NOAA TM NWS WR7

UNITED STATES
DEPARTMENT OF
COMMERCE
PUBLICATION

NOAA Technical Memorandum NWS WR74

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

Thunderstorms and Hail Days Probabilities in Nevada

CLARENCE M. SAKAMOTO

Western Region

SALT LAKE CITY,
UTAH

April 1972

NOAA TECHNICAL MEMORANDA
National Weather Service, Western Region Subseries

The National Weather Service (NWS) Western Region (WR) Subseries provides an informal medium for the documentation and quick dissemination of results not appropriate, or not yet ready, for formal publication. The series is used to report on work in progress, to describe technical procedures and practices, or to relate progress to a limited audience. These Technical Memoranda will report on investigations devoted primarily to regional and local problems of interest mainly to personnel, and hence will not be widely distributed.

Papers 1 to 23 are in the former series, ESSA Technical Memoranda, Western Region Technical Memoranda (WRTM); papers 24 to 59 are in the former series, ESSA Technical Memoranda, Weather Bureau Technical Memoranda (WBTM). Beginning with 60, the papers are part of the series, NOAA Technical Memoranda NWS.

Papers 1 to 23, except for 5 (revised edition) and 10, are available from the National Weather Service Western Region, Scientific Services Division, P. O. Box 11188, Federal Building, 125 South State Street, Salt Lake City, Utah 84111. Papers 5 (revised edition), 10, and all others beginning with 24 are available from the National Technical Information Service, U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, Va. 22151. Price: $3.00 paper copy; $0.95 microfiche. Order by accession number shown in parentheses at end of each entry.

ESSA Technical Memoranda

WRTM 1	Some Notes on Probability Forecasting. Edward D. Diemer, September 1965. (Out of print.)
WRTM 2	Climatological Precipitation Probabilities. Compiled by Lucianne Miller, December 1965.
WRTM 3	Western Region Pre- and Post-FP-3 Program, December 1, 1965 to February 20, 1966. Edward D. Diemer, March 1966.
WRTM 4	Use of Meteorological Satellite Data. March 1966.
WRTM 5	Station Descriptions of Local Effects on Synoptic Weather Patterns. Philip Williams, Jr., April 1966 (revised November 1967, October 1969). (PB-178000)
WRTM 6	Improvement of Forecast Wording and Format. C. L. Glenn, May 1966.
WRTM 7	Final Report on Precipitation Probability Test Programs. Edward D. Diemer, May 1966.
WRTM 8	Interpreting the RAREP. Herbert P. Benner, May 1966 (revised January 1967). (Out of print.)
WRTM 9	A Collection of Papers Related to the 1966 NMC Primitive-Equation Model. June 1966.
WRTM 10	Sonic Boom. Loren Crow (6th Weather Wing, USAF, Pamphlet), June 1966. (Out of print.) (AD-479366)
WRTM 11	Some Electrical Processes in the Atmosphere. J. Latham, June 1966.
WRTM 12	A Comparison of Fog Incidence at Missoula, Montana, with Surrounding Locations. Richard A. Dightman, August 1966. (Out of print.)
WRTM 13	A Collection of Technical Attachments on the 1966 NMC Primitive-Equation Model. Leonard W. Snellman, August 1966. (Out of print.)
WRTM 14	Application of Net Radiometer Measurements to Short-Range Fog and Stratus Forecasting at Los Angeles. Frederick Thomas, September 1966.
WRTM 15	The Use of the Mean as an Estimate of "Normal" Precipitation in an Arid Region. Paul C. Kangieser, November 1966.
WRTM 16	Some Notes on Acclimatization in Man. Edited by Leonard W. Snellman, November 1966.
WRTM 17	A Digitalized Summary of Radar Echoes Within 100 Miles of Sacramento, California. J. A. Youngberg and L. B. Overaas, December 1966.
WRTM 18	Limitations of Selected Meteorological Data. December 1966.
WRTM 19	A Grid Method for Estimating Precipitation Amounts by Using the WSR-57 Radar. R. Granger, December 1966. (Out of print.)
WRTM 20	Transmitting Radar Echo Locations to Local Fire Control Agencies for Lightning Fire Detection. Robert R. Peterson, March 1967. (Out of print.)
WRTM 21	An Objective Aid for Forecasting the End of East Winds in the Columbia Gorge, July through October. D. John Coparanis, April 1967.
WRTM 22	Derivation of Radar Horizons in Mountainous Terrain. Roger G. Pappas, April 1967.
WRTM 23	"K" Chart Applications to Thunderstorm Forecasts Over the Western United States. Richard E. Hambidge, May 1967.

ESSA Technical Memoranda, Weather Bureau Technical Memoranda (WBTM)

WBTM 24	Historical and Climatological Study of Grinnell Glacier, Montana. Richard A. Dightman, July 1967. (PB-178071)
WBTM 25	Verification of Operational Probability of Precipitation Forecasts, April 1966-March 1967. W. W. Dickey, October 1967. (PB-176240)
WBTM 26	A Study of Winds in the Lake Mead Recreation Area. R. P. Augulis, January 1968. (PB-177830)
WBTM 27	Objective Minimum Temperature Forecasting for Helena, Montana. D. E. Olsen, February 1968. (PB-177827)
WBTM 28	Weather Extremes. R. J. Schmidli, April 1968 (revised July 1968). (PB-178928)
WBTM 29	Small-Scale Analysis and Prediction. Philip Williams, Jr., May 1968. (PB-178425)
WBTM 30	Numerical Weather Prediction and Synoptic Meteorology. Capt. Thomas D. Murphy, U.S.A.F., May 1968. (AD-673365)
WBTM 31	Precipitation Detection Probabilities by Salt Lake ARTC Radars. Robert K. Belesky, July 1968. (PB-179084)
WBTM 32	Probability Forecasting--A Problem Analysis with Reference to the Portland Fire Weather District. Harold S. Ayer, July 1968. (PB-179289)
WBTM 33	Objective Forecasting. Philip Williams, Jr., August 1968. (AD-680425)
WBTM 34	The WSR-57 Radar Program at Missoula, Montana. R. Granger, October 1968. (PB-180292)
WBTM 35	Joint ESSA/FAA ARTC Radar Weather Surveillance Program. Herbert P. Benner and DeVon B. Smith, December 1968 (revised June 1970). (AD-681857)
WBTM 36	Temperature Trends in Sacramento--Another Heat Island. Anthony D. Lentini, February 1969. (Out of print.) (PB-183055)
WBTM 37	Disposal of Logging Residues Without Damage to Air Quality. Owen P. Cramer, March 1969. (PB-183057)
WBTM 38	Climate of Phoenix, Arizona. R. J. Schmidli, P. C. Kangieser, and R. S. Ingram. April 1969. (Out of print.) (PB-184295)
WBTM 39	Upper-Air Lows Over Northwestern United States. A. L. Jacobson, April 1969. (PB-184296)
WBTM 40	The Man-Machine Mix in Applied Weather Forecasting in the 1970s. L. W. Snellman, August 1969. (PB-185068)
WBTM 41	High Resolution Radiosonde Observations. W. S. Johnson, August 1969. (PB-185673)
WBTM 42	Analysis of the Southern California Santa Ana of January 15-17, 1966. Barry B. Aronovitch, August 1969. (PB-185670)
WBTM 43	Forecasting Maximum Temperatures at Helena, Montana. David E. Olsen, October 1969. (PB-185762)
WBTM 44	Estimated Return Periods for Short-Duration Precipitation in Arizona. Paul C. Kangieser, October 1969. (PB-187763)
WBTM 45/1	Precipitation Probabilities in the Western Region Associated with Winter 500-mb Map Types. Richard A. Augulis, December 1969. (PB-188248)

