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SECTION 5

U. S. AND WORLD SURFACE EXTREMES

5.1 United States Surface Extremes. Most NASA programs involving the launch and reentry of aerospace vehicles are conducted in the United States. This section provides the extremes of those atmospheric variables not included elsewhere in this document that are critical to such programs. Statistical data discussed in this section include air temperature, snowfall, hail, and atmospheric pressure. The second part of this section, World Surface Extremes, provides a more general discussion of atmospheric extremes on a global scale.

5.1.1 Environments Included:

(a) Air temperature, extreme maximum and minimum;

(b) Snowfall: snow loads, 24-h maximum and storm maximum;

(c) Hail, maximum size;

(d) Atmospheric pressure, extreme maximum and minimum.

Information is available for other extreme atmospheric parameters relative to the principal locations covered by this document by consulting the appropriate section in this document.

5.1.2 Source of Data. The extremes presented have been prepared using data from National Weather Service stations and published articles, such as reference 5.1. These extremes represent the highest or lowest extreme value measured at each station. The length of record varies from station to station, but most values represent more than 15 years of record. Where unusual geographical features in a local area affect an extreme value (such as the minimum temperature on a high mountain peak), it will not, in general, be shown on the maps presented unless a National Weather Service station is located there.

The extremes noted reflect measurements during the available period of record for essentially all meteorological parameters. Because this period of record covers only a few decades for most locations, it is obvious that there is a finite risk that the extreme values presented will be exceeded in future years. However, the values shown are considered appropriate as criteria guidelines for use in critical engineering design studies relative to probable occurrence of atmospheric extremes during expected operational lifetime.

5.1.3 Extreme Design Environments. The values of extreme maxima and minima in this section are for design guidelines and may or may not exactly reflect extrapolation (theoretical or otherwise) of actual measured values over the available period of record.

5.1.3.1 Air Temperature. The distribution, by state and location, of extreme maximum air temperatures in the United States is shown in figure 5.1, while figure 5.2 shows the extreme minimum temperature distribution. Given in Table 5.1 are the extreme U.S. temperatures (°F) together with their locations and dates of occurrence (Ref. 5.2). To convert to °C, use the formula: °C = 5/9 (°F–32). The maps (Figs. 5.3 and 5.4) from reference 5.3 show the mean temperature and standard deviations of the temperatures for January and July.

To estimate the temperature $\hat{T}$ that is less than or equal to a probability p (corresponding to the normal distribution), from figures 5.3 and 5.4, find from the appropriate figure, by interpolation as needed, the mean temperature $\overline{T}$ and the standard deviation S_T and substitute these in the equation

$$\hat{T} = \overline{T} + S_T y_S \; [°F] \; . \qquad (5.1)$$

Values of y_s for various normal probability levels are shown below:

Cold Temperatures (Fig. 5.3)		Hot Temperatures (Fig. 5.4)	
p	y_S	p	y_S
0.20	0.84	0.80	+0.84
0.10	–1.28	0.90	+1.28
0.05	–1.65	0.95	+1.65*
0.025	–1.96	0.975	+1.96
0.01	–2.33	0.99	+2.33

*The 95th percentile value is recommended for hot-day design ambient temperatures over runways for landing-takeoff performance calculation using figure 5.4; the 5th percentile is recommended for cold-day design.

5.1.3.2 Snowfall—Snow Load. The maps in figures 5.5 and 5.6 show the maximum depth of snow and the corresponding snow loads for the contiguous United States. Figure 5.5 shows the maximum depth for a 24-h period; figure 5.6 shows the maximum depth and the corresponding snow loads for a snow period. The storm total map shows the same snow depth as in the 24-h map in the southern low elevation areas of the United States since snow storms seldom exceed 24 h in these areas. The greatest 24-h snowfall was 1,930 mm (76 in) at Silver Lake, Colorado, on April 14–15, 1921. One storm gave 4,800 mm (189 in) at Mt. Shasta Ski Bowl, California, from February 13 to 19, 1959 (Ref. 5.4). The greatest snowfall in one calendar month is 9,906 mm (390 in) which occurred at Tamarack, California, during January of 1911.

The terrain combined with the general movement of weather patterns has a great effect on the amount of fall, accumulation, and melting of the snow. Also, the length of a single storm varies from various areas. In some areas in mountain regions, much greater amounts of snowfall have been recorded than shown on the maps. Also, the snow in these areas may remain for the entire winter. For example, in a small valley near Soda Springs, CA, a seasonal snow accumulation of 7.9 m (26 ft) with a density of about 0.35 g/cm^3 was recorded. This gives a snow load of 2,772 kg/m^2 (567.7 lb/ft^2). Such a snow pack at Soda Springs is the greatest on record in the United States and was nearly double the previous records in the same area. A study of the maximum snow loads in the Wasatch Mountains of Utah showed that for a 100-year return period at 2,740 m (9,000 ft) altitude, a snow load of 1,220 kg/m^2 (250 lb/ft^2) could be expected (Ref. 5.5).

Snow characteristics and loading for particular sites are given in subsection 7.4.

5.1.3.3 Hail. The distribution of maximum-sized hailstones in the United States is shown in figure 5.7. The sizes are for single hailstones and not conglomerates of several hailstones frozen together. The largest officially recorded hailstone in the United States weighed 757 g (1.67 lb). It fell September 3, 1970, at Coffeyville, KS (Ref. 5.4). Subsection 7.5 presents further information concerning hail characteristics and climatology.

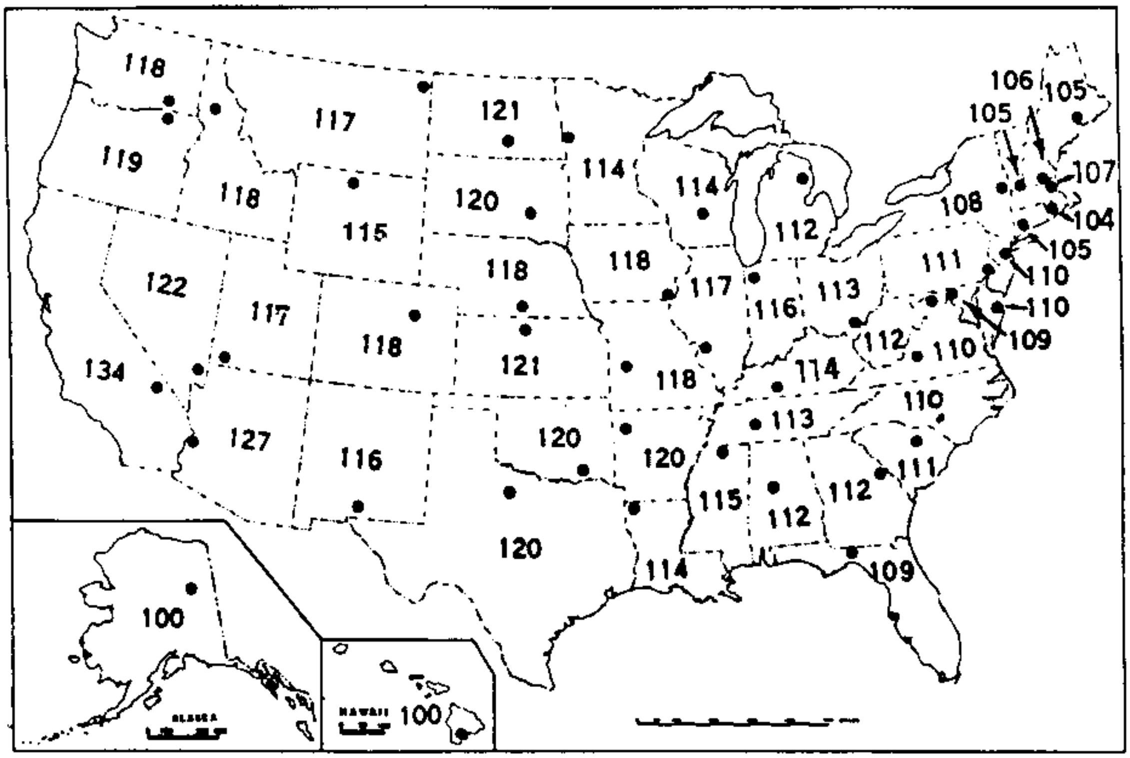

FIGURE 5.1 Highest Temperatures (°F) of Record and Locations, by States.

