ATTACHMENT 1

TO

NSD920243

COOPER NUCLEAR STATION

NRC DOCKET NO. 50-298, DPR-46

N131-1189

Nebraska Public Power District

DESIGN CALCULATIONS COVER SHEET

Title: Review of ENERCON Calc. NPP1-SBO-009	Calculation No. 92-023
	Supersedes Calc. No. 89-1924
System/Structure: EE	Task Identification No. NA
Component: NA	Design Change No. NA
Classification: ☒ Essential	Discipline: Electrical
☐ Non-Essential	*ASME Stress reports shall be approved by Registered P.E.

NPPD Generated Calculation		Non NPPD Generated Calculation	
Prepared By	Date	Prepared By ENERCON (Companies Name)	Date 1-7-92
Checked By	Date	NPPD Reviewed By J. Hockaday	Date 2-21-92
Design Verification By	Date	NPPD Approval [signature]	Date 2-24-92
Approved By	Date		

Calc. Description:

Utilizes existing weather data taken at the CNS site and from the National Severe Storm Forecast Center (NSSFC) to determine the SW and ESW Groups for CNS and provide justification that the NUMARC 87-00 values are not applicable to CNS.

Design Basis or References:

1. USAR Vol I, II.8.0
2. TECH. SPECS. NA

Attachments:

A. NPP1-SBO-009 w/Att.

B.

Rev. No.	Revision Description	Prepared By/Date	Checked or Reviewed By/Date (Circle One)	Design Verification/Date	Approved By/Date

NON-NPPD GENERATED CALCULATION:

PREPARED BY: ENERCON DATE: 1-7-92

REVIEWED BY: J. Hackney DATE: 2-21-92

NEDC 92-023 "REVIEW OF ENERCON CALCULATION NPP1-SBO-009, REV. 0"

A. PURPOSE

This NEDC utilizes existing weather data taken at the CNS site and from the National Severe Storm Forecast Center (NSSFC) to determine the SW and ESW groups for CNS and provide justification that the NUMARC values 87-00 values are not applicable to CNS.

B. REQUIREMENTS

1) Court, Arnold, "Some New Statistical Techniques in Geophysics", Statistical Laboratory, University of California at Berkeley, circa 1951. This is listed as Attachment 1 to this NEDC.

2) Simiu, Emil, and Robert H. Scanlan, Excerpts from Wind Effects on Structures, Second Edition, John Wiley & Sons, New York, 1986. This is listed as Attachment 2 to this NEDC.

3) Cooper Nuclear Station Site Specific Wind Speed Data. This is listed as Attachment 3 to this NEDC.

4) Variation of Wind Speed with Elevation (Attachment 4 to this NEDC).

5) Summary of Probability Plot Correlation Coefficient (PPCC) Method, listed as Attachment 5 to this NEDC.

6) NSSFC Program 'TORPLOT' Output for CNS, listed as Attachment 6 to this NEDC.

C. ASSUMPTIONS

1) The data provided by the NSSFC is assumed to be correct and the computer calculations provided are performed correctly.

2) The wind speed data provided to ENERCON by NPPD is correct.

NON-NPPD GENERATED CALCULATION:

PREPARED BY: ENERCON DATE: 1-7-92

REVIEWED BY: J. Hockney DATE: 2-21-92

3) Court's technique and Simiu's technique both employ Type I distributions for description of the CNS wind speed database, which provides the optimum fit at most weather stations and is considered reasonable to assume an appropriate method.

D. METHODOLOGY

1) This calculation employs extreme value statistical methods to estimate the maximum wind speeds at CNS based on the existing site-specific database. The calculation first follows the extreme value statistical methods developed by Arnold Court and Simiu.

2) Data at the 10-meter elevation will be used for most of the calculations and are considered the reference basis. Missing data at the 10-meter elevation was completed by using data at other elevations and correcting (transpositioning) to the 10-meter elevation. The 10-meter data was conservatively used to determine the probability of occurrence of winds at the 30 meter elevation without transpositioning the data to the 30-meter elevation.

3) Simiu's technique for predicting extreme values of wind was used as a second check for the Court Method with similar results.

4) In order to verify that the Type I distribution is appropriate for characterization of the CNS wind speed database, the probability plot correlation coefficient (PPCC) method has made used to determine the best fitting distribution. This evaluation indicates that the Type I distribution is correct.

E. CONCLUSIONS

1) Court's method resulted in a probability of 6.7803E-8 /yr, which places CNS in ESW Group 1.

2) Court's method resulted in a h_3 of 1.012E-3/yr, which places CNS in SW Group 2.

NON-NPPD GENERATED CALCULATION:

PREPARED BY: ENERCON DATE: 1-7-92

REVIEWED BY: J. Hackney DATE: 2-21-92

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3) Using the 'TORPLOT' data provided by the NSSFC, the probability of tornado occurrence is $2.357*10^{-4}$ event per year, giving a $h_2 = 2.357*10^{-4}$ yr^{-1} for use in the CNS severe weather evaluation.

4) The Simiu's method resulted in a probability of 3.264E-8 /yr, which places CNS in the ESW Group 1.

5) The Simiu's method resulted in a h_3 of 7.0954E-04 yr^{-1}, which places CNS is SW Group 2.

6) The PPCC method resulted in a probability of 1.200E-5 /yr, which place CNS in ESW Group 1.

7) The PPCC method resulted in a h_3 of 4.528E-04, which places CNS in SW Group 2.

8) The error analysis, discussed in Section 7, indicates a very high confidence that the extreme values calculated are conservative.

9) Using Table 3-5a of NUMARC 87-00, the combination of weather groups ESW1 and SW2 indicates that CNS is a 'P1" plant.

10) The methodology used in this NEDC is correctly used and the results have been correctly calculated. It is concluded from the values generated in this NEDC, the CNS minimum allowable EDG target availability is 0.950.

SHEET 1 of 38
JOB NO NP-119 DATE 1/7/92
PROJECT CNS STATION BLACKOUT
SUBJECT SITE-SPECIFIC WEATHER EVALUATION
CLIENT NPPD ORIGINATOR E. HOLCOMB E. Holcomb 2/10/92
REVIEWER [illegible] APPROVED [illegible]
CALCULATION NO. NPP1-SBO-009

CALCULATION NPP1-SBO-009

COOPER NUCLEAR STATION (CNS)

SITE-SPECIFIC WEATHER DATA EVALUATION

FOR STATION BLACKOUT (SBO)

SHEET ___
JOB NO NP-119 DATE 1/7/92
PROJECT CNS STATION BLACKOUT
SUBJECT SITE-SPECIFIC WEATHER EVALUATION
CLIENT NPPD ORIGINATOR E. HOLCOMB
REVIEWER ___ APPROVED ___
CALCULATION NO. NPP1-SBO-009

REVIEWER'S STATEMENT

This calculation was reviewed in detail and was found to be complete and accurate. The conclusions were found to reasonable and justified. Major portions of the review consisted of the following:

1. References were reviewed for proper citation. Referenced equations were reviewed and found to be correct regarding their appropriate use and accuracy of transposition into this document.

2. The methodology and assumptions were reviewed and found to be both reasonable, appropriately implemented, and conservative. All numeric calculations were verified. Specifically, the following items are noted:

- All CNS weather data base monthly extreme wind speed values listed in Table 1 were cross-checked against the original CNS documentation and no errors were found. Editing of the data base followed appropriate methodology and the calculations were correct. The mean and standard deviation of the set of monthly extreme wind speed values were independently calculated and found to be correct.
- References in this calculation to Court's technique for extreme wind values (documentation in Attachment 1) were reviewed. The criteria for the use of Court's technique for extreme wind values were met, and the numerical calculations were found to be correct. The conclusions regarding the CNS station blackout weather groups were deemed to be accurate.

SHEET 3
JOB NO NP-119 DATE 1/7/92
PROJECT CNS STATION BLACKOUT
SUBJECT SITE-SPECIFIC WEATHER EVALUATION
CLIENT NPPD ORIGINATOR E. HOLCOMB
REVIEWER [initials] APPROVED [initials]
CALCULATION NO. NPP1-SBO-009

REVIEWER'S STATEMENT

- The use of NSSFC tornado data was considered to be consistent with NRC methodology in NUREG-1032, and appropriately used in this calculation.
- References in this calculation to Simiu's technique for extreme wind values (documentation in Attachment 2) were reviewed. The criteria for the use of Simiu's technique for predicting extreme wind values were met, and the resulting numerical calculations and conclusions regarding the CNS station blackout weather groups were found to be correct.
- The PPCC methodology documented in Attachment 5 was reviewed and considered appropriately applied in this calculation, demonstrating that the CNS data is fitted by a type I distribution.
- The evaluation determining the level of confidence in the CNS ESW and SW weather group categories is appropriate.
- The reviewer agrees with the conclusion that the CNS minimum allowable EDG target reliability is 0.950.

John Brandon
2/12/92

TABLE OF CONTENTS

OBJECTIVE

The purpose of this calculation is to evaluate the Cooper Nuclear Station (CNS) site-specific weather database and estimate the extreme wind values for various return periods. The results will be used to evaluate the CNS weather groupings for determination of the requisite emergency diesel generator (EDG) reliability, according to the criteria of NUMARC 87-00, RG 1.155 and the Station Blackout (SBO) Rule, 10CFR50.63.

This calculation supersedes calculation NPP1-SBO-005, since more rigorous techniques will be used to estimate the extreme wind values.

CALCULATION OVERVIEW - This calculation involves the following principal steps:

1. A brief introduction is provided.

2. Highlights of the analytical methodology are presented.

3. The CNS wind speed database is presented. Preparatory to application of extreme value statistical methods, the mean and standard deviation of the data are calculated.

4. Court's method is applied to the CNS data. Extreme winds are calculated for various return periods. The CNS station blackout weather groups are determined. Tornado data in the vicinity of CNS are presented.

5. Similar to item 4, Simiu's technique is applied to the CNS data to determine the extreme winds and the SBO weather groups.

6. Both Simiu's technique and Court's method employ a Type I distribution to fit the CNS data. The Probability Plot Correlation Coefficient (PPCC) method is used to establish that a Type I distribution indeed provides the best fit.

7. The level of confidence in the weather group determination is addressed.

8. The CNS emergency diesel generator target reliability is established, based on NUMARC 87-00 methods and the CNS weather group determination.

9. A brief summary is provided. References, tables and the necessary attachments complete the document.

1.0 INTRODUCTION

Using the methods outlined in Chapter 3 of NUMARC 87-00 (Reference 1), weather data, power grid design, availability of emergency alternating current (EAC) power supplies, and diesel generator test data all factor into the required SBO coping duration and the target EDG reliability. Both of these have been determined for CNS. As documented in Reference 2, the required coping duration is 4 hours, and the target EDG reliability is 0.95.

Weather data factor into the above determinations. As noted in Reference 2, the CNS severe weather (SW) group and the extremely severe weather (ESW) group were previously determined to be 'SW2' and 'ESW1', respectively. This resulted in an offsite power (OSP) design characteristic group of P1.

The CNS Station Blackout Safety Evaluation Report (Reference 3) was issued in August of 1991. In the SER, the 'SW' and 'ESW' classifications were challenged, the result being that the OSP grouping and the target EDG reliability for CNS were also questioned by the NRC. The staff recommended that:

> *"The licensee should use data provided in the NUMARC 87-00, i.e., severe weather (SW) group "3" and extremely severe weather (ESW) group "3", or provide further justification to demonstrate that the NUMARC values are not applicable to Cooper Nuclear Station. In lieu of the above, the licensee should provide additional plant specific weather data to include the extreme weather conditions in support of its ESW and SW group classifications."*

In Reference 4, the Nebraska Public Power District (NPPD, or the 'District') committed in its initial response to the SER to:

> *"revise the existing Cooper Nuclear Station (CNS) plant specific weather calculation to further support our SW and ESW group classifications."*

Since CNS has a meteorological tower and over 16 years of data, it is appropriate to use the site-specific weather data rather than the NUMARC 87-00 values.

Using CNS data and methods of extreme value statistics, the weather data groupings, the OSP design characteristic and the target EDG reliability will be developed in this calculation to meet the above commitment.

2.0 METHODOLOGY

This calculation employs extreme value statistical methods to estimate the maximum wind speeds at CNS based on the existing site-specific database. Two primary methods are followed, both of which use a Type I exponential distribution to describe the CNS wind speed data. These methods enable calculation of the frequency of occurrence of high winds. The frequency is then used to determine the CNS station blackout ESW and SW groups mentioned in Section 1.

Given a dataset consisting of 'N' extreme values, each one of which has itself been derived from a large number of observations, extreme value statistics provides a way to predict maximum or minimum values occurring outside of the recorded time interval for the data of interest. For example, suppose we have a dataset consisting of the maximum wind speeds at a given location over a 15-year period, and that we wish to estimate the peak wind speeds that would occur over a 100-year time period. References 5 and 6 outline methodology for making extrapolations to 100 years and beyond.

This calculation first follows the extreme value statistical methods developed by Arnold Court (Reference 5). Court's treatment is included herein as Attachment 1. Methods developed by Simiu (Reference 6) are also used, both to supplement Court's treatment and also as a cross-check. Excerpts from Simiu's work are provided in Attachment 2. The method which yields the more conservative extreme wind speeds is used for subsequent analysis, which includes a discussion of the confidence level in the extreme wind speeds, the return periods, and the CNS weather group determinations.

To ensure that a Type I distribution is indeed appropriate for CNS, the Probability Plot Correlation Coefficient (PPCC) method is used to identify the optimum distribution with which to fit the data. The PPCC method is explained in Attachment 5. Results obtained with the PPCC method are compared to those obtained from Simiu's and Court's procedures.

At CNS, a 16-year dataset of monthly extreme wind values has been compiled. From this dataset, the maximum wind speed for longer time periods will be calculated for purposes of the NUMARC 87-00 'SW' and 'ESW' group determinations. The CNS dataset is presented in the next section.

3.0 CNS WIND SPEED DATABASE

The CNS wind speed database used in this calculation spans a 16-year time period from 1975-1990. These data are provided in Attachment 3.

For each month, the daily average wind speed and the maximum hourly average are recorded for various elevations above the ground. The maximum hourly average wind speed is the parameter of interest here. This represents the maximum recorded hourly average wind speed for the entire month. For a 30-day month, this value is the maximum of 30x24 or 720 recordings. Hence, each monthly maximum is an extreme wind speed value which is based on a large number of observations.

Data at the 10-meter elevation will be used for most of the calculations herein and are considered the reference basis. Transposition of the data to other elevations will be performed as required, although the data at the 10-meter and 35-feet elevations will be used interchangeably without correction. As used herein, this is conservative.

Using the data in Attachment 3, the yearly maximum hourly average wind speeds for CNS are summarized in Table 1. The maximum for the 16-year time period is 40.1 mph.

3.1 Correction of Wind Speed Data to Other Elevations

It is possible to use wind speed data recorded at one elevation to determine the wind speed at another elevation. The procedure for doing so is explained in Attachment 4, which has been extracted from Reference 7. Repeating Eqn. 2.4.1 of Att. 4,

$$(1)\quad U(z) = \frac{\ln (z/z_0)}{\ln (10/z_0)} U(10), \text{ where}$$

z = height above ground (meters),

z_0 = roughness length (meters), and

U = wind speed; $U(z)$ and $U(10)$ to be expressed in the same units.

Note that '10' meters could be replaced by another elevation since it is merely a reference point.

3.2 Editing of Database

The CNS weather database used herein spans 1975 to 1990. Hence, there are 16 x 12, or 192 monthly extreme values of wind speed in this database.

From the tables in Attachment 3, it can be seen that data were not recorded at the 10-meter elevation for September 1979, nor for February, March and April of 1984. However, the dataset can be completed using the recordings at other elevations along with Equation (1).

Using Att. 3 for September of 1979, at 318 ft. (96.93 meters), Umax = 32.7 mph. From Equation (1),

$$U(10) = \frac{\ln(10/z_0)}{\ln(z/z_0)} * U(z)$$

Let z = 96.93 meters. Choose z_0 = 0.05 for the roughness length in open terrain, with confidence that the answer will be correct within 1 or 2%. (See Attachment 4). Then, the 10.67 meter (35 ft.) wind speed is

$$U(10) \cong U(10.67) = \frac{\ln(10.67/0.05)}{\ln(96.93/0.05)} * 32.7 \text{ mph} = 23.2 \text{ mph}$$

Using a similar procedure for 1984, with z = 100 meters from Att. 3, yields the other data points:

	U(100)	U(10)
February 1984	46.0 mph	32.1 mph
March 1984	38.0	26.5 mph
April 1984	40.0	27.9 mph

From Attachment 3, and including the four edited values, the CNS wind speed database is listed in Table 2 from 1975 to 1990.

3.3 Mean and Standard Deviation

The mean of the set of extreme wind values is 24.17 mph, calculated by summing the monthly values and dividing by 192. The mean is denoted by $\overline{X}$.

The standard deviation of the dataset is 5.314 mph, calculated according to

$$(2) \qquad S.D. = \left\{ \frac{\sum_{i=1}^{N} (x_i - \overline{x})^2}{N} \right\}^{1/2}, \textit{where}$$

x_i is the i^{th} sample and N is the number of samples, 192 in this case.[a]

(a) Using (N-1) in the denominator of equation (2), the standard deviation is 5.328 mph.

4.0 APPLICATION of COURT's TECHNIQUE for EXTREME VALUES

In Sections 2.1 through 2.6 of Attachment 1, Arnold Court reviews the theory of extreme values. Court notes that both the sample size, N, and the number of observations, n, should be large for the methods to be applicable. For the CNS weather database, N = 192, and n = 672 to 744, depending on the month being recorded. Hence, according to the criteria given on pages 61 and 62 of Attachment 1, enough wind speed data exist to enable meaningful application of the theory of extreme values.

In Section 2.10 of Attachment 1, an application of the extreme value theory dealing with wind speeds is provided. Following the procedure on 'Worksheet 2', page 73 of Attachment 1, and using Court's nomenclature, the expected values of extreme wind will be calculated for CNS.

As noted above, N = 192. From Table 2,

$\bar{x}$ = 24.171354 mph (the mean of the extremes)
and s_x = 5.314246 (the standard deviation).

Linearly interpolating in Table III (p.65) for N = 192 yields

$$\bar{y}_N = 0.5668 \ (\textit{the reduced mean}), \text{ and}$$

$$\sigma_N = 1.23428 \ (\textit{the standard deviation of the theoretical variate}).$$

Continuing according to Worksheet 2,

$$1/a = \frac{S_x}{\sigma_n} = 4.30554 \quad \text{and} \quad \bar{y}_N \cdot 1/a = 2.44038$$

The theoretical mode of the sample, u, is

$$\hat{x} \equiv u = \bar{x} - (\bar{y}_N \cdot 1/a) = 21.73 \ mph$$

The line of expected extremes can be developed from the theoretical mode. However, inspection of the sorted wind speed data extremes in Table 2 indicates that it is more conservative to use the actual mode of the dataset. By inspection of Table 2,

$$\hat{x} = 28 \text{ mph} = u.$$

The line of expected extremes of wind speed 'x' is

(3b) $x = u + (1/a \cdot y)$

$= 28 + 4.30554\, y$ (mph).

Here, y is the reduced variate, or the double natural logarithm of probability distribution function ϕ of the wind speed variable 'x', i.e.

(4) $y = -\ln[-\ln \phi(x)]$.

With Court's technique, for maximum values,

(5) $\phi(x) = \exp[-\exp(-a(x-\hat{x})]$, which amounts to using a Type I exponential distribution to describe the CNS wind speed.

From equation 2.10 of Att. 1, the return period, $\bar{T}_x$, is

(6a) $\bar{T}_x = 1/[1 - \phi(x)]$, or

(6b) $\phi(x) = 1 - 1/\bar{T}_x$

Substituting (6b) into (4) yields

(7) $y = -\ln[-\ln(1 - 1/\bar{T}_x)]$

Hence, given the return period, y is known, and the maximum wind speed follows directly from equation (3b).

Note also that the return period is related to the probability of occurrence 'p' by

(8) $\bar{T}_x = 1/p(x)$

and that the probability of nonoccurrence is

(9) $q(x) = 1 - p(x) = \phi(x)$.

Based on the preceding discussion, the maximum wind speed for CNS can be tabulated for various return periods based on the site specific wind speed data.

Return Period $\bar{T}_x$	Probability of Nonoccurrence q(x)	Reduced Variate y	Maximum Wind Speed x
34 years*	0.971	3.51147	43.1 mph
40 years	0.975	3.67625	43.8 mph
50 years	0.98	3.90194	44.8 mph
100 years	0.99	4.60015	47.8 mph

The problem can also be worked in reverse. That is, given a maximum wind speed, the return period and hence the expected frequency of occurrence can be determined. This will be done in the next section of this calculation, in conjunction with the NUMARC 87-00 methods for determination of the ESW and SW group.

4.1 Extremely Severe Weather (ESW) Group

The ESW categories are listed in Table 3-1 of NUMARC 87-00. To determine the ESW Group, it is necessary to calculate the annual frequency of storms with sustained winds greater than or equal to 125 mph.

An elevation of 30 meters above the ground is representative of transmission line height. Using the logarithmic relationship, a wind speed of 125 mph at 30 meters is equivalent to 103.5 mph at 10 meters, i.e.

$$U(10) = \frac{\ln(10/0.05)}{\ln(30/0.05)} * U(30) = 0.82826 * 125 \text{ mph}$$

$$= 103.5 \text{ mph}$$

It will be conservative to use the 10-meter wind for the evaluation which follows.

* CNS plant design life.

From equation 2.24 of Attachment 1, for large return periods,

(10) $\bar{T}_x = \exp[\bar{y}_N + (x - \bar{x})(\sigma_N/S_x)]$

Let x = 103.5 mph as developed above. Using the parameters developed on sheet 13 in eqn. (10) above yields

$\bar{T}_x$ = 1.7698E8 months = 1.4749E7 years

from which

$p = 1/\bar{T}_x = 6.7803E-8\ yr^{-1}$.

From Table 3-1 of NUMARC 87-00, noting that $p \ll e < 3.3E-4$, Court's method indicates that CNS is in ESW Group 1.

4.2 Severe Weather (SW) Group

Section 3.2.1, Part 1C of NUMARC 87-00 outlines the method to determine the estimated frequency 'f' of loss-of-offsite power due to severe weather, i.e.

(11) $f = (1.3 * 10^{-4}) * h_1 + b * h_2 + (1.2 * 10^{-2}) * h_3 + c * h_4$,

where, for Cooper Nuclear Station,

h_1 =	30 inches	(Annual snowfall for CNS, from Table 3-3 of NUMARC 87-00
b =	12.5	(CNS has multiple rights-of-way)
h_2 =	0.0002357	(Tornadoes of 'F2' severity, or greater, see Attachment 6 herein and Section 4.3 below)
and c =	0.	(CNS has no vulnerability to salt spray)

In the CNS site-specific weather data evaluation, we seek to determine h_3. As defined in NUMARC 87-00, h_3 is the annual expectation of storms for the site with wind velocities between 75 and 124 mph.

To evaluate h_3, select 75 mph as the cutoff. This is conservative, since storms with higher wind speeds are less frequent. It is further conservative to consider the 75 mph wind speed as occurring at 30 meters.

Using the logarithmic law as before and transposing to 10 meters,

$$U(10) = 0.82826 * U(30) = 0.82826 * 75 \text{ mph} = 62.12 \text{ mph}$$

Let x = 62.12 mph. Substitution as before in equation (10) yields

$$\bar{T}_x = 1.1857E4 \text{ months} = 9.8811E2 \text{ years},$$

from which

$$p = 1.012\ E\text{-}3\ yr^{-1} = h_3$$

Substitution into equation (11) gives

$$f = (1.3E\text{-}4) * 30 + 12.5 * 0.0002357 + 0.012 * 1.012E\text{-}3$$

$$= 6.858E\text{-}3 = 0.00686$$

From Table 3-4 of NUMARC 87-00, Court's method indicates that CNS is in SW Group 2.

4.3 CNS Tornado Data

To procure CNS site specific tornado data, the National Severe Storm Forecast Center (NSSFC) was contacted. The NSSFC has provided a computer output listing from Program TORPLOT, which summarizes all reported tornado activity in the site vicinity from 1950 through 1988. The subject computer output is presented in Attachment 6. The 'TORPLOT' evaluation area is a 2-degree square centered at CNS, i.e. at Brownville, Nebraska. The output lists data and time of storm occurrence, storm damage class, storm path length and width of touchdown, and other interesting information. 'TORPLOT' wind speed data are instantaneous, ground level winds. The instantaneous wind speed is assumed to apply over the entire evaluation quadrant. To assist in the interpretation of the 'TORPLOT' output, a tornado damage class scale is provided in Table 5. An excerpt from the 'TORPLOT' output is shown in Table 6.

Appendix A of Reference 9 describes the methods used by the USNRC to develop loss-of-offsite power relationships. The methodology reported by the NRC is consistent with the 'TORPLOT' program, in which probabilities are assumed to apply uniformly across the 2-degree square, based on the available data. From the 'TORPLOT' output, the frequency of tornadoes of severity F2 or greater striking in the vicinity of the site is obtained. This frequency is assumed to apply anywhere within the site, i.e. the tornado is assumed to affect the switchyard or transformers if it strikes at all.

The NUMARC 87-00 evaluation criterion for SW conditions is the probability of tornado occurrence with wind speeds greater than or equal to 113 mph in the site vicinity.[a] Referring to Table 6, and using the conservative evaluation criterion of 113 mph, the 'TORPLOT' database, which contains 68 events, indicates that the probability of tornado occurrence is $2.357*10^{-4}$ events per year, for a mean severe storm return interval of 4243 years. Hence, $h_2 = 2.357*10^{-4}$ yr^{-1} for use in the CNS severe weather evaluation.

(a) Note that power plant transmission systems are designed for wind speeds of 125 mph, based on the National Electric Safety Code.

5.0 SIMIU's TECHNIQUE for ESTIMATING MAXIMUM WIND SPEED

In Reference 6, Simiu discusses a technique for predicting extreme values of wind. Excerpts from Reference 6 are provided in Attachment 2. Repeating equation A1.74 of Ref. 6, and using Simiu's notation,

$$(12)\quad \hat{G}_X(p) = \bar{X} + s(y-0.5772)\sqrt{6}/\pi,$$

where $\bar{X}$ and s are the mean value and standard deviation, respectively, of the sample of the extreme wind values, y is the reduced variate, and $\hat{G}_x(p)$ is the estimated extreme value of wind for a given probability of nonoccurrence 'p'. The mean and standard deviation of the wind speed database have been calculated according to equations A1.72 and A1.73 of Attachment 2 and are listed in Table 2.

Choose a 100-year return period for comparison to the results in Section 4. Using the set of monthly extremes, $\bar{N} = 12 * 100 = 1200$, and $y = -\ln[-\ln(1-1/\bar{N})] = 7.08966$. Using equation (12) and the monthly mean and standard deviation from Table 2 gives

$$\hat{G}_X(p) = 24.17 + 5.314\ (7.08966 - 0.5772)\sqrt{6}/\pi$$
$$= 51.15 \text{ mph}$$

This compares reasonably well with the 100-year extreme of 47.8 mph calculated in Section 4, with Simiu's technique yielding a more conservative value by 7% compared to Court's method.

5.1 ESW Group

From page 87 of Attachment 2, for $\bar{N}$ large, note that

(13) $y = -\ln[-\ln(1-1/\bar{N})] \cong \ln \bar{N}$

Substitution of (13) into (12) and solving for $\bar{N}$ yields

(14) $$\bar{N} = \exp\left\{\frac{(\hat{G}_x(p) - \bar{X}) \cdot \pi}{\sqrt{6} \cdot s} + 0.5772\right\}$$

Now, using $\hat{G}_x(p) = 103.5$ mph and the values of $\bar{X}$ and s from Table 2, substitution into eqn. (14) yields

$\bar{N}$ = 3.676 E8 months, or

$\bar{N}$ = 3.063 E7 years.

For comparison to Table 3-1 of NUMARC 87-00,

$e = 1/\bar{N} = 3.264\text{E-}8\ yr^{-1}$,

with the result that CNS is in ESW Group 1.

5.2 SW Group

Proceeding as in Section 5.1, with $\hat{G}_X$ (p) = 62.12 mph, equation (14) yields

$$\bar{N} = \exp\left\{ \frac{(62.12 - 24.17135)\,\pi}{\sqrt{6} * 5.314246} + 0.5772 \right\}$$

$$= 16912 \text{ months} = 1409.4 \text{ years}$$

Hence, $h_3 = 1/\bar{N} = 7.0954E\text{-}04\ yr^{-1}$

Substituting h_3 into equation (11), as before,

$$f = (1.3E\text{-}4) * 30 + 12.5 * 0.0002357 + (1.2E\text{-}2) * 7.0954E\text{-}04$$
$$= 6.855E\text{-}3 = 0.0069$$

Hence, from Table 3-4 of NUMARC 87-00, CNS is in SW Group 2.

92-023

6.0 PPCC METHOD

Court's technique and Simiu's method have both employed Type I distributions for desciption of the CNS wind speed database. These distributions exhibit the same form but have slightly different constants in the functional expressions. The constants depend on values used to characterize the data, such as the mode, mean, standard deviation, or location and scale parameters.

Based on the discussion in Section 3.5 of Reference 7, a Type I distribution provides the optimum fit at most weather stations. It is, therefore, considered reasonable to assume that the CNS data would be well fitted by a Type I distribution.

However, to ensure that a Type I distribution is indeed appropriate for characterization of the CNS wind speed database, the probability plot correlation coefficient (PPCC) method has been used to determine the best fitting distribution. The PPCC method is described in Section A1.6 of Reference 6 and also in Reference 7. Basically, the method examines a Type I distribution and a number of Type II distributions, as defined respectively by equations 3.1.1 and 3.1.2 of Attachment 5. Via a least squares method, a correlation coefficient is determined for each distribution, according to equation 3.1.3.

The procedure summarized in Attachment 5 was performed for a Type I distribution (GAMMA = INFINITY and equation 3.1.1) and for forty-two Type II distributions (different, finite values of GAMMA from 1 to 1000 in equation 3.1.2 of Att. 5) using computer programs developed by the National Bureau of Standards, which are documented in Reference 8. The extreme value analysis computer program output for the CNS data is listed in Tables 3 and 4. Using Table 3, it is seen that this procedure verifies that the Type I distribution does indeed provide the best fit for the CNS wind speed database. The maximum value of the PPCC occurs for the Type I distribution and is $r_d = 0.96444$.

Using equation 3.1.1 of Att. 5 and the values in Table 3 for gamma = infinity, the best fitting distribution is

$$(15)\quad F_I(v) = \exp\left[-\exp\left\{\frac{-(v - 21.837)}{4.079}\right\}\right]$$

where 'v' is the wind speed. This distribution is similar to those used previously in this calculation. It yields a 100-yr extreme wind estimate of v_{100} = 50.58 mph for CNS, which is very close to the value yielded by Simiu's method in Section 5.

The extreme wind values predicted by the PPCC method are listed in Table 4 for various return periods. Since the computations were made using the CNS monthly extremes, the return periods in Table 4 are also in months.

Two extreme wind values are of interest. As before, 103.5 mph and 62.12 mph are used to determine the ESW and SW categories, respectively. Intepolating in Table 4 for v = 62.12 mph gives a return period of about 26,499 months, or 2208.27 years.

Taking the reciprocal of this number yields h_3 = 4.528E-04 for determination of the SW Group. Using equation (11) as before, with this value of h_3 yields

f = 6.852E-3 = 0.00685,

again with the result from NUMARC 87-00 Table 3-4 that CNS is in <u>SW Group 2.</u>

Regarding the ESW category, an extreme wind value of 103.5 is not listed in Table 4. However, using the much more conservative maximum tabulated value of 78.20 mph yields a return period of 1,000,000 months, or 83333.3 years, i.e.

$\bar{N}$ >> 83333.3 years

f << 1.200 E-5 yr^{-1} << 3.3E-4 yr^{-1}.

Hence, from NUMARC 87-00 Table 3-1, the PPCC method also indicates that CNS is in <u>ESW Group 1.</u>

7.0 ERROR ANALYSIS

In this section, the level of confidence is evaluated regarding the determination of the ESW and SW categories for CNS. For a given category, the maximum wind speed is estimated for the minimum return period allowed by the category. The standard deviation of the sampling error of the wind speed estimator is calculated. The upper bound wind speed in the error band in then evaluated by comparison to the allowable ESW and SW wind speeds.

7.1 ESW Group

For ESW Group 1, Table 3-1 of NUMARC 87-00 gives

$$e < 3.3E-4 \text{ yr}^{-1},$$

or $1/e > 3030.30$ years

Hence, take N = 3031 years = 36372 months.

From equation A1.74 of Attachment 2, using the method of moments,

$$\hat{G}_X(p) = \bar{X} + s(y-0.5772)\sqrt{6}/\pi \text{ , where}$$

$$y = -\ln(-\ln p), \text{ and}$$

$$p = 1 - 1/\bar{N}.$$

For $\bar{N}$ = 36,372, and using the mean and standard deviation of the set of monthly extreme values from Table 2, the maximum expected wind speed in 3031 years is

$$\hat{G}_X(p) = 65.29 \text{ mph}$$

The standard deviation in the estimate of the maximum wind speed is given by

$$SD[\hat{G}_X(p)] = \frac{\sqrt{6}}{\pi}\left[\frac{\pi^2}{6} + 1.1396(y-0.5772)\frac{\pi}{\sqrt{6}} + 1.1(y-0.5772)^2\right]^{\frac{1}{2}}\frac{s}{\sqrt{n}}$$

from equations A1.70 and A1.76 of Attachment 2. With N = 36,372, s = 5.314246, and n = 192 (the sample size), the standard deviation is

$$SD\ [\hat{G}_X(p)] = 3.34 \text{ mph}$$

To a 99.7% confidence level, the 3031-year maximum wind will fall within the band defined by

$$\hat{V}_{R,m} = \hat{G}_x(p) \pm 3 * SD\ [\hat{G}_x(p)], \text{ or}$$

$$\hat{V}_{R,m} \leq 65.29 + 3 * 3.34 \text{ mph}$$

$$\leq 75.30 \text{ mph.}$$

Since the ESW category 1 minimum allowable return period was used in the above calculation, as opposed to the return periods actually computed using the CNS data, it is apparent that there is considerable margin in the ESW category '1' determination. Further, conservatively correcting to 10 meters, the allowable ESW wind speed is 103.5 mph. Since 75.30 mph is substantially less than the allowable ESW wind speed, there is further conservatism and very high confidence in the conclusion that CNS is in ESW Group 1.

7.2 SW Group

It has been determined in this calculaton that CNS is in SW Group 2. From Table 3-4 of NUMARC 87-00, category SW2 requires that

$$f < 0.0100$$

Using the previously established values for snowfall and tornado occurrence, solving equation (11) for the maximum allowable frequency of high winds in category SW 2 yields

$$h_3 < \frac{0.0100 - (30 * 1.3E\text{-}4) - 12.5(0.0002357)}{0.012}$$

i.e. want $h_3 < 0.2628\ yr^{-1}$. This gives $1/h_3 > 3.805$ years = 45.66 months. Conservatively using N = 50 months in Table 4 gives

$$\hat{V}_{R,m} = 37.76 \text{ mph.}$$

The maximum allowable wind speed in the SW evaluation is 75 mph. Conservatively assuming this occurs at 30 meters and correcting to 10 meters gives 62.12 mph for the maximum wind allowed by SW Group 2. Since 37.76 mph is substantially less than 62.12 mph, further quantitative analysis is not required. Clearly, there is a significant margin in the SW2 categorization for CNS and very high confidence in this conclusion.

8.0 EDG TARGET RELIABILITY

Using Table 3-5a of NUMARC 87-00, the combination of weather groups ESW1 and SW2 indicates that Cooper Nuclear Station is a 'P1' plant.

From Reference 2, CNS is in EAC Group 'C'. For a required SBO coping duration of 4 hours, Table 3-8 of NUMARC 87-00 indicates that the minimum allowable EDG target reliability is 0.950.

9.0 SUMMARY

A site-specific weather data evaluation has been performed for CNS as part of its response to the Station Blackout Rule. The evaluation shows that a Type I exponential distribution provides and excellent fit to the CNS plant specific database for monthly extreme wind values. Three methods, all employing Type I distributions and methods of extreme value statistics, indicate that CNS is in station blackout weather groups ESW1 and SW2, to a high degree of confidence. The resulting conclusion is that CNS is a 'P1' plant with a target EDG reliability of 0.95.

10.0 REFERENCES

1. Guidelines and Technical Bases for NUMARC Initiatives Addressing Station Blackout at Light Water Reactors, NUMARC 87-00, Revision 1, August 1991.

2. Enercon Services, Inc., "Station Blackout Coping Assessment for the Cooper Nuclear Station", Report No. NPP1-PR-01, Revision 1, dated January 11, 1990.

3. Letter from Paul W. O'Connor, USNRC, to Guy R. Horn, NPPD, "Cooper Nuclear Station-Safety Evaluation of the Response to the Station Blackout Rule (TAC No. 68534)", Docket No. 50-298, dated August 22, 1991.

4. Letter from G. R. Horn, NPPD to the USNRC Document Control Desk, "Response to Recommendations on Station Blackout, 10CFR50.63 Cooper Nuclear Station", NLS9100631, dated September 30, 1991.

5. Court, Arnold, "Some New Statistical Techniques in Geophysics", Statistical Laboratory, University of California at Berkeley, circa 1951. (Extracted from Advanced Geophysics, Vol. I)

6. Simiu, Emil, and Robert H. Scanlan, Wind Effects on Structures, Second Edition, John Wiley & Sons, New York, 1986.

7. Simiu, Emil, Changery, Michael J. and James J. Filliben, "Extreme Wind Speeds at 129 Stations in Contiguous U.S.", NBS Building Science Series #118, March 1979.

8. Simiu, Emil and J. J. Filliben, "Statistical Analysis of Extreme Winds," Technical Note 868, National Bureau of Standards, Washington, D.C., 1975.

9. Baranowsky, P. W., "Evaluation of Station Blackout Accidents at Nuclear Power Plants", NUREG-1032, June 1988.

SHEET 30
JOB NO. NP-119 DATE 1/7/92
PROJECT CNS STATION BLACKOUT
SUBJECT SITE-SPECIFIC WEATHER EVALUATION
CLIENT NPPD ORIGINATOR E. HOLCOMB
REVIEWER [illegible] APPROVED
CALCULATION NO. NPP1-SBO-009

TABLE 1

SUMMARY of MAXIMUM WIND SPEED DATA[a] for COOPER NUCLEAR STATION

YEAR	WIND SPEED @ 10-METER ELEVATION[b]
1975	30.0 mph
1976	37.0
1977	34.5
1978	40.1
1979	29.1
1980	28.0
1981	31.0
1982	36.0
1983	33.0
1984	32.1
1985	29.1
1986	29.1
1987	25.3
1988	30.3
1989	33.6
1990	27.9

Notes: (a) See Attachment 3 for complete wind speed database. Wind speeds above are maximum hourly average values for each year.

(b) 10-meter and 35-ft. data in Attachment 3 are both assumed to apply at 10 meters.

NPM- 58Ø -009

Table 2

1975-1980 COOPER NUCLEAR STATION 72 SAMPLES

	I-TH MONTH	CNS 10M HOURLY AVG MAX WIND	(XI-XBAR)	ASCENDING ORDER SORTED DATA	(XI-XBAR)**2
JAN 1975	1	18	-18.37135	9.8	337.50665
	2	16	-13.37135	10.8	178.79311
	3	29	-13.37135	10.8	178.79311
	4	28	-10.77135	13.4	116.02287
	5	27	-9.17135	15	84.11274
	6	18	-9.17135	15	84.11274
	7	23	-9.07135	15.1	82.28947
	8	23	-8.77135	15.4	76.93665
	9	20	-8.57135	15.6	73.46611
	10	27	-8.17135	16	66.77103
	11	30	-8.17135	16	66.77103
	12	27	-8.17135	16	66.77103
JAN 1976	13	28	-8.17135	16	66.77103
	14	29	-7.97135	16.2	63.54249
	15	28	-7.37135	16.8	54.33696
	16	37	-7.17135	17	51.42832
	17	28	-7.17135	17	51.42832
	18	34	-6.97135	17.2	48.59978
	19	19	-6.47135	17.7	41.87842
	20	22	-6.47135	17.7	41.87842
	21	20	-6.27135	17.9	39.32988
	22	23	-6.27135	17.9	39.32988
	23	28	-6.17135	18	38.08561
	24	28	-6.17135	18	38.08561
JAN 1977	25	26	-6.17135	18	38.08561
	26	28	-6.17135	18	38.08561
	27	32	-6.07135	18.1	36.86134
	28	34	-5.97135	18.2	35.65707
	29	25	-5.87135	18.3	34.47280
	30	25	-5.87135	18.3	34.47280
	31	24	-5.57135	18.6	31.03999
	32	28.4	-5.57135	18.6	31.03999
	33	19	-5.57135	18.6	31.03999
	34	21.4	-5.17135	19	26.74290
	35	34.5	-5.17135	19	26.74290
	36	26.6	-5.17135	19	26.74290
JAN 1978	37	27.5	-5.17135	19	26.74290
	38	33.2	-4.97135	19.2	24.71436
	39	25.5	-4.77135	19.4	22.76582
	40	25.8	-4.77135	19.4	22.76582
	41	31.2	-4.77135	19.4	22.76582
	42	40.1	-4.67135	19.5	21.82155
	43	21.7	-4.67135	19.5	21.82155
	44	21.2	-4.47135	19.7	19.99301
	45	19.9	-4.47135	19.7	19.99301
	46	18.2	-4.27135	19.9	18.24447
	47	17.7	-4.27135	19.9	18.24447
	48	28	-4.17135	20	17.40020
JAN 1979	49	21.5	-4.17135	20	17.40020
	50	35	-4.17135	20	17.40020
	51	29.1	-4.07135	20.1	16.57592

Table 2 (cont'd)

NPP1-SBØ-009
EH [illegible] 32

	52	12.8	-3.17135	21	10.05749
	53	15.4	-3.17135	21	10.05749
	54	13.4	-3.17135	21	10.05749
	55	10.8	-3.17135	21	10.05749
	56	5.8	-3.07135	21.1	9.43322
	57	23.2	-2.97135	21.2	8.82895
	58	27	-2.77135	21.4	7.66040
	59	19.9	-2.67135	21.5	7.13613
	60	24.7	-2.57135	21.6	6.61186
JAN 1980	61	24	-2.47135	21.7	6.10759
	62	25	-2.17135	22	4.71478
	63	28	-2.17135	22	4.71478
	64	23	-2.17135	22	4.71478
	65	18	-2.17135	22	4.71478
	66	15	-2.07135	22.1	4.29051
	67	17	-1.77135	22.4	3.13770
	68	15	-1.67135	22.5	2.79342
	69	26	-1.57135	22.6	2.46915
	70	26	-1.37135	22.8	1.88061
	71	24	-1.27135	22.9	1.61634
	72	25	-1.17135	23	1.37207
JAN 1981	73	22	-1.17135	23	1.37207
	74	30	-1.17135	23	1.37207
	75	30	-1.17135	23	1.37207
	76	31	-1.17135	23	1.37207
	77	23	-1.17135	23	1.37207
	78	30	-1.07135	23.1	1.14780
	79	21	-0.97135	23.2	0.94353
	80	17	-0.87135	23.3	0.75926
	81	20	-0.77135	23.4	0.59499
	82	26	-0.67135	23.5	0.45072
	83	25	-0.47135	23.7	0.22217
	84	28	-0.37135	23.8	0.13790
JAN 1982	85	28	-0.27135	23.9	0.07363
	86	32	-0.17135	24	0.02936
	87	34	-0.17135	24	0.02936
	88	36	-0.17135	24	0.02936
	89	28	-0.17135	24	0.02936
	90	27	-0.17135	24	0.02936
	91	22	-0.17135	24	0.02936
	92	19	-0.17135	24	0.02936
	93	19	-0.17135	24	0.02936
	94	16	0.02865	24.2	0.00082
	95	33	0.32865	24.5	0.10801
	96	24	0.42865	24.6	0.18374
JAN 1983	97	30	0.52865	24.7	0.27947
	98	24	0.52865	24.7	0.27947
	99	24	0.52865	24.7	0.27947
	100	33	0.62865	24.8	0.39520
	101	28	0.72865	24.9	0.53092
	102	27	0.82865	25	0.68665
	103	22	0.82865	25	0.68665
	104	16	0.82865	25	0.68665
	105	23	0.82865	25	0.68665
	106	21	0.82865	25	0.68665
	107	27	0.82865	25	0.68665

Table 2 (cont'd) *NPP1- SBØ-009*

33

	108	19	0.92865	25.1	0.86278
JAN 1984	109	18	1.12865	25.3	1.27384
	110	22.1	1.12865	25.3	1.27384
	111	26.5	1.32865	25.5	1.76530
	112	27.9	1.32865	25.5	1.76530
	113	27	1.32865	25.5	1.76530
	114	27.5	1.52865	25.7	2.33676
	115	16	1.62865	25.8	2.65249
	116	16.8	1.62865	25.8	2.65249
	117	23.7	1.82865	26	3.34395
	118	23.5	1.82865	26	3.34395
	119	25.7	1.82865	26	3.34395
	120	22.4	1.82865	26	3.34395
JAN 1985	121	28.2	2.02865	26.2	4.11540
	122	21	2.32865	26.5	5.42259
	123	29.1	2.42865	26.6	5.89832
	124	28	2.42865	26.6	5.89832
	125	26.6	2.42865	26.6	5.89832
	126	21	2.42865	26.6	5.89832
	127	17.7	2.62865	26.8	6.90978
	128	19.7	2.82865	27	8.00124
	129	22.1	2.82865	27	8.00124
	130	26.6	2.82865	27	8.00124
	131	25.5	2.82865	27	8.00124
	132	25.5	2.82865	27	8.00124
JAN 1986	133	29.1	2.82865	27	8.00124
	134	25.3	2.82865	27	8.00124
	135	26.8	2.82865	27	8.00124
	136	29.1	3.02865	27.2	9.17270
	137	27.3	3.12865	27.3	9.78842
	138	17.2	3.12865	27.3	9.78842
	139	20.1	3.32865	27.5	11.07988
	140	17.9	3.32865	27.5	11.07988
	141	19.7	3.72865	27.9	13.90280
	142	18.3	3.72865	27.9	13.90280
	143	25.1	3.82865	28	14.65853
	144	18.3	3.82865	28	14.65853
JAN 1987	145	24	3.82865	28	14.65853
	146	25.3	3.82865	28	14.65853
	147	22.9	3.82865	28	14.65853
	148	24	3.82865	28	14.65853
	149	23.3	3.82865	28	14.65853
	150	19.4	3.82865	28	14.65853
	151	18.6	3.32865	28	14.65853
	152	18.6	3.82865	28	14.65853
	153	19.5	3.82865	28	14.65853
	154	22.5	3.82865	28	14.65853
	155	17.9	3.82865	28	14.65853
	156	22.6	3.82865	28	14.65853
JAN 1988	157	28.8	4.02865	28.2	16.22999
	158	28.3	4.12865	28.3	17.04572
	159	30.3	4.12865	28.3	17.04572
	160	27.3	4.22865	28.4	17.88145
	161	24.2	4.62865	28.8	21.42436
	162	18.6	4.82865	29	23.31582
	163	19.4	4.82865	29	23.31582

Table 2 (cont'd)

34

NPP1- SB∅-009

EH JM

	164	19.4	4.82865	29	23.21582
	165	24.7	4.92865	29.1	24.29155
	166	25.8	4.92865	29.1	24.29155
	167	28	4.92865	29.1	24.29155
	168	26.6	4.92865	29.1	24.29155
JAN 1989	169	23.9	5.82865	30	33.97311
	170	24.5	5.82865	30	33.97311
	171	23.6	5.82865	30	33.97311
	172	24.8	5.82865	30	33.97311
	173	20.3	5.82865	30	33.97311
	174	19.2	5.82865	30	33.97311
	175	15.6	6.12865	30.3	37.56030
	176	15.1	6.82865	31	46.63040
	177	23.8	7.02865	31.2	47.40186
	178	21.1	7.82865	32	61.28770
	179	26.2	7.82865	32	61.28770
	180	24.9	7.92865	32.1	62.86342
JAN 1990	181	27.2	8.82865	33	77.94499
	182	23.4	8.82865	33	77.94499
	183	21.6	9.02865	33.2	81.51645
	184	24.7	9.42865	33.6	88.89936
	185	22.8	9.82865	34	96.60228
	186	27.9	9.82865	34	96.60228
	187	18.1	9.82865	34	96.60228
	188	16.2	10.32865	34.5	106.68092
	189	19.5	10.82865	35	117.25957
	190	30	11.82865	36	139.91686
	191	24.6	12.82865	37	164.57415
DEC 1990	192	23.1	15.92865	40.1	253.72176

XBAR	SDEV
24.17135416	5.314246011

35

NPPI-SBØ-009

EXTREME VALUE ANALYSIS

THE SAMPLE SIZE N = 192
THE SAMPLE MEAN = 24.1713638
THE SAMPLE STANDARD DEVIATION = 5.3281384
THE SAMPLE MINIMUM = 5.8000002
THE SAMPLE MAXIMUM = 40.0999985

EXTREME VALUE TYPE 2 TAIL LENGTH PARAMETER (GAMMA)	PROBABILITY PLOT CORRELATION COEFFICIENT	LOCATION ESTIMATE	SCALE ESTIMATE	TAIL LENGTH MEASURE
1.00	0.45931	23.5311928	0.1077400	10.18011
2.00	0.73942	20.3295918	2.2544682	3.39672
3.00	0.83864	16.1745930	5.9701371	2.47043
4.00	0.88058	11.9588499	10.0186853	2.14609
5.00	0.90250	7.7709918	14.1325731	1.98712
6.00	0.91567	3.6100259	18.2566051	1.89429
7.00	0.92437	-0.5315249	22.3780956	1.83394
8.00	0.93051	-4.6594353	26.4944649	1.79175
9.00	0.93505	-8.7775307	30.6056957	1.76069
10.00	0.93855	-12.8884935	34.7124748	1.73691
11.00	0.94131	-16.9941120	38.8155136	1.71814
12.00	0.94355	-21.0955887	42.9154510	1.70297
13.00	0.94540	-25.1938152	47.0127869	1.69045
14.00	0.94695	-29.2894363	51.1079865	1.67996
15.00	0.94827	-33.3830185	55.2014046	1.67103
16.00	0.94940	-37.4748650	59.2932854	1.66335
17.00	0.95039	-41.5653076	63.3838997	1.65667
18.00	0.95126	-45.6545525	67.4733887	1.65082
19.00	0.95203	-49.7427826	71.5619278	1.64564
20.00	0.95271	-53.8302345	75.6496887	1.64102
21.00	0.95333	-57.9168510	79.7367096	1.63689
22.00	0.95388	-62.0028419	83.8230667	1.63316
23.00	0.95438	-66.0882111	87.9088593	1.62979
24.00	0.95483	-70.1732254	91.9942093	1.62672
25.00	0.95525	-74.2578201	96.0791473	1.62391
30.00	0.95689	-94.6753159	116.4984510	1.61287
35.00	0.95803	-115.0871120	136.9117740	1.60516
40.00	0.95887	-135.4954830	157.3213200	1.59947
45.00	0.95952	-155.9011690	177.7281490	1.59510
50.00	96003	-176.3053890	198.1331790	1.59164
60.00	0.96079	-217.1099550	238.9392700	1.58651
70.00	0.96133	-257.9118960	279.7422490	1.58289
80.00	0.96173	-298.7120360	320.5431520	1.58019
90.00	0.96204	-339.5108340	361.3425600	1.57811
100.00	0.96228	-380.3088380	402.1412960	1.57645
150.00	0.96301	-584.2916260	606.1256100	1.57152
200.00	0.96337	-788.2689820	810.1040650	1.56908
250.00	0.96359	-992.2446290	1014.0803200	1.56763
350.00	0.96384	-1400.1929900	1422.0296600	1.56666
500.00	0.96402	-2012.1134000	2033.9495800	1.56546
750.00	0.96416	-3031.9772900	3053.8134800	1.56377
1000.00	0.96423	-4051.8378900	4073.6762700	1.56330
INFINITY	0.96444 MAX	21.8378620	4.0794487	1.56187

TABLE 5

36
NPP1-SBØ-009
8/24/81

RETURN PERIOD (IN MONTHS)	PREDICTED EXTREME WIND BASED ON EXTREME VALUE TYPE 1 DISTRIBUTION
2.0	23.33
3.0	25.52
4.0	26.92
5.0	27.96
6.0	28.78
7.0	29.47
8.0	30.05
9.0	30.56
10.0	31.02
20.0	33.95
30.0	35.64
40.0	36.83
50.0	37.76
60.0	38.51
70.0	39.14
80.0	39.69
90.0	40.17
100.0	40.60
192.0	43.27
200.0	43.44
300.0	45.10
400.0	46.27
500.0	47.19
600.0	47.93
700.0	48.56
800.0	49.10
900.0	49.59
1000.0	50.02
2000.0	52.84
3000.0	54.50
4000.0	55.67
5000.0	56.58
6000.0	57.33
7000.0	57.96
8000.0	58.50
9000.0	58.98
10000.0	59.41
50000.0	65.98
100000.0	68.80
500000.0	75.37
1000000.0	78.20 mph