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

NOAA Technical Memorandum NWSTM WR-74

THUNDERSTORMS AND HAIL DAYS PROBABILITIES IN NEVADA

Clarence M. Sakamoto
Climatologist for Nevada
National Weather Service
Reno, Nevada

WESTERN REGION
TECHNICAL MEMORANDUM NO. 74

SALT LAKE CITY, UTAH
APRIL 1972

TABLE OF CONTENTS

		Page
List of Tables		iii-iv
I.	Introduction	1
II.	Procedure	2-4
III.	Data	4
IV.	Computer Program	4-6
V.	Results	6-8
VI.	Acknowledgment	8
VII.	References	8

LIST OF TABLES

		Page
Table 1.	Summary of Model Selection for Thunderstorm and Hail Days in Nevada	9
Table 2A.	Computed and Observed Cumulative Probabilities of Monthly Number of Thunderstorm Days at Elko, Nevada, January - June	10
Table 2B.	Computed and Observed Cumulative Probabilities of Monthly Number of Thunderstorm Days at Elko, Nevada, July - December	11
Table 3A.	Computed and Observed Cumulative Probabilities of Monthly Number of Thunderstorm Days at Ely, Nevada, January - June	12
Table 3B.	Computed and Observed Cumulative Probabilities of Monthly Number of Thunderstorm Days at Ely, Nevada, July - December	13
Table 4A	Computed and Observed Cumulative Probabilities of Monthly Number of Thunderstorm Days at Las Vegas, Nevada, January - June	14
Table 4B.	Computed and Observed Cumulative Probabilities of Monthly Number of Thunderstorm Days at Las Vegas, Nevada, July - December	15
Table 5A.	Computed and Observed Cumulative Probabilities of Monthly Number of Thunderstorm Days at Reno, Nevada, January - June	16
Table 5B.	Computed and Observed Cumulative Probabilities of Monthly Number of Thunderstorm Days at Reno, Nevada, July - December	17
Table 6A.	Computed and Observed Cumulative Probabilities of Monthly Number of Thunderstorm Days at Winnemucca, Nevada, January - June	18
Table 6B.	Computed and Observed Cumulative Probabilities of Monthly Number of Thunderstorm Days at Winnemucca, Nevada, July - December	19
Table 7.	Mean and Variance of Annual Thunderstorm and Annual Hail Days at Five Locations in Nevada	20
Table 8.	Calculated and Observed Cumulative Probabilities of Annual Thunderstorm Days at Five Locations in Nevada	21

LIST OF TABLES (Continued)

		Page
Table 9.	Calculated and Observed Cumulative Probabilities of Annual Hail Days at Five Locations in Nevada	22
Table 10.	Sample Program Output Showing the Maximum Likelihood Parameter Estimate and Probabilities for Selected Number of Thunderstorm Days at Ely, Nevada	23
Table 11.	Sample Program Output Showing Probabilities of Selected Number of Annual Hail Days at Winnemucca, Nevada	24
Table 12.	Comparison of Parameter K Estimates by Method of Maximum Likelihood, Method of Moments and "By Eye" for Thunderstorm Probabilities in Nevada	25

THUNDERSTORM AND HAIL DAYS PROBABILITIES IN NEVADA

ABSTRACT

A computer program was developed to provide probabilities for selected number of thunderstorm days in a month and in a year. In addition, probabilities for selected number of hail days in a year were determined. Two distribution models were tested in the analysis: (a) Poisson and (b) negative binomial. The program determines which of these two models is appropriate. Furthermore, if the negative binomial model is selected, tests are conducted to determine whether estimation of the parameters is to be made by the method of moments or by the method of maximum likelihood. A procedure for estimating efficient estimates of the parameters utilizing reiterative process and the curvilinear model is described. Estimates by this procedure compare favorably with those obtained "by eye".

The program was applied to five locations in Nevada. Results show that for Nevada, the Poisson distribution fits the monthly thunderstorm days for the months November through April, while the negative binomial fits this variable better from May through October. The negative binomial model also fits the annual thunderstorm days in Nevada. Annual hail days distribution favored the Poisson distribution where the frequency was small. The negative binomial fitted the annual hail days distribution at Ely and Elko. Cumulative probabilities are presented for these variables at the five sites, including Elko, Ely, Las Vegas, Reno, and Winnemucca.

I. INTRODUCTION

Frequency of thunderstorms or hail in an area can be an important concern in planning for an installation of equipment or manpower. Thunderstorms also imply the possibility of flash floods, and, consequently, necessary precautions must be considered in the development of a watershed for its varied uses.

Climatological probabilities provide quantitative information on the chance of occurrence of these meteorological phenomena and can be useful in a decision where cost-benefit analysis is vital. The purpose of this study is to analyze the frequency of occurrence of thunderstorm and hail days in Nevada and to derive probabilities for these events.