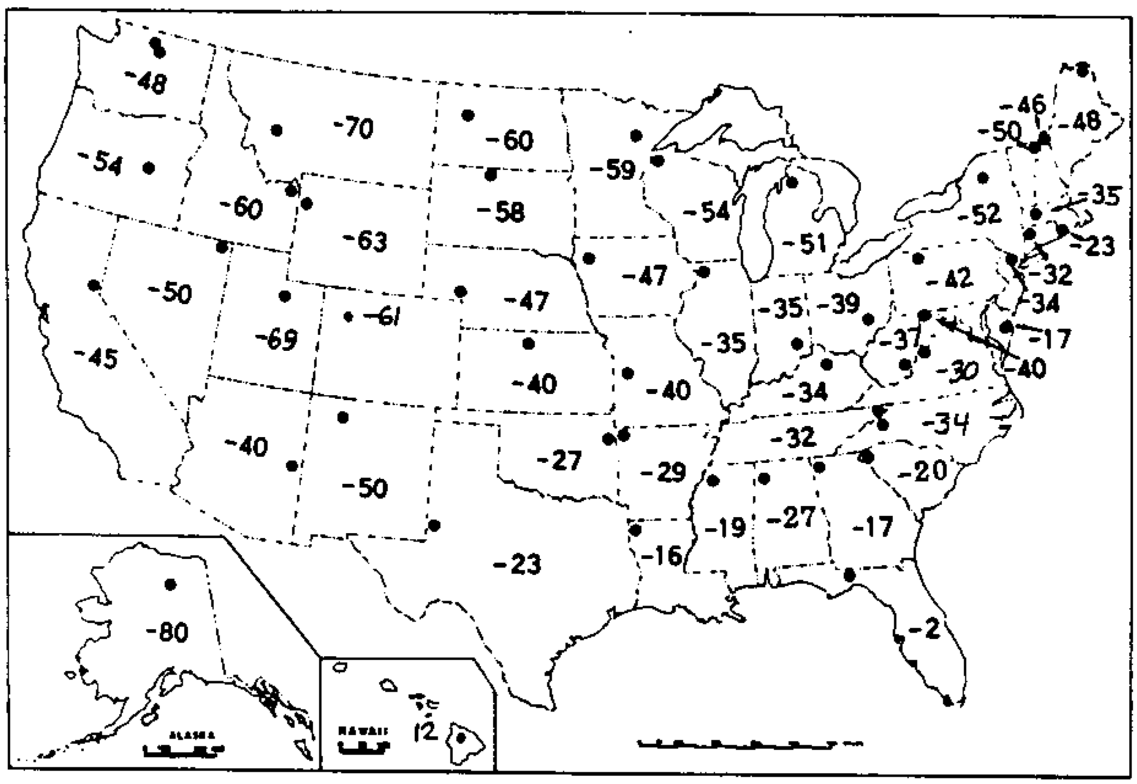

FIGURE 5.2 Lowest Temperatures (°F) of Record and Locations, by States.

Table 5.1 Extremes of temperature and sea level pressure for the United States (ref. 5.1).

Temperature (°C (°F))		Location	Date	Sea-Level Pressure (N/m^2 (mb) (in))	Location	Date
High				High		
Contiguous United States	57 (134)	Greenland Ranch, CA	July 10, 1913	106,400 (1,064.0) (31.42)	Miles City, MT	Dec. 24, 1983
Hawaii	38 (100)	Pahala	April 27, 1931	102,670 (1,026.7) (30.32)	Honolulu	Feb. 10, 1919
Alaska	38 (100)	Fort Yukon	June 27, 1915	107,860 (1,078.6) (31.85)	Northway	Jan. 31, 1989
Low				Low		
Contiguous United States	-57 (−70)	Rogers Pass, MT	Jan. 20, 1954	95,490 (954.9) (28.20)	Canton, NY Block Island, RI	Jan. 3, 1913 Mar. 7, 1932
U.S. (Hurricane)	—	—	—	89,230 (892.3) (26.35)	Matecumbe Key, FL	Sept. 2, 1935
Hawaii	−11 (12)	Mauna Kea Observatory	May 17, 1979	97,200 (972.0) (28.70)	Barking Sands	Nov. 23, 1982
Alaska	−62 (−80)	Prospect Creek	Jan. 23, 1971	92,500 (925.0) (27.31)	Dutch Harbor	Oct. 25, 1977

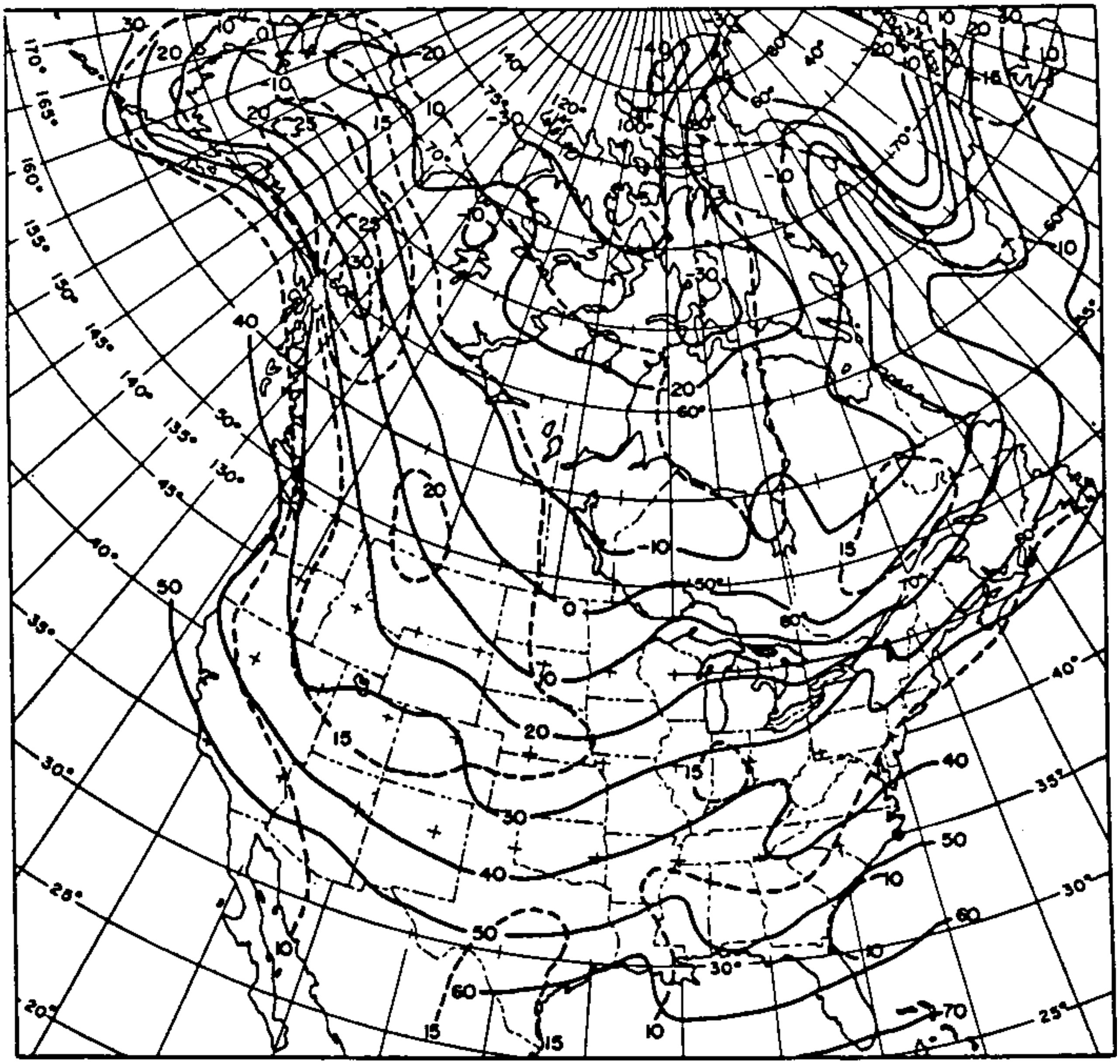

FIGURE 5.3 <u>Isotherms of January Hourly Surface Temperatures. (Approximate Mean Values (°F) are Shown by Solid Lines, Standard Deviations (°F) By Broken Lines. The Approximations were Made to Give Best Estimates of Lower 1- to 20-Percentile Values of Temperature by Normal Distribution (Ref. 5.3)</u>.