TABLE 4

Table 5

Tornado Damage Scale

Scale	F(wind speed - mph)	Damage	Pl (miles)	Pw (width)
-	Less than 40	(little or no damage)	Less than .3	Less than 6
0	40-72	Light	0.3-10	6-17 yds
1	73-112	Moderate	1.0-3.1	18-55 yds
2	113-157	Considerable	3.2-9.9	56-175 yds
3	158-206	Severe	10-31	176-556 yds
4	207-260	Devastating	32-99	0.3-0.9 mi
5	261-318	Incredible	100-315	1.0-3.1 mi

```
                 Tornadoes within 125. NM of BROWNSVILLE, NE

Following for global area within  125. NM radius of  40.35     95.63

The average F-scale is  1.20 which corresponds to  81. mph.
The average PL-scale is     1.17885; The average PL type path length is      1.290; True average length is    5.172
The average PW-scale is     1.34166; The average PW type path width is       .0342 True average width is      .078
The average area using average PL & PW computed by 10.**(.5*(pl+pw)-3.)  is    .018
The summation of the individual areas computed from PL & PW   245.06 divided by  1033 yields average area of     .238
The average area scale is     3.67386; The average area scale type area is     .048
The average length times the average width is      .403
True average length =     5.17
True average  width =      .079
True average   area =      .835
                    Probability =    .2652E-03 Mean Return Interval is   3770.94
 For winds exceeding  40 mph   prob =   .2652E-03 Mean Return Interval is   3770.94   based on  806 events
 For winds exceeding  73 mph   prob =   .2624E-03 Mean Return Interval is   3811.26   based on  608 events
 For winds exceeding 113 mph   prob =   .2354E-03 Mean Return Interval is   4247.38   based on  299 events
 For winds exceeding 158 mph   prob =   .1611E-03 Mean Return Interval is   6206.38   based on   88 events
 For winds exceeding 207 mph   prob =   .7385E-04 Mean Return Interval is  13541.75   based on   29 events
 For winds exceeding 261 mph   prob =   .1538E-04 Mean Return Interval is  65012.33   based on    3 events

                               F-0      F-1      F-2      F-3      F-4      F-5

Average PL length              .47      .99     2.25     5.13     7.28    14.65

Average PW width               .01      .01      .03      .06      .10      .22

Average PL & PW area           .01      .08      .36      .94     1.27     3.16

Average based on F          246.00   371.00   262.00    76.00    29.00     3.00

Average path length           1.14     2.80     7.04    16.20    20.15    37.64

Average path width             .02      .05      .10      .20      .27      .42

Average true area              .04      .22      .89     3.76     5.71    13.02

Average based on F          195.00   302.00   211.00    59.00    26.00     3.00

The following is for local area (two degrees square centered on latitude  40.35 longitude   95.63)
True average length =     5.16
True average  width =      .087
True average   area =      .858
                    Probability =    .2630E-03 Mean Return Interval is   3802.37
 For winds exceeding  40 mph   prob =   .2630E-03 Mean Return Interval is   3802.37   based on  173 events
 For winds exceeding  73 mph   prob =   .2592E-03 Mean Return Interval is   3858.15   based on  138 events
 For winds exceeding 113 mph   prob =   .2357E-03 Mean Return Interval is   4243.06   based on   68 events
 For winds exceeding 158 mph   prob =   .1464E-03 Mean Return Interval is   6829.97   based on   24 events
 For winds exceeding 207 mph   prob =   .3445E-04 Mean Return Interval is  29029.31   based on    7 events
 For winds exceeding 261 mph   prob =   .0000E+00 Mean Return Interval is *********   based on    0 events
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NPPT-SBØ-009
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38

Table 6

NSSFC Program 'TORPLOT' Output for CNS

Attachment 1

Court's Extreme Value Technique

Some New Statistical Techniques in Geophysics

ARNOLD COURT

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CONTENTS

1. INTRODUCTION

1.1. General

Statistical theories and methods are being applied increasingly in all fields of science, especially in geophysics. Until the 1930s, the physical sciences generally used only the rudimentary methods of statistics, preferring, for example, the Gaussian probable error to the analytically stronger and more versatile standard error (or deviation). Statistical theorems and methods developed in the preceding half-century were employed much more in the biological and social sciences than in the physical.

In the last few decades, however, the physical sciences have adopted a more modern statistical outlook. Geophysics in particular has made rapid strides in adopting statistical practices, and many techniques have been developed for the special requirements of its various component sciences. Some of these techniques are described in detail in this article, in order to acquaint a large circle of geophysicists with their potentialities.

A preliminary discussion of some fundamental aspects of statistics which often are overlooked in geophysical applications, and an explanation of a rediscovered simple method of estimating two normal components from a bimodal distribution are given in this section. The article is largely devoted, in Section 2, to a discussion of the likelihood of occurrence (return period) of extreme values, and the most recent method for estimating them, the theory of extreme values. The final section mentions briefly an even newer development, the statistics of circular variables, still in the descriptive stage.

Applications, interpretation, and limitations of the techniques, rather than underlying theory and proof, are stressed. The only statistical knowledge presumed of the reader is that of a first course in statistics: least squares computations, characteristics of the normal distribution, and simple correlation.

Symbols and notation used in this article are listed at the end of this article. Most of the symbols are those used in the various original papers, but some of the notation is novel, since statistics has developed so rapidly that its notation and symbolism have not yet been fully standardized. In recent years, the overbar ($\bar{x}$) has been accepted to designate the mean; in this article, in addition, the tilde ($\tilde{x}$) denotes the median and the circumflex ($\hat{x}$) the mode. Grave and acute accents ($\grave{x}$ and $\acute{x}$) indicate the largest and smallest values, respectively.

The classical statistical methods of geophysics have been presented recently in great detail by Conrad and Pollak [1]. Some more modern statistical concepts, however, are not included there, and may be overlooked by geophysicists. In the following paragraphs certain aspects are discussed which may make more accurate the application of statistics to geophysics.

1.2. Methods

Statistical methods are of two general categories: *descriptive* and *analytical*. Both depend in large part on the theory of probability which, in the words of Laplace, is merely common sense reduced to figures.

Descriptive methods are those which compress many figures into a few to represent them adequately for the purpose at hand; these methods are largely those formerly known as the *calculus of observations*. They involve few assumptions about the nature of the original figures, and consider the figures as such, and not as samples. Descriptive methods permit computation of means, modes, medians, and of variances and higher moments, as well as of correlations between two or more variables.

Analytical methods use the descriptive techniques to determine how well the observations agree with the theoretical model which they are assumed to follow. From the character of the model, in turn, and the descriptive results, the analytical procedures can indicate the accuracy of generalizations from the data, and of comparisons with other observations.

Emphasis, in most elementary courses in statistics, on the analytical aspects has obscured, for many geophysicists, both the limitations and the utility of the purely descriptive methods of the calculus of observations. Whereas description takes the data as they are, analysis considers them only as a *sample* of a population or universe. This parent population, in turn, is *assumed* to have certain characteristics, whose numerical values are estimated from the description of the sample.

Establishing that the sample does in fact have the attributes of the parent population is therefore essential to any analysis, yet in many cases this correspondence is not established at all. For example, the standard deviation can be computed for any set of figures as a valid measure of the amount of dispersion, but only if the figures are shown to follow a "normal" distribution can it be assumed that two-thirds of them fall within one standard deviation from the mean.

Descriptive methods alone may suffice for many geophysical applications—more so than in the biological and social sciences—where a mass of data is to be reduced to a few characteristic figures (means, modes, variances), without any inferences about the parent population or any detailed comparisons with other sets of observations. But statistical *analysis* of geophysical data must start with a clear expression of the population of which the data are considered to be a sample, and establishment that the sample is indeed drawn from such a population.

For many sets of geophysical data, "It is clear that one cannot define a population out of which the given sample was drawn at random." [2] Most geophysical data concern measurements of a variable which is continuous in both time and space, and may be relatively uniform over certain ranges of one or both. A single reading of air temperature, or magnetic intensity, or sea-swell length, may be considered as a sample of conditions at the spot of observation during a short interval of time, such as a few minutes; or it may be a sample of conditions over a small area, a few inches to a few miles in radius.

That is, an instantaneous reading is "chosen at random" from all possible similar readings which could have been made at any of an infinite number of other times during the interval, or at an infinite number of places in the vicinity. But when the element is averaged in time it is no longer a sample with respect to time: the parent population of a series of mean daily values (temperature, magnetic activity, or sea-swell length) is composed of all possible values for the vicinity, each averaged in time.

Furthermore, while the individual reading or mean daily value may be a *random* sample from an infinite population, a series of such readings is not a random sample, but a *stratified* sample: one from each of several distinguishable divisions (e.g., days) or strata of the population. Consequently, many analytical procedures, particularly tests of significance, are not strictly applicable to such data.

1.3. Functions

The extensive computations required for statistical description or analysis are laborious if done by hand, but can be done rapidly on modern computing machines. Recent improvements in such machines, in fact, have permitted great simplifications in the routine computations, in that involved calculations can be done more rapidly than simpler calculations which require additional manipulation. Unfortunately, these advances are rarely reflected in elementary textbooks, which describe methods applicable to manual computation, perhaps aided by an adding machine.

For example, combination of observations into classes is desirable when a large mass of data is to be summarized manually, but imposes some loss in accuracy as the price for convenience. With modern machines, individual observations can be squared and the results added in less time than is required to select class limits, assemble data into classes, and perform the computations. Consequently, the classic rules as to the number and size of classes no longer are very important.

Quantitative data or measurements, however, already are grouped by classes, defined by the unit of measurement even though the variable measured is itself continuous. Any further grouping usually is inadvisable.

Likewise, although the standard deviation is defined basically as the square root of the mean of the squares of all *deviations* from the mean (root mean square), in practice it is obtained most readily by the "variable squared" method: the square root of the difference between the mean of the squares of all the original observations and the square of the mean of the observations. Individual departures from the mean need not be computed at all.

Statistical analysis involves the comparison of observed data with a theoretical model, expressed mathematically in either of two ways, one the integral of the other.

A *frequency distribution* represents a set of data, observed or theoretical, of finite size; when all frequencies are reduced to percentages of the total sample size, the result is a *probability distribution*. In either form, this function, denoted by $f(x)$, represents the *density* of the distribution of frequency or probability, and when plotted on cartesian paper it yields a characteristic curve—"bell-shaped" for the normal curve.

The *area* under such a curve represents cumulative frequencies or probabilities; consequently, the *cumulative probability* function is the integral of the probability density distribution or function: $F(x) = \int_{-\infty}^{x} f(t)dt$. The graphing of such an integral, if computed from one end of the distribution to the other, yields an *ogive*, or cumulative frequency or probability graph; in hydrology, a time-frequency ogive has been called a "duration curve." On cartesian paper the cumulative probability ogive of a normal distribution is S-shaped or "sigmoid"; special "probability paper" (Section 1.4) transforms this curve into a straight line.

Each form of frequency function, the density distribution and its integral, has separate uses. In general, the density distribution is used to graph the theoretical function for comparison with a graph of observed values, while its integral, the cumulative probability function, is used for numerical comparison of the agreement between theory and observations, and for discussion and conclusions after correspondence is established. While a density distribution curve can be approximated from area values, and theoretical ordinates can be compared numerically with observed frequencies, such procedures are not as correct as the proper use of the two functions.

1.4. Graphics

For any cumulative probability function, whose ogive plotted on cartesian paper is a sinuous curve, a special graph paper can be designed on which the ogive becomes a straight line. Such papers were first designed by engineers, and they are used chiefly in that field. "Though mathematicians look with disfavor on the use of graphical methods in the evaluation of statistical parameters, engineers find them very convenient and time saving, especially if the accuracy required is not too great." [3]

Graph paper for the normal probability paper was designed and introduced in 1914 by Hazen [4] without comment, and explained in 1916 by his coworker Whipple [5], who also presented a logarithmic normal paper previously suggested by Hazen; revision of this paper has recently been proposed by Kottler [6]. As soon as the statistical theory of extreme values (Sections 2.5 *et seq.*) was introduced into the United States, Powell [7] designed a probability paper for its function (Section 2.8). Other probability papers include the "Probit" and "Logit" graphs of Berkson and Gumbel's new "Range" paper [8].

The chief virtue of any probability paper is that a set of data which plots along a straight line on it can be assumed to be drawn from a population whose distribution is that on which the paper is based. A further advantage is that such a straight line, whether drawn by inspection or fitted mathematically, can be used to obtain estimates of other values, such as the expected frequency of a given value or the value with a given probability of occurrence.

However, probability paper cannot be used alone to determine how well data follow the assumed distribution, e.g., to test for "normality," because a straight line cannot be fitted to plotted points by inspection: the paper is not linear, and slight departures from a straight line are magnified at both ends. "A Log-Probability Chart should be used only to represent an exact ogive by a straight line but not to judge how the data fit it. It is impossible to achieve any reliable judgment by mere inspection of such a graph." [6]

To plot a set of values on any probability paper they must be arranged in order of magnitude and their cumulative rank established. The smallest value is No. 1, the next-smallest No. 2, etc.; if the smallest occurs twice, it has Nos. 1 and 2, and the next-smallest is No. 3, etc. Alternatively, the largest value may be No. 1.

However, there has been little agreement on how to plot these cumulative ranks on probability paper. If the ranks are divided by the number of observations, N, then the last one is unity, which is at infinity on the graph paper. Compromises have been suggested, by which either $\frac{1}{2}$ or 1 is subtracted from the rank before division by N, or division by $2N$; these either omit an observation or distort the original data [9].

Certain theoretical considerations indicate advantages in dividing each cumulative rank by $N + 1$ for plotting; in addition to providing more realistic frequency values, this method permits all observations to be plotted on graph paper. This procedure is used in analysis by the theory of extreme values (Section 2.8).

1.5. *Components*

Typical of the subordination of descriptive methods to analytical procedures is the neglect of a very simple and useful technique for estimating two normal components in any frequency distribution. Many measurements, in geophysics as well as other sciences, involve variables which are not uniform but include subvariables of different basic characteristics.

For example, Landsberg [10] has shown that observed thermal gradients in the earth's crust fall into two groups, possibly for sedimentary and metamorphic rocks, respectively. Similarly, in middle latitudes the tropopause may be either high and cold (tropical) or low and not so cold (polar), so that a frequency distribution of daily tropopause height determinations has two definite modes.

A general method for finding two normal components in any distribution, assuming nothing about them except their existence, was presented by Pearson [11] in the first of his famous "Contributions to the Mathematical Theory of Evolution" before the Royal Society on November 16, 1893. It requires solution of a complete ninth degree equation involving the first five moments of the given distribution.

Pearson applied this method not only to markedly skewed distributions, in which the presence of two components is indicated strongly, but to some which are quite symmetrical (although not normal) to find components with identical means but differing standard deviations. His general method applies even when one of the components is negative, i.e., the given distribution is the difference between normal ones.

To Edgeworth's [12] suggestion for simplifying assumptions, Pearson [13] retorted that the "process is not so laborious that it need be discarded for rough methods of approximation based upon dropping the fundamental nonic and guessing suitable solutions." However, Charlier [14] considered the general solution "a very laborious operation," and developed simple solutions for two special cases: (1) where means are assumed for the two components and (2) where the variances of the two components are assumed to be equal.

Charlier's development, published in English in a journal of the University of Lund (Sweden), attracted little attention, and no mention of it appears in his later textbook nor does it seem to have been used by anyone else. Of the two methods, the first, involving assumption of the means of the two components, is far simpler than the second, which requires computation of the fourth moment of the given distribution and solution of a cubic equation.

However, Charlier devoted little space to the first method and expanded on the second, terming it the "abridged method for dissecting frequency curves." Since the cubic equation involved is actually one step in the general solution, "hence it is no loss of time to begin with this approximate method." He felt that assuming equal variances for two components "is of a more general character" than assuming values for their means: "Especially in biology it is a fairly probable supposition that two types found together in nature possess *nearly* equal standard deviations. We may then use this method to separate the two components."

He admitted that "this abridged method is applicable only when there are *a priori* reasons for the assumption that the two components have nearly equal standard deviations. There are many problems where no such reasons exist," such as those involving several sets of errors to a reading, each set being of a different type and magnitude.

In geophysics, equal variances may be present in some cases, but in general the first method, of assumed means, is the most applicable. Both methods, and one further simplification, are presented in the next paragraph, without the theoretical basis or development and in more condensed and modern notation [15].

1.6. Separation

In obviously bimodal distributions, and many unimodal ones with pronounced "humps" or "shelves," means M_1 and M_2 for two supposed components may be apparent. Their departures from the mean M of the given distribution,

$$M - M_1 = m_1 \quad \text{and} \quad M_2 - M = m_2 \tag{1.1}$$

give the variances of the two components:

$$\begin{cases} \sigma_1^2 = \sigma^2 - 2m_1m_2/3 - (m_1^2/3 + \nu_3/3m_2) \\ \sigma_2^2 = \sigma^2 - 2m_1m_2/3 - (m_2^2/3 - \nu_3/3m_1) \end{cases} \tag{1.2}$$

where σ^2 and ν_3 are the variance and third moment of the given distribution. The total areas or frequencies of each component depend only on the assumed means:

$$N_1 = Nm_2/(m_1 + m_2) \quad \text{and} \quad N_2 = Nm_1/(m_1 + m_2) \tag{1.3}$$

Finally, from a table of the normal frequency distribution ordinates (Section 1.5), $\phi(t)$, the ordinates of each component at any distance (in t units) from the mean may be found, since

$$y_1 = (N_1/\sigma_1)\phi(t) \quad \text{and} \quad y_2 = (N_2/\sigma_2)\phi(t) \tag{1.4}$$

The larger component always corresponds to the smaller departure from the mean, which in turn is m_1 if ν_3 is positive, m_2 if negative. Should impossible means be assumed for the two components, σ_1^2 or σ_2^2 will be negative, indicating no real solution.

However, the method of assumed means does not give a unique solution: usually trial of several pairs of means is required to find one set yielding two components which, added together, closely approximate the given distribution. The best pair of means generally has maximum ordinates agreeing well with the observed values, due regard being given to the contribution each component makes to the other's peak.

Such agreement can be made as close as desired by assuming values of the maximum ordinates $\hat{y}_1$ and $\hat{y}_2$ in addition to the means M_1 and M_2. Then

$$\sigma_1 = N_1/\sqrt{2\pi}\ \hat{y}_1 \quad \text{and} \quad \sigma_2 = N_2/\sqrt{2\pi}\ \hat{y}_2 \tag{1.5}$$

In effect, this short cut to Charlier's procedure replaces the standard deviation and skewness of the original distribution by a subjective evaluation which may be more effective for some distributions, but is not of as general applicability in finding two normal components.

Assuming the two presumed components to have equal variances, instead of assuming values for their means, led Charlier to a cubic equation involving the difference between the variances of the given distribution and the assumed components:

$$z^3 + \tfrac{1}{2}(\nu_4 - 3\sigma^4)z + \tfrac{1}{8}\nu_3^2 = 0 \tag{1.6}$$

where $z = \sigma_1^2 - \sigma^2$ and ν_4 is the fourth moment of the distribution. The discriminant of this cubic,

$$C^2 = (\sigma^{12}/216)\,(13.5\alpha_3^4 + E^3) \tag{1.7}$$

where $\alpha_3 = \nu_3/\sigma^3$ is the skewness and $E = (\nu_4/\sigma^4) - 3$ the excess, almost always is positive, indicating only one real root:

$$z = 0.4082\sigma^2\,(\sqrt[3]{-3.6742\alpha_3^2 + \gamma} - \sqrt[3]{+3.6742\alpha_3^2 + \gamma}) \tag{1.8}$$

where $\gamma = \sqrt{13.5\alpha_3^4 + E^3}$.

Except for almost symmetrical and very flat-topped distributions, γ is positive, so that z will be negative, and $\sigma_1^2 < \sigma^2$. But if $-z > \sigma^2$, then σ_1^2 is negative, and there is no actual solution, indicating that the assumption of equal variances is unwarranted. If the assumption is justified, and σ_1 is real, the means are:

$$\begin{cases} M_1 = M - m_1 = M - (\nu_3/6) - \sqrt{(\tfrac{1}{4}\nu_3)^2 - z} \\ M_2 = M + m_2 = M - (\nu_3/6) + \sqrt{(\tfrac{1}{4}\nu_3)^2 - z} \end{cases} \tag{1.9}$$

The areas N_1 and N_2 of the two components are found from equation 1.3 as before.

2. Extremes

2.1. Intervals

Extremes of any distribution of observations are of interest because they afford a rough indication of the range of the variable: extremes which have occurred may be expected to occur again. In geophysics, extremes are of greater importance than in many other sciences, because many questions of engineering design hinge on the most extreme value to be expected. Dams must be constructed to withstand the maximum flood anticipated in the lifetime of the structure, skyscrapers must be designed with the most severe earthquake in mind, chimneys should be able to endure the strongest wind, communications circuits should operate during the most severe magnetic and electrical disturbances, and piers must be located and constructed to withstand the heaviest anticipated surf.

In all such problems, specified calculated risks may be taken if the likelihood of occurrence of these extremes can be estimated within known limits of accuracy. The basis for such estimates of risk, and methods for their calculation, are explained first in this section. Then follows a discussion of the most recent method of estimating the most extreme value to be expected in a given period, the statistical theory of extreme values.

By definition:

> An event which happens H times in N trials has a *relative frequency* of occurrence of H/N, and an *apparent return period* of $T = N/H$.

The apparent return period, or reciprocal of the relative frequency, is therefore the *average* interval between recurrences of the event in the particular series of trials. Despite the rigor of this definition, it has not been fully appreciated, and there even have been some attempts to prove it.

Distinctions have been drawn, in hydrology, between two kinds of return periods: the "exceedance interval" and "recurrence interval," respectively the average periods between exceedances and recurrences of an event. These distinctions may be justified in dealing with discrete variables, such as number of points on a throw of two dice, but they grow meaningless for continuous variables as the unit of measurement becomes smaller. The distinction is part of the earlier empirical approach to the problems, which has been superseded by the recent advances outlined in this article.

Events for which relative frequencies and return periods are estimated are defined in one of two ways: by time or by magnitude. Events defined by time are the largest (or smallest) individual values during a given interval, such as a month, year, or solar cycle. Events defined by magnitude are those values which exceed some predetermined base, such as a temperature of 100°F or an earthquake intensity of 6.0; the time unit is usually much smaller than that used for the first type.

In particular, most hydrologic analyses use the relative frequency and apparent return periods of *annual* floods (maximum stream discharge), ignoring the second-highest floods of each year although some of them may be greater than the largest floods of other years. To rectify this apparent fault, other analyses use all floods exceeding the base value ("partial-duration series"), so that "the recurrence interval is the average interval between floods of a given size regardless of their relationship to the year or any other period of time." [16] It is less than the recurrence interval computed on the annual basis, although "for large floods the two approach numerical equality."

2.2. Frequency

If the occurrence or recurrence of an event depends on so many independent factors that it may be considered to follow the laws of chance, its relative frequency usually is assumed to be the same as the *probability of occurrence* in any one trial. This equivalence, which appears intuitively sound to the engineer, is questioned by the mathematician, and has encountered much statistical discussion.

It is the subject of an early theorem, acclaimed as one of the foundations of probability theory, proven by James Bernoulli in his *Ars conjectandi* (published posthumously in 1713):

> As the number of trials increases, the probability approaches unity that the relative frequency of occurrence will differ by less than any desired amount from the true probability of occurrence.

This theorem does not say that the relative frequency itself approaches the true probability as a limit, although Rietz [17] proposed such a statement as the basic definition of probability, from which Bernoulli's theorem would be an immediate consequence. In recent years these fundamental assumptions of probability theory have been the subject of renewed discussion [18].

In most geophysical problems, the true probability is unknown and must be inferred from the relative frequency. "Bernoulli, himself, in establishing his theory, had in mind the approximate evaluation of unknown probabilities from repeated experiments," Uspensky [19] pointed out, quoting Bernoulli as saying: "If somebody for many preceding years had observed the weather and noticed how many times it was fair or rainy, . . . by these very observations he would be able to discover the ratio of cases which in the future might favor the occurrence or failure of the same event under similar circumstances."

While the relative frequency based on very many occurrences provides a reasonable estimate of the true probability of occurrence, the relative frequency in a few occurrences is not at all reliable. Probability estimates usually are made in terms of two limits which are expected, with some given degree of confidence, to include the true value; for a given relative frequency, the greater the degree of confidence, the wider the interval in which the true probability is estimated to be. The limits of the estimate converge sharply as the number of trials on which it is based increases; this is shown by Table I, for 95% confidence, based on a diagram by Clopper and Pearson [20], which has been reproduced widely [21]; a similar table is presented by Snedecor [22] without explanation.

TABLE I. Limits of estimate of true probability with 95% confidence from relative frequency based on samples of varying size.

	Number of Trials = Sample Size					
Rel. freq.	10	20	30	50	100	1000
.00	.00 to .31	.00 to .17	.00 to .12	.00 to .07	.00 to .04	.00 to .01
.10	.00 to .43	.01 to .32	.03 to .27	.05 to .22	.07 to .17	.08 to .12
.20	.02 to .57	.05 to .44	.07 to .39	.10 to .34	.12 to .30	.17 to .22
.30	.06 to .66	.12 to .55	.15 to .50	.18 to .45	.21 to .40	.27 to .33
.40	.11 to .75	.18 to .64	.22 to .60	.26 to .55	.30 to .50	.37 to .43
.50	.17 to .82	.27 to .73	.31 to .69	.35 to .65	.40 to .60	.47 to .53

Table I shows, for example, that a relative frequency of 0.20 based on 10 trials (2 occurrences in 10 years) may arise from true probabilities anywhere between 0.02 and 0.57. For the same relative frequency observed in 50 trials the corresponding limits are 0.10 to 0.34. Based on 1000 trials the limits are only 0.17 to 0.22. Estimates of the true probabilities based on the rather small samples used in geophysics have very wide confidence intervals—so wide as to vitiate many computations based on them.

Probably the most valuable contribution of the theory of extreme values, discussed in detail later in this section, is that it provides an estimate of the true probability of occurrence of extreme values based, not on one extreme alone, but on all the values. An estimated relative frequency or return period obtained by this method, as outlined in Section 2.9, is the closest obtainable approximation to the true probability or return period.

2.3. Probability

Return periods, observed or estimated, are used extensively in various branches of geophysics, especially in hydrology for flood analysis. Nevertheless, the significance of the return period is not well known, although it can be developed as a corollary of the oldest problem in the theory of probability. In this problem, 300 years ago, Pascal found that while the probability of a double six on any one throw of two dice is $\frac{1}{36}$ and its return period is therefore 36 throws, there is better than a 50-50 chance of obtaining at least one double six in only 25 throws.

In general, the probability that an event x_r, whose probability of occurrence in a single trial is $p = 1 - q$ and whose return period is therefore $\check{T} = 1/p$, will *not occur in any of N trials* is (notation as in List of Symbols, page 82):

$$P(\dot{x}_N < x_r) = q^N = (1 - p)^N = (1 - 1/\check{T})^N \quad (2.1)$$

Consequently, the probability of *at least one occurrence in N trials* is:

$$P(\dot{x}_N \geq x_r) = 1 - q^N = 1 - (1 - 1/\check{T})^N \quad (2.2)$$

In Pascal's dice problem, $p = \frac{1}{36}$, and for $P(\dot{x}_N \geq x_r) = P(\dot{x}_N < x_r) = \frac{1}{2}$, $N = \log(\frac{1}{2})/\log(\frac{35}{36}) = 24.6$.

Similarly, the probability of *occurrence for the first time on the Nth trial* is the compound probability of non-occurrence in $N - 1$ trials and of occurrence in one trial:

$$P[(\dot{x}_{N-1} < x_r)(x_N \geq x_r)] = pq^{N-1} = q^{N-1} - q^N = (\check{T} - 1)^{N-1}/\check{T}^N \quad (2.3)$$

This probability is greatest on the first trial, and decreases with each successive trial because the probability of occurrence on the preceding trials increases. In Pascal's dice problem, the probability of a double six for the first time on the Nth trial (equation 2.3) decreases, while that for a double six in at least one of N trials (equation 2.2) increases, as follows:

N:	1	2	3	4	5	10	15	20	25	30	36
$P(x_N \geq x_r)$:	.028	.027]	.026	.026	.025	.022	.019	.016	.014	.012	.010
$P(\dot{x}_N \geq x_r)$:	.028	.055	.081	.107	.132	.246	.345	.431	.506	.471	.638

A fourth relationship, extensively used in some probability problems, but rarely of direct interest in geophysics, gives the probability of *exactly H occurrences in N trials:*

$$P[(\dot{x}_N \geq x_r) = H] = [N!/H!(N - H)!]p^H q^{N-H} = [N!/H!(N - H)!](\check{T} - 1)^{N-H}/\check{T}^N \quad (2.4)$$

The factorial terms are the binomial coefficient, usually written $\binom{N}{H}$ but formerly written as ${}_NC_H$ or C_H^N; they represent the number of combinations of N objects taken H at a time. For no occurrences, $H = 0$ and the coefficient becomes unity, so equation 2.4 reduces to equation 2.1; for exactly one occurrence, $H = 1$ and the coefficient becomes simply N, so equation 2.4 is N times equation 2.3: the probability of exactly one occurrence in N trials is N times as great as the probability of occurrence for the first time on the Nth trial.

The significance of these equations, especially equations 2.1 and 2.3, becomes clearer if the number of trials N is expressed as a fraction of the true return period $\hat{T}$ by the substitution $N = \hat{T}/r$, where r is any positive number. This substitution permits the evaluation of the equations as $\hat{T}$ increases without limit, since by the definition of e, the base of natural logarithms, the limit of $(1 - a/\hat{T})^{\hat{T}}$ as $\hat{T}$ increases is e^{-a}. Thus the probability that an event x_T, whose return period is $\hat{T}$, *will not occur* within $N = \hat{T}/r$ trials, is (from equation 2.1),

$$(2.5) \qquad P(\hat{x}_N < x_T) = [(\hat{T} - 1)/\hat{T}]^{\hat{T}/r} \xrightarrow[\hat{T} \to \infty]{} e^{-1/r}$$

Likewise, the probability that x_T will *occur for the first time* on the $N = \hat{T}/k$ trial is (from equation 2.3),

$$(2.6) \qquad P[(\hat{x}_{N-1} < x_T)(x_N \geq x_T)] = (\hat{T} - 1)^{(\hat{T}/r)-1}/\hat{T}^{\hat{T}/r} \xrightarrow[\hat{T} \to \infty]{} 0$$

2.4. Risks

These equations illuminate the nature of the intervals between recurrences of x_T in a very long series of trials, of which the average interval $\hat{T}$ is by definition the return period. The median $\check{T}$ is the period with a 50% probability of at least one occurrence (Pascal's original problem), $P(\hat{x}_N \geq x_T) = 1 - e^{-1/r} = \frac{1}{2}$. As $\hat{T}$ increases, $1/r$ approaches log 2 $= 0.69315$, so that the median is a little more than $\frac{2}{3}$ of the average, i.e., $\check{T} \doteq 0.7\hat{T}$. The mode, $\tilde{T}$, or most frequent interval between recurrences, is always 0: there is more chance that an extreme value will recur on the next trial following an occurrence (interval 0) than that it will recur for the first time on any specific trial thereafter, but this probability for any specific trial approaches 0 as $\hat{T}$ increases without limit.

When $r = 1$, that is $N = \hat{T}$, the probability by equations 2.4 and 2.5 for various occurrences of an event x_T during a very long period equalling its average return period $\hat{T}$ approach:

0 occurrences	$1/e = 0.36788$
1 occurrence	$1/e = 0.36788$
2 or more occurrences	$= 0.26424$
	1.00000

Consequently, the probability that the event x_T will occur at least once in an infinitely long series is 0.63212, not much less than the value 0.638 given above for occurrences of a double six in 36 throws of two dice. Actually, the limiting values can be used for practical purposes whenever $\hat{T}$ exceeds 10 or 15, as shown in Table II.

Practical application of these findings can be made readily in terms of calculated risks. The probability (equations 2.1 and 2.5) that an event x_T, whose return period is $\hat{T}$, *will not occur* in any of $N = \hat{T}/r$ trials is also the probability that in each of these trials the variable x will be less than the value x_T. This in turn may be considered as the confidence that a structure, designed to withstand a maximum event

TABLE II. Factor r by which desired lifetime N must be multiplied to obtain design return period T_d for various calculated risks U (equation 2.8).

Calculated risk, U		.632	.500	.400	.333	.300	.250	.200	.100	.050
Desired life, N	2	1.27	1.71	2.22	2.73	3.06	3.73	4.74	9.75	19.76
	10	1.05	1.49	2.01	2.52	2.85	3.52	4.52	9.52	19.57
	∞	1.00	1.44	1.96	2.47	2.80	3.45	4.48	9.49	19.50

whose return period is $\hat{T}$, *will not fail* in a shorter period $\hat{T}/r$. Thus the confidence is 50% that a bridge designed to withstand a 100-year flood, but which will fail in the slightly larger 101-year flood, will not be washed out in less than about 70 years; the confidence that it will not be washed out in 100 years is only 37 percent—the risk of such failure is consequently 63 percent.

Conversely, for any desired lifetime $N = \hat{T}/r$, and a *calculated risk* of failure U within a lesser interval, the *design return period* T_d can be determined by substituting for N in equation 2.2 and solving for r:

$$(2.7) \qquad U = P(\hat{x}_r \geq x_T) = 1 - (1 - 1/T_d)^{T_d/r} \xrightarrow[T_d \to \infty]{} 1 - e^{-1/r}$$

$$(2.8) \qquad r = \log (1 - 1/T_d)^{T_d}/\log (1 - U) \xrightarrow[T_d \to \infty]{} -1/\log (1 - U)$$

Values of r are given in Table II for various calculated risks U and for lifetimes N of 2 and 10 (trials, e.g. years) as calculated from the exact first portion of equation 2.8, as well as the limiting values from the second part. These limiting values are approached so rapidly that they may be used with sufficient accuracy for any desired lifetimes greater than 10 or 15. This table indicates, for example, that a tower which is to last 50 years, with a risk of only 10% of failure due to strong winds before that time, should be designed for the strongest wind expected in $T_d = 50 \times 9.49 = 475$ years.

Tables II and I show dif[illegible]nt aspects of the same fundamental fact: that the intervals between recurrences of an event are variable. This fact, though known intuitively and demonstrable as a corollary of a problem solved more than 300 years ago, has not been used extensively in numerical estimates. One of the few investigations of the problem, by Thomas [23], used a different version of equation 2.4 (for the probability of exactly H occurrences in N trials), considered as a general expression of which others such as equations 2.1, 2.2, and 2.3 are special cases. By this more indirect method, conclusions analagous to those presented here were reached, and the resulting tables are reproduced in a recent textbook [24].

2.5. Theory

Use of Table II implies accurate estimation of the magnitude of x_d, the "design extreme" whose return period T_d is obtained from the table for the desired lifetime N and calculated risk U. Such estimation, however, is subject to the limitations of Table I as long as it is based on only the observed relative frequency of the extreme in question. Improvement in the estimate can be achieved only by increasing the size of the sample from which the relative frequency is determined, or by weighting or correcting the estimate in some way.

The most obvious weighting procedure is to consider all the observed extremes instead of only the extremes equalling or exceeding the required value. In effect, this process increases the sample size synthetically, and thus narrows the confidence limits of the estimate. The various empirical weighting procedures proposed in the last few decades have been replaced in recent years by a newer method, with theoretical foundations: the statistical theory of extreme values.

From foundations laid during the previous 15 years, the statistical distribution of the extreme values in a sample was developed during the 1930s by Dr. Emil J. Gumbel [25]. (The fundamentals of the theory are summarized by Kendall [26].) After applying the theory to such widely diverse things as the ages of the oldest inhabitants of each region and the intervals between radioactive emissions, Gumbel adapted it to flood analysis and introduced it in this form [27] shortly after coming to the United States in 1940.

The theory attracted widespread interest, and was adapted by others [7, 28] for hydrological computations, and applied to breaking strength [29] problems, the determination of gust loads on aircraft [30], and to climatic evaluations [31]; additional refinements were made by Gumbel [32].

The theory applies to the largest (or smallest) values in each of N independent sets of n independent observations each, drawn from the same population. This parent population must be distributed according to some exponential law (as is the normal distribution), so that it is unlimited but tends to zero as the variable increases or decreases; the distribution also must possess all moments.

While based on these premises, in practice the theory may be applied

to many cases in which some of the conditions are met only approximately. In particular, it may be used for extremes of distributions which are limited at either end, as long as the limits are well beyond the region of observation. Temperature has a definite lower limit (absolute zero) and possibly an upper limit, but since these are far removed from the values observed on earth, extremes of air temperature (or water, or rocks) may be analyzed by the theory. Similarly, rainfall amounts and flood stages can be analyzed if the smallest values in each set are still well above zero: the highest flood stage of each year in a perennial river can be analyzed, but not the highest stage in a dry wash which may have no water at all for several years in a row.

The fundamental theorem of the theory of extreme values is:

> In a set of N independent extremes $x_1, x_2, x_3, \ldots x_N$, each being the extreme of one of N sets of n observations each of an unlimited, exponentially-distributed variable, as both N and n grow large the cumulative probability that any one of these N extremes will be less (greater, for smallest values) than any chosen quantity, x, approaches the double exponential expression

$$q(x) = \Phi(x) = \exp[-e^{\mp a(x-\hat{x})}] \tag{2.9}$$

In the exponent, the − sign applies for largest extremes, the + sign for smallest extremes; "exp" is another way of writing "e to the power": $\exp(x) = e^x$. This expression gives the probability of nonoccurrence $q(x)$ of the event x in a single trial, and thus affords a way of determining the probability of occurrence $p = 1 - q = 1 - \Phi(x)$ used in Sections 2.3 and 2.4. Consequently, the return period of extremes equal to or exceeding x is

$$\hat{T}_x = 1/[1 - \Phi(x)] \tag{2.10}$$

Introduction of the expression for $\Phi(x)$, equation 2.9, into equation 2.10 yields a most unwieldy expression, so that in practice the probability of non-occurrence, $\Phi(x)$, is obtained first, and then the return period is found.