A thunderstorm day is defined as the occurrence-day of at least one thunderstorm cloud (cumulonimbus) accompanied by lightning and thunder. It may or may not be accompanied by strong gusts of wind, rain, or hail. A hail day is a day when precipitation in the form of ice is produced by convective clouds. During the winter, smaller-sized frozen droplets fall, usually smaller in size than hail. These are called "small hail" and, for the purpose of this study, "small hail" and hail have not been differentiated.

II. PROCEDURE

Thom (6) has indicated that the Poisson or the negative binomial distribution can be potentially applied to rare events, such as tornado frequency, tropical cyclone frequency, hail frequency, etc. The Poisson distribution has the mean equal to the variance. If the variance increases above the mean, the distribution tends to fit the negative binomial. Generalized guidelines as to which of the two models is appropriate are available but, until the proper tests are conducted, one cannot objectively determine which model is appropriate. A test of hypothesis, using χ^2 distribution with n-1 degrees of freedom, is used to determine whether the Poisson or the negative binomial distribution is desirable. It is given by:

$$\chi^2_{n-1} = \frac{n\Sigma x^2}{\Sigma x} - \Sigma x \qquad (1)$$

where: variable x is the number of event days and n is the sample size.

The Poisson probability function is given by:

$$f(x) = \mu^x \frac{e^{-\mu}}{x!} \qquad (2)$$

where: f(x) is the probability of having, for example, exactly x hail days for the period in question. μ is the population mean.

Expressed in natural logarithms, the Poisson density function is:

$$\ln P = x \ln \bar{x} - \ln x\,! - \bar{x} \qquad (3)$$

where: P is the probability of exactly x hail days and $\bar{x}$ is the sample mean.

The negative binomial probability function can be given by (1):

$$f(x) = \frac{(k + x-1)!}{x!\ (k-1)!} \left[\frac{p^x}{(1 + p)^{k + x}}\right] \qquad (4)$$

where: k and p are the parameters of the distribution. These parameters can be initially estimated by the method of moments:

$$k = \frac{\bar{x}^2}{s^2 - \bar{x}} \qquad (5)$$

and

$$p = \frac{s^2 - \bar{x}}{\bar{x}}$$

where: $\bar{x}$ and s^2 are the sample mean and variance, respectively.

Expressed in natural logarithms, the density function for the negative binomial is:

$$\ln P = k \ln\left(\frac{1}{1 + p}\right) + \ln K + x \ln\left(\frac{p}{p + 1}\right) \qquad (6)$$

where: P is the probability of x event days for the period in question.

K is defined as:

$$K = \frac{(k + x - 1)!}{x!\ (k-1)!} \qquad (7)$$

The moments method of estimating the parameters p and k is not always efficient. Fisher (3) has provided equation 8, a method of testing whether the efficiency of the moments method is less than 90% by:

$$C = \left(1 + \frac{1}{p}\right) (k + 2) \qquad (8)$$

If $C < 20$, the method of maximum likelihood estimates should be used. If $C > 20$, the method of moments suffices.

The maximum likelihood procedure involves writing the likelihood function,

$$L = \prod_{i=1}^{n} f(x_i, p, k) \qquad (9)$$

and maximizing the logarithm of L, by taking the partial derivative of the logarithm of L with respect to p and k. When set to zero, and solving, the two parameter estimates are determined. Taking the partial derivative of equation (4) with respect to p, and setting to zero,

$$L_1 = \frac{\partial \log L}{\partial p} = \frac{\Sigma x}{p} - \frac{nk + \Sigma x}{1 + p} = 0 \qquad (10)$$

Substituting $\bar{x}$ for $\Sigma x/n$, the mean of the sample is found to be the product of the parameters. Thus $\bar{x} = k\,p$ is the first equation.

Taking the partial derivative with respect to k, setting to zero, and using Haldane's (4) equation, which does not involve gamma functions, we obtain:

$$L_2 = \frac{\partial \log L}{\partial k} = kn \log \left(1 + \frac{\bar{x}}{k}\right) - \Big[(g_1 + g_2 + \ldots g_R) +$$

$$\frac{k}{k+1}(g_2 + g_3 + \ldots + g_R) + \frac{k}{k+2}(g_3 + g_4 + \ldots + g_R) +$$

$$\ldots + \frac{k\,(g_R)}{k + R - 1}\Big] = 0 \qquad (11)$$

where g_1, g_2, ... g_R are the observed frequencies for the number of thunderstorm or hail days, $x = 1, 2, \ldots, R$ is the largest x. $\bar{x}$ = sample mean; n = number of years; k = parameter estimate. Thom (7) suggests solving this equation by trial and error or by plotting a few values of L_2 against k. The value of k at $L_2 = 0$ is the final estimate of the maximum likelihood estimator of the parameter k. The maximum likelihood estimator of p is solved by substituting k in $\bar{x}$ = kp which was previously obtained.

III. DATA

Two sources of records were utilized to summarize information needed for the analysis. These were the Local Climatological Data (8) and the Climatological Records Book for each location.

IV. COMPUTER PROGRAM

A FORTRAN IV program was developed for the analysis of thunderstorm and hail days that facilitates the solution to the estimation of probabilities for these events. In the program, values of L_2 (see Procedure) were calculated reiteratively by selecting values of k in equation 11 and solving for L_2. The program then searches for the transition of negative and positive values of L_2. Several values of L_2 are selected from both sides of the transition point and subjected to the second order polynomial (curvilinear) equation. The final value of k is determined by setting the derived curvilinear equation to zero and solving for k by the quadratic equation. This procedure was done after repeated trials of curve fitting and the curvilinear model was determined to fit the observed curve very well. The above procedure eliminates the tedious process of curve fitting by eye.