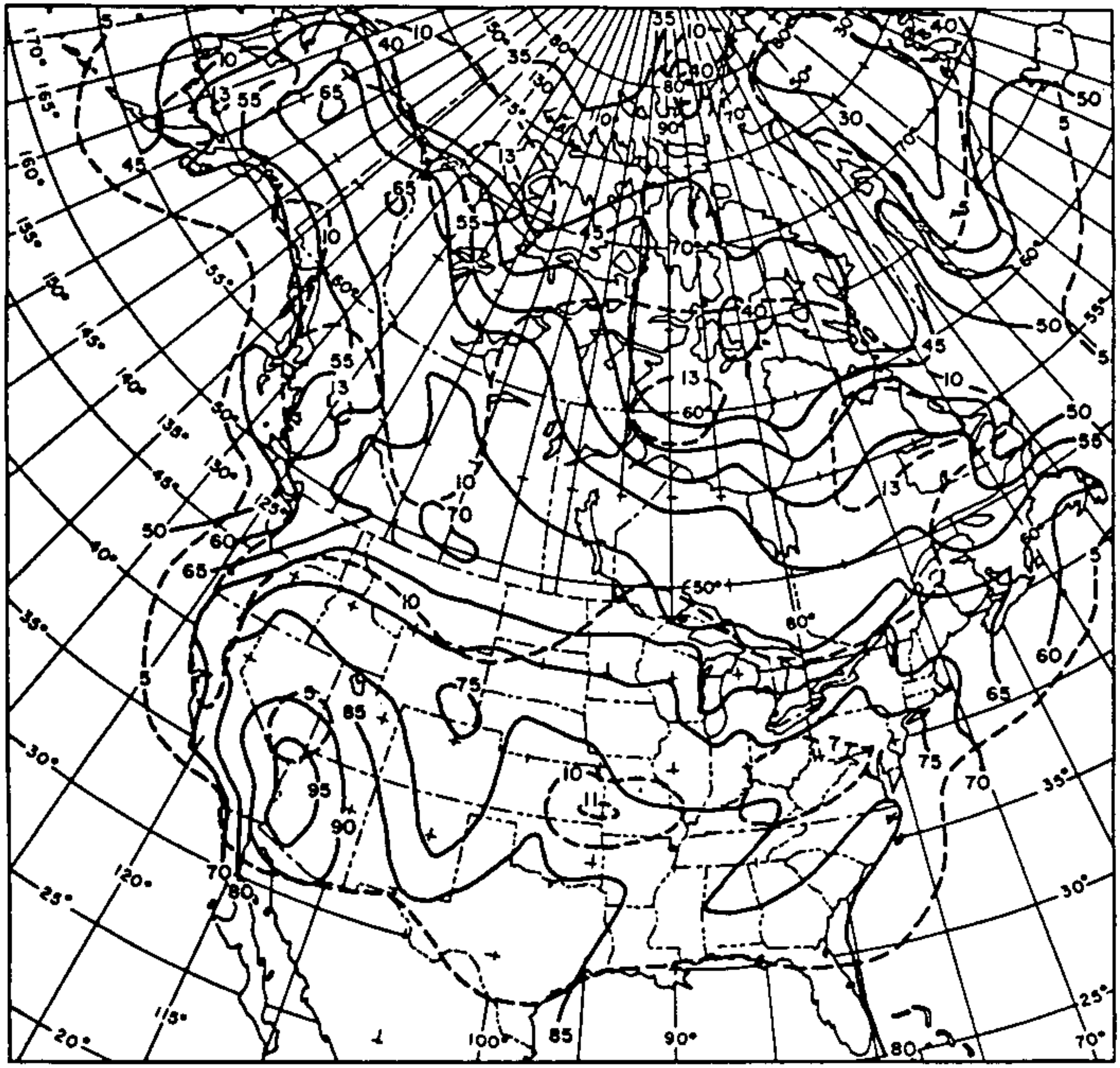

FIGURE 5.4 Isotherms of July Hourly Surface Temperatures. (Approximate Mean Values (°F) are Shown by Solid Lines, Standard Deviations (°F) By Broken Lines. The Approximations were Made to Yield the Best Estimates of Upper 80- to 99-Percentile Values by Normal Distribution (Ref. 5.3).

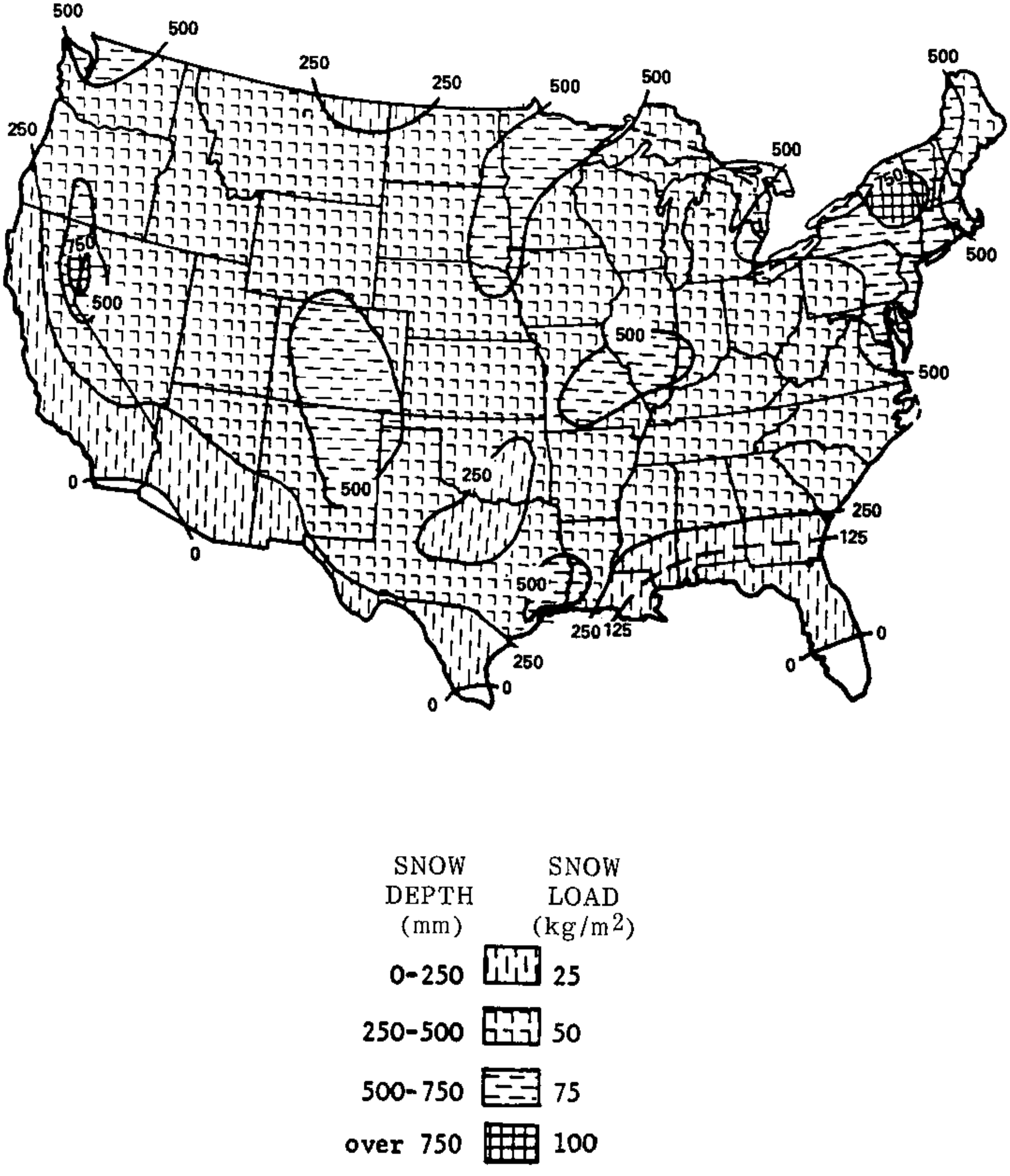

FIGURE 5.5 Extreme 24-h Maximum Snowfall (mm) and Maximum Snow Load.

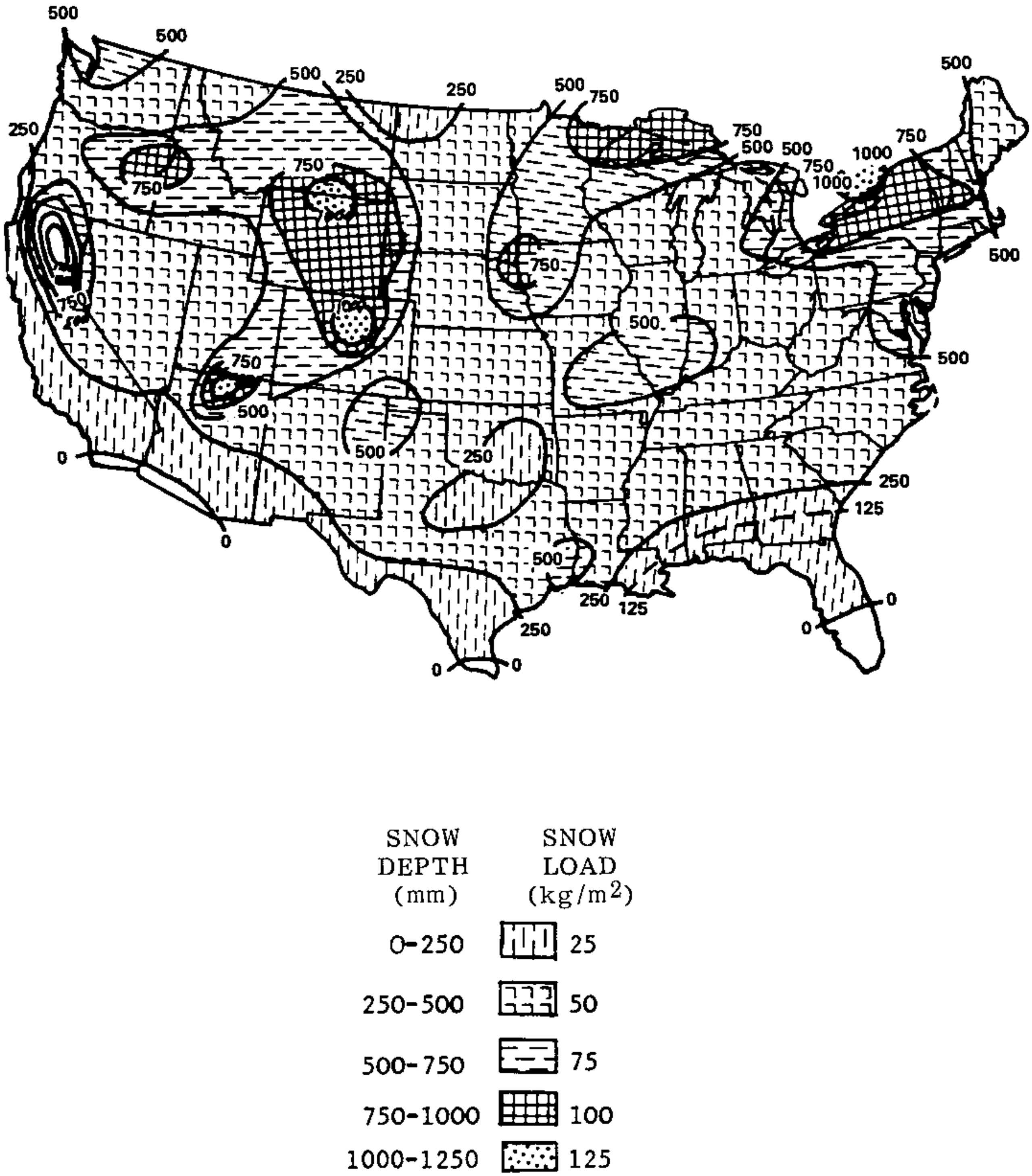

FIGURE 5.6 Extreme Storm Maximum Snowfall (mm) and Maximum Snow Load.