2.6 Description

The manner in which this probability of non-occurrence, $\Phi(x)$, varies with x is shown by differentiation:

$$\Phi'(x) = a \cdot e^{\mp a(x-\hat{x})}\,\Phi(x) \tag{2.11}$$

Further differentiation shows that the density of probability (Section 1.5) is a maximum at $x = \hat{x}$, i.e., that $\hat{x}$ is theoretically the most frequent value (mode) of the set of extremes being considered. Graphing reveals the density function (equation 2.11) to be a generally bell-shaped curve, roughly similar to the normal curve but skewed markedly (to the right for largest values, to the left for smallest values), so that the mean is different from the mode (it is greater for largest values, less for smallest values).

The skewness of the density of probability curve shows that there is a greater likelihood of very great extremes than of very small ones, i.e., than of extremes which are closest to the mean of the parent values. Although derivation of the theory of extreme values is far beyond the scope of this article, some intuitive basis for it can be mentioned.

In any fair-sized sample drawn from a normal distribution, or from one of the same general unimodal, unlimited type, it is almost certain that there will be at least one value as much as one standard deviation greater than the mean. On the other hand, since the distribution from which the extremes are drawn has no limits, a few such samples will contain values greater than the mean by more than three standard deviations. Consequently, when the extremes of each of many such samples are considered as a group, they are found to range from around one standard deviation above the mean of the original distribution up to a few very large values, but to be concentrated close to the lower end of this range.

The skewness of the density distribution of the extreme value function is shown in Fig. 1, which also illustrates the relation between a set of extremes and the observations from which it is drawn. The large histogram, to which a normal curve has been fitted, shows the frequency of occurrence of the highest temperature of each summer day (June-July-August) at Washington, D. C., during 74 years—a total of 6,808 daily observations [33].

In the lower right a solid histogram shows the frequency of occurrence of the highest temperature in each of the 74 summers, with an extreme value probability density curve fitted to it. Since the daily values are by 5°F class intervals, the scale for the annual values has been multiplied by 5 to make the two curves comparable.

One moral of Fig. 1 is that even a small set of extreme values must represent a relatively large number of actual observations, since each value in the set of N extremes is itself the extreme of a large number, n, of readings: here $N = 74$, $n = 92$, since this example involves the extremes of each of 74 sets of observations each containing 92 observations. The theory of extreme values assumes both N and n to be large, and in general it should not be applied if either is less than 20, and preferably 30 or even 50.

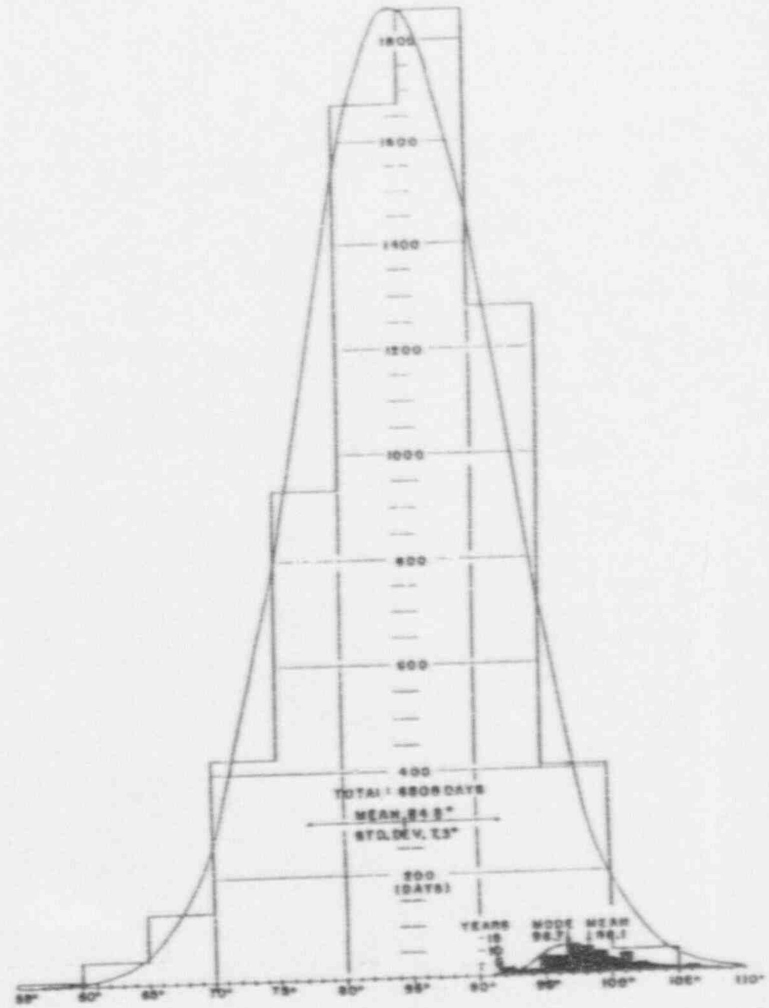


FIG. 1. Frequencies of highest temperatures of each summer day and year. Washington, D. C., 74 years (1872–1945), June-July-August.

The highest daily temperatures in Fig. 1 are not fitted too well by a normal curve—they are skewed somewhat to the right, but not as much as would be required if they were independent values and thus subject to the theory of extreme values. Incidentally, the analysis of the extremes applies only to summer: in five of the 74 years, the highest temperature of the year came outside the three summer months, once in May and four times in September.

2.7. Parameters

In the density distribution (equation 2.11) of extreme values, the inflection points, where curvature changes from convex upward around the mode to concave in the tails, are at $x - \tilde{x} = \pm 0.9624/a$; in the normal curve, the inflection points are at $\pm\sigma$. Thus $1/a$ is somewhat analagous to σ, in that it indicates the degree of dispersion of the various extremes about their mode; consequently, "a" itself is a measure of concentration about the mode.

This measure of concentration, a, and theoretical mode, $\tilde{x}$, of any set of extremes depend in theory on the density distribution $f(x)$ of the entire set of values and on its integral, the cumulative probability function $F(x)$:

(2.12) $$a = n\, f(x) \quad \text{and} \quad F(\tilde{x}) = 1 - 1/n$$

Since these theoretical definitions require knowledge of the density distribution of the population from which the set of extreme values has been drawn, and in general the only knowledge of this population is derivable from the sample, these definitions cannot be used in practice. Instead, these two values are estimated by the theory of least squares from the data of the sample (as explained in Section 2.8), using two theoretical quantities:

(2.13) $$a = \sigma_N/s_x \quad \text{and} \quad \tilde{x} = \bar{x} \mp s_x(\bar{y}_N/\sigma_N)$$

Here $\bar{x}$ is the mean and s_x the standard deviation of the set of extremes, while the mean $\bar{y}_N$ and standard deviation σ_N of a theoretical variate depend only on the sample size N, and thus can be tabulated for ready use. Table III gives their values for every integer of N from 15 to 100, and for selected greater sample sizes; linear interpolation is adequate when $N > 100$ since as N increases both quantities approach limiting values asymptotically. Table III was computed by Dr. Gumbel [31].

Because the double exponential form of the basic equation (2.9) imposes difficulties in computation and analysis, it is reduced to linear form by taking the double ("iterated natural") logarithm of both sides; a new variate, $y = -\log[-\log \Phi(x)]$, is called the *reduced variate:*

(2.14) $$y = \pm a\,(x - \tilde{x})$$

Solved for x, this equation becomes

(2.15) $$x = \tilde{x} \pm y/a$$

With the definitions of Eq. 2.13 introduced, this expression becomes

(2.16) $$x = \bar{x} \pm (s_x/\sigma_N)(y - \bar{y}_N)$$

TABLE III. Reduced means and standard deviations of reduced extremes.

Sample size N	Reduced mean $\bar{y}_N$	Std. dev. σ_N	Sample size N	Reduced mean $\bar{y}_N$	Std. dev. σ_N	Sample size N	Reduced mean $\bar{y}_N$	Std. dev. σ_N
15	.5128	1.0206	50	.5485	1.1607	85	.5578	1.1973
16	.5157	1.0316	51	.5489	1.1623	86	.5580	1.1980
17	.5181	1.0411	52	.5493	1.1638	87	.5581	1.1987
18	.5202	1.0493	53	.5497	1.1658	88	.5583	1.1994
19	.5220	1.0565	54	.5501	1.1667	89	.5585	1.2001
20	.5236	1.0628	55	.5504	1.1681	96	.5586	1.2007
21	.5252	1.0696	56	.5508	1.1696	91	.5587	1.2013
22	.5268	1.0754	57	.5511	1.1708	92	.5589	1.2020
23	.4283	1.0811	58	.5515	1.1721	93	.5591	1.2026
24	.5296	1.0864	59	.5518	1.1734	94	.5592	1.2032
25	.5309	1.0915	60	.4421	1.1747	95	.5593	1.2038
26	.5320	1.0961	61	.5524	1.1759	96	.5595	1.2044
27	.4332	1.1004	62	.5527	1.1770	97	.5596	1.2049
28	.5343	1.1047	63	.5530	1.1782	98	.5598	1.2055
29	.5353	1.1086	64	.5533	1.1793	99	.5599	1.2060
30	.5362	1.1124	65	.5535	1.1803	100	.5600	1.206[illegible]
31	.5371	1.1159	66	.5538	1.1814	150	.5646	1.22534
32	.5380	1.1193	67	.5540	1.1824			
33	.5388	1.1226	68	.5543	1.1834	200	.5672	1.23598
34	.5396	1.1255	69	.5545	1.1844	250	.5688	1.24292
35	.5402	1.1285	70	.5548	1.1854			
36	.5410	1.1313	71	.5550	1.1863	300	.5699	1.24786
27	.5418	1.1339	72	.5552	1.1873			
38	.5424	1.1.63	73	.5555	1.1881	400	.5714	1.25450
39	.5430	1.1388	74	.5557	1.1890			
40	.5436	1.1413	75	.5559	1.1898	500	.5724	1.25880
41	.5442	1.1436	76	.5561	1.1906			
42	.5448	1.1458	77	.5563	1.1915			
43	.5453	1.1480	78	.5565	1.1923	750	.5738	1.26506
44	.5458	1.1499	79	.5567	1.1930			
45	.5463	1.1519	80	.5569	1.1938	1000	.5745	1.26851
46	.5458	1.1538	81	.5570	1.1945			
47	.5473	1.1557	82	.5572	1.1953	Inf.	.5772	1.28255
48	.5477	1.1574	83	.5574	1.1959			
49	.5481	1.1590	84	.5576	1.1967			

where, as before, the upper sign is used for extremes of maximums, the lower for those of minimums. This equation gives the *expected extreme* for any set of N extremes, that is, the extreme value for which the true return period $\bar{T}$ corresponds to the probability given by y.

In this form, the results of application of the theory of extreme values to a set of extremes can be compared with results given by earlier, more empirical formulas. A "general formula for hydrologic frequency analysis," applicable to all analyses of the probabilities or return periods of extreme values, has recently been proposed by Chow [34]. With notation altered to conform to the remainder of this article, it is:

$$x = \bar{x} + Ks_x \qquad (2.17)$$

where x is the departure of an individual observation (flood) from the mean $\bar{x}$ of the series, s_x is the standard deviation of x (i.e., of the series), and K is a "frequency factor . . . which depends upon the law of occurrence" of the particular event.

The only difference between various methods, each of which assumes a different law of occurrence, is in their definition of K, computation of which in some cases is quite laborious and requires extensive tables. By dividing equation 2.17 by $\bar{x}$, Chow obtained an expression for the "y-mean ratio" (in his notation y is used where x is used here) in terms of K and the coefficient of variation:

$$x/\bar{x} = 1 + K(s_x/\bar{x}) \qquad (2.18)$$

This form he considered more useful than the first (2.17) in comparing various formulas.

From equation 2.16, the "frequency factor" for the theory of extreme values is:

$$K = \pm(y - \bar{y}_N)/\sigma_N \qquad (2.19)$$

Since y is the double logarithm ("iterated natural logarithm") of the probability, and $\bar{y}_N$ and σ_N depend only on the sample size, K can be tabulated readily, as in Table IV. With the values in this table, the

TABLE IV. Values of $K = \pm(y_T - \bar{y}_N)/\sigma_N$ for various probabilities $\Phi(x)$ and various sample sizes N.

	$\Phi(x) = 1 - 1/T$						
N	0.999	0.990	0.980	0.960	0.950	0.900	0.800
15	6.265	4.005	3.321	2.631	2.310	1.703	0.967
20	6.006	3.836	3.179	2.517	2.302	1.625	0.919
25	5.812	3.728	3.088	2.444	2.235	1.575	0.888
30	5.727	3.653	3.026	2.393	2.188	1.541	0.866
40	5.578	3.554	2.943	2.326	2.126	1.495	0.838
50	5.478	3.491	2.889	2.283	2.086	1.466	0.820
70	5.359	3.413	2.824	2.230	2.038	1.430	0.797
100	5.261	3.349	2.770	2.187	1.998	1.401	0.779
200	5.130	3.263	2.698	2.129	1.944	1.362	0.755

expected extreme x whose probability of not being equalled or exceeded (equation 2.9) is $\Phi(x) = \exp(-e^{-y})$, and therefore whose return period is (equation 2.10) $T_x = 1/[1 - \Phi(x)]$, can be computed if the mean $\bar{x}$ and standard deviation σ_x of N extremes are available. For example, the extreme expected to occur (on the average over a long period) once in 100 years [$\Phi(x) = 0.990$] is 3.65 s_x greater than the mean of $N = 30$ extremes.

Conversely, the expected return period $\bar{T}_x$ corresponding to any given extreme value x can be obtained from equations 2.10, 2.13, and 2.14, but the resulting expression is cumbersome, and the determination is easier by the methods outlined in Section 2.10.

2.8. Computations

Certain computations based on the theory of extreme values can be made directly from a set of extremes (obtaining the mean $\bar{x}$ and standard deviation s_x) by the use of Tables III or IV, and equations 2.16 or 2.17. For complete analysis of a set of extremes, however, and in particular to determine how well the set follows the theory, it is more convenient to graph the data, using a special extreme probability paper.

On this paper, one of the coordinates is linear, for the observed extremes (denoted by x), while the other is double logarithmic, for $\Phi(x)$ which is (equation 2.9) a double exponential expression. In the original version of this paper [7, 27], the double-logarithmic coordinate was the abscissa; in a revised version [31] the coordinates are reversed so that the observed values, denoted by x, are plotted along the abscissa as is customary, and the double-logarithmic scale is the ordinate. To facilitate plotting and analysis, there are two other ordinate scales: at the left a linear scale for the reduced variate y, and at the right a quasilogarithmic scale for the return period T.

Extreme probability paper is identical in function and use to other probability papers (Section 1.4), and observations are plotted on it by rank and magnitude. Each extreme is plotted at an abscissa corresponding to its value and at an ordinate, on the double-logarithmic scale, corresponding to its cumulative rank divided by $N + 1$. All such points are then connected by short straight lines, producing a zig-zag line which should, if the entire set follows the theory of extreme values, approximate a straight line.

This straight line is simply equation 2.14 or 2.15, which was fitted to the observations by a method of least squares: the estimates of a and $\bar{x}$ (equation 2.13) actually minimize the sum of the diagonal distances from the line to each plotted point representing one of the observed extremes. Ordinary least squares procedure minimizes the sums of either the horizontal or vertical departures, but this method provides a best fit, independent of whether x or y is considered as the independent variable.

This "line of expected extremes" is expressed customarily by equation 2.15, since in practice specific values of x are determined for various probabilities as represented by y, such as 0 and 5. This procedure, however, implies no dependence of x on y: they are mutually dependent.

To indicate how well the line fits the observations, a confidence band can be drawn on both sides of it. Generally, the limits of this band are chosen so that there is a probability of 0.68268 (corresponding to $\pm\sigma$ of the normal distribution) that the extreme corresponding to any frequency $\Phi(x)$ will fall within the band. For frequencies from 0.15 to 0.85, the width of this band is obtained by dividing a certain theoretical value, here called h, by $a\sqrt{N}$, so that the limits of the band (sometimes called control curves) are, by equation 2.16,

$$x = \bar{x} \pm K s_x \pm h/a\sqrt{N} \tag{2.20}$$

where the first double sign is + for largest values, − for smallest values, and the second gives, respectively, the upper and lower limits of the band. Values of h for various frequencies are:

Freq. $\Phi(x)$:	.150	.200	.300	.400	.500	.600	.700	.800	.850
h:	1.255	1.243	1.268	1.337	1.443	1.598	1.835	2.241	2.585

For frequencies greater than 0.85, the width of the 0.68269 confidence band is calculated for the largest and next-to-largest extremes:

$$\Delta_{x,N} = \pm 1.1407/a \qquad \Delta_{x,N-1} = \pm 0.7592/a[(N-1)/N] \tag{2.21}$$

On either side of the line of expected extremes, intervals as obtained by dividing the tabular values above by $a\sqrt{N}$ are plotted at the corresponding frequencies; the values computed from equation 2.21 are laid off similarly at the frequencies of the largest and next-to-largest observed values, but symmetrically about the line and not about the points representing those observed extremes. Two lines are drawn connecting the points so plotted, forming a characteristic horn-shaped figure; technically, the two lines should be drawn smoothly, with a french curve, but in practice short straight lines are adequate. For frequencies greater than that of the largest observed extreme, the confidence band is extended parallel to the line of extremes at the same width as for the largest value.

Figure 2 shows, for the same data represented by the solid histogram of Fig. 1, the zig-zag plot of the 74 observed extremes, their "line of expected extremes," and the confidence band centered on this line. The scales and grid of Fig. 2 are skeletonized from extreme probability graph paper. Since the ordinate of this paper is doubly logarithmic, most of the

observations are concentrated in the lower part of the diagram: the median (frequency .500 or return period 2) is less than a third of the way up the figure. Because the largest and next-to-largest values in this

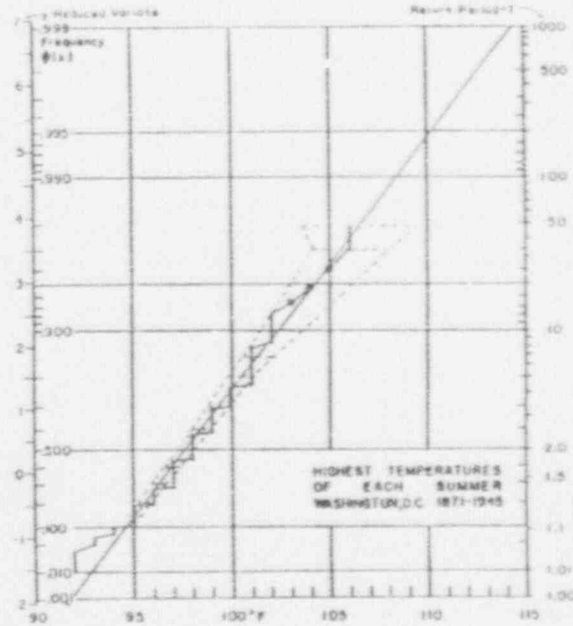


FIG. 2. Highest temperatures of each summer at Washington, D. C. (1871–1945) plotted on extreme probability graph and fitted by line of expected extremes, with confidence band added.

particular example are equal in value (a not uncommon occurrence in some sets of extremes), the confidence band broadens markedly for the last value. In Figure 2 the confidence band has not been extended past the largest observed value, as may be done.

2.9. *Evaluations*

If about two-thirds of the observed extremes as plotted on the extreme probability paper fall within the confidence band, the extremes may be considered to be represented adequately by the theory of extreme values. Usually the largest few values will show the greatest departures from the line, but unless one of them is well outside the confidence band it is not subject to serious question.

The probability p_Δ that the greatest extreme x_N of the sample will depart, by an amount equal to or less than Δ (its actual departure), from its expected value x_T as given by the line of expected extremes (or by equations 2.16 or 2.17) is

$$p_\Delta = \exp(-e^{-a\Delta}) - \exp(-e^{a\Delta}) \qquad (2.22)$$

Values of $a\Delta$, the "relative departure," for various probabilities are:

Probability, p_Δ:	0.0100	0.1000	0.3000	0.5000	0.6827	0.7500	0.9000
Rel. departure, $a\Delta$:	0.0136	0.1342	0.4200	0.7429	1.1407	1.2940	2.2511

When the actual departure Δ of the largest extreme from its expected value is multiplied by "a" (equation 2.13), this table permits estimation of the probability that the largest extreme of the given set could have such a departure.

Another method of determining the reliability of the largest extreme, if it deviates markedly from the expected value, is to omit it from an entire new computation of $\bar{x}$, s_x, and the line of expected extremes, and then determine its relative departure from the new line for evaluation by the above table.

When the most extreme value of a set of extremes is very different from its expected value, which is based on it and all the others in the set, it may be so as the result of chance: there is always a probability of 0.01 that the 100-year value will occur on the next trial (i.e. year). But such a departure warrants investigation of the original data for possible errors in observation, recording, or transcription.

When the two or three most extreme values depart markedly from the expected values, or when many of the observations plot outside the confidence band, the observations simply may not follow the theory of extreme values, for any of several reasons:

a. The set of extremes in question may not be independent.

b. The individual extremes may not be comparable, i.e., may not be extremes of samples from the same population. For example, annual wind extremes at a weather station where the anemometer height or exposure has changed markedly through the years do not follow the theory; nor do maximum annual river stages (heights) if the channel width increases irregularly with the height.

c. The original population, from which independent samples are presumed to have been drawn with each sample yielding a separate extreme, may not be unimodal and unlimited. Maximum relative humidity values would not follow the theory (except in very arid areas) because the upper limit (100%) is within the range of the observations.

Lack of correspondence between observation and theory does not discredit the theory: it merely shows that the theory of extreme values cannot be used to analyze the observations. Thus, unless it has been

established that the variable in question does fall within the scope of the theory, a complete analysis, using a confidence band on extreme probability paper, is desirable before any conclusions are drawn.

2.10 *Applications*

Most practical applications of the theory of extreme values, in geophysics as elsewhere, are concerned primarily with return periods. The information desired usually is either the return period of some specified extreme value, or else the converse, the greatest extreme to be expected within some specified period. Either of these questions can be answered satisfactorily, together with the confidence limits of the answers.

As demonstrated in Sections 2.3 and 2.4, the return period $\hat{T}$ is the average of all the intervals between recurrences of an event in a long series, but half of the intervals will be less than about .7 of this average, and the most probable interval is zero. The probability that an event will not occur until the end of its return period is only 0.37, which is also the probability that it will occur exactly one time before the end of the period.

Confidence limits of the return period also can be expressed in another way. Instead of a single value, the return period can be indicated by the interval within which there is a given probability P_T that the extreme x_T (whose return period is T) will occur. The limits of this interval are bT and T/b, where $e^{-1/b} - e^{-b} = P_T$. This gives, for various values of P_T:

P_T:	.100	.300	.500	.68269	.750	.900	.95450
b:	1.146	1.522	2.105	3.129	3.909	9.503	21.485
$1/b$:	.873	.657	.475	.319	.256	.105	.0465

Thus the probability is .68 that the extreme value x_1 will occur for the first time in at least $.32\hat{T}_x$ and in no more than $3.13\hat{T}_x$.

The first of the two questions concerning extremes, that of the return period $\hat{T}_x$ for a specified extreme value x, is difficult to answer directly. Combination of equations 2.10, 2.13, and 2.14 gives

$$\hat{T}_x = 1/[1 - \exp\{-\exp[\bar{y}_N \pm (x - \bar{x})(\sigma_N/s_x)]\}] \qquad (2.23)$$

Fortunately, as x increases, this converges toward

$$\hat{T}_x \xrightarrow[T_x \to \infty]{} \exp[\bar{y}_N \pm (x - \bar{x})(\sigma_N/s_x)] = e^y \qquad (2.24)$$

In both these equations, the + applies to largest values, the − to smallest. Thus, with the mean $\bar{x}$ and standard deviation s_x of the set of extremes, and the values of $\bar{y}_N$ and σ_N in Table III, $\hat{T}_x$ can be calculated. Usually it is simpler, however, to obtain it graphically: it is read on the return period scale, at the right of the extreme probability paper, opposite the point of intersection of the line of expected extremes with the desired value of x, as given on the abscissa scale at the bottom of the sheet. (Equations 2.23 and 2.24 indicate the nature of the relationship between the return period scale on the right side of the extreme probability paper, the frequency scale in the body of the paper, and the reduced variate scale along the left side; all three scales are indicated in Fig. 2.)

The second question concerning extremes, that of the probable extreme with a given return period T_x, is much simpler: it is answered by equation 2.16 and Table III, or equation 2.17 and Table IV, using $\bar{x}$ and s_x in either case. Or the probable extreme can be read directly on the extreme probability paper: it is the abscissa at which the line of expected extremes intersects the appropriate return period line.

Once the expected extremes, x_1 and x_2, for any two return periods, T_1 and T_2, are determined, the expected extremes x_T for any other return period T_x can be determined:

$$x_T = x_1 + [x_2 - x_1][(y_T - y_1)/(y_2 - y_1)] \tag{2.25}$$

In this equation, the last fraction involving only the reduced variates (y) depends only on the lengths of the two periods T_1 and T_2, and is called Z_T. For two convenient periods of 10 and 100 trials (years), values of

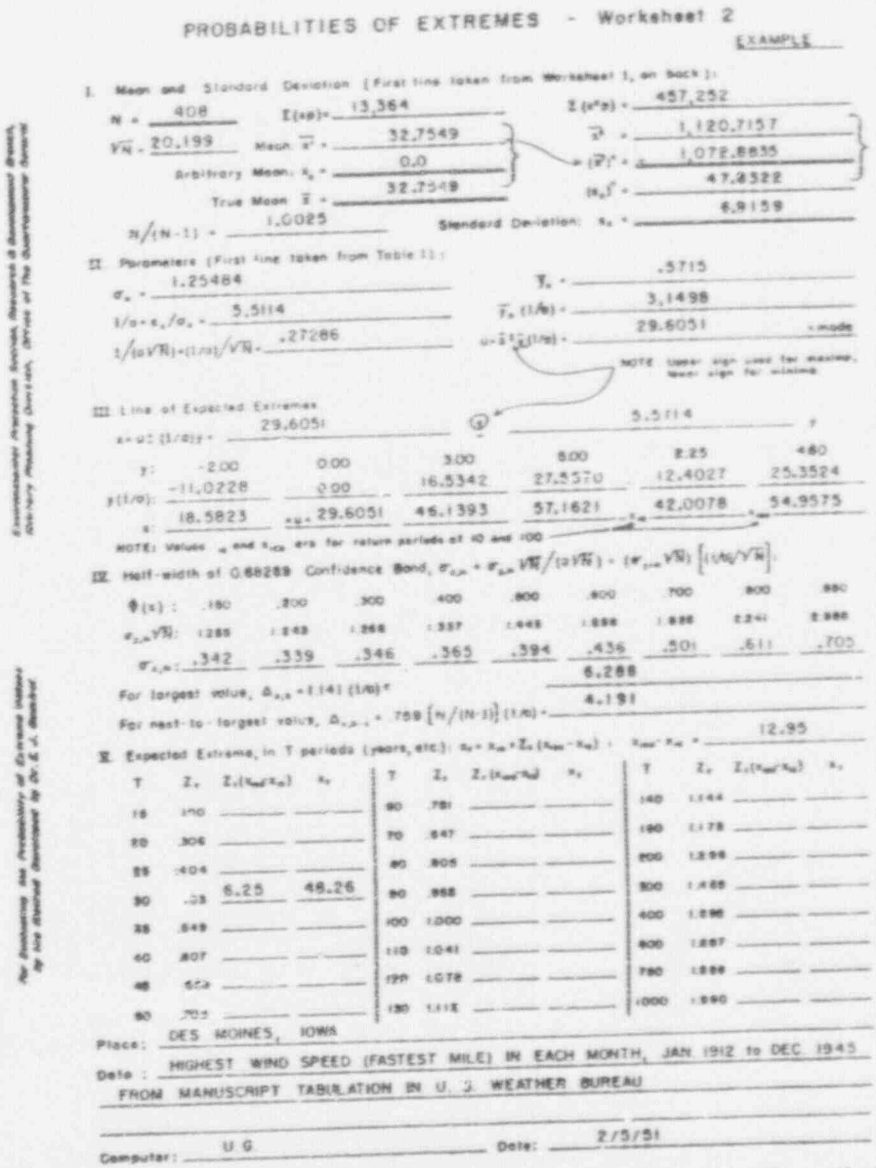
TABLE V. Factor (Z_T) by which difference between 100-year and 10-year extremes must be multiplied to give excess over 10-year value of extreme to be expected in T years.

T	Z_T	T	Z_T	T	Z_T
15	.18018	60	.78118	140	1.14399
20	.30634	70	.84717	150	1.17306
25	.40352	80	.90451	200	1.29607
30	.48257	90	.95497	300	1.46941
35	.54924	100	1.00000	400	1.59159
40	.60682	110	1.04080	500	1.68666
45	.65759	120	1.07812	750	1.85937
50	.70287	130	1.11230	1000	1.98186

Z_T for various other return periods T_x are given in Table V, which can be used to determine the expected extreme for those periods:

$$x_T = x_{10} + Z_T(x_{100} - x_{10}) \tag{2.26}$$

Most of the computations discussed in this and preceding Sections are arranged in logical order on a "Worksheet 2," reproduced as Fig. 3. "Worksheet 1," printed on the reverse of the original of this form, provides space for arranging the extremes in order, computing their mean and standard deviation, and their cumulative frequencies and plotting


PROBABILITIES OF EXTREMES - Worksheet 2

EXAMPLE

I. Mean and Standard Deviation (First line taken from Worksheet 1, on back):

N = 408 Σ(xn) = 13,364 Σ(x²n) = 457,252

√N = 20.199 Mean x' = 32.7549 x'² = 1,120.7157

Arbitrary Mean: x_a = 0.0 $(\bar{x}')^2$ = 1,072.8835

True Mean $\bar{x}$ = 32.7549 $(s_x)^2$ = 47.8322

N/(N-1) = 1.0025 Standard Deviation: s_x = 6.9159

II. Parameters (First line taken from Table II):

σ_N = 1.25484 $\bar{y}_N$ = .5715

$1/a = s_x/\sigma_N$ = 5.5114 $\bar{y}_N(1/a)$ = 3.1498

$1/(a\sqrt{N}) = (1/a)/\sqrt{N}$ = .27286 $u = \bar{x} \mp \bar{y}_N(1/a)$ = 29.6051 = mode

NOTE: Upper sign used for maxima, lower sign for minima

III. Line of Expected Extremes

$x = u \pm (1/a)y$ = 29.6051 ± 5.5114 y

y:	-2.00	0.00	3.00	5.00	2.25	4.60
y(1/a):	-11.0228	0.00	16.5342	27.5570	12.4027	25.3524
x:	18.5823	= u = 29.6051	46.1393	57.1621	x_{10} = 42.0078	x_{100} = 54.9575

NOTE: Values x_{10} and x_{100} are for return periods of 10 and 100

IV. Half-width of 0.68269 Confidence Band, $\sigma_{x,N} = \sigma_{y,N}\sqrt{N}/(a\sqrt{N}) = (\sigma_{y,N}\sqrt{N})[(1/a)/\sqrt{N}]$

Φ(x):	.150	.200	.300	.400	.500	.600	.700	.800	.850
$\sigma_{y,N}\sqrt{N}$:	1.255	1.243	1.268	1.337	1.443	1.598	1.838	2.241	2.585
$\sigma_{x,N}$:	.342	.339	.346	.365	.394	.436	.501	.611	.705

For largest value, $\Delta_{x,N}$ = 1.141 (1/a) = 6.288

For next-to-largest value, $\Delta_{x,N-1}$ = .759 [N/(N-1)] (1/a) = 4.191

V. Expected Extreme, in T periods (years, etc.): $x_T = x_{10} + Z_T(x_{100} - x_{10})$; $x_{100} - x_{10}$ = 12.95

T	Z_T	$Z_T(x_{100}-x_{10})$	x_T	T	Z_T	$Z_T(x_{100}-x_{10})$	x_T	T	Z_T	$Z_T(x_{100}-x_{10})$	x_T
15	.180			60	.781			140	1.144		
20	.306			70	.847			150	1.173		
25	.404			80	.905			200	1.296		
30	.483	6.25	48.26	90	.955			300	1.469		
35	.549			100	1.000			400	1.592		
40	.607			110	1.041			500	1.687		
45	.658			120	1.078			750	1.859		
50	.703			130	1.112			1000	1.982		

Place: DES MOINES, IOWA

Data: HIGHEST WIND SPEED (FASTEST MILE) IN EACH MONTH, JAN 1912 to DEC 1945 FROM MANUSCRIPT TABULATION IN U. S. WEATHER BUREAU

Computer: U G Date: 2/5/51

FIG. 3. Example of computation form for evaluating extremes by the methods discussed in Sections 2.7 to 2.10. Only those portions of the worksheet necessary to answer a particular question need be used. (Taken from [31].)

positions. These two worksheets, and the form of the extreme probability paper used with them, were developed from Gumbel's original work by the Climatology Unit, Environmental Protection Section, Research and Development Branch, Office of The Quartermaster General; they are discussed in a report of this Unit [31], from which Fig. 3 is taken. This example involves winds, rather than the temperatures of Figs. 1 and 2, to present a different application of the theory and method.

2.11. Conclusion

This Section has shown that a combination of classic probability theory and the very recent theory of extreme values permits accurate analysis and evaluation of the extremes of many geophysical elements. The highest temperature, strongest wind, severest earthquake, greatest magnetic disturbance, or worst flood which has occurred or been exceeded only 5 times in 50 years has a relative frequency of 5 in 50 or 0.10, but the best estimate, with 95% confidence, is that its true probability is somewhere between 0.05 and 0.22. Thus its return period is not necessarily 10 years, but is somewhere between 4.5 and 20 years. When all the 50 observations are considered, instead of only the 5 which have equalled or exceeded the value in question, then the theory of extreme values provides a reasonably accurate method of estimating the return period—or the expected extreme for any given return period.

Even after the return period is established, however, the chances are two out of three that the value in question will occur within a shorter interval, and are also two out of three that it will occur in at least 0.32 and no more than 3.13 times the return period. For engineering and similar applications, the *design return period* T_d can be determined (Section 2.4) for any desired lifetime N and calculated risk U of failure in less than T_d:

$$T_d \doteq -N/\log(1 - U) = rN \tag{2.27}$$

Table II provides a simple way of determining T_d for most risks U actually used.

Once this design return period is established, the expected extreme corresponding to it (x_T) can be obtained by the theory of extreme values. This is done most simply by equation 2.17 ($x_T = \bar{x} + Ks_x$) and Table IV, for K; this requires only the mean $\bar{x}$ and standard deviation s_x of N extremes, provided that extremes of the type in question are known to follow the theory reasonably well.

Fundamentally, the theory of extreme values involves the development on strictly theoretical grounds of a function (equation 2.9) for the probability that a given extreme value will not be equalled or exceeded by any one of a very large set of extreme values, obtained as specified. Observed extremes are then fitted to this function by an ingenious least squares procedure, involving in addition several approximations based on the assumption that the sample of observed extremes is so large that limiting (asymptotic) values can be used.

This procedure is essentially similar to that used for the "normal" distribution, and many other statistical and mathematical "laws," in which observed data are fitted to a theoretical function. As is often the case in many other fields, the theoretical function has been found to apply to samples which depart markedly from the original premises (small in number, not wholly independent, not unlimited, etc.). In some cases, however, other samples which apparently should follow the theory equally well do not do so, for some reason which may not be apparent.

Hitherto, many distributions of extreme values, falling within the scope of the theory of extreme values, have been analyzed by other methods. Chief of these has been the logarithmic normal distribution; that is, the logarithms of the individual extremes have been considered to be normally distributed (Section 1.4). Some of the earlier hydrologic analyses used a logarithmic transformation, and more recently the breaking strengths and analogous properties (e.g., water penetrability) have been evaluated by using logarithms.

As yet, no simple method has been proposed to determine whether an actual set of observed data are fitted better by one theoretical function than another. Familiarity with the logarithmic normal procedure, and the complexity of the extreme value theory in its earlier stages, has caused many investigators to prefer the former. It is hoped that the exposition of the theory of extreme values in this section will enable geophysicists and others to determine for themselves whether the newer theory cannot be used to greater advantage in analyzing any problem involving extremes.

3. Circular Distributions

3.1. Requirement

Circular variables are those which vary continuously through all angles of a circle, in contrast to the more familiar linear variables, which may have no limits or be limited on one or both ends. More so than any other science to which statistics is applied, geophysics has many problems involving circular variables: many elements (e.g., winds, tidal forces, magnetic fields) vary around the compass, and almost all geophysical elements vary continuously with time through a day, a lunar month, a solar (27-day) cycle, or a year. Hitherto, such data have been analyzed either as though they were linear, or as trigonometric functions, especially through the use of Fourier series, in which several sine or cosine terms of different amplitudes and periods are added to approximate the original data.

As long as a circular variable does not extend completely around the circle, it can be linearized for statistical analysis without great error. Ocean swells reaching a beach have a total variation in direction of about half a circle, and all days of snowfall in temperate latitudes occur in about half a year. In such cases, statistical analysis based on the normal distribution, or any other linear distribution, is adequate: it may be considered that the variable has no limits on either side. However, when all directions, hours, or months are represented in the distribution of the variable, the linear approach cannot be justified: there is no more logic in considering the day to start and end with midnight than at noon or 7 A.M., and changes in the limits can affect any analysis seriously.

Approximation of a circular variable by a Fourier series avoids the difficulty of artificial limits, but introduces another artificiality: the periods of the various terms usually have no physical basis. What, for example, is the significance of a half-yearly term in a series approximating the annual course of air temperature or geomagnetic intensity? At best, comparison of two circular variables by Fourier series can indicate the phase retardation, i.e., the amount by which the peak of the curve lags behind some point, such as the solstices for temperature. Furthermore, Fourier analysis cannot be applied readily to spatial variables, i.e., those involving directions such as wind.

3.2. *Description*

During the last year, a *circular normal probability function* has been described by Gumbel [35, 36]; when developed it will permit circular variables to be analyzed in the same way that linear variables now are discussed with the aid of the linear "normal curve." The circular normal distribution has the same theoretical basis as the linear normal one: it assumes a large number of random "errors," or departures from the mean, with the frequency of the departures varying inversely with their magnitude.

A crude experiment illustrating the theory of the circular normal distribution is provided by a tiltable roulette wheel. When horizontal, the frequencies of the numbers on which the ball alights is uniform around the wheel. The more it is tilted, the more the frequencies concentrate toward the numbers at the bottom, regardless of their value. When the wheel is inclined by 30° or 40°, the distribution is confined to the two or three numbers at the bottom.

In the equation of the circular normal distribution, the degree of concentration of the variable at one time or direction is indicated by a parameter, denoted by k. This parameter is 0 for a uniform circular distribution, and has no upper limit, although values of k exceeding 3 indicate so great a concentration within a narrow sector that the distribution may be considered as linear. Thus k, a measure of concentration around the mean, is in many ways analogous to the reciprocal of the standard deviation σ of the linear normal distribution, since σ is a measure of dispersion around the mean; k in analogous to "α" in the theory of extreme values (Section 2.7).

The density of probability of the circular normal distribution is:

$$\Phi(\alpha, k) = \frac{1}{I_0(k)} e^{k \cos \alpha} \tag{3.1}$$

where α is the angle measured from the mean, and the denominator involves an incomplete Bessel function of the first kind of zero order for a pure imaginary argument, and has real values.

This function is completely specified by the two parameters, α, the angular departure from the mean, and k, the measure of concentration about the mean. In turn, k may be estimated by the method of maximum likelihood from the observations themselves: it is uniquely determined by the length of the *vector mean* $\bar{a}$ of the data (Table VI). The vector mean is simply the vector sum of the data divided by the total number of *units*, not observations.

TABLE VI. Values of the parameter k of the circular normal distribution corresponding to lengths of the vector mean, $\bar{a}$.

$\bar{a}$	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.000	.020	.040	.060	.080	.100	.120	.140	.160	.181
.1	.201	.221	.242	.262	.283	.303	.324	.345	.366	.387
.2	.408	.430	.451	.473	.495	.516	.539	.561	.584	.606
.3	.629	.652	.676	.700	.724	.748	.772	.797	.823	.848
.4	.874	.900	.927	.954	.982	1.010	[illegible]	1.068	1.098	1.128
.5	1.159	1.191	1.223	1.257	1.291	1.326	1.362	1.398	1.436	1.475
.6	1.515	1.557	1.600	1.645	1.691	1.739	1.790	1.842	1.896	1.954
.7	2.014	2.077	2.144	2.214	2.289	2.369	2.455	2.547	2.646	2.754
.8	2.871	3.000	3.143	3.301	3.479	3.680	3.911	4.177		

For observations which have magnitude as well as direction (such as wind speed by directions or flood stages by dates), the division is by the total number of units (miles per hour, or feet) rather than by the total number of observations; there is no distinction for data which are merely frequencies of occurrence (such as number of hours of wind from each direction or number of people dying per month).

3.3. Procedure

In fitting a circular normal curve to observed data, the first step is to compute the ***resultant direction*** (time or date is considered as a direction) and *length*, which together form the *vector mean*. Basically, two methods for such computation are available: graphical and trigonometric. Each has several variants.

In the graphical method, vectors representing all the observations of each class are added, on plain or ruled paper or on a circular plotting board. Magnitude of the resultant vector, from the start of the first to the end of the last, is measured with a scale, and its direction determined by a protractor. Alternatively, the vectors may be plotted on a polar diagram and their components parallel to two perpendicular axes measured by a scale. From the algebraic sums of each component, the resultant is found as in the first method.

In the trigonometric method, components of each vector are obtained by multiplying it by the appropriate sine and cosine values; after addition, the two components are then used to determine the direction of the resultant by a tangent formula, and its magnitude either from a sine or cosine relation or from the root mean square.

From the vector mean, the proper value of k is found from Table VI, and the equation of the function may be written directly. Or, the observed and theoretical frequencies for each class interval (sector) may be compared, numerically or graphically.

For a numerical comparison of theoretical and observed frequencies, the observations must be regrouped into sectors so that one will be centered on the resultant direction. For example, if the resultant of a series of monthly observations turns out to be 86° (1 Jan. being 0° and 360°), the data originally grouped as 0–30°, 30–60°, 60–90°, etc., must be grouped into the following sectors: 11–41°, 41–71°, 71–101°, etc. The number of observations falling within these new classes can then be compared with the theoretical expectancies, as obtained from the appropriate area table, and multiplied by the number of observations.

In the present stage of development of the circular normal theory, such numerical comparison is not very practical or fruitful. Unless the original data were reported to much greater accuracy than the classes used (such as directions to the nearest degree or time to the nearest minute or day of the year), no basis is as yet available for regrouping them into the new classes based on the resultant. Only in case the resultant happens to fall close to the center of one of the original classes (sectors) can most observational series be compared numerically with the expected frequencies. Furthermore, as yet no criterion has been developed for the goodness of fit of observations to theory (such as is provided by the chi-square test in linear normal theory, or the confidence band in the theory of extreme values).

3.4. Graphing

Comparison of observations and theory can be made most readily and satisfactorily by graphing both the data and the theoretical density of probability. From a carefully drawn graph of the probability density, the expected frequency for each of the original classes (sectors) can be estimated for comparison with the observed frequencies. This eliminates the need to regroup the data for comparison with the probability values given in the area tables.

Such estimates will be most accurate, and any graphical representation or comparison of circular variables more meaningful, if equivalent polar paper is used instead of the customary polar coordinate graph paper. On equivalent polar paper, concentric circles are drawn at distances from the center corresponding to the *square root* of the indicated numbers, instead of the numbers themselves as on the customary paper. Thus, on equivalent polar paper, for each sector the *area is directly proportional to the frequency* which it represents.

The same results may be obtained on conventional polar coordinate paper by using the square roots of the observed and theoretical frequencies. Since equivalent polar paper is not generally available, Table VII gives the square roots, rather than the actual values, of the radius vectors for unit-area circular normal distributions with various k values. This table is condensed from a more extensive one [36], which itself required a complex computational procedure. Table VII gives values for 10° intervals, but satisfactory curves can be plotted by using ordinates at intervals of 20° or 30°.

To obtain a curve for comparison with one plotted from the square roots of n observations grouped into w equal sectors (including any with no observations), the tabular values must be multiplied by $\sqrt{n/w}$; when observations are expressed as percentages, no multiplication of the tabular values is required. In either case, however, square roots of the observed values must be used, until equivalent polar paper becomes available.

Although the principle of equivalent polar paper is obvious, it does not seem to have been applied to any great extent in geophysics, or in graphic presentation generally. Yet a sector is a truer representation of observations which may have fallen anywhere within it than the conventional radius bar or vector, centered in the sector with length directly proportional to the number of observations or their sum or mean.

A similar use of square roots in polar graphing was proposed by Leighly [37] almost a quarter-century ago, but was little used; he did not suggest square-root graph paper. The term "equivalent" for the square-root paper developed for use in graphing the circular normal distribution was suggested by Leighly as the internationally-understood term implying areal equivalence.

3.5. *Limitations*

As previously indicated, circular normal probability theory is a completely new branch of statistics, and as yet has not been developed to the point of general utility. So far, the basic function has been established, and tables computed for the probability function itself (areas of sectors) and the density of probability (radius vectors), Table VII.

Perhaps the most significant aspect of the development at present is the finding that the vector mean of a unimodal distribution of a circular variable uniquely characterizes the degree of concentration of the variable about the angular mean or resultant direction. This vector mean, translated into the parameter k of the distribution function, affords an index of the degree of concentration. Thus, values of k can be computed for various distributions for comparative purposes: the relative concentrations of winds at various places, or at different hours or months in the same place, can be compared.

Such comparison can be only qualitative, however, since no relation comparable to the "t-test" has yet been developed. This is hardly surprising: although the linear normal distribution was developed more than a century ago, the t-test is barely 40 years old. While the circular normal function, with its cosine exponent and incomplete Bessel function, is far more complicated than the linear normal one, its development can proceed rapidly because of analogies with the linear case.

Another serious limitation on the use of the circular normal theory at present is that it applies properly only to unimodal distributions. Many circular distributions in geophysics, however, are bimodal or trimodal. Depending on the period of time covered, wind distributions may show several peaks, flood crests on some rivers come either in early spring (snow melt) or early summer (heavy rains), and so on. Until a method of separating such distributions into two normal components (as can be done for the linear case, as explained in Sections 1.5 and 1.6) bimodal distributions must be regrouped into broader classes (sectors) to form a unimodal distribution for comparison with the circular normal curve.

Whether indices of skewness and kurtosis can be developed for the