Sample sizes from 10 to 40 years are the suggested limits for this program. This restriction results from the insertion of the Chi-square values at the 0.05 level of significance to test the adequacy of the Poisson distribution. To minimize the program size, a relationship was established between the degrees of freedom and the Chi-square values. Values for this relationship can be found in an elementary statistics test. The resultant equation at the 0.05 level of significance is:

$$Y = 4.54921 + 1.41672D - 0.0036744D^2 \qquad (12)$$

where:

Y = Chi-square value at the 0.05 level

D = degrees of freedom

The program was designed for five specific locations. If more locations are required, cards 5, 11, 12, 35, and 38 should be changed accordingly.[2] Furthermore, a maximum of 55 thunderstorm or hail days has been set. If more days (up to 99) are necessary, cards number 2, 3, 18, 39, 67, 108, 126, in the main program and cards 3 and 4 in subroutine NEGBINO need be changed to the appropriate number of days. A blank card is inserted between each new station.

---

[2] Card numbers refer to the numbers listed on the extreme left margin of the program, as for example, 2:.

Card format is as follows. Blanks are read as zeros.

Columns	Remarks
1-2	Blank
3-6	Station number
7	Blank
8-11	Year (for monitor purpose; not necessary in program)
13-16	January (01) and number of thunderstorms (00 to 55)
17	Blank
18-21	February (02) and number of thunderstorms (00 to 55)
22	Blank
23-26	March (03) and number of thunderstorms (00 to 55), etc.
72	Blank
73-74	Annual thunderstorm days (00 to 55)
75	Blank
76-77	Annual hail days (00 to 55)
78-80	Blank

V. RESULTS

Probability Models

Table I shows the summary of model selection for the five locations in Nevada. The results indicate that for the monthly distribution, model selection for estimating probabilities of selected number of thunderstorm days depends on the season, and hence, the climate of a particular region. The data suggest that for the period from November through April, the Poisson model is preferred in Nevada, while the negative binomial distribution is appropriate for the period May through October.

There were 11 cases where the selected model did not coincide with the majority model. However, seven of these cases involved maximum differences of less than .023 between the Poisson and negative binomial distribution. The maximum difference between these two models in the other four cases was .108 for zero number of thunderstorm days. In view of the few cases with these differences, the results of the computer selection were retained in the probability tables shown in Tables 2A through 6B, which also show the observed cumulative distribution. The observed and computed probabilities were compared and tested with the Kolmogorov-Smirnov test (5) and all results were within tolerance at the .10 level of significance.

For annual thunderstorm days, the negative binomial model was selected at all stations. For annual hail days, however, only Ely and Elko were associated with the negative binomial; whereas, Reno, Winnemucca, and Las Vegas were fitted with the Poisson distribution. As shown in Table 7, the means at Ely and Elko are larger than the other three sites. Furthermore, the variance is considerably larger than the mean at Ely and Elko. The selection of either of two models for probabilities of annual number of hail days in Nevada suggests that climatic difference is a factor in the selection of the distribution model. Therefore, each climatic region should be analyzed separately to determine the proper selection of the model that fits the data. Calculated cumulative probabilities from the model as well as observed cumulative frequencies for annual thunderstorm and annual hail days are shown in Tables 8 and 9, respectively. The Kolmogorov-Smirnov test showed that the selected models fitted the observed data at the .10 level of significance.

Illustration of reading these probability tables follows: The computed probabilities for "0" number of thunderstorm or hail days are the chance of none occurring at each of the sites. For example, in Table 9, the probability of no hail at Las Vegas is .875. The probability of exactly x number of hail days, for example, x = 5 days at Ely is .717 minus .596 or .121; the probability of less than 5 days is .717; the probability of greater than 5 hail days at Ely is 1.000 minus .717 or .283. Probabilities for other selected number of days and sites are determined similarly.

Computer Outputs

Sample outputs from the computer program are shown in Tables 10 and 11. Table 10 illustrates an example of the output for the negative binomial distribution, utilizing the maximum likelihood procedure for estimating the parameters k and p. Table 11 is an example of the output for annual hail days probabilities at Winnemucca.

Comparison of the computer program procedure used for estimating the parameter k, when L_2 (Equation 11) is zero and that for estimating k by graphical (eye) procedure is shown in Table 12. Estimate of the parameter by the method of moments is also included. Excellent agreement is indicated by the results between the computer and "by eye".

It is concluded that the procedure utilized in this study is both a reliable and a rapid method for calculating the parameters of the negative binomial distribution by the maximum likelihood method.

VI. ACKNOWLEDGMENT

This study started as a joint term paper with my wife, Winifred, in her Computer Programming course at the University of Nevada. Through this project we both learned the rudiments of computer programming with many of its frustrating moments. Dr. Young Koh, College of Agriculture Statistician, was helpful and aided our efforts when the program seemed impossible to debug. To these two, the author expresses sincere gratitude.

VII. REFERENCES

1. BLISS, C. I., and R. A. Fisher. "Fitting the Negative Binomial Distribution to Biological Data," *Biometrics*, pp. 176-196, June 1953.

2. FISHER, R. A. "Note on the Efficient Fitting of the Negative Binomial," *Biometrics*, pp. 197-200, June 1953.

3. FISHER, R. A. "The Negative Binomial Distribution," *Annals of Eugenics*, Vol. 11, pp. 182-187, 1941.

4. HALDANE, J. B. S. "The Fitting of Binomial Distributions," *Annals of Eugenics*, Vol. 11, pp. 179-181, 1941.

5. MASSEY, F. J., Jr. "The Kolmogorov-Smirnov Test for Goodness of Fit," *American Statistical Association Journal*, Vol. 46, pp. 68-78, 1951.

6. THOM, H. C. S. "Some Methods of Climatological Analysis," *World Meteorological Organization Technical Note No. 81*, pp. 30-34, 1966.

7. THOM, H. C. S. "The Frequency of Hail Occurrence," *Archiv fur Meteorologie, Geophysik und Bioklimatologie*, Series B, Band 8, 2, Heft, pp. 185-194, 1957.

8. U. S. DEPARTMENT OF COMMERCE, National Oceanic and Atmospheric Administration, Environmental Data Service. *Local Climatological Data for Reno, Ely, Elko, Las Vegas, Winnemucca.*

9. WILLIAMSON, E., and M. H. BRETHERTON. *Tables of the Negative Binomial Probability Distribution*, pp. 7-15, John Wiley and Sons, 1963.

