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AN AUTOMATED TECHNIQUE FOR ESTIMATING DAILY PRECIPITATION OVER THE STATE OF VIRGINIA

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WALLOPS FLIGHT CENTER
WALLOPS ISLAND, VA 23337

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SECTION 1 - INTRODUCTION

A dependable environmental data base is required by the agriculturalist in his crop management practices and problems. Much of this is provided directly. An important indirect channel is computerized crop management models such as those developed by Virginia Polytechnic Institute and State University (VPI&SU), aimed at optimizing irrigation procedures and controlling plant diseases and pests. These models require reliable estimates of precipitation on a day-to-day basis in near real time. Daily observations of precipitation reported on a network of rain gages provides accurate data for the immediate vicinity of each gage. If the distribution of gages were uniform and sufficiently dense (say several hundred gages over the state of Virginia) and if all measurements were made at the same time of day, and made immediately available to the computer, then interpolation between gages should provide a reliable estimate field for the entire state. In practice, meeting these criteria is both difficult and expensive. Furthermore, convective rain, the predominant type during the growing season, is usually sharply discontinuous, frequently invalidating straightforward interpolative methods.

A number of investigators have developed and tested methods to estimate precipitation using meteorological satellite data. See Barrett[1 & 2], Chan[3], Follansbee and Oliver[4], Follansbee[5], Griffith et al.[6], Martin and Scherer[7], Scofield and Oliver[8], and Woodley and Sax[9]. These techniques show varying skill in delineating precipitation patterns in the data-sparse areas between gages. Geostationary satellites, which provided complete cloud photograph coverage of the United States every half hour during daylight hours in the visible spectrum and around-the-clock in the IR, are particularly useful.

An excellent technique based on geostationary satellite data developed by Scofield and Oliver[8], has been used successfully by the Synoptic Analysis Branch of the National Environmental Satellite Service (NESS) in support of the Quantitative Precipitation Branch (QPB) and the Weather Service Forecast Office (WSFO) of the National Weather Service (NWS) in estimating heavy precipitation and flood situations. Another such technique, developed jointly by the University of Wisconsin and the National Hurricane and Experimental Meteorology Laboratory, Miami, Florida, has been used in support of the GATE project of the Global Atmospheric Research Program. See Martin et al.[10] and Griffith et al.[11]. Both methods depend in large part on the following

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facts taken from Scofield and Oliver[8] and Woodley et al.[12] regarding rain clouds:

1. Bright clouds in the visible imagery produce more rain than darker clouds.
2. Bright clouds in the visible imagery and clouds with cold tops in the infrared imagery which are expanding in areal coverage produce more rainfall than those not expanding.
3. Decaying clouds produce little or no rainfall.
4. Clouds with cold tops in the IR imagery produce more rain than those with warmer tops.
5. Clouds with cold tops that are becoming warmer produce little or no rain.
6. Merging of cumulonimbus clouds increases the rainfall rate of the merging clouds.
7. Most of the significant rainfall occurs in the upwind (at anvil level) portion of a convective system. The highest and coldest clouds form where the thunderstorms are most vigorous and the rain heaviest. These cold clouds get thinner downwind and look warmer in IR imagery as the anvil material blows away from its origin over the updraft.

The Scofield/Oliver technique was tentatively selected as a model for making daily estimates of precipitation over Virginia because of its great success in estimating flood-producing rains over the United States in near real time Scofield and Oliver[13], Scofield[14&15]. Experiment with this technique, which was developed primarily for very heavy convective rains during the warmer months of the year, suggested that modifications would be advisable when applying it to light rain situations, to synoptic scale storms, and (especially) to winter storms. Time being of the essence in the operational mode, it was decided to follow the hourly changes and movements of storm clouds in the enhanced infrared (EIR) only, rather than the half-hourly in both the EIR and visible imagery, as called for in the Scofield/Oliver scheme. Scofield[15] tried this approach on the large synoptic storm over the north-eastern United States on October 9, 1976, with encouraging results. This variation of the Scofield/Oliver technique will be referred to hereafter as the S technique.

Hourly radar charts from the National Facsimile Circuit of NWS, and hourly radar reports from Patuxent, Maryland and Bristol, Tennessee were used to locate areas of heavier rain, but (generally speaking) not to estimate amounts.

SECTION 2 - PRELIMINARY STUDIES

Seven storms occurring between May and November 1978 were analyzed by hand. Isohyets of hourly rainfall estimates, based on the S technique slightly modified by radar reports, were drawn on the map of Virginia and its immediate vicinity. From these isohyetal charts, estimates for 25 stations equipped with rain gages were tabulated for each hour from 1200Z (noon Greenwich Mean Time) on one day to 1200Z the following day. The hourly estimates were summed and compared with observed rainfall amounts at the 25 stations for the same time period. The results ranged from excellent to poor. Obviously, to be operationally effective, estimates adjacent to these stations would have to be adjusted to the gage readings. Furthermore, the 25 stations, which report daily on National Facsimile and/or Service C Teletype Circuits, should be supplemented by as many volunteer stations as feasible.

Eventually a simplified and rapid method of estimating rain from satellite imagery was designed as a possible alternative to the more laborious and time-consuming S technique. This quick (Q) technique assigned rain for a given hour in accordance with the cloud top temperature in the EIR imagery at the end of that hour. (Later the cloud top temperature at the beginning of the hour was used.) The digital enhancement (Mb) curve was used: areas shaded medium gray (-32 to -41°C) were assigned 0.05 inch of rain; areas shaded light gray (-41 to -52°C) were assigned 0.10 inch, areas of dark gray (-52 to -58°C) were assigned 0.25 inch; black areas (-58 to -62°C) were designated 0.50 inch; repeat gray level areas (-62 to -80°C) were designated 1.00 inch, and white areas (below -80°C) were assigned 1.50 inches. (See Table 2-1.)

Table 2-1. Cloud Top Temperature vs Precipitation Used in 1978 Storms

Enhanced Shade (Mb curve)	Temperature Range (°C)	Precipitation (inches)
Medium gray	-32 to -41	0.05
Light gray	-41 to -52	0.10
Dark gray	-52 to -58	0.25
Black	-58 to -62	0.50
Repeat gray	-62 to -80	1.00
White	Below -80	1.50

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The Q technique gave larger errors than the S technique in estimating precipitation at the 25 daily reporting stations for the seven 1978 storms. However, it was never intended that either method be used alone as an operational tool. Ideally, any operational satellite technique should be corrected for "ground truth" observed rain at all gages in the network, and modified by interpolation of the gage readings. Or, put another way, an isohyetal field based on the gage readings alone should be modified by reference to the satellite estimate field. Satellite methods have the advantage of covering the entire field, but fail to provide exactly accurate estimates at given points. On the other hand, gage networks provide exact measurements at fixed points, but the interpolations are inexact. This suggests that optimal results are likely to be obtained by a judicious blend of the two. With this in mind, nine methods of estimating 24-hour precipitation over the state were designed and tested on the seven storms of 1978. These nine methods will be referred to as G, S, Q, Sm, Qm, Sa, Qa, Sam and Qam.

Method G used 24-hour precipitation amounts from a network of 63 rain gages to interpolate the estimate field. The interpolation method is described in the next section. This network consisted of 25 stations which report daily on the NWS facsimile and teletype circuits, and 38 stations reporting several months after the fact in NWS Climatological Data Summaries (CDS). Forty-nine stations' reports from the CDS were held in reserve as control data for verification purposes. (See Figure 2.1)

The S and Q methods are the S and Q techniques described above. The Sm method produces an estimate field from the mean of the S value and G value at each point in the field. The Qm method takes the mean between the Q and G values at each point to obtain the Qm field.

Considering the gage reading to be ground truth at the gage location, the error for S at each analysis gage location was computed and an error field derived by interpolation. S values at all points in the state were adjusted by this error field to get the Sa field. This is the Sa method. The same procedure was used to adjust the Q values and obtain the Qa field. This is the Qa method.

The Sam method takes the mean between the Sa and G values at each point to obtain the Sam field. The Qam method obtains the Qam field from the mean of the Qa value and G value at each point. (In actual practice the interpolations were made only for the control station locations, in order to verify each method.)

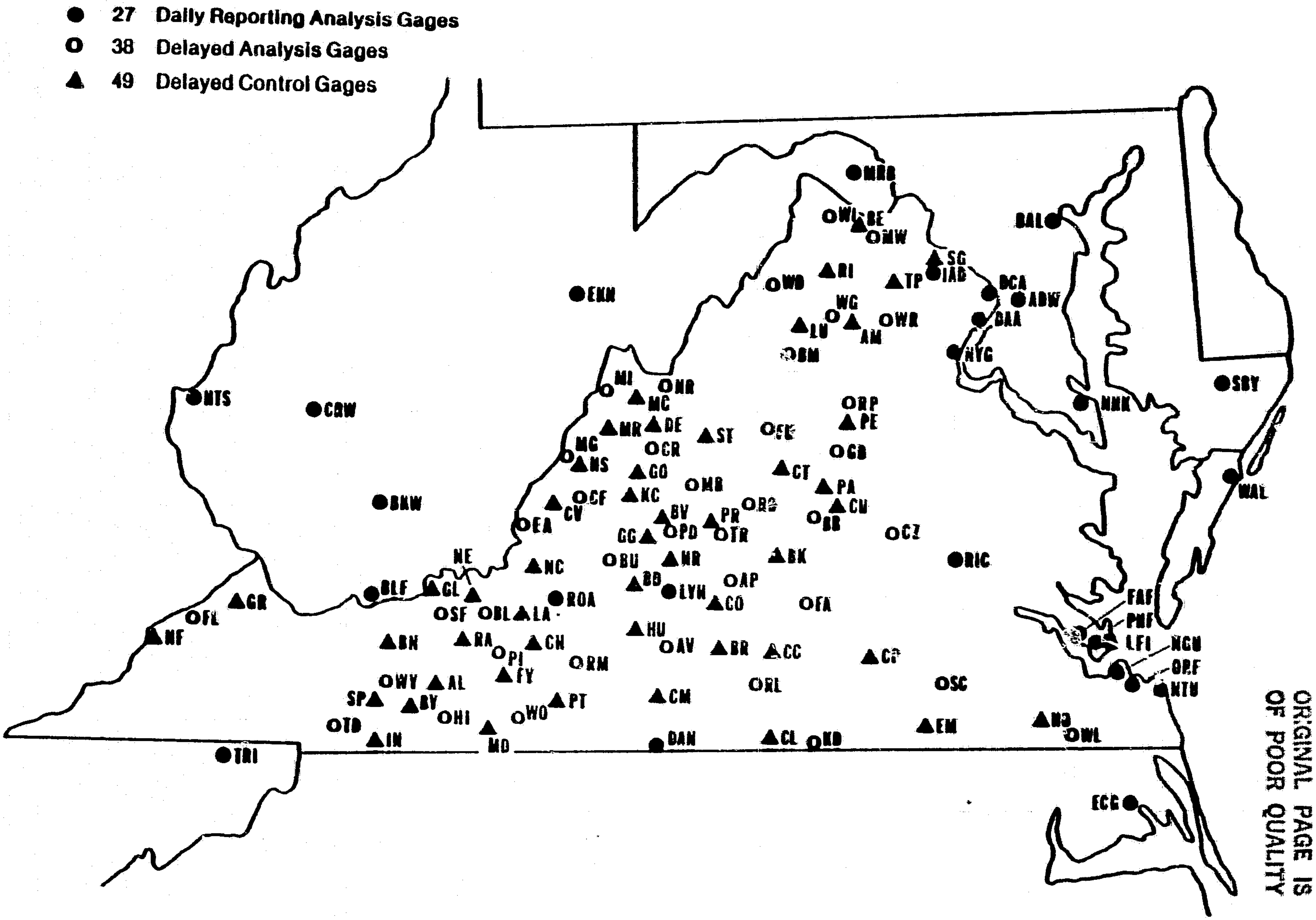

Figure 2-1. Stations Used in Analysis and Verification in 1978 Storms

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Each of the nine methods was tested for each of the seven storms in 1978, using the 49 control stations for verification. Table 2-2 gives composite scores for each method for the seven storms taken together, including mean absolute error, mean algebraic error (bias), and the correlation coefficient for each method versus observed precipitation. The Qa method obtained the best scores, but the Qam and Sam, ranking second and third, respectively, were almost as good. The Q method ranked a poor last, and the S method is next to the last, but decidedly superior to Q. The G method is in the middle of the group, but it shows the highest correlation coefficient on three of the storms, and the least absolute error on two storms. Table 2-3 through 2-9 show the performance of each method on each individual storm.

These scores suggest that although either satellite method taken alone will seldom produce the best estimates state-wide, estimates based on the Q method, when adjusted by observed gage readings, may frequently be more accurate than estimates based on interpolations between observed gage measurements alone. The scores also indicate that it is safe to adopt the various Q methods while abandoning the labor-intensive, time-consuming S methods.

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Table 2-2. Composite Scores for each Method for Seven 1978 Storms Combined

Method	Correlation Coefficient		Mean Error (Absolute)*		Mean Error (Algebraic)*	
G	0.824	(6)	0.200	(4)	-0.014	(3)
S	0.713	(8)	0.257	(8)	-0.123	(8)
Q	0.481	(9)	0.336	(9)	-0.197	(9)
Sm	0.835	(4)	0.200	(4)	-0.070	(6)
Qm	0.820	(7)	0.235	(7)	-0.109	(7)
Sa	0.827	(5)	0.209	(6)	-0.016	(5)
Qa	0.845	(1)	0.194	(1)	-0.006	(1)
Sam	0.841	(2)	0.196	(3)	-0.014	(3)
Qam	0.841	(2)	0.194	(1)	-0.010	(2)

N=317. Mean Rain at Control Stations: 0.574 inch.

NOTE: Numbers in parentheses indicate rank. *Inches.

Table 2-3. Scores for Storm May 4-5, 1978

Method	Correlation Coefficient	Mean Error (Absolute)*	Mean Error (Algebraic)*
G	<u>0.915</u>	0.188	-0.01
S	0.598	0.441	-0.36
Q	-0.192	0.773	-0.69
Sm	0.875	0.264	-0.19
Qm	0.835	0.420	-0.38
Sa	0.899	0.213	-0.06
Qa	0.904	0.198	<u>0.00</u>
Sam	0.914	0.194	-0.04
Qam	0.913	<u>0.187</u>	-0.01

N=46. Mean rain at control stations: 1.370 inches.

NOTE: Best scores are underlined. *Inches.

Table 2-4. Scores for Storm May 31-June 1, 1978

Method	Correlation Coefficient	Mean Error (Absolute)*	Mean Error (Algebraic)*
G	0.776	0.052	+0.04
S	0.838	<u>0.015</u>	+0.01
Q	0.670	<u>0.015</u>	<u>0.00</u>
Sm	<u>0.907</u>	0.028	+0.03
Qm	0.828	0.026	+0.02
Sa	0.735	0.044	+0.03
Qa	0.814	0.050	+0.04
Sam	0.767	0.048	+0.04
Qam	0.805	0.051	+0.04

N=45. Mean rain at control stations: 0.014 inch.

<u>NOTE</u>: Best scores underlined. *Inches.

Table 2-5. Scores for Storm June 8-9, 1978

Method	Correlation Coefficient	Mean Error (Absolute)*	Mean Error (Algebraic)*
G	<u>0.867</u>	<u>0.130</u>	-0.03
S	0.550	0.259	-0.10
Q	0.142	0.285	<u>0.00</u>
Sm	0.826	0.149	-0.06
Qm	0.754	0.170	-0.01
Sa	0.813	0.171	+0.03
Qa	0.810	0.150	-0.03
Sam	0.862	0.139	<u>0.00</u>
Qam	0.849	0.132	-0.03

N=44. Mean rain at control stations: 0.459 inch.

<u>NOTE</u>: Best scores underlined. *Inches.

Table 2-6. Scores for Storm June 21-22, 1978

Method	Correlation Coefficient	Mean Error (Absolute)*	Mean Error (Algebraic)*
G	0.363	0.301	+0.04
S	0.282	0.314	-0.03
Q	0.435	0.244	-0.06
Sm	0.368	0.278	0.00
Qm	0.439	0.263	-0.01
Sa	0.409	0.320	+0.02
Qa	0.541	0.254	+0.04
Sam	0.406	0.295	+0.03
Qam	0.477	0.276	+0.04

N=46. Mean rain at control stations: 0.369 inch.

NOTE: Best scores underlined. *Inches.

Table 2-7. Scores for Storm July 14-15, 1978

Method	Correlation Coefficient	Mean Error (Absolute)*	Mean Error (Algebraic)*
G	0.576	0.192	+0.05
S	0.425	0.188	-0.02
Q	0.280	0.193	-0.08
Sm	0.595	0.174	+0.01
Qm	0.581	0.165	-0.02
Sa	0.599	0.173	+0.03
Qa	0.544	0.190	+0.08
Sam	0.632	0.176	+0.04
Qam	0.567	0.188	+0.07

N=43. Mean rate at control stations: 0.222 inch.

NOTE: Best scores underlined. *Inches.

Table 2-8. Scores for Storm July 31-August 1, 1978

Method	Correlation Coefficient	Mean Error (Absolute)*	Mean Error (Algebraic)*
G	0.195	0.415	-0.20
S	0.499	0.384	-0.26
Q	0.366	0.403	<u>-0.15</u>
Sm	<u>0.522</u>	0.369	-0.23
Qm	0.462	<u>0.365</u>	-0.17
Sa	0.488	0.380	-0.18
Qa	0.453	0.384	-0.17
Sam	0.411	0.388	-0.19
Qam	0.357	0.395	-0.19

N=48. Mean rate at control stations: 0.536 inch.

<u>NOTE:</u> Best scores underlined. *Inches.

Table 2-9. Scores for Storm November 16-17, 1978

Method	Correlation Coefficient	Mean Error (Absolute)*	Mean Error (Algebraic)*
G	<u>0.851</u>	<u>0.105</u>	+0.01
S	0.109	0.180	-0.10
Q	-0.440	0.418	-0.40
Sm	0.638	0.118	-0.05
Qm	0.657	0.220	-0.19
Sa	0.574	0.144	+0.02
Qa	0.802	0.123	<u>0.00</u>
Sam	0.755	0.114	+0.02
Qam	0.846	0.110	+0.01

N=45. Mean rate at control stations: 0.554 inch.

NOTE: Best scores underlined. *Inches.

SECTION 3 - DESCRIPTION OF AUTOMATED TECHNIQUE

Photographs of Virginia and vicinity taken by the geostationary satellite located over the equator at 75° west longitude consist of very small picture elements (pixels). Due to foreshortening at the latitude of Virginia, each pixel is a photograph of a rectangular area 9.7 kilometers north-south and 6.2 kilometers east-west. There are 4879 of these cells in the rectangle enclosing the state of Virginia and its immediate vicinity. The information in each pixel is the cell's cloud top temperature to the nearest whole degree Celsius. If digital cloud data could be accessed at need, a linear relationship between cloud top temperature and hourly precipitation might be used. This would be a great refinement of the scale shown in Table 2-1.

NASA was fortunate in arranging for receipt of the digital IR and visible imagery for Virginia on a continuing basis. The dedicate source is the National Meteorological Center (NMC) of NWS located at Camp Springs, Maryland. Hourly digital imagery, both IR and visible, is stored in NMC's data tank. Each picture, if needed, must be acquired by NASA (later by VPI&SU) via auto-dial within 18 hours of picture-taking time (before it is erased in order to store more recent pictures.)

As a consequence of this data breakthrough, a number of options and strategies under consideration were abandoned. These included time-consuming hand analysis of satellite imagery by a professional meteorologist, transfer of hourly isohyetal analysis to bit-pad equipment using a cursor, and complicated summation of the isohyetal fields to get 24-hour totals for all cells. Since these slower procedures were abandoned, no description is necessary.

The system now in use consists of two computer programs written in FORTRAN. See Appendix A for a complete listing of these programs. The first program computes the satellite estimate (Q) field from the hourly digital IR imagery. The second program computes the final estimate for the entire state area by comparing five preliminary estimates of 24-hour precipitation (Q, G, Qa, Qm and Qam) with control raingage readings and determining which of the five methods gives the best estimate for the day. The final estimate is then produced by incorporating control gage readings into the winning method.

The satellite estimation program consists of the main drive routine RAINDR and five subroutines: PREPRO, RDATA, QUICK, LOOKUP, and RAINSM (see Appendix A).

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RAINDR processes each hour of satellite IR imagery as follows: First, in subroutine PREPRO, the raw data