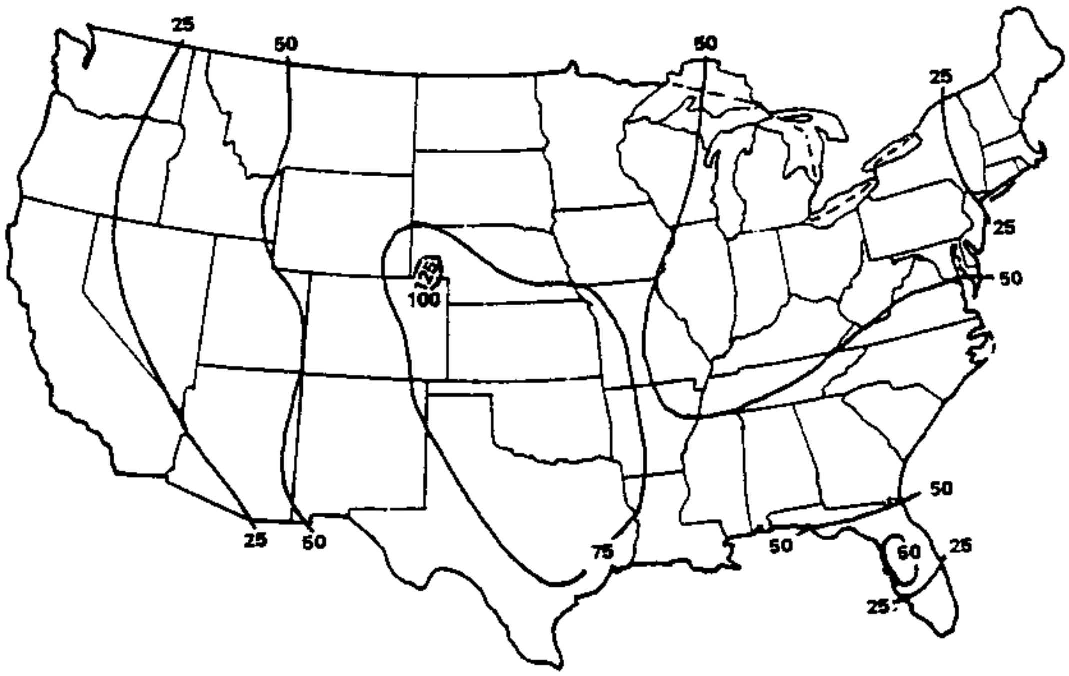

FIGURE 5.7 Extreme Maximum Hailstone Diameters (mm).

5.1.3.4 Atmospheric Pressure. Atmospheric pressure extremes normally given in the literature are given as the pressure which would have occurred if the station were at sea level. The surface weather map published by the United States National Weather Service uses sea-level pressures for the pressure values to assist in map analysis and forecasting. These sea-level pressure values are obtained from the station pressures by use of the hydrostatic equation:

$$-dP = \rho g dZ \quad (5.2)$$

where

dP = pressure difference

ρ = density

g = gravity

dZ = altitude difference.

These sea level data are valid only for design purposes at locations with elevations near sea level. As an example, when the former highest officially reported sea level pressure observed in the United States of 106,330 N/m^2 (1,063.3 mb) occurred at Helena, MT (Ref. 5.6), the actual station pressure was approximately 92,100 N/m^2 (921 mb) because the station is 1,187 m (3,893 ft) above mean sea level.

Figures 5.8 and 5.9 show the general distribution of extreme maximum and minimum station pressures in the United States. Because of the direct relationship between pressure and station elevation, figures 5.10 through 5.13 should be used with the station elevation to obtain the extreme maximum and minimum pressure values for any location in the United States. Similar maps and graphs in U.S. Customary Units are given in Reference 5.7.

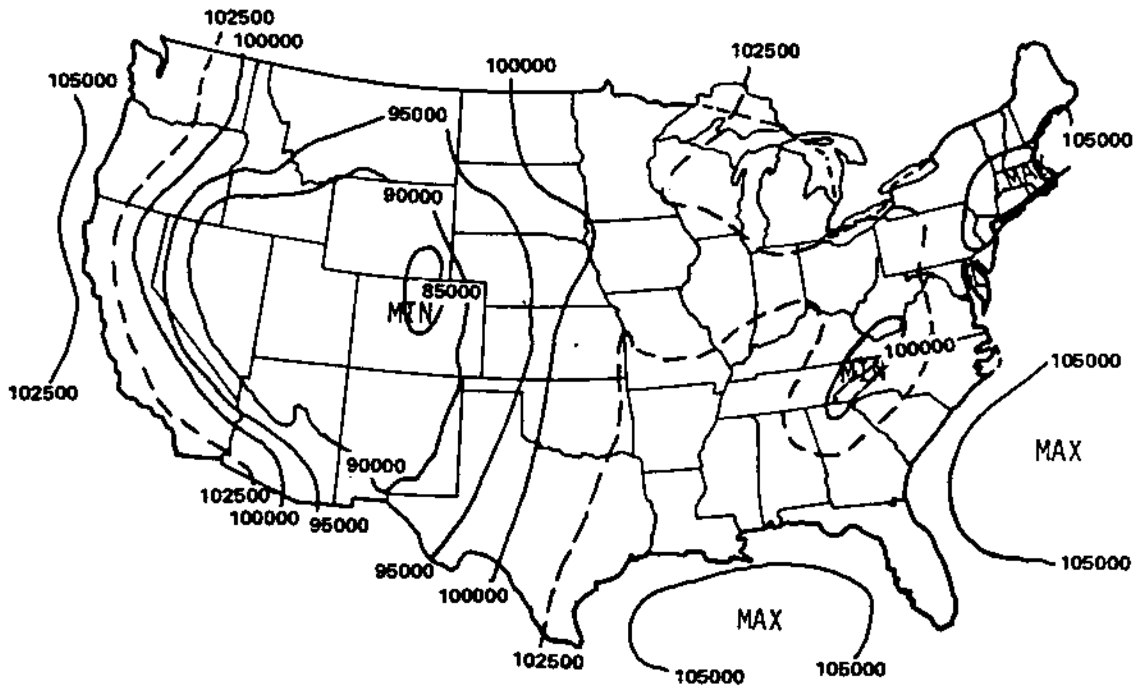

FIGURE 5.8 Maximum Absolute Station Pressure (N/m^2).