TABLE I

SUMMARY OF MODEL SELECTION FOR THUNDERSTORM AND HAIL DAYS IN NEVADA

Period	Location				
	Ely	Reno	Elko	Winnemucca	Las Vegas
Jan	P*	None	P	P	P
Feb	N	P	P	P	P
Mar	P	P	P	P	P
Apr	P	P	P	P	N
May	N	N	N	N	P
Jun	N	N	P	N	P
Jul	N	N	P	N	N
Aug	N	N	N	N	N
Sep	N	P	N	N	N
Oct	N	N	N	P	N
Nov	P	N	P	N	P
Dec	P	N	P	P	P
Ann	N	N	N	N	N
Annual Hail	N	P	N	P	P

*P = Poisson; N = Negative Binomial

TABLE 2A

COMPUTED (C) AND OBSERVED (O) CUMULATIVE PROBABILITIES OF MONTHLY NUMBER OF THUNDERSTORM DAYS AT ELKO, NEVADA, FROM JANUARY THROUGH JUNE (1941 - 1970)

No.	JAN		FEB		MAR		APR		MAY		JUN	
Days	C	O	C	O	C	O	C	O	C	O	C	O
0	.875	.867	.717	.733	.693	.700	.393	.500	.114	.033	.020	.067
1	.992	1.000	.955	.933	.947	.933	.760	.700	.273	.300	.102	.167
2	1.000		.995	1.000	.994	1.000	.931	.867	.432	.433	.258	.333
3					.999		.985	1.000	.572	.633	.460	.400
4							.997		.685	.767	.655	.500
5									.773	.833	.806	.733
6									.839	.867	.903	.967
7									.887	.867	.956	.967
8									.922	.900	.982	1.000
9									.946	.900	.993	
10									.963	.900	.998	
11									.975	.900		
12									.983	1.000		
13									.989			
14									.993			
15									.995			

TABLE 2B

COMPUTED (C) AND OBSERVED (O) CUMULATIVE PROBABILITIES OF MONTHLY NUMBER OF THUNDERSTORM DAYS AT ELKO, NEVADA, FROM JULY THROUGH DECEMBER (1941 - 1970)

No.	JUL		AUG		SEP		OCT		NOV		DEC	
Days	C	O	C	O	C	O	C	O	C	O	C	O
0	.006	.033	.063	.100	.317	.333	.636	.633	.819	.800	.875	.867
1	.038	.067	.180	.167	.587	.533	.858	.833	.983	1.000	.992	1.000
2	.119	.167	.324	.300	.766	.767	.944	.967	.999		1.000	
3	.256	.400	.468	.467	.872	.867	.977	.967				
4	.429	.400	.597	.500	.932	.967	.991	1.000				
5	.604	.533	.704	.667	.964	.967	.996					
6	.752	.633	.789	.767	.982	.967						
7	.860	.800	.851	.867	.991	1.000						
8	.928	.933	.897	.900	.995							
9	.966	.967	.930	.933								
10	.985	1.000	.953	1.000								
11	.994		.969									
12	.998		.980									
13			.987									
14			.991									
15			.995									
16			.997									

TABLE 3A

COMPUTED (C) AND OBSERVED (O) CUMULATIVE PROBABILITIES OF MONTHLY NUMBER OF THUNDERSTORM DAYS AT ELY, NEVADA, FROM JANUARY THROUGH JUNE (1941 - 1970)

No.	JAN		FEB		MAR		APR		MAY		JUN	
Days	C	O	C	O	C	O	C	O	C	O	C	O
0	.905	.900	.903	.900	.648	.667	.231	.300	.061	.033	.038	.067
1	.995	1.000	.963	.933	.929	.900	.569	.533	.185	.166	.118	.100
2			.984	1.000	.990	1.000	.817	.833	.340	.433	.228	.233
3			.992		.999		.938	.900	.495	.500	.350	.266
4			.996				.983	.966	.632	.600	.471	.400
5			.996				.996	1.000	.742	.633	.581	.600
6									.825	.867	.676	.667
7									.884	.933	.754	.800
8									.925	.933	.817	.900
9									.953	.933	.865	.933
10									.970	.967	.902	.933
11									.982	.967	.930	.933
12									.989	1.000	.950	.933
13									.993		.965	.967
14									.996		.976	.967
15											.983	.967
16											.988	.967
17											.992	.967
18											.995	.967
19											.996	1.000
20												

TABLE 3B

COMPUTED (C) AND OBSERVED (O) CUMULATIVE PROBABILITIES OF MONTHLY NUMBER OF THUNDERSTORM DAYS AT ELY, NEVADA, FROM JULY THROUGH DECEMBER (1941 - 1970)

No.	JUL		AUG		SEP		OCT		NOV		DEC	
Days	C	O	C	O	C	C	C	O	C	O	C	O
0	.021	.033	.005	.000	.192	.133	.466	.467	.716	.700	.766	.800
1	.068	.100	.024	.000	.442	.500	.706	.700	.955	.967	.970	.933
2	.135	.167	.062	.100	.654	.700	.837	.833	.995	1.000	.997	1.000
3	.217	.233	.120	.100	.801	.733	.909	.900				
4	.305	.267	.196	.266	.891	.900	.949	.933				
5	.395	.367	.285	.266	.943	.967	.971	.967				
6	.480	.466	.379	.333	.971	.967	.984	1.000				
7	.560	.500	.474	.400	.986	.967	.991					
8	.632	.533	.563	.566	.993	1.000	.995					
9	.695	.633	.644	.633	.997		.997					
10	.750	.733	.716	.667								
11	.796	.766	.776	.800								
12	.835	.833	.827	.867								
13	.868	.866	.867	.934								
14	.894	.866	.900	.934								
15	.916	.966	.925	.967								
16	.934	.966	.945	.967								
17	.948	.966	.960	.967								
18	.959	1.000	.971	.967								
19	.968		.979	.967								
20	.975		.985	.967								
21	.981		.989	.967								
22	.985		.992	.967								
23	.988		.995	.967								
24	.991		.996	1.000								
25	.993											
26	.995											
27	.996											

TABLE 4A

COMPUTED (C) AND OBSERVED (O) CUMULATIVE PROBABILITIES OF MONTHLY NUMBER OF THUNDERSTORM DAYS AT LAS VEGAS, NEVADA, FROM JANUARY THROUGH JUNE (1940-1971)

