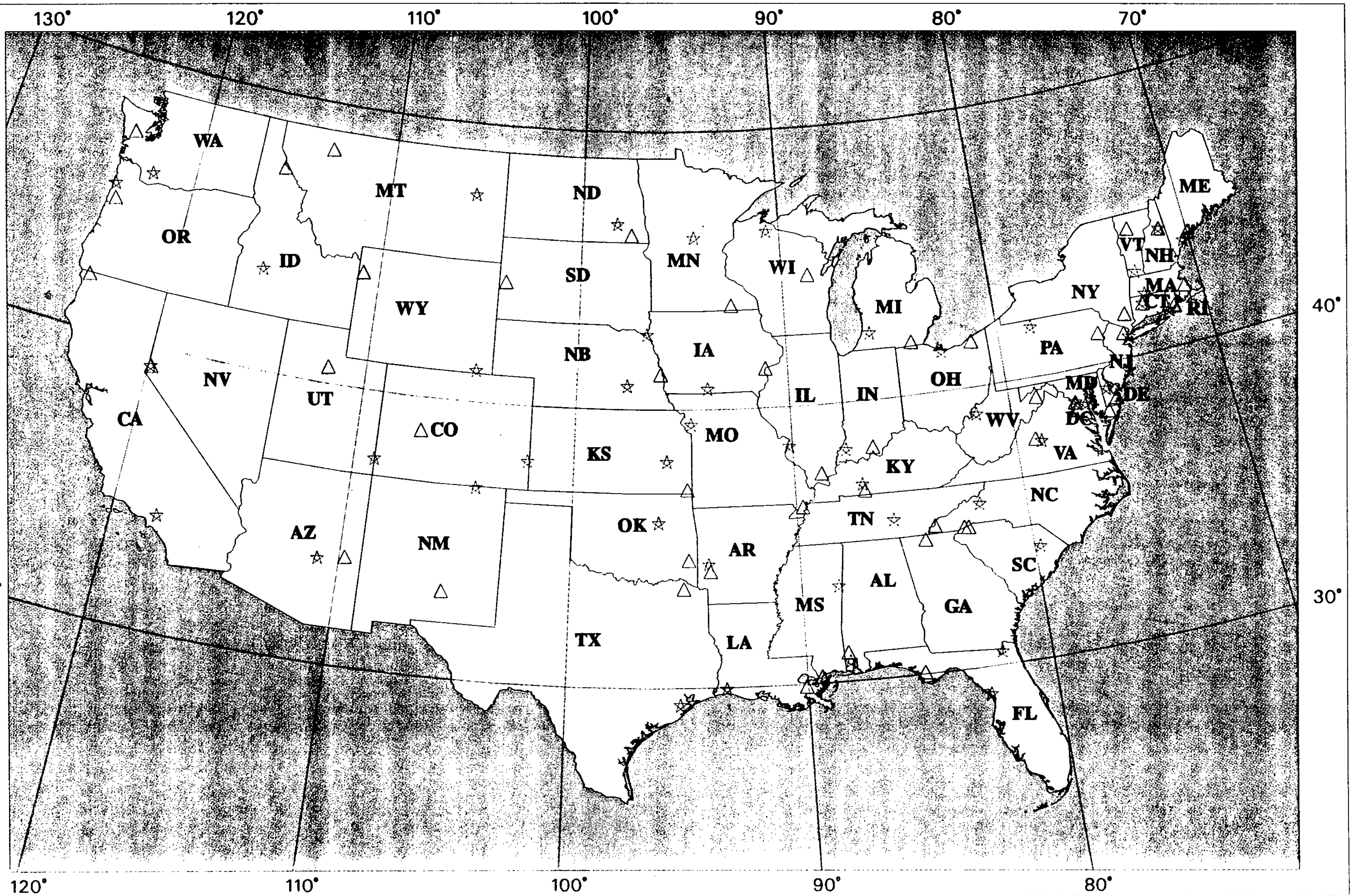
MI	MIO	112	07/13/1936	44°39'N	84°08'W	963
MN	MOORHEAD	114	07/06/1936	46°53'N	96°45'W	904
MO	WARSAW	118	07/14/1954	38°15'N	93°23'W	705
MO	UNION	118	07/14/1954	38°27'N	91°00'W	560
MS	HOLLY SPRINGS	115	07/29/1930	34°46'N	89°27'W	600
MT	MEDICINE LAKE	117	07/05/1937	48°30'N	104°30'W	1950
NB	MINDEN	118	07/24/1936	40°30'N	98°57'W	2169
NC	FAYETTEVILLE	110	08/21/1983	35°03'N	78°53'W	213
ND	STEELE	121	07/06/1936	46°51'N	99°55'W	1857
NH	NASHUA	106	07/04/1911	42°45'N	71°28'W	126
NJ	RUNYON	110	07/10/1936	40°26'N	74°20'W	18
NM	WASTE IS PLANT	122	06/27/1994	32°23'N	103°48'W	3418
NV	LAUGHLIN	125	06/29/1994	35°10'N	114°37'W	605
NY	TROY	108	07/22/1926	42°44'N	73°41'W	35
OH	GALLIPOLIS	113	07/21/1934	38°49'N	82°12'W	673
OK	TIPTON	120	06/27/1994	34°30'N	99°08'W	1350
OR	PENDLETON	119	08/10/1898	45°40'N	118°47'W	1074
PA	PHOENIXVILLE	111	07/10/1936	40°08'N	75°31'W	100
RI	PROVIDENCE	102	08/02/1975	41°49'N	71°24'W	51
SC	CAMDEN	111	05/28/1954	34°16'N	80°36'W	170
SD	GANNVALLEY	120	07/05/1936	44°02'N	98°59'W	1750
TN	PERRYVILLE	113	08/09/1930	35°37'N	88°02'W	377
TX	SEYMOUR	120	08/12/1936	33°35'N	99°16'W	1291
UT	SAINT GEORGE	117	07/05/1985	37°06'N	113°35'W	2880
VA	BALCONY FALLS	110	07/15/1954	37°38'N	79°27'W	725
VT	VERNON	105	07/04/1911	42°47'N	72°32'W	310
WA	ICE HARBOR DAM	118	08/05/1961	46°15'N	118°53'W	475
WI	WISCONSIN DELLS	114	07/13/1936	43°38'N	89°46'W	900
WV	MARTINSBURG	112	07/10/1936	39°27'N	77°58'W	435
WY	BASIN	114	07/12/1900	44°23'N	108°02'W	3500