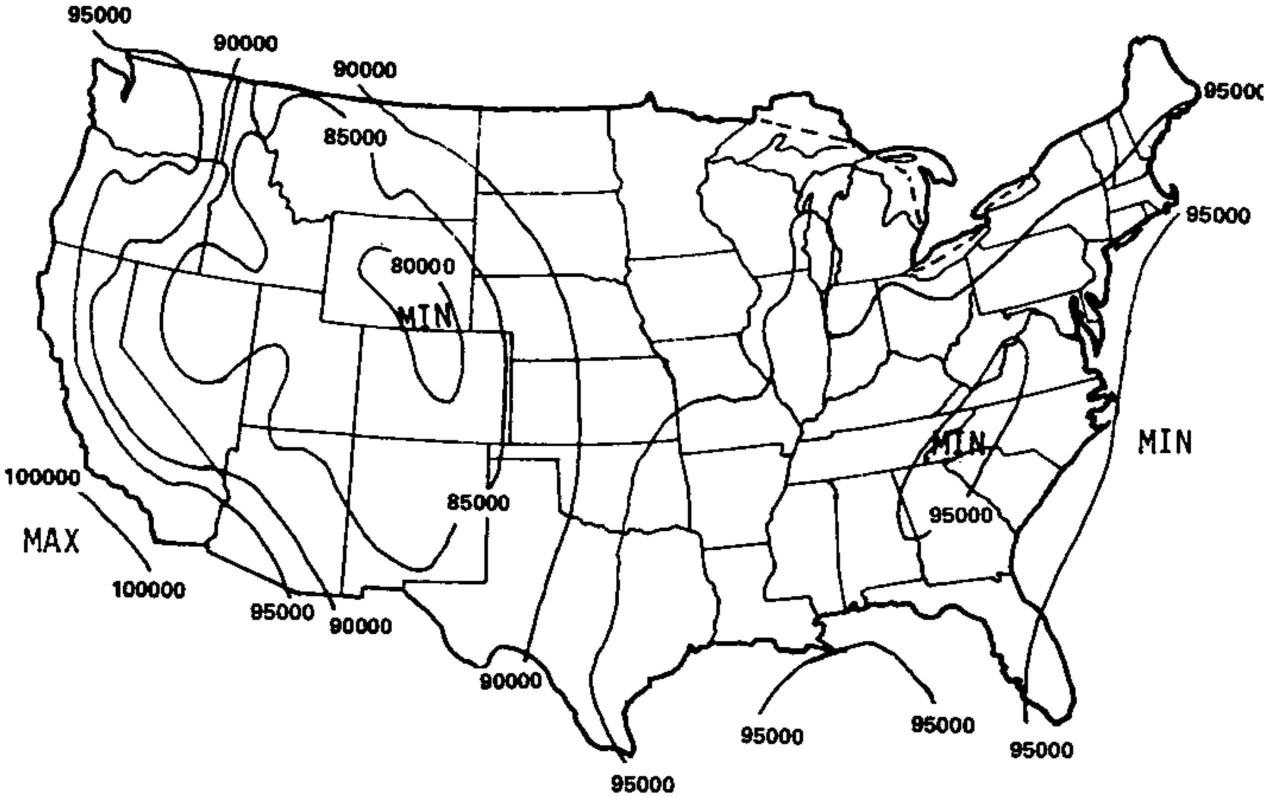

FIGURE 5.9 Maximum Absolute Station Pressure (N/m^2)

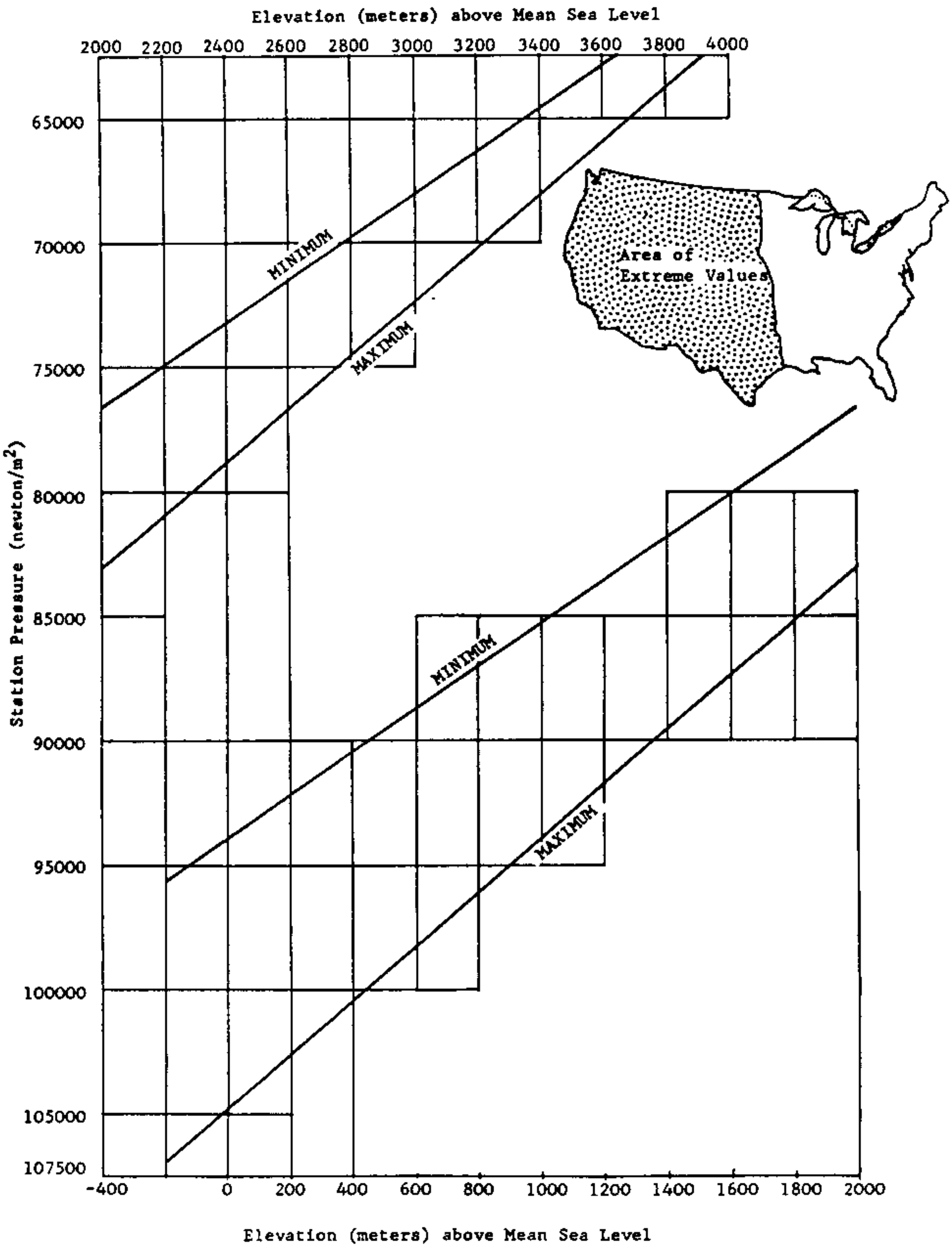

FIGURE 5.10 Extreme Pressure Values Versus Elevation for Western United States.

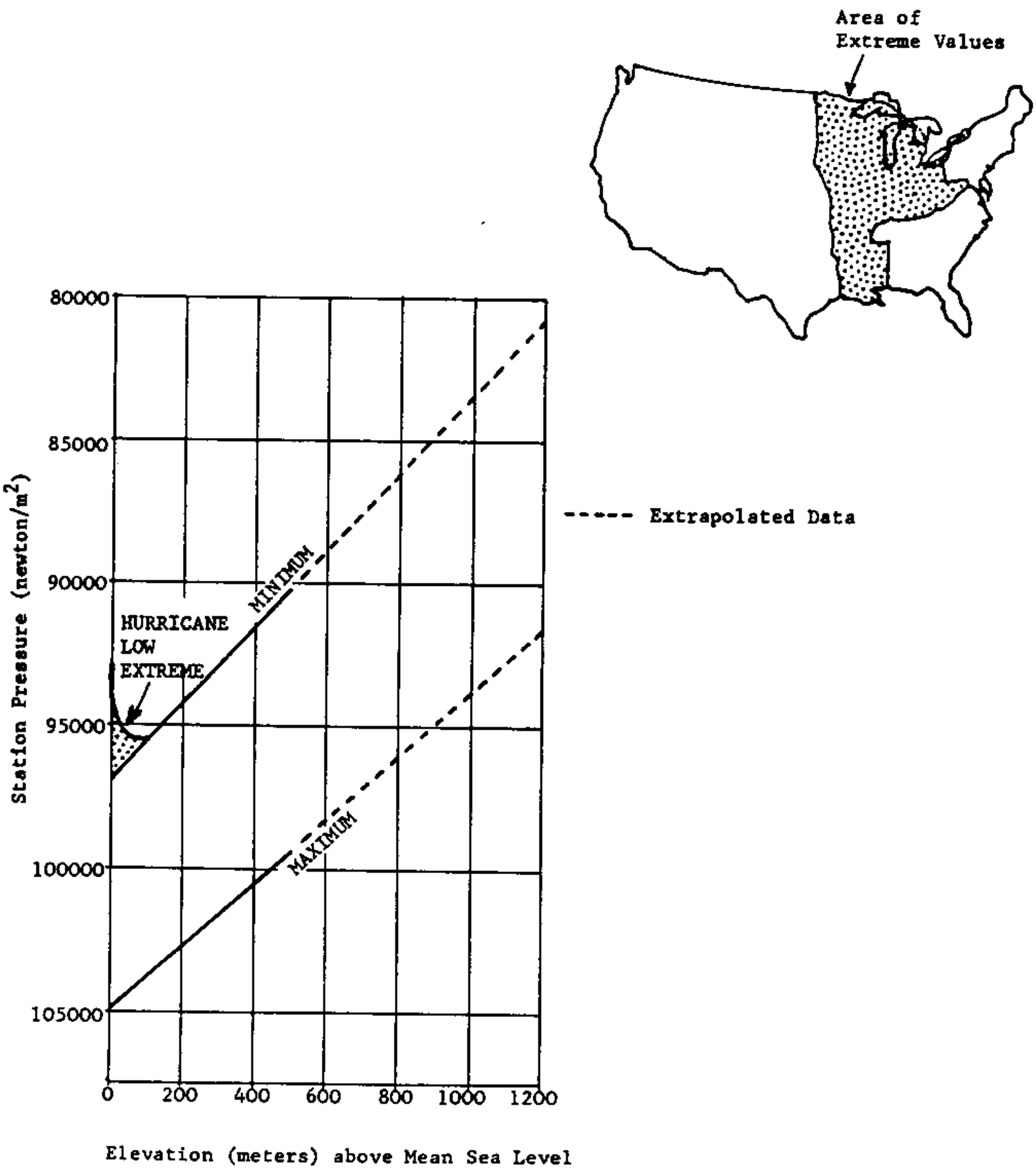

FIGURE 5-11 Extreme Pressure Values Versus Elevation for Central United States.