No.	JAN		FEB		MAR		APR		MAY		JUN	
Days	C	O	C	O	C	O	C	O	C	O	C	O
0	.967	.967	.792	.833	.875	.833	.642	.633	.380	.400	.407	.400
1	1.000	1.000	.977	.967	.992	1.000	.858	.867	.748	.700	.773	.767
2			.998	1.000	1.000		.942	.933	.926	.967	.937	.933
3							.976	.967	.983	.967	.987	1.000
4							.989	1.000	.997	1.000	.998	
5							.996					

TABLE 4B

COMPUTED (C) AND OBSERVED (O) CUMULATIVE PROBABILITIES OF MONTHLY NUMBER OF THUNDERSTORM DAYS AT LAS VEGAS, NEVADA, FROM JULY THROUGH DECEMBER (1941-1971)

No.	JUL		AUG		SEP		OCT		NOV		DEC	
Days	C	O	C	O	C	O	C	O	C	O	C	O
0	.032	.067	.110	.166	.381	.400	.581	.567	.847	.867	.967	.967
1	.118	.167	.262	.166	.661	.600	.750	.800	.988	.900	1.000	1.000
2	.251	.300	.416	.400	.825	.800	.838	.867	.999	1.000		
3	.406	.367	.553	.633	.913	.967	.891	.900				
4	.558	.500	.666	.633	.958	.967	.925	1.000				
5	.688	.633	.755	.700	.980	.967	.948					
6	.790	.700	.823	.800	.991	1.000	.963					
7	.864	.867	.874	.833	.996		.974					
8	.915	.900	.911	.933			.981					
9	.949	1.000	.937	.967			.986					
10	.970		.956	.967			.990					
11	.983		.970	.967			.993					
12	.990		.979	1.000			.995					
13	.995		.986				.996					
14	.997		.990									
15			.993									
16			.996									

TABLE 5A

COMPUTED (C) AND OBSERVED (O) CUMULATIVE PROBABILITIES OF MONTHLY NUMBER OF THUNDERSTORM DAYS AT RENO, NEVADA, FROM JANUARY THROUGH JUNE (1941 - 1970)

No. Days	JAN		FEB		MAR		APR		MAY		JUN	
	C	O	C	O	C	O	C	O	C	O	C	O
0	1.000	1.000	.967	.967	.936	.933	.670	.633	.230	.200	.191	.167
1			1.000	1.000	.998	1.000	.938	.967	.479	.467	.396	.433
2							.992	1.000	.673	.667	.570	.567
3							.999		.804	.800	.702	.700
4									.887	.900	.798	.800
5									.936	.900	.865	.867
6									.965	1.000	.911	.900
7									.981		.942	.933
8									.990		.962	.967
9									.995		.975	.967
10									.997		.984	.967
11											.990	1.000
12											.994	
13											.996	
14												
15												

TABLE 5B

COMPUTED (C) AND OBSERVED (O) CUMULATIVE PROBABILITIES OF MONTHLY NUMBER OF THUNDERSTORM DAYS AT RENO, NEVADA, FROM JULY THROUGH DECEMBER (1941 - 1970)

No.	JUL		AUG		SEP		OCT		NOV		DEC	
Days	C	O	C	O	C	O	C	O	C	O	C	O
0	.085	.167	.256	.233	.380	.433	.807	.833	.945	.967	.945	.967
1	.228	.200	.449	.500	.748	.733	.925	.967	.991	.967	.991	.967
2	.389	.333	.594	.633	.926	.867	.966	.967	.998	1.000	.998	1.000
3	.540	.466	.700	.667	.983	.967	.984	.967				
4	.666	.567	.780	.767	.997	1.000	.992	.967				
5	.765	.733	.838	.800			.996	1.000				
6	.838	.900	.881	.867								
7	.891	.933	.912	.900								
8	.928	.967	.936	.900								
9	.953	.967	.953	.967								
10	.970	1.000	.965	.967								
11	.981		.975	.967								
12	.988		.981	1.000								
13	.992		.986									
14	.995		.990									
15			.993									
16			.995									
17			.996									
18												
19												
20												

TABLE 6A

COMPUTED (C) AND OBSERVED (O) CUMULATIVE PROBABILITIES OF MONTHLY NUMBER OF THUNDERSTORM DAYS AT WINNEMUCCA, NEVADA, FROM JANUARY THROUGH JUNE (1941 - 1970)

No.	JAN		FEB		MAR		APR		MAY		JUN	
Days	C	O	C	O	C	O	C	O	C	O	C	O
0	.967	.967	.875	.900	.819	.800	.435	.367	.219	.233	.146	.167
1	1.000	1.000	.992	.967	.983	1.000	.797	.933	.421	.367	.328	.333
2			1.000	1.000	.999		.948	.967	.581	.633	.497	.467
3							.990	1.000	.701	.767	.635	.633
4							.998		.789	.800	.742	.667
5									.852	.833	.821	.800
6									.897	.867	.878	.867
7									.929	.933	.917	.967
8									.951	.967	.944	.967
9									.966	.967	.963	.967
10									.977	1.000	.976	1.000
11									.984		.984	
12									.989		.990	
13									.993		.993	
14									.995		.996	
15									.997			

TABLE 6B

COMPUTED (C) AND OBSERVED (O) CUMULATIVE PROBABILITIES OF MONTHLY NUMBER OF THUNDERSTORM DAYS AT WINNEMUCCA, NEVADA, FROM JULY THROUGH DECEMBER (1941 - 1970)

No.	JUL		AUG		SEP		OCT		NOV		DEC	
Days	C	O	C	O	C	O	C	O	C	O	C	O
0	.160	.200	.240	.233	.355	.333	.420	.500	.894	.933	.936	.933
1	.347	.333	.442	.400	.640	.667	.785	.733	.965	1.000	.998	1.000
2	.512	.433	.597	.567	.814	.800	.943	.833	.986			
3	.647	.567	.712	.667	.908	.900	.988	1.000	.994			
4	.750	.633	.795	.767	.956	.967	.998		.997			
5	.825	.800	.855	.833	.979	.967						
6	.879	.900	.898	.867	.990	1.000						
7	.917	.900	.928	.933	.996							
8	.944	.967	.950	.967								
9	.962	.967	.965	1.000								
10	.975	.967	.975									
11	.983	1.000	.983									
12	.989		.988									
13	.993		.992									
14	.995		.994									
15			.996									