MINIMUM TEMPERATURES △

ST	SITE	MIN	DATE	LAT	LONG	ELEV (ft)
AK	PROSPECT CREEK	-80	01/23/1971	66°48'N	150°40'W	1100
AL	NEW MARKET	-27	01/30/1966	34°55'N	86°26'W	760
AR	POND	-29	02/13/1905	36°24'N	94°28'W	1250
AZ	HAWLEY LAKE	-40	01/07/1971	33°59'N	109°45'W	8180
CA	BOCA	-45	01/20/1937	39°23'N	120°06'W	5532
CO	MAYBELL	-61	02/01/1985	40°31'N	108°05'W	5920
CT	FALLS VILLAGE	-32	02/16/1943	41°57'N	73°32'W	585
DC	WASHINGTON	-15	02/11/1899	38°54'N	77°02'W	10
DE	MILLSBORO	-17	01/17/1893	38°36'N	75°18'W	20
FL	TALLAHASSEE	-2	02/13/1899	30°27'N	84°17'W	193
GA	CCC CAMP F-16	-17	01/27/1940	34°31'N	85°12'W	1000
HI	MAUNA KEA	12	05/17/1979	19°49'N	155°28'W	13770
IA	ELKADER	-47	02/03/1996	42°51'N	91°24'W	759
ID	ISLAND PARK DAM	-60	01/18/1943	44°24'N	111°19'W	6285
IL	MOUNT CARROLL	-35	01/22/1930	42°06'N	89°59'W	817
IL	ELIZABETH	-35	02/03/1996	42°19'N	90°13'W	792
IN	NEW WHITELAND	-36	01/19/1994	39°33'N	86°06'W	785
KS	LEBANON	-40	02/13/1905	39°49'N	98°33'W	1812
KY	SHELBYVILLE	-37	01/19/1994	38°12'N	85°12'W	730
LA	MINDEN	-16	02/13/1899	32°37'N	93°17'W	194
MA	CHESTER	-35	01/12/1981	42°17'N	72°59'W	640
MD	OAKLAND	-40	01/13/1912	39°25'N	79°24'W	2461
ME	VAN BUREN	-48	01/19/1925	47°10'N	67°57'W	510
MI	VANDERBILT	-51	02/09/1934	45°09'N	84°40'W	785
MN	TOWER	-60	02/02/1996	47°49'N	92°16'W	1350
MO	WARSAW	-40	02/13/1905	38°15'N	93°23'W	700
MS	CORINTH	-19	01/30/1966	34°56'N	88°31'W	420
MT	ROGERS PASS	-70	01/20/1954	47°04'N	112°22'W	5470