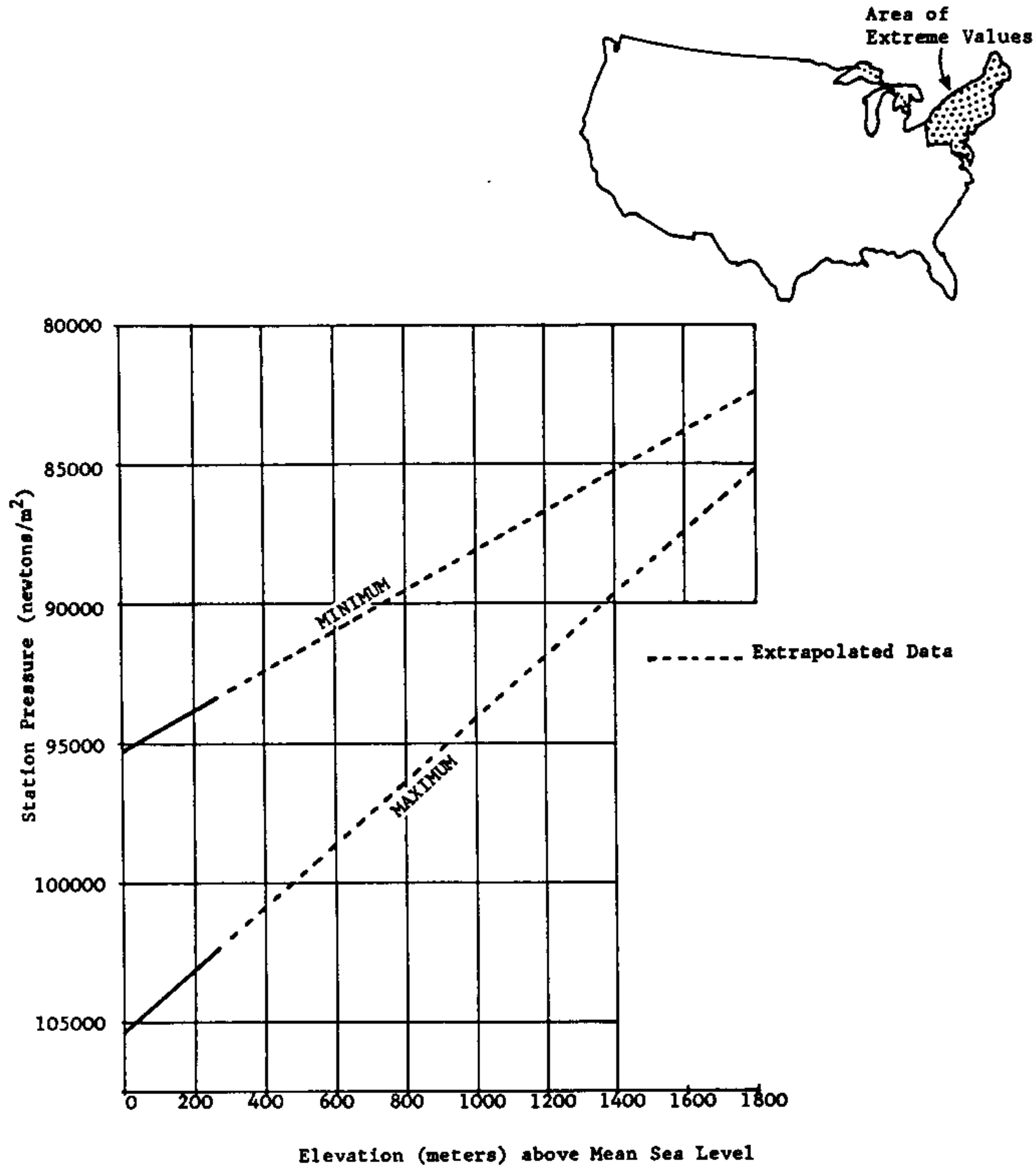

FIGURE 5.12 Extreme Pressure Values Versus Elevation for Northeastern United States.

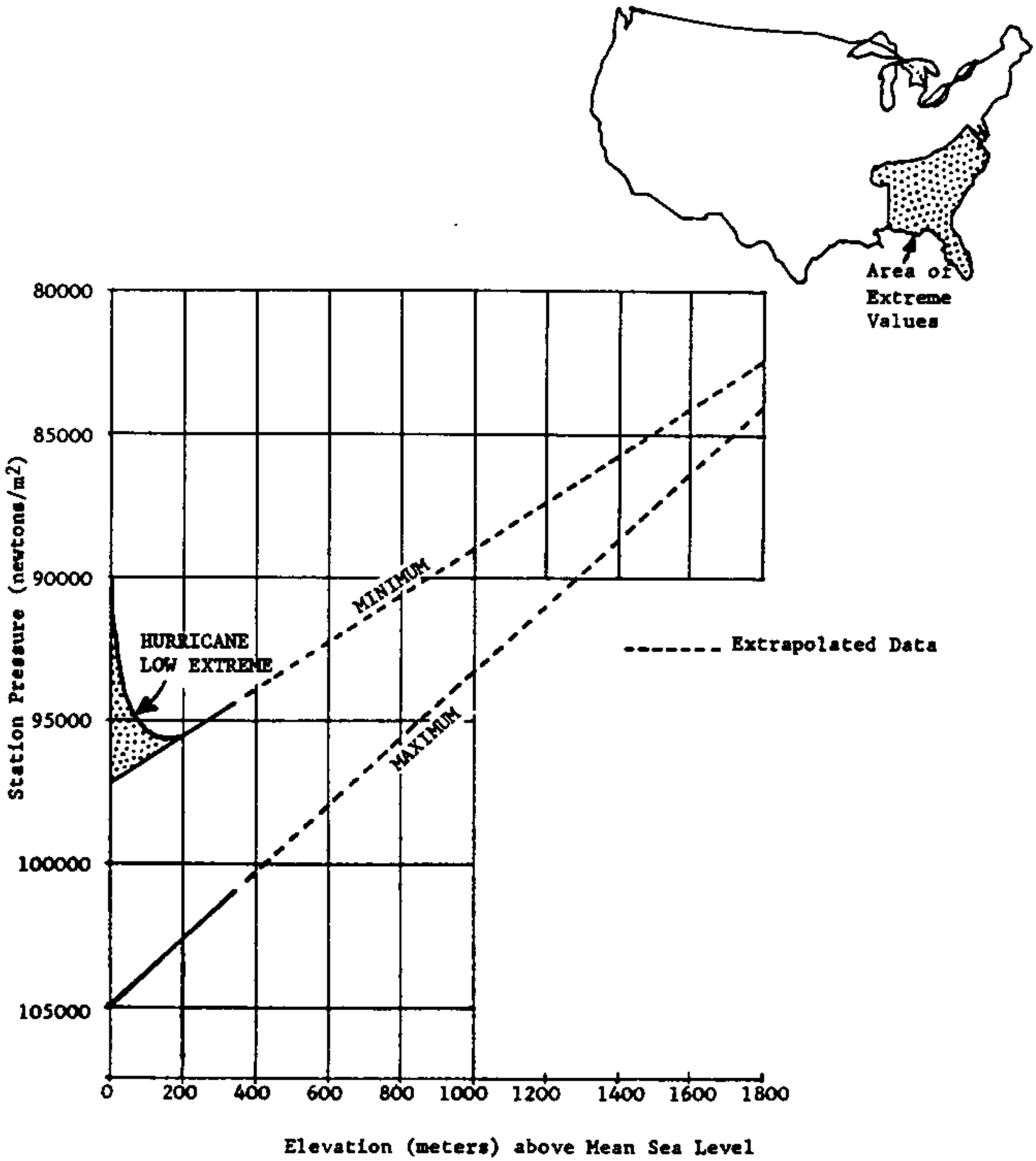

FIGURE 5.13 Extreme Pressure Values Versus Elevation for Southeastern United States.

Extreme temperatures and sea-level pressures for the United States are given in Table 5.1 (Refs. 5.2, 5.6, 5.8, and 5.9). Reference 5.9 also contains surface atmosphere extreme criteria for vehicle launch and transportation areas.

5.2 World Surface Extremes. This section provides world extreme values for temperature, dew point, precipitation, pressure, wind speed, etc.

5.2.1 Sources of Data. A great amount of atmospheric data has been collected throughout the world. Various agencies have collected data in a form that may be used for statistical studies. “World Weather Records” (Ref. 5.10), compiled by the National Oceanic and Atmospheric Administration, provides another summary of mean values of meteorological data. A publication entitled, “Weather Extremes” (Ref. 5.1) is extremely valuable for its listing of extreme values of surface meteorological parameters.

The Earth Sciences Laboratory of the U.S. Army Topographic Laboratories at Fort Belvoir, VA, has collected worldwide data on meteorological extremes which are published in AR 70-38 (Ref. 5.11). For AR 70-38, the Earth Sciences Laboratory prepared world maps that show worldwide absolute maximum and absolute minimum temperatures. These maps are reproduced in this section in Figures 5.14 and 5.15.