TABLE 7

MEAN AND VARIANCE OF ANNUAL THUNDERSTORM AND ANNUAL HAIL DAYS AT FIVE LOCATIONS IN NEVADA (1941 - 1970)

	Thunderstorm		Hail	
Locations	Mean	Variance	Mean	Variance
Elko	24.23	39.47	2.67	6.09
Ely	31.97	97.69	4.27	7.24
Las Vegas	13.47	25.84	.13	.12
Reno	13.50	37.22	1.17	1.11
Winnemucca	15.43	47.08	2.40	3.14

TABLE 8

CALCULATED (C) AND OBSERVED (O) CUMULATIVE PROBABILITIES OF ANNUAL THUNDERSTORM DAYS AT FIVE LOCATIONS IN NEVADA (1941 - 1970)

No. Days	LOCATIONS									
	ELKO		ELY		LAS VEGAS		RENO		WINNEMUCCA	
	C	O	C	O	C	O	C	O	C	O
0	.000	.000	.000	.000	.000	.000	.001	.000	.000	.000
1	.000	.000	.000	.000	.001	.000	.003	.000	.002	.000
2	.000	.000	.000	.000	.002	.000	.009	.000	.007	.033
3	.000	.000	.000	.000	.007	.000	.021	.000	.017	.033
4	.000	.000	.000	.000	.018	.033	.042	.033	.032	.067
5	.001	0.33	.000	.000	.037	.033	.072	.067	.055	.100
6	.002	.033	.000	.000	.066	.067	.112	.167	.086	.133
7	.005	.033	.000	.000	.108	.167	.162	.167	.123	.133
8	.010	.033	.001	.000	.162	.167	.219	.233	.167	.133
9	.018	.033	.002	.000	.227	.200	.283	.300	.217	.167
10	.030	.033	.003	.000	.300	.367	.349	.367	.272	.233
11	.048	.067	.005	.000	.380	.367	.418	.433	.329	.267
12	.072	.100	.009	.000	.460	.433	.485	.533	.387	.333
13	.103	.133	.013	.000	.540	.500	.551	.600	.446	.400
14	.143	.133	.020	.000	.615	.567	.612	.600	.503	.467
15	.189	.133	.028	.000	.684	.667	.669	.633	.558	.467
16	.242	.200	.039	.000	.745	.733	.720	.633	.610	.567
17	.300	.300	.053	.000	.798	.800	.765	.667	.658	.667
18	.362	.300	.070	.133	.842	.833	.805	.767	.702	.700
19	.426	.333	.090	.133	.879	.867	.839	.799	.743	.733
20	.491	.433	.113	.200	.908	.867	.869	.799	.779	.733
21	.554	.533	.139	.200	.931	.933	.894	.867	.811	.833
22	.615	.567	.168	.233	.949	.967	.914	.899	.840	.867
23	.672	.700	.200	.267	.963	.967	.932	.966	.865	.900
24	.724	.700	.235	.333	.973	1.000	.946	.966	.886	.900
25	.770	.800	.272	.333	.981		.957	1.000	.905	.900
30	.924	.900	.475	.433	.998		.988		.964	1.000
35	.981	1.000	.667	.533			.997		.987	
40	.996		.814	.767					.996	
45			.906	.933						
50			.942	.967						
55			.942	1.000						

TABLE 9

CALCULATED (C) AND OBSERVED (O) CUMULATIVE PROBABILITIES OF ANNUAL HAIL DAYS AT FIVE LOCATIONS IN NEVADA (1941 - 1970)

No. Days	LOCATIONS									
	ELKO		ELY		LAS VEGAS		RENO		WINNEMUCCA	
	C	O	C	O	C	O	C	O	C	O
0	.160	.100	.044	.000	.875	.867	.311	.333	.091	.100
1	.370	.300	.147	.100	.992	1.000	.674	.633	.308	.367
2	.561	.567	.292	.100	1.000		.887	.867	.570	.600
3	.710	.733	.450	.233			.969	1.000	.779	.767
4	.815	.867	.596	.633			.993		.904	.867
5	.886	.933	.717	.800			.999		.964	.933
6	.931	.933	.809	.833					.988	.967
7	.959	.933	.876	.867					.997	1.000
8	.976	.933	.922	.900						
9	.986	.967	.952	.933						
10	.992	.967	.971	.967						
11	.995	1.000	.983	1.000						
12			.990							
13			.994							
14			.997							
15										

<u>TABLE 10</u>

SAMPLE PROGRAM OUTPUT SHOWING THE MAXIMUM LIKELIHOOD PARAMETER ESTIMATE AND PROBABILITIES FOR SELECTED NUMBER OF THUNDERSTORM DAYS AT ELY, NEVADA

SEPTEMBER THUNDERSTORM DAYS AT ELY

MEAN= 2.133 VARIANCE= 3.499 NO. OF YEARS= 30

MAXIMUM LIKELIHOOD METHOD OF PARAMETER ESTIMATE

K= 3.368 P= .633

PERIOD= 9 MODEL IS NEGATIVE BINOMIAL

TABLE 9. CHANCE OF SELECTED NUMBER OF THUNDERSTORM DAYS AT ELY NEVADA (1941-1970) FOR THE SEPTEMBER PERIOD.

THUNDERSTORM DAYS	PROBABILITY	CUMULATIVE PROBABILITY
0	.1916	.1916
1	.2502	.4417
2	.2119	.6536
3	.1470	.8006
4	.0908	.8914
5	.0519	.9433
6	.0281	.9713
7	.0146	.9859
8	.0073	.9932
9	.0036	.9968

TABLE II

SAMPLE PROGRAM OUTPUT SHOWING PROBABILITIES OF SELECTED NUMBER OF ANNUAL HAIL DAYS AT WINNEMUCCA, NEVADA, WITH THE POISSON DISTRIBUTION

ANNUAL HAIL DAYS AT WINNEMUCCA

MEAN= 2.400 VARIANCE= 3.145 NO. OF YEARS= 30

PERIOD= 14 MODEL IS POISSON

TABLE14. CHANCE OF SELECTED NUMBER OF HAIL DAYS AT WINNEMUCCA NEVADA (1941-1970) FOR THE ANNUAL PERIOD.