NB	CAMP CLARKE	-47	02/12/1899	41°43'N	103°12'W	3700
NC	MT MITCHELL	-34	01/21/1985	35°44'N	82°17'W	6525
ND	PARSHALL	-60	02/15/1936	47°57'N	102°08'W	1929
NH	PITTSBURG	-46	01/28/1925	45°03'N	71°24'W	1575
NJ	RIVER VALE	-34	01/05/1904	40°59'N	74°01'W	70
NM	GAVILAN	-50	02/01/1951	36°26'N	106°23'W	7350
NV	SAN JACINTO	-50	01/08/1937	41°53'N	114°47'W	5200
NY	OLD FORGE	-52	02/18/1979	43°43'N	74°58'W	1720
OH	MILLIGAN	-39	02/10/1899	39°43'N	82°06'W	875
OK	WATTS	-27	01/18/1930	36°07'N	94°34'W	958
OR	SENNECA	-54	02/10/1933	44°08'N	118°58'W	4700
PA	SMETHPORT	-42	01/05/1904	41°49'N	78°27'W	1500
RI	KINGSTON	-23	01/11/1942	41°29'N	71°32'W	100
SC	CAESARS HEAD	-19	01/21/1985	35°07'N	82°38'W	3115
SD	McINTOSH	-58	02/17/1936	45°55'N	101°21'W	2277
TN	MOUNTAIN CITY	-32	12/30/1917	36°29'N	81°48'W	2471
TX	SEMINOLE	-23	02/08/1933	32°43'N	102°39'W	3275
UT	PETER'S SINK	-69	02/01/1985	41°55'N	111°31'W	8092
VA	MT LAKE BIO STA	-30	01/22/1985	37°23'N	80°32'W	3870
VT	BLOOMFIELD	-50	12/30/1933	44°46'N	71°37'W	915
WA	MAZAMA	-48	12/30/1968	48°36'N	120°24'W	2120
WA	WINTHROP	-48	12/30/1968	48°28'N	120°11'W	1755
WI	DANBURY	-55	02/04/1996	46°01'N	92°22'W	908
WV	LEWISBURG	-37	12/30/1917	37°48'N	80°27'W	2200
WY	YELLOWSTONE PARK	-66	02/09/1933	44°10'N	110°45'W	7500

MAP 4

U.S. PRECIPITATION EXTREMES BY STATE



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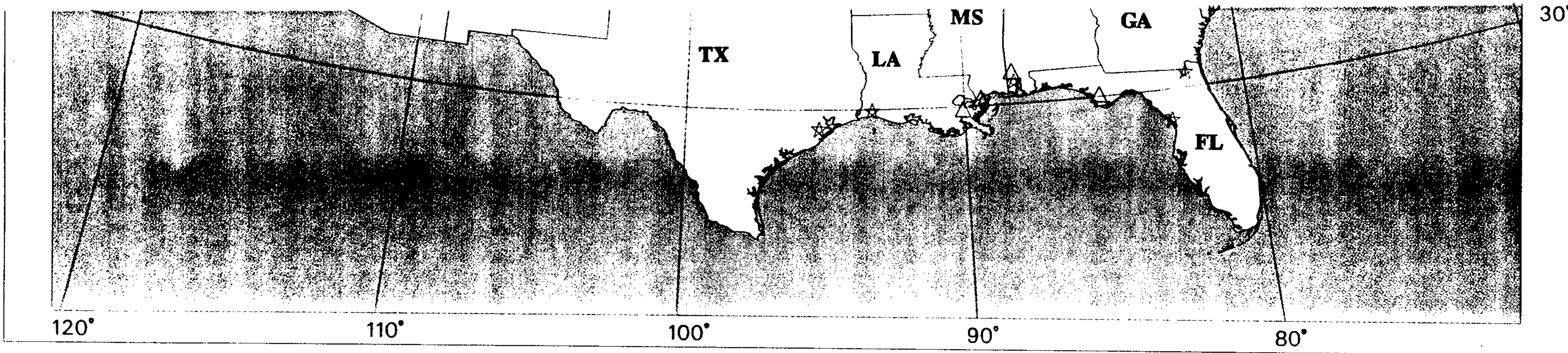

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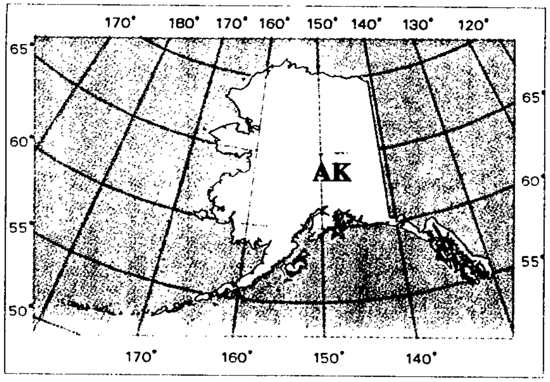
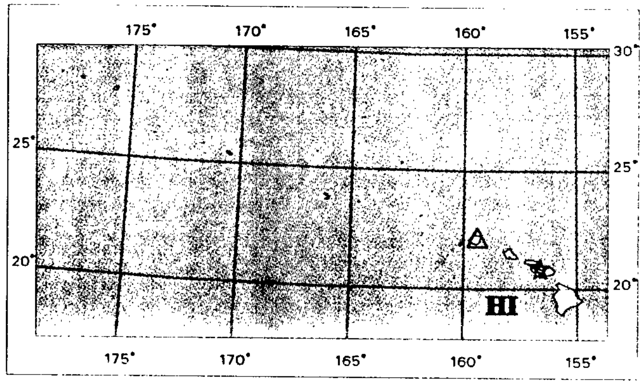




Compiled and Produced By:

Topographic Technology Laboratory
U.S. Army Topographic Engineering Center
Alexandria, Virginia

For: Weather and Climate Extremes, 1997

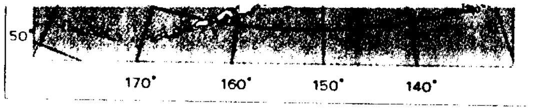
24-HOUR PRECIPITATION ☆

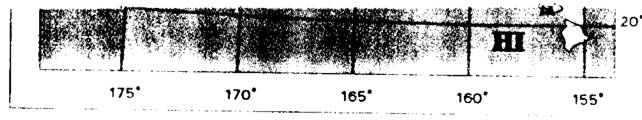
ST	SITE	24-HR	DATE	LAT	LONG	ELEV (ft)
AK	ANGOON	15.20	10/12/1982	57°30'N	134°35'W	15
AL	AXIS	20.33	04/13/1955	30°45'N	88°10'W	36
AR	BIG FORK	14.06	12/03/1982	34°29'N	93°58'W	1100
AZ	WORKMAN CREEK	11.40	09/05/1970	33°49'N	110°55'W	6970
CA	HOEGEES CAMP	26.12	01/23/1943	34°13'N	118°02'W	2760
CO	HOLLY	11.08	06/17/1965	38°03'N	102°07'W	3390
CT	BURLINGTON	12.77	08/19/1955	41°49'N	72°58'W	450
DC	WASHINGTON	7.31	08/12/1928	38°54'N	77°02'W	10
DE	DOVER	8.50	07/13/1975	39°10'N	75°32'W	30
FL	YANKEETOWN	38.70	09/05/1950	29°02'N	82°43'W	5
GA	ST GEORGE	18.00	08/29/1911	30°31'N	82°02'W	77
HI	KILAUEA PLANTATION	38.00	01/25/1956	22°13'N	159°25'W	180
IA	DECATUR CO	16.70	08/05/1959	40°46'N	93°50'W	1110
ID	RATTLESNAKE CREEK	7.17	11/23/1909	43°37'N	115°44'W	4000
IL	E ST LOUIS	16.54	06/15/1957	38°37'N	90°09'W	410
IN	PRINCETON	10.50	08/06/1905	38°21'N	87°34'W	480
KS	BURLINGTON	12.59	06/01/1941	38°12'N	95°45'W	1010
KY	DUNMOR	10.40	06/28/1960	37°05'N	86°60'W	610
LA	HACKBERRY	22.00	08/28/1962	29°60'N	93°21'W	10
MA	WESTFIELD	18.15	08/19/1955	42°07'N	72°45'W	220
MD	JEWELL	14.75	07/27/1897	38°45'N	76°37'W	165
ME	PORTLAND	13.32	10/21/1996	43°38'N	70°18'W	43
MI	BLOOMINGDALE	9.78	09/01/1914	42°23'N	85°57'W	750
MN	FORT RIPLEY	10.84	07/22/1972	46°10'N	94°22'W	1140
MO	EDGERTON	18.18	07/20/1965	39°30'N	94°38'W	856
MS	COLUMBUS	15.68	07/09/1968	33°30'N	88°25'W	190
MT	CIRCLE	11.50	06/20/1921	47°25'N	105°35'W	2440
NB	YORK	13.15	07/08/1950	40°52'N	97°36'W	1610
NC	ALTAPASS	22.22	07/16/1916	35°53'N	82°01'W	2600
ND	LITCHVILLE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

ANNUAL PRECIPITATION △

ST	SITE	ANN	YEAR	LAT	LONG	ELEV (ft)
AK	MACLEOD HARBOR	332.29	1976	59°53'N	147°45'W	40
AL	CITRONELLE	98.22	1961	31°05'N	88°14'W	331
AR	NEWHOPE	98.55	1957	34°14'N	93°53'W	850
AZ	HAWLEY LAKE	58.92	1978	33°59'N	109°45'W	8180
CA	MONUMENTAL	153.54	1909	41°58'N	123°48'W	2420
CO	RUBY	92.84	1897	38°52'N	107°05'W	10000
CT	BURLINGTON	78.53	1955	41°48'N	72°58'W	460
DC	WASHINGTON	61.33	1889	38°54'N	77°02'W	10
DE	LEWES 1 S.W.	72.75	1948	38°46'N	75°09'W	10
FL	WEWAHITCHKA	112.43	1966	30°07'N	85°12'W	50
GA	FLAT TOP	112.16	1959	34°51'N	84°30'W	3600
HI	KUKUI	704.83	1982	20°54'N	156°35'W	5788
IA	MUSCATINE	74.50	1851	41°25'N	91°03'W	680
ID	ROLAND (WEST PORTAL)	81.05	1933	47°21'N	115°40'W	4150
IL	NEW BURNSIDE	74.58	1950	37°35'N	88°46'W	560
IN	MARENGO	97.38	1890	38°22'N	86°21'W	570
KS	COLUMBUS	67.02	1985	37°10'N	94°50'W	900
KY	RUSSELVILLE	79.68	1950	36°51'N	86°53'W	590
LA	NEW ORLEANS (AUDUBON)	113.74	1991	29°58'N	90°04'W	6
MA	PEMBROKE	72.19	1983	42°05'N	70°48'W	74
MD	SALISBURY	72.59	1948	38°22'N	75°36'W	50
ME	BRUNSWICK	75.64	1845	43°55'N	69°58'W	70
MI	ADRIAN	64.01	1881	41°54'N	84°02'W	770
MN	GRAND MEADOW	51.53	1911	43°42'N	92°34'W	1340
MO	PORTAGEVILLE	92.77	1957	36°26'N	89°42'W	280
MS	WAVELAND	104.36	1991	30°17'N	89°23'W	8
MT	SUMMIT	55.51	1953	48°20'N	113°21'W	5210
NB	OMAHA	64.52	1869	41°17'N	96°01'W	980
NC	ROSMAN	129.60	1964	35°09'N	82°49'W	[illegible]

(2)





Topographic Technology Laboratory
U.S. Army Topographic Engineering Center
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For: Weather and Climate Extremes, 1997

24-HOUR PRECIPITATION ☆

ST	SITE	24-HR	DATE	LAT	LONG	ELEV (ft)
AK	ANGOON	15.20	10/12/1982	57°30'N	134°35'W	15
AL	AXIS	20.33	04/13/1955	30°45'N	88°10'W	36
AR	BIG FORK	14.06	12/03/1982	34°29'N	93°58'W	1100
AZ	WORKMAN CREEK	11.40	09/05/1970	33°49'N	110°55'W	6970
CA	HOEGEES CAMP	26.12	01/23/1943	34°13'N	118°02'W	2760
CO	HOLLY	11.08	06/17/1965	38°03'N	102°07'W	3390
CT	BURLINGTON	12.77	08/19/1955	41°49'N	72°58'W	450
DC	WASHINGTON	7.31	08/12/1928	38°54'N	77°02'W	10
DE	DOVER	8.50	07/13/1975	39°10'N	75°32'W	30
FL	YANKEETOWN	38.70	09/05/1950	29°02'N	82°43'W	5
GA	ST GEORGE	18.00	08/29/1911	30°31'N	82°02'W	77
HI	KILAUEA PLANTATION	38.00	01/25/1956	22°13'N	159°25'W	180
IA	DECATUR CO	16.70	08/05/1959	40°46'N	93°50'W	1110
ID	RATTLESNAKE CREEK	7.17	11/23/1909	43°37'N	115°44'W	4000
IL	E ST LOUIS	16.54	06/15/1957	38°37'N	90°09'W	410
IN	PRINCETON	10.50	08/06/1905	38°21'N	87°34'W	480
KS	BURLINGTON	12.59	06/01/1941	38°12'N	95°45'W	1010
KY	DUNMOR	10.40	06/28/1960	37°05'N	86°60'W	610
LA	HACKBERRY	22.00	08/28/1962	29°60'N	93°21'W	10
MA	WESTFIELD	18.15	08/19/1955	42°07'N	72°45'W	220
MD	JEWELL	14.75	07/27/1897	38°45'N	76°37'W	165
ME	PORTLAND	13.32	10/21/1996	43°38'N	70°18'W	43
MI	BLOOMINGDALE	9.78	09/01/1914	42°23'N	85°57'W	750
MN	FORT RIPLEY	10.84	07/22/1972	46°10'N	94°22'W	1140
MO	EDGERTON	18.18	07/20/1965	39°30'N	94°38'W	856
MS	COLUMBUS	15.68	07/09/1968	33°30'N	88°25'W	190
MT	CIRCLE	11.50	06/20/1921	47°25'N	105°35'W	2440
NB	YORK	13.15	07/08/1950	40°52'N	97°36'W	1610
NC	ALTAPASS	22.22	07/16/1916	35°53'N	82°01'W	2600
ND	LITCHVILLE	8.10	06/29/1975	46°39'N	98°12'W	1470
NH	MT WASHINGTON	10.38	02/11/1970	44°16'N	71°18'W	6262
NJ	TUCKERTON	14.81	08/19/1939	39°36'N	74°20'W	20
NM	LAKE MALOYA	11.28	05/19/1955	36°59'N	104°22'W	7400
NV	MT ROSE HWY STA	7.13	01/31/1963	39°20'N	119°53'W	7360
NY	NYC CENTRAL PARK	11.17	10/09/1903	40°46'N	73°58'W	130
OH	SANDUSKY	10.51	07/12/1966	41°27'N	82°42'W	610
OK	SAPULPA	15.50	09/04/1940	35°60'N	96°07'W	740
OR	GLENORA	10.17	12/21/1915	45°20'N	123°50'W	575
PA	SMETHPORT	34.50	07/17/1942	41°49'N	78°27'W	1510
RI	WESTERLY	12.13	09/17/1932	41°22'N	71°50'W	40
SC	EFFINGHAM	13.25	07/15/1916	34°05'N	79°46'W	110
SD	ELK POINT	8.00	09/10/1900	42°41'N	96°40'W	1127
TN	McMINNVILLE	11.00	03/28/1902	35°41'N	85°46'W	900
TX	ALVIN	43.00	07/26/1979	29°26'N	95°15'W	50
UT	BUG POINT	6.00	09/05/1970	37°38'N	109°03'W	6600
VA	NELSON CO	27.00	08/20/1969	37°46'N	78°53'W	500
VT	SOMERSET	8.77	11/04/1927	42°58'N	72°57'W	2080
WA	MT MITCHELL (#2)	14.26	11/24/1986	46°02'N	122°10'W	3600
WI	MELLEN	11.72	06/24/1946	46°20'N	90°40'W	1150
WV	ROCKPORT	19.00	07/18/1889	39°04'N	81°33'W	700
WY	CHEYENNE	6.06	08/01/1985	41°08'N	104°49'W	6126

ANNUAL PRECIPITATION △

ST	SITE	ANN	YEAR	LAT	LONG	ELEV (ft)
AK	MACLEOD HARBOR	332.29	1976	59°53'N	147°45'W	40
AL	CITRONELLE	98.22	1961	31°05'N	88°14'W	331
AR	NEWHOPE	98.55	1957	34°14'N	93°53'W	850
AZ	HAWLEY LAKE	58.92	1978	33°59'N	109°45'W	8180
CA	MONUMENTAL	153.54	1909	41°58'N	123°48'W	2420
CO	RUBY	92.84	1897	38°52'N	107°05'W	10000
CT	BURLINGTON	78.53	1955	41°48'N	72°58'W	460
DC	WASHINGTON	61.33	1889	38°54'N	77°02'W	10
DE	LEWES 1 S:W	72.75	1948	38°46'N	75°09'W	10
FL	WEWAHITCHKA	112.43	1966	30°07'N	85°12'W	50
GA	FLAT TOP	112.16	1959	34°51'N	84°30'W	3600
HI	KUKUI	704.83	1982	20°54'N	156°35'W	5788
IA	MUSCATINE	74.50	1851	41°25'N	91°03'W	680
ID	ROLAND (WEST PORTAL)	81.05	1933	47°21'N	115°40'W	4150
IL	NEW BURNSIDE	74.58	1950	37°35'N	88°46'W	560
IN	MARENGO	97.38	1890	38°22'N	86°21'W	570
KS	COLUMBUS	67.02	1985	37°10'N	94°50'W	900
KY	RUSSELVILLE	79.68	1950	36°51'N	86°53'W	590
LA	NEW ORLEANS (AUDUBON)	113.74	1991	29°58'N	90°04'W	6
MA	PEMBROKE	72.19	1983	42°05'N	70°48'W	74
MD	SALISBURY	72.59	1948	38°22'N	75°36'W	50
ME	BRUNSWICK	75.64	1845	43°55'N	69°58'W	70
MI	ADRIAN	64.01	1881	41°54'N	84°02'W	770
MN	GRAND MEADOW	51.53	1911	43°42'N	92°34'W	1340
MO	PORTAGEVILLE	92.77	1957	36°26'N	89°42'W	280
MS	WAVELAND	104.36	1991	30°17'N	89°23'W	8
MT	SUMMIT	55.51	1953	48°20'N	113°21'W	5210
NB	OMAHA	64.52	1869	41°17'N	96°01'W	980
NC	ROSMAN	129.60	1964	35°09'N	82°49'W	2200
ND	MILNOR	37.98	1944	46°16'N	97°27'W	2600
NH	MT WASHINGTON	130.14	1969	44°16'N	71°18'W	6260
NJ	PATERSON	85.89	1882	40°55'N	74°11'W	100
NM	WHITE TAIL	62.45	1941	33°10'N	105°28'W	7450
NV	MT ROSE RESORT	59.03	1969	39°21'N	119°52'W	7300
NY	WAPPINGERS FALLS	82.06	1903	41°36'N	73°55'W	200
OH	LITTLE MOUNTAIN	70.82	1870	41°38'N	81°16'W	1260
OK	KIAMICHI TOWER	84.47	1957	34°38'N	94°49'W	2350
OR	VALSETZ	168.88	1937	44°50'N	123°39'W	1150
PA	MT. POCONO	81.64	1952	41°07'N	75°22'W	1910
RI	KINGSTON	70.21	1983	41°29'N	71°31'W	100
SC	CAESAR'S HEAD	101.65	1961	35°07'N	82°38'W	3120
SD	DEADWOOD	48.42	1946	44°23'N	103°44'W	4550
TN	HAW KNOB	114.88	1957	35°19'N	84°02'W	4900
TX	CLARKSVILLE	109.38	1873	33°37'N	95°03'W	440
UT	ALTA	108.54	1983	40°36'N	111°47'W	8760
VA	MONTEBELLO	81.78	1972	37°52'N	79°08'W	2450
VT	MT. MANSFIELD	92.88	1983	44°32'N	72°49'W	3950
WA	WYNCOCHEE OXBOW	184.56	1931	47°20'N	123°38'W	670
WI	EMBARRASS	62.07	1884	44°40'N	88°42'W	808
WV	ROMNEY	94.01	1948	39°21'N	78°45'W	820
WY	GRASSY LAKE DAM	55.46	1945	44°08'N	110°50'W	7240

MAP 5

VII. CONCLUSION

From the foregoing examples and discussions of weather extremes and their records, several points seem to stand out:

a. For each meteorological and climatological element, there are certain conditions or combinations of conditions that tend to favor the occurrence of extreme values. These conditions are most likely to be present at particular geographical areas or during particular times of the year. Also, there are upper and lower limits of the extreme values that could possibly occur. The records shown on the maps considered in this report appear to be within the limits of possibility and to have occurred in places and at times in which the necessary conditions could be expected to happen. However, occurrences of equal or greater extremity could have happened at other places in the same general areas, or at other times in the same places without being recorded or without being publicized. There is no routine exchange of such information between different countries.

b. For each meteorological and climatological element, there are factors of site, instrumentation, and observational procedure that can affect the measured values. To ensure uniformity of measurements, certain standardized equipment and procedures are recommended by the World Meteorological Organization. However, standardized equipment can malfunction, and errors can be made in observation and recording, even under standard procedures. Further, improvements in the reliability of measurements continue to be made as knowledge of both technology and the physical environment increases. Linacre (1992) discusses the various types of meteorological instrumentation in terms of the accuracy of measurements. Some of the earlier records might have different values if measured with the newest instruments and procedures. Even now, extremes are sometimes not measured exactly, or at all, because they exceed the scale of standard meteorological instruments or their rate of response. For these reasons, it is not to be assumed that any one of the values shown on the maps considered in this publication is correct to the tenth of a decimal place. However, those for which a claim for record extreme is made were obtained under conditions that were acceptable to the responsible weather service organizations.

c. Considerable research remains to be done on both the general subject of extreme weather and climate, and on the records of individual extreme occurrences. There is more to be learned about the causes of extreme conditions as well as their absolute limits, frequencies, and distributions in time and place. Further search would yield additional records of extremes and of categories of extremes that are not included on the present maps.

d. Advanced readers with strong mathematics and statistical backgrounds may wish to examine the body of literature that exists for <u>extreme-value analysis</u>. The primary focus of extreme-value analysis is on estimating the greatest or smallest value that an element can reach and how often this value will occur during some discrete time period. An essential work is that of Gumbel (1958). Compilations of the various methods used in extreme-value analysis can be obtained in Essenwanger (1976) and Farago and Katz (1990). One of the focuses of extreme-value research, namely high temperature, has become extremely topical in view of the global climate warming issues that have arisen recently. Some of the many professional journal articles that have addressed this issue are those of Brown and Katz (1995); Mearns, Katz and Schneider (1984); Wigley (1985 & 1988); Idso and Balling (1992); Vedin (1990); and, Katz and Brown (1992).

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APPENDIX

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PERIODICALS

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[Bimonthly magazine; popular articles on weather and climate; questions and answers; monthly weather summaries; book reviews]

CLIMATE DATA AND PUBLICATIONS

National Climate Data Center, 151 Patton Ave., Room 120, Asheville, NC 28801-5001
(704) 259-0682; Internet -- http://ncdc.noaa.gov/
[Historical climatic data; special publications and reports; on-line access to many reports and data sets]

PROFESSIONAL ORGANIZATIONS

American Meteorological Society, 45 Beacon Street, Boston, MA 02108
Internet -- http://ametsoc.org/AMS/index.html
[Professional society; meteorological and climate journals; local chapters throughout the U.S.]

National Weather Association, 6704 Wolke Court, Montgomery, AL 36116-2134
Internet -- http://www.infi.net/~cwt//nwa-page.html
[Professional society; primary focus on operational meteorology]

WEB SITES

The Weather Channel, 2600 Cumberland Parkway, NW, Atlanta, GA 30339
Internet -- http://www.weather.com/
[Books; videos; multimedia; education materials]

The Weather Shops
Internet -- http://www.intellicast.com/wxshops/
[Books; videos; posters; educational materials]

National Weather Service
Internet -- http://www.nws.noaa.gov/data.shtml
[weather data; forecasts; marine and aviation weather]

MISCELLANEOUS

Weather Guide Calendar
Accord Publishing Ltd., Denver, CO
[annual calendar; weather photos; climate data; extreme events; articles on severe and unusual weather phenomena]

Photo Credits - Back Cover. Unless otherwise stated, photos courtesy of Weatherwise, Heldref Publications. Clockwise from upper left: lenticular clouds (Persenia Whittern); flooding (U.S. Army); mammatus clouds (Paul Markowski); hurricane (Dr. Fritz Hasler, NASA); lightning bolts (U.S. Army); roll cloud (Bruce Burkman); high waves (James Redman); icing (U.S. Army). Center top: tornado (Mary Hurley). Bottom center: soil desiccation cracks (Brad Rippey).