TABLE VII. Radius vectors (ordinates) of the circular normal probability function. Tabular values are square roots of distances from center (pole) at indicated angles α from mean (resultant) to a curve of unit total area. To obtain curve for comparison with observed distribution of n observations divided among w sectors and plotted according to the square roots of their observed frequencies by sectors, tabular values must be multiplied by $\sqrt{n/w}$. When equivalent polar paper (square root) is used, tabular values should be squared.

α = angle from mean or resultant

k	Mean	±10°	±20°	±30°	±40°	±50°	±60°	±70°	±80°	±90°	±100°	±110°	±120°	±130°	±140°	±150°	±160°	±170°	180°
0.2	1.100	1.098	1.093	1.085	1.074	1.061	1.046	1.030	1.012	0.995	0.978	0.962	0.946	0.933	0.922	0.912	0.906	0.902	0.900
0.4	1.197	1.194	1.183	1.166	1.143	1.115	1.084	1.050	1.015	0.980	0.947	0.916	0.887	0.862	0.841	0.824	0.812	0.805	0.803
0.6	1.292	1.286	1.269	1.241	1.204	1.160	1.112	1.060	1.008	0.957	0.908	0.864	0.824	0.789	0.760	0.738	0.722	0.712	0.709
0.8	1.381	1.373	1.348	1.309	1.258	1.197	1.131	1.062	0.992	0.926	0.864	0.808	0.758	0.716	0.682	0.655	0.636	0.624	0.621
1.0	1.465	1.454	1.422	1.370	1.304	1.226	1.141	1.054	0.969	0.889	0.815	0.749	0.692	0.644	0.606	0.576	0.556	0.543	0.539
1.2	1.543	1.529	1.489	1.424	1.341	1.246	1.143	1.040	0.940	0.847	0.763	0.690	0.628	0.576	0.535	0.504	0.482	0.469	0.465
1.4	1.616	1.599	1.549	1.471	1.372	1.258	1.139	1.019	0.906	0.802	0.711	0.632	0.565	0.512	0.469	0.438	0.416	0.403	0.398
1.6	1.682	1.662	1.603	1.511	1.395	1.264	1.128	0.994	0.869	0.756	0.658	0.573	0.507	0.452	0.410	0.378	0.356	0.344	0.340
1.8	1.744	1.720	1.652	1.546	1.413	1.264	1.112	0.965	0.829	0.709	0.606	0.521	0.452	0.398	0.356	0.325	0.304	0.292	0.288
2.0	1.800	1.773	1.695	1.575	1.425	1.260	1.092	0.932	0.788	0.662	0.557	0.470	0.402	0.348	0.308	0.279	0.259	0.247	0.244
2.2	1.853	1.822	1.734	1.599	1.432	1.251	1.069	0.898	0.747	0.617	0.509	0.423	0.356	0.304	0.266	0.238	0.219	0.209	0.205
2.4	[illegible]	1.867	1.769	1.619	1.436	1.238	1.043	0.863	0.705	0.573	0.465	0.380	0.314	0.265	0.228	0.203	0.185	0.176	0.172
2.6	1.947	1.908	1.800	1.635	1.436	1.223	1.016	0.828	0.665	0.530	0.423	0.340	0.277	0.230	0.196	0.172	0.156	0.147	0.145
2.8	1.989	1.947	1.828	1.649	1.433	1.206	0.988	0.792	0.625	0.490	0.385	0.304	0.244	0.199	0.168	0.146	0.132	0.124	0.121
3.0	2.029	1.983	1.853	1.659	1.428	1.187	0.958	0.756	0.587	0.453	0.349	0.271	0.214	[illegible]	0.143	0.123	0.111	0.103	0.101
3.2	2.066	2.016	1.876	1.667	1.421	1.167	0.928	0.721	0.551	0.417	0.316	0.241	0.187	0.149	0.122	0.104	0.093	0.086	0.084
3.4	2.102	2.048	1.897	1.673	1.412	1.145	0.898	0.687	0.516	0.384	0.286	0.215	0.164	0.129	0.104	0.088	0.078	0.072	0.070
3.6	2.135	2.078	1.916	1.678	1.401	1.123	0.868	0.653	0.482	0.353	0.258	0.191	0.144	0.111	0.089	0.074	0.065	0.060	0.058
3.8	2.167	2.106	1.933	1.680	1.390	1.099	0.838	0.621	0.451	0.324	0.233	0.169	0.125	0.096	0.076	0.063	0.054	0.050	0.048
4.0	2.198	2.132	1.948	1.681	1.377	1.078	0.809	0.590	0.421	0.297	0.210	0.150	0.109	0.082	0.064	0.053	0.045	0.042	0.040

NPP1-SBX-009 1-20

circular case remains to be seen, as well as many other applications analogous to those of the linear normal curve. Obviously, there are opportunities for many people to develop this new branch of statistics, of such potential value to geophysics.

At present the circular normal theory affords only (1) a measure of the concentration of a circular variable about its resultant and (2) a normal function to which the observations can be compared qualitatively. Yet its development is of benefit to geophysics simply by pointing out that "average" times or dates should be computed vectorially, as are "average" directions, and that circular variables cannot be analyzed adequately by the linear methods of classical statistics.

List of Symbols and Notation

(Section in which first usage is made shown in parentheses)

- a parameter of distribution of extreme values (2.5)
- b factor defining interval of occurrence of extreme value (2.10)
- E excess of distribution $= \nu_4/\sigma^4 - 3$ (1.6)
- e base of natural logarithms $= 2.7182818281$ (2.4)
- $F(x)$ cumulative probability function (1.3)
- $f(x)$ probability density function $= F'(x)$ (1.3)
- H number of occurrences of an event (2.1)
- h factor defining confidence band of extreme values (2.8)
- $I_0(k)$ Bessel function of first kind of zero order for pure imaginary argument (3.2)
- K frequency factor in frequency analyses (2.7)
- k parameter of circular normal distribution (3.2)
- M mean of a bimodal distribution; M_1, M_2 means of components (1.6)
- m_1, m_2 departures of component means from common mean (1.6)
- N size of sample: number of observations in bimodal distribution (1.6); number of trials (2.1); number of observed extremes (2.5); desired lifetime (2.4)
- n number of values in each sample from which extreme is taken (2.5)
- p probability of occurrence (2.3)
- q probability of non-occurrence $= 1 - p$ (2.3)
- r ratio of return period to number of trials $= T/N$ (2.3); of design return period to desired lifetime $= T_d/N$ (2.4)
- s_x standard deviation of x (2.7)
- T return period of an event $= 1/p$ (2.1); T_d = design return period (2.4)
- t normalized deviate of a variable $= (\bar{x} - x)/\sigma$ (1.6)
- w number of sectors of circular distribution (3.4)
- x a variable; an extreme value (2.5)
- y ordinate (1.6); reduced variate of extreme value function (2.7); $\bar{y}_N$ = theoretical mean (2.7)
- Z_T factor to obtain extreme expected in T years (2.10)
- s difference between variances of bimodal distribution and of components $= \sigma_1^2 - \sigma^2$ (1.6)
- α angle of circular distribution measured from mean $\bar{\alpha}$ (3.2)
- α_3 ν_3/σ^3 = skewness (1.6)
- Δ departure of extreme value from expected (2.8)

- ν_3, ν_4 third and fourth moments (1.6)
- π 3.1415926535 (1.6)
- ϕ function of t (1.6)
- Φ of extreme value x (2.5), of circular distribution (3.2)
- σ standard deviation (1.6); σ_N = theoretical standard deviation (2.7)

Notation

- x a variable (2.3)
- x_N Nth value of x (2.3)
- $\bar{x}$ mean of all values of x; $\bar{x}_N$ = mean of N values of x (2.7)
- $\check{x}$ median of all values of x (2.3)
- $\hat{x}$ mode of all values of x (2.4)
- $\dot{x}$ largest of all values of x; $\dot{x}_N$ = largest among N values (2.3)
- $\acute{x}$ smallest of all values of x; $\acute{x}_N$ = smallest of N values (2.3)
- x' first derivative of x (1.3)
- $x!$ factorial $x = 1 \cdot 2 \cdot 3 \cdot 4 \cdot \ldots \cdot x$ (2.3)
- $\doteq$ approximately equal (2.4)
- $\rightarrow$ approaches as a limit (2.3)
- log natural logarithm (2.4)

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Attachment 2

Excerpts from

Wind Effects on Structures

by

Emil Simiu

NPM-SBϕ-009
EH 1/4 2-2

WIND EFFECTS ON STRUCTURES

AN INTRODUCTION TO WIND ENGINEERING

SECOND EDITION

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NPPI-SBØ-009 2-4
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in which sheltering effects by small-scale obstacles are present, the data may be adjusted by using a procedure presented in [3-4].

A situation commonly encountered in practice is one in which, while the anemometer may not have been moved, the roughness of the terrain surrounding the anemometer has changed significantly over the years as a result of extensive land development. In such situations, the adjustment of the data to a common roughness may pose insurmountable problems, unless detailed information on the phases of the land development is available.

Anemometer elevation and location changes are listed for most U.S. weather stations in Local Climatological Data Summaries [3-3].

3.2 ESTIMATION OF EXTREME WIND SPEEDS IN WELL-BEHAVED CLIMATES

Infrequent winds (e.g., hurricanes) that are meteorologically distinct from and considerably stronger than the usual annual extremes are referred to herein as extraordinary winds. Climates in which extraordinary winds may not be expected to occur are referred to as well behaved. In such climates it is reasonable to assume that each of the data in a series of the largest annual wind speeds contributes to the description of the probabilistic behavior of the extreme winds. A statistical analysis of such a series can therefore be expected to yield useful predictions of long-term wind extremes.

Thus, in a well-behaved climate, at any given station a random variable may be defined, which consists of the largest yearly wind speed. If the station is one for which wind records over a number of consecutive years are available, then the cumulative distribution function (CDF) of this random variable may be estimated to characterize the probabilistic behavior of the largest annual wind speeds. The basic design wind speed is then defined as the speed corresponding to a specified value p of the CDF or, equivalently, to a specified mean recurrence interval $\bar{N}$.* A wind corresponding to an $\bar{N}$-year mean recurrence interval is commonly referred to as the $\bar{N}$-year wind.

This section is devoted to the question of estimating (a) the CDF of the largest annual speeds and (b) errors inherent in the wind speed predictions. Such errors include, in addition to those associated with the quality of the data (see Sect. 3.1), *modeling* errors and *sampling* errors. Modeling errors are due to an inadequate choice of the probabilistic model itself. Sampling errors are a consequence of the limited size of the samples from which the distribution parameters are estimated and become, in theory, vanishingly small as the sample size increases indefinitely.

3.2.1 Probabilistic Modeling of Largest Yearly Wind Speeds

Several probability distributions have been proposed to model extreme wind behavior. These include: the Type I distribution of the largest values (Eq. A1.39),

*Recall that $\bar{N} = 1/(1-p)$ (see Appendix A1, Eq. A1.45).

2-6
NPPI-SBØ-009

eters of the distribution and, hence, the value of the variate corresponding to a given mean recurrence interval.* However, inherent in these estimates are sampling errors. A measure of the magnitude of the latter can be obtained by calculating *confidence intervals* for the quantity being estimated, that is, intervals of which it can be stated—with a specified confidence that the statement is correct—that they contain the true, unknown value of that quantity. Techniques that can be used to estimate the $\bar{N}$-year wind, and confidence intervals for the $\bar{N}$-year wind, are discussed in some detail in Sect. A1.6. One of these techniques is presented and illustrated below.

Using the approximation $-\ln[-\ln(1-1/\bar{N})] \simeq \ln \bar{N}$, it follows from Eq. A1.74 (which is based on the method of moments) that the estimated value $\hat{v}_{\bar{N}}$ of the $\bar{N}$-year wind $v_{\bar{N}}$ is

$$\hat{v}_{\bar{N}} \simeq \bar{X} + 0.78(\ln \bar{N} - 0.577)s \qquad (3.2.1)$$

where $\bar{X}$ and s are, respectively, the sample mean and the sample standard deviation of the largest yearly wind speeds for the period of record.

As previously noted, inherent in the estimates of $v_{\bar{N}}$ are sampling errors. It follows from Eqs. A1.76 and A1.70 (which are based on the method of moments) that the standard deviation of the sampling errors in the estimation of $v_{\bar{N}}$ can be written as

$$SD(\hat{v}_{\bar{N}}) \simeq 0.78[1.64 + 1.46(\ln \bar{N} - 0.577) + 1.1(\ln \bar{N} - 0.577)^2]^{1/2} \frac{s}{\sqrt{n}} \qquad (3.2.2)$$

where n is the sample size.

Example

At Great Falls, Montana, the largest yearly fastest-mile wind speeds at 10 m above ground during the period 1944–1977 (sample size $n = 34$) were [3-9]:

57, 65, 62, 58, 64, 65, 59, 65, 59, 60, 64, 65, 73, 60, 67, 50, 74
60, 66, 55, 51, 60, 55, 60, 51, 51, 62, 51, 54, 52, 59, 56, 52, 49

(mph). The sample mean and the sample standard deviation for these data are $\bar{X} = 59$ mph and $s = 6.41$ mph. From Eqs. 3.2.1 and 3.2.2 it follows that for $\bar{N} = 50$ years and $\bar{N} = 1{,}000$ years,

$$\hat{v}_{50} \simeq 76 \text{ mph} \qquad SD(\hat{v}_{50}) \simeq 3.7 \text{ mph}$$

$$\hat{v}_{1000} \simeq 91 \text{ mph} \qquad SD(\hat{v}_{1000}) \simeq 6.4 \text{ mph}$$

If it is assumed that the largest yearly wind speeds are described by a Rayleigh distribution,† the $\bar{N}$-year wind, denoted by $v^R_{\bar{N}}$, can be obtained from Eq. A1.65

*In Appendix A1 this value is denoted by $G_X(p)$, where $p = 1 - 1/\bar{N}$ and $\bar{N}$ is the mean recurrence interval. In this chapter the notation $G_Y(1 - 1/\bar{N}) = v_{\bar{N}}$ is used.

†It is recalled that the Weibull distribution with tail length parameter $\gamma = 2$ is commonly referred to as the Rayleigh distribution. Note that of all Weibull distributions with $\gamma \geq 2$, the Rayleigh distribution is the closest to the Type I distribution (i.e., it has the longest tail).

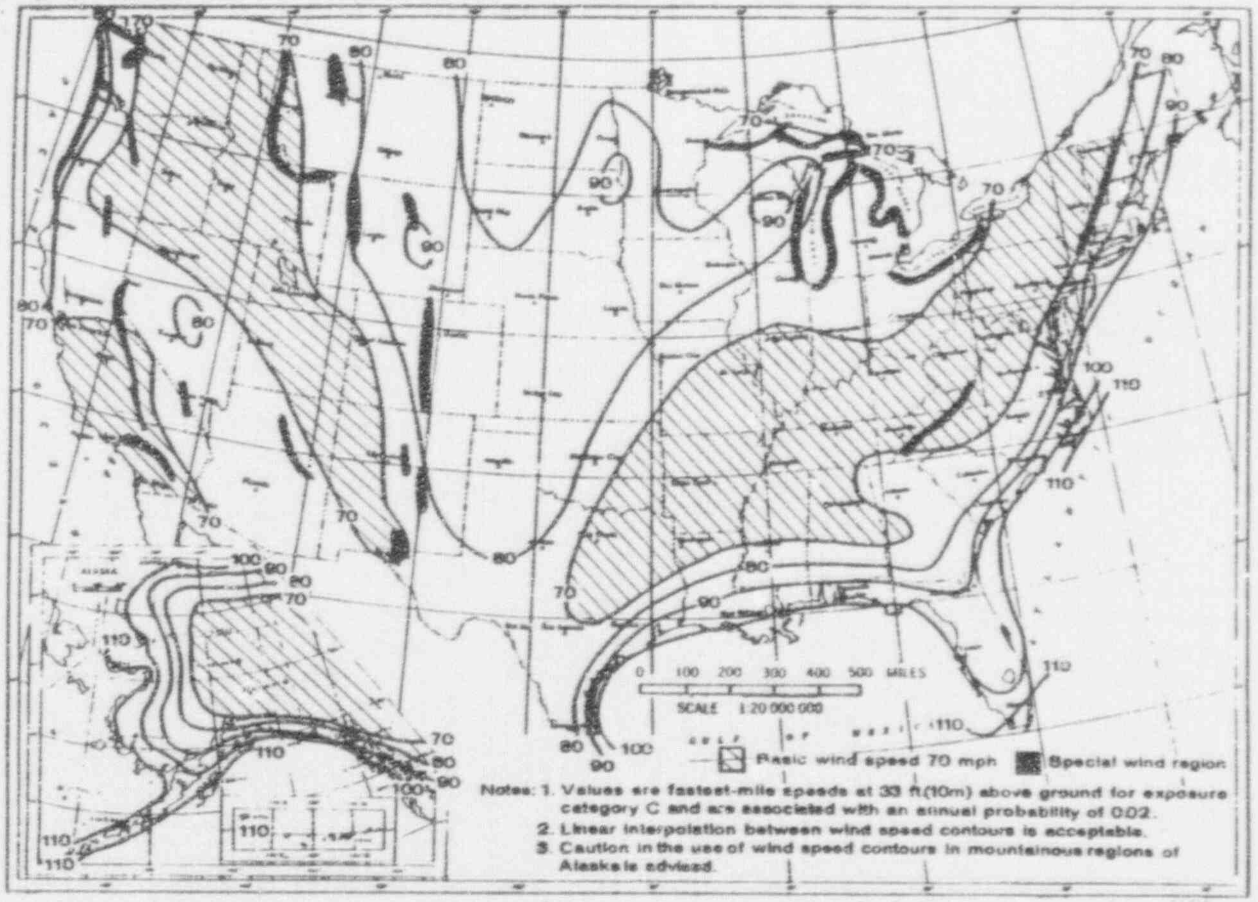

FIGURE 3.2.1. Map of basic design wind speeds. Reproduced with permission from American National Standard A58.1 *Building Code Requirements for Minimum Design Loads in Buildings and Other Structures*, copyright 1982 by the American National Standards Institute. Copies of this standard may be purchased from the American National Standards Institute at 1430 Broadway, New York, NY 10018.

NPPI-586-009
2-8

NPP1-SB0-009
EH 1/4 2-2

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in which sheltering effects by small-scale obstacles are present, the data may be adjusted by using a procedure presented in [3-4].

A situation commonly encountered in practice is one in which, while the anemometer may not have been moved, the roughness of the terrain surrounding the anemometer has changed significantly over the years as a result of extensive land development. In such situations, the adjustment of the data to a common roughness may pose insurmountable problems, unless detailed information on the phases of the land development is available.

Anemometer elevation and location changes are listed for most U.S. weather stations in Local Climatological Data Summaries [3-3].

3.2 ESTIMATION OF EXTREME WIND SPEEDS IN WELL-BEHAVED CLIMATES

Infrequent winds (e.g., hurricanes) that are meteorologically distinct from and considerably stronger than the usual annual extremes are referred to herein as extraordinary winds. Climates in which extraordinary winds may not be expected to occur are referred to as well behaved. In such climates it is reasonable to assume that each of the data in a series of the largest annual wind speeds contributes to the description of the probabilistic behavior of the extreme winds. A statistical analysis of such a series can therefore be expected to yield useful predictions of long-term wind extremes.

Thus, in a well-behaved climate, at any given station a random variable may be defined, which consists of the largest yearly wind speed. If the station is one for which wind records over a number of consecutive years are available, then the cumulative distribution function (CDF) of this random variable may be estimated to characterize the probabilistic behavior of the largest annual wind speeds. The basic design wind speed is then defined as the speed corresponding to a specified value p of the CDF or, equivalently, to a specified mean recurrence interval $\bar{N}$.* A wind corresponding to an $\bar{N}$-year mean recurrence interval is commonly referred to as the $\bar{N}$-year wind.

This section is devoted to the question of estimating (a) the CDF of the largest annual speeds and (b) errors inherent in the wind speed predictions. Such errors include, in addition to those associated with the quality of the data (see Sect. 3.1), *modeling* errors and *sampling* errors. Modeling errors are due to an inadequate choice of the probabilistic model itself. Sampling errors are a consequence of the limited size of the samples from which the distribution parameters are estimated and become, in theory, vanishingly small as the sample size increases indefinitely.

3.2.1 Probabilistic Modeling of Largest Yearly Wind Speeds

Several probability distributions have been proposed to model extreme wind behavior. These include: the Type I distribution of the largest values (Eq. A1.39),

*Recall that $\bar{N} = 1/(1-p)$ (see Appendix A1, Eq. A1.45).

2-5
NPP1 - SB0-009
EA 13

the Type II distribution of the largest values (Eq. A1.42), and the Weibull distribution (Eq. A1.65). Extreme wind speeds inferred from any given sample of wind speed data depend on the type of distribution on which the inferences are based. For large mean recurrence intervals ($\bar{N} > 50$ years, say) estimates based on the assumption that a Type II distribution is valid are higher than corresponding estimates obtained by using a Type I distribution, while estimates based on a Weibull distribution with tail length parameter $\gamma \geqslant 2$ are lower.*

According to [3-5], extreme winds in well-behaved climates may be assumed to be best modeled by a Type II distribution with $\mu = 0$ and $\gamma = 9$. However, subsequent research has shown that this assumption is not borne out by analyses of extreme wind speed data [3-6, 3-7, 3-8]. In [3-6], 37 year-series of 5 minute largest yearly speeds measured at stations with well-behaved climates were subjected to the probability plot correlation coefficient test (see Sect. A1.6) to determine the tail length parameter of the best fitting distribution of the largest values. Of these series, 72% were best fit by Type I distributions or by Type II distributions with $\gamma = 13$ (which differ insignificantly from the Type I distribution); 11% by Type II distributions with $7 \leqslant \gamma < 13$; and 17% by Type II distribution with $2 \leqslant \gamma < 7$. Virtually the same percentages were obtained in [3-7] from the analysis of sets of 37 data generated by the Monte Carlo simulation from a population with a Type I distribution. On the other hand, the analysis of sets generated by Monte Carlo simulation from a Type II distribution with tail length parameter $\gamma = 9$ led to percentages differing significantly from those corresponding to the actual wind speed data. On the basis of these results it can be confidently stated that in well-behaved climates extreme wind speeds are modeled more realistically by the Type I than by the Type II distribution with $\gamma = 9$. This conclusion was reinforced by studies reported in [3-8], in which techniques similar to those of [3-7] were used in conjunction with wind speed data at one hundred United States weather stations obtained from [3-9].

As indicated earlier, the Type I distribution results in lower estimates of the extreme wind speeds than the Type II distribution with $\gamma = 9$. An interesting result obtained in [3-8] is that at most stations in the United States even the Type I distribution appears to be an unduly severe model of the wind speeds corresponding to large mean recurrence intervals; at these stations a better fit to the data is obtained by Weibull distributions with $\gamma \geqslant 2$. Thus, structural reliability calculations based on the assumption that the Type I distribution holds are in most cases likely to be conservative [3-10].

3.2.2 Estimation of and Confidence Intervals for the $\bar{N}$-year Wind: Numerical Example

It is shown in Sect. A1.6 that, given a set of data with a Type I extreme value underlying distribution, several techniques can be used to estimate the param-

*The differences between speeds estimated on the basis of Type II distributions and the Type I distribution increase as γ decreases. Differences between speeds based on the Type I distribution and Weibull distributions increase as γ increases.

2-6
NPPM-SBØ-009
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eters of the distribution and, hence, the value of the variate corresponding to a given mean recurrence interval.* However, inherent in these estimates are sampling errors. A measure of the magnitude of the latter can be obtained by calculating *confidence intervals* for the quantity being estimated, that is, intervals of which it can be stated—with a specified confidence that the statement is correct—that they contain the true, unknown value of that quantity. Techniques that can be used to estimate the $\bar{N}$-year wind, and confidence intervals for the $\bar{N}$-year wind, are discussed in some detail in Sect. A1.6. One of these techniques is presented and illustrated below.

Using the approximation $-\ln[-\ln(1-1/\bar{N})] \simeq \ln \bar{N}$, it follows from Eq. A1.74 (which is based on the method of moments) that the estimated value $\hat{v}_{\bar{N}}$ of the $\bar{N}$-year wind $v_{\bar{N}}$ is

$$\hat{v}_{\bar{N}} \simeq \bar{X} + 0.78(\ln \bar{N} - 0.577)s \tag{3.2.1}$$

where $\bar{X}$ and s are, respectively, the sample mean and the sample standard deviation of the largest yearly wind speeds for the period of record.

As previously noted, inherent in the estimates of $v_{\bar{N}}$ are sampling errors. It follows from Eqs. A1.76 and A1.70 (which are based on the method of moments) that the standard deviation of the sampling errors in the estimation of $v_{\bar{N}}$ can be written as

$$SD(\hat{v}_{\bar{N}}) \simeq 0.78[1.64 + 1.46(\ln \bar{N} - 0.577) + 1.1(\ln \bar{N} - 0.577)^2]^{1/2} \frac{s}{\sqrt{n}} \tag{3.2.2}$$

where n is the sample size.

Example

At Great Falls, Montana, the largest yearly fastest-mile wind speeds at 10 m above ground during the period 1944–1977 (sample size $n = 34$) were [3-9]:

57, 65, 62, 58, 64, 65, 59, 65, 59, 60, 64, 65, 73, 60, 67, 50, 74
60, 66, 55, 51, 60, 55, 60, 51, 51, 62, 51, 54, 52, 59, 56, 52, 49

(mph). The sample mean and the sample standard deviation for these data are $\bar{X} = 59$ mph and $s = 6.41$ mph. From Eqs. 3.2.1 and 3.2.2 it follows that for $\bar{N} = 50$ years and $\bar{N} = 1{,}000$ years,

$$\hat{v}_{50} \simeq 76 \text{ mph} \qquad SD(\hat{v}_{50}) \simeq 3.7 \text{ mph}$$

$$\hat{v}_{1000} \simeq 91 \text{ mph} \qquad SD(\hat{v}_{1000}) \simeq 6.4 \text{ mph}$$

If it is assumed that the largest yearly wind speeds are described by a Rayleigh distribution,† the $\bar{N}$-year wind, denoted by $v^R_{\bar{N}}$, can be obtained from Eq. A1.65

*In Appendix A1 this value is denoted by $G_X(p)$, where $p = 1 - 1/\bar{N}$ and $\bar{N}$ is the mean recurrence interval. In this chapter the notation $G_X(1-1/\bar{N}) = v_{\bar{N}}$ is used.

†It is recalled that the Weibull distribution with tail length parameter $\gamma = 2$ is commonly referred to as the Rayleigh distribution. Note that of all Weibull distributions with $\gamma \geq 2$, the Rayleigh distribution is the closest to the Type I distribution (i.e., it has the longest tail).

2-7
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(with $\gamma = 2$) as follows:

$$v_{\bar{N}}^{R} \simeq \bar{X} + \frac{s}{0.463}\left[(\ln \bar{N})^{1/2} - 0.886\right] \tag{3.2.3}$$

where $\bar{X}$ and s are defined as in Eq. 3.2.1. In the case of Great Falls, $\bar{X} = 59$ mph and $s = 6.41$ mph, so that $v_{50}^{R} = 74$ mph and $v_{1000}^{R} = 83$ mph, versus $v_{50} = 76$ mph and $v_{1000} = 91$ mph, as estimated in the preceding example by assuming the validity of the Type I distribution. As indicated previously, in engineering calculations it is prudent to assume the validity of the Type I distribution (Eq. 3.2.1), rather than using Eq. 3.2.3. This conservative approach was adopted in developing the map of basic design wind speeds (i.e., fastest-mile wind speeds at 10 m above ground in open terrain, with a 50-year mean recurrence interval) included in the American National Standard A58.1 [2-49] (Fig. 3.2.1).

As shown in Sect. A1.6, the probabilities that $v_{\bar{N}}$ is contained in the intervals $\hat{v}_{\bar{N}} \pm SD(\hat{v}_N)$, $\hat{v}_{\bar{N}} \pm 2SD(\hat{v}_N)$, and $\hat{v}_{\bar{N}} \pm 3SD(\hat{v}_{\bar{N}})$ are approximately 68%, 95%, and 99%, respectively. These intervals are referred to as the 68%, 95%, and 99% confidence intervals for $v_{\bar{N}}$, and are shown for the 34-year Great Falls sample in line (1) of Table 3.2.1.

It is also shown in Sect. A1.6 that the width of the confidence intervals can be reduced if a more efficient estimator is used; however, the intervals cannot be narrower than those obtained by using the Cramér–Rao (C.R.) lower bound (Eq. A1.77). For the Great Falls sample, the confidence intervals based on the latter are shown in line (2) of Table 3.2.1. It is seen that the differences between the results of lines (1) and (2) of Table 3.2.1 are small. This is consistent with the conclusion of Sect. A1.6 that the efficiency of the method of moments (Eq. 3.2.1) is generally adequate for structural design purposes.

It is noted that, in Table 3.2.1, the errors in the estimation of the 50-year wind are of the order of 10% at the 95% confidence level. Since the wind pressures are proportional to the wind speeds (see Chapter 4), the corresponding errors in the estimation of the pressures are of the order of 20%.

TABLE 3.2.1. Confidence Intervals for the $\bar{N}$-year Wind at Great Falls

Confidence level	68%		95%		99%	
Mean recurrence interval, $\bar{N}$ (years)	50	1000	50	1000	50	1000
(1) Estimated by method of moments	76 ± 3.7	91 ± 6.4	76 ± 7.4	91 ± 12.8	76 ± 11.1	91 ± 19.2
(2) Estimated using C.R. lower bound	76 ± 3.1	91 ± 5.0	76 ± 6.2	91 ± 10.0	76 ± 9.3	91 ± 15.0

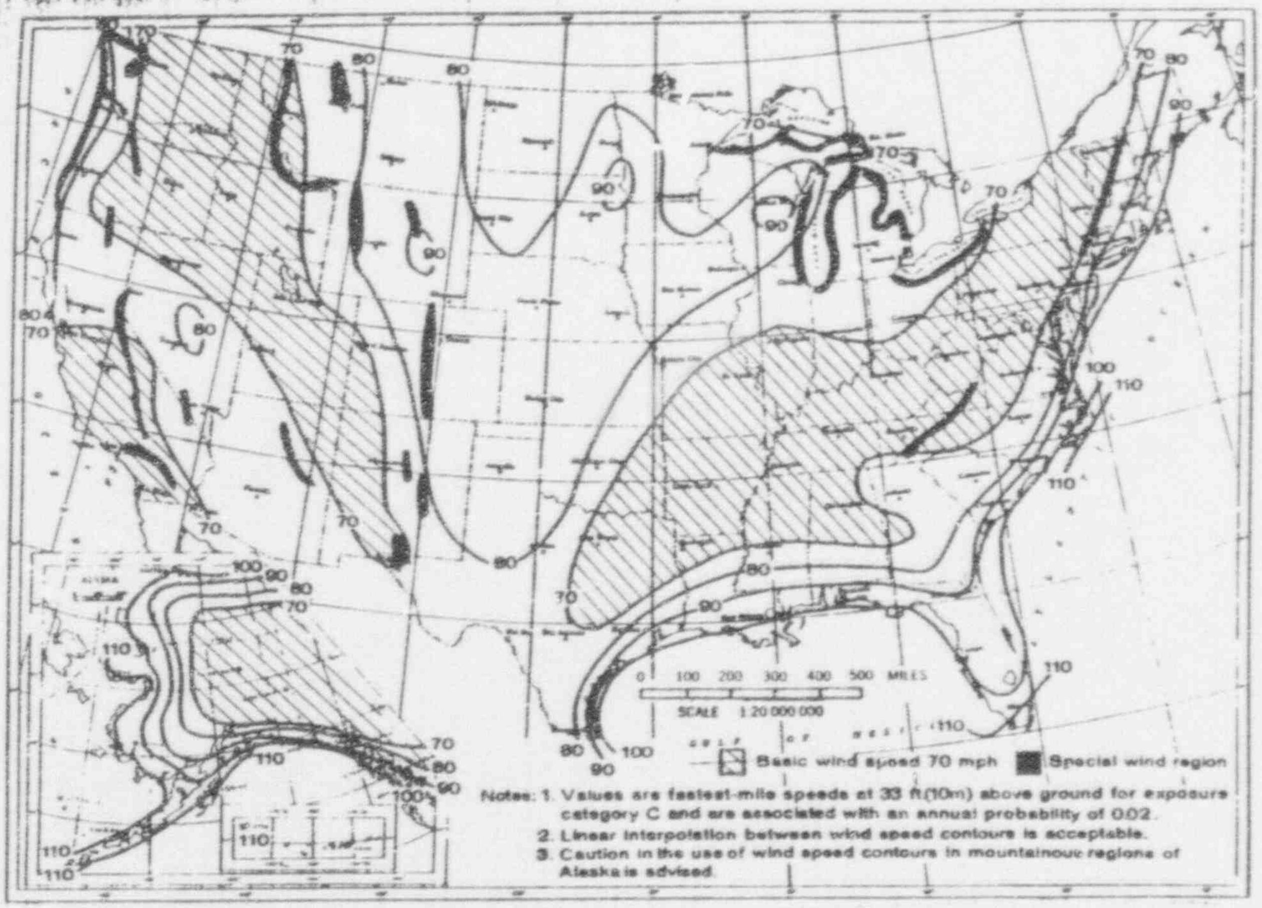

FIGURE 3.2.1. Map of basic design wind speeds. Reproduced with permission from American National Standard A58.1 *Building Code Requirements for Minimum Design Loads in Buildings and Other Structures*, copyright 1982 by the American National Standards Institute. Copies of this standard may be purchased from the American National Standards Institute at 1430 Broadway, New York, NY 10018.

2-9
NPP1-SB0-009
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An alternative approach to accounting for sampling errors, which applies the theorem of total probability, is suggested in [3-51].

3.2.3 Methods for Estimating the Extreme Speeds at Locations with Insufficient Largest Yearly Wind Speed Data

There are about one hundred U.S. weather stations for which reliable and relatively long wind speed records are available (i.e., records over periods of, say, 20 years or more). Some of these stations cover areas of tens of thousands of square miles, over which—for meteorological reasons or owing to topographic effects—the extreme wind climate is not necessarily uniform. There arises therefore in practice the problem of estimating extreme wind speeds at various locations where long-term records of the largest yearly wind speed data do not exist.

Estimates of Extreme Wind Speeds in a Marine Environment. Reference 3-11 lists three methods that are in principle available to carry out such estimates for marine environments where the extreme speeds are associated with extratropical storms. The first method makes use of climatological information on various parameters of the storm and of physical models relating those parameters to the surface wind speeds. It is shown in Sect. 3.3 that such a method can be applied to estimate extreme wind speeds in hurricane-prone regions. However, as noted in [3-11], owing to the complexity of the surface wind patterns in extratropical storms, the usefulness of this method appears to be uncertain in regions where such storms are dominant.

A second method listed in [3-11] is the use of objective analysis schemes. These consist of: (a) an initial guess at the surface wind on a regular grid, (b) an automated procedure for screening wind reports from ships to eliminate erroneous readings, and (c) a procedure for correcting the initial guess on the basis of the usable set of ship reports, which involves relations among the surface wind speeds, sea-level pressures, and air and sea temperatures. Details on objective analysis schemes and of errors currently inherent in such schemes (which may range from 10% to 30%) are given in [3-11].

The third method listed in [3-11] is referred to as direct kinematic analysis. The method, which involves subjective judgment by experienced analysts, consists of synthesizing discrete meteorological observations to obtain a continuous field represented in terms of streamlines and isotachs. Objective or kinematic analyses applied to a sufficient number of strong storms make it possible to provide estimates of extreme winds that may occur at any one location. As indicated in [3-11], one of the major difficulties in conducting such analyses is that much of the vast store of existing data is currently not accessible in readily usable form.

Estimation of Extreme Wind Speeds from Short-Term Records. A practical procedure for estimating extreme wind speeds at locations where long-term data are not available is described in [3-12]. The method, whose applicability

2-10 NPP1- SB6-009 EH

was tested for a large number of U.S. weather stations, makes it possible to infer the probabilistic behavior of extreme winds from data consisting of the largest monthly wind speeds recorded over a period of three years or longer. Estimates based on the monthly speeds, denoted by $\hat{v}_{\bar{N},m}$, are obtained by rewriting Eq. A1.74 as follows:

$$\hat{v}_{\bar{N},m} \simeq \bar{X}_m + 0.78[\ln(12\bar{N}) - 0.577]s_m \tag{3.2.4}$$

where $\bar{X}_m$ and s_m are, respectively, the sample mean and the sample standard deviation of the largest monthly wind speed data, and $\bar{N}$ = mean recurrence interval in years.

The standard deviation of the sampling error in the estimation of $\hat{v}_{\bar{N},m}$ is obtained from Eqs. A1.76 and A1.70 as

$$SD(\hat{v}_{\bar{N},m}) = 0.78\{1.64 + 1.46[\ln(12\bar{N}) - 0.577] + 1.1[\ln(12\bar{N}) - 0.577]^2\}^{1/2}\,\frac{s_m}{\sqrt{n_m}} \tag{3.2.5}$$

where n_m = sample size.

Example

At Great Falls, the sample mean and the sample standard deviation of the largest monthly fastest-mile wind speeds at 10 m above ground for the period September 1968 through August 1971* (sample size $n_m = 36$) are $\bar{X}_m = 42$ mph, $s_m = 6.96$ mph. From Eqs. 3.2.4 and 3.2.5, the estimates for $\bar{N} = 50$ years and $\bar{N} = 1000$ years are:

$$\hat{v}_{50,m} \simeq 74 \text{ mph} \qquad SD(\hat{v}_{50,m}) \simeq 6.23 \text{ mph}$$

$$\hat{v}_{1000,m} = 90 \text{ mph} \qquad SD(\hat{v}_{1000,m}) = 8.85 \text{ mph}$$

It is seen that the estimated speeds based on the set of 36 largest monthly data are only slightly lower than those obtained from the set of 34 largest yearly speeds ($\hat{v}_{50} = 76$ mph and $\hat{v}_{1000} = 91$ mph; see Sect. 3.2.2); however, the sampling errors are larger.

Similar calculations carried out for 67 sets of records taken at 36 stations are reported in [3-12], where it was found that the differences $\hat{v}_{50,m} - \hat{v}_{50}$, where $\hat{v}_{50}$ is the 50 year wind speed estimated from long-term largest yearly data, were less than $SD(\hat{v}_{50,m})$ in 66% of the cases and less than twice the value of $SD(\hat{v}_{50,m})$ in 95% of the cases. This remarkable result, confirmed by additional calculations reported in [3-13], indicates that the estimates based on largest monthly wind speeds recorded over three years or more provide a useful description of the extreme wind speeds in regions with a well-behaved wind climate.

Inferences concerning the probabilistic model of the extreme wind climate

*For the actual data, see the Local Climatological Data summaries for the years 1968–1971.

2-11
NPP1-SBØ-009
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have also been attempted from data consisting of largest daily wind speeds [3-12], or of wind speeds measured at 1-hour intervals [3-14]. One problem that arises in this respect is that data recorded on two successive days are generally strongly correlated. Nevertheless, as shown in [3-14], in practice such correlation has a negligible effect on the statistical estimates, and the assumption of statistical independence among the data can therefore be used. However, a second and more serious problem is that the daily (or hourly) data reflect a large number of events (e.g., morning breezes) that are altogether unrelated meteorologically to the storms associated with the extreme winds. These events can be viewed as noise that obscures the information relevant to the description of the extreme wind climate. Indeed, it was verified in [3-12] that estimates of extreme winds based on daily data differ significantly from estimates obtained for long-term records of largest yearly speeds. This conclusion is *a fortiori* true for inferences based on hourly data.

3.3 ESTIMATION OF EXTREME WIND SPEEDS IN HURRICANE-PRONE REGIONS

We now consider the prediction of extreme winds in climates characterized by the occurrence of hurricanes. It was suggested in Sect. 3.2 that in a well-behaved wind climate each of the data in a series of the largest yearly speeds contributes to the description of the probabilistic behavior of the extreme winds. However, in a hurricane-prone region most of the speeds in a series of the largest yearly winds are considerably lower than the extreme speeds associated with hurricanes; they may therefore be irrelevant from a structural safety point of view. This situation is illustrated by the plot of Fig. 3.3.1, which shows the 5-min largest speeds recorded at Corpus Christi, Texas between 1912 and 1948 [3-6]. It may then be argued that in hurricane-prone regions the series of the largest yearly speeds cannot provide useful statistical information on winds of interest to the structural designer, much in the same way as the population of a first-grade classroom—which might include a teacher—is of little use in a statistical study of the height of adults. That this is the case is suggested below.

The abscissa in Fig. 3.3.1 represents the reduced variate

$$y = -\ln\left[-\ln\left(1 - \frac{1}{\bar{N}}\right)\right]$$

where $\bar{N}$ is the mean recurrence interval. In virtue of Eqs. A1.43 and A1.45, a Type I extreme value cumulative distribution function would be represented in Fig. 3.3.1 by a straight line, the intercept and slope of which would be equal to the distribution parameters μ and σ, respectively. To the extent that the population of largest yearly speeds would be described by a Type I distribution, the actual data would then fit, approximately, a straight line. In Fig. 3.3.1 this is roughly the case as far as the winds of less than hurricane force are concerned. However, if—as in Fig. 3.3.1—the hurricane-force winds are included in the

2-12
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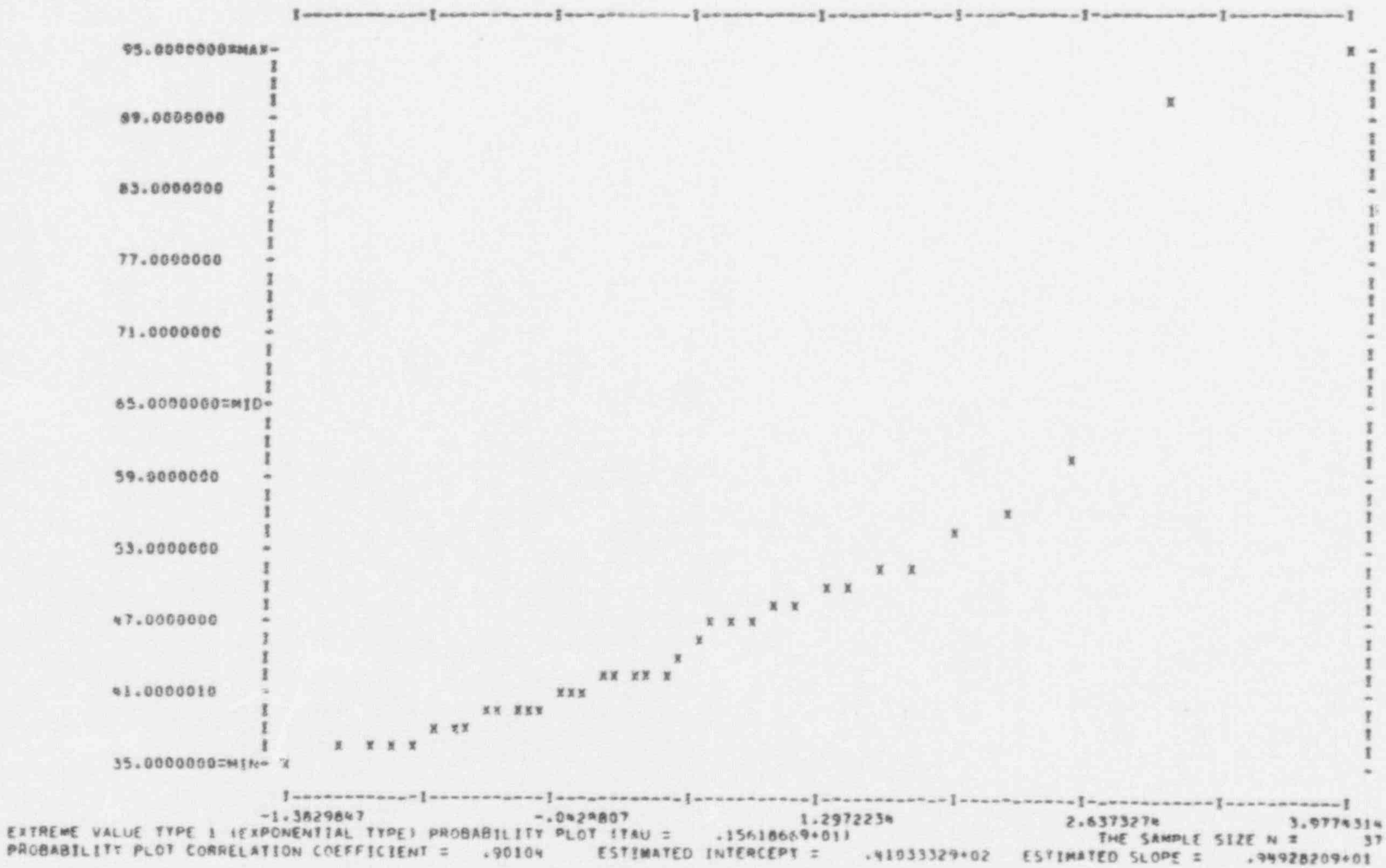

FIGURE 3.3.1. Probability plot of 1912–1948 annual largest speeds at Corpus Christi, Texas [3-6].

2-13
NPP1 - SBØ-009
874

It is noted that if X and Y are independent, then $\mathrm{Corr}(X, Y) = 0$. This follows immediately from Eqs. A1.26, A1.18, and A1.24. However, the relation $\mathrm{Corr}(X, Y) = 0$ does not necessarily imply the independence of X and Y [A1-4].

A1.5 PROBABILITY DISTRIBUTIONS COMMONLY USED IN WIND ENGINEERING

The Geometric Distribution

Consider an experiment of the type known as *Bernoulli trials* in which (a) the only possible outcomes are the occurrence and the nonoccurrence of an event A, (b) the probability p of event A in any one trial is constant, and (c) the outcomes of the trials are independent of each other.

Let the random variable N be equal to the number of the trial in which the event A occurs for the first time. The probability $p(n)$ that event A will first occur on the nth trial is equal to the probability that event A will *not* occur on each of the first $n-1$ trials and *will* occur on the nth trial. Since the probability of nonoccurrence of event A in one trial is $1-p$ (Eq. A1.2) and since the n trials are independent, it follows from the multiplication rule (Eq. A1.8)

$$p(n) = (1-p)^{n-1}p \qquad (n = 1, 2, 3, \ldots) \tag{A1.30}$$

This probability distribution is known as the *geometric distribution* with parameter p.

The probability $P(n)$ that event A will occur at least once in n trials can be found in the following manner. The probability that event A will *not* occur in n trials is $(1-p)^n$. The probability that it will occur at least once is therefore

$$P(n) = 1 - (1-p)^n \tag{A1.31}$$

The expected value of N is, by virtue of Eq. A1.22, in which Eq. A1.30 is used,

$$\bar{N} = \sum_{n=1}^{\infty} n(1-p)^{n-1}p \tag{A1.32}$$

The sum of this series can be shown to be

$$\bar{N} = 1/p \tag{A1.33}$$

The quantity $\bar{N}$ is referred to as the *return period*, or the *mean recurrence interval*, of event A.

Examples

1. For a die, the probability that a "four" occurs is $p = \frac{1}{6}$. If the total number of trials is large, it may be expected that, in the long run, a "four" will appear on the average once in $\bar{N} = 1/\frac{1}{6} = 6$ trials.

2. A structure is designed so that the stresses in its members will attain the allowable stress under the action of extreme winds with a 50-year mean re-

2-14
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currence interval. The probability of occurrence in any one year of winds for which $\bar{N}=50$ is $p=1/\bar{N}=0.02$ (Eq. A1.33). The probability that the allowable stress will be attained at least once in n years is given by Eq. A1.31. For $n=25$ years, $P(25)=1-(1-0.02)^{25}\simeq 0.396$; for $n=50$ years, $P(50)\simeq 0.63$.

The Poisson Distribution

Consider a class of events, each of which may occur independently of the others and with equal likelihood at any time of an interval $0\leq t\leq T$. A random variable is defined, which consists of the number N of events that will occur during an arbitrary time interval $\tau=t_2-t_1$ $(t_1\geq 0,\ t_1<t_2\leq T)$. Let $p(n,\tau)$ denote the probability that n events will occur during the interval τ. If it is assumed that $p(n,\tau)$ is not influenced by the occurrence of any number of events at times outside this interval, it can be proved [A1-4] that

$$p(n,\tau)=\frac{(\lambda\tau)^n}{n!}e^{-\lambda\tau}\qquad (n=0,1,2,3,\ldots) \tag{A1.34}$$

If Eqs. A1.24 and A1.25 are used, it is found that the expected value and the variance of n are both equal to $\lambda\tau$. Since $\lambda\tau$ is the expected number of events occurring during time τ, the parameter λ is called the *average rate of arrival* of the process and represents the expected number of events per unit of time.

The applicability of Poisson's distribution may be illustrated in connection with the question of the incidence of telephone calls in a telephone exchange [A1-5]. Consider an interval of, say, a quarter of an hour, during which the average rate of arrival of calls is constant. During any subinterval, the incidence of a number n of calls is as likely as during any other equal subinterval. In addition, it may be assumed that individual calls are independent of each other. Therefore, Eq. A1.34 applies to any time interval lying within the quarter of an hour.

Normal and Lognormal Distributions

Consider a random variable X which consists of a sum of small, independent contributions $X_1, X_2, \ldots, X_n$. It can be proved [A1-1] that, under very general conditions, if n is large the probability density function of X is

$$f(x)=\frac{1}{\sqrt{2\pi}\sigma_x}\exp\left(\frac{-(x-\mu_x)^2}{2\sigma_x^2}\right) \tag{A1.35}$$

where $\mu_x=E(X)$ and $\sigma_x^2=\mathrm{Var}(X)$ are the mean value and the variance of X, respectively. This statement is known as the *central limit theorem*. The distribution represented by Eq. A1.35 is called *normal* or *Gaussian*. It can be shown that the probability distribution of a linear function of a normally distributed variable is normal. Also, the sum of two or more independent normally distributed variables is normally distributed.

Normal distributions are used in a wide variety of physical and engineering applications, for example, the description of errors in measurements. At the

2-15
NPPI-5B∅-009

same time, it should be carefully noted that many phenomena may not be normally distributed, for example, the extreme wind speeds occurring at any given geographical location.

If the distribution of the variable $Z = \log X$ is normal, the distribution of the variable X is said to be *lognormal*.

Type I and Type II Distributions of the Largest Values. Mean Recurrence Intervals

Let the variable X be the maximum of n independent random variables $Y_1, Y_2, \ldots, Y_n$ [A1-6]. Since the inequality $X \leq x$ implies $Y_i \leq x$ for *all* i ($i = 1, 2, \ldots, n$), it follows that

$$F(X \leq x) = \text{Prob}(Y_1 \leq x,\ Y_2 \leq x, \ldots, Y_n \leq x) \qquad \text{(A1.36a)}$$

$$= F_{Y_1}(x) F_{Y_2}(x) \ldots F_{Y_n}(x) \qquad \text{(A1.36b)}$$

where, to obtain Eq. A1.36*b* from Eq. A1.36*a*, the generalized form of Eq. A1.8 was used. The probabilities $F_{Y_i}(y)$ are referred to as the underlying (or the *initial*) distributions of the variables Y_i. The latter are said to constitute the *parent population* from which the largest values X have been extracted. In the particular case in which all the variables Y_i have the same probability distribution $F_Y(y)$, Eq. A1.36 becomes

$$F_X(x) = [F_Y(x)]^n \qquad \text{(A1.37)}$$

In the case in which they are unlimited to the right, the initial variables Y are said to have distributions of the *exponential type* if their cumulative distribution functions converge (with increasing y) toward unity at least as fast as an exponential function; the initial variables Y are said to be of the *Cauchy type* if

$$\lim_{y \to \infty} [1 - F(y)] y^k = A \qquad (A > 0;\ k > 0) \qquad \text{(A1.38)}$$

As the number n becomes very large, the distributions $F_X(x)$ of the largest values approach limits known as the *Type I* and the *Type II* distributions according as the initial distributions are of the exponential and of the Cauchy type, respectively [A1-4, A1-7].

The cumulative distribution function for the *Type I distribution of the largest values* (also referred to as the *Type I Extreme Value* distribution, or the Gumbel distribution) is

$$F_I(x) = \exp\{-\exp[-(x-\mu)/\sigma]\} \begin{cases} -\infty < x < \infty \\ -\infty < \mu < \infty \\ 0 < \sigma < \infty \end{cases} \qquad \text{(A1.39)}$$

In Eq. A1.39, μ and σ are referred to as the location and the scale parameter, respectively.* It can be shown, using Eqs. A1.24 and A1.25, that the mean

*As shown in Eqs. A1.40 and A1.41, these parameters are *not* the expectation and the standard deviation of X.

2-16
NPP1 - SBØ-009
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value and the standard deviation of X are

$$E(X) = \mu + 0.5772\sigma \tag{A1.40}$$

$$SD(X) = \frac{\pi}{\sqrt{6}}\sigma \tag{A1.41}$$

The cumulative distribution function for the *Type II distribution of the largest values* (also referred to as the *Type II Extreme Value* distribution, or the generalized *Fréchet* distribution) is

$$F_{II}(x) = \exp\{-[(x-\mu)/\sigma]^{-\gamma}\} \begin{cases} \mu < x < \infty \\ -\infty < \mu < \infty \\ 0 < \sigma < \infty \\ \gamma > 0 \end{cases} \tag{A1.42}$$

where μ, σ, and γ are the location, the scale, and the shape (or tail length) parameter, respectively [A1-8]. In the particular case $\mu = 0$, Eq. A1.42 is referred to as the Fréchet (as opposed to generalized Fréchet) distribution.

Equations A1.39 and A1.42 may be inverted to yield the so-called *percent point function*, that is, the value x of the random variable that corresponds to any given value of the cumulative distribution function. In the case of the Type I distribution

$$x(F_I) = \mu - \sigma \ln(-\ln F_I) \tag{A1.43}$$

whereas for the Type II distribution

$$x(F_{II}) = \mu + \sigma(-\ln F_{II})^{-1/\gamma} \tag{A1.44}$$

It is convenient to denote the cumulative distribution function value F_I or F_{II} by p and $x(F_I)$ or $x(F_{II})$ by $G_X(p)$. Then, for the Type I distribution

$$G_X(p) = \mu - \sigma \ln(-\ln p) \tag{A1.43a}$$

and for the Type II distribution

$$G_X(p) = \mu + \sigma(-\ln p)^{-1/\gamma} \tag{A1.44a}$$

From the definition of p and Eq. A1.2 it follows that $\text{Prob}(X > x) = 1 - p$. Let the random variable X represent the extreme annual wind speed at some given location. Each year may then be viewed as a trial in which the event that the wind speed X will exceed some value x has the probability of occurrence $1 - p$. By virtue of Eq. A1.33, the mean recurrence interval of this event is

$$\bar{N} = \frac{1}{1-p} \tag{A1.45a}$$

Thus, the wind speed x corresponding to a mean recurrence interval $\bar{N}$ is equal to the value of the percent point function of X corresponding to

$$p = 1 - \frac{1}{\bar{N}} \tag{A1.45b}$$

2-17
NPP1-SBØ-009

Relations Between Type I and Type II Extreme Value Distributions

Let the Type II distribution be written as

$$F_{II}(y)=\exp\{-[(y-\mu_{II})/\sigma_{II}]^{-\gamma}\} \qquad \text{(A1.46)}$$

(In the present context it is convenient to denote the location and scale parameter of the Type II distribution by μ_{II} and σ_{II}, respectively). If the transformation

$$y-\mu_{II}=\exp x \qquad \text{(A1.47)}$$

is applied to Eq. A1.46, the expression obtained is a Type I distribution with parameters

$$\mu=\ln \sigma_{II} \qquad \text{(A1.48)}$$

$$\sigma=\frac{1}{\gamma} \qquad \text{(A1.49)}$$

It is now shown [A1-12] that as γ approaches infinity, a Type II distribution approaches a Type I distribution.

Consider the distribution of the standardized variate

$$Z=\frac{X-\mathrm{loc}(X)}{\mathrm{scale}(X)} \qquad \text{(A1.50)}$$

where loc(X) and scale (X) are measures of location and scale, respectively, of the distribution of X. Examples of measures of location of a random variable X are its expected value $E(X)$ and its median $G_X(0.5)$. Examples of measures of scale of a random variable X are its standard deviation $SD(X)$, its interquartile difference $\delta_{50}=G_X(0.75)-G_X(0.25)$, and its 95% difference $\delta_{95}=G_X(0.975)-G_X(0.025)$.

The percent point function $G_Z(p)$ is given by

$$G_Z(p)=\frac{G_X(p)-\mathrm{loc}(X)}{\mathrm{scale}(X)} \quad (0<p<1) \qquad \text{(A1.51)}$$

With no loss of generality, a reduced variate with $\mu=0$ and $\sigma=1$ may be used in the demonstration. Substituting Eq. A1.44*a* with $\mu=0$ and $\sigma=1$ into Eq. A1.51 and choosing, for simplicity, loc$(X)=G_X(0.5)$ and scale$(X)=\delta_{95}$,

$$G_Z(p)=\frac{[-\ln(p)]^{-1/\gamma}-[-\ln(0.5)]^{-1/\gamma}}{[-\ln(0.975)]^{-1/\gamma}-[-\ln(0.025)]^{-1/\gamma}} \quad (0<p<1) \qquad \text{(A1.52)}$$

As $\gamma\to\infty$, this expression becomes indeterminate. However, application of L'Hospital's rule yields, after simplification,

$$G_Z(p)=\frac{-\ln[-\ln(p)]-\{-\ln[-\ln(0.5)]\}}{-\ln[-\ln(0.975)]-\{-\ln[-\ln(0.025)]\}} \quad (0<p<1) \qquad \text{(A1.53)}$$

As can be seen from Eqs. A1.43*a*, the terms in the numerator and denominator of Eq. A1.53 are, respectively, the percent point function, the median, and the 95% difference of the reduced variate for the Type I distribution. It has thus

2-18
NPP1- SBØ -009
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been demonstrated that, as γ approaches infinity, a standardized Type II variate approaches a standardized Type I variate and, hence, a Type II distribution asymptotically approaches a Type I distribution.

Type I Distributions: Mode of the Largest Value from a Sample of Size n as an Approximation of the Percent Point Function $G_X[1/(1-n)]$

Let Z be the largest of a set of n values of a random variable X, each of which has a Type I Extreme Value distribution (Eq. A1.39). The cumulative distribution function of this largest value is

$$F_n(z) = [F_I(z)]^n = \exp[-n \exp(-w)] \tag{A1.54}$$

where

$$w = \frac{z-\mu}{\sigma} \qquad \begin{array}{c} -\infty < z < \infty \\ -\infty < \mu < \infty \\ 0 < \sigma < \infty \end{array} \tag{A1.55}$$

The corresponding probability density function is

$$f_n(z) = \frac{1}{\sigma} n \exp[-ne^{-w} - w] \tag{A1.56}$$

The root of the equation

$$\frac{df_n(z)}{dz} = \frac{1}{\sigma^2} n \exp[-ne^{-w} - w][ne^{-w} - 1] = 0 \tag{A1.57}$$

is, by definition, the mode* of the largest of the set of n values considered. From Eq. A1.57 it follows immediately

$$e^{-w} = \frac{1}{n} \tag{A1.58}$$

or, if Eq. A1.55 is used,

$$\text{mode}(Z) = \mu - \sigma \ln \frac{1}{n} \tag{A1.59}$$

Consider now the initial random variable X. Since X has a Type I distribution, its percent point function is

$$G_X(p) = \mu - \sigma \ln(-\ln p) \tag{A1.43a}$$

or, making use of Eq. A1.45 in which $\bar{N}$ is the mean recurrence interval

$$G_X\left(1 - \frac{1}{\bar{N}}\right) = \mu - \sigma \ln\left[-\ln\left(1 - \frac{1}{\bar{N}}\right)\right] \tag{A1.60}$$

*It is recalled that the mode of a variable X is the value of that variable most likely to occur in any given trial (Sect. A1.4).

In the particular case in which $\bar{N} = n$

$$G_X\left(1-\frac{1}{n}\right) = \mu - \sigma \ln\left[-\ln\left(1-\frac{1}{n}\right)\right] \tag{A1.61}$$

In Eq. A1.61, $G_X(1-1/n)$ is the value of X corresponding to the mean recurrence interval n.

It can be verified that for n sufficiently large, say, $n > 10$,

$$\ln\left[-\ln\left(1-\frac{1}{n}\right)\right] \simeq \ln\left(\frac{1}{n}\right) \tag{A1.62}$$

(For example, for $n = 20$, the right and left members of Eq. A1.63 are equal to -2.970 and -2.996, respectively. For $n = 40$, they are equal to -3.676 and -3.689, respectively.) It follows therefore that

$$G_X\left(1-\frac{1}{n}\right) \simeq \mu - \sigma \ln\frac{1}{n} = \text{mode}(Z) \tag{A1.63}$$

Equation A1.63 shows that if X is a random variable with a Type I distribution, the mode of the largest value in a sample of n values of X is very nearly equal to the value of the random variable corresponding to the mean recurrence interval n [A1-9].

An interesting experimental verification of this statement is provided by the data of [A1-11], which cover a period of 37 years. For example, for the first five sets of [A1-11], the values of the largest of the maximum yearly wind speeds recorded in 37 years, v_{max}, and the values of the estimated 37-year wind, v_{37}, are (in mph)

	Cairo (Ill.)	Alpena (Mich.)	Tatoosh Isl. (Wash.)	Williston (N.D.)	Richmond (Virginia)
v_{max}	51	50	84	50	48
v_{37}	52	51	81	52	50

The probability that the largest of a set of n values of the random variable X with a Type I distribution is contained in a given interval can be easily calculated using Eq. A1.54. For example, from a 37-year record of the largest annual wind speeds at Richmond, Virginia the values of μ and σ were estimated to be 36.8 mph and 3.78 mph, respectively [A1-11]. Using these values, the probability that the largest wind speed $Z = V_{max}$ in a set of $n = 37$ largest annual speeds is contained, say, in the interval $V_{37}(1 \pm 0.24) = 50 \pm 12$ can be estimated as follows:

$$P(38 \leq Z \leq 62) = \int_{38}^{62} f_{37}(z)\,dz = F_{37}(62) - F_{37}(38) = 0.95 \tag{A1.63a}$$

2-20
NPP1-SB∅-009
Ex. 11

Joint Extreme Value Distributions

The joint Type I Extreme Value probability distribution of two correlated variables X, Y has the expression

$$F_{XY}(x, y) = \exp\left\{-\left[\exp\left(-m\frac{x-\mu_x}{\sigma_x}\right)+\exp\left(-m\frac{y-\mu_y}{\sigma_y}\right)\right]^{1/m}\right\} \tag{A1.64a}$$

where

$$m = (1-\rho_{XY})^{-1/2} \tag{A1.64b}$$

and the correlation coefficient $\rho_{XY} \geqslant 0$ [A1-23]. It can be verified that for probabilities of interest in structural reliability calculations (e.g., $F_{XY}(x, y) > 0.99$) and for values $\rho_{XY} \leqslant 0.7$, say,

$$F_{XY}(x, y) \cong F_X(x)F_Y(y) \tag{A1.64c}$$

where $F_X(x)$ and $F_Y(y)$ are the Type I Extreme Value distributions of X and Y, respectively, that is, it may be assumed that X and Y are statistically independent.

The Weibull Distribution

The Weibull cumulative distribution function is

$$F(x) = 1-\exp\left[-\left(\frac{x-\mu}{\sigma}\right)^{\gamma}\right] \tag{A1.65}$$

The expected value and the standard deviation of the variate $(x-\mu)/\sigma$ are, respectively, $\Gamma(1/\gamma+1)$ and $\{\Gamma(2/\gamma+1)-[\Gamma(1/\gamma+1)]^2\}^{1/2}$, where Γ is the gamma function, and are listed here for various values of γ [A1-8].

	1.2	1.6	2.0	2.2	2.6	3.0	3.2	3.6	4.0	6.0
Expected Value	0.9407	0.8966	0.8862	0.8856	0.8882	0.8930	0.8957	0.9011	0.9064	0.9264
Standard Deviation	0.7872	0.5737	0.4632	0.4249	0.3670	0.3245	0.3072	0.2780	0.2543	0.1850

For $\gamma \cong 3.6$, the shape of the Weibull distribution is similar to that of the normal distribution. The Weibull distribution with parameter $\gamma = 2$ is commonly referred to as the Rayleigh distribution.

A1.6 PROBABILITY THEORY AND STATISTICAL DATA

Goodness of Fit

Data obtained—or that may be obtained—from actual observations may be viewed as observed values of random variables. The behavior of the data is then assumed to be described by models governing the behavior of random variables, that is, by such mathematical models as are used in probability theory.

2-21
NPPI- SBØ-009

In practical applications two important problems must be dealt with. First, from the nature of the phenomenon being investigated (or on the basis of observations), an inference must be made on the probability distribution that will adequately describe the behavior of the data. Second, the data must be used for drawing inferences on the parameters of the distribution or on some of its characteristics, for example, the mean or the standard deviation.

In practice, given a set of observed data, or a *data sample*, it is hypothesized that its behavior can be modeled by means of some probability distribution believed to be appropriate. This hypothesis must then be tested. Tests incorporate quantitative measures of the degree of agreement, or *goodness of fit*, between the data and the hypothetical distribution or, conversely, of the degree to which the data deviate from that distribution. If the measure of this deviation is appropriately small, then the hypothesis will be accepted, and vice-versa. Associated with the testing of a hypothesis is a *level of significance*, that represents the probability of rejecting the hypothesis when it is in fact true. Tests commonly used in applications, including the well-known χ^2 test, are discussed, for example, in [A1-1] and [A1-4]. Brief mention is made of the probability plot correlation coefficient test [A1-10] that has been used in the study of the behavior of extreme winds [A1-11, A1-12]. The probability plot correlation coefficient is defined as

$$r_D = \frac{\sum (X_i - \bar{X})[M_i(D) - \overline{M(D)}]}{[\sum (X_i - \bar{X})^2 \sum (M_i(D) - \overline{M(D)})^2]^{1/2}} \qquad \text{(A1.66)}$$

in which $\bar{X} = \sum X_i/n$, $\overline{M(D)} = \sum M_i(D)/n$, n is the sample size, and D is the probability distribution being tested. The quantities X_i are obtained by a rearrangement of the data set: X_1 is the smallest, X_2 the second smallest, ..., X_i the i-th smallest of the observations in the set. The quantities $M_i(D)$ are obtained as follows. Given a random variable X with probability distribution D and given a sample size n, it is possible from probabilistic considerations to derive mathematically the distributions of the smallest, second smallest, and, in general, the i-th smallest values of X in that sample. The quantities $M_i(D)$ are the medians of each of these distributions.

If the data were generated by the distribution D, then, aside from a location and scale factor, X_i will be approximately equal to the theoretical values $M_i(D)$ for all i so that the plot of X_i versus $M_i(D)$ (referred to as probability plot) will be approximately linear. This linearity will, in turn, result in a near-unity value of r_D. Thus, the better fit of the distribution D to the data the closer r_D will be to unity.

To test whether the behavior of a given set of extreme data is better described by a Type I distribution or by a Type II distribution with some unknown value of the tail length parameter γ, the probability plot correlation coefficient r_D is computed for a large number of extreme value distributions, defined by various values of γ suitably spaced from $\gamma = 1$ to $\gamma = \infty$ (it is recalled that $\gamma = \infty$ corresponds to a Type I distribution). The variable in these distributions is written in standardized form so that for any given set of data the coefficients r_D depend

2-22
NPP1-SBØ-009

solely upon γ, that is, are independent of the location and scale parameters μ and σ on which, therefore, no prior assumptions need to be made [A1-11]. The distribution that best fits the data is that which corresponds to the largest of the calculated values of r_D.

Estimation of Distribution Parameters

From the data of a sample it is, in principle, possible to make inferences on the parameters of the distribution that describes the behavior of the population from which the data are extracted (or on characteristics of the distribution, e.g., the mean). An *estimator* may be defined as a function $\hat{\alpha}(X_1, X_2, \ldots, X_n)$ of the sample values such that $\hat{\alpha}$ is a reasonable approximation to the unknown value α of the distribution parameter (or characteristic). The particular numerical value assumed by an estimator in a given case is referred to as an *estimate*. As a function of random variables, $\hat{\alpha}(X_1, X_2, \ldots, X_n)$ is itself a random variable. This is illustrated by the following example.

Consider the observed sequence of 14 outcomes of an experiment consisting of the tossing of a coin:

$$\text{H T T T H T H H T H H H T H} \tag{A1.67a}$$

The random numbers associated with this experiment are the numbers zero and one, which are assigned to the outcome heads and to the outcome tails, respectively. The data sample corresponding to the observed outcomes is then:

$$0, 1, 1, 1, 0, 1, 0, 0, 1, 0, 0, 0, 1, 0 \tag{A1.67b}$$

This sample is assumed to be extracted from an infinite population that, in the case of an ideally fair coin, will have a mean value, denoted in this case by α, equal to $\frac{1}{2}$. A reasonable estimator for the mean α is the sample mean $\hat{\alpha}$*

$$\hat{\alpha} = \frac{1}{n} \sum_{i=1}^{n} X_i \tag{A1.68}$$

where n is the sample size (number of observations) and X_i are the observed data. In the case of the sample consisting of all 14 observations in A1.67*b*, $\hat{\alpha} = \frac{3}{7}$. If the samples consisting of the first seven and of the last seven observations in A1.67*b* are used, $\hat{\alpha} = \frac{4}{7}$ and $\hat{\alpha} = \frac{2}{7}$, respectively.

As a random variable, an estimator $\hat{\alpha}$ will have a certain probability distribution with a nonzero dispersion about the true value α. Thus, given a sample of statistical data, it is not possible to calculate the true value α of the parameter sought. Rather, *confidence intervals* can be estimated of which it can be stated, with a specified confidence level q (level of significance $1-q$), that they will contain the unknown value α.

In order that the confidence interval corresponding to a given confidence level q be as narrow as possible, it is desirable that the estimator used be *efficient*.

*The symbol ^ is used to denote estimated value.

2-23
NPP1- SBØ-009
E4

Of two different possible estimators $\hat{\alpha}_1$ and $\hat{\alpha}_2$ of the same parameter α, the estimator $\hat{\alpha}_1$ is said to be more efficient if $E[(\hat{\alpha}_1-\alpha)^2]<E[(\hat{\alpha}_2-\alpha)^2]$.

Details on procedures for estimating distribution parameters can be found, for example, in [A1-1] and [A1-4] (see also [A1-17] and [A1-22]). The question of parameter estimation for the Type I Extreme Value distribution—which is widely used in the study of extreme wind speeds—will be examined subsequently in this appendix. Before proceeding to this topic it is useful to discuss first the simulation of the behavior of a Type I Extreme Value distribution by means of numerical techniques commonly referred to as Monte Carlo methods.

Monte Carlo Methods. Simulation of a Type I Extreme Value Process

As defined in [A1-13], Monte Carlo methods comprise that branch of experimental mathematics that is concerned with experiments on random numbers. The simulation of the phenomenon of interest is achieved by subjecting available sequences of random numbers to appropriate transformations. The new sequences thus obtained may be viewed as data, the sample statistics of which are representative of the statistical properties of the phenomenon concerned. Examples of engineering applications of Monte Carlo methods can be found in [A1-4] and [A1-14].

The simulation of the behavior of a random variable with a given distribution is a simple application of Monte Carlo techniques that is now discussed. It is assumed that the distribution is Extreme Value Type I with given parameters μ and σ (Eq. A1.39).

Consider a sequence of n uniformly distributed random numbers $0<Y_i<1$ ($i=1,2,\ldots,n$) such as are listed in [A1-14] or as may be generated by procedures discussed in [A1-2], [A1-13], or [A1-14]. These numbers are viewed as probabilities of occurrence of the data $X(Y_i)$ obtained by the following transformation (Eq. A1.43):

$$X(Y_i)=\mu-\sigma\ln(-\ln Y_i) \quad \text{(A1.69)}$$

From the sample of size n, $X(Y_i)$ ($i=1,2,\ldots,n$), it is possible to obtain estimates of μ and σ (i.e., the distribution parameters) and of $G_X(p)$ (the percent point function corresponding to any given value of p, see Eq. A1.43*a*). Since, as was previously indicated, the estimates are random variables, the estimates will differ, in general, from the known parameters and percent point function of the underlying distribution. The procedure just described can be repeated a large number M of times. Then M sets of values $\hat{\mu}$, $\hat{\sigma}$, and $\hat{G}_X(p)$ and corresponding histograms can be obtained. From those sets it is possible to calculate summary statistics (such as the mean, the variance, the standard deviation) for $\hat{\mu}$, $\hat{\sigma}$, and $\hat{G}_X(p)$.

A Monte Carlo study of the behavior of a random variable with a Type I distribution conducted for the purpose of predicting extreme wind speeds was first reported in [A1-15]. A similar study, subsequently conducted by the writers, is now summarized. The parameter values of Eq. A1.69 used in this study were $\mu=36.8$ and $\sigma=3.78$ (these values in mph represent estimates of

2-24
NPP1-580-009

Type I distributions found in [A1-11] to best fit the annual extreme wind speeds recorded in Richmond, Virginia between 1912 and 1948). Two sets of 100 samples each were generated, the size of the samples being $n = 25$ for the first set and $n = 50$ for the second. The main results of the study are listed in Table A1.1. For example: $G_X(0.98) = 51.57$ (calculated from the underlying distribution with parameters $\mu = 36.8$, $\sigma = 3.78$); the mean of the 100 estimates $\hat{G}_X(0.98)$ based on the samples of size $n = 25$ is $\text{Mean}[\hat{G}_X(0.98)] = 52.58$; the standard deviation of these estimates is $s[\hat{G}_X(0.98)] = 3.46$; the largest of the estimated $\hat{G}_X(0.98)$ is $\max[\hat{G}_X(0.98)] = (1 + 16.6/100) \times \{\text{Mean}[\hat{G}_X(0.98)]\} = \text{Mean}[\hat{G}_X(0.98)] + 2.5s[\hat{G}_X(0.98)]$. A histogram of the estimates $\hat{G}_X(0.999)$ for the 100 samples of size $n = 50$ is shown in Fig. A1.5.

The results of Table A1.1 were obtained by fitting a Type I Extreme Value distribution to the data samples generated from sequences of random numbers by Eq. A1.69. However, it is conceivable that, because of the random character of the sampling, the behavior of some of the samples would be better described by Type II Extreme Value distributions rather than by a Type I distribution. To verify whether this is indeed the case, the probability plot correlation coefficient test was applied to each of the samples. The results obtained, which are independent of the parameters μ and σ of the underlying distribution, are shown in Table A1.2.

As shown in Sect.3.2, percentages such as those of Table A1.2 can be compared to similar percentages obtained from the analysis of measured extreme wind speed data in an attempt to draw inferences on the applicability of the Type I distribution to the modeling of extreme wind behavior in certain types of climate. For details on such inferences, see [A1-21].

TABLE A1.1. Monte Carlo Simulation of a Type I Extreme Value Process

		μ	σ	$G_X(0.98)$	$G_X(0.99)$	$G_X(0.999)$
Original (Underlying) Distribution		36.80	3.78	51.67	54.24	62.97
Mean[a]	$n = 25$	36.90	4.01	52.58	55.38	64.64
	$n = 50$	36.80	3.89	51.92	54.63	63.60
Standard Deviation[a]	$n = 25$	0.86	0.81	3.46	4.00	5.8[illegible]
	$n = 50$	0.65	0.50	2.14	2.49	3.61
Maximum Deviation Below	$n = 25$	5.90	52.00	19.60	21.30	25.70
Mean[a] (Percent of Mean)	$n = 50$	3.80	32.00	10.20	11.00	13.60
Maximum Deviation Above	$n = 25$	6.60	64.00	16.60	19.00	25.50
Mean[a] (Percent of Mean)	$n = 50$	4.00	32.00	10.70	12.00	14.70
Maximum Deviation Below	$n = 25$	2.50	2.60	3.00	3.00	2.80
Mean[a] (Standard Deviations)	$n = 50$	2.20	2.50	2.50	2.50	2.40
Maximum Deviation Above	$n = 25$	2.80	3.20	2.50	2.60	2.80
Mean[a] (Standard Deviations)	$n = 50$	2.30	2.50	2.60	2.60	2.60

[a] Estimated from 100 samples of size n.

2-25
NPP1-SBφ-009
Ex 17

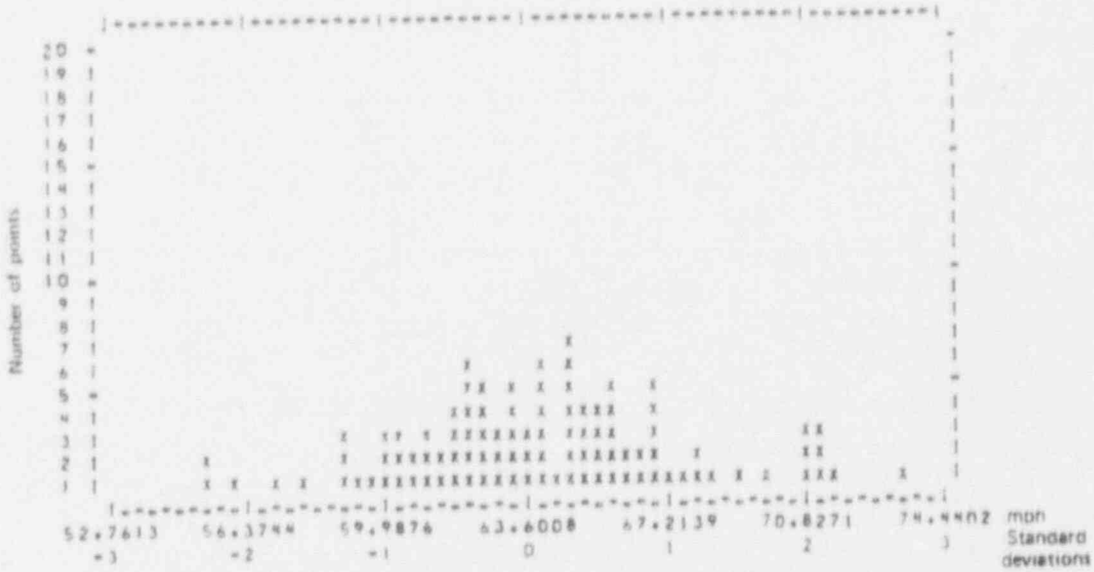

FIGURE A1.5. Histogram of estimated values $\hat{G}_X$ (0.999) for 100 samples of size $n = 50$.

TABLE A1.2. Percentage of Samples from a Population with a Type I Distribution that are Best Fit by Type I and Type II Distributions

Extreme Value Distribution		Sample Size $n = 25$	Sample Size $n = 50$
Type I or Type II ($\gamma \geq 13$)		57	77
Type II	$7 \leq \gamma < 13$	13	12
	$2 \leq \gamma < 7$	30	11

Estimators for the Type I Extreme Value Distribution

A classical method of approaching the problem of estimation is the *method of moments*. In this method it is assumed that the distribution parameters can be obtained by replacing the expectation and the mean square value of the random variable X by the corresponding statistics of the sample. In the case of the Type I distribution, using Eqs. A1.40 and A1.41,

$$\hat{\sigma} = \frac{\sqrt{6}}{\pi} s \tag{A1.70}$$

$$\hat{\mu} = \bar{X} - 0.5772\hat{\sigma} \tag{A1.71}$$

2-26
NPP1-SBØ-009

where $\bar{X}$ and s are the sample mean and the sample standard deviation, respectively, that is,

$$\bar{X} = \frac{1}{n} \sum X_i \tag{A1.72}$$

$$s = \left[\frac{1}{n} \sum (X_i - \bar{X})^2 \right]^{1/2} \tag{A1.73}$$

From the estimators (A1.70) and (A1.71) the following estimator of $G_X(p)$ can be constructed:

$$\hat{G}_X(p) = \bar{X} + s(y - 0.5772)\sqrt{6}/\pi \tag{A1.74}$$

where

$$y = -\ln(-\ln p) \tag{A1.75}$$

Under the assumption that the random variables $\bar{X}$ and s defined by Eqs. A1.72 and A1.73 are, asymptotically, normally distributed, it can be shown [A1-7, pp. 10, 174, and 228] that for large samples of size n

$$SD[\hat{G}_X(p)] = \left[\frac{\pi^2}{6} + 1.1396(y - 0.5772) \frac{\pi}{\sqrt{6}} + 1.1(y - 0.5772)^2 \right]^{1/2} \frac{\hat{\sigma}}{\sqrt{n}} \tag{A1.76}$$

A more efficient estimator of $G_X(p)$ has been developed by Lieblein on the basis of the *method of order statistics* [A1-7, A1-16, A1-17]. A method frequently used in applications is based on *least squares fitting* of a straight line to the data on probability paper. This method is used in the computer program of [A1-11]. A simplified approximate version of this method is presented in [A1-7, pp. 34, 227, and 228]. For a discussion of other estimation methods used for the Type I distribution, for example, the maximum likelihood method, the reader is referred to [A1-7] and [A1-18].

It can be shown that the standard deviation of any estimator of a parameter is larger than, or at least equal to, a theoretically specified standard deviation known as the *Cramér–Rao lower bound*. In the case of the percent point function of a Type I distribution, the Cramér–Rao lower bound is

$$SD_{CR}[\hat{G}_X(p)] = (0.60793y^2 + 0.51404y + 1.10866)^{1/2} \frac{\hat{\sigma}}{\sqrt{n}} \tag{A1.77}$$

where y is given by Eq. A1.75 [A1-19]. For $n=25$ and $n=50$, the ratio $(1/\sigma)SD_{CR}[\hat{G}_X(p)]$ is now compared with the ratios $(1/\sigma)SD[\hat{G}_X(p)]$, where $SD[\hat{G}_X(p)]$ denotes the standard deviation of the percent point function estimated by the method of moments, by Lieblein's method of order statistics, and by the method of least squares fitting.

In Table A1.3 the quantities of line (1) were calculated by Eq. A1.76. The quantities of line (2) were obtained from [A1-16, p. 131] (through multiplication of corresponding quantities given for $n=10$ by $\sqrt{10/25}$ and $\sqrt{10/50}$ or of quantities given for $n=20$ by $\sqrt{20/25}$ and $\sqrt{20/50}$). The quantities of line (3) were

TABLE A1.3. Ratios $(1/\sigma)SD[\hat{G}_x(p)]$ and $(1/\sigma)SD_{CR}[\hat{G}_x(p)]$

		Estimation Method $\bar{N}$	$n=25$				$n=50$			
			20	50	100	1000	20	50	100	1000
(1)		Moments	0.65	1.02	1.13	1.45	0.46	0.72	0.80	1.03
(2)	$\frac{1}{\sigma} SD[\hat{G}_x(p)]$	Order Statistics (Liebiein)	0.62		0.90	1.32	0.43		0.64	0.93
(3)		Least Squares		0.92	1.06	1.55		0.57	0.66	0.96
(4)	$(1/\sigma)\, SD_{CR}[\hat{G}_x(p)]$	(Cramér–Rao Lower Bound)	0.57	0.70	0.81	1.16	0.40	0.49	0.57	0.82

2-27
NPPI-580-009
ERK JJS

obtained from Table A1.1* (as shown in [A1-11], these quantities are independent of the parameters μ and σ used in the calculations). Finally, the quantities of line (4) were calculated by Eq. A1.77.

Assume that $\hat{G}_X(p)$ is normally distributed. The approximate statement can then be made that the interval $\hat{G}_X(p) \pm SD[\hat{G}_X(p)]$ will contain the true unknown parameter $G_X(p)$ in about 68% of the cases. This interval (referred to as the 68% confidence interval) is said to correspond to the 68% *confidence level*. For the interval $\hat{G}_X(p) \pm 2SD[\hat{G}_X(p)]$ the percentage rises to 95%, while for the interval $\hat{G}_X(p) \pm 3SD[\hat{G}_X(p)]$ it rises to over 99% (99.7%). As noted above, these percentages should be viewed as only approximate; however, the approximation is satisfactory for reasonable sample sizes such as are used in the analysis of wind speed data.

Estimation Methods and Reliability of Extreme Wind Speed Predictions

It is of interest to examine the effect of the estimation methods upon the reliability of predictions of extreme wind speeds corresponding to mean recurrence intervals used in structural engineering calculations.† Consider, for example, the case $n=25$. The 68% confidence interval for the 100-year wind, $x_{100} = G_X(0.99)$, is $\hat{G}_X(0.99) \pm SD[\hat{G}_X(p)]$. If the most reliable method of estimation of Table A1.3—the order statistics method—is used, then the interval is $\hat{G}_X(0.99) \pm 0.90\sigma \simeq \hat{G}_X(0.99) \pm 0.7s$ (Eq. A1.70). If, on the other hand, the least reliable method of Table A1.3—the method of moments—is used, then the estimated interval is $\hat{G}_X(0.99) \pm 0.88s$.

Numerous analyses of wind records show that the ratios $s/\bar{X}$ are of the order of 0.07 to 0.15 [A1-11, A1-15]. Then the 68% confidence intervals obtained by the method of order statistics and by the method of moments are (using the ratio $s/\bar{X} = 0.12$) $\hat{G}_X(0.99)[1 + 0.061]$ and $\hat{G}_X(0.99)[1 + 0.077]$, respectively. The difference between the respective reliabilities of the estimates of the values of X corresponding to $p = 0.99$ (or, in virtue of Eq. A1.45, to a mean recurrence interval $\bar{N} = 100$ years) is seen to be quite small, that is, of the order of 2%. Results of similar calculations carried out for $p = 0.95$, $p = 0.99$, $p = 0.999$; $n = 25$, $n = 50$; and $s/\bar{X} = 0.12$, are shown in Table A1.4. The differences between the reliabilities of the various procedures can be verified to be negligible also for $s/\bar{X} = 0.07$ and $s/\bar{X} = 0.15$.

It is seen from Table A1.4 that any of the methods listed will provide an acceptable estimate of the order of magnitude of the 68% confidence limits. The width of the 95% confidence limits is approximately twice the width of the 68% limits: for example, for $\bar{N} = 20$ and $n = 25$, the nondimensionalized 95% confidence limit estimated by the method of moments is 1 ± 0.098. The dif-

*The standard deviation of $\hat{G}_X(p)$ in line (3) is an estimate based on a finite sample. In accordance with the convention adopted herein, the notation s rather than SD should therefore be used for the quantities of line (3). This was not done in Table A1.3 for the sake of clarity.

†Of two different possible estimators $\hat{\alpha}_1$ and $\hat{\alpha}_2$ of the same quantity α, the estimator $\hat{\alpha}_1$ is said to be more reliable than $\hat{\alpha}_2$ if (assuming the estimators to be unbiased) $SD(\hat{\alpha}_1) < SD(\hat{\alpha}_2)$ [A1-16].

TABLE A1.4. 68% Confidence Intervals[a] Based on Various Estimation Methods and on the Cramér–Rao Lower Bounds

	$n = 25$				$n = 50$			
p	0.95	0.98	0.99	0.999	0.95	0.98	0.99	0.999
$\bar{N}$	20	50	100	1000	20	50	100	1000
Method of Moments	1 ± 0.049	1 ± 0.073	1 ± 0.077	1 ± 0.085	$1 + 0.035$	1 ± 0.052	1 ± 0.055	1 ± 0.060
Method of Order Statistics (Lieblein)	1 ± 0.047		1 ± 0.061	1 ± 0.078	1 ± 0.033		1 ± 0.044	1 ± 0.056
Least Squares Method		1 ± 0.066	1 ± 0.072	1 ± 0.091		1 ± 0.047	1 ± 0.051	1 ± 0.065
Cramér–Rao Lower Bound	1 ± 0.043	1 ± 0.055	1 ± 0.068	1 ± 0.068	1 ± 0.031	1 ± 0.036	1 ± 0.030	1 ± 0.049

[a]Nondimensionalized with respect to $\hat{G}_x[1 - 1/\bar{N}]$.

2-30
NPP1- 5BØ-009

ferences between estimates based on various procedures are seen to remain acceptably small for the 95% confidence limits as well.

It has previously been shown (Eq. A1.64) that if X is a random variable with a Type 1 distribution, it is possible to view the largest value in a sample of n values of X as an estimator of the value of X corresponding to a mean recurrence interval n. While this estimator has the obvious advantage of extreme simplicity, its reliability is relatively poor. This can be shown by the following example. If Eq. A1.76 is used to estimate the 95% confidence interval for the 37-year wind speed at Richmond, Virginia ($\hat{\mu} = 36.8$ mph, $\hat{\sigma} = 3.78$ mph; see [A1-11]), the interval obtained is (50 ± 5) mph. Using the largest value in a set of 37 values as an estimator of the 37-year wind, the estimated 95% confidence limit interval obtained is (50 ± 12) mph (see Eq. A1.63a), that is, an interval more than twice as wide as the interval estimated by the method of moments.

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2-31
NPP1-580-009
EH, 17

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SHEET 3-1 of 19
JOB NO. NP-119 DATE 1/7/92
PROJECT CNS STATION BLACKOUT
SUBJECT SITE-SPECIFIC WEATHER EVALUATION
CLIENT NPPD ORIGINATOR E. HOLCOMB
REVIEWER APPROVED
CALCULATION NO. NPP1-SBO-009

Attachment 3

Cooper Nuclear Station Site-Specific

Wind Speed Data

NPPI-SB6-009
3-2

Table 3.3-19. Monthly wind speed statistics, Cooper Nuclear Station, January-December 1975.

	Wind Speed (mph)			
	35 ft Wind Speed		318 ft Wind Speed	
Month	Mean	Hourly Maximum	Mean	Hourly Maximum
Jan.	7	18	15	37
Feb.	7	16	14	32
Mar.	3	29	16	45
Apr.	12	28	18	39
May	10	27	16	35
June	7	18	13	45
July	7	23	11	29
Aug.	9	23	15	34
Sep.	8	20	11	25
Oct.	9	27	13	32
Nov.	11	30	14	38
Dec.	9	27	13	36
Annual	8	30	14	45

 NPPI-SB4-009 EH JM 3-3

Table 3.3-19 Monthly wind speed statistics, Cooper Nuclear Station, January-December 1976.

	Wind Speed (mph)			
	35 ft Wind Speed		318 ft Wind Speed	
Month	Mean	Hourly Maximum	Mean	Hourly Maximum
January	11	28	15	34
February	11	29	16	45
March	11	35	15	44
April	11	37	16	44
May	9	20	13	34
June	10	34	14	42
July	8	19	11	26
August	8	22	12	28
September	8	20	11	28
October	8	23	10	28
November	10	28	12	36
December	10	28	13	35
Annual	10	~~28~~ 37 EH	11	~~35~~ 45 EH

Table 3.3-19. Monthly wind speed statistics, Cooper Nuclear Station, January - December 1977.

	Wind Speed (mph)			
	35 ft Wind Speed		318 ft Wind Speed	
Month	Mean	Hourly Maximum	Mean	Hourly Maximum
January	9.5	26.0	12.9	40.0
February	10.4	28.0	14.2	42.0
March	12.4	32.0	16.8	37.0
April	10.1	34.0	14.5	47.0
May	9.9	25.0	14.2	36.0
June	8.9	25.0	13.5	36.0
July	9.3	24.0	14.8	41.7
August	8.2	28.4	11.9	29.6
September	7.2	19.0	13.5	38.4
October	8.4	21.4	15.1	39.1
November	11.2	34.5	15.3	45.1
December	11.4	26.6	15.9	34.9
Annual	9.7	34.5	14.4	47.0

Table 3-1. Summary of meteorological data measured at Cooper Nuclear Station, January - December 1978.

	Meteorological Data											
	35 ft Temperature					35 ft			318 ft			
Month	Mean (F)	Mean Min. (F)	Mean Max. (F)	Abs. Min. (F)	Abs. Max. (F)	Direction Prevailing	Mean Speed (mph)	Max. Speed (mph)	Direction Prevailing	Mean Speed (mph)	Max. Speed (mph)	Precip. Total (in)
January	14.1	6.3	21.8	-9.8	44.4	NNW	4.2	27.5	NNW	13.3	37.9	0.08
February	17.2	9.8	23.6	-15.8	42.5	NW	8.7	33.2	N	11.5	37.7	0.47
March	35.2	26.5	43.5	-11.3	80.4	N	8.3	25.5	NNW	12.7	33.5	0.11
April	53.0	45.1	60.9	30.5	78.8	ESE	11.6	25.8	S	16.6	36.3	3.04
May	61.1	53.4	69.1	38.1	86.1	E	8.6	31.2	SE	13.3	39.6	3.60
June	73.1	63.7	82.4	50.4	98.5	SSE	9.0	40.1	S	13.6	52.4	2.86
July	76.6	67.9	85.2	60.8	96.0	S	6.7	21.7	S	13.0	30.5	5.11
August	75.4	65.4	86.1	51.8	95.4	SSE	6.6	21.2	SSE	11.1	36.6	1.12
September	71.0	61.3	81.4	47.1	95.4	S	6.4	19.9	S	12.3	28.4	6.44
October	54.1	42.9	67.0	32.7	86.1	N,S	6.8	18.2	NNW,S	12.0	29.1	0.62
November	40.9	33.8	49.2	14.0	77.5	N,S	6.2	17.7	N,SSW	9.8	23.7	1.36
December	27.2	20.2	35.3	4.9	47.8	NW	7.9	28.0	N	12.5	30.6	0.23

Table 3-1. Summary of meteorological data measured at the Cooper Nuclear Station, January-December 1979.

	Meteorological Data												
	35 ft temperature					35 ft			318 ft				
Month	Mean (F)	Mean Min (F)	Mean Max (F)	ABS Min (F)	ABS Max (F)	Direction Pre-vailing	Mean Speed (mph)	Max Speed (mph)	Direction Pre-vailing	Mean Speed (mph)	Max Speed (mph)	Precip. Total (in)
January	12.6	5.0	19.5	-8.9	40.0	NNW	6.3	21.5	NNW	13.1	35.0	0.70
February	17.0	8.0	25.0	-16.0	42.4	N	6.0	25.0	NNW	12.6	34.0	0.02
March	38.8	31.0	47.5	16.2	73.3	NNW	7.4	29.1	NNW	18.1	41.5	3.22
April	50.5	41.0	59.8	23.5	75.9	ESE	4.0	10.8	ESE,SE	14.3	32.3	1.61
May	62.4	52.0	72.6	38.5	85.9	S	3.8	15.4	S	15.6	43.2	1.40
June	72.1	62.0	82.1	45.2	94.0	S	3.2	13.4	S	12.5	38.6	2.06
July	74.5	67.0	85.0	55.0	94.4	SE	2.7	10.8	SSE	11.0	29.7	4.40
August*	74.0	65.0	83.4	38.2	94.1	ENE	2.6	5.8	S	15.1	28.0	3.20
September	67.8	56.0	79.9	40.1	88.3	a	a	~~a~~ 23.2*	S	13.4	32.7	1.20
October	55.9	44.0	67.8	30.6	85.4	NNW	5.9	27.0	NNW	14.1	32.8	3.99
November	39.0	31.0	47.9	20.2	68.8	S,WNW	8.0	19.9	NW	13.5	26.9	1.55
December	33.1	24.0	42.9	-0.1	61.6	NNW	8.1	24.7	NNW	14.4	34.0	0.19
Annual	50.0	40.7	59.6	-16.0	94.4	NNW	5.7	29.1	NNW,S	14.0	43.2	23.54

a = No Data Available

* calculated from 318 ft. data using logarithmic relation

HAZLETON ENVIRONMENTAL SCIENCES

Table 3-1. Summary of meteorological data measured at the Cooper Nuclear Station, Brownville, Nebraska, January-December 1980.

Month	318-ft Wind Mean Speed (mph)	318-ft Wind Max Speed (mph)	318-ft Wind Prevailing Direction	35-ft Wind Mean Speed (mph)	35-ft Wind Max Speed (mph)	35-ft Wind Prevailing Direction	35-ft Temperature Mean (C)	35-ft Temperature Mean Max (C)	35-ft Temperature Mean Min (C)	35-ft Temperature Abs Max (C)	35-ft Temperature Abs Min (C)	Precipitation Total (in.)
January	13.1	38		7.2	24		-3.0	1.4	-7.3	13.5	-23.8	0.66
February	11.7	38	NNW-N[a]	6.5	25	NNW-N[a]	-4.5	-0.2	-9.0	10.6	-22.3	0.17
March	15.2	31		8.2	28		2.0	6.7	-2.7	19.0	-19.9	1.92
April	13.6	34		7.6	23		11.4	16.7	5.8	30.4	-1.6	1.80
May	12.0	31	ESE-SSE[a]	5.7	18	NNW-N[a,b]	17.2	22.8	11.4	30.4	3.3	1.49
June	13.2	33		5.7	15		23.5	29.5	17.5	39.7	12.1	0.86
July	12.7	30		4.6	17		26.9	33.0	21.2	39.8	14.7	0.82
August	13.1	29	SE-S[a]	5.1	15	SSE-S[a]	24.8	30.6	19.[illegible]	36.3	14.1	2.70
September	13.2	41		5.5	26		19.6	25.8	13.2	34.1	1.7	0.44
October	13.3	36		6.2	26		9.2	15.5	3.4	24.4	-5.0	1.39
November	12.7	30	NNW-N[a]	8.6	24	NNW-N,SSE-S[a]	6.2	12.0	0.7	26.5	-10.3	0.29
December	12.4	30		9.0	25		-1.4	3.0	-5.6	16.5	-21.0	1.68
Annual	13.0	41	NNW-N,SSE-S	6.7	28	NNW-N,SSE-S	11.3	16.4	5.7	39.8	-23.8	14.22

[a] Prevailing direction is given for each quarter of the year; January-March, April-June, July-September, October-December.
[b] Only 61% of the wind data at 35-ft level was recovered during this quarter.

NPP1-5B0-609
EH JM 5-8

TABLE 4-1 SUMMARY OF METEOROLOGICAL DATA MEASURED AT THE COOPER NUCLEAR STATION, BROWNVILLE, NEBRASKA, JANUARY 1981-DECEMBER 1981.

	JAN	FEB	MAR	APR	MAY	JUN
318-Ft Wind						
Mean Speed (mph)	11	17	14	16	14	13
Maximum Speed (mph)	28	39	33	38	31	37
Direction of Maximum Speed	NNW	N	SSW	SSW	S	SSW
Date of Maximum Speed	6	10	28,29	3	22	13
Prevailing Direction (a)			NW-N			SSE-SSW
35-Ft Wind						
Mean Speed (mph)	8	11	9	11	9	9
Maximum Speed (mph)	22	30	30	31	23	30
Direction of Maximum Speed	NNW	N	WSW	SSW	SSW,SSE,S	SSW
Date of Maximum Speed	6	10	31	3	3,16,21	13
Prevailing Direction (a)			NW-N			SSE-SSW
35-Ft Ambient Temperature						
Mean (C)	-1.9	-0.5	6.3	15.1	15.6	22.6
Departure from Normal (C) (b)	1.9	0.2	2.2	3.0	-2.0	0.0
Maximum (C)	18.4	19.0	23.1	30.6	27.9	33.4
Date of Maximum	24	25	30	26	29	8
Minimum (C)	-15.8	-25.9	-7.5	1.6	-1.4	11.9
Date of Minimum	17	11	8	6	11	1
Precipitation						
Total (in.)	0.22	0.00	0.94	1.68	2.37	1.75
Departure from Normal (in.) (b)	-0.66	-1.05	-1.30	-1.33	-2.30	-4.31
Rain Days (c)	1	0	7	7	8	12
Maximum in a Single Day (in.)	0.22		0.63	0.46	0.93	0.59
Date	31		4	12	18	15
Maximum in a Single Hour (in.)	0.11		0.21	0.46	0.17	0.23
Date	31		4	12	17,18	25

(a) Prevailing direction is derived from the quarterly joint frequency tables and is reported for the quarterly period only. The quarterly periods used are: Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec.
(b) The climatological normals were derived from NOAA climatological data for Auburn, Nebraska.
(c) Rain days are defined as a day in which 0.01 in. of rain or rain equivalent of frozen precipitation has fallen.

NPPI-SBØ-009
EZ JM 3-9

1981

TABLE 4-1 (CONT.)

	JULY	AUG	SEP	OCT	NOV	DEC	Annual
318-Ft Wind							
Mean Speed (mph)	10	9	13	15	14	12	13
Maximum Speed (mph)	28	24	28	37	36	37	39
Direction of Maximum Speed	SSE	NNW	NNW	NW	N	NW	N
Date of Maximum Speed	24	7	26	17	19	3	10 Feb
Prevailing Direction[(a)]			SSE-SSW			SSE-SSW	SSE-SSW
35-Ft Wind							
Mean Speed (mph)	7	6	7	9	9	8	9
Maximum Speed (mph)	21	17	20	26	25	28	31
Direction of Maximum Speed	WSW	NNW, SSW, SW	NW, NNW	WNW	WNW, NNW	NW	SSW
Date of Maximum Speed	17	7,14	26	17	18,19	3	3 Apr
Prevailing Direction[(a)]			SSE-SSW			SE-S	SE-S
35-Ft Ambient Temperature							
Mean (C)	23.7	21.6	18.5	10.9	5.9	-3.4	10.6
Departure from Normal (C)[(b)]	-1.4	-2.7	-0.8	-2.9	0.6	-2.3	-1.0
Maximum (C)	35.2	31.7	31.9	25.3	18.4	13.7	35.2
Date of Maximum	14	30	29	5	17	7	14 Jul
Minimum (C)	14.2	12.1	2.0	-4.5	-7.5	-28.6	-28.6
Date of Minimum	28	11	18	23	21	19	19 Dec
Precipitation							
Total (in.)	4.77	4.87	3.15	1.84	1.58	0.43	23.60
Departure from Normal (in.)[(b)]	0.66	0.39	-0.92	-0.68	0.42	-0.62	-11.70
Rain Days[(c)]	10	11	3	6	2	2	69
Maximum in a Single Day (in.)	[illegible].88	1.67	1.17	1.13	1.44	0.27	1.67
Date	26	5	7	3	1	16	5 Aug
Maximum in a Single Hour (in.)	0.45	0.73	0.75	0.41	0.35	0.05	0.75
Date	22	5	7	3	1	16,27	7 Sep

NPP1-SBØ-009
3-10

TABLE 4-1 SUMMARY OF METEOROLOGICAL DATA MEASURED AT THE COOPER NUCLEAR STATION, BROWNVILLE, NEBRASKA, JANUARY 1982-DECEMBER 1982.

	JAN	FEB	MAR	APR	MAY	JUN
318-Ft Wind						
Mean Speed (mph)	14	11	13	15	12	9
Maximum Speed (mph)	39	27	38	45	35	35
Direction of Maximum Speed	WNW	N	SW	NW	S	S
Date of Maximum Speed	22	22	30	2	9	14
Prevailing Direction[a]			NW-N			SSE-SSW
35-Ft Wind						
Mean Speed (mph)	9	10	11	12	9	7
Maximum Speed (mph)	28	32	34	36	28	27
Direction of Maximum Speed	WNW	SSW,NNE,N-NNW	W	NW	SSW	WNW
Date of Maximum Speed	22	12,23,24	30	2	9,10	14
Prevailing Direction[a]			NNW-NNE			SSE-SSW
35-Ft Ambient Temperature						
Mean (C)	-9.8	-3.7	3.3	9.9	17.5	19.8
Departure from Normal (C°)[b]	-6.0	-3.0	-0.8	-2.2	-0.1	-2.8
Maximum (C)	5.9	21.2	18.7	26.8	28.4	33.0
Date of Maximum	27	22	12, 30	2	4	29
Minimum (C)	-28.1	-22.0	-14.5	-6.9	6.4	8.1
Date of Minimum	10	6	6	6	7	1
Precipitation						
Total (in.)	0.69	0.27	1.05	0.96	6.96	2.41
Departure from Normal (in.)[b]	-0.19	-0.78	-1.19	-2.05	2.29	-3.65
Rain Days[c]	7	6	10	5	18	6
Maximum in a Single Day (in.)	0.41	0.11	0.25	[illegible]	2.64	1.28
Date	22	17	19	28	20	8
Maximum in a Single Hour (in.)	0.19	0.03	0.14	0.11	0.88	0.84
Date	22	17	19	5, 28	20	8

[a] Prevailing direction is derived from the quarterly and annual joint frequency tables and is reported for the quarterly and annual periods only. The quarterly periods used are: Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec.

[b] The climatological normals were derived from NOAA climatological data for Auburn, Nebraska.

[c] Rain days are defined as a day in which 0.01 in. of rain or rain equivalent of frozen precipitation has fallen.

NPPI-SBd-004
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1982

TABLE 4-1 (CONT.)

	JULY	AUG	SEP	OCT	NOV	DEC	Annual
318-Ft Wind							
Mean Speed (mph)	10	9	11	13	13	11	12
Maximum Speed (mph)	28	24	29	33	40	28	45
Direction of Maximum Speed	ENE	WSW	S	NW	NNW	NW	NW
Date of Maximum Speed	20	4	28	19	12	18	2 Apr
Prevailing Direction[a]			SSE-SSW			SSE-SSW	SSE-SSW
35-Ft Wind							
Mean Speed (mph)	7	5	6	5	7	7	8
Maximum Speed (mph)	22	19	19	16	33	24	36
Direction of Maximum Speed	SSW	WSW	S	W	NNW	SW	NW
Date of Maximum Speed	5	4	28	11	12	13	2 Apr
Prevailing Direction[a]			SE-S			SSE-SSW	SSE-SSW
35-Ft Ambient Temperature							
Mean (C)	25.4	22.3	18.1	12.3	3.3	0.0	9.9
Departure from Normal (C°)[b]	0.3	-2.0	-1.2	-1.5	-2.0	1.1	-1.7
Maximum (C)	36.3	35.5	29.7	29.5	18.8	16.3	36.3
Date of Maximum	3	3	1	5	9	1	3 Jul
Minimum (C)	14.8	12.2	2.8	-3.3	-11.1	-13.6	-28.1
Date of Minimum	31	11	21	21	24	29	10 Jan
Precipitation							
Total (in.)	1.71	7.47	0.93	0.88	0.79	3.32	27.44
Departure from Normal (in.)[b]	-2.40	2.99	-3.14	-1.64	-0.37	2.27	-7.86
Rain Days[c]	8	15	4	6	4	8	97
Maximum in a Single Day (in.)	[illegible]	[illegible]	0.50	0.38	0.47	1.31	2.64
Date	6	12	6	28	11	27	20 May
Maximum in a Single Hour (in.)	0.45	1.19	0.25	0.16	0.13	0.51	1.19
Date	6	12	6	8	11	1	12 Aug

Table 3-1. Summary of Meteorological Data Measured at the Cooper Nuclear Station, January 1983 through December 1983

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
318-Ft Wind													
Mean Speed (mph)	13.2	12.5	15.5	15.8	13.9	11.8	13.1	10.4	14.6	[illegible]	14.1	14.9	13.6
Maximum Speed (mph)	39.0	29.0	33.0	44.0	36.0	33.0	30.0	25.0	36.0	[illegible]	41.0	33.0	44.0
Direction of Maximum Speed	NNW	NNW	SSE,SE	NNW	SE	S	SSW,SW	S	NNW	[illegible]	NNW	NW	NNW
Date of Maximum Speed	11	2	4	2	1	12	3	20	20	[illegible]	9	24	2Apr
35-Ft Wind													
Mean Speed (mph)	9.0	7.5	9.7	10.5	10.0	7.9	7.8	5.9	[illegible]	7.5	9.1	10.1	8.7
Maximum Speed (mph)	30.0	24.0	24.0	33.0	28.0	27.0	22.0	16.0	23.0	21.0	27.0	29.0	33.0
Direction of Maximum Speed	NNW	NNW	NNW	N	SW	S	SW	-m-	NNW	-m-	-m-	-m-	N
Date of Maximum Speed	11	2	27	2	6	12	3	15	20	27	9	24	2Apr
35-Ft Ambient Temperature													
Mean (°F)	-m-	-m-	-m-	45.7	58.9	71.2	80.0	81.3	69.4	54.1	40.7	12.1	56.7
Maximum (°F)	-m-	-m-	-m-	78.5	86.0	89.5	100.5	104.0	94.5	88.0	[illegible]	35.0	104.0
Date of Maximum	N/A	N/A	N/A	26	27	30	22	17	9	2	2	8	17Aug
Minimum (°F)	-m-	-m-	-m-	28.5	39.0	44.5	62.0	61.5	33.5	34.5	13.5	-17.5	[illegible]
Date of Minimum	N/A	N/A	N/A	18	8	1	25	12	23	13	29	22	22Dec
Precipitation													
Total (in.)	0.18	0.68	1.03	[illegible]	1.34	2.87	0.19	0.64	3.10	0.75	3.54	0.14	15.52
Rain Days[a]	5	2	6	8	9	8	2	4	6	4	5	4	63
Maximum in a Single Day (in.)	0.07	0.67	0.40	0.31	0.29	0.76	0.17	0.48	1.82	0.57	1.20	0.10	1.82
Date	26	1	26	12	13,18	17	13	23	19	21	9	20	19Sep
Maximum in a Single Hour (in.)	0.02	0.13	0.17	0.21	0.12	0.37	0.10	0.29	[illegible]	0.13	0.55	0.05	1.09
Date	29	1	15	12	18	17	13	23	19	21	3	20	19Sep

[a]Rain days are defined as a day in which 0.01 in. of rain or rain equivalent of frozen precipitation has fallen.
Note: -m- indicates missing data; N/A indicates Not Available.

NPPD - SBd-C09 5-12

Table 3-1. Summary of Meteorological Data Measured at the Cooper Nuclear Station, January 1984 through December 1984

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
100-m Wind													
Mean Speed (mph)	13.6	15.9	14.6	18.3	13.0	13.0	11.4	10.9	13.0	12.6	14.9	14.3	13.8
Maximum Speed (mph)	51.0	46.0	38.0	40.0	37.0	43.0	25.7	26.0	30.4	32.0	34.5	30.4	51.0
Direction of Maximum Speed	NNW	NNW	NW	NW,NNW	NW	S		S	S	W	NNW	N	NNW
Date of Maximum Speed	29	5	7	29	25	7	8	31	7	18	10	24	29Jan
60-m Wind[a]													
Mean Speed (mph)	-m-	-m-	-m-	-m-	11.5	12.3	9.9	9.0	11.3	10.6	13.1	12.8	11.3
Maximum Speed (mph)	-m-	-m-	-m-	-m-	37.0	40.0	22.9	22.8	30.6	29.5	31.8	29.3	40.0
Direction of Maximum Speed	-m-	-m-	-m-	-m-	NNW	S	S	SSE	S,SSW	W	NNW	N	S
Date of Maximum Speed	N/A	N/A	N/A	N/A	25	7	9	31	7	18	10	24	7Jun
10-m Wind													
Mean Speed (mph)	6.5	-m- *	-m- *	-m- *	8.5	8.4	6.8	5.8	7.6	7.0	9.0	9.0	7.6
Maximum Speed (mph)	18.0	-m- 32.1	-m- 26.5	-m- 27.9	27.0	27.5	16.0	16.8	23.7	23.5	25.7	[illegible].4	27.5
Direction of Maximum Speed	-m-	-m-	-m-	-m-	N	S	S	SSE	S	W	NNW	[illegible]	S
Date of Maximum Speed	3	N/A	N/A	N/A	25	7	14	31	7	18	10	[illegible]	7Jun
10-m Ambient Temperature													
Mean (°C)	-4.6	2.0	0.2	9.1	15.9	23.2	24.8	25.1	18.1	12.7	6.0	-0.1	11.9
Maximum (°C)	10.3	18.3	12.2	26.4	28.5	31.6	36.7	38.2	35.6	26.4	20.8	20.7	38.2
Date of Maximum	29	22	25	26	18	26	8	28	6	3	14	28	28Aug
Minimum (°C)	-23.3	-16.7	-11.4	0.8	3.5	10.0	16.7	12.8	-3.0	-[illegible]	-4.7	-15.9	-23.3
Date of Minimum	20	5	8	6	8	3	29	23	29	2[illegible]	28	6	20Jan
10-m Dew Point Temperature[a]													
Mean (°C)	-m-	-m-	-m-	-m-	8.1	15.6	16.0	15.9	9.5	6.5	-2.1	-6.5	7.7
Maximum (°C)	-m-	-m-	-m-	-m-	20.0	23.1	21.9	23.1	19.9	16.4	11.5	13.7	23.1
Date of Maximum	N/A	N/A	N/A	N/A	24	14	10	6	23	27	9	28	14Jun 6Aug
Minimum (°C)	-m-	-m-	-m-	-m-	-4.5	6.7	9.4	4.2	-5.8	-4.2	-14.1	-24.5	-24.5
Date of Minimum	N/A	N/A	N/A	N/A	9	2	7	30	29	23	15	6	6Dec

* calculated based on 100-m. data using logarithmic relation

Table 3-1. Summary of Meteorological Data Measured at the Cooper Nuclear Station for January 1, 1985 through December 31, 1985

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
100-m Wind													
Mean Speed (mph)	15.1	12.6	13.8	14.4	13.8	13.9	11.0	11.6	14.8	12.8	12.5	15.1	13.4
Maximum Speed (mph)	36.0	27.5	36.0	40.5	36.5	37.1	25.1	34.7	29.5	35.8	34.2	33.8	40.5
Direction of Maximum Speed	NNW	NNW	W	S	WSW	SSE	WNW	N	NW	S	NNW	NW	S
Date of Maximum Speed	25	23	4	19	11	23	11	5	23	7	6	17	19Apr
60-m Wind													
Mean Speed (mph)	13.8	11.3	13.0	13.6	11.9	12.0	9.1	9.6	12.7	10.9	11.4	13.5	11.9
Maximum Speed (mph)	34.4	25.9	36.9	36.7	32.4	31.3	22.1	31.3	28.9	33.6	32.7	31.1	36.9
Direction of Maximum Speed	NNW	NNW	S	S,SSE	WSW	SSE	NNW(2)	N	S	S	NNW	NW	S
Date of Maximum Speed	25	23	26	19	11	23	4	5	19	7	6	17	26Mar
10-m Wind													
Mean Speed (mph)	10.4	8.0	9.1	10.0	8.5	8.4	6.0	6.4	8.4	6.9	7.5	9.5	8.2
Maximum Speed (mph)	28.2	21.0	29.1	28.0	26.6	21.0	17.7	19.7	22.1	26.6	25.5	25.5	29.1
Direction of Maximum Speed	NNW	NNW	S	SSW(2)	WSW	SE	NNW	N	NW	NW(2)	NNW	NW	S
Date of Maximum Speed	25	16	26	18	11	23	4	5	23	4	6	17	26Mar
10-m Ambient Temperature													
Mean (Degree C)	-6.5	-3.6	7.9	13.5	19.0	21.0	24.8	21.4	17.7	12.7	0.7	-6.0	10.3
Maximum (Degree C)	9.9	13.4	22.7	30.0	30.2	35.2	35.5	34.1	33.1	24.5	20.4	7.5	35.5
Date of Maximum	6	28	26	18	25	8	9	31	2	16	18	30	9July
Minimum (Degree C)	-25.4	-23.0	-3.1	-3.5	7.9	8.5	14.5	11.4	2.8	-0.5	-13.6	-21.6	-25.4
Date of Minimum	19	6	4	1	18	13	3	26	30	1	30	18	19Jan
10-m Dew Point Temperature													
Mean (Degree C)	-11.8	-9.1	-1.1	5.3	10.3	12.3	16.9	17.2	12.8	5.9	-4.1	-10.6	3.8
Maximum (Degree C)	-1.0	9.2	12.0	16.6	21.5	23.6	22.9	25.5	23.7	17.5	15.3	1.7	25.5
Date of Maximum	18	21	3	29	30	24	12	9	1	18	18	30	9Aug
Minimum (Degree C)	-29.8	-27.4	-11.9	-10.1	-2.0	-2.2	7.5	10.3	-2.0	-5.9	-16.7	-25.6	-29.8
Date of Minimum	31	1	4	8	2	17	4	10	30	28	27	14	31Jan

Table 3-1. Summary of Meteorological Data Measured at the Cooper Nuclear Station for January 1, 1986 through December 31, 1986

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
100-m Wind													
Mean Speed (mph)	15.5	12.3	15.8	16.7	12.7	11.6	12.1	11.1	12.2	12.2	13.5	11.1	13.1
Maximum Speed (mph)	37.1	35.6	34.2	38.0	34.9	28.2	27.3	27.3	32.9	26.8	36.7	28.9	38.0
Direction of Maximum Speed	NW	WNW	NNW	WNW	S	NNE	S	S,SSE	SW	N	N	WNW	WNW
Date of Maximum Speed	4	25	5	14	4	29	5	12	28	31	25	29	14Apr
60-m Wind													
Mean Speed (mph)	13.6	11.0	14.4	14.8	10.9	10.0	10.4	9.1	10.5	10.3	11.9	9.5	11.4
Maximum Speed (mph)	35.1	31.8	35.8	34.9	34.2	23.0	26.8	24.6	27.7	24.4	33.1	22.8	35.8
Direction of Maximum Speed	NW	NNW	S	W	S	NNE	S	SSE	WSW	N	N	NNW	S
Date of Maximum Speed	4	20	24	14	4	29	5	12	28	31	25	29	24Mar
10-m Wind													
Mean Speed (mph)	9.5	7.7	10.1	10.5	7.6	6.9	7.0	5.9	7.1	6.8	8.1	6.6	7.8
Maximum Speed (mph)	29.1	25.3	26.8	29.1	27.3	17.2	20.1	17.9	19.7	18.3	25.1	18.3	29.1
Direction of Maximum Speed	NW	NNW	NNW,S	W	S	SSW	S	SSE	S	NNW	W	NNW	W
Date of Maximum Speed	4	20	5,24	14	4	26	5	18	28	11	7	29	14Apr
10-m Ambient Temperature													
Mean (Degree C)	0.5	-2.7	8.3	13.0	18.1	24.5	25.8	21.1	20.1	12.8	2.3	-0.2	12.0
Maximum (Degree C)	16.3	16.2	31.4	29.5	29.1	34.6	35.0	31.4	30.8	25.1	17.7	9.3	35.0
Date of Maximum	20	26	29	24	31	28	24	25	26	7	21	14	24July
Minimum (Degree C)	-18.9	-22.0	-10.8	-2.0	7.2	13.4	14.8	7.9	7.1	1.0	-16.4	-12.1	-22.0
Date of Minimum	27	12	7	14	19	12	21	28	8	14	11	10	12Feb
10-m Dew Point Temperature													
Mean (Degree C)	-7.3	-6.2	0.4	4.8	8.9	15.2	18.5	14.8	14.0	7.3	-3.7	-3.9	5.2
Maximum (Degree C)	2.7	8.5	13.1	17.2	17.5	23.1	23.4	21.6	21.0	18.0	11.1	4.1	23.4
Date of Maximum	31	2	31	29	9	29	30	17	24	2	7	7	30July
Minimum (Degree C)	-26.2	-23.8	-17.8	-9.0	-2.9	7.5	11.7	2.0	2.4	-5.3	-20.0	-17.8	-26.2
Date of Minimum	26	12	7	14	1	2	20	28	7	13	13	10	26Jan

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Table 3-1. Summary of Meteorological Data Measured at the Cooper Nuclear Station for January 1, 1987 through December 31, 1987

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
100-m Wind													
Mean Speed (mph)	13.6	13.5	14.1	13.9	13.1	10.1	12.8	10.9	12.0	13.3	14.5	14.5	13.0
Maximum Speed (mph)	30.7	37.3	33.1	31.8	39.7	35.0	33.0	29.7	29.5	30.2	27.6	31.4	39.7
Direction of Maximum Speed	NW	NNW	E	S	S	N	SSE	W	NE	NNW	S	S	S
Date of Maximum Speed	29	28	17	19	27	12	26	6	9	1	21	30	27May
60-m Wind													
Mean Speed (mph)	11.8	11.2	12.2	11.9	11.5	8.8	10.9	9.2	9.8	11.2	12.3	12.6	11.1
Maximum Speed (mph)	28.5	34.4	28.2	29.9	35.2	31.0	24.5	27.5	26.2	27.8	30.0	30.3	35.2
Direction of Maximum Speed	NW	NNW	ESE	S	S	N	S	SSE	NE	NNW	SW	S	S
Date of Maximum Speed	29	28	17	19	27	12	18	18	9	1	12	30	27May
10-m Wind													
Mean Speed (mph)	8.5	7.4	8.9	8.4	8.1	6.2	7.6	6.2	6.2	7.4	8.5	8.9	7.7
Maximum Speed (mph)	24.0	25.3	22.9	24.0	23.3	19.4	18.6	18.6	19.5	22.9	17.9	22.6	25.3
Direction of Maximum Speed	NW	NNW	NW	NNW	S	N	SSE	SSW	NE	NW	S	S	NNW
Date of Maximum Speed	29	28	1	1	27	12	17	18	9	5	21	30	28Feb
10-m Ambient Temperature													
Mean (Degree C)	-1.3	3.5	7.0	13.6	20.4	24.0	26.0	22.4	18.3	10.0	5.0	1.0	12.7
Maximum (Degree C)	14.5	17.7	23.3	32.2	31.6	34.8	36.8	37.9	31.4	29.5	19.0	11.8	37.9
Date of Maximum	13	13	6	26	19	14	31	1	4	1	12	10	1Aug
Minimum (Degree C)	-16.6	-8.3	-8.7	-3.7	8.5	11.9	13.6	11.4	8.3	-4.0	-2.0	-11.7	-16.6
Date of Minimum	23	18	30	3	22	4	14	31	30	11	30	31	23Jan
10-m Dew Point Temperature													
Mean (Degree C)	-7.4	-3.8	-.2	2.4	10.9	15.3	17.9	15.7	10.9	1.8	0.3	-3.0	7.6
Maximum (Degree C)	3.3	4.5	11.5	14.8	19.7	22.5	23.9	23.8	18.7	15.3	12.1	9.6	23.9
Date of Maximum	12	14	22	19	26	15	6	15	15	31	15	8	6July

NPPI-584-009
3-16

NPPI - SBØ - 009
EH /M 5-17

Table 3-1. Summary of Meteorological Data Measured at the Cooper Nuclear Station for January 1, 1988 through December 31, 1988

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
100-m Wind													
Mean Speed (mph)	13.7	14.4	16.4	14.6	15.8	13.3	10.8	12.6	13.8	12.7	15.4	13.6	13.9
Maximum Speed (mph)	36.2	40.3	35.6	34.7	34.1	24.[illegible]	28.3	29.7	34.9	31.8	32.6	30.9	40.3
Direction of Maximum Speed	WNW	NNW	NW	NNW	S	S	S	N	W	NNW	NW	NNW	NNW
Date of Maximum Speed	12	14	12	5	7	21	15	22	19	22	5	14	14Feb
60-m Wind													
Mean Speed (mph)	12.3	12.6	14.4	12.8	14.0	11.4	9.3	10.8	11.9	11.0	14.1	12.0	12.2
Maximum Speed (mph)	33.6	37.2	36.0	32.3	32.5	24.2	26.4	28.2	32.2	31.1	33.2	32.2	37.2
Direction of Maximum Speed	WNW	NNW	SSW	NNW	S	S	WNW	N	W	NNW	NW	NNW	NNW
Date of Maximum Speed	12	14	27	5	7	7	8	22	19	22	5	14	14Feb
10-m Wind													
Mean Speed (mph)	9.0	8.9	10.3	8.8	9.7	7.6	6.2	7.0	7.8	7.5	10.1	8.4	8.4
Maximum Speed (mph)	28.8	28.3	30.3	27.3	24.2	18.6	19.4	19.4	24.7	25.8	28.0	26.6	30.3
Direction of Maximum Speed	WNW	NNW	SSW	WNW	WNW	S	WNW	NNW	W	NW	NW	NNW	SSW
Date of Maximum Speed	12	14	27	26	9	13	8	22	19	23	5	14	27Mar
10-m Ambient Temperature													
Mean (Degree C)	-4.7	-3.5	4.8	11.2	20.4	25.1	24.8	25.3	20.2	10.7	6.0	0.6	11.8
Maximum (Degree C)	15.2	21.1	27.6	28.0	31.5	38.4	36.6	37.9	34.0	26.0	21.2	18.3	38.4
Date of Maximum	29	26	22	8	18	25	31	15	17	14	15	2	25June
Minimum (Degree C)	-18.3	-23.1	-10.6	-0.5	9.8	8.1	13.4	6.6	5.5	-3.5	-8.2	-13.9	-23.1
Date of Minimum	26	11	14	16	17	10	1	28	24	28	28	15	11Feb
10-m Dew Point Temperature													
Mean (Degree C)	-9.3	-9.6	-4.5	-0.2	8.2	11.6	16.4	15.5	10.8	0.7	-1.6	-7.2	2.5
Maximum (Degree C)	7.4	1.8	13.1	11.5	17.2	21.2	23.9	24.0	19.5	12.1	15.3	5.7	24.0
Date of Maximum	29	21	24	2	31	22	14	17	18	22	15	26	17Aug
Minimum (Degree C)	-24.9	-26.0	-19.2	-14.2	-4.3	-1.9	9.8	0.9	-0.1	-10.0	-12.8	-21.6	-26.0
Date of Minimum	4	11	14	18	9	9	21	28	6	30	28	16	11Feb

NPPI-SBØ-009 3-18

Table 3-1. Summary of Meteorological Data Measured at the Cooper Nuclear Station for January 1, 1989 through December 31, 1989

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
100-m Wind													
Mean Speed (mph)	13.5	12.4	14.2	13.6	13.2	11.5	10.4	10.7	12.3	13.4	14.5	13.4	12.7
Maximum Speed (mph)	28.9	30.5	39.2	28.8	34.3	27.8	26.3	24.6	35.8	30.3	33.6	30.1	39.2
Date/Hour of Maximum Speed	31/24	1/4	14/16	8/9	29/15	2/23	29/18	28/22	22/17	26/15	27/18	2/13	MAR14
60-m Wind													
Mean Speed (mph)	12.0	11.2	13.3	12.6	11.3	10.0	9.3	9.1	10.5	11.8	12.9	11.9	11.4
Maximum Speed (mph)	28.0	29.7	37.2	28.3	36.1	26.1	23.7	[illegible]	33.7	29.3	32.3	30.0	37.2
Date/Hour of Maximum Speed	31/24	1/4	14/16	8/9	29/15	20/16	29/18	28/22	22/17	26/15	27/18	2/13	MAR14
10-m Wind													
Mean Speed (mph)	8.3	8.7	9.9	9.6	8.2	6.7	6.2	6.0	6.5	7.3	8.7	8.1	7.8
Maximum Speed (mph)	23.9	24.5	33.6	24.8	28.3	19.2	17.6	15.1	23.8	21.1	26.2	24.9	33.6
Date/Hour of Maximum Speed	31/24	1/4	14/16	8/2	29/15	2/23	29/18	28/22	22/17	[illegible]	27/18	2/13	MAR14
10-m Ambient Temperature													
Mean (Degree C)	2.0	-7.3	4.6	13.5	17.0	21.2	25.3	23.8	17.8	13.6	4.8	-6.8	10.8
Maximum (Degree C)	19.5	9.7	27.0	34.1	35.0	34.3	36.2	36.7	31.3	30.7	19.3	17.9	36.7
Date of Maximum	31	25	26	26	29	21	10	4	7	13	11	5	AUG4
Minimum (Degree C)	-11.5	-24.6	-13.1	-4.8	1.8	9.2	15.0	9.9	17.0	-4.7	-12.1	-29.4	-29.4
Date of Minimum	9	3	5	10	7	16	16	8	23	20	28	22	DEC22
10-m Dew Point Temperature													
Mean (Degree C)	-6.2	-13.3	-3.9	1.1	2.7	*999	16.7	15.3	7.9	3.9	-4.9	-21.8	-.27
Maximum (Degree C)	6.0	2.1	13.2	16.1	12.7	*999	21.2	22.8	22.5	15.0	10.6	3.0	22.8
Date of Maximum	31	25	26	27	8	*999	30	26	7	5	13	5	AUG26
Minimum (Degree C)	-19.0	-30.0	-18.3	-16.4	-8.5	*999	10.6	5.5	7.9	-8.3	-20.6	-30.8	-30.8
Date of Minimum	8	3	6	9	6	*999	21	7	23	20	16	15	DEC15

* 999 = Denotes Missing Data

Table 3-1. Summary of Meteorological Data Measured at the Cooper Nuclear Station
for January 1, 1990 through December 31, 1990

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
<u>100-m Wind</u>													
Mean Speed (mph)	14.3	13.6	14.0	14.8	13.7	14.1	12.6	11.8	11.3	15.0	7.2	13.1	12.9
Maximum Speed (mph)	34.4	33.2	35.7	38.4	31.3	38.3	26.7	24.2	26.9	39.0	21.9	31.6	39.0
Date/Hour of Maximum Speed	27/8	13/9	13/21	10/2	18/17	19/5	19/20	3/1	27/5	17/19	30/14	3/7	OCT17
<u>60-m Wind</u>													
Mean Speed (mph)	12.6	11.9	12.5	13.9	12.3	12.9	11.3	9.6	9.6	11.7	12.6	11.6	11.9
Maximum Speed (mph)	33.6	32.1	33.1	31.3	31.2	41.6	25.4	21.5	25.1	36.0	33.5	29.6	41.6
Date/Hour of Maximum Speed	27/8	13/10	13/21	23/17	18/17	19/4	7/17	17/14	22/13	17/19	20/17	3/7	JUN19
<u>10-m Wind</u>													
Mean Speed (mph)	8.5	8.0	5.4	9.8	8.6	8.9	7.4	6.1	6.2	9.0	8.5	8.3	7.9
Maximum Speed (mph)	27.2	23.4	21.6	24.7	22.8	27.9	18.1	16.2	19.5	30.8	24.6	23.1	30.8
Date/Hour of Maximum Speed	27/8	24/3	11/16	1/12	7/18	19/4	7/16	17/14	22/13	17/20	21/11	3/7	OCT17
<u>10-m Ambient Temperature</u>													
Mean (Degree C)	1.9	0.8	6.0	11.3	15.5	26.6	25.2	24.6	21.3	16.0	8.4	-3.8	12.6
Maximum (Degree C)	18.1	22.2	24.4	29.1	29.3	34.8	39.0	35.6	36.2	32.8	26.7	16.6	39.0
Date of Maximum	16	12	12	23	7	28	4	31	6	5	1	11	JUL4
Minimum (Degree C)	-9.4	-17.2	-6.9	-3.9	4.9	8.0	11.7	12.5	3.9	-2.0	-6.0	-22.4	-22.4
Date of Minimum	1	17	[illegible]	12	1	4	14	7	23	28	28	22	DEC22
<u>10-m Dew Point Temperature</u>													
Mean (Degree C)	-5.2	-7.5	-0.4	1.2	7.0	15.5	14.8	16.5	10.4	4.4	0.0	-9.3	4.0
Maximum (Degree C)	11.3	2.5	16.6	15.0	16.3	23.0	21.2	23.4	21.9	15.5	13.9	5.1	23.4
Date of Maximum	16	7	10	22	15	13	1	28	1	2	20	14	AUG28
Minimum (Degree C)	-15.9	-20.6	-17.5	-15.5	-7.1	1.9	6.3	7.6	-2.9	-8.8	-10.6	-30.0	-30.0
Date of Minimum	12	17	3	5	1	3	14	6	23	28	7	22	DEC22

* 999 = Denotes Missing Data

Attachment 4

Variation of Wind Speed with Elevation

Note: The information in Attachment 4 has been extracted from the following document:

Simiu, Emil, Changery, Michael J. and James J. Filliben, "Extreme Wind Speeds at 129 Stations in the Contiguous U.S.", NBS Building Science Series #118, March 1979.

4-2
NPPI-5BΦ-009
EH JM

Nashville, TN	(1963 & 1972)
Abilene, TX	(1971)
Amarillo, TX	(1972)
Brownsville, TX	(1963)
Corpus Christi, TX	(1955, 1961 & 1970)
Port Arthur, TX	(1972)
Salt Lake City, UT	(1968)
Burlington, VT	(1968)
Lynchburg, VA	(1962 & 1967)

2.3 ROUGHNESS CONDITIONS AT AIRPORT STATIONS

In an attempt to ensure that the terrain roughness conditions are uniform among all the sets of data being analyzed, only airport stations have been considered herein. In principle, it may be assumed that at such stations open exposure conditions prevail. Nevertheless the mere fact that wind speed measurements are taken at an airport station does not necessarily ensure that the wind climatological conditions reflected by these measurements are identical, from the standpoint of the terrain exposure, to those prevailing at a different airport. For example, it is noted in Reference 2 that the estimated 50-year wind at Chicago Midway Airport is about 15 mph less than at the Chicago O'Hare airport. The probable reason for this difference is that the terrain around the Chicago Midway Airport is relatively heavily built-up. Similar considerations might explain to some extent the difference between the estimated 50-year winds at the Washington National Airport and the Baltimore-Washington International Airport, which are estimated in this report to be 66 mph and 75 mph respectively. Thus, in interpreting airport data for the purpose of developing wind maps, it is appropriate to take into account the possibility that, at the airport of concern, the terrain exposure conditions might differ somewhat from those defined as "open" (e.g., in Reference 3).

2.4 VARIATION OF WIND SPEED WITH HEIGHT ABOVE GROUND

To ensure the micrometeorological homogeneity of the data at any given station it is necessary to reduce all the wind speeds recorded at that station to a common elevation. The elevation chosen for this purpose is 10m above ground.

The mean wind profile near the ground in homogeneous terrain is given by the well-known logarithmic law, which may be written in the form:

$$U(z) = \frac{\ln \frac{z}{z_o}}{\ln \frac{10}{z_o}} U(10) \qquad (2.4.1)$$

4-3
NPP1-SBØ-009
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where z = height above ground and z_o = roughness length, both expressed in meters. In open terrain, z_o may vary from, say, 0.03m to 0.10m. In this report the reduction of the data to an elevation of 10m is based on the assumption z_o = 0.05m. It can be verified that the errors inherent in the assumption z_o = 0.05m -- when in fact the values z_o = 0.03m or z_o = 0.10m were correct -- are small (of the order of 1% or 2%).

An approximation to Eq. 2.4.1 is given by the power law

$$U(z) = \left(\frac{z}{10}\right)^{\alpha} U(10) \qquad (2.4.2)$$

where, for open terrain conditions, it is generally assumed $\alpha = 1/7$ (3). It is noted that Eq. 2.4.1, and therefore its approximate equivalent given by Eq. 2.4.2, is valid for mean wind speeds averaged over a relatively long time interval, e.g., one hour. The question thus arises of expressing the variation with height of the fastest-mile wind speed, which is averaged over a relatively short time (30 to 90s or so).

To obtain an approximate expression for the fastest-mile wind profile, note that it may be assumed, approximately,

$$\frac{U_{pk} - U_{fm}}{U_{pk} - U} = \frac{1}{2} \qquad (2.4.3)$$

where U_{pk} = peak wind speed, U_{fm} = fastest-mile speed, and U = hourly mean speed (see, e.g., Reference 4, p. 62). The expression for U_{pk} can, in open terrain, be written as

$$U_{pk}(z) = U(z) + 3\,\overline{u'^2}^{1/2} \qquad (2.4.4)$$

where $\overline{u'^2}^{1/2}$ = r.m.s of longitudinal velocity fluctuations, and

$$\overline{u'^2}^{1/2} \approx \frac{U(10)}{\ln \frac{10}{z_o}} \qquad (2.4.5)$$

where z_o is expressed in meters (see Reference 4, pp. 45 and 54).

It can be verified by using Equations 2.4.1, 2.4.3, 2.4.4 and 2.4.5 that, within the anenometer elevation range of interest in this report, it is possible to write approximately

4-4
NPP1-SBØ-009

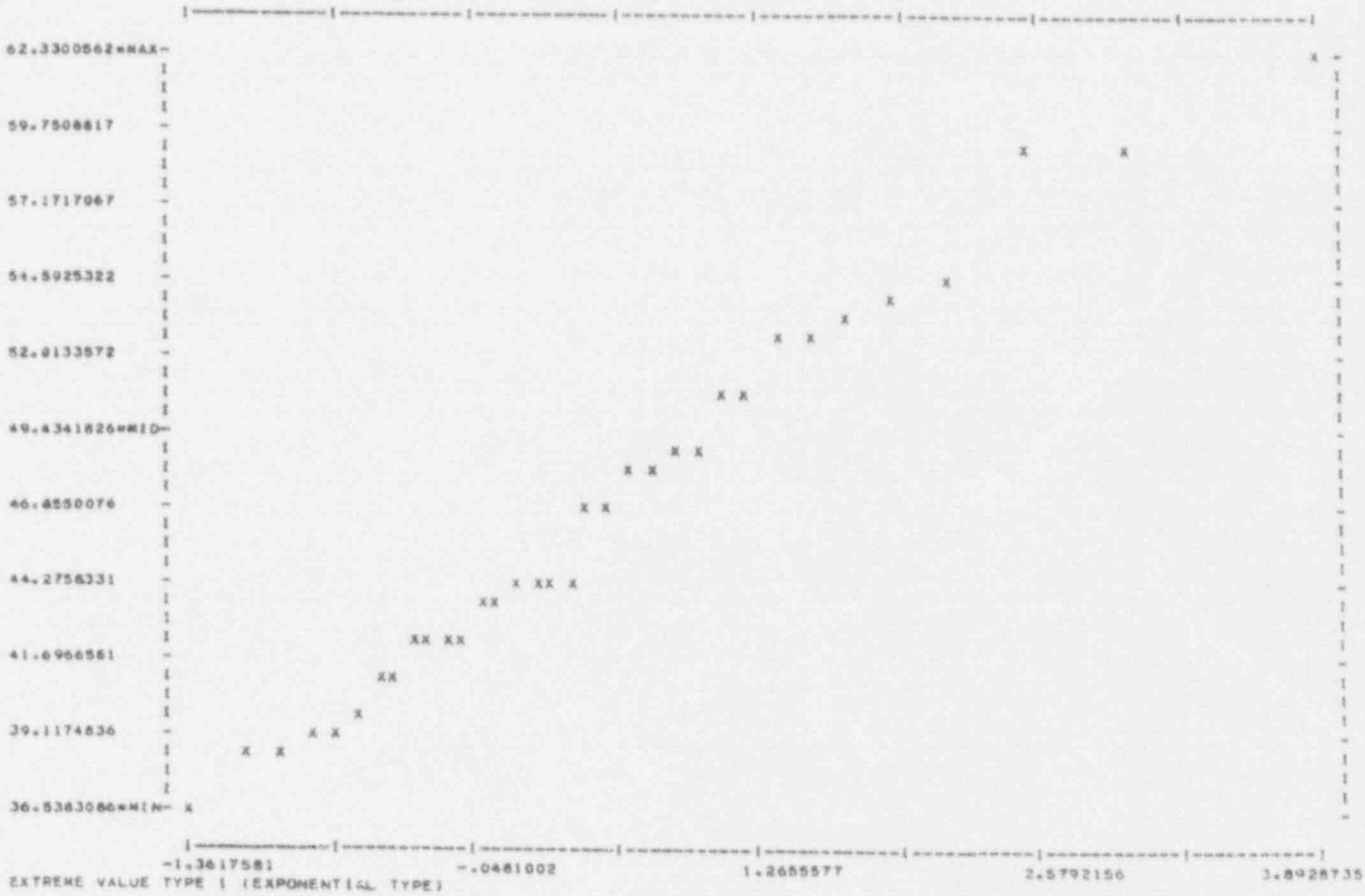
$$\frac{U_{fm}(10)}{U_{fm}(z)} = \frac{U(10)}{U(z)} \left(1 + \frac{z-10}{10} 0.02\right) \qquad (2.4.6)$$

where z is expressed in meters. The errors inherent in Equation 2.4.6 are of the order of -1 to 3%,the higher errors being on the conservative side (i.e., yielding slightly higher fastest-mile values at 10m above ground than would be obtained by a more "exact" expression). Eq. 2.4.6 has been employed to obtain the corrected speeds at 10m above ground in this report.

Attachment 5

Summary of Probability Plot Correlation Coefficient (PPCC) Method

5-2
NPP1-SBO-009



3. STATISTICAL ANALYSIS

3.1 OBJECTIVE OF STATISTICAL PROCEDURE

Probabilistic considerations, as well as available empirical evidence suggest that the asymptotic probability distributions of the largest values with unlimited upper tail are an appropriate model for the behavior of the largest yearly wind speed. There are two such distributions, known as the Type I and Type II distributions of the largest values, whose cumulative distributions functions, $F_I(v)$ and $F_{II}(v)$, respectively, are of the form

$$F_I(v) = \exp\left[-\exp\left(-\frac{v-\mu}{\sigma}\right)\right]; -\infty < v < \infty;$$

$$-\infty < \mu < \infty;\ 0 < \sigma < \infty \qquad (3.1.1)$$

5-3
NPPI-SB4-009
EH JM

$$\text{and } F_{II}(v) = \exp\left[-\left(\frac{v-\mu}{\sigma}\right)^{-\gamma}\right];\ \mu < v < \infty;$$

$$-\infty < \mu < \infty;\ 0 < \sigma < \infty;\ \gamma > 0 \qquad (3.1.2)$$

in which μ, σ, and γ are location, scale, and tail length parameters, respectively. Actually, the Type I distribution may be shown to be a Type II distribution with $\gamma = \infty$ (see Reference 4, p. 422); however, it is convenient to refer to it separately.

The data were analyzed using -- with minor modifications -- a computer program listed in Reference 5. For convenience, the main features of the procedure used in the analysis of the data are summarized in this section.

The procedure consists of three distinct stages. In the first stage the value of γ (Eq. 3.1.2) is determined which yields the closest fit to the observed data set (recall that $\gamma = \infty$ corresponds to an extreme value type I distribution). The "closest fit" criterion used in this stage is the so-called maximum probability plot correlation coefficient criterion. The probability plot correlation coefficient is defined as

$$r_D = \text{Corr}(X,M) = \frac{\Sigma(X_i - \overline{X})\,[M_i(D) - \overline{M(D)}]}{\{\Sigma(X_i - \overline{X})^2\ \Sigma[M_i(D) - \overline{M(D)}]^2\}^{1/2}} \qquad (3.1.3)$$

in which $\overline{X} = \Sigma X_i/n$; $\overline{M(D)} = \Sigma M_i(D)/n$; n=sample size; and D = probability distribution tested. The quantities X_i are obtained by a rearrangement of the data set: X_1 is the smallest; X_2 the second smallest; and X_i the ith smallest of the observations in the set. The quantities $M_i(D)$ are obtained as follows. Given a random variable X with probability distribution D and given an integer sample size n, it is possible from probabilistic considerations to derive mathematically the distributions of the smallest, second smallest, and generally the ith smallest values of X in a sample of size n. There are various quantities that can be utilized to measure the location of the distribution of the ith smallest value X_i (e.g., the mean, the median, or the mode). It is convenient to use the median as a measure of location in Eq. 3.1.3 -- these medians of the distribution of the ith smallest value being denoted by $M_i(D)$.

If the data set was generated by the distribution D, then aside from a location and scale factor, X_i will be approximately equal to $M_i(D)$ for all i, and so the plot of X_i versus $M_i(D)$ [referred to as probability plot] will be approximately linear. This linearity will, in turn, result in a near unity value in r_D. Thus, the better the fit of the distribution, D, to the data, the closer r_D will be to unity.

NPPI-SB4-009
5-4
87 CM

The procedure just described makes use of 46 extreme value Type II distributions defined by various values of γ from 1-25 in steps of 1, from 25-50 in steps of 5, from 50-100 in steps of 10, from 100-500 in steps of 50, from 500-1,000 in steps of 250, and $\gamma = \infty$. For any given data set, 46 probability plot correlation coefficients are computed corresponding to these distributions, and the distribution with the maximum probability plot correlation coefficient is chosen as the one which best fits the data (see, for example, computer output for Dallas, Texas, Section 4). The final result from this first stage is a value, γ_{opt}, of γ corresponding to the estimated best fitting distribution.

The second stage in the procedure consists of estimating the location and scale parameters, μ and σ, respectively, in Eqs. 3.1.1 and 3.1.2 for the observed data set and for the determined optimal value, γ_{opt}, as determined in stage 1. Estimates of the location and scale follow directly from the basic probability plot approach. If a least-squares line is fit to the probability plot corresponding to γ_{opt}, then the computed intercept and slope of the fitted line serve as estimates for the unknown location and scale parameters, μ and σ. In terms of the X_i and $M_i(D)$, these estimated location and scale values, $\hat{\mu}$ and $\hat{\sigma}$, are as follows:

$$\hat{\sigma} = \frac{\Sigma(X_i - \overline{X})[M_i(D) - \overline{M(D)}]}{\Sigma[M_i(D) - M(D)]^2} \qquad (3.1.4)$$

$$\hat{\mu} = \overline{X} - \hat{\sigma}\,\overline{M(D)} \qquad (3.1.5)$$

The third and final stage in the procedure determines the predicted wind speed v_N, for various intervals N of interest. The estimate for v_N is

$$v_N = \hat{\mu} + \hat{\sigma} G_{X_{\gamma_{opt}}} \left(1 - \frac{1}{N}\right) \qquad (3.1.6)$$

in which γ_{opt} = the optimal value of γ (as determined in stage 1); $\hat{\mu}$ and $\hat{\sigma}$ are the estimates of the location and scale parameters, μ and σ in Eqs. 3.1.1 and 3.1.2 (as determined in stage 2); and $G_{X\gamma_{opt}}(p)$ = the percentage point function of the best fitting extreme value distribution. If $\gamma_{opt} \neq \infty$ (i.e., if a member of the extreme value type II family provides the best fit), then

$$G_{X_{\gamma opt}}(p) = (-\ln p)^{-1/\gamma} \qquad (3.1.7)$$

5-5
NPPI-SBA-004
EH JM

If $\gamma_{opt} = \infty$ (i.e., if the extreme value type 1 distribution provides the best fit), then

$$G_{X_{\gamma opt}}(p) = -\ln(-\ln p) \qquad (3.1.8)$$

In effect, the procedure described in this section is an automated equivalent of probability paper plotting in which 46 types of probability paper, corresponding to 46 extreme value distributions, would be used and in which fitting would be carried out on the basis of the least-squares method, rather than by eye.

3.2 PROBABILITY PLOTS

A majority of the Type I probability plots generated by the computer from the data taken at the 129 stations fit a straight line reasonably well (see, e.g., plot included in computer output for Ely, Nevada, Section 4). However, in a number of cases the fit was relatively poor. A discussion of various reasons leading to a poor fit is presented in Section 3.5. To provide an idea of various types of deviations from a Type I distribution, probability plots were included in Section 4 for the following stations: Indianapolis, Indiana; Des Moines, Iowa; Topeka, Kansas; Wichita, Kansas; Boston, Massachusetts; Nantucket, Massachusetts; Detroit, Michigan; Grand Rapids, Michigan; Minneapolis, Minnesota; Missoula, Montana; Omaha, Nebraska; Valentine, Nebraska; Ely, Nevada; Albuquerque, New Mexico; Albany, New York; Abilene, Texas; and North Head, Washington.

3.3 ESTIMATION OF SAMPLING ERRORS

As indicated in Section 1, the computer output of Section 7 includes estimates of the standard deviation of the sampling errors, i.e., errors that are a consequence of the limited size of the data sample from which the Type I distribution parameters are estimated. Two such estimates were used. One estimate is based on the method of moments and has the following expression given by Gumbel in Reference 6 (pp. 10,174 and 228):

$$SD(\hat{v}_N) = \left[\frac{\pi^2}{6} + \frac{1.1396(y-0.5772)}{\sqrt{6}} + 1.1(y-0.5772)^2\right]^{1/2} \frac{\hat{\sigma}}{\sqrt{n}} \qquad (3.3.1)$$

in which $SD(\hat{v}_N)$ = the (estimated) standard deviation the sampling error in the estimation of the N-year wind

$$y = -\ln\left[-\ln\left(1 - \frac{1}{N}\right)\right] \qquad (3.3.2)$$

$\hat{\sigma}$ = the estimated value of the scale parameter; and n = the sample size.

A lower bound for the estimated sampling error is given by the following expression:

$$SD_{CR}(\hat{v}_N) = (0.60793y^2 + 0.514y + 1.10866)^{1/2} \frac{\hat{\sigma}}{\sqrt{n}} \qquad (3.3.3)$$

where the notations are the same as in Equation 3.3.1. Equation 3.3.3 is commonly referred to as the Cramer-Rao lower bound (7).

3.4 SUMMARY OF RESULTS

The results of the analysis are summarized in Table 3.4.1, in which the following notations are used:

- n = sample size
- $\overline{X}$ = sample mean
- s = sample standard deviation
- v_{max} = sample maximum
- γ_{opt} = value of optimal tail length parameter (see section 3.1)
- $\hat{v}_n$ = estimated extreme wind corresponding to a n-year return period, based on Type I distribution
- ppcc = probability plot correlation coefficient (see Section 3.1) for Type I distribution
- $\hat{v}_{50}$ = estimated 50-year wind speed
- $SD(\hat{v}_{50})$ = estimated standard deviation of sampling error for 50-year wind speed.

5-7
NPP1-SBØ-009
8/84 JM

3.5 TYPE I VERSUS TYPE II DISTRIBUTION

Of the 129 stations listed in Table 3.4.1, 15 stations [marked with the superscript (c) in Table 3.4.1 and listed in Appendix 1] have been noted to have largest yearly speed records that may not provide a reliable basis for predicting extreme winds. The remaining 114 stations may be divided into three categories characterized by the value of the optimal tail length parameter γ_{opt}, as shown in Table 3.5.1.

Table 3.5.1 Classification of Stations According to Value of γ_{opt}

Category	Range of γ_{opt}	Number of Stations	Percentage
I	$13 \leq \gamma_{opt} < \infty$	89	78%
II	$7 \leq \gamma_{opt} < 13$	11	10%
III	$2 \leq \gamma_{opt} < 7$	14	12%

The sample size for the stations of Table 3.5.1 varies between n=10 and n=45.

It is noted that the percentages of Table 3.5.1 are in qualitative agreement with those found from the analysis reported in Reference 8, in which all sample sizes were n = 37. This tends to confirm the hypothesis advanced in Reference 8 to the effect that, for stations in well-behaved wind climates, the best fit of a Type II (rather than Type I) distribution to a set of extreme wind data might be attributed to a sampling error in the estimation of the tail length parameter. This hypothesis does not exclude the possibility that stations exist for which a Type II distribution might provide an appropriate description of the wind climate; however, according to the results of both Reference 8 and Table 3.5.1, the number of such stations, if they exist, is very likely to be small. Thus, it appears justified to assume, as in Reference 8, that the Type I distribution of the largest values provides in general a better description of the wind climate than Type II distributions with small values of the tail length parameter (say, $2 \leq \gamma \leq 12$).

3.6 LARGEST WIND SPEED IN A SAMPLE OF SIZE N AND THE N-YEAR WIND

It is shown in Reference 9 (see also Reference 4, p. 423) that, if a variate X has a Type I distribution, the mode of the largest value in a sample of n values of X is very nearly equal to the value of the variate corresponding to the mean return period n (recall that the mode of a variate X is the value of that variable most likely to occur in any given trial). It can be seen from Table .5.1 that, for most sets for which γ_{opt} is large, the ratio $v_{max}/\hat{v}_n$ is indeed close to unity.

Attachment 6

NSSFC Program 'TORPLOT' Output for CNS

6-2
NPP1-SB∅-009
EH JM

NATIONAL SEVERE STORMS FORECAST CENTER
TORNADO DATA

The enclosed tornado listing provides information on all reported tornadoes in the area indicated since 1950. The various entries, and tables are explained below. If you have additional questions, please write or call the National Severe Storms Forecast Center, Room 1728, 601 E. 12th St., Kansas City, MO. 64106, phone (816) 426-3367.

The item-by-item listing shows the year, month, date and time of occurrence of each tornado in Central Standard Time.

The columns labeled SEQ and SEG indicate the sequence number and segment number of each tornado. Sequence numbers are assigned chronologically within each state. The first tornado in 1973 in Ohio is given sequence number 1 for the state of Ohio that year. Many tornadoes have lengthy paths that cross county or state lines. Some change direction quickly. In such cases the tracks are broken into segments that are denoted by segment numbers. A tornado with 3 segments has the same sequence number, but a different segment number, for each separate segment. The statistics in the tables are based only on the initial touchdown points.

The Latitude and Longitude of the beginning and ending points of each tornado are shown followed by the overall length and width. Deaths and injuries for each segment are listed, followed by Damage Class. Damage Class numbers range from 1 to 9 and provide an estimate of the damage according to the table (#1) below.

The columns labeled FPP provide the Fujita-Pearson scale estimates of Force, Path Length and Path Width. All three scales are logarithmic with values ranging from "-" for the smallest category to +5 for the largest.

The following table (#2) shows the range in each scale. The Path Length and the Path Width values represent estimates as to the actual amount of ground contact for each tornado. For instance, if a tornado had an overall length of 45 miles but made actual ground contact only 60 percent of the time the Path Length scale value would be a 3.

The AZRAN column indicates the azimuth and range from the center point. 129/83 indicates the tornado touchdown was 129 degrees (southeast) at 83 nautical miles from the center point.

A circular plot of tornado touchdown points is enclosed. The city of interest is at the center of the plot, north is at the top, east at the right, etc. Each digit represents the number of touchdowns in a small square area, about 2 miles on a side. Thus, what might be plotted as 21 actually represents 2 touchdowns in one square and 1 touchdown in the adjacent square.

6-3

NPP1-SBØ-009

[illegible]

The four frequency tables provide detailed information about the time of day, time of year and length and width characteristics of tornadoes in the area of interest.

The Path Width vs Path Length table is computed from the Pl and Pw data. Also, the mean path length and mean path areas are computed from the Pl and Pw data. When the length and width scale values are converted back to length and width figures the minimum values in each range are used. For example, a Pl value of 3 is converted to a length of 10 miles in the calculation.

The monthly and hourly distribution tables indicate the favored times of day and year for tornadoes in each area. Monthly and hourly percentages are shown on the hourly distribution table. Mean times are shown for each month and for the entire year. These times should be interpreted and used in conjunction with the hourly percentages in examining the diurnal trend of tornadoes. All times in these tables are Central Standard Time.

The latitude and longitude of the center point used by the search program is listed at the upper right of the Hourly Distribution Table. These figures are in degrees and hundredths. The map scale used in the circular plot is compatible with the WSR 57 radar map, 125 nautical mile range.

Table #1 (Damage Class)

1	Less than $50
2	$50 to $500
3	$500 to $5,000
4	$5,000 to $50,000
5	$50,000 to $500,000
6	$500,000 to $5 million
7	$5 Million to $50 Million
8	$50 Million to $500 Million

Table #2 (FPP Scale)

Scale	F (mph)	Damage	Pl (miles)	Pw (width)
-	Less than 40	(little or no damage)	Less than .3	Less than 6
0	40-72	Light	0.3-10	6-17 yds
1	73-112	Moderate	1.0-3.1	18-55 yds
2	113-157	Considerable	3.2-9.9	56-175 yds
3	158-206	Severe	10-31	176-556 yds
4	207-260	Devastating	32-99	0.3-0.9 mi
5	261-318	Incredible	100-315	1.0-3.1 mi

GRENIER

DEST=GRENIER USER=VERF QUEUE=LPT DEVICE=@LPB
SEQ=34299 QPRI=177 CPL=132 LPP=66 COPIES=1 PAGES=215
/DELETE

CREATED: 20-MAR-89 20:08:30
ENQUEUED: 20-MAR-89 20:38:18
PRINTING: 20-MAR-89 20:38:19

PATH=:UDD:TDU:BEVERLY:TORPLOT

TORPLOT

NSSFC /SYSB/ Kansas City MO

AOS/VS II RELEASE 1.00.00.00
AOS/VS II KLPT-32 REVISION 1.00.00.00

6-4
NPPI-SBØ-009
E# [illegible]

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F	P	P	AZRAN	Area sq.mi
*50	5	4	2100	IA	001	1	4057	9544	0	0	0	0	0	0	1	1			353./ 36.	.00
*50	5	8	1920	IA	002	1	4102	9516	4101	9513	2	60	0	0	0	2		3	22./ 44.	.32
*50	5	5	540	KS	004	2	3937	9537	3951	9531	15	132	0	12	5	3	3	3	179./ 44.	3.82
50	5	8	2117	KS	008	1	3924	9739	0	0	0	0	0	1	4	1			239./110.	.00
50	5	8	2130	KS	009	1	3943	9746	0	0	0	0	0	0	0	1			249./106.	.00
50	5	9	1	KS	010	1	3912	9635	0	0	0	0	0	0	4				213./ 82.	.00
50	5	26	1730	KS	017	1	3923	9658	3927	9647	5	12	0	0	4	1	2	1	227./ 85.	.12
50	7	1	1200	KS	022	1	3842	9705	0	0	0	0	0	0	4	2		0	214./120.	.00
50	7	1	1200	KS	023	1	3918	9655	0	0	0	0	0	1	4	1			221./ 87.	.00
50	7	8	2245	KS	025	1	3949	9648	0	0	1	27	0	0	4	1	0	2	239./ 63.	.05
*50	5	5	2210	NE	001	1	4023	9548	4017	9541	4	140	0	1	4	2	2	4	285./ 8.	1.23
50	6	22	2100	NE	004	1	4011	9802	4012	9759	2	0	0	0	0	0	1	1	265./110.	.00
50	7	15	1730	NE	005	1	4148	96"5	4144	9625	9	132	0	33	6	4	2	3	334./ 97.	2.37
50	9	21	1730	NE	006	1	4043	9649	4043	9623	11	20	0	0	3	1	3	1	292./ 58.	.43
*51	3	2	2030	KS	002	1	3950	9543	0	0	0	0	0	0	2				187./ 31.	.00
51	5	2	1930	KS	010	1	3902	9548	0	0	0	3	0	0	2	1		0	186./ 79.	.00
*51	5	2	2030	KS	011	1	3924	9524	0	0	0	0	0	0	2	1			169./ 58.	.00
51	5	9	700	KS	013	1	3918	9530	3920	9528	2	0	0	0	2	1	1	1	174./ 63.	.00
51	5	9	2100	KS	014	1	3847	9533	0	0	0	0	0	0	0	0			178./ 94.	.00
51	5	21	100	KS	022	1	3902	9638	0	0	0	0	0	0	2	2		0	218./101.	.00
51	5	25	1430	KS	024	1	3927	9730	0	0	0	0	0	0	3	1			238./102.	.00
51	5	25	1600	KS	025	1	3916	9711	3919	9708	4	132	1	0	5	3	2	3	228./ 97.	1.09
51	5	25	1800	KS	026	1	3956	9726	0	0	0	0	0	0	3	2			253./ 87.	.00
51	5	30	2250	KS	028	1	3924	9711	0	0	0	0	0	0	3				232./ 92.	.00
51	5	30	2250	KS	029	1	3908	9703	3913	9656	8	0	0	0	3	1	2	2	222./ 98.	.00
51	5	30	2250	KS	030	1	3917	9701	0	0	0	0	0	0	3	0			225./ 91.	.00
51	5	30	2250	KS	031	1	3915	9635	0	0	0	0	0	0	3				214./ 79.	.00
*51	5	30	2250	KS	032	1	3921	9627	3924	9619	7	0	0	0	3	1	2	2	212./ 71.	.00
*51	5	30	2250	KS	033	1	3924	9602	0	0	0	0	0	0	3				198./ 60.	.00
*51	5	30	2250	KS	034	1	3928	9544	0	0	0	0	0	0	3				185./ 53.	.00
*51	5	31	2345	KS	035	1	3922	9524	3924	9521	3	132	0	0	3	2	1	3	170./ 60.	.83
51	6	1	2000	KS	036	1	3944	9759	3947	9747	11	0	0	0	3	1	3	2	251./115.	.00
51	6	8	1330	KS	046	1	3825	9537	0	0	0	180	0	0	2	1	0	4	180./116.	.27
51	6	8	1700	KS	047	1	3853	9521	0	0	0	0	0	0	3	2		1	171./ 89.	.00
51	6	15	1915	KS	048	1	3904	9549	0	0	0	30	0	0	4	0	0	2	186./ 77.	.03
51	6	17	2300	KS	052	1	3837	9505	0	0	0	0	0	0	3				166./107.	.00
51	7	22	50	KS	065	1	3929	9735	3924	9729	7	0	0	0	3		2	2	240./104.	.00
51	8	24	730	KS	073	1	3840	9510	0	0	0	0	0	0	3				168./103.	.00
51	8	31	1620	KS	076	1	3840	9657	0	0	0	0	0	0	4				211./118.	.00
*51	5	25	2100	MO	001	1	4024	9510	0	0	0	3	0	0	3	1	0	0	82./ 22.	.00
51	7	8	2015	MO	004	1	3913	9401	3915	9401	0	30	0	0	4	2	0	2	132./101.	.01
51	4	30	900	NE	001	1	4105	9800	0	0	0	15	0	0	3	1	0	1	292./116.	.01
52	6	2	1830	IA	003	1	4154	9524	4153	9520	3	30	0	1	0	2	1	2	6./ 94.	.21
52	4	22	1730	KS	002	1	3911	9645	0	0	0	0	0	0	0				217./ 87.	.00
52	5	21	1930	KS	007	1	3941	9752	0	0	0	30	0	0	4	2	0	2	249./111.	.01
52	5	22	1745	KS	008	3	3859	9513	3904	9443	27	132	0	3	5	4	3	3	167./ 84.	6.86
52	5	22	1745	KS	008	3	3908	9509	3908	9441	22	0	0	0	4	2	3	2	163./ 76.	.00
52	6	21	1900	KS	010	1	3908	9509	3908	9441	22	0	0	0	4	2	3	2	163./ 76.	.00
52	8	14	2130	KS	018	1	3841	9701	0	0	1	30	0	0	4	2	0	2	213./119.	.09
*52	11	17	1	KS	019	1	3940	9552	0	0	0	0	0	0	0	1			195./ 42.	.00
52	5	7	1600	MO	005	1	4006	9432	0	0	1	120	0	0	2	1	1	3	107./ 53.	.34
52	5	22	1900	MO	006	1	3854	9416	3856	9414	2	132	0	1	5	2	1	3	144./109.	.73
*52	11	16	1600	MO	009	1	4027	9504	4034	9441	19	180	0	2	4	3	3	4	77./ 27.	6.65
52	6	26	2000	NE	006	1	4038	9656	4035	9655	2	0	0	0	0	2	1	1	298./ 62.	.00
*52	8	13	1930	NE	008	2	4113	9635	4056	9613	27	35	0	20	5	4	3	2	320./ 77.	1.71
52	8	13	1745	NE	009	2	4128	9717	4115	9623	24	390	0	1	0	3	3	4	312./100.	18.13

"*" before year means event ocurred within a 2 degree square centered on central point

6-5
NPP1-SBØ-009

6-6
NPP1-58Ø-009
EH

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F	F	P	AZRAN	Area sq.mi
53	3	21	1245	IA	001	1	4214	9541	0	0	0	0	0	2	3	1		1	359./113.	.00
53	3	21	1300	IA	002	1	4203	9543	4156	9552	11	190	0	0	4	1	3	4	358./102.	3.80
53	5	10	1515	IA	006	1	4052	9320	4056	9314	6	0	0	0	4	4	2	3	73./109.	.00
53	6	7	2100	IA	015	3	4222	9529	4313	9423	16	250	0	0	0	2	2	4	3./121.	7.64
53	6	7	2230	IA	019	2	4125	9335	4152	9145	115	60	0	0	0	2	5	3	50./100.	13.15
53	6	27	1545	IA	020	1	4127	9442	0	0	0	30	1	2	5	5		2	32./ 78.	.00
*53	6	27	1645	IA	021	1	4101	9505	0	0	0	30	0	0	4	1		2	32./ 47.	.00
53	6	27	1715	IA	022	1	4123	9335	0	0	0	30	0	2	4	1		2	56./111.	.00
53	5	9	2110	KS	003	1	3948	9754	3959	9748	13	0	0	0	4	3	3	2	252./110.	.00
53	5	16	1530	KS	009	1	3832	9652	0	0	2	66	0	0	3	1	1	3	208./123.	.31
53	6	19	1335	KS	020	1	3836	9704	3836	9654	8	0	0	0	4	2	2	1	213./125.	.00
*53	6	19	1500	KS	021	1	3936	9536	0	0	0	0	0	0	0	2		1	178./ 45.	.00
53	6	22	1900	KS	024	1	3903	9622	0	0	0	0	0	0	0				204./ 85.	.00
53	7	4	1600	KS	027	1	3930	9730	0	0	1	30	0	0	3	0	1	2	239./100.	.06
53	8	2	1500	KS	029	1	3943	9647	3945	9643	4	0	0	0	3	1	2	1	234./ 65.	.00
53	4	28	1900	NE	002	1	4053	9745	0	0	0	0	0	0	2				288./101.	.00
53	5	9	2245	NE	004	3	4015	9734	4046	9703	44	264	5	82	6	3	4	3	266./ 89.	22.39
53	5	10	110	NE	006	1	4058	9717	0	0	0	0	0	0	3				295./ 83.	.00
*53	5	10	600	NE	007	1	4011	9556	4003	9552	9	0	0	0	3	1	2	1	234./ 17.	.00
*53	5	10	1330	NE	008	1	4038	9552	0	0	0	10	0	0	3	0		1	328./ 20.	.00
53	5	29	2130	NE	011	1	4103	9815	0	0	0	0	0	0	0	1		1	290./124.	.00
53	6	7	1500	NE	016	1	4047	9810	4052	9815	7	0	0	0	4	2	2	1	283./118.	.00
53	6	7	1500	NE	017	1	4030	9813	4053	9805	4	0	0	0	3	0	2	1	284./121.	.00
53	6	7	1500	NE	018	1	4112	9717	4125	9657	22	0	0	2	6	1	3	2	304./ 90.	.00
53	6	7	1900	NE	028	1	4135	9633	0	0	1	0	0	5	0	0	1	1	331./ 86.	.00
53	6	7	1600	NE	029	1	4121	9704	4125	9657	7	0	0	2	5	2	2	1	313./ 88.	.00
53	6	7	1845	NE	030	1	4133	9613	4134	9610	4	0	0	1	4	2	2	1	339./ 77.	.00
*53	7	3	1530	NE	036	1	4107	9627	4104	9623	4	0	0	0	3		2	1	321./ 59.	.00
53	7	21	1600	NE	039	1	4049	9729	0	0	0	0	0	0	3	1	0	1	288./ 89.	.00
53	7	26	1630	NE	040	1	4160	9642	0	0	0	0	0	0	2				329./ 92.	.00
53	7	26	2000	NE	041	1	4127	9720	4135	9715	5	0	0	0	0	1	2	2	311./101.	.00
53	8	2	1530	NE	043	1	4005	9645	4005	9642	2	0	0	0	3	2	1	1	253./ 54.	.00
54	4	5	1710	IA	002	1	4202	9432	4206	9423	2	264	0	1	5	2	1	4	26./112.	1.43
*54	4	5	1730	IA	003	1	4036	9514	4040	9510	3	200	0	0	0	3	2	4	51./ 24.	1.31
*54	4	5	1745	IA	004	1	4040	9453	4043	9440	11	100	0	0	2	2	3	3	61./ 39.	2.25
*54	4	5	1815	IA	005	1	4041	9444	0	0	0	60	0	0	2	1		2	64./ 46.	.00
54	6	9	2200	IA	016	1	4217	9443	4223	9434	6	132	1	0	5	4	2	3	19./123.	1.55
*54	3	12	1220	KS	002	1	3935	9528	0	0	0	0	0	0	3	1			171./ 47.	.00
54	3	18	1115	KS	005	1	3848	9658	0	0	0	0	0	0	3	1			214./112.	.00
54	3	18	1135	KS	006	1	3902	9655	0	0	2	132	0	0	3	1	1	3	217./ 99.	.50
54	3	18	1215	KS	008	1	3837	9612	0	0	2	132	0	0	2	1	1	3	194./107.	.50
54	3	18	1225	KS	009	1	3845	9607	0	0	0	0	0	0	3	2			193./ 99.	.00
54	3	18	1230	KS	010	1	3841	9558	0	0	0	0	0	0	2	1			189./101.	.00
54	3	18	1310	KS	011	1	3854	9542	0	0	0	0	0	0	3	1			182./ 87.	.00
54	3	18	1315	KS	012	1	3847	9533	0	0	0	0	0	0	3	2			178./ 94.	.00
*54	3	18	1515	KS	013	1	3951	9531	0	0	2	40	0	0	2		1	2	170./ 30.	.19
54	3	18	1330	KS	014	1	3916	9516	0	0	0	30	0	0	0	1		2	165./ 67.	.00
54	3	18	1200	KS	015	1	3923	9646	0	0	0	10	0	0	3	1	0	1	222./ 79.	.01
*54	3	18	1200	KS	016	1	3940	9531	0	0	0	0	0	0	0	2			173./ 41.	.00
54	3	24	2030	KS	017	1	3844	9503	0	0	0	0	0	0	3	2		1	164./101.	.00
54	4	5	1845	KS	021	1	3911	9655	3917	9646	9	0	0	0	0	2	2	1	220./ 92.	.00
*54	4	5	1930	KS	022	1	3922	9557	3921	9553	3	30	0	0	4	1	1	2	194./ 61.	.19
54	4	10	1830	KS	023	1	3820	9531	0	0	0	0	0	0	3	2		1	177./121.	.00
54	5	31	1610	KS	036	1	3853	9443	0	0	2	0	0	0	4	2	1	1	154./ 98.	.00
54	6	11	2000	KS	042	1	3337	9613	0	0	0	0	0	0	0				197./109.	.00

'*' before year means event ocurred within a 2 degree square centered on central point

6-7

NPP1-SBd-009

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	ste Seq	Total # seq	Lat beg'	Lon beg'	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F	P	P	AZRAN	Area sq.mi
54	6	21	1615	KS 049	1	3922	.745	3922	9761	3	0	0	0	0	1	1	1	239./115.	.00
54	6	30	1830	KS 050	1	3852	9449	0	0	1	0	0	0	3	0	0	0	157./ 97.	.00
54	8	5	1830	KS 058	1	3831	9522	0	0	2	60	0	0	4	1	1	3	174./111.	.23
54	8	5	2015	KS 059	1	3837	9516	0	0	1	90	0	2	4	1	0	3	171./105.	.17
54	8	22	1600	KS 062	1	3940	9809	0	0	2	240	0	0	0	0	1	4	251./123.	.91
54	5	7	1600	MO 023	1	4005	9430	0	0	0	3	0	0	2	0	0	0	107./ 54.	.00
*54	,)	31	1445	MO 026	2	4023	9525	4027	9501	10	132	0	0	4	2	3	3	79./ 10.	2.69
54	6	2	1730	MO 028	1	3945	9330	3952	9323	10	45	0	0	4	1	2	2	110./105.	.37
54	6	14	2100	MO 029	1	4002	9429	0	0	0	3	0	0	2	0	0	0	110./ 56.	.00
*54	6	15	1300	MO 030	1	4003	9516	0	0	0	3	0	0	1	1	0	0	137./ 25.	.00
*54	6	11	30	NE 006	1	4024	9601	0	0	0	0	0	0	3	0		0	280./ 15.	.00
54	6	17	2315	NE 009	2	4205	9703	4212	9642	15	49	1	0	5	3	3	2	329./122.	1.46
*54	7	20	1700	NE 012	1	4018	9615	0	0	1	10	0	0	3	1	0	1	264./ 25.	.02
54	7	30	1610	NE 014	1	4052	9737	0	0	1	264	0	0	4	2	1	4	289./ 95.	.75
54	8	23	330	NE 016	1	4210	9640	0	0	0	0	0	0	3	0		0	337./118.	.00
*55	4	3	1900	IA 001	1	4045	9502	0	0	0	132	0	0	3	1	0	3	49./ 36.	.13
55	4	4	1610	IA 002	1	4146	9359	4156	9355	4	132	0	0	4	2	2	3	41./113.	1.20
*55	4	23	1310	IA 005	1	4038	9514	0	0	1	9	0	0	4	2	0	1	67./ 25.	.03
55	4	23	1600	IA 006	1	4063	9421	4048	9419	4	132	0	0	4	3	2	3	69./ 62.	1.05
55	5	6	1615	IA 007	1	4139	9519	4148	9505	7	60	0	0	4	2	2	3	10./ 79.	.90
55	4	27	1900	KS 007	1	3902	9716	0	0	0	0	0	0	0	1		1	224./110.	.00
55	5	26	27	KS 014	1	3838	9547	3919	9455	66	0	0	0	5	2	4	2	184./103.	.00
*55	5	26	1730	KS 016	1	3941	9659	3946	9453	7	66	0	1	4	2	2	3	143./ 50.	.95
*55	5	27	2040	KS 026	1	3?26	9635	0	0	0	0	0	0	0				219./ 70.	.00
55	6	2	2130	KS 039	1	3925	9759	3934	9740	19	0	0	0	3	1	3	1	243./122.	.00
55	6	3	1200	KS 042	1	3938	9746	0	0	0	0	0	0	0	0			246./108.	.00
55	6	4	1945	KS 072	1	3934	9717	0	0	0	0	0	0	0				238./ 90.	.00
55	6	30	1840	KS 089	1	3933	9738	0	0	1	0	0	0	0	1	1	1	243./104.	.00
55	6	30	1915	KS 091	1	3935	9717	0	0	0	0	0	0	0				239./ 89.	[illegible]
55	9	21	1550	KS 097	1	3818	9533	0	0	0	10	0	0	3	2	0	1	178./123.	.01
55	3	14	1730	MO 001	3	3939	9415	3940	9401	8	75	0	1	5	3	2	3	123./ 76.	1.24
55	3	14	1740	MO 002	1	3918	9413	3920	9410	3	75	0	0	4	2	2	3	134./ 91.	.30
55	3	14	1800	MO 003	1	3921	9414	0	0	0	30	0	0	1	1	0	2	133./ 88.	.02
55	4	23	1330	MO 011	1	4031	9432	4033	9429	3	30	0	1	4	2	1	2	79./ 51.	.20
*55	4	23	1330	MO 012	1	4026	9518	4028	9518	2	30	0	0	4	2	1	2	72./ 16.	.13
55	4	26	300	MO 016	1	4019	9339	0	0	1	30	0	0	1	1	1	2	91./ 91.	.06
55	5	26	1800	MO 019	1	39.0	9540	0	0	0	3	0	1	4	0	0	0	124./110.	.00
55	5	26	1900	MO 021	1	3950	9313	0	0	0	3	0	0	3	1	0	0	106./116.	.00
55	5	26	1900	MO 022	1	3950	9313	0	0	0	3	0	0	0	0	0	0	106./116.	.00
55	5	27	2100	MO 025	1	3844	9424	0	0	0	3	0	0	3	1	0	0	149./113.	.00
55	9	24	430	MO 029	1	3838	9410	0	0	0	3	0	0	4	1	0	0	146./124.	.00
55	4	27	2130	NE 001	1	4044	9647	0	0	0	0	0	0	3	1	0	1	294./ 57.	.00
55	5	26	1700	NE 004	1	4219	9630	4223	9633	5	5	0	0	0	1	2	0	342./124.	.05
55	6	4	1900	NE 009	1	4001	9730	0	0	0	0	0	0	0	1		1	257./ 88.	.00
55	6	4	2125	NE 010	1	4127	9602	0	0	0	0	0	0	0	0	0	1	345./ 68.	.00
55	7	9	2200	NE 017	1	4104	9748	0	0	0	0	0	0	4	1			294./107.	.00
55	9	20	2000	NE 031	1	4014	9758	4018	9753	6	0	0	0	3	1	2	1	266./107.	.00
*56	5	29	2300	IA 004	1	4121	9457	4123	9453	4	15	0	0	2	2	2	1	27./ 67.	.12
56	5	29	2030	KS 019	1	4000	9638	3952	9638	4	0	0	0	0	1	2	2	245./ 51.	.00
56	6	18	620	KS 024	1	3915	9454	0	0	0	8	0	0	3	2	0	1	153./ 74.	.01
*56	6	19	1715	KS 025	1	3937	9637	0	0	0	0	0	0	0	1		1	226./ 63.	.00
*56	6	26	200	KS 030	1	3945	9622	0	0	0	0	0	0	0			1	223./ 49.	.00
56	7	2	1645	KS 033	1	3848	9511	3848	9507	1	0	0	0	0	2	1	2	167./ 95.	.00
56	7	7	2200	KS 038	1	[illegible]	9520	3848	9513	7	0	0	0	3	1	2	2	171./ 89.	.00
*56	12	4	1800	KS 059	1	3946	9457	0	0	0	15	0	1	0		0	1	138./ 47.	.01

"*" before year means event ocurred within a 2 degree square centered on central point

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	sta	Seq	Total # seq	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F	P	P	AZRAN	Area sq.mi
56	4	2	100	MO	010	1	4026	9415	4029	9414	1	9	0	0	3	1	1	1	85./ 63.	.03
*56	4	28	300	MO	013	1	3935	9446	0	0	2	10	0	0	2	1	1	1	139./ 61.	.04
56	7	2	1430	MO	016	1	3923	9413	0	0	0	3	0	0	2	1	0	0	131./ 88.	.00
56	7	11	2200	MO	018	1	4032	9437	0	0	0	3	0	0	1	0	0	0	77./ 48.	.00
*56	4	2	2245	NE	001	1	4022	9550	4024	9547	3	30	0	0	3	2	1	2	276./ 9.	.20
56	4	28	115	NE	002	1	4015	9723	4029	9642	39	0	0	1	5	3	4	2	266./ 80.	.00
56	5	10	2000	NE	004	1	4127	9624	4133	9616	4	132	0	0	3	1	2	3	332./ 74.	1.22
56	5	12	2000	NE	005	1	4120	9736	0	0	4	0	0	0	4	1	1	1	304./106.	.00
*56	5	12	2200	NE	006	1	4117	9600	4115	9557	3	0	0	0	5	1	1	1	344./ 59.	.03
56	5	29	2130	NE	007	1	4004	9652	4006	9649	2	0	0	0	4	2	1	2	253./ 59.	.00
56	5	30	1630	NE	008	1	4035	9750	4038	9746	2	90	0	0	4	1	1	3	278./101.	.42
56	6	6	1845	NE	011	1	4033	9740	4022	9728	16	0	0	3	5	2	3	2	277./ 93.	.00
56	6	6	1920	NE	012	1	4044	9553	4042	9651	2	0	0	1	3	2	1	1	292./ 61.	.00
56	6	6	1930	NE	013	1	4046	9652	0	0	0	0	0	1	3	1	0	1	294./ 61.	.00
*56	6	6	1930	NE	014	1	4053	9634	0	0	1	30	0	0	0	1	1	2	304./ 51.	.09
56	7	1	200	NE	019	1	4158	9655	0	0	0	0	0	0	3	0	0	0	329./113.	.00
56	7	18	1900	NE	024	1	4124	9637	0	0	0	0	0	0	0				325./ 77.	.00
*56	7	28	430	NE	025	1	4049	9558	0	0	1	30	0	0	3	1	1	2	331./ 31.	.06
56	7	30	1530	NE	026	1	4120	9638	0	0	0	0	0	0	3	1	0		323./ 74.	.00
*56	9	3	1700	NE	029	1	4012	9606	0	0	2	0	0	0	0	1	1	1	247./ 23.	.00
*57	4	25	1130	IA	002	1	4106	9500	0	C	0	30	0	0	4	0		2	32./ 53.	.00
*57	5	25	2315	IA	006	1	409[illegible]	9507	4058	9503	1	300	0	0	4	0	1	4	35./ 41.	1.11
57	5	30	1435	IA	010	1	4144	9528	0	0	0	0	0	0	0				5./ 83.	.09
57	5	30	1650	IA	011	1	4211	9502	0	0	0	0	0	0	0				14./113.	.00
57	7	4	228	IA	016	1	4212	9512	0	0	0	0	0	1	1	1			10./113.	.00
57	7	21	1100	IA	017	1	4045	9348	0	0	0	0	0	0	0				74./ 87.	.00
57	4	22	1645	KS	003	1	3917	9707	3920	9704	4	90	0	0	3	1	2	3	227./ 94.	.74
57	4	22	1645	KS	004	1	3917	9707	3920	9704	4	90	0	0	3	1	2	3	227./ 94.	.74
57	5	20	1650	KS	026	1	3923	9744	3953	9712	44	120	0	0	5	4	4	3	239./113.	10.15
57	5	20	1450	KS	027	1	3928	9738	0	0	0	0	0	0	0	2		1	240./107.	.00
57	5	20	1450	KS	028	1	3931	9738	0	0	0	0	0	0	0	2		1	242./105.	.00
57	5	20	1450	KS	029	1	3931	9739	0	0	0	0	0	0	0	2		1	242./105.	.00
57	5	20	1450	KS	030	1	3934	9734	3938	9729	6	0	0	0	0	3	2	1	242./101.	.00
57	5	20	1937	KS	034	1	3830	9526	3832	9520	5	0	0	0	0	3	2	1	175./111.	.00
57	6	11	1800	KS	044	1	3852	9516	3854	9512	2	0	0	0	0	2	1	1	168./ 91.	.00
57	6	11	1945	KS	045	1	3858	9548	0	0	0	18	0	0	0	0	0	2	155./ 83.	.01
57	6	11	2004	KS	046	1	3856	9449	0	0	0	30	0	0	4	1	0	2	156./ 93.	.01
57	6	14	105	KS	048	1	3859	9652	0	0	0	0	0	0	0	1		1	215./100.	.00
57	6	21	2000	KS	055	1	3942	9745	0	0	0	0	0	0	0			1	248./105.	.00
57	6	21	2330	KS	058	1	3859	9456	3901	9446	9	120	0	2	5	1	2	3	158./ 88.	2.10
57	6	22	2300	KS	062	1	3854	9710	0	0	0	6	0	3	3			1	219./113.	.00
57	5	20	1700	MO	011	1	3951	9421	3957	9413	7	60	0	0	4	2	2	3	117./ 66.	.30
57	5	20	1937	MO	013	1	3912	9412	3917	9359	12	10	0	0	4	2	3	1	136./ 96.	.25
*57	6	7	1600	MO	027	1	4002	9500	0	0	0	12	0	0	2	1	0	1	123./ 35.	.00
57	6	7	2000	MO	028	1	3938	9435	0	0	0	3	0	0	1	0	0	0	132./ 65.	.00
57	6	14	400	MO	030	1	3949	9335	0	0	0	90	0	0	4	1	0	3	109./100.	.09
57	6	22	0	MO	033	1	3900	9433	3915	9424	19	3	0	0	2	2	3	0	149./ 95.	.11
57	7	21	1530	MO	034	1	4032	9345	0	0	0	3	0	0	3	0	0	0	83./ 87.	.00
57	4	25	1915	NE	008	3	4035	9734	4111	9602	89	0	1	8	6	4	3	3	279./ 89.	.00
57	4	25	1900	NE	009	1	4022	9757	4039	9724	27	66	0	0	5	3	3	3	271./106.	3.43
*57	5	9	1540	NE	010	1	4032	9618	4039	9611	10	36	0	0	4	2	2	2	290./ 32.	.69
*57	5	13	1843	NE	012	1	4108	9602	0	0	2	0	0	0	3	1	1	1	339./ 50.	.00
*57	5	13	1900	NE	013	1	4114	9601	0	0	0	0	0	0	1	1			342./ 56.	.00
*57	5	16	1200	NE	014	1	4109	9616	0	0	0	0	0	0	3	1	0	0	329./ 53.	.00
57	5	20	1420	NE	020	1	4004	9516	0	0	0	0	0	0	1				262./122.	.00

"*" before year means event ocurred within a 2 degree square centered on central point

6-8
NPP1-SBC-009
[illegible]

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	sta	Seq	Total # seq	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F	P	P	AZRAN	Area sq.mi
57	5	20	1600	NE	022	1	4004	9730	4042	9620	60	0	0	0	5	2	4	2	259./ 87.	.00
57	5	20	1720	NE	023	1	4041	9715	4050	9650	12	0	0	0	4	2	3	2	285./ 76.	.00
57	6	6	2130	NE	026	1	4056	9727	4100	9725	4	0	0	0	3	1	2	1	293./ 89.	.00
57	6	13	1820	NE	028	1	4129	9737	4128	9733	3	0	0	0	3	1	1	1	307./112.	.00
57	6	13	1830	NE	029	1	4107	9708	0	0	0	0	0	0	3	1	0	0	304./ 82.	.00
*57	6	15	1400	NE	031	1	4014	9619	4016	9612	6	0	0	0	0	1	2	1	257./ 72.	.00
57	6	15	2015	NE	032	1	4047	9714	4056	9704	13	0	0	0	4	2	3	1	290./ 77.	.00
*57	6	15	2100	NE	033	1	4111	9633	4121	96[illegible]1	17	0	0	0	4	1	3	2	320./ 65.	.00
57	6	15	2000	NE	034	1	4102	9647	0	0	0	0	0	0	1	1			307./ 67.	.00
57	6	21	1815	NE	036	1	4054	9728	4054	9721	6	0	0	0	5	3	2	2	292./ 89.	.00
57	6	21	1830	NE	037	1	4121	9719	0	0	1	30	0	0	2	1	1	2	308./ 97.	.06
57	6	21	1852	NE	038	1	4106	9630	0	0	0	0	0	0	1				310./ 71.	.00
57	6	27	1900	NE	039	1	4012	9735	4014	9744	9	0	0	0	4	1	2	2	265./105.	.00
57	6	27	1935	NE	040	1	4020	9748	4024	9743	6	0	0	0	1	0	2	1	269./ 99.	.00
57	7	2	2030	NE	042	1	4159	9655	0	0	0	0	0	0	1	1	0	1	330./113.	.00
57	7	19	1330	NE	048	1	4123	9730	0	0	0	0	0	0	0	1			306./106.	.00
57	7	19	1730	NE	049	1	4047	9804	4059	9804	13	0	0	0	4		3	1	283./114.	.00
57	7	19	1730	NE	050	1	4047	9804	4059	9804	13	0	0	0	0		3	1	283./114.	.00
57	7	19	1730	NE	051	1	4047	9804	4059	9804	13	0	0	0	0		3	1	283./114.	.00
57	8	16	1600	NE	053	1	4001	9905	0	0	0	0	0	0	0				260./114.	.00
58	3	30	1500	IA	002	1	4140	9341	0	0	0	0	0	0	0				48./118.	.00
58	6	22	1500	IA	009	1	4043	9335	0	0	1	15	0	0	3	1	1	1	74./ 97.	.03
58	7	14	1815	IA	011	2	4104	9436	4050	9434	6	30	0	1	5	3	2	2	67./ 64.	.37
*58	4	4	1730	KS	001	1	3933	9559	0	0	1	0	0	0	1		0	1	199./ 51.	.00
58	5	31	1945	KS	004	1	3840	9511	0	0	1	16	0	0	4	2	0	2	165./103.	.03
58	5	31	1845	KS	005	1	3844	9513	3847	9510	3	0	0	0	4	2	2	1	169./ 99.	.00
*58	6	12	207	KS	013	1	3925	9556	0	0	0	0	0	0	0				194./ 58.	.00
58	6	12	1608	KS	017	1	3915	9631	0	0	0	0	0	0	0	1		1	212./ 78.	.00
58	6	12	1630	KS	019	1	3902	9600	3902	9555	4	60	0	0	4	2	2	3	192./ 81.	.46
*58	6	12	1745	KS	020	1	3944	9523	3945	9507	7	60	0	0	0		2	3	163./ 39.	.81
58	6	14	2030	KS	023	1	3843	9500	384[illegible]	9451	7	9	0	0	0	0	2	1	153./102.	.12
58	6	15	300	KS	025	1	3840	9627	0	0	0	0	0	0	0	0			201./108.	.00
58	6	22	1340	KS	027	1	3905	9443	0	0	0	8	0	0	0	1	0	1	151./ 87.	.00
58	6	24	2130	KS	028	1	3829	9614	0	0	2	15	0	0	0	1	1	1	194./115.	.06
58	7	11	45	KS	031	1	3900	9534	0	0	0	0	0	0	0	2		1	178./ 81.	.00
58	7	11	103	KS	032	1	3855	9551	0	0	0	0	0	0	0	2		1	187./ 87.	.00
58	7	11	120	KS	033	1	3920	9551	0	0	0	0	0	0	0	1		1	189./ 62.	.00
58	7	11	200	KS	034	1	3843	9449	0	0	1	0	0	0	0	1	0	1	159./105.	.00
58	11	17	1020	KS	044	1	3911	9502	0	0	0	0	0	0	3	2			158./ 75.	.00
58	11	17	1055	KS	046	1	3830	9537	0	0	0	0	0	0	0	2			180./111.	.00
58	11	17	1100	KS	047	1	3837	9525	0	0	0	0	0	0	2	2			174./104.	.00
58	11	17	1110	KS	048	1	3845	9523	0	0	0	0	0	0	0	1			173./ 97.	.00
58	11	17	1115	KS	049	1	3906	9506	0	0	0	0	0	0	0				162./ 79.	.00
58	6	15	1630	MO	013	1	4035	9337	0	0	0	3	0	0	4	1	0	0	81./ 93.	.00
58	6	24	2135	MO	014	1	3908	9359	0	0	0	10	0	0	4	1	0	1	134./106.	.01
58	6	24	2230	MO	015	1	3904	9350	0	0	0	10	0	0	4	1	0	1	133./114.	.01
58	7	7	30	MO	016	1	4000	9348	0	0	0	3	0	0	4	1	0	0	104./ 87.	.00
58	7	17	730	MO	018	1	3920	9401	0	0	2	10	0	0	5	2	1	1	129./ 97.	.04
58	7	17	207	MO	019	1	4033	9532	0	0	0	3	0	0	3	1	0	0	21./ 1[illegible]	.00
*58	7	27	400	MO	020	1	3939	9327	0	0	0	3	0	0	3	1	0	0	113./110.	.00
*58	10	8	1945	MO	025	3	4025	9438	4027	9409	17	90	2	7	5	3	3	3	85./ 46.	3.06
*58	11	16	1750	MO	026	1	4021	9504	0	0	0	30	0	0	3	1	0	2	90./ 26.	.01
58	11	17	1330	MO	028	1	4025	9302	4030	9259	3	15	0	0	4	1	1	1	87./119.	.10
58	11	17	1345	MO	030	1	4003	9327	4013	9316	9	15	0	0	5	2	2	1	100./102.	.26
58	11	17	1400	MO	031	1	4012	9356	4016	9354	4	30	0	0	5	2	2	2	97./ 78.	.29

"*" before year means event ocurred within a 2 degree square centered on central point

6-9
NPP1-SBØ-009
E34 [illegible]

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	Sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AZRAN	Area sq.mi
58	4	4	1600	NE	001	1	4057	9708	0	0	0	0	0	0	1	1	299./ 78.	.00
+58	4	4	1745	NE	002	1	4041	9552	4047	9551	6	0	0	0	3	1 2	332./ 23.	.00
58	5	14	1540	NE	003	1	4005	9736	0	0	0	0	0	0	1		260./ 92.	.00
58	5	30	300	NE	005	1	4132	9621	0	0	0	45	0	0	2	1 0 2	336./ 78.	.01
58	6	4	1900	NE	008	1	4046	9705	0	0	0	0	0	0	4		291./ 70.	.00
58	7	3	1430	NE	026	2	4009	9651	4018	9616	32	0	0	2	5	2 4 1	258./ 57.	.00
58	7	8	2035	NE	030	1	4121	9714	0	0	0	0	0	0	2	0 0	310./ 94.	.00
+58	7	10	55	NE	031	1	4035	9633	0	0	1	0	0	0	2	1 0	289./ 44.	.00
58	7	11	100	NE	033	1	4027	9721	0	0	0	0	0	0	5		274./ 79.	.00
58	8	4	2100	NE	044	1	4150	9725	0	0	0	0	0	0	3	1	318./119.	.00
+58	8	5	1730	NE	045	1	4117	9636	0	0	0	0	0	0	3	0 0	322./ 71.	.00
+58	8	5	1830	NE	046	1	4059	9610	0	0	0	0	0	0	4	1	328./ 45.	.00
58	8	5	1830	NE	047	1	4052	9759	0	0	0	44	0	0	3	1 0 2	286./111.	.02
+58	8	5	2200	NE	048	1	4036	9623	0	0	0	0	0	0	5	1	294./ 37.	.00
58	8	5	2300	NE	049	1	4057	9736	0	0	0	0	0	0	5	1	292./ 96.	.00
+58	8	23	1550	NE	052	1	4030	9544	0	0	0	0	0	0	3	0 0	313./ 10.	.00
+58	9	5	1700	NE	054	1	4100	9615	0	0	0	0	0	0	3		324./ 45.	.00
+59	5	4	2120	IA	001	1	4110	9510	4114	9507	2	30	0	0	4	1 1 2	23./ 53.	.14
59	5	4	2220	IA	002	1	4142	9455	4145	9451	1	30	0	0	3	2 1 2	22./ 87.	.08
59	5	4	2223	IA	003	1	4112	9424	4115	9419	2	30	0	0	3	2 1 2	48./ 75.	.16
59	5	4	2223	IA	004	1	4117	9430	4123	9425	2	30	0	0	3	2 1 2	42./ 76.	.16
59	5	4	2230	IA	005	1	4154	9420	4206	9415	14	45	0	0	4	2 3 2	32./110.	1.23
59	5	10	1300	IA	010	1	4130	9438	4156	9405	20	120	0	1	6	4 3 3	*3./ 82.	4.68
+59	5	10	1430	IA	011	1	4056	9503	0	0	1	60	0	0	3	2 1 3	37./ 44.	.11
59	5	10	1700	IA	013	1	4132	9332	0	0	1	15	0	0	3	1 1 1	55./118.	.03
59	5	10	1753	IA	014	1	4136	9336	0	0	0	15	0	0	3	2 0 1	51./118.	.01
+59	5	19	1345	IA	015	1	4059	9444	0	0	1	60	0	0	3	2 1 3	47./ 56.	.11
59	5	20	1900	IA	016	1	4042	9309	4052	9254	17	132	0	5	5	4 3 3	79./115.	4.35
+59	5	26	800	IA	017	1	4036	9538	4049	9545	[illegible]	120	0	0	4	2 2 3	360./ 15.	.73
59	5	2	1200	KS	003	1	3951	9639	3927	9628	18	0	0	0	4	2 3 2	237./ 56.	.00
59	5	4	1749	KS	013	1	3915	9725	3915	9718	4	30	0	0	5	2 2 2	231./105.	.25
59	5	4	1830	KS	015	1	3933	9710	3935	9706	4	30	0	0	[illegible]	2 2	236./ 85.	.24
59	5	4	1930	KS	019	1	3838	9642	0	0	2	0	0	0	[illegible]	1 1	206./114.	.00
59	5	4	1930	KS	020	1	3839	9658	0	0	0	0	0	0	[illegible]	1	211./120.	.69
59	5	4	2015	KS	021	2	3901	9618	3901	9607	9	264	0	0	4	1 3 4	201./ 86.	4.92
+59	5	4	2030	KS	022	1	3955	9549	3935	9538	25	528	0	0	5	2 3 5	198./ 27.	25.02
+59	5	18	1850	KS	027	1	3949	9537	0	0	0	30	0	0	4	3 0 2	179./ 32.	.03
+59	5	18	1900	KS	028	1	3944	9525	0	0	1	264	0	0	5	2 1 4	165./ 38.	.50
+59	5	18	1935	KS	029	1	3944	9520	3939	9516	6	120	0	0	5	1 2 3	160./ 39.	1.54
59	5	29	1900	KS	046	1	3915	9605	[illegible]	0	2	60	0	0	0	0 1 3	198./ 66.	.23
59	5	29	1930	KS	048	1	3947	9654	0	0	0	45	0	0	3	1 0 2	241./ 67.	.02
59	5	29	1930	KS	[illegible]49	1	3949	9647	0	0	0	0	0	1	0	2 1	239./ 62.	.00
59	6	11	1545	KS	051	1	3910	9441	0	0	0	0	0	0	0	1 1	148./ 84.	.00
59	6	18	1800	KS	052	1	3830	9612	0	0	0	0	0	0	0	1 1	193./114.	.00
59	12	26	1745	KS	066	1	3302	9719	0	0	2	0	0	0	0	2 1 1	225./111.	.00
+59	5	4	2130	MO	007	1	4017	9500	4034	9443	24	60	0	0	3	1 3 3	98./ 29.	2.79
+59	5	10	1600	MO	010	1	4031	9510	0	0	0	5	0	0	4	2 0 0	65./ 24.	.00
59	5	18	2300	MO	011	1	3943	9414	0	0	0	5	0	0	3	1 0 0	120./ 75.	.00
+59	5	20	2200	MO	012	1	3954	9442	0	0	0	5	0	0	4	1 0 0	122./ 51.	.00
59	5	20	2330	MO	013	1	4028	9345	4031	9339	6	3	0	0	4	1 2 0	85./ 56.	.04
+59	9	26	800	MO	016	1	[illegible]	9448	0	0	0	3	0	3	3	1 0 0	126./ 47.	.00
59	9	26	800	MO	017	1	4011	9433	4012	9430	2	15	0	0	4	1 1 1	101./ 51.	.08
+59	9	26	807	MO	018	1	4001	9451	0	0	0	3	0	0	3	[illegible] 0 0	119./ 41.	.00
59	9	26	930	MO	019	2	4019	9345	4022	9337	0	15	0	0	4	2 2 1	91./ 86.	.02
+59	5	2	1315	NE	001	1	4104	9623	0	0	0	18	0	0	3	1 0 2	322./ 55.	.01

"+" before year means event ocurred within a 2 degree square centered on central point

6-10
NPPT-SBØ-009
E24

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	Sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AZRAN	Area sq.mi
59	5	4	1530	NE	004	1	4107	9801	0	0	0	0	0	0	3	1	293./117.	.00
59	5	4	1615	NE	005	1	4128	9743	4131	9732	10	0	0	0	3	1 2 1	306./115.	.00
59	5	4	1630	NE	006	1	4109	9654	0	0	0	0	0	1	3	1	31[illegible]/ 75.	.00
59	5	4	1900	NE	007	1	4129	9743	0	0	0	0	0	0	3	0	[illegible]116.	.00
59	5	4	1900	NE	008	1	4105	9747	0	0	0	0	0	0	3		[illegible]07.	.00
59	5	4	1930	NE	009	1	6007	9640	4015	9636	9	0	0	0	4	1 2 1	[illegible] 69.	.00
*59	5	20	2100	NE	011	1	4114	9637	0	0	12	0	0	0	4	2 2 1	[illegible] 69.	.00
59	5	20	1900	NE	012	1	4127	9646	0	0	0	0	0	0	4	1 1	[illegible] 83.	.00
59	5	20	1900	NE	013	1	4002	9702	4021	9623	40	0	0	0	4	1 4 1	25[illegible] 67.	.00
59	5	20	2100	NE	014	1	4126	9630	0	0	0	30	0	0	4	1 0 2	329./ 75.	.02
59	5	26	1730	NE	017	1	4153	9654	0	0	7	0	0	0	2	0	328./108.	[illegible]
59	5	28	1845	NE	022	1	4049	9743	0	0	0	0	0	0	3	0 2	255./ 99.	.00
59	6	20	1425	NE	031	1	4101	9737	0	0	1	0	0	0	4	1 1 1	294./ 98.	[illegible]
*59	7	3	2200	NE	036	1	4026	9633	4026	9628	4	0	0	0	4	1 2 1	277./ 42.	.00
59	8	9	600	NE	039	1	4120	9657	0	0	1	0	0	0	4	1 1	315./ 84.	.00
59	8	28	1700	NE	042	1	4026	9806	0	0	0	0	0	0	4		273./113.	.00
59	8	30	1700	NE	043	1	4055	9652	0	0	4	0	0	0	4	2 1 2	301./ 65.	.00
*59	9	21	200	NE	044	1	4021	9555	0	0	0	0	0	0	1	1 0 1	270./ 13.	.00
60	4	16	1630	IA	003	1	4048	9318	4054	9310	9	60	0	0	4	2 2 3	76./109.	1.11
60	5	5	1900	IA	005	1	4158	9448	4203	9433	4	45	0	0	5	2 2 2	21./104.	.36
60	5	5	2130	IA	006	1	4140	9357	0	0	1	30	0	0	4	1 1 2	44./109.	.06
60	6	16	1230	IA	011	1	4123	9334	0	0	2	45	0	0	4	2 1 2	56./112.	.17
*60	8	6	2230	IA	017	1	4112	9508	0	0	0	0	0	0	0	1 1	24./ 56.	.00
60	8	18	1330	IA	018	1	4115	9428	0	0	0	30	0	0	4	1 2	43./ 78.	.00
*60	11	27	2315	IA	027	1	4044	9505	4047	9500	5	30	0	0	4	1 2 2	47./ 34.	.32
60	4	13	1700	KS	002	1	3854	9732	0	0	1	45	0	0	3	2 0 2	226./124.	.09
60	4	15	1500	KS	003	1	3903	9550	0	0	0	0	0	0	1	0	159./ 83.	.00
60	4	16	1700	KS	005	1	3829	9517	3835	9510	8	23	0	0	4	3 2 2	172./113.	.37
60	5	15	1910	KS	016	1	3914	9713	0	0	0	0	0	0	2	0	228./100.	.00
60	5	16	50	KS	018	1	3912	9720	0	0	0	30	0	0	4	2 0 2	229./105.	.02
60	5	16	110	KS	019	1	3930	9704	3932	9659	4	75	0	0	4	1 2 3	232./ 94.	.64
*60	5	16	200	KS	020	1	3946	9629	3952	9616	6	0	0	0	4	2 1	228./ 53.	.00
60	5	19	1730	KS	022	1	3909	9620	3911	9557	18	0	0	12	7	4 3 2	204./ 79.	.00
60	5	19	1830	KS	023	2	3911	9557	3916	9526	22	264	1	92	6	4 3 4	192./ 72.	11.15
60	5	19	1806	KS	024	1	3914	9526	3913	9513	9	0	0	1	0	3 2 3	172./ 68.	.00
60	5	19	1930	KS	025	1	3913	9513	3919	9500	8	0	0	1	0	3 2 2	164./ 71.	.00
60	5	19	2030	KS	027	1	3906	9540	0	0	6	0	0	0	1	1	181./ 75.	.00
60	5	19	2045	KS	028	1	3907	9540	3909	9544	4	0	0	0	3	2 2 1	161./ 74.	.00
60	5	24	1430	KS	032	1	3848	9610	3852	9602	6	5	0	0	3	1 2 0	195./ 96.	.06
*60	6	1	1645	KS	038	1	3946	9608	3943	9607	3	10	0	0	4	0 1 2	213./ 42.	.18
60	6	1	1745	KS	039	1	3859	9716	0	0	0	0	0	0	1	1	223./112.	.00
60	6	1	1745	KS	040	1	3859	9709	0	0	0	0	0	0	1	0	221./108.	.00
60	11	27	1930	KS	057	1	3837	9702	0	0	0	0	0	0	3	1	212./123.	.00
60	11	27	1955	KS	058	1	3933	9739	0	0	2	50	0	2	5	3 1 2	243./105.	.19
*60	1	12	1420	MO	001	1	4016	9454	4017	9453	0	5	0	0	4	1 0	98./ 34.	.00
60	3	29	1630	MO	003	1	4005	9337	0	0	0	30	0	0	4	1 0 2	100./ 94.	.02
60	4	16	1530	MO	007	2	4018	9426	4025	9356	24	90	0	4	4	3 3 3	93./ 55.	4.22
60	4	16	1715	MO	008	2	4028	9305	4032	9251	12	30	0	0	4	2 3 2	86./101.	.69
60	5	16	130	MO	012	1	4010	9355	0	0	0	3	0	0	3	1 0 0	98./ 79.	.00
60	5	19	2320	MO	019	1	3947	9305	0	0	1	12	0	0	3	1 1 1	106./122.	.03
60	6	4	1915	MO	020	1	4031	9332	0	0	0	5	0	0	4	1 0 0	84./ 96.	.00
60	6	11	1615	MO	023	1	3917	9358	0	0	0	5	0	0	3	1 0 0	130./100.	.00
60	6	29	1825	MO	024	1	3900	9358	0	0	0	15	0	0	3	1 0 1	136./112.	.01
*60	6	29	1900	MO	025	1	3945	9451	3954	9425	25	30	0	0	4	2 3 2	135./ 51.	1.43
*60	6	29	2000	MO	026	1	4037	9452	4036	9452	1	5	0	0	4	1 1 0	112./ 35.	.01

"*" before year means event ocurred within a 2 degree square centered on central point

6-12
NPP1-SBd-009

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AZRAN	Area sq.mi
60	12	4	2050	MO	03[illegible]	2	3915	9403	3924	9355	8	5	0	0	4	2 3 2	132./ 99.	.08
60	5	5	1630	NE	002	1	4142	9714	0	0	0	0	0	0	3		318./108.	.00
*60	5	16	230	NE	003	1	4009	9557	0	0	0	0	0	0	4	1	230./ 19.	.00
*60	5	19	1830	NE	008	1	4012	9530	0	0	0	0	0	0	3	1	146./ 11.	.00
*60	6	14	2200	NE	016	1	4014	9541	0	0	1	0	0	0	4	1 1 2	198./ 7.	.00
60	6	15	2000	NE	020	1	4142	9617	0	0	0	0	0	0	4	2	340./ 86.	.00
60	6	29	1700	NE	034	1	4000	9757	0	0	0	0	0	0	5	1 0 0	259./109.	.00
*60	6	29	1900	NE	035	1	4004	9535	0	0	0	44	0	0	3	1 0 2	172./ 17.	.04
61	4	20	1530	IA	001	1	4118	9430	4120	9427	3	30	0	0	4	1 1 2	42./ 77.	.20
61	4	23	837	IA	002	2	4043	9344	4041	9225	34	180	0	2	6	2 4 4	76./ 89.	11.77
*61	5	7	820	KS	019	1	3958	9537	0	0	0	0	0	0	4	2 1	178./ 23.	.00
61	5	7	1500	KS	020	1	3907	9506	0	0	0	0	0	0	0		161./ 78.	.00
61	5	31	2115	KS	023	1	3949	9737	0	0	0	0	0	0	4	2 1	251./ 97.	.00
61	7	20	1730	KS	034	1	3925	9705	0	0	0	0	0	0	1	0 1	230./ 87.	.00
*61	7	20	1935	KS	036	1	3953	9548	0	0	0	0	0	0	0		195./ 29.	.00
*61	10	12	1540	KS	038	1	3941	9535	0	0	0	0	0	0	2	1 1	177./ 40.	.00
61	10	12	1610	KS	039	1	3919	9547	0	0	1	0	0	0	3	2 1 1	186./ 62.	.00
*61	10	12	1630	KS	040	1	3931	9528	0	0	0	0	0	0	0		171./ 51.	.00
*61	10	12	1645	KS	041	1	3921	953[illegible]	3923	9532	3	0	0	0	2	0 2 1	178./ 60.	.00
61	10	12	1730	KS	042	1	3916	9523	3918	9518	5	0	0	0	4	1 2 1	170./ 66.	.00
61	10	12	1810	KS	043	1	3857	9545	0	0	1	0	0	0	2	0 1 1	212./ 99.	.09
61	10	12	2006	KS	044	1	3907	9512	0	0	0	0	0	0	0	1	165./ 77.	.00
*61	4	20	1[illegible]30	MO	014	1	3951	9450	0	0	0	3	0	0	3	0 0 0	129./ 49.	.00
61	4	22	200	MO	015	1	3846	9413	0	0	0	15	0	0	4	1 0 1	145./116.	.01
61	4	25	220	MO	016	1	3843	9359	3844	9351	7	15	0	0	3	1 2 1	142./125.	.21
61	4	23	1400	MO	017	1	3845	9410	0	0	0	3	0	0	3	1 0 0	144./118.	.00
61	5	7	1745	MO	023	2	3918	9403	3920	9355	4	15	0	2	4	2 2 1	131./ 97.	.13
61	5	7	1820	MO	026	2	3923	9337	3925	9325	5	15	0	0	4	2 2 1	122./110.	.16
61	5	7	1810	MO	027	1	4020	9348	0	0	0	5	0	0	3	1 0 0	91./ 84.	.00
61	7	22	2100	MO	033	1	3950	9409	385[illegible]	9406	2	40	0	0	4	2 1 2	142./115.	.16
62	5	7	2130	IA	004	1	4104	9422	0	0	0	75	0	0	4	0 3	53./ 72.	.04
62	5	18	1430	IA	005	1	4136	9528	4138	9532	4	15	0	0	5	1 1	6./ 75.	.12
62	5	18	1700	IA	006	1	4206	9554	4208	9551	3	60	0	0	4	1 1 3	354./106.	.39
62	5	28	2100	IA	008	1	4110	9312	4118	9303	3	60	0	0	5	2 2 3	66./120.	.41
62	5	18	2110	KS	007	1	3905	9632	0	0	0	0	0	0	2	1	209./ 87.	.00
62	5	27	1545	KS	010	1	3914	9500	0	0	0	0	0	0	3	2	156./ 73.	.00
62	5	24	1815	KS	015	1	3835	9602	0	0	0	0	0	0	3	0 1	190./108.	.00
62	5	25	1900	KS	016	1	3950	9809	0	0	0	0	0	0	3	0 1	255./120.	.00
62	5	26	1915	KS	017	1	3828	9610	0	0	0	0	0	0	3	1 1	193./114.	.00
62	5	26	1925	KS	018	1	3834	9611	0	0	2	60	0	0	3	2 1 3	194./110.	.23
62	5	26	1948	KS	019	1	3858	9542	0	0	2	0	0	4	5	3 1 2	182./ 83.	.00
62	5	27	2030	KS	021	1	3930	9718	3933	9714	2	15	0	0	3	1 1 1	237./ 93.	.07
62	5	27	2059	KS	022	1	3949	9726	0	0	0	0	0	0	3	1	249./ 90.	.00
62	5	25	1600	KS	025	1	3820	9607	3823	9605	1	90	0	6	5	2 1 3	191./123.	.33
62	5	28	1640	KS	028	1	3850	9554	3856	9547	1	60	0	0	5	2 2 3	188./ 92.	.21
62	5	28	1720	KS	029	1	3918	9532	0	0	0	0	0	0	6	1 1	176./ 63.	.00
*62	5	31	1345	KS	031	1	3942	9536	3948	9536	6	4	0	0	2	2 2 0	178./ 39.	.05
*62	5	31	1345	KS	032	1	3948	9538	0	0	0	0	0	0	0	1 0	180./ 33.	.00
*62	5	31	1345	KS	033	1	3941	9526	0	0	0	0	0	0	0	1 1	167./ 41.	.00
62	7	11	2220	KS	051	1	3902	9523	0	0	0	0	0	0	3	2 1	172./ 80.	.00
*62	8	6	1740	KS	054	1	3931	9547	3923	9540	7	200	0	3	5	4 2 4	188./ 50.	2.95
62	8	6	1740	KS	055	1	3917	9543	0	0	0	0	0	0	5	1 1	183./ 64.	.00
62	8	6	1840	KS	056	1	3911	9534	0	0	0	0	0	0	2	2 0	172./ 70.	.00
62	8	6	1840	KS	057	1	3910	9533	0	0	0	0	0	0	2	2 1	177./ 71.	.00
62	8	5	1840	KS	058	1	3910	9532	0	0	0	0	0	0	2	1 1	176./ 71.	.00

'*' before year means event ocurred within a 2 degree square centered on central point

6-13
NPPI-SBØ-009
#4, 13

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	Ste	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	P	P	P	AZRAN	Area sq.mi
62	8	6	1900	KS	059	1	3847	9515	3845	9511	2	0	0	0	5	3	1	1	169./ 96.	.00
62	8	6	1940	KS	060	1	3848	9520	0	0	0	0	0	0	0	1		1	171./ 94.	.00
62	8	6	1940	KS	061	1	3847	9524	0	0	0	0	0	0	0	1		1	173./ 95.	.00
62	5	28	1900	MO	004	1	3921	9435	3922	9432	2	15	0	0	4	1	1	1	141./ 77.	.08
*62	5	31	1345	MO	006	1	3957	9500	0	0	0	3	0	0	1	0	0	0	129./ 38.	.00
*62	5	31	1345	MO	007	1	3958	9459	0	0	0	3	0	0	1	0	0	0	128./ 38.	.00
62	7	15	100	MO	019	1	3916	9350	0	0	1	3	0	0	3	1	1	0	128./106.	.01
*62	7	21	725	MO	020	2	3957	9457	3953	9445	5	30	0	1	4	1	3	2	127./ 40.	.33
62	5	7	1830	NE	002	1	4136	9630	0	0	1	0	0	5	4	2	1	1	333./ 84.	.00
62	6	6	1845	NE	030	1	4104	9746	0	0	0	0	0	0	2	0		1	294./106.	.00
62	6	6	2110	NE	031	1	4058	9711	0	0	0	0	0	0	0	0		1	298./ 79.	.00
62	7	21	2030	NE	039	1	4106	9747	4124	9730	25	264	0	1	5	3	3	4	295./107.	12.70
62	8	4	1530	NE	041	1	4019	9749	0	0	1	120	0	0	3	1	1	3	269./100.	.27
*63	4	18	1700	IA	005	1	4110	9450	0	0	0	60	0	0	4	2		3	36./ 61.	.00
*63	4	18	1710	IA	006	1	4120	9438	4122	9435	0	60	0	0	4	2	0	3	37./ 74.	.08
63	5	12	1545	IA	011	1	4213	9612	4218	9555	15	15	0	0	4	2	3	1	347./115.	.44
63	5	12	1645	IA	012	1	4140	9430	0	0	0	0	0	0	4	1		1	33./ 94.	.00
*63	4	28	1620	KS	002	2	3948	9619	4000	9555	25	30	0	0	2	2	3	2	224./ 46.	1.44
*63	4	28	1645	KS	003	1	3950	9617	0	0	0	0	0	0	0	1			224./ 43.	.00
*63	4	28	1645	KS	004	1	3951	9616	0	0	0	0	0	0	0	1			224./ 42.	.00
63	5	4	1740	KS	005	1	3826	9526	0	0	0	0	0	0	2	1			175./115.	.00
63	9	4	300	KS	025	1	3904	9520	0	0	0	0	0	0	2	1		1	170./ 75.	.00
*63	4	22	30	MO	005	1	4008	9513	0	0	0	5	0	0	4	1	0	0	124./ 23.	.00
63	5	15	1	MO	010	1	3932	9419	0	0	0	3	0	0	2	1	0	0	129./ 28.	.00
63	5	15	210	MO	012	1	3916	9351	0	0	0	5	0	0	4	1	0	0	128./105.	.00
*63	4	28	1500	NE	001	1	4023	9553	4027	9550	5	90	1	8	4	3	2	3	280./ 12.	.90
63	4	29	1600	NE	002	1	4135	9701	4140	9647	13	90	0	0	4	2	3	3	320./ 97.	2.29
63	4	28	1630	NE	003	1	4049	9732	4050	9729	2	54	0	0	0	1	1	3	288./ 91.	.29
63	4	28	1700	NE	004	1	4005	9708	4006	9704	3	120	0	0	4	2	1	3	257./ 71.	.84
63	4	28	1645	NE	005	1	4044	9708	0	0	1	0	0	0	0	0	1	1	289./ 72.	.00
63	5	14	2200	NE	007	1	4035	9735	0	0	1	15	0	0	5	1	1	1	279./ 90.	.03
63	6	5	2000	NE	011	1	4141	9648	0	0	1	0	0	0	3	1	1	1	327./ 96.	.00
*64	4	12	1645	IA	001	1	4040	9514	4050	9506	13	120	1	28	6	4	3	3	44./ 26.	3.06
*64	4	12	1650	IA	002	1	4054	9503	0	0	2	45	0	0	4	2	1	2	59./ 42.	.17
*64	4	12	1730	IA	003	1	4115	9444	0	0	0	60	0	0	4	1	0	3	37./ 68.	.02
64	4	12	1730	IA	004	1	4055	9428	4101	9420	9	0	0	0	5	2	2	3	57./ 63.	.00
*64	4	20	2140	IA	005	1	4045	9528	4047	9525	3	90	0	0	4	2	1	3	17./ 25.	.59
*64	4	20	2200	IA	006	1	4054	9523	0	0	0	105	0	1	5	2		3	19./ 35.	.00
64	4	20	2230	IA	007	1	4124	9503	4124	9455	6	105	0	1	4	3	2	3	23./ 68.	1.37
64	4	26	1910	IA	008	1	4036	9416	4059	9400	15	90	0	0	4	2	3	3	62./ 70.	2.57
64	5	7	1830	IA	020	1	4150	9433	0	0	2	60	0	0	4	2	1	3	29./101.	.23
*64	6	19	1910	IA	029	1	4043	9521	4050	9511	3	105	0	2	6	3	2	4	30./ 25.	.71
*64	6	19	2021	IA	030	1	4044	9503	4050	9453	3	60	0	1	5	3	2	2	49./ 35.	.38
64	6	22	1830	IA	032	1	4136	9347	4139	9358	10	60	0	0	5	2	2	3	48./112.	1.14
64	6	22	1840	IA	033	1	4044	9345	0	0	1	60	0	0	5	2	1	3	75./ 89.	.11
*64	6	22	1900	IA	034	1	4045	9536	4050	9529	2	120	0	0	5	3	1	3	4./ 24.	.37
*64	6	22	1900	IA	035	1	4042	9527	4046	9514	6	120	0	0	5	4	2	3	22./ 23.	1.39
64	6	22	1900	IA	036	1	4056	9359	4103	9347	13	120	0	0	5	2	3	3	65./ 83.	2.99
64	8	20	2100	IA	042	1	4040	9356	0	0	0	15	0	0	4	0	0	1	76./ 80.	.01
64	8	27	2000	IA	044	1	4126	9502	0	0	1	15	0	0	4	2	0	1	23./ 70.	.03
64	9	3	1100	IA	051	1	4217	9542	0	0	0	0	0	0	3	1		1	359./116.	.00
*64	9	22	1510	IA	054	1	4039	9514	4048	9507	4	90	0	0	5	2	2	3	43./ 26.	82
C4	4	2	1800	KS	002	1	3857	9508	3855	9500	7	0	0	0	0	1	2	2	164./ 87.	[illegible]
64	4	12	1526	KS	004	1	3845	9529	3912	9514	33	264	0	3	6	3	4	4	176./ 96.	16.93
64	4	13	1620	KS	010	1	3852	9605	0	0	0	0	0	0	3	1		1	193./ 91.	.00

"*" before year means event ocurred within a 2 degree square centered on central point

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	Sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F	P	P	AIRAN	Area sq.mi
64	4	20	1935	KS	013	1	3927	9705	39-6	9657	11	15	0	0	4	2	3	1	231./ 86.	.32
*64	4	20	2145	KS	014	1	3931	9522	0	0	0	0	0	0	4			1	166./ 51.	.00
*64	4	20	2200	KS	015	1	3944	9511	0	0	0	0	0	0	4			1	151./ 42.	.00
64	4	20	2140	KS	016	1	3842	9447	0	0	0	0	0	0	3	2		1	158./107.	.00
64	4	22	1800	KS	027	1	3841	9543	0	0	0	0	0	0	3			1	207./112.	.00
64	4	22	1800	KS	029	1	3845	9639	0	0	0	0	0	0	[illegible]			1	206./107.	.00
64	4	22	1830	KS	030	1	3829	9609	0	0	0	0	0	0	3			1	192./115.	.00
64	4	22	1830	KS	033	1	3829	9603	0	0	0	0	0	0	0			1	190./114.	.00
64	4	22	1845	KS	034	1	3840	9544	0	0	0	0	0	0	3			1	183./101.	.00
64	4	22	1900	KS	035	1	3533	9517	0	0	0	0	0	1	3	2		1	171./109.	.00
64	4	22	1900	KS	036	1	3832	9451	0	0	0	0	0	0	0			1	161./115.	.00
64	4	22	1915	KS	037	1	3835	9448	0	0	0	0	0	0	3			1	160./113.	.00
64	4	22	1915	KS	038	1	3846	9451	0	0	0	0	0	0	3	1		1	159./102.	.00
64	4	26	1545	KS	042	1	3820	9459	0	0	0	0	0	0	2	1		1	166./125.	.00
64	4	26	1825	KS	043	1	3834	9519	0	0	0	0	0	0	0			1	172./108.	.00
64	4	26	1930	KS	044	1	3849	9457	0	0	0	0	0	0	0			1	161./ 97.	.00
64	4	26	1940	KS	045	1	3851	9446	0	0	0	0	0	0	0			1	156./ 99.	.00
64	4	26	1950	KS	046	1	3846	9459	0	0	0	0	0	0	0			1	154./106.	.00
64	5	25	1802	KS	059	1	3820	9616	0	0	0	0	0	0	0			1	194./125.	.00
*64	6	11	1200	KS	069	1	3940	9536	0	0	0	0	0	0	0	0		1	178./ 41.	.00
64	6	13	300	KS	072	1	3942	9628	0	0	0	0	0	0	0			1	202./106.	.00
64	6	18	1810	KS	074	1	3853	9553	0	0	0	0	0	0	0	0		1	188./ 89.	.00
64	6	21	1910	KS	077	1	3954	9730	0	0	0	0	0	0	0	0		1	253./ 90.	.00
64	6	21	1910	KS	078	1	3857	9722	3902	9714	9	0	0	0	4	3	2	1	224./117.	.00
64	6	21	1925	KS	079	1	3657	9711	0	0	0	0	0	0	0	2		1	221./111.	.00
64	6	21	2320	KS	080	1	3920	9617	0	0	0	0	0	0	0	0		1	206./ 68.	.00
64	6	22	1430	KS	081	1	3951	9638	0	0	0	0	0	0	0			1	237./ 55.	.00
*64	6	22	1510	KS	082	1	3938	9548	0	0	0	0	0	0	0	0		1	190./ 44.	.00
*64	8	20	1720	KS	085	1	3952	9532	3954	9529	1	15	0	0	0	1	1	1	171./ 29.	.05
*64	8	20	1730	KS	087	1	3951	9528	0	0	0	9	0	0	0	1		1	166./ 31.	.00
64	4	12	1745	MO	005	1	3940	9425	3945	9422	1	15	0	0	3	1	1	1	126./ 70.	.04
64	4	12	1830	MO	006	4	3842	9424	3856	9407	8	30	1	10	6	3	3	2	150./115.	.47
*64	4	12	2220	MO	008	1	4017	9459	4023	9449	11	24	0	0	6	2	3	2	98./ 30.	.51
64	5	26	1500	MO	010	1	3907	9407	0	0	1	15	0	0	3	1	1	1	136./102.	.04
64	6	11	1430	MO	011	1	3926	9409	0	0	0	3	0	0	3	1	0	0	129./ 88.	.00
*64	6	22	1700	MO	014	1	3946	9451	0	0	1	15	0	0	4	1	1	1	134./ 50.	.03
64	8	20	1930	MO	018	1	3954	9426	0	0	1	3	0	0	3	1	1	0	116./ 61.	.01
64	8	20	2130	MO	019	1	4014	9304	0	0	0	3	0	0	3	1	0	0	93./119.	.00
64	9	22	1730	MO	020	1	4003	9408	0	0	0	3	0	0	3	1	0	0	105./ 71.	.00
64	9	22	1750	MO	021	1	4003	9350	0	0	4	30	0	0	3	1	2	2	102./ 85.	.23
*64	4	23	1900	NE	003	1	4041	9630	4058	9626	9	0	0	0	4	1	2	1	297./ 44.	.00
64	4	25	1630	NE	005	1	4001	9755	4036	9734	22	0	0	0	4	2	3	1	259./107.	.00
64	5	6	530	NE	015	1	4147	9621	0	0	0	0	0	0	4	1	0	1	340./ 92.	.00
64	5	6	550	NE	016	1	4119	9648	4121	9645	3	0	0	0	4	2	1	1	318./ 78.	.00
64	5	23	1900	NE	018	1	4118	9642	4118	9637	4	264	0	0	4	1	2	4	320./ 75.	2.16
64	5	23	2100	NE	020	1	4053	9713	4046	9705	8	18	0	0	5	2	2	2	292./ 78.	.29
64	5	25	2110	NE	021	1	4116	9706	0	0	0	0	0	0	0	0		1	310./ 86.	.00
64	6	8	1745	NE	022	1	4009	9753	4018	9741	14	0	0	0	5	1	3	1	263./104.	.00
64	6	8	1900	NE	023	1	4024	9655	4030	9643	12	0	0	0	4	2	3	1	273./ 59.	.00
64	6	11	1900	NE	025	1	4036	9751	0	0	0	0	0	0	0	1		1	278./102.	.00
64	6	11	1900	NE	026	1	4052	9735	0	0	0	0	0	0	0	0		1	289./ 94.	.00
64	6	11	1900	NE	027	1	4054	9706	0	0	0	0	0	0	0	0		1	296./ 74.	.00
64	6	11	1900	NE	028	1	4037	9658	0	0	0	0	0	0	0	1		1	285./ 63.	.00
64	6	11	1900	NE	029	1	4025	9744	0	0	0	0	0	0	0	1		1	272./ 96.	.00
64	6	11	1900	NE	030	1	4018	9741	0	0	0	0	0	0	0			1	268./ 94.	.00

"*" before year means event ocurred within a 2 degree square centered on central point

6-14
NPPI-SBØ-009
E26

6-15
NPPI-586-009
Ex 1

Tornadoes within 125 NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	Sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AZRAN	Area sq.mi
65	5	24	2010	IA	016	1	4123	9344	0	0	0	0	0	0	0	1 0	56./106.	.00
65	5	25	2140	IA	017	1	4124	9502	0	0	0	50	0	0	4	2 3	25./ 69.	.00
*65	7	8	2110	IA	029	1	4032	9542	0	0	0	0	0	0	3	2 2	346./ 11.	.00
65	9	7	100	IA	039	1	4202	9510	0	0	1	30	0	0	4	2 1 2	12./103.	.06
65	9	9	1230	IA	040	1	4202	9558	0	0	1	30	0	0	4	1 1 2	352./102.	.06
65	9	9	1300	IA	041	1	4203	9554	4207	9543	10	30	0	0	5	2 3 2	353./103.	.59
65	9	20	1830	IA	044	1	4103	9346	4103	9341	0	45	0	0	5	2 0 2	64./ 94.	.07
65	5	25	1900	KS	036	1	3927	9708	0	0	0	0	0	0	4	1	232./ 88.	.00
65	6	4	1930	KS	048	1	3831	9542	3841	9515	5	60	0	0	4	1 2 3	182./110.	.61
65	6	21	1500	KS	052	1	3916	9633	0	0	0	0	0	0	4	2 1	213./ 78.	.00
65	6	27	1605	KS	053	1	3914	9630	0	0	0	0	0	0	4	1 1	211./ 78.	.00
65	7	9	1500	KS	056	1	3952	9450	0	0	0	0	0	0	5	1 1	157./ 97.	.00
65	8	27	330	KS	061	1	3905	9445	0	0	0	0	0	0	0	0 1	151./ 95.	.00
*65	9	13	1520	KS	064	1	3935	9509	0	0	0	0	0	0	4	1	154./ 51.	.00
*65	9	20	1400	KS	065	1	3945	9510	0	0	0	0	0	0	4		147./ 39.	.00
65	9	20	2145	KS	069	1	3343	9506	0	0	0	0	0	0	5		166./101.	.00
*65	4	10	1330	MO	107	1	3929	9502	0	0	2	30	0	0	1	0 1 3	152./ 59.	.11
65	4	10	1515	MO	009	1	3947	9425	3952	9416	9	15	0	7	5	2 2 1	121./ 65.	.28
65	4	10	1645	MO	010	1	4005	9342	4011	9333	10	30	0	1	5	2 3 2	100./ 90.	.60
65	4	10	1710	MO	011	2	3957	9347	4003	9336	11	15	0	1	4	2 3 1	106./ 88.	.34
65	4	10	1930	MO	012	1	3839	9407	0	0	0	15	0	0	4	1 0 1	145./124.	.01
65	5	26	210	MO	014	1	3846	9420	3849	9409	1	15	0	0	4	1 1 1	147./113.	.03
65	5	26	215	MO	015	1	3858	9421	3901	9417	4	150	0	4	5	2 2 3	144./102.	1.27
65	5	26	300	MO	016	1	3920	9332	0	0	0	3	0	0	2	0 0 0	122./115.	.00
65	6	4	1520	MO	017	1	3836	9421	0	0	0	3	0	0	2	0 0 0	150./121.	.00
65	9	18	1700	MO	021	1	4018	9401	0	0	1	6	0	0	1	0 1 1	94./ 74.	.01
65	9	20	1800	MO	022	1	4015	9404	0	0	0	3	0	0	3	1 0 0	95./ 72.	.00
65	9	20	1830	MO	023	1	3903	9334	3912	9325	13	30	0	0	3	2 3 2	129./124.	.74
65	9	20	2230	MO	025	1	3854	9423	0	0	1	9	0	0	5	2 1 1	146./105.	.03
65	9	20	2300	MO	026	1	3933	9330	0	0	2	15	0	0	4	1 1 1	116./110.	.06
65	5	8	1540	NE	004	1	4010	9734	4043	9717	20	0	0	0	0	3 3 1	263./ 89.	.00
*65	5	8	1700	NE	008	1	4049	9626	0	0	0	0	0	0	0	1 1	308./ 46.	.00
65	5	8	1730	NE	011	1	4053	9756	0	0	0	0	0	0	0	1 1	287./109.	.00
65	5	8	1735	NE	012	1	4056	9813	4102	9809	7	0	0	0	0	1 2 1	287./122.	.00
65	5	8	1800	NE	014	1	4125	9721	4144	9709	12	0	0	0	0	2 3 1	310./100.	.00
65	5	14	2140	NE	017	1	4054	9812	0	0	0	0	0	0	0	1 1	286./121.	.00
65	5	15	1100	NE	018	1	4119	9732	0	0	0	0	0	0	0	0 1	304./103.	.00
65	5	15	1102	NE	019	1	4120	9658	0	0	0	0	0	0	0	0 0 1	314./ 84.	.00
65	5	25	1255	NE	026	1	4053	9740	0	0	0	0	0	0	0	0 0 1	289./ 95.	.00
65	5	25	1725	NE	029	1	4007	9710	0	0	0	0	0	0	0		259./ 72.	.00
65	5	25	2015	NE	032	1	4104	9753	0	0	0	0	0	0	0		293./111.	.00
65	6	25	1714	NE	039	1	4011	9811	0	0	0	0	0	0	0	1	265./117.	.00
*65	7	1	1700	NE	041	1	4043	9625	4039	9611	13	0	0	1	5	3 3 1	302./ 42.	.00
*65	7	1	1715	NE	042	1	4046	9625	0	0	2	0	0	0	0	1 1 1	305./ 44.	.00
*65	7	1	1615	NE	043	1	4040	9551	4046	9536	13	0	0	0	5	1 3 1	333./ 21.	.00
66	5	17	100	IA	006	1	4142	9416	0	0	2	120	0	0	4	2 1 3	37./102.	.45
66	5	23	630	IA	007	1	4050	9420	0	0	0	15	0	0	1	1 0 1	64./ 66.	.01
66	6	11	1745	IA	013	1	4134	9333	4140	9321	3	45	0	0	4	2 2 2	52./119.	.32
66	7	26	1515	IA	024	1	4133	9406	0	0	0	0	0	0	0		44./100.	.00
66	10	14	1215	IA	028	1	4047	9435	0	0	1	30	0	0	4	2 1 2	61./ 54.	.09
*66	10	14	1450	IA	031	1	4050	9438	0	0	0	0	0	0	0	2	57./ 54.	.00
66	10	14	1515	IA	033	1	4048	9420	0	0	0	0	0	0	3		65./ 65.	.00
66	10	14	1600	IA	035	1	4136	9349	4144	9336	2	15	0	0	6	2 1 1	48./111.	.08
66	4	19	1525	KS	001	1	3855	9448	3858	9440	3	45	0	4	6	3 2 2	156./ 94.	.34
66	5	11	1345	KS	002	1	3939	9712	3941	9706	2	30	0	0	5	3 1 2	240./ 94.	.16

"*" before year means event ocurred within a 2 degree square centered on central point

6-16
NPP1-SBØ-009

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	ste	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AZRAN	Area sq.mi
*66	5	11	1345	KS	003	1	3934	9632	0	0	0	0	0	0	0		222./ 63.	.00
66	5	11	1415	KS	004	1	3939	9640	3940	9623	7	0	0	0	0	2 1	229./ 64.	.00
66	5	11	1415	KS	027	1	3910	9548	3912	9537	2	1v8	0	0	4	3 1 4	186./ 71.	.76
66	5	15	1740	KS	009	1	3909	9441	0	0	2	0	0	5	4	2 1 1	148./ 84.	.00
66	6	8	1737	KS	019	1	3908	9709	3913	9701	4	30	0	0	4	2 2 2	224./102.	.26
66	6	8	1800	KS	020	1	3904	9646	3916	9646	8	198	0	50	6	3 2 4	214./ 93.	3.11
66	6	8	1900	KS	021	1	3855	9555	3905	9535	21	264	16	450	8	5 3 4	189./ 87.	10.63
66	6	8	2000	KS	022	1	3910	9511	3916	9450	15	60	1	2	5	4 3 3	164./ 74.	1.81
66	6	8	1915	KS	023	1	3914	9502	3916	9453	8	0	0	0	4	2 2 2	157./ 73.	.00
66	6	12	1631	KS	026	1	3903	9527	0	0	0	0	0	0	0	1 1	174./ 29.	.00
66	8	20	1628	KS	033	1	3936	9730	0	0	1	0	0	0	3	0 0 1	242./ 97.	.00
66	9	2	1630	KS	034	1	3912	9742	0	0	1	5	0	0	0	0 0 0	234./118.	.01
66	9	15	1545	LA	012	1	3955	9258	0	0	0	15	0	0	2	0 0 1	101./125.	.06
66	4	19	1600	MO	002	1	3953	9406	0	0	2	6	0	0	4	1 1 1	112./ 76.	.03
66	4	19	1630	MO	003	1	3956	9324	0	0	2	6	0	0	3	1 0 1	104./105.	.02
*66	4	29	1830	MO	005	1	4027	9503	0	0	2	9	0	0	3	1 1 1	77./ 27.	.01
66	5	11	1800	MO	006	1	3913	9359	0	0	0	3	0	0	2	1 0 0	131./103.	.00
*66	5	23	[illegible]	MO	014	1	4027	9513	4028	9506	6	15	0	0	4	2 2 1	72./ 20.	.18
66	6	5	1800	MO	018	1	4054	9417	0	0	0	3	0	0	3	1 0 0	96./ 62.	.00
66	6	12	1545	MO	020	1	3918	9431	0	0	0	3	0	0	1	0 0 0	141./ 82.	.00
66	5	22	1730	NE	003	1	4045	9748	4111	9733	15	0	0	0	0	1 3 1	284./102.	.00
66	5	22	1900	NE	004	1	4150	9628	0	0	0	0	0	0	0	1	337./ 96.	.00
66	5	22	1948	NE	005	1	4107	9648	4110	9636	10	0	0	1	0	2 3 1	311./ 70.	.00
*67	6	7	1900	IA	038	1	4033	9503	0	0	2	60	0	0	5	1 1 3	57./ 32.	.23
67	6	8	2130	IA	041	1	4203	9542	4207	9536	5	90	0	0	4	1 2 3	358./104.	.96
67	6	9	2300	IA	043	1	4103	9347	4108	9340	3	90	0	0	5	2 1 3	63./ 94.	.57
67	6	9	2330	IA	044	1	4102	9319	0	0	2	120	0	0	4	2 1 3	69./113.	.45
67	6	20	2300	IA	051	1	4142	9542	0	0	0	0	0	0	4		358./ 81.	.00
67	7	30	1950	IA	053	1	4138	9334	0	0	0	0	0	0	0		50./120.	.00
*67	6	7	1525	KS	005	1	3946	9541	0	0	0	0	0	0	0		184./ 35.	.00
67	6	11	1725	KS	014	1	3906	9600	3925	9547	14	0	0	0	5	1 3 1	193./ 77.	.00
67	6	11	1800	KS	015	2	3910	9540	3945	9520	44	0	0	0	5	3 4 2	181./ 71.	.00
67	9	23	1655	KS	026	1	3954	9742	0	0	3	0	0	0	3	1 1 1	254./ 99.	.00
*67	1	24	1150	MO	001	1	3936	9456	3941	9453	6	30	0	0	5	2 2	144./ 55.	.36
67	1	24	1235	MO	002	1	3927	9414	0	0	2	15	0	0	4	2 1 1	130./ 84.	.07
67	1	24	1250	MO	003	2	3906	9415	3915	9403	13	60	2	18	6	3 3 3	139./ 99.	1.52
67	1	24	1250	MO	004	1	3933	9403	0	0	2	30	0	0	4	0 1 0	123./ 88.	.11
67	1	24	1400	MO	005	1	3953	9329	0	0	0	3	0	0	1	0 0 0	106./103.	.00
67	[illegible]	[illegible]	1420	MO	006	1	4016	9301	4022	9257	3	15	0	0	4	1 2 1	92./120.	.11
67	4	[illegible]	1945	MO	013	1	3830	9434	0	0	0	3	0	0	1	0 0 0	156./122.	.00
67	4	16	1945	MO	014	1	3846	9430	0	0	0	3	0	0	1	0 0 0	151./109.	.00
67	4	21	1230	MO	016	1	3937	9435	0	0	0	3	0	0	1	1 0 [illegible]	132./ 65.	.00
67	4	21	1300	MO	017	1	3944	9414	0	0	0	15	0	0	3	1 0 1	120./ 74.	.00
67	4	21	1300	MO	018	1	4001	9406	4004	[illegible]	8	27	0	0	4	2 2 2	106./ 73.	.44
67	4	21	1315	MO	019	1	3955	9355	0	0	0	3	0	0	1	0 0 0	108./ 83.	.00
67	4	21	1320	MO	020	1	3928	9346	3936	9333	14	132	0	0	5	3 3 3	122./101.	[illegible].69
67	4	21	1410	MO	021	2	4007	9325	4007	9316	1	15	0	7	4	2 2 1	98./103.	.03
67	4	21	1410	MO	022	1	3939	9314	3941	9311	3	60	0	0	5	2 1 3	111./119.	.36
67	4	21	1420	MO	023	1	3942	9310	3959	9207	53	150	[illegible]	2	5	4 3 4	109./120.	15.07
67	4	21	1503	MO	025	1	3906	9339	0	0	0	3	0	0	1	0 0 0	129./119.	.00
*67	5	18	1855	MO	035	1	4026	9523	0	0	0	3	0	0	3	0 0 0	66./ 12.	.00
*67	5	27	1630	MO	036	1	4026	9539	4026	9509	2	15	0	0	3	1 1 1	82./ 22.	.07
67	6	7	1900	MO	038	1	3924	9436	3926	9432	0	15	0	0	4	1 0 1	140./ 74.	.01
*67	6	9	2145	MO	039	1	4015	9505	0	0	0	3	0	0	2	0 0 0	103./ 26.	.00
67	6	10	1100	MO	041	1	3901	9335	0	0	0	5	0	0	1	0 0 0	130./125.	.00

"*" before year means event ocurred within a 2 degree square centered on central point

6-17
NPPI-SBØ-009
E24

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AZRAN	Area sq.mi
67	6	12	15	MO	043	1	3911	9429	0	0	1	15	0	0	6	1 1 1	143./ 88.	.03
67	6	12	100	MO	044	1	4016	9402	0	0	0	15	0	0	3	1 0 1	94./ 73.	.00
67	8	18	1730	MO	034	1	3844	9421	3839	9417	1	15	0	0	2	1 1 1	148./114.	.04
*67	3	30	1845	NE	001	1	4119	9620	0	0	0	0	0	0	3	1	331./ 66.	.00
67	5	10	1845	NE	002	1	4032	9648	0	0	0	0	0	0	5	1	282./ 54.	.00
67	6	7	1715	NE	007	1	4007	9656	4014	9540	6	0	0	0	5	2 2 1	257./ 61.	.00
67	6	9	1915	NE	008	2	4018	9734	4028	9640	14	0	0	2	5	2 3 2	268./ 89.	.00
*67	6	9	1938	NE	009	1	4035	9623	4039	9611	11	0	0	0	4	2 3 2	292./ 37.	.00
67	6	11	1535	NE	011	1	4003	9817	0	0	0	0	0	0	0	1	263./123.	.00
67	6	11	1600	NE	012	1	4004	9816	0	0	0	0	0	0	3	1	262./122.	.00
67	6	13	1840	NE	017	1	4135	9744	0	0	1	0	0	0	0	1 1 1	308./120.	.00
67	6	13	2000	NE	023	1	4156	9628	0	0	0	0	0	0	0	0 1	339./102.	.00
67	6	13	2100	NE	024	1	4203	9705	0	0	0	0	0	0	0	0 1	328./121.	.00
67	6	13	2245	NE	025	1	4048	9810	4100	9755	18	0	0	0	0	2 3 1	283./115.	.00
67	6	14	130	NE	026	1	4209	9629	0	0	0	0	0	0	5	2 0 1	341./114.	.00
67	6	15	1630	NE	036	1	4050	9713	4144	9613	80	0	0	0	5	0 4 1	292./ 78.	.00
67	8	1	1500	NE	038	1	4159	9650	0	0	2	0	0	0	4	2 1 1	331./112.	.00
67	9	20	1710	NE	039	1	4000	9747	0	0	0	0	0	0	0	1	258./101.	.00
*68	4	16	1800	IA	006	1	4043	9527	0	0	2	60	0	0	4	2 1 3	21./ 24.	.23
*68	4	16	1800	IA	007	1	4040	9530	0	0	0	0	0	0	3	2 0 1	19./ 20.	.00
68	5	15	1645	IA	013	1	4143	9456	0	0	2	75	0	1	4	1 1 3	21./ 88.	.28
68	6	24	1835	IA	021	1	4142	9600	0	0	0	0	0	0	0		349./ 83.	.00
68	6	24	1935	IA	022	1	4136	9548	0	0	0	0	0	0	0		354./ 75.	.00
68	4	16	1900	KS	001	1	3904	9610	3924	9535	30	0	0	0	4	2 3 1	198./ 81.	.00
68	5	2	1950	KS	005	1	3912	9642	0	0	0	0	0	0	0	0 1	216./ 85.	.00
*68	4	16	1805	MO	005	1	4034	9532	0	0	0	3	0	0	4	1 0 0	19./ 14.	.00
*68	4	16	1816	MO	006	1	4029	9536	0	0	1	10	0	0	4	1 1 1	11./ 8.	.02
*68	5	13	1600	MO	009	1	4021	9452	0	0	0	5	0	0	4	1 0 0	90./ 35.	.00
68	5	15	1530	MO	011	1	3850	9403	3853	9358	5	60	0	2	5	2 2 3	151./117.	.55
68	5	15	1545	MO	012	1	3917	9402	3920	9400	3	15	0	0	4	1 2 1	131./ 98.	.11
68	5	15	1600	MO	013	3	3853	9346	3900	9333	7	15	0	0	4	2 3 1	135./124.	.20
68	5	15	1600	MO	014	1	3903	9333	3906	9329	1	15	0	0	4	1 1 1	129./125.	.04
*68	4	15	1825	NE	001	1	4011	9605	0	0	0	0	0	0	4	2 1	244./ 23.	.00
*68	4	16	1810	NE	002	1	4023	9550	0	0	1	0	0	0	4	2 1 1	282./ 9.	.00
*68	6	24	1840	NE	011	1	4121	9620	0	0	0	0	0	0	3	0	332./ 68.	.00
68	6	24	215	NE	012	1	4132	9624	0	0	0	0	0	0	0	1 1	334./ 79.	.00
68	7	8	1600	NE	014	1	4153	9643	0	0	1	18	0	0	0	1 2	332./104.	.04
68	7	30	1540	NE	018	1	4156	9726	0	0	0	0	0	0	0		320./124.	.00
68	7	30	1725	NE	019	1	4110	9739	4107	9732	6	60	0	2	5	2 2 3	298./103.	.79
68	7	30	1400	NE	020	1	4050	9735	4050	9732	2	0	0	0	4	2 1	288./ 93.	.00
*68	8	18	1745	NE	021	1	4115	9557	4115	9532	21	0	0	0	6	3 3 2	345./ 56.	.00
69	6	4	1445	IA	003	1	4124	9526	0	0	1	60	0	0	4	1 3	8./ 64.	.11
69	6	22	1540	IA	007	1	4122	9334	0	0	0	0	0	0	4		57./111.	.00
69	6	22	1535	IA	008	1	4124	9336	0	0	0	0	0	0	0		55./111.	.00
69	6	28	1100	IA	014	1	4200	9512	4203	9508	4	60	0	0	5	2 2 3	11./101.	.55
69	7	16	1815	IA	020	1	4209	9428	4209	9424	3	60	0	0	5	1 1 3	26./120.	.39
69	7	16	2334	IA	022	1	4131	9330	0	0	0	0	0	0	4		54./119.	.00
69	7	26	1347	IA	023	1	4220	9536	4202	9525	9	60	0	0	5	3 2 3	1./119.	1.03
69	7	26	1630	IA	024	1	4207	9519	4205	9506	11	0	0	0	5	2 3 2	8./107.	.00
69	9	26	1930	IA	028	1	4205	9426	0	0	1	60	0	0	4	1 1 3	27./117.	.11
69	5	5	1835	KS	002	1	3818	9529	0	0	2	0	0	0	3	1 1 1	177./123.	.00
69	5	7	1300	KS	003	1	3904	9518	0	0	0	6	0	0	0	0 0 1	169./ 79.	.00
69	6	17	1600	KS	008	1	3840	9636	3842	9629	3	11	0	6	5	2 1 1	204./111.	.07
*69	6	26	1345	KS	012	1	3936	9617	0	0	0	0	0	0	3	1 0 1	214./ 54.	.00
69	7	9	1550	KS	015	1	3909	9644	0	0	0	0	0	0	0	0 1	215./ 85.	.00

"*" before year means event ocurred within a 2 degree square centered on central point

6-18
NPPI-58Ø-009

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F	P	P	AZRAN	Area sq.mi
69	7	9	1700	KS	016	2	3857	9506	3859	9458	7	0	0	4	5	2	2		164./ 85.	.00
69	6	4	1615	MO	002	1	3836	9422	0	0	0	3	0	0	1	0	0	0	151./121.	.00
69	4	4	1720	MO	003	1	3843	9359	0	0	0	45	0	1	5	2	0	2	142./123.	.03
69	4	25	1810	MO	005	1	3855	9422	0	0	0	15	0	0	4	1	0	1	145./104.	.01
69	6	22	300	MO	007	1	3911	9436	0	0	0	15	0	0	4	1	0	1	146./ 85.	.01
69	6	26	1830	MO	013	2	3911	9438	39-8	9429	5	30	0	5	4	3	3	2	146./ 84.	.32
69	6	26	1835	MO	014	1	3914	9442	0	0	0	30	0	0	5	2	0	2	147./ 80.	.03
69	6	26	1900	MO	015	1	3917	9417	3919	9410	6	30	0	0	4	1	2	2	136./ 90.	.38
69	6	26	1900	MO	016	1	3925	9413	0	0	0	5	0	0	4	1	0	0	130./ 86.	.00
*69	6	29	1850	MO	017	1	4018	9449	0	0	0	3	0	0	1	0	0	0	95./ 37.	.00
69	6	29	1957	MO	018	1	4015	9437	4017	9431	5	30	0	0	5	2	2	2	97./ 47.	.33
69	7	7	1630	MO	019	1	3902	9434	0	0	0	5	0	0	2	1	0	0	145./ 87.	.00
*69	7	25	1926	MO	020	1	3947	9449	0	0	0	6	0	0	5	2	0	1	132./ 51.	.00
69	5	31	1605	NE	003	1	4023	9644	0	0	0	0	0	0	0	0		1	272./ 50.	.00
69	6	22	300	NE	006	1	4127	9746	0	0	0	0	0	0	4	1		1	305./116.	.00
69	6	22	530	NE	007	1	4142	9720	0	0	0	0	0	0	0	1		1	317./111.	.00
69	7	16	1615	NE	014	1	4111	9725	4113	9733	3	0	0	0	3	0	2	1	302./ 95.	.00
69	7	16	1645	NE	015	1	4111	9725	0	0	0	0	0	0	0	0		1	302./ 95.	.00
69	7	16	1650	NE	016	1	4124	9715	0	0	0	0	0	0	0	1		1	311./ 96.	.00
69	8	6	1940	NE	020	1	41?9	9735	0	0	0	0	0	0	0			1	308./111.	.03
70	5	12	1930	IA	006	1	4123	9514	4126	9507	1	120	0	0	5	2	1	3	15./ 69.	.29
70	5	22	1800	IA	009	1	4131	9430	0	0	0	0	0	0	3				36./ 87.	.00
70	6	19	2130	KS	024	1	3942	9711	0	0	0	0	0	0	0				241./ 82.	.00
70	11	5	1745	KS	029	1	3905	9538	0	0	1	90	0	0	4	2	1	3	180./ 76.	.17
70	6	12	1335	MO	016	1	3917	9330	0	0	0	3	0	0	1	0	0	0	123./118.	.00
70	6	12	1340	MO	017	1	3925	9333	3929	9330	2	15	0	0	2	1	1	1	119./110.	.08
70	6	12	1400	MO	018	1	3923	9315	0	0	0	3	0	0	1	0	0	0	116./125.	.00
70	9	2	1603	MO	033	1	3840	9404	0	0	0	9	0	0	2	0	0	1	144./125.	.01
70	9	7	1730	MO	035	1	4005	9316	0	0	0	6	0	0	4	1	0	1	98./110.	.00
70	6	10	1640	NE	002	1	4117	9657	0	0	0	0	0	0	4	2		1	313./ 82.	.00
70	6	15	2225	NE	007	1	4126	9657	4133	9609	34	180	0	0	0	2	4	4	318./ 98.	11.72
*70	6	15	2235	NE	009	1	4010	9610	0	0	0	0	0	0	0	1		1	246./ 27.	.00
70	7	14	1830	NE	011	1	4029	9653	4030	9647	5	0	0	0	4	2	2	1	278./ 58.	.00
71	5	5	1715	IA	001	1	4049	9421	0	0	1	60	0	0	4	2	1	3	64./ 65.	.11
*71	5	5	1720	IA	002	1	4045	9438	0	0	2	120	0	12	5	3	1	3	62./ 51.	.45
*71	5	5	1800	IA	003	1	4047	9454	0	0	0	0	0	1	4	2		2	52./ 42.	.00
*71	5	6	930	IA	004	1	4103	9447	0	0	1	30	0	0	2	1	1	2	42./ 57.	.06
*71	5	23	1428	IA	012	1	4043	9520	0	0	0	0	0	0	2	0		2	30./ 21.	.00
*71	5	23	1640	IA	013	1	4044	9456	0	0	0	0	0	0	4	1		2	54./ 39.	.00
71	5	23	1750	IA	014	1	4052	9436	0	0	0	0	0	0	1	1		2	57./ 56.	.00
71	6	6	2100	IA	023	1	4206	9533	0	0	2	30	0	0	4	1	1	2	14./109.	.11
71	6	6	2122	IA	024	1	4219	9617	0	0	1	30	0	3	4	0	1	2	366./121.	.06
71	5	17	2305	KS	010	1	3915	9719	0	0	1	0	0	0	3	1	1	0	230./102.	.00
71	5	21	1340	KS	012	1	3844	9649	0	0	2	140	0	0	0	1	1	3	210./112.	.53
71		31	1900	KS	017	1	3848	9439	0	0	0	30	0	0	3	1	0	2	154./104.	.05
71	6	6	2015	KS	023	1	3848	9637	0	0	2	60	0	0	5	3	1	3	206./104.	.23
71	6	6	2125	KS	024	1	3853	9555	0	0	0	0	0	0	0	1	0	0	188./ 89.	.00
71	6	9	2030	KS	026	1	3902	9738	0	0	0	60	0	0	0	1	0	3	230./122.	.02
71	7	9	1415	KS	033	1	3828	9616	3831	9612	4	0	0	0	0	2	2	2	195./117.	.00
71	5	31	1935	MO	013	1	3900	9417	0	0	0	5	0	0	0	1	0	0	142./103.	.00
71	6	22	1800	MO	019	1	3946	9331	0	0	0	15	0	0	4	1	0	1	110./104.	.01
71	7	23	1812	MO	023	1	3915	9338	0	0	0	3	0	0	0	0	0	0	130./101.	.00
71	8	3	1300	MO	024	1	3918	9348	0	0	0	1	0	0	0	0	0	0	127./106.	.00
71	11	1	1730	MO	026	1	3941	9414	0	0	1	8	0	0	4	1	1	1	122./ 76.	.02
71	5	5	1415	NE	002	1	4105	9755	4110	9747	9	15	0	0	3	0	2	1	293./112.	.26

"*" before year means event occurred within a 2 degree square centered on central point

6-19
NPPD-SBØ-007
EA [illegible]

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	Sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AZRAN	Area sq.mi
*71	5	23	1515	NE	006	1	[illegible]	9637	4126	9630	15	21	0	[illegible]	0	1 3 2	320./ 69.	.60
*71	5	30	2230	NE	019	1	4016	9606	0	0	0	0	0	[illegible]	0	0 1	257./ 22.	.00
71	6	4	1515	NE	021	1	4049	9755	4054	9752	6	0	0	0	4	0 2 1	285./107.	.00
71	6	4	1611	NE	022	1	4105	9736	0	0	0	0	0	0	0	0 1	296./ 99.	.00
71	6	4	2030	NE	025	1	4047	9748	4116	9709	47	0	0	0	5	1 4 1	285./102.	.00
71	6	6	1700	NE	029	1	4142	9741	0	0	0	0	0	0	3	0 1	311./122.	.00
71	6	6	1730	NE	030	1	4105	9752	0	0	0	0	0	0	3	0 1	305./ 77.	.00
71	6	6	2000	NE	031	1	4048	9641	0	0	0	0	0	0	3	0 1	300./ 55.	.00
71	6	6	2000	NE	032	1	4048	9641	0	0	0	0	0	0	3	0 1	300./ 55.	.00
71	6	6	2030	NE	033	1	4016	9645	0	0	0	0	0	0	3	0 1	264./ 51.	.00
*71	6	6	2130	NE	034	1	4115	9558	0	0	0	0	0	0	3	0 1	344./ 58.	.00
*71	6	6	2130	NE	035	1	4108	9554	0	0	0	0	0	0	3	0 1	346./ 49.	.00
71	6	13	1630	NE	039	1	4101	9801	0	0	0	0	0	0	0	0 1	[illegible]	.00
71	6	13	1730	NE	C40	1	4103	9711	0	0	0	0	0	0	0	0 1	301./ 82.	.00
72	6	7	[illegible]	IA	004	1	4209	[illegible]	0	0	2	60	0	0	3	2 1 3	15./112.	.23
72	6	7	1130	IA	005	1	4204	9452	0	0	1	60	0	0	4	2 1 3	18./109.	.11
*72	6	13	1345	IA	006	1	4052	9550	0	0	1	30	0	0	4	1 1 2	344./ 32.	.06
*72	6	13	1530	IA	007	1	4045	9450	0	0	0	30	0	0	3	1 0 2	57./ 44.	.03
72	6	13	1640	IA	008	1	4107	9403	0	0	2	30	0	0	4	2 1 2	57./ 85.	.11
72	7	6	1610	IA	011	1	4224	9542	4227	9538	4	45	0	0	5	1 2 2	359./123.	.41
72	7	6	1613	IA	012	1	4213	9546	0	0	1	30	0	0	4	1 1 2	357./117.	.06
72	7	14	1827	IA	013	1	4036	9413	0	0	1	30	0	0	4	1 1 2	77./ 66.	.06
72	9	10	1955	IA	018	1	4134	9511	4138	9506	6	30	0	0	4	1 2 2	15./ 76.	.36
72	9	12	1530	IA	019	1	4130	9542	4135	9539	6	30	0	0	4	2 2 2	358./ 69.	.35
72	9	12	1800	IA	020	1	4103	9428	0	0	0	30	0	0	4	0 0 2	51./ 67.	.03
72	9	12	1819	IA	021	1	4110	9411	4120	9352	20	60	0	0	4	1 3 3	53./ 82.	2.28
72	4	30	2115	KS	011	1	3855	9716	0	0	1	90	0	6	5	3 0 3	221./114.	.26
72	4	30	2216	KS	012	1	3845	9446	0	0	0	70	0	0	5	2 3	157./104.	.00
72	5	26	1423	KS	030	1	3931	9753	0	0	0	3	0	0	2	0 0 0	244./116.	.00
72	6	24	1645	KS	031	1	3936	9753	0	0	0	4	0	0	3	0 0 0	247./113.	.00
72	7	2	1710	KS	032	1	3848	9555	0	0	0	10	0	0	0	1 0 1	188./ 94.	.01
72	8	22	15	KS	040	1	3901	9451	0	0	0	5	0	0	4	1 0 0	155./ 88.	.00
*72	12	30	130	MO	010	1	3953	9445	0	0	2	15	0	0	4	1 1 1	125./ 49.	.06
*72	5	23	1330	NE	004	1	4041	9553	0	0	0	0	0	0	0	0 0 0	330./ 23.	.00
*72	5	25	1345	NE	005	1	4040	9602	0	0	0	0	0	0	0	0 0 0	416./ 26.	.00
72	5	23	1553	NE	006	1	4042	9809	0	0	0	0	0	0	0	0 3 0	290./116.	.00
72	5	23	1645	NE	007	1	4047	9830	0	0	0	0	0	0	0	0 0 0	284./1[illegible]1.	.00
72	5	23	1650	NE	008	1	4127	9711	0	0	0	0	0	0	0	0 0 0	313./ 96.	.00
72	5	23	1722	NE	011	1	4121	9710	0	0	0	0	0	0	0	0 0 0	311./ 91.	.00
72	5	23	1750	NE	012	1	4015	9547	0	0	0	0	0	0	0	0 0 0	267./ 53.	.00
72	5	23	1812	NE	013	1	4114	9719	0	0	0	0	0	0	0	0 0 0	305./ 93.	.00
*72	5	27	1412	NE	014	1	4052	9632	0	0	0	3	0	0	0	0 0 0	307./ 51.	.00
72	5	27	1535	NE	015	1	4137	9640	0	0	0	0	0	0	0	0 0 0	329./ 89.	.00
*72	6	7	1616	NE	016	1	4119	9554	0	0	0	3	0	0	0	0 0 0	344./ 39.	.00
72	6	16	1248	NE	017	1	4046	9743	0	0	0	0	0	0	0	0 0	265./ 98.	.00
72	6	18	1703	NE	018	1	[illegible]	9815	0	0	0	6	0	0	3	1 0 1	283./122.	.00
72	6	18	1925	NE	019	1	[illegible]	9806	0	0	0	3	0	0	0	0 0 0	280./114.	.00
72	7	1	1710	NE	020	1	4149	9737	0	0	0	5	0	0	0	0 0 0	315./125.	.00
73	4	19	1700	IA	002	1	4212	9518	0	0	1	90	0	0	4	1 1 3	8./112.	.17
73	4	19	1815	IA	003	1	4046	9406	4048	9403	3	90	0	0	4	1 1 3	70./ 74.	.59
73	4	19	1820	IA	004	1	4103	9421	0	0	1	60	0	0	4	1 1 3	54./ 72.	.11
73	4	19	2000	IA	005	1	4106	9330	0	0	2	120	0	0	4	2 1 3	61./ 93.	.43
73	6	16	1745	IA	016	1	4105	9356	0	0	1	15	0	0	4	0 1 1	60./ 89.	.01
73	9	25	2359	IA	026	1	4133	9520	0	0	0	0	0	0	4	2 1	51./ 73.	.00
73	3	13	1820	KS	008	1	3853	9449	3857	9449	4	10	0	0	4	0 2 1	157./ 96.	.09

"*" before year means event ocurred within a 2 degree square centered on central point

6-20
NPP1-5BØ-009
E34

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	ste	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AZRAN	Area sq.mi
*73	4	19	2330	KS	011	1	3953	9529	0	0	0	30	0	0	1	2 0 2	165./ 29.	.01
*73	4	30	2130	KS	013	1	3927	9514	0	0	0	30	0	0	1	0 2	161./ 57.	.00
*73	5	6	1630	KS	016	1	3935	9540	0	0	0	40	0	0	2	0 0 2	182./ 46.	.02
73	9	25	1715	KS	034	2	3903	9735	3954	9652	69	20	0	2	7	3 4 2	229./120.	2.65
73	9	25	1630	KS	035	1	3913	9736	3921	9733	3	20	0	0	5	2 2 1	235./111.	.15
73	9	25	2330	KS	041	1	3929	9720	3933	9715	4	20	0	0	5	2 2 1	237./ 94.	.17
73	9	26	200	KS	042	1	3921	9705	0	0	2	10	0	0	5	2 1 1	228./ 90.	.05
73	11	20	2200	KS	055	1	3949	9720	0	0	0	6	0	0	4	1 0 1	248./ 85.	.00
73	11	20	55	KS	056	1	3817	9545	0	0	1	10	0	0	5	2 0 1	183./124.	.02
73	4	19	1700	MO	009	2	4005	9424	4010	9417	1	15	0	0	3	2 2 1	106./ 59.	.05
73	4	19	1800	MO	010	1	3942	9412	0	0	[illegible]	15	0	0	3	2 1 1	121./ 77.	.03
73	4	20	1655	MO	018	1	3919	9330	0	0	5	0	0	0	[illegible]	2 2 1	122./117.	.00
73	4	21	1420	MO	028	2	4020	9333	4028	9319	13	132	0	1	5	4 3 3	91./ 95.	3.45
73	5	1	1330	MO	031	1	3905	9336	0	0	0	15	0	0	3	2 0 1	128./121.	.01
73	5	7	1220	MO	037	1	3919	9424	0	0	0	6	0	0	4	2 0 1	138./ 85.	.01
*73	6	16	1545	MO	065	1	3946	9450	0	0	6	0	0	14	6	2 2 2	134./ 51.	.00
73	7	18	1730	MO	068	1	3921	9404	0	0	0	0	0	0	0	1 1	150./ 94.	.00
73	6	30	740	NE	003	1	4103	9745	0	0	0	0	0	0	4	0 0	296./107.	.00
73	5	26	1400	NE	005	1	4110	9727	0	0	0	0	0	0	4	0 3	301./ 96.	.00
73	5	26	1515	NE	006	1	4045	9742	0	0	0	0	0	0	0	0 1	286./ 98.	.00
73	5	26	1630	NE	007	1	4126	9720	0	0	0	0	0	0	3	0 1	310./100.	.00
73	6	2	2030	NE	008	1	4002	9804	0	0	0	0	0	0	2	1 2	260./113.	.00
73	7	3	2130	NE	012	1	4115	9645	0	0	0	0	0	0	6	1 1	319./ 76.	.00
73	9	25	2120	NE	017	1	4006	9736	0	0	0	0	0	0	4	0 1	261./ 92.	.00
73	10	9	2000	NE	019	1	4142	9712	0	0	1	0	0	0	4	0 0 1	319./107.	.00
74	4	28	1400	IA	001	1	4139	9328	0	0	0	0	0	0	2	0 0	51./125.	.00
*74	5	13	1630	IA	004	1	4103	9504	4113	9453	6	6	0	0	5	3 2 1	29./ 54.	.08
74	6	18	2135	IA	021	1	4144	9337	4131	9332	9	120	2	50	7	4 2 3	47./123.	2.12
74	7	3	1635	IA	024	1	4206	9451	0	0	0	0	0	0	0	0 0	18./111.	.00
74	3	8	100	KS	001	7	3838	9642	3940	9530	28	66	0	0	5	2 4 3	206./114.	3.59
74	4	19	1645	KS	002	1	3947	9747	3958	9740	4	5	0	0	3	1 2 0	251./105.	.04
74	4	19	1650	KS	003	1	3934	9737	0	0	0	5	0	0	3	1 0 0	243./103.	.00
74	5	10	1820	KS	008	1	3954	9759	3954	9748	2	6	0	0	3	1 1 1	256./112.	.03
74	5	17	1930	KS	013	1	3930	9802	3927	9800	0	6	0	0	3	0 0 1	245./122.	.01
74	6	8	1845	KS	022	3	3825	9613	3856	9552	26	528	6	177	7	4 4 3	193./119.	26.33
74	3	8	130	MO	001	1	3934	9356	3947	9330	27	30	0	0	4	1 3 2	121./ 92.	1.56
74	5	13	1830	MO	010	1	3955	9425	3958	9417	7	15	0	0	4	1 2 1	115./ 62.	.22
74	6	8	1900	MO	014	1	4013	9433	0	0	0	0	0	0	4	0 0	99./ 50.	.00
*74	6	8	2200	MO	015		4012	9503	4017	9453	10	120	0	0	4	1 3 3	109./ 28.	2.39
74	4	20	1555	NE	010		4006	9756	4036	9729	33	0	0	0	4	3 3 1	262./107.	.00
74	5	10	1815	NE	016	1	4002	9806	0	0	1	70	0	0	6	2 1 3	260./115.	.13
*74	5	13	1620	NE	017	1	4015	9627	0	0	0	0	0	0	4	1 1	261./ 38.	.00
74	5	25	1036	NE	021	1	4100	9734	0	0	0	0	0	0	3	1 1	294./ 96.	.00
74	8	17	1115	NE	027	1	4032	9810	0	0	0	0	0	0	0	0 0	275./116.	.00
*74	8	30	1842	NE	030	1	4024	9615	4026	9611	4	0	0	0	5	1 2 1	276./ 28.	.00
74	10	30	1330	NE	032	1	4126	9728	0	0	0	0	0	0	4	0 0	308./103.	.00
75	3	23	1510	IA	001	1	4036	9331	0	0	0	0	0	0	3	0 0	81./ 38.	.00
*75	4	23	1455	IA	003	1	4045	9449	0	0	0	0	0	0	0	0 0	57./ 44.	.00
75	5	6	1600	IA	005	1	4124	9551	4132	9540	13	150	0	0	4	2 3 3	351./ 64.	3.76
75	5	6	1620	IA	006	1	4128	9552	4137	9548	5	0	0	0	[illegible]	2 2 2	351./ 68.	.00
75	5	7	1730	IA	007	1	4149	9530	0	0	0	0	0	0	4	2 1	4./ 88.	.00
75	5	7	1800	IA	008	1	4139	9513	4148	9512	5	0	0	0	4	2 4 2	13./ 80.	.00
75	5	7	1815	IA	009	1	4104	9422	0	0	0	0	0	0	0	0 0	33./ 72.	.00
75	5	7	1900	IA	010	1	4049	9350	0	0	0	0	0	0	4	2 1	71./ 56.	.00
75	5	7	1930	IA	011	1	4102	9347	0	0	10	0	0	0	5	2 2 1	84./ 33.	.00

"*" before year means event occurred within a 2 degree square centered on central point

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F	P	P	AZRAN	Area sq.mi
75	6	14	1233	IA	021	1	4131	9354	4131	9347	6	0	0	0	3	1	2	1	48./105.	.00
*75	6	18	600	IA	022	1	4040	9514	0	0	0	0	0	0	4	2		1	44./ 26.	.00
75	6	18	500	IA	023	1	4122	9330	0	0	0	0	0	0	3	2		1	58./114.	.00
75	6	23	1705	IA	025	1	4046	9329	0	0	0	0	0	0	4	1		1	76./101.	.00
75	4	27	1805	KS	002	1	3936	9808	0	0	0	3	0	0	3	0	0	0	249./124.	.00
75	5	22	1330	KS	005	1	3945	9813	3949	9810	1	10	0	0	4	1	0	1	253./125.	.02
75	9	10	1650	KS	013	1	3905	9614	0	0	0	1	0	0	1	0	0	0	200./ 81.	.00
*75	12	13	2305	KS	017	1	3950	9605	3955	9547	1	90	0	0	5	1	1	3	214./ 37.	.29
75	4	23	1440	MO	002	1	3942	9358	3946	9346	9	120	1	3	6	4	2	3	117./ 86.	2.11
75	4	23	1605	MO	003	2	3944	9321	3947	9305	11	150	0	2	5	3	[illegible]	3	109./112.	3.31
*75	11	29	1630	MO	015	1	3946	9451	0	0	3	45	0	0	4	1	1	2	134./ 50.	.26
75	11	29	1810	MO	016	1	3914	9350	0	0	8	15	0	0	5	0	2	1	129./107.	.23
*75	12	5	140	MO	017	1	3922	9453	3922	9447	5	8	0	0	4	1	2	1	149./ 65.	.05
75	12	14	330	MO	018	1	3944	9400	0	0	0	6	0	0	3	1	0	1	116./ 84.	.01
75	3	27	1600	NE	001	1	4113	9725	0	0	0	18	0	0	3	1	0	2	303./ 96.	.02
*75	3	27	1645	NE	002	1	4115	9504	0	0	0	90	0	4	5	2	0	3	340./ 57.	.09
75	4	27	930	NE	006	1	4010	9734	0	0	0	6	0	0	3	2	0	1	263./ 59.	.00
75	4	27	1100	NE	007	1	4029	9700	4057	9656	3	12	0	0	5	1	2	1	277./ 63.	.07
75	4	27	1125	NE	008	1	4049	9640	0	0	0	3	0	0	4	0	0	0	301./ 55.	.00
75	5	6	1345	NE	016	1	4158	9712	4212	9714	16	50	0	1	5	3	3	3	324./120.	1.54
*75	5	6	1535	NE	017	2	4110	9604	4117	9601	7	80	3	133	5	4	2	3	328./ 53.	1.15
*75	5	6	1500	NE	018	1	4117	9635	4120	9635	1	5	0	0	3	0	1	1	323./ 71.	.01
75	5	10	1745	NE	022	1	4104	9737	0	0	0	3	0	0	3	0	0	0	297./100.	.00
*75	5	22	1555	NE	027	1	4101	9558	0	0	0	5	0	0	0	0	0	0	339./ 43.	.00
75	5	25	1900	NE	028	1	4024	9700	0	0	0	5	0	0	0	0	0	0	273./ 63.	.00
75	5	25	1900	NE	029	1	4203	9624	0	0	0	0	0	0	2	0	0	0	341./108.	.00
75	5	25	1900	NE	030	1	4208	9629	0	0	0	0	0	0	2	0	0	0	341./113.	.00
75	5	25	1915	NE	031	1	4018	9700	0	0	0	0	0	0	0	0	0	0	267./ 63.	.00
75	6	2	1445	NE	036	1	4048	9718	0	0	0	60	0	0	0	0	0	3	290./ 80.	.01
75	6	2	1710	NE	038	1	4007	9640	0	0	0	8	0	0	5	2	0	1	254./ 49.	.00
75	6	15	2130	NE	039	1	4121	9757	4045	9702	19	60	0	0	5	3	3	3	300./120.	2.16
75	6	19	330	NE	042	1	4039	9707	4041	9705	0	15	0	0	4	1	0	1	285./ 70.	.02
*75	6	18	530	NE	043	1	4022	9551	4038	9550	1	60	0	0	5	1	1	3	276./ 10.	.21
75	6	20	2330	NE	057	1	4134	9731	0	0	0	15	0	0	4	0	0	1	306./123.	.01
*75	9	4	115	NE	076	1	4011	9528	0	0	0	0	0	0	5	0		0	143./ 13.	.00
75	12	13	2130	NE	077	1	4002	9735	4007	9728	4	18	0	0	5	2	2	2	258./ 92.	.14
*75	12	13	2340	NE	078	1	4013	9614	0	0	1	15	0	0	4	2	0	1	254./ 29.	.03
76	4	14	2015	IA	001	1	4146	9401	4148	9355	1	20	0	0	2	2	0	2	40./112.	.04
76	4	23	1920	IA	002	1	4118	9516	4121	9313	1	10	0	0	0	1	1	1	62./121.	.02
*76	5	28	1800	IA	003	1	4055	9536	0	0	0	30	0	0	4	1	0	2	3./ 34.	.03
76	6	12	1830	IA	004	4	4123	9356	4149	9320	3	30	0	0	4	1	4	1	49./102.	.22
76	6	12	1930	IA	005	2	4124	9402	4127	9344	1	30	0	0	1	1	3	2	49./ 96.	.09
76	6	13	1415	IA	007	2	4143	9406	4159	9401	18	30	0	0	5	3	3	2	40./107.	1.07
76	6	13	1430	IA	008	2	4156	9352	4211	9336	22	264	0	9	7	5	3	4	40./123.	11.01
76	6	13	1500	IA	012	2	4125	9508	4137	9450	10	30	0	0	4	2	3	2	19./ 68.	.59
76	6	26	1715	IA	015	1	4127	9536	4129	9530	5	60	0	6	6	4	2	3	1./ 66.	.58
76	7	28	123	IA	016	1	4131	9321	0	0	*	30	0	0	4	2	1	2	56./124.	.07
76	8	11	1415	IA	017	1	4204	9444	0	0	2	30	0	0	4	2	0	2	21./111.	.11
76	3	29	1330	KS	002	1	3924	9744	0	0	2	5	0	0	0	0	0	0	240./113.	.02
*76	4	17	1845	KS	008	2	3933	9627	3947	9618	1	84	0	0	5	1	3	3	218./ 61.	.29
76	4	14	1845	NE	003	1	4007	9713	4013	9712	6	7	0	0	5	1	2	1	259./ 74.	.09
76	4	15	1815	NE	004	1	4044	9743	0	0	0	0	0	0	5	1		1	284./ 97.	.00
76	4	15	1900	NE	005	1	4022	9806	4023	9753	11	30	0	0	5	2	3	2	271./113.	.65
76	4	23	1855	NE	006	1	4001	9640	4006	9631	9	18	0	0	4	1	2	2	247./ 52.	.33
76	5	13	1521	NE	007	1	4028	9645	0	0	0	3	0	0	0	0	0	0	278./ 31.	.00

"*" before year means event ocurred within a 2 degree square centered on central point

6-22
NPP1-5BØ-009

Tornadoes within 125. KM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	sta	Seq	Total # seq	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F	P	P	BERAN	Area sq.mi
*76	6	26	1643	NE	014	1	4114	9610	0	0	1	15	0	23	6	1	1	1	336./ 58.	.03
77	5	4	1915	IA	011	1	4147	9432	0	0	1	0	0	0	0		1		30./ 99.	.00
77	5	4	1926	IA	012	1	4131	9434	0	0	1	9	0	0	4		1	1	28./102.	.02
77	5	19	1428	IA	019	1	4219	9450	0	0	1	6	0	0	3		1	1	17./123.	.01
77	8	15	1600	IA	029	1	4158	9546	0	0	0	6	0	0	0		0	1	356./ 97.	.00
77	8	15	1845	IA	030	1	4144	9336	0	0	0	18	0	0	0		0	2	48./123.	.01
77	9	23	1700	IA	035	1	4148	9456	0	0	1	3	0	0	4		1	0	20./ 92.	.01
77	5	4	1130	KS	004	1	3827	9448	3836	9441	4	15	0	0	5	2	2	1	161./121.	.14
77	5	4	1900	KS	005	2	3848	9522	3855	9449	12	90	0	1	6	3	4	3	172./ 94.	2.09
77	5	4	1900	KS	006	1	3853	9448	3854	9439	3	21	0	0	5	2	1	2	156./ 96.	.13
77	5	5	1740	KS	007	1	3857	9538	3859	9537	1	9	0	0	3	1	0	1	180./ 84.	.02
77	5	4	1315	MO	006	1	3900	9355	3912	9330	13	30	1	5	6	3	3	2	135./114.	.75
77	5	4	1705	MO	008	3	3913	9418	3921	9406	14	90	0	5	3		3	3	138./ 92.	2.40
77	5	4	1900	MO	009	3	3919	9400	3926	9307	47	264	0	1	6	4	4	4	129./ 98.	23.91
77	5	21	1645	MO	011	1	4016	9410	0	0	1	30	0	0	4	1	1	2	94./ 67.	.05
77	5	21	1900	MO	012	1	4007	9337	4010	9334	4	45	0	0	4	1	2	2	99./ 94.	.37
77	11	8	2055	MO	016	1	3903	9434	0	0	1	30	0	0	4	0	0	2	148./ 92.	.06
77	11	20	915	MO	017	1	3908	9417	0	0	0	0	0	0	3	0		0	139./ 96.	.00
77	4	16	1500	NE	003	1	4128	9630	0	0	1	15	0	0	4		1	1	330./ 75.	.04
77	5	4	1520	NE	006	1	4136	9708	4143	9707	8	60	0	0	5	3	2	3	318./101.	.92
77	5	4	1525	NE	007	1	4156	9716	0	0	0	6	0	0	0		0	1	322./120.	.00
77	5	4	1615	NE	008	1	4119	9649	0	0	0	6	0	0	3		0	1	317./ 79.	.01
77	5	16	2000	NE	013	1	4054	9731	0	0	0	9	0	0	0				231./ 92.	.00
*77	5	26	1420	NE	038	1	4120	9637	0	0	0	9	0	0	2		0	1	323./ 74.	.00
77	6	17	1110	NE	044	2	4044	9743	4040	9739	3	21	0	0	5	1	1	2	284./ 97.	.23
77	7	7	310	NE	048	2	4209	9642	4200	9615	25	23	0	0	6		3	2	336./118.	1.10
77	7	24	538	NE	054	1	4138	9633	0	0	0	0	0	0	5			1	332./ 87.	.00
77	7	30	130	NE	055	1	4202	9633	0	0	0	0	0	0	5			1	338./109.	.00
77	8	3	2335	NE	056	1	4004	9740	0	0	0	0	0	0	5				260./ 95.	.00
77	8	15	2030	NE	059	1	4048	9640	0	0	0	0	0	0	4			0	300./ 54.	.00
77	8	20	1950	NE	060	1	4135	9610	0	0	0	0	0	0	6			0	342./ 78.	.00
77	9	11	1840	NE	066	2	4035	9820	4041	9816	3	3	0	0	4		2	0	276./124.	.02
*78	6	19	2115	IA	005	1	4042	9530	0	0	0	5	0	0	4	1	0	0	16./ 22.	.00
78	6	25	1630	IA	007	1	4215	9433	0	0	0	3	0	0	0		0	0	23./124.	.00
78	7	5	1940	IA	014	1	4219	9514	0	0	1	67	0	0	4		1	3	9./119.	.13
78	5	11	1700	KS	003	1	3837	9459	3836	9446	1	30	0	1	6	2	1	2	164./109.	.07
78	5	23	1830	KS	007	1	3849	9543	3849	9538	1	9	0	1	5	2	1	1	182./ 92.	.02
78	5	31	1600	KS	011	2	3919	9623	3928	9543	7	390	3	1	5	3	2	4	209./ 71.	5.47
78	6	17	1815	KS	013	1	3841	9539	3841	9531	4	45	16	3	5	1	2	2	180./100.	.37
78	6	17	1820	KS	014	1	3837	9527	0	0	0	1	0	0	1	0	0	0	175./104.	.00
78	6	19	1815	KS	016	1	395[illegible]	9514	0	0	0	2	0	0	4	0	0	0	257./123.	.00
78	7	6	1645	KS	023	1	4003	9653	0	0	0	0	0	0	0			0	250./ 61.	.00
78	4	5	2140	MO	001	1	3905	9420	0	0	0	15	0	[illegible]	3	1	0	1	161./ 97.	.00
78	5	12	1720	MO	008	1	3958	9351	0	0	1	60	0	[illegible]	5		1	3	106./ 85.	.11
78	4	7	1740	NE	003	1	4005	9520	0	0	0	3	0	0	2	2	0	0	263./125.	.00
78	4	7	2135	NE	004	2	4052	9516	4107	9745	31	23	0	1	7		3	2	285./123.	1.39
78	4	7	2336	NE	005	2	4111	9725	4118	9722	8	15	0	0	6		2	1	302./ 95.	.24
78	4	7	2350	NE	006	1	4116	9713	0	0	2	6	0	0	4		1	1	308./ 90.	.02
78	4	8	340	NE	007	1	4126	9602	0	0	0	3	0	0	2		0	0	345./ 67.	.00
78	5	28	2050	NE	019	1	4207	9642	0	0	0	0	0	0	0			0	336./116.	.00
78	5	30	1625	NE	020	1	4037	9727	4040	9724	4	9	0	0	5	2	2	1	281./ 84.	.07
78	5	30	1730	NE	021	1	4035	9714	0	0	1	6	0	0	4		1	1	281./ 74.	.01
78	5	30	1800	NE	022	1	4013	9746	0	0	0	6	0	0	4		0	1	266./ 98.	.01
'8	5	30	1900	NE	023	1	4013	9735	0	0	1	6	0	0	4		1	1	265./ 90.	.01
78	5	30	1820	NE	024	1	4018	9544	0	0	0	0	0	0	0			1	267./ 50.	.00

"*" before year means event ocurred within a 2 degree square centered on central point

6-23
NPPI-5BØ-009
E24

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	Sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AZRAN	Area sq.mi
78	6	19	1915	NE	026	1	4026	9544	0	0	0	3	0	0	4	0 0	276./ 51.	.00
78	6	19	1915	NE	027	1	4025	9726	0	0	4	2	0	0	6	2 0	273./ 82.	.02
78	7	6	1657	NE	032	2	4000	9659	4000	9655	3	30	0	0	6	2 2 2	251./ 66.	.20
78	7	6	1700	NE	033	1	4001	9646	0	0	1	9	0	0	4	1 1	249./ 56.	.02
78	7	18	2230	NE	035	1	4016	9644	0	0	0	6	0	0	5	0 1	264./ 51.	.00
78	7	21	1700	NE	038	1	4003	9708	0	0	0	7	0	0	4	0 1	255./ 70.	.01
*78	9	13	1620	NE	042	1	4009	9614	4010	9609	2	30	0	0	3	1 0	246./ 30.	.15
79	3	13	2300	IA	001	1	4123	9502	0	0	0	9	0	0	2	1 0 1	24./ 68.	.01
*79	3	29	1810	IA	003	1	4035	9457	4054	9434	29	150	0	1	6	3 3 3	66./ 34.	8.43
79	3	29	2020	IA	004	3	4046	9423	4122	9335	56	150	0	4	6	3 4 3	68./ 62.	16.15
79	3	29	2040	IA	005	1	4125	9330	4131	9321	9	18	0	0	5	2 2 2	56./116.	.31
79	6	23	2040	IA	026	1	4140	9412	4132	9401	13	12	0	0	5	1 3 1	39./102.	.33
79	7	10	1925	IA	027	1	4136	9354	0	0	0	9	0	0	2	0 0 1	46./108.	.00
79	7	27	1830	IA	030	1	4124	9501	0	0	1	18	0	0	4	1 1 2	24./ 69.	.03
79	7	30	222	IA	032	2	4217	9539	4211	9512	24	30	0	0	5	1 3 2	360./116.	1.37
79	7	30	315	IA	033	1	4147	9343	0	0	0	9	0	0	4	0 0 1	45./121.	.00
*79	9	28	1928	IA	048	3	4055	9546	4032	9513	39	160	2	14	3	3 4 3	350./ 35.	11.83
*79	9	5	2345	IA	051	1	4049	9517	0	0	0	9	0	0	4	1 0 1	30./ 32.	.01
79	3	13	2050	KS	001	1	3956	9643	3959	9639	1	45	0	0	5	1 1 2	243./ 56.	.13
*79	3	29	1735	KS	002	2	3945	9522	3947	9518	1	15	0	0	3	0 0 1	161./ 38.	.04
79	4	11	1700	KS	005	1	3906	9544	3909	9541	0	9	0	1	5	1 3 0	184./ 75.	.01
79	5	19	1423	KS	012	1	3943	9751	0	0	0	3	0	0	4	0 0 0	250./109.	.00
79	6	19	1500	KS	013	1	3942	9730	0	0	0	3	0	0	4	1 0 0	246./ 95.	.00
79	10	13	1650	KS	027	4	3911	9738	3928	9622	28	120	0	11	4	2 3 3	233./116.	6.39
79	10	13	1740	KS	028	3	3915	9621	3934	9525	54	60	0	5	5	2 4 3	207./ 74.	6.17
*79	10	21	1945	KS	029	1	3934	9520	3936	9518	2	30	0	1	5	1 1 2	164./ 49.	.17
79	4	11	1925	MO	006	2	3915	9426	3930	9413	20	30	0	9	5	2 3 2	140./ 86.	1.15
79	5	19	1430	NE	005	1	4026	9743	4028	9740	3	2	0	0	2	0 1 1	273./ 95.	.01
79	6	19	1535	NE	007	1	4147	9640	0	0	2	6	0	0	5	1 1 1	332./ 49.	.02
79	8	23	1630	NE	018	1	4031	9315	4019	9809	10	3	0	0	0	0 3 0	275./120.	.05
79	8	20	1815	NE	019	1	4020	9804	4025	9759	7	3	0	0	1	0 2 0	269./111.	.04
79	10	13	1505	NE	020	1	4007	9737	4009	9733	4	15	0	0	5	1 2 1	261./ 92.	.12
80	5	29	2100	IA	007	1	4150	9550	0	0	1	9	0	0	4	1 1 1	354./ 89.	.02
80	5	29	2120	IA	008	1	4207	9456	0	0	0	9	0	0	4	1 0 1	16./110.	.00
80	6	2	630	IA	010	1	4039	9325	4039	9319	5	24	0	0	5	2 2 2	90./102.	.24
80	6	2	700	IA	011	1	4040	9301	0	0	2	9	0	3	6	1 1 1	81./121.	.03
80	6	2	735	IA	012	2	4038	9255	4043	9233	20	24	0	5	6	2 3 2	82./125.	.91
80	6	2	1545	IA	013	2	4037	9355	4035	9319	31	42	0	0	6	4 3 2	78./ 80.	2.51
80	6	5	1200	IA	015	1	4136	9337	4137	9336	2	12	0	0	5	1 1 1	50./116.	.05
80	5	14	1920	IA	018	2	4115	9344	4108	9336	10	9	0	0	5	1 2 1	58./101.	.19
80	6	14	1920	IA	019	2	4115	9344	4108	9336	10	9	0	0	5	1 2 1	58./101.	.19
80	7	4	2130	IA	024	1	4122	9456	4124	9453	3	18	0	0	4	1 1 2	27./ 69.	.12
80	5	31	1445	KS	005	1	3911	9615	3907	9614	5	0	0	0	4	1 2 0	204./ 77.	.00
80	5	31	1555	KS	006	1	3903	9534	0	0	2	66	0	0	5	2 1 3	178./ 78.	.2"
80		31	1640	KS	007	2	3858	9506	3858	9458	1	0	0	1	5	2 2 0	163./ 87.	.00
80	7	9	1415	KS	014	1	3944	9800	0	0	0	3	0	0	4	0 0 0	251./115.	.00
80	5	12	1600	MO	004	1	3907	9329	3914	9300	5	30	0	0	5	2 2 2	126./124.	.31
80		29	1835	NE	005	1	4029	9729	4038	9728	3	3	0	0	3	1 1 0	275./ 85.	.02
80	5	29	2000	NE	006	3	4114	9701	4129	9646	8	24	0	2	6	1 3 2	310./ 82.	.39
80	5	29	1940	NE	007	1	4029	9729	0	0	0	1	0	0	0	0 0 0	275./ 85.	.00
80	5	29	1945	NE	003	1	4010	9736	4015	9732	2	5	0	0	5	1 1 0	263./ 91.	.02
80	6	2	330	NE	011	1	4014	9736	0	0	2	90	0	0	4	2 1 3	266./ 90.	.34
80	6	3	2132	NE	017	3	4054	9817	4051	9817	3	510	0	18	6	2 2 3	285./125.	3.34
80	6	3	2206	NE	018	2	4050	9817	4050	9803	7	600	0	2	6	1 2 3	284./124.	8.91
80	6	5	440	NE	019	1	4146	9710	0	0	0	2	0	0	3	1 0 0	321./109.	.00

"*" before year means event ocurred within a 2 degree square centered on central point

6-24

NPP1-SBØ-009

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	ste	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AIRAN	Area sq.mi
50	6	14	2010	NE	024	1	4140	9734	0	0	0	3	0	0	0	0 0 0	312./117.	.00
80	7	4	1145	NE	027	1	4042	9726	0	0	0	6	0	0	2	0 0 1	284./ 85.	.00
80	10	16	135	NE	035	2	4065	9818	4051	9814	5	6	0	0	6	1 2 1	281./124.	.06
81	3	29	920	IA	001	1	4130	9502	0	0	0	6	0	0	4	1 1	21./ 74.	.00
81	4	3	1840	IA	002	1	4157	9410	4201	9406	5	9	0	0	0	0 2 1	34./116.	.10
81	4	3	2010	IA	003	1	4045	9314	0	0	0	0	0	0	0	0 0	78./112.	.00
81	4	10	1730	IA	007	1	4130	9333	0	0	8	9	0	0	3	0 5 1	54./116.	.14
81	4	10	1755	IA	009	1	4128	9322	4134	9316	6	0	0	0	4	0 2 0	57./122.	.00
*81	4	11	1940	IA	011	1	4041	9445	4043	9453	5	15	0	2	6	2 2 1	64./ 45.	.15
*81	5	23	1432	IA	012	1	4042	9503	0	0	0	0	0	0	0	0 0	52./ 34.	.00
*81	5	23	1432	IA	013	1	4108	9500	0	0	0	0	0	0	0	0 0	31./ 55.	.00
81	5	23	1515	IA	014	1	4126	9439	0	0	0	0	0	0	0	0 0	34./ 79.	.00
81	5	23	1530	IA	015	1	4127	9443	0	0	0	0	0	0	0	0 0	32./ 78.	.00
81	5	23	1602	IA	016	1	4125	9430	0	0	0	0	0	0	0	0 0	39./ 82.	.00
81	5	23	1615	IA	017	1	4125	9418	0	0	0	0	0	0	0	0 0	43./ 88.	.00
81	5	23	1636	IA	018	1	4127	9414	0	0	0	0	0	0	0	0 0	44./ 91.	.00
81	5	23	1700	IA	019	1	4042	9419	4049	9403	12	39	0	0	5	2 3 2	71./ 63.	.95
81	5	23	1728	IA	020	1	4123	9405	0	0	0	0	0	0	3	1 0	47./ 95.	.00
81	6	7	1818	IA	022	1	4102	9347	0	0	0	9	0	0	3	1 1	66./ 93.	.00
81	6	7	2030	IA	023	1	4038	9318	0	0	0	0	0	0	3	1 0	81./103.	.00
*81	6	14	2022	IA	028	1	4102	9444	0	0	0	0	0	0	4	0 0	45./ 58.	.00
81	4	3	1705	KS	003	1	3903	9614	0	0	0	0	0	0	3	1 0	[illegible]./ 85.	.00
*81	4	3	1800	KS	004	1	3947	9500	0	0	1	10	0	0	5	2 1 1	139./ 45.	.03
81	4	13	1735	KS	005	1	3854	9549	0	0	0	0	0	0	1	0 0	186./ 87.	.00
81	5	23	1515	KS	014	1	3911	9454	0	0	2	10	0	0	2	0 1 1	154./ 78.	.04
81	5	23	1515	KS	015	1	3822	9514	0	0	1	15	0	0	6	2 1 1	171./120.	.04
81	5	25	1550	KS	019	1	3857	9606	0	0	0	5	0	0	0	0 0 0	195./ 87.	.00
81	6	19	1830	KS	021	1	3858	9516	3855	9508	6	60	1	33	7	3 2 3	168./ 85.	.72
81	6	20	1758	KS	022	1	3351	9645	0	0	0	5	0	0	0	0 0 0	155./ 99.	.00
81	6	21	300	KS	023	1	3907	9643	0	0	0	5	0	0	0	0 0 0	216./ 90.	.00
*81	6	24	1745	KS	024	1	3942	9632	0	0	0	5	0	0	0	0 0 0	227./ 57.	.00
81	6	29	1612	KS	027	1	3844	9533	0	0	0	5	0	0	0	0 0 0	178./ 97.	.00
81	7	19	845	KS	035	1	3908	9539	0	0	0	45	0	9	5	2 0 2	181./ 73.	.03
*81	4	13	1428	MO	001	1	3957	9513	0	0	2	30	0	0	1	0 0 2	141./ 31.	.16
*81	4	13	1442	MO	002	1	3958	9458	0	0	2	30	0	0	1	0 1 2	127./ 38.	.11
*81	4	13	1451	MO	003	1	3958	9513	0	0	1	30	0	0	3	1 1 2	140./ 30.	.06
81	4	13	1839	MO	004	1	4012	9425	0	0	1	30	0	0	5	1 1 2	99./ 56.	.06
81	5	23	1553	MO	013	1	3917	9446	3919	9442	4	15	0	0	1	0 2 1	148./ 76.	.12
81	5	15	645	MO	017	1	3855	9432	0	0	1	15	0	1	5	1 1 1	149./100.	.03
81	6	19	1943	MO	019	1	3838	9433	3839	9425	3	15	0	0	0	0 2 1	154./115.	.10
81	6	17	2010	MO	020	1	3838	9434	0	0	1	15	0	0	0	0 1 1	154./114.	.03
81	6	21	1758	MO	023	1	3853	9434	0	0	1	15	0	0	0	0 1 1	150./101.	.03
81	6	21	1814	MO	024	1	3902	9436	0	0	1	15	0	0	0	0 1 1	149./ 93.	.03
81	6	21	1814	MO	025	1	3848	9430	0	0	1	15	0	0	0	0 1 1	150./107.	.03
81	6	21	1838	MO	026	1	3900	9434	0	0	0	15	0	0	2	0 0 1	148./ 95.	.01
81	6	21	2005	MO	027	1	3829	9436	0	0	1	15	0	0	0	0 1 1	157./122.	.03
81	6	29	1805	MO	030	1	3855	9423	0	0	1	15	0	0	0	0 1 1	146./104.	.03
81	4	3	1315	NE	001	1	4035	9736	4037	9729	6	15	0	0	0	0 2 1	279./ 91.	.19
81	4	3	1600	NE	002	1	4052	9711	0	0	0	9	0	0	2	0 0 1	294./ 77.	.00
81	4	3	1615	NE	003	1	4052	9652	4053	9642	5	15	0	0	5	2 2 1	299./ 64.	.15
81	7	14	1725	NE	009	1	4053	9721	0	0	0	45	0	0	4	1 0 2	292./ 84.	.02
81	7	19	2010	NE	011	1	4159	9716	4156	9713	4	15	0	0	5	1 2 1	323./122.	.12
82	3	19	530	IA	001	1	4037	9428	0	0	2	30	0	0	3	1 1 2	73./ 55.	.11
82	4	2	1410	IA	002	1	4127	9410	0	0	0	15	0	0	4	1 0 1	65./ 93.	.01
32	5	15	1410	IA	005	1	4123	9316	0	0	9	0	0	0	4	1 0 0	60./123.	.00

"*" before year means event ocurred within a 2 degree square centered on central point

6-25
NPPI-580-009
[illegible]

Tornadoes within 1[illegible]WNSVILLE, NE

Yr	Mo	Day	Time (CST)	Ste	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AZRAN	Area sq.mi
82	3	15	1600	IA	006	1	4122	9535	0	0	0	0	0	0	1	0 0 0	2./ 68.	.00
82	5	20	930	IA	012	1	4123	9359	0	0	0	0	0	0	1	0 0 0	50./ 97.	.00
82	6	8	2015	IA	021	1	4107	9329	0	0	0	3	0	0	1	0 0 0	65./108.	.00
82	6	15	100	IA	022	1	4052	9313	0	0	0	3	0	0	4	1 0 0	74./114.	.00
82	6	15	130	IA	023	1	4136	9337	0	0	0	15	0	0	5	1 0 2	50./118.	.01
82	6	15	130	IA	024	1	4117	9411	0	0	0	3	0	0	4	1 0 0	49./ 86.	.00
82	6	17	1700	IA	025	1	4150	9407	0	0	0	3	0	0	1	0 0 0	37./112.	.00
82	7	17	1430	IA	029	1	4200	9358	0	0	0	15	0	0	4	1 0 1	37./124.	.01
82	11	11	1520	IA	033	1	4144	9337	0	0	0	9	0	0	3	0 0 0	47./123.	.01
82	5	15	2225	KS	022	1	3845	9449	0	0	0	0	0	0	1	0 0 0	158./103.	.30
82	5	15	2228	KS	023	1	3839	9441	0	0	0	0	0	0	1	0 0 0	156./111.	.00
82	5	15	2306	KS	024	1	3534	9458	0	0	0	0	0	0	1	0 0 0	164./111.	.00
82	5	18	1200	KS	025	1	3843	9612	0	0	0	0	0	0	1	0 0 0	195./102.	.00
82	5	20	1445	KS	031	1	3927	9747	0	0	0	0	0	0	0	0 0 0	242./113.	.00
82	5	25	1530	KS	034	1	3846	9439	0	0	0	0	0	0	0	0 0 0	154./106.	.00
*82	5	28	1700	KS	035	1	3936	9511	0	0	0	0	0	0	4	1 0 0	155./ 50.	.00
*82	5	28	1705	KS	036	1	3946	9505	3947	9501	3	30	0	0	0	0 2 2	144./ 43.	.21
82	5	28	2014	KS	039	2	3835	9600	3838	9538	20	5	0	0	0	0 3 0	189./107.	.19
82	5	28	2025	KS	040	1	3824	9532	0	0	0	0	0	0	4	0 0 0	178./117.	.00
82	5	28	2030	KS	041	1	3825	9550	3835	9543	10	15	0	0	4	0 2 1	185./113.	.29
*82	6	8	1915	KS	044	1	3922	9558	3926	9547	10	60	0	0	5	2 3 3	195./ 51.	1.23
82	6	3	2106	KS	045	1	3917	9531	0	0	0	1	0	0	1	0 0 0	175./ 64.	.03
82	6	3	2125	KS	046	1	3919	9518	0	0	0	1	0	0	:	0 0 0	166./ 64.	.00
82	11	11	1608	KS	057	2	3822	9530	3825	9526	4	30	0	0	4	1 2 2	177./119.	.23
82	4	2	1430	MO	007	1	3903	9411	3908	9407	6	90	0	0	5	1 2 3	139./103.	1.15
82	4	2	1432	MO	008	1	3906	9408	0	0	2	210	0	0	4	1 1 4	138./101.	.80
82	4	2	1525	MO	011	1	3910	9333	0	0	1	9	0	0	2	1 1 1	126./120.	.02
82	5	28	1810	MO	040	1	3853	9410	0	0	0	15	0	0	1	0 0 1	142./112.	.01
82	5	28	1938	MO	041	1	3945	9412	0	0	0	15	0	0	3	1 0 1	119./ 75.	.01
82	10	8	1505	MO	047	1	3924	9435	0	0	0	15	0	0	4	1 0 1	140./ 75.	.01
*82	4	15	1836	NE	001	2	4030	9612	4032	9607	4	21	0	0	5	2 2 2	289./ 27.	.20
*82	4	15	1915	NE	002	1	4034	9610	0	0	0	9	0	0	2	0 0 1	298./ 28.	.01
82	5	11	1720	NE	006	1	4001	9815	0	0	0	6	0	0	1	0 0 1	261./122.	.00
82	5	11	1736	NE	009	1	4012	9811	0	0	0	6	0	0	2	1 0 1	266./117.	.00
82	5	20	1735	NE	012	2	4134	9704	4137	9652	10	9	0	0	3	2 2 1	319./ 97.	.19
82	5	26	1530	NE	015	1	4100	9759	0	0	0	9	0	0	5	2 0 1	290./113.	.01
82	6	14	1927	NE	024	1	4057	9649	0	0	0	6	?	0	1	0 0 1	304./ 65.	.00
82	6	14	2030	NE	025	1	4044	9816	4051	9808	10	9	0	0	6	2 3 1	281./122.	.15
82	6	14	2030	NE	026	1	4014	9748	0	0	0	6	0	0	4	1 0 1	266./100.	.00
82	6	14	2115	NE	027	1	4024	9657	0	0	0	15	0	0	5	2 0 1	273./ 60.	.01
82	6	30	1654	NE	030	1	4021	9758	0	0	0	6	0	0	1	0 0 1	270./107.	.00
*83	5	1	1330	IA	001	1	4038	9540	4042	9535	6	6	0	3	6	2 2 1	355./ 17.	.07
*83	5	1	1340	IA	002	2	4052	9518	4057	9508	10	6	0	0	5	1 3 1	26./ 34.	.12
*83	5	1	1330	IA	003	1	4042	9513	0	0	1	6	0	0	3	0 1 1	42./ 28.	.01
*83	5	1	1410	IA	005	1	4037	9503	0	0	1	3	0	0	2	0 1 0	39./ 31.	.01
83	5	1	1500	IA	006	1	4138	9452	0	0	2	6	0	0	4	1 1 1	24./ 84.	.02
83	5	6	1700	IA	008	1	4134	9557	4145	9545	14	6	0	0	5	2 3 1	349./ 74.	.19
*83	5	6	1750	IA	009	1	4050	9501	0	0	0	9	0	0	5	1 0 1	44./ 40.	.00
83	5	6	1856	IA	010	1	4133	9406	0	0	0	3	0	0	3	1 0 0	44./10[illegible].	.00
83	5	6	1858	IA	011	1	4140	9337	0	0	0	6	0	0	4	1 0 1	49./120.	.01
83	5	6	1900	IA	012	1	4135	9332	0	0	1	18	0	0	6	2 1 2	32./120.	.03
83	5	27	1717	IA	013	1	4158	9453	0	0	1	6	0	0	4	1 1 1	19./103.	.01
83	5	27	1810	IA	016	1	4141	9433	0	0	0	6	0	0	4	1 0 1	31./ 94.	.01
83	7	2	222	IA	026	1	4146	9343	0	0	0	6	0	0	0	0 0 1	45./121.	.00
83	7	3	1702	IA	027	1	4104	9427	0	0	0	6	0	0	1	0 0 1	51./ 69.	.00

"*" before year means event ocurred within a 2 degree square centered on central point

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F	P	P	AZRAN	Area sq.mi
83	9	5	1805	IA	030	1	4223	9604	0	0	2	35	0	0	5	2	1	2	351./124.	.18
83	5	6	1730	KS	004	1	3854	9552	3903	9535	15	45	1	25	7	3	3	2	187./ 88.	1.57
*83	5	12	1620	KS	005	1	3941	9526	0	0	2	15	0	0	4	0	1	1	167./ 41.	.07
83	5	18	1415	KS	008	2	3943	9655	3946	9645	9	5	0	0	3	0	2	0	237./ 70.	.09
83	5	18	1625	KS	009	1	3954	9703	0	0	0	5	0	0	2	0	0	0	248./ 71.	.00
83	5	27	1730	KS	012	1	3818	9551	3822	9550	4	15	0	0	5	1	2	1	185./123.	.13
83	5	27	1736	KS	013	1	3855	9725	0	0	0	5	0	0	2	0	0	0	274./120.	.00
83	6	10	1630	KS	020	1	3933	9738	0	0	0	2	0	0	1	0	0	0	243./104.	.00
83	6	10	1316	KS	021	1	39[illegible]6	9721	0	0	0	2	0	0	1	0	0	0	235./ 97.	.00
*83	6	13	1925	KS	027	1	3945	9521	0	0	0	2	0	0	2	0	0	0	160./ 37.	.00
83	6	18	319	KS	028	1	3936	9700	0	0	0	2	0	0	1	0	0	0	235./ 78.	.00
*83	6	18	1755	KS	029	1	3935	9637	0	0	0	2	0	0	4	0	0	0	225./ 65.	.00
83	9	25	2015	KS	031	1	3947	9752	0	0	0	5	0	0	4	0	0	0	252./108.	.00
83	5	27	1846	MO	022	1	4029	9418	0	0	0	4	0	0	3	0	0	0	83./ 61.	.00
*83	5	1	1226	NE	001	1	4019	9610	4020	9606	3	6	0	0	4	1	2	1	265./ 24.	.04
83	6	13	1306	NE	009	2	4150	9703	4133	9658	5	6	0	0	5	1	2	1	325./109.	.06
83	6	13	1300	NE	010	1	4142	9709	0	0	6	6	0	0	4	1	0	1	320./106.	.00
84	4	26	1710	IA	002	3	4219	9455	4239	9448	23	60	0	0	6	2	3	3	15./122.	2.70
84	4	26	1913	IA	004	1	4203	9431	0	0	0	30	0	0	2	0	0	2	26./113.	.03
84	6	7	1542	IA	009	1	4225	9535	4235	9521	16	45	0	1	6	2	3	2	1./124.	1.41
*84	6	7	1543	IA	010	1	4110	9504	4127	9445	25	45	0	8	6	2	3	2	29./ 55.	2.18
84	6	7	1610	IA	012	1	4219	9523	4227	9513	12	30	0	1	6	2	3	2	5./117.	.71
*84	6	7	1558	IA	015	3	4044	9502	4059	9444	23	30	0	3	6	3	3	2	50./ 36.	1.32
84	6	7	1554	IA	024	1	4101	9325	0	0	0	15	0	0	4	1	0	1	68./108.	.01
84	6	7	1945	IA	025	1	4041	9414	4044	9402	11	45	1	3	6	2	3	2	73./ 67.	.94
84	6	7	2033	IA	026	1	4044	9321	0	0	0	15	0	0	4	1	0	1	78./106.	.01
84	6	11	1823	IA	028	1	4125	9419	0	0	0	0	0	0	4	0	0	0	43./ 87.	.00
84	6	11	1850	IA	029	1	4135	9343	0	0	0	0	0	0	3	0	0	0	49./113.	.00
84	6	11	1928	IA	030	1	4137	9337	0	0	0	0	0	0	0	0	0	0	50./118.	.00
84	6	11	1955	IA	031	1	4136	9337	0	0	0	0	0	0	3	0	0	0	50./118.	.00
84	6	17	1343	IA	044	1	4131	9537	0	0	0	3	0	0	3	0	0	0	1./ 70.	.00
84	6	21	1720	IA	043	1	4140	9450	0	0	2	15	0	0	0	0	1	1	24./ 87.	.07
*84	6	26	1818	IA	054	1	4116	9523	0	0	0	6	0	0	2	0	0	1	12./ 56.	.00
84	9	9	1614	IA	059	1	4146	9343	0	0	2	15	0	0	4	1	1	1	45./121.	.06
84	2	11	1805	KS	003	1	3831	9448	0	0	2	6	0	1	4	1	1	1	160./117.	.02
84	4	26	2125	KS	015	1	3926	9553	0	0	0	30	0	4	5	2	0	2	199./ 75.	.03
84	4	26	2145	KS	016	1	3914	9543	3921	9534	11	120	0	1	6	2	3	3	183./ 67.	2.58
*84	4	25	2220	KS	017	3	3924	9526	3948	9505	33	360	0	9	7	3	4	4	171./ 55.	22.71
84	4	29	1425	KS	032	1	3825	9624	0	0	0	30	0	0	3	0	0	2	197./121.	.03
*84	6	7	1533	KS	038	1	3949	9543	3959	9526	18	90	0	5	6	2	3	3	187./ 32.	3.22
84	6	7	1345	KS	044	1	3846	9644	0	0	0	0	0	0	0	0	0	0	208./108.	.00
84	10	31	1823	KS	061	1	3850	9538	0	0	1	30	1	0	5	1	1	2	180./ 91.	.06
84	10	31	1940	KS	062	1	3914	9507	0	0	1	30	0	1	5	1	1	2	160./ 71.	.05
84	4	26	2320	MO	005	1	4012	9433	4014	9424	8	30	0	0	5	2	2	2	100./ 50.	.47
84	6	7	2130	MO	016	1	3952	9406	0	0	1	30	0	0	5	2	1	2	112./ 76.	.08
84	6	7	2200	MO	017	1	3958	9349	3959	9346	2	30	0	1	6	2	1	2	105./ 87.	.16
*84	6	8	1650	MO	018	1	4012	9502	0	0	0	15	0	0	0	1	0	1	108./ 29.	.01
*84	6	8	1702	MO	019	1	4012	9452	0	0	1	15	0	0	4	1	1	1	104./ 36.	.03
84	5	18	1545	NE	005	1	4052	9800	0	0	0	3	0	0	4	1	0	0	286./112.	.00
84	6	4	1803	NE	012	1	4041	9817	0	0	0	3	0	0	0	1	0	0	279./122.	.00
*84	6	7	1800	NE	016	1	4006	9607	0	0	0	15	0	0	3	1	0	1	236./ 27.	.01
84	6	12	1657	NE	030	1	4016	9748	4017	9733	10	60	0	5	6	3	3	3	267./ 99.	1.22
84	6	12	1803	NE	031	1	4054	9650	4054	9630	13	45	0	0	6	2	3	2	301./ 64.	1.19
*84	6	12	1920	NE	032	1	4048	9609	4055	9559	9	30	0	0	6	2	2	2	319./ 36.	.54
*84	6	12	1830	NE	033	1	4052	9556	0	0	0	15	0	0	3	2	0	1	336./ 34.	.01

"*" before year means event ocurred within a 2 degree square centered on central point

6-26
NPPT-SBØ-009
[illegible]

6-27
NPP1-5BØ-009

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	Ste	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AZRAN	Area sq.mi
84	6	17	1610	NE	040	1	4141	9743	0	0	0	9	0	0	0	0 0 1	311./123.	.00
84	6	17	1630	NE	041	1	4153	9715	0	0	1	15	0	0	5	2 1 1	322./117.	.03
84	6	17	1700	NE	042	1	4155	9659	4201	9656	5	12	0	0	6	1 2 1	327./112.	.13
[illegible]	6	17	1720	NE	043	1	4202	9643	0	0	0	12	0	0	4	1 0 1	334./112.	.01
84	6	17	1800	NE	044	2	4145	9634	4148	9628	5	6	0	0	4	1 [illegible] 1	334./ 94.	.06
84	7	5	1930	NE	048	1	4001	9648	0	0	0	12	0	0	5	1 0 1	250./ 57.	.02
85	5	11	1458	IA	003	1	4131	9326	0	0	1	15	0	0	4	0 1 1	55./121.	.03
85	6	16	2000	IA	010	1	4101	9428	0	0	0	3	0	0	0	0 0 0	53./ 66.	.00
*85	6	23	1549	IA	012	1	4117	9509	0	0	0	5	0	0	0	0 0 0	21./ 60.	.00
*85	6	23	1606	IA	013	1	4113	9509	0	0	0	5	0	0	0	^ 0 0	23./ 56.	.00
*85	6	23	1612	IA	014	1	4114	9510	0	0	1	15	0	1	5	. 1 1	22./ 57.	.04
85	6	26	1400	IA	015	1	4105	9422	0	0	0	3	0	0	0	0 0 0	52./ 72.	.00
85	6	26	1425	IA	016	1	4109	9425	0	0	0	3	0	0	0	0 0 0	49./ 73.	.00
85	6	26	1437	IA	017	1	4137	9408	0	0	0	3	0	0	0	0 0 0	42./101.	.00
85	9	22	2020	IA	027	1	4052	9329	0	0	0	15	0	0	6	2 0 1	72./102.	.01
85	4	13	1305	KS	003	1	3830	9549	0	0	0	9	0	0	3	0 0 1	184./111.	.00
85	8	1	1711	KS	013	2	3853	9727	3856	9720	2	120	0	0	3	1 2 3	224./122.	.49
85	8	3	1700	KS	014	1	3853	9729	0	0	0	1	0	0	0	0 0 0	224./123.	.00
85	8	17	1718	KS	016	1	3845	9624	0	0	2	15	0	0	5	3 1 1	201./100.	.06
85	8	17	1725	KS	017	1	3843	9615	0	0	0	1	0	0	0	0 0 0	196./102.	.00
85	8	17	1928	KS	018	1	3827	9615	0	0	0	1	0	0	0	0 0 0	194./118.	.00
85	5	26	1735	MO	005	1	3945	9430	0	0	0	15	0	0	0	0 0 1	125./ 63.	.01
85	5	26	1815	MO	006	1	3924	9419	0	0	0	15	0	0	0	0 0 1	133./ 84.	.01
*85	5	30	1824	MO	009	3	3936	9456	3931	9440	15	15	0	5	5	1 3 1	144./ 55.	.44
85	5	30	1828	MO	010	1	3935	9429	0	0	0	15	0	0	0	0 0 1	131./ 70.	.01
*85	6	17	2156	MO	012	1	3949	9431	0	0	0	5	0	0	0	0 0 0	132./ 45.	.00
85	6	21	1809	MO	013	1	3945	9411	0	0	0	5	0	0	0	0 0 0	118./ 76.	.00
85	3	3	1730	NE	002	1	4053	9753	0	0	0	15	0	0	4	1 0 1	287./107.	.00
85	3	3	1910	NE	003	1	4102	9736	0	0	0	15	0	0	4	1 0 1	295./ 98.	.00
85	3	3	1815	NE	004	1	4101	9726	4103	9723	3	15	0	0	5	1 1 1	296./ 91.	.10
85	4	19	1715	NE	005	1	4117	9730	0	0	0	15	0	0	4	1 0 1	304./101.	.00
85	4	19	1737	NE	006	1	4115	9708	0	0	1	90	0	0	6	1 1 3	309./ 87.	.17
*85	4	19	1830	NE	007	1	4039	9611	0	0	0	9	0	0	0	0 0 1	306./ 31.	.00
85	4	21	2245	NE	016	1	4019	9748	0	0	1	18	0	0	5	1 1 2	269./ 99.	.03
85	5	10	2155	NE	026	1	4053	9720	0	0	0	120	0	4	6	2 0 3	293./ 84.	.11
85	6	23	1725	NE	036	1	4054	9727	0	0	0	12	0	0	0	1 0 1	292./ 89.	.00
85	6	23	1740	NE	037	1	4106	9737	0	0	2	12	0	0	5	1 1 1	297./100.	.05
85	8	5	2027	NE	041	1	4038	9518	0	0	0	12	0	0	0	0 0 1	278./123.	.00
86	3	18	1603	IA	001	1	4125	9439	0	0	0	6	0	0	4	1 0 1	35./ 78.	.00
86	4	26	2105	IA	004	1	4201	9526	0	0	0	6	0	0	0	0 0 0	5./100.	.00
86	5	9	1836	IA	009	2	4136	9350	4135	9347	2	3	0	0	0	0 0 0	47./110.	.02
86	5	9	1840	IA	010	1	4135	9351	0	0	0	3	0	0	0	0 0 0	47./109.	.00
86	5	9	1848	IA	011	1	4134	9350	0	0	0	3	0	0	0	0 0 0	48./109.	.00
86	5	9	1855	IA	012	1	4137	9350	0	0	0	3	0	0	0	0 0 0	47./111.	.00
86	5	9	1909	IA	013	2	4137	9350	4137	9346	3	3	0	0	0	0 0 0	47./111.	.02
86	5	9	1912	IA	014	1	4137	9353	0	0	0	3	0	0	0	0 0 0	46./109.	.00
86	5	9	1940	IA	015	1	4151	9355	0	0	0	3	0	0	0	0 0 0	40./115.	.00
86	5	9	1949	IA	016	2	4141	9348	4141	9348	0	3	0	0	0	0 0 0	46./115.	.00
86	[illegible]	10	1352	IA	017	1	4049	9336	0	0	0	3	0	0	3	0 0 0	73./ 96.	.00
86	6	10	2005	IA	019	1	4059	9316	0	0	0	3	0	0	2	0 0 0	70./116.	.00
86	6	29	2105	IA	023	1	4151	9434	0	0	1	15	0	0	6	2 1 1	28./102.	.03
86	6	29	2150	IA	024	1	4131	9432	0	0	2	22	0	0	5	2 1 2	35./ 96.	.09
86	5	29	2235	IA	025	1	4135	9344	4136	9337	6	15	0	0	4	2 2 1	49./113.	.17
86	7	8	2015	IA	026	1	4039	9359	0	0	0	3	0	0	0	0 0 0	77./ 77.	.00
86	7	8	2145	IA	027	1	4043	9359	0	0	0	3	0	0	0	0 0 0	70./ 90.	.00

"*" before year means event ocurred within a 2 degree square centered on central point

6-28
NPP1-SBØ-009

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F	P	P	AZRAN	Area sq.mi
86	7	13	2247	IA	028	1	4101	9349	0	0	1	15	0	0	5	2	1	1	64./ 91.	.03
86	7	13	2320	IA	029	1	4053	9335	0	0	0	12	0	0	5	1	0	1	71./ 98.	.01
86	7	28	2005	IA	034	1	4206	9536	0	0	0	3	0	0	0	0	0	0	1./103.	.00
86	9	28	1648	IA	039	2	4145	9336	4146	9300	30	75	0	0	6	4	3	1	47./124.	4.40
86	4	13	1845	KS	011	1	3949	9738	3949	9736	0	8	0	0	5	0	0	1	251./ 98.	.00
86	5	6	2030	KS	013	2	3852	9649	3855	9630	17	60	0	0	5	1	3	3	212./105.	1.97
86	5	16	1500	KS	020	1	3922	9717	3924	9705	10	30	0	0	4	1	[illegible]	2	232./ 97.	.62
*86	9	22	1520	KS	031	1	4000	9520	0	0	1	24	0	0	5	0	1	2	147./ 25.	.05
*86	9	22	1530	KS	032	1	3949	9545	0	0	0	7	0	0	4	0	0	1	190./ 32.	.00
86	4	5	1803	NE	007	1	4048	9740	4048	9740	0	6	0	0	0	0	0	1	286./ 96.	.00
86	4	13	1930	NE	013	1	4052	9732	4052	9732	0	6	0	0	4	1	0	1	290./ 92.	.00
86	4	26	1908	NE	016	1	4010	9734	4018	9725	12	12	0	0	5	2	3	1	263./ 89.	.28
86	4	26	1955	NE	017	1	4045	9658	4045	9658	0	6	0	0	2	0	0	1	292./ 65.	.00
86	6	10	1933	NE	025	2	4029	9317	4030	9815	2	15	0	0	3	1	1	1	274./121.	.06
86	6	29	2002	NE	031	1	4118	9733	0	0	0	15	0	0	4	1	0	1	303./104.	.01
86	6	29	2012	NE	032	1	4115	9740	0	0	0	15	0	0	5	1	0	1	301./107.	.01
86	7	5	1643	NE	035	1	4037	9750	0	0	0	9	0	0	1	0	0	1	279./101.	.00
86	7	24	1620	NE	039	1	4142	9745	0	0	0	6	0	0	5	1	0	1	310./125.	.00
86	9	5	1930	NE	049	1	4020	9819	0	0	0	15	0	0	1	1	0	1	270./123.	.01
86	9	18	2228	NE	054	1	4041	9816	0	0	1	12	0	0	4	2	1	1	279./121.	.02
*87	5	17	1820	IA	006	1	4042	9443	4042	9436	4	4	0	0	3	0	2	0	63./ 47.	.04
*87	5	20	2245	IA	008	1	4103	9500	4105	9456	4	6	0	0	5	1	2	1	34./ 51.	.05
*87	5	26	1344	IA	0[illegible]	2	4115	9536	4145	9520	37	15	0	0	6	1	4	1	2./ 54.	1.06
*87	5	26	1515	IA	010	1	4046	9522	0	0	1	12	0	0	5	1	1	1	26./ 28.	.02
87	5	26	1525	IA	011	1	4127	9537	0	0	1	6	0	0	4	1	1	1	1./ 66.	.01
*87	5	26	1535	IA	012	1	4059	9507	0	0	0	6	0	0	4	0	0	1	32./ 43.	.00
*87	5	26	1630	IA	013	1	4119	9520	0	0	0	12	0	0	4	1	0	1	13./ 60.	.00
87	5	31	1444	IA	015	2	4129	9512	4128	9501	9	6	0	0	3	1	2	1	16./ 71.	.11
87	5	31	1540	IA	016	1	4144	9402	0	0	1	6	0	0	3	0	1	1	41./110.	.01
87	6	12	1850	IA	018	1	4150	9556	0	0	0	6	0	0	3	0	0	1	351./ 90.	.01
87	6	24	2044	IA	019	1	4104	9421	0	0	0	6	0	0	2	0	0	1	53./ 72.	.00
87	7	5	1720	IA	020	1	4210	9614	0	0	0	4	0	0	0	0	0	0	346./112.	.00
*87	7	8	2320	IA	025	1	4039	9509	0	0	1	7	0	0	4	1	1	1	31./ 29.	.01
87	7	18	1810	IA	030	1	4214	9606	0	0	0	4	0	0	1	0	0	0	330./115.	.00
87	5	18	1607	KS	004	1	3827	9623	3829	9621	2	90	0	0	6	2	2	3	197./119.	.30
87	5	18	1635	KS	005	1	3824	9615	0	0	0	15	0	0	5	1	2	1	194./121.	.01
*87	5	27	1451	KS	006	1	3943	95[illegible]	3949	9532	7	30	0	0	5	1	2	2	177./ 38.	.42
*87	5	27	1530	KS	007	1	3959	[illegible]	0	0	1	30	0	0	5	1	1	2	149./ 26.	.05
87	6	22	1440	KS	011	1	3839	9[illegible]24	0	0	0	15	0	0	0	0	0	1	199./109.	.01
87	6	27	2347	KS	014	1	3938	9755	3934	9743	11	30	0	0	3	0	3	2	248./116.	.66
87	6	28	20	KS	015	1	3921	9727	0	0	0	9	0	0	3	0	0	1	235./103.	.00
87	7	7	1900	KS	019	1	3859	9555	0	0	0	3	0	0	0	0	0	0	189./ 83.	.00
87	3	14	1715	NE	002	1	4012	9804	0	0	0	6	0	0	4	1	0	1	265./112.	.00
87	5	19	1830	NE	006	1	4037	9806	0	0	0	12	0	0	3	0	0	1	278./113.	.00
87	5	19	1835	NE	007	1	4048	[illegible]	0	0	0	12	0	0	3	0	0	1	284./111.	.00
87	5	19	1950	NE	008	1	4135	9735	0	0	0	9	0	0	1	0	0	1	311./115.	.00
87	6	24	1820	NE	014	1	4041	9657	0	0	0	9	0	0	4	1	0	1	288./ 63.	.00
87	6	28	2045	NE	017	1	4023	9800	0	0	0	6	0	0	2	0	0	1	271./105.	.00
87	8	17	2130	NE	026	1	4009	9710	0	0	0	15	0	0	5	2	0	1	260./ 71.	.01
88	5	7	1945	IA	007	1	4203	9536	0	0	2	6	0	0	3	0	1	1	1./102.	.02
*88	5	7	2210	IA	008	1	4120	9557	4127	9549	10	22	0	0	6	2	2	2	346./ 61.	.44
88	5	8	1104	IA	009	3	4128	9322	4134	9314	6	9	0	0	5	1	3	1	57./122.	.12
88	5	8	1210	IA	010	1	4044	9319	0	0	2	9	0	0	5	1	1	1	78./105.	.03
88	5	9	1259	IA	011	4	4037	9320	4056	9227	35	13	0	0	5	2	4	1	81./106.	.88
*88	5	21	1206	IA	031	1	4036	9525	0	0	0	6	0	0	4	0	0	1	33./ 18.	.01

"*" before year means event ocurred within a 2 degree square centered or central point

6-29
NPPI-SBd-009

Tornadoes within 125. NM of BROWNSVILLE, NE

Yr	Mo	Day	Time (CST)	sta	Seq	Total # seg	Lat begin	Lon begin	Lat end	Lon end	Length miles	Width 10's ft	Deaths	Injuries	Damage Class	F P P	AZRAN	Area sq.mi
*88	7	15	1514	IA	033	1	4116	9552	0	0	2	30	0	42	7	2 1 2	349./ 56.	.13
*88	7	15	1516	IA	034	1	4116	9552	0	0	2	22	0	34	7	3 1 2	349./ 56.	.12
*88	7	15	1519	IA	035	1	4114	9555	4116	9552	3	22	0	12	7	1 1 2	346./ 55.	.14
88	7	15	1820	IA	036	1	4141	9446	0	0	0	4	0	0	4	0 0 0	26./ 89.	.00
*88	7	15	1845	IA	037	1	4115	9441	0	0	0	10	0	0	5	1 0 1	38./ 69.	.02
*88	8	22	300	IA	040	1	4059	9531	0	0	0	6	0	0	5	0 0 1	8./ 38.	.01
*88	8	22	1330	IA	041	1	4107	9450	4109	9445	4	15	0	0	5	1 2 1	38./ 59.	.14
88	11	15	1610	IA	042	2	4044	9307	4044	9304	2	3	0	0	2	0 1 0	79./117.	.01
88	11	15	1629	IA	043	1	4054	9302	4057	9258	4	18	0	4	5	2 2 2	74./122.	.17
88	3	24	1437	KS	001	1	3853	9459	0	0	0	7	0	0	3	0 0 1	160./ 88.	.00
88	7	9	1632	KS	013	1	3934	9759	0	0	0	6	0	0	3	0 0 1	247./118.	.01
88	7	15	1940	KS	015	1	3906	9710	0	0	0	6	0	0	2	0 0 1	224./104.	.01
88	7	15	1900	KS	016	1	923	9658	0	0	0	6	0	0	2	0 0 1	227./ 85.	.01
88	11	15	1406	KS	021	1	3903	9541	3907	9536	6	21	0	22	6	2 2 1	182./ 78.	.26
88	11	15	1430	KS	022	1	3920	9531	0	0	0	6	0	0	2	0 0 1	175./ 61.	.00
*88	11	15	1445	KS	023	1	3931	9524	0	0	0	6	0	0	2	0 0 1	168./ 51.	.00
*88	11	15	1455	KS	024	1	3938	9521	0	0	0	12	0	0	4	1 0 1	163./ 45.	.01
*88	5	7	2152	NE	002	3	4107	9625	4112	9607	19	22	2	1	6	2 [illegible] 2	321./ 59.	.30
88	5	20	1520	NE	005	1	4146	9648	0	0	0	6	0	0	5	1 0 1	328./100.	.01
88	7	9	1130	NE	014	1	4120	9657	0	0	0	12	0	0	3	0 0 1	315./ 84.	.00
*54	4	5	1720	MO	001	2	4033	9523	4037	9516	7	270	0	2	5	4 1 4	43./ 17.	3.92
57	5	20	1937	KS	012	3	3827	9530	3859	9424	69	132	44	207	6	5 4 3	177./114.	17.41
60	4	15	1800	KS	006	2	3835	9439	3842	9432	8	132	0	2	5	3 2 3	156./116.	2.04
61	5	7	1645	KS	023	7	3910	9456	3917	9425	28	45	0	12	6	4 3 2	155./ 75.	2.45
*62	5	31	1345	KS	008	2	3954	9458	0	0	0	0	0	0	0	1 1 1	131./ 41.	.00
64	4	12	1630	KS	004	2	3914	9531	3923	9452	13	132	1	22	6	3 3 3	157./ 73.	3.27
*65	4	10	1440	KS	008	3	3925	9507	3940	9445	26	0	0	11	4	3 3 3	157./ 61.	.00
68	5	15	1445	KS	010	2	3838	9439	3838	9436	2	0	0	0	4	3 1 1	156./113.	.00
70	4	29	1430	MO	001	2	4025	9359	4037	9329	14	132	0	0	5	2 3 3	87./ 75.	3.71
*71	5	18	1435	KS	011	7	3921	9506	3952	9416	11	30	0	6	4	1 3 2	158./ 65.	.65
76	4	14	1630	KS	002	3	3946	9813	4003	9735	31	99	0	1	5	2 4 3	254./124.	5.62
*79	3	29	1800	MO	002	2	4029	9509	4042	9455	19	150	0	20	0	4 3 3	70./ 73.	5.47
*83	5	1	1415	NE	004	3	4048	9553	4059	9508	41	12	0	3	5	[illegible]	337./ 29.	.93
84	6	7	2058	MO	023	8	4025	9402	4135	9151	138	60	3	64	6	3 3 3	87./ 73.	15.76
84	6	17	1524	NE	042	2	4148	9613	4150	9557	13	9	0	0	5	1 3 1	343./ 91.	.24
86	9	18	1930	KS	052	3	3956	9759	4002	9755	7	150	0	7	6	2 2 3	257./111.	2.29

'*' before year means event ocurred within a 2 degree square centered on central point

Tornadoes in 125. NM of BROWNSVILLE, NE

Path length scale (mi)

Path Width Scale	0	1	2	3	4	5	MSG	SUM
0:	180	155	42	11	1	0	5	394
1:	11	125	66	52	8	0	1	263
2:	13	88	53	49	8	1	3	215
3:	3	34	53	40	9	1	0	140
4:	0	7	5	10	5	0	0	27
5:	0	0	0	1	0	0	0	1
MSG:	41	149	14	6	0	0	106	316
SUM:	248	558	233	159	31	2	115	1356

Path length scale (mi)

F Scale	0	1	2	3	4	5	MSG	SUM
0:	192	34	19	3	1	0	71	320
1:	148	122	71	29	4	0	95	469
2:	38	78	82	56	9	1	46	310
3:	2	11	25	29	9	0	0	76
4:	0	1	9	16	3	0	0	29
5:	0	0	0	2	1	0	1	4
MSG:	14	17	9	5	0	0	103	148
SUM:	394	263	215	140	27	1	316	1356

Area scale (log10(area)+5.)

F Scale	1	2	3	4	5	6	7	8	9	10
0:	57	82	40	13	1	0	0	0	0	0
1:	13	80	122	80	14	0	0	0	0	0
2:	0	10	53	113	31	4	0	0	0	0
3:	0	0	3	19	29	8	0	0	0	0
4:	0	0	0	1	20	5	0	0	0	0
5:	0	0	0	0	0	3	0	0	0	0

Path width scale (mi)

F Scale	0	1	2	3	4	5	MSG	SUM
0:	158	128	18	4	2	0	10	320
1:	68	237	84	41	5	0	34	469
2:	9	119	95	67	7	2	12	310
3:	0	10	23	33	10	0	0	76
4:	0	1	4	19	5	0	0	29
5:	0	0	1	1	2	0	0	4
MSG:	14	63	8	4	0	0	59	148
SUM:	248	558	233	169	31	2	115	1356

6-30
NPPI-5B0-009

National Severe Storms Forecast Center

Kansas City MO 64106

National Severe Storms Forecast Center

Kansas City MO 64106

Frequency Tables for Tornadoes within125.NM of BROWNSVILLE, NE 40.35 95.63

Distribution by month and date

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	SUM
JAN	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	7
FEB	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			1
MAR	0	1	3	0	0	0	0	2	0	0	0	1	1	4	0	0	0	14	1	0	2	0	1	2	0	0	2	0	5	2	0	44
APR	0	7	9	6	5	0	4	1	0	9	3	9	10	3	6	14	1	2	15	12	11	14	12	0	4	17	6	12	3	5		203
MAY	8	5	0	31	10	17	20	12	14	16	9	8	7	3	17	9	3	17	12	24	6	8	29	4	20	28	15	15	13	19	21	420
JUN	4	11	3	12	2	20	32	19	8	6	24	18	19	15	17	5	15	12	17	4	20	20	6	11	2	13	7	4	15	4		364
JUL	7	5	6	4	4	5	5	9	7	2	7	0	2	4	9	5	2	4	6	3	6	2	1	2	0	6	2	3	0	9	1	128
AUG	1	2	4	2	5	10	0	0	1	0	1	0	2	1	3	1	5	3	0	9	0	4	1	1	1	0	2	2	0	2	1	67
SEP	0	2	2	2	4	0	2	0	3	2	1	3	2	0	1	0	0	3	0	10	3	6	1	1	5	6	0	2	0	0		61
OCT	0	0	0	0	0	0	0	2	1	0	0	7	0	4	0	1	0	3	0	0	1	0	0	0	0	0	0	0	0	1	2	22
NOV	1	0	0	0	0	0	0	2	0	0	2	0	0	0	6	2	9	0	0	3	0	0	0	0	0	0	3	0	2	0		30
DEC	0	0	0	2	1	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	9

Date of initial touchdown using Central Standard Time

6-32
NPPT-SBØ-009

National Severe Storms Forecast Center

Kansas City MO 64106

Frequency Tables for Tornadoes within125.NM of BROWNSVILLE, MO 40.35 95.63

Hourly Distribution - CST

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	SUM	PCT	Mean Time
JAN	0	0	0	0	0	0	0	0	0	0	0	1	3	0	1	0	0	0	0	0	0	0	0	0	7	1.	1315
FEB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0.	1805
MAR	0	2	0	0	0	1	0	0	0	1	0	2	7	6	1	2	4	5	7	0	5	0	0	1	44	3.	1554
APR	1	2	2	3	0	0	0	1	1	2	0	3	1	10	19	12	27	29	35	29	3	11	8	4	203	15.	1739
MAY	4	5	5	3	0	2	3	1	2	2	1	4	9	23	34	40	46	47	52	62	20	26	21	8	420	31.	1748
JUN	4	7	3	7	2	3	4	2	0	0	0	5	6	11	15	23	35	34	57	56	40	30	11	9	364	27.	1837
JUL	4	6	6	2	2	1	0	2	1	0	0	3	2	2	7	10	18	18	11	9	8	5	8	3	128	9.	1831
AUG	1	0	0	3	0	0	1	1	0	0	0	1	0	3	1	4	6	14	12	7	4	5	2	2	67	5.	1824
SEP	0	2	2	1	1	0	0	0	3	1	0	1	1	1	1	6	8	10	8	4	3	2	2	4	61	4.	1810
OCT	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	3	5	2	4	2	2	0	0	0	22	2.	1712
NOV	2	0	0	0	0	0	0	0	0	1	2	3	0	2	5	1	5	3	1	2	1	0	1	1	30	2.	1549
DEC	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	2	9	1.	2242
SUM	16	27	18	20	5	7	8	7	7	7	3	23	30	59	87	101	154	163	189	171	87	80	53	34	1356	100.	1760
PCT	1.	2.	1.	1.	0.	1.	1.	1.	1.	1.	0.	2.	2.	4.	6.	7.	11.	12.	14.	13.	6.	6.	4.	3.	100.		

Hour of initial touchdown in Central Standard Time

Tornadoes within 125. NM of BROWNSVILLE, NE

Following for global area within 125. NM radius of 40.35 95.63

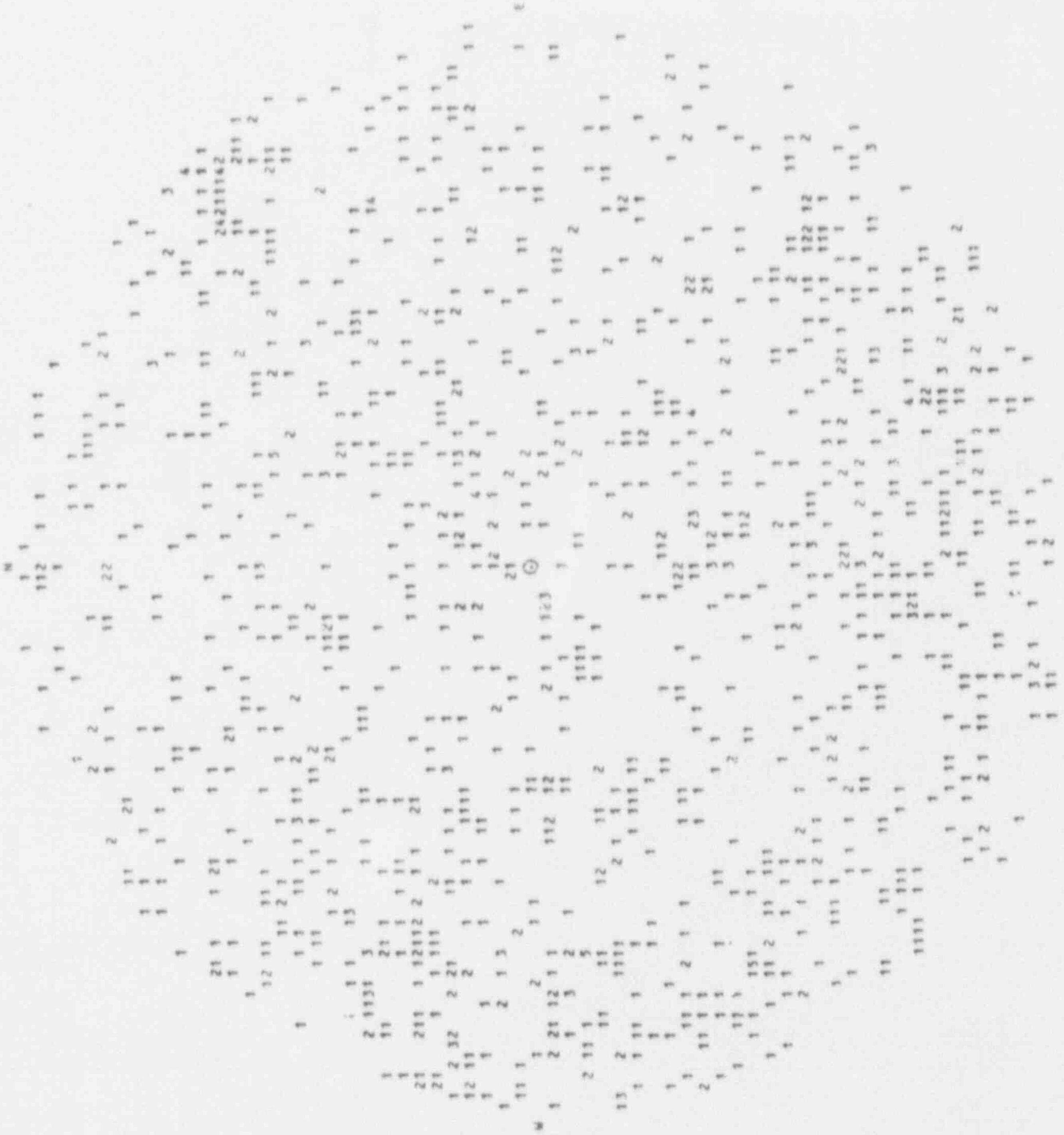
```
The average F-scale is  1.20 which corresponds to  81. mph.
The average PL-scale is    1.17885; The average PL type path length is     3.290; True average length is    5.172
The average PW-scale is    1.34166; The average PW type path width is      .034; True average width is     .078
The average area using average PL & PW computed by 10.**(.5*(pl+pw)-3.)  is    .018
The summation of the individual areas computed from PL & PW   245.06 divided by  1031 yields average area of     .238
The average area scale is    3.67384; The average area scale type area is     .045
The average length times the average width is     .403
True average length =    5.17
True average  width =    .078
True average   area =    .835
                    Probability =    .2652E-03 Mean Return Interval is   3770.94
 For winds exceeding  40 mph   prob =   .2652E-03 Mean Return Interval is   3770.94   based on  806 events
 For winds exceeding  73 mph   prob =   .2624E-03 Mean Return Interval is   3811.26   based on  608 events
 For winds exceeding 113 mph   prob =   .2354E-03 Mean Return Interval is   4247.38   based on  299 events
 For winds exceeding 158 mph   prob =   .1611E-03 Mean Return Interval is   6206.38   based on   88 events
 For winds exceeding 207 mph   prob =   .7385E-04 Mean Return Interval is  13541.75   based on   29 events
 For winds exceeding 261 mph   prob =   .1538E-04 Mean Return Interval is  65012.53   based on    3 events
```

	F-0	F-1	F-2	F-3	F-4	F-5
Average PL length	.47	.98	2.25	5.13	7.78	14.65
Average PW width	.01	.01	.03	.06	.10	.22
Average PL & PW area	.01	.08	.36	.94	1.27	3.16
Average based on #	246.00	371.00	262.00	76.00	29.00	3.00
Average path length	1.14	2.80	7.04	16.20	20.15	37.64
Average path width	.02	.06	.10	.20	.27	.42
Average true area	.04	.22	.59	3.76	5.71	13.02
Average based on #	198.00	309.00	211.00	59.00	26.00	3.00

```
The following is for local area (two degrees square centered on latitude  40.35 longitude   95.63)
True average length =    5.16
True average  width =    .087
True average   area =    .858
                    Probability =    .2630E-03 Mean Return Interval is   3802.37
 For winds exceeding  40 mph   prob =   .2630E-03 Mean Return Interval is   3802.37   based on  175 events
 For winds exceeding  73 mph   prob =   .2592E-03 Mean Return Interval is   3858.15   based on  138 events
 For winds exceeding 113 mph   prob =   .2357E-03 Mean Return Interval is   4243.05   based on   68 events
 For winds exceeding 158 mph   prob =   .1464E-03 Mean Return Interval is   6829.97   based on   24 events
 For winds exceeding 207 mph   prob =   .3445E-04 Mean Return Interval is  29029.31   based on    7 events
 For winds exceeding 261 mph   prob =   .0000E+00 Mean Return Interval is *********   based on    0 events
```

6-33
NPP1-580-009

6-34
NPP1- SBφ-009
EH



1 1 1 111 1
1
5

Tornado plots within 125. NM of BROWNSVILLE, NE Total 1356
Total may differ from path length & path width
matrix because not all events have PL & PW scale recorded

40.35 95.63

6-35
NPPI- SBØ-009