5.2.2 World Extremes Over Continents. To present all the geographic extremes properly, many large maps similar to figures 5.14 and 5.15 would be required; therefore, only worldwide extremes of each parameter will be discussed, and available references on each parameter will be given. Individual geographic extremes will be mentioned when pertinent.

5.2.2.1 Temperature. Absolute maximum and absolute minimum world temperature extremes are shown in figures 5.14 and 5.15. Some geographical extreme air temperatures of record are given in Table 5.2.

Temperatures of the ground are normally hotter than the air temperatures during the daytime. In Loango, Congo, Africa, temperatures of the ground as high as 82 °C (180 °F) have been measured. At Stuart, Australia, the sand has reached temperatures so hot that matches dropped into it burst into flame.

In the design of equipment for worldwide ground environment operations, MIL-STD-210C (Ref. 5.12) now uses extreme temperature values of 58 °C (136 °F) for a hot temperature and –68 °C (–90 °F) for a cold temperature (excluding Antarctic extremes).

Long-term extremes of high temperature that would be expected to occur at least once during a 10 to 60 year period, in the hottest part of the world, are given in Table 5.3 (Ref. 5.12). These extreme temperature values were derived from a statistical analysis of 57 years of temperature data from Death Valley, CA, which is considered representative of conditions in the Sahara Desert. Such temperatures persist for 1 or 2 hours during the day.

Long-term extremes of low temperature that would be expected to occur at least once during a 10 to 60 year period, in the coldest area of the world, are presented in Table 5.4 (Ref. 5.12). These values were derived from a statistical analysis of 16 years of Ojmjakon, Russia, data. The extreme low temperatures will persist for longer periods since they occur during polar darkness. (Also see references 5.13 and 5.14 regarding probabilities of surface temperature extremes.)

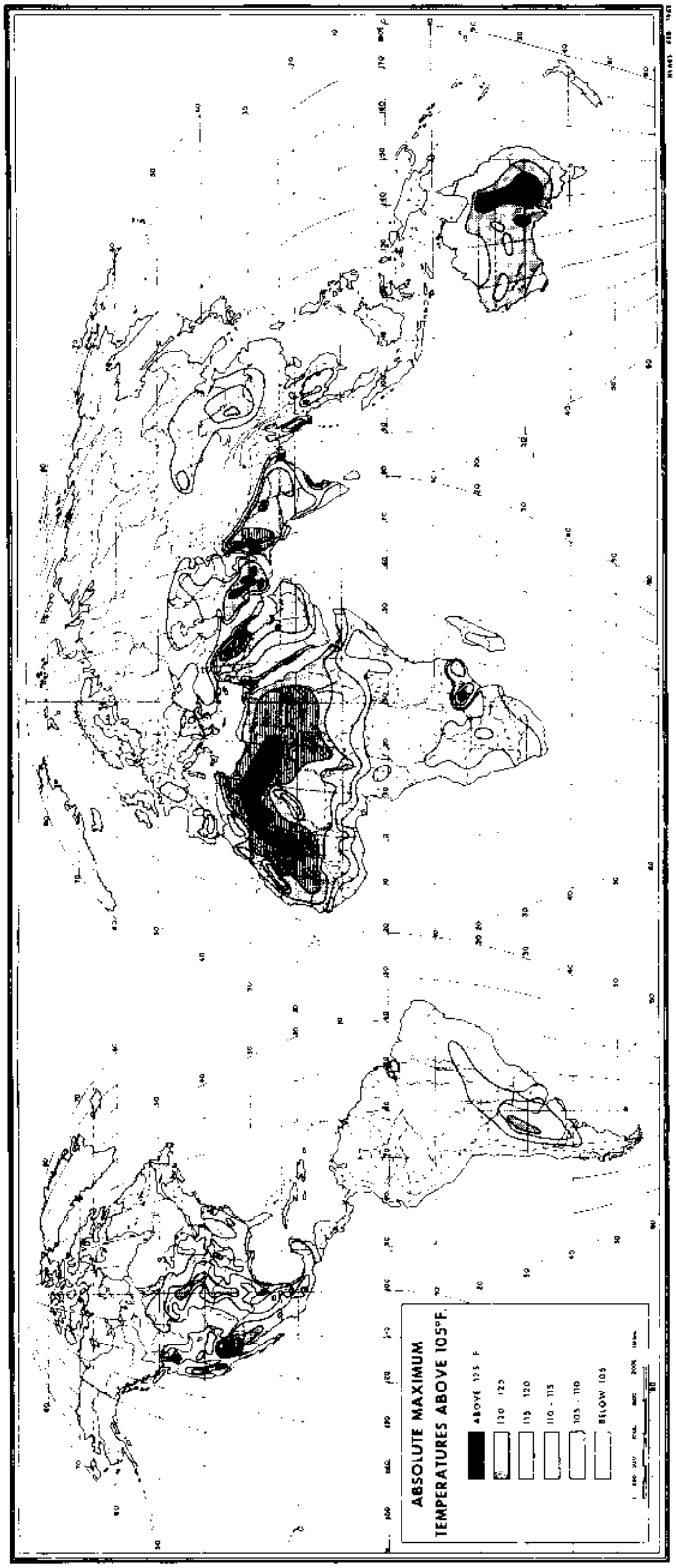

Figure 5.14 Worldwide geographic absolute maximum temperatures above 41 °C (105 °F) (ref. 5.11).

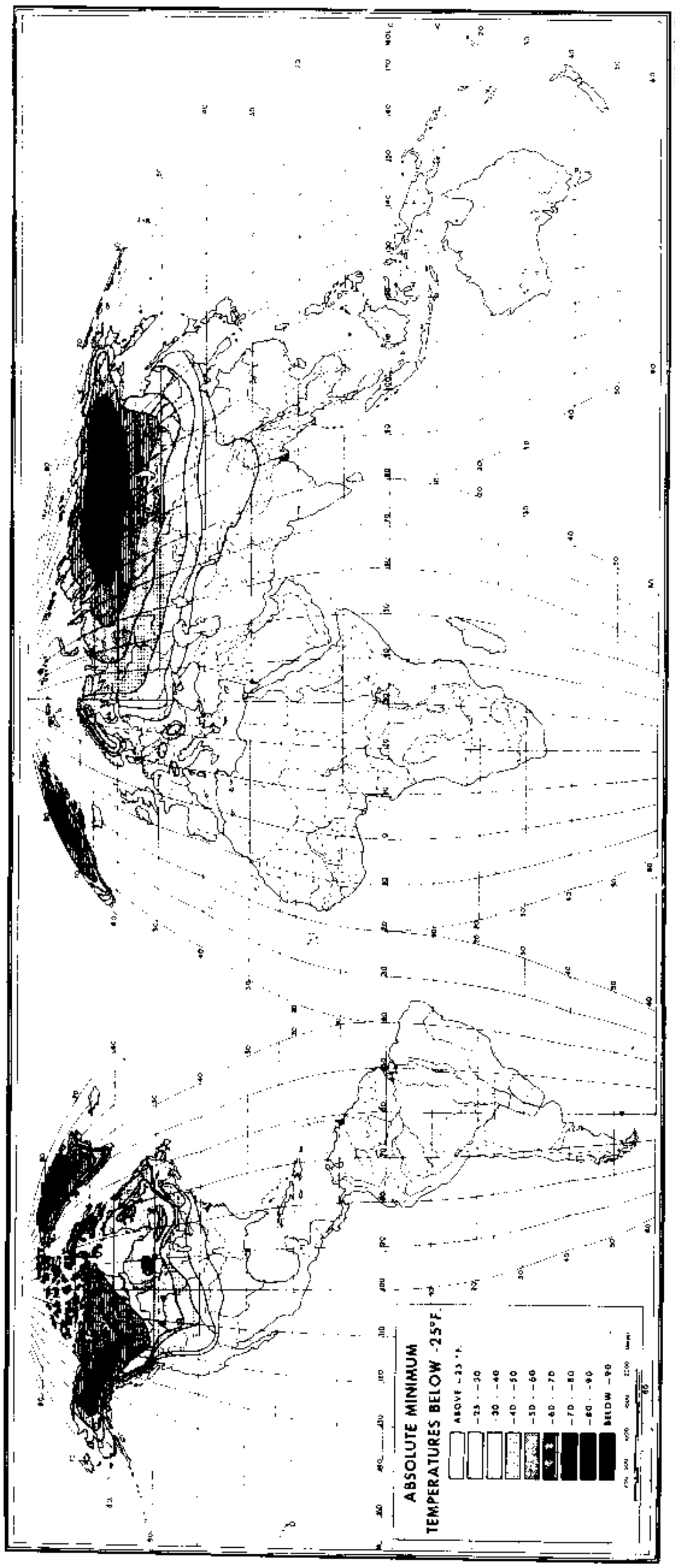

Figure 5.15 Worldwide geographic absolute minimum temperatures below −32 °C (−25 °F) (ref. 5.11).

TABLE 5.2 Extreme Surface Air Temperatures of Record.

Location	Air Temperature of Record (°C (°F))
Salah, Africa	48 (118), mean daily maximum for 45 days 53 (127), absolute maximum
El Azizia, Libya*	58 (136), absolute maximum
Tirat Tsvi, Israel	54 (129), absolute maximum
Death Valley, California*	57 (134), absolute maximum for U.S.
Cloncurry Queensland, Australia	53 (128), absolute maximum
Vostok, Antarctica	–89 (–129), absolute minimum
Ojmjakon, Siberia	–68 (–90), absolute minimum
Northice, Greenland	–66 (–87), absolute minimum
Prospect Creek Camp, Alaska	–62 (–80), absolute minimum
Rogers Pass, Montana	–57 (–70), absolute minimum for U.S.
Snag, Yukon Territory, Canada	–63 (–81), absolute minimum for North America

*The validity of these temperatures has been questioned; see reference 5.4.

TABLE 5.3 Extreme High Surface Temperatures[1] With Relation to Long-Term Exposure (Ref. 5.12).

Temperatures (°C (°F))		
Exposure Period in Years		
10	30	60
53 (128)	54 (130)	55 (131)

[1] Based on Death Valley, CA, data.

TABLE 5.4 Extreme Low Surface Temperatures[2] with Relation to Long-Term Exposure (5.12).

Temperatures (°C (°F))		
Exposure Period in Years		
10	30	60
–65 (–86)	–67 (–89)	–69 (–92)

[2] Based on Ojmjakon, Russia, data. Temperatures in Antactica were not considered in the study.

5.2.2.2 Dew Point. High dew points associated with high temperatures near large bodies of water can be detrimental to equipment and make living conditions very uncomfortable. Some examples of this atmospheric condition are:

a. The northern portion of the Arabian Sea in April and May, to 29 °C (85 °F) dew point.

b. The Red Sea in July, to 32 °C (89 °F) dew point.

c. The Caribbean Sea (includes the western end of Cuba and the Yucatan Peninsula, Mexico) in July, to 27 °C (81 °F) dew point.

d. The northern portion of the Gulf of California, to 30 °C (86 °F) dew point.

e. The Persian Gulf (Sharjah, Arabia) in July, to 34 °C (93 °F) dew point.

A discussion on atmospheric humidity is presented in section 6.

5.2.2.3 Precipitation. The worldwide distribution of precipitation is extremely variable; some areas do not receive rain for years, while others receive torrential rain many months of the year. Precipitation is also seasonal; for example, Cherrapunji, India, with its world record total of 2,647 cm (1,042 in) of precipitation in a year, has a mean monthly precipitation of less than 2.54 cm (1 in) in December and January. Arica, Chile, had no rain between October 1903 through December 1917. The longest dry period for a United States location was 767 days for Bagdad, CA (October 3, 1912, to November 8, 1914).

The heaviest precipitation for greater than 12 hours usually occurs in monsoon weather. High rates of rainfall for short periods (under 12 hours) usually occur during thunderstorms and over much smaller areas than the monsoon rain. Some world records for various periods of rainfall are given in Table 5.5 (Ref. 5.4).

For in-depth information on precipitation, see section 7.

TABLE 5.5 World Rainfall Records.

Station	Time Period	Amount (in) (cm)
Unionville, Maryland	1 min	1.23 (3.1)
Plum Point, Jamaica	15 min	8.0 (20)
Holt, Missouri	60 min	12.0 (31)
D'Hanis, Texas	3 h	20.0 (51)
Foc-Foc, LaReunion Island	12 h	45.0 (114)
Foc-Foc, LaReunion Island	1 day	72.0 (183)
Cherrapunji, India	30 days	366.14 (930)
Cherrapunji, India	1 year	1,041.73 (2,647)
Highest average annual precipitation: World: 460 in (1,168 cm), Mt. Waialeale, Kauai, Hawaii Contiguous U.S.: 144 in (366 cm), Wynoochee, Washington Lowest average annual precipitation: World: 0.03 in (0.08 cm), Arica, Chile U.S.: 1.63 in (4.4 cm), Death Valley, California		

5.2.2.4 Pressure. Surface atmospheric pressure extremes for use in design must be derived from the measured station pressures, not from the calculated sea level pressures that are usually published.

Station pressures have great variability between stations because of the difference in altitude of the stations. The lowest station pressures occur at the highest altitudes. The highest station pressures occur at either the lowest elevation stations (below sea level), or in the arctic regions in cold air masses at or near sea level.

Court (Ref. 5.15) has published an interesting discussion on world pressure extremes. Some typical extreme high and low pressure values are given in Table 5.6 (Refs. 5.1 and 5.4).

Surface and aloft pressure values are given in subsections 3.3.2 and 3.4.2, respectively.

TABLE 5.6 Extreme Pressure Values for Selected Areas.

Station	Elevation Above Sea Level (m (ft))	Sea-Level Pressure (mb)	
		Lowest	Highest
Lahasa, Tibet	3,685 (12,090)	645*	652*
Sedom, Israel	–389 (–1,275)	—	1,081.8
Portland, Maine	19 (61)	—	1,056
Northway, Alaska	NA	—	1,078.6
Qutdligssat, Greenland	3 (10)	—	1,063.4
In the Typhoon Tip, 16°44' N., 137°46' E., October 12, 1979	0	870**	—
Agata, Siberia	261 (855)	—	1,083.8

*Monthly means.
**Lowest sea level pressure of record.

5.2.2.5 Ground Wind. World extreme surface winds have occurred in several types of meteorological conditions: tornadoes, hurricanes or typhoons, mistral winds, and Santa Ana winds. In design, each type of wind needs special consideration. For example, the probability of tornado winds is very low compared with the probability of mistral winds, which may persist for days. The world's highest recorded peak wind speed gust of 103 m/s (231 mph) occurred at Mt. Washington, New Hampshire, on April 12, 1934. The highest 5-min average wind speed of 84 m/s (188 mph) also occurred at Mt. Washington (5.1). Section 2 presents a complete discussion of winds.

5.2.2.5.1 Tornadoes and Whirlwinds. Tornadoes are rapidly revolving circulations (vortices) normally associated with a cold front squall line or with warm, humid, unsettled weather; they usually occur in conjunction with a severe thunderstorm. Although a tornado is extremely destructive, the average tornado path is only about 400 m (1/4 mi) wide and seldom more than 26 km (16 mi) long, but there have been a few instances in which tornadoes have caused heavy destruction along paths more than 1.6 km (1 mi) wide and 483 km (300 mi) long. The probability of any one point being in a tornado path is very small; therefore, design of structures to withstand tornadoes is usually not considered except for special situations. Velocities have been estimated to exceed 134 m/s (260 knots or 300 mi/h) in tornadoes. See section 12 for further information regarding tornadoes.

A whirlwind is a small-scale, rotating column of air. The most extreme whirlwind is a tornado. Dust devils and waterspouts are the smaller and far less intense whirlwinds. The largest Florida Keys water spouts can produce tangential wind speeds up to 90 m/s (200 mi/h); while large, mature dust devils have yielded wind velocities up to 40 m/s (90 mi/h).

5.2.2.5.2 Hurricanes (Typhoons). Hurricanes (also called typhoons, willy-willies, tropical cyclones, and many other local names) are large storms of considerable intensity which originate in tropical regions between the equator and 25° latitude. Hurricanes are always accompanied by heavy rain. Since the hurricanes of the West Indies are as intense as others throughout the world, design winds based upon these hurricanes would be representative for any geographical area.

Section 2 gives hurricane design winds for the area of Kennedy Space Center, FL. Although the highest winds recorded in a hurricane in the area of KSC, FL, were lower than winds from thunderstorms in the

same area, the probability still exists that much higher winds could result from hurricanes in the vicinity of KSC.
For extremes applicable to equipment, Table 5.7 from a study of 19 years of wind data for Naha, Okinawa (in the Pacific typhoon belt) (5.12), is representative of all hurricane areas of the world. The maximum gust velocity observed in the United States is 89.4 m/s (174 knots or 200 mi/h), recorded during hurricane Camille. Elsewhere, typhoon winds have been recorded at speeds up to 100 m/s
(195 knots or 224 mi/h) (Ref. 5.4).

See section 12 for further information regarding hurricanes.

5.2.2.5.3 Mistral Winds. The mistral wind is a strong polar current between a large anticyclone and a low pressure center. These winds frequently have a temperature below freezing. The mistral of the Gulf of Lions and the Rhone Valley, France, is the best known of these winds. Although winds of 37 m/s (83 mph) have been recorded in the area of Marseilles, France, much higher winds have occurred to the west of Marseilles in the more open terrain, where even railway trains have been blown over. Mistrals blow in the Rhone Valley for about 100 days a year.

5.2.2.5.4 Santa Ana Winds. In contrast to the mistrals, the Santa Ana winds, which occur in southern California west of the coast range of mountains, are hot and dry and have speed up to 21 m/s (41 knots). Similar winds, called Fohn winds, occur in the Swiss Alps and in the Andes, but, because of the local topography, they have lower speeds. The destructiveness of these winds is not from their speeds, but from their high temperatures and dryness, which can do considerable damage to blooming trees, crops, exposed equipment and instruments that may be sensitive to prolonged heat and dryness.

TABLE 5.7 Extreme Winds in Hurricane (Typhoon) Areas with Relation to Risk and Desired Lifetime (3.1 m Reference Height).

Extreme Wind Speeds (m s^{-1})*†				
Planned Lifetime (years)				
Risk (%)	2	5	10	25
10	*69 †61	79 72	86 80	97 91

*Based on 2-s gusts (annual extreme)
†Based on 1-min steady wind associated with the 2-s gust

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