HAIL DAYS	PROBABILITY	CUMULATIVE PROBABILITY
0	.0907	.0907
1	.2177	.3084
2	.2613	.5697
3	.2090	.7787
4	.1254	.9041
5	.0602	.9643
6	.0241	.9884
7	.0083	.9967

TABLE 12

COMPARISON OF PARAMETER K ESTIMATES BY METHOD OF MAXIMUM LIKELIHOOD (MXL), METHOD OF MOMENTS (MOM) AND "BY EYE" FOR THUNDERSTORM PROBABILITIES IN NEVADA

	ELKO			ELY			LAS VEGAS			RENO			WINNEMUCCA		
Period	MXL	MOM	EYE	MXL	MOM	EYE	MXL	MOM	EYE	MXL	MOM	EYE	MXL	MOM	EYE
May	2.228	1.819	2.226	4.013	4.067	4.017	---	---	---	2.277	3.447	2.273	1.377	1.573	1.366
Jun	---	---	---	3.499	3.197	3.497	---	---	---	1.784	1.739	1.779	2.042	2.560	2.040
Jul	---	---	---	3.047	3.927	3.037	---	6.750	---	3.060	4.522	3.064	1.855	2.361	1.849
Aug	3.315	4.735	3.316	5.831	5.474	5.831	2.180	2.614	2.174	1.035	1.109	1.037	1.227	1.652	1.222
Sep	1.833	2.133	1.833	3.368	3.333	3.373	1.704	2.169	1.700	---	---	---	1.960	2.138	1.956
Oct	.840	1.065	.840	.902	1.044	.896	.382	.271	.381	.259	.190	.247	---	---	---
Ann	---	24.233	---	---	15.548		---	14.652	---	7.282	7.682	7.282	6.236	7.526	6.241

Western Region Technical Memoranda: (Continued)

No. 45/2 Precipitation Probabilities in the Western Region Associated with Spring 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189434)
No. 45/3 Precipitation Probabilities in the Western Region Associated with Summer 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189414)
No. 45/4 Precipitation Probabilities in the Western Region Associated with Fall 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189435)
No. 46 Applications of the Net Radiometer to Short-Range Fog and Stratus Forecasting at Eugene, Oregon. L. Yee and E. Bates. December 1969. (PB-190476)
No. 47 Statistical Analysis as a Flood Routing Tool. Robert J. C. Burnash . December 1969. (PB-188744)
No. 48 Tsunami. Richard A. Augulis. February 1970. (PB-190157)
No. 49 Predicting Precipitation Type. Robert J. C. Burnash and Floyd E. Hug. March 1970. (PB-190962)
No. 50 Statistical Report of Aeroallergens (Pollens and Molds) Fort Huachuca, Arizona 1969. Wayne S. Johnson. April 1970. (PB-191743)
No. 51 Western Region Sea State and Surf Forecaster's Manual. Gordon C. Shields and Gerald B. Burdwell. July 1970. (PB-193102)
No. 52 Sacramento Weather Radar Climatology. R. G. Pappas and C. M. Veliquette. July 1970. (PB-193347)
No. 53 Experimental Air Quality Forecasts in the Sacramento Valley. Norman S. Benes. August 1970. (PB-194128)
No. 54 A Refinement of the Vorticity Field to Delineate Areas of Significant Precipitation. Barry B. Aronovitch. August 1970.
No. 55 Application of the SSARR Model to a Basin Without Discharge Record. Vail Schermerhorn and Donald W. Kuehl. August 1970. (PB-194394).
No. 56 Areal Coverage of Precipitation in Northwestern Utah. Philip Williams, Jr., and Werner J. Heck. September 1970. (PB-194389)
No. 57 Preliminary Report on Agricultural Field Burning vs. Atmospheric Visibility in the Willamette Valley of Oregon. Earl M. Bates and David O. Chilcote. September 1970. (PB-194710)
No. 58 Air Pollution by Jet Aircraft at Seattle-Tacoma Airport. Wallace R. Donaldson. October 1970. (COM-71-00017)
No. 59 Application of P.E. Model Forecast Parameters to Local-Area Forecasting. Leonard W. Snellman. October 1970. (COM-71-00016)

NOAA Technical Memoranda NWS

No. 60 An Aid for Forecasting the Minimum Temperature at Medford, Oregon. Arthur W. Fritz, October 1970. (COM-71-00120)
No. 61 Relationship of Wind Velocity and Stability to SO_2 Concentrations at Salt Lake City, Utah. Werner J. Heck, January 1971. (COM-71-00232)
No. 62 Forecasting the Catalina Eddy. Arthur L. Eichelberger, February 1971. (COM-71-00223)
No. 63 700-mb Warm Air Advection as a Forecasting Tool for Montana and Northern Idaho. Norris E. Woerner. February 1971. (COM-71-00349)
No. 64 Wind and Weather Regimes at Great Falls, Montana. Warren B. Price, March 1971.
No. 65 Climate of Sacramento, California. Wilbur E. Figgins, June 1971. (COM-71-00764)
No. 66 A Preliminary Report on Correlation of ARTCC Radar Echoes and Precipitation. Wilbur K. Hall, June 1971. (COM-71-00829)
No. 67 Precipitation Detection Probabilities by Los Angeles ARTC Radars. Dennis E. Ronne, July 1971. (COM-71-00925)
No. 68 A Survey of Marine Weather Requirements. Herbert P. Benner, July 1971. (COM-71-00889)
No. 69 National Weather Service Support to Soaring Activities. Ellis Burton, August 1971. (COM-71-00956)
No. 70 Predicting Inversion Depths and Temperature Influences in the Helena Valley. David E. Olsen, October 1971. (COM-71-01037)
No. 71 Western Region Synoptic Analysis-Problems and Methods. Philip Williams, Jr., February 1972.
No. 72 A Paradox Principle in the Prediction of Precipitation Type. Thomas J. Weitz, February 1972.
No. 73 A Synoptic Climatology for Snowstorms in Northwestern Nevada. Bert L. Nelson, Paul M. Fransioli, and Clarence M. Sakamoto, February 1972. (COM-72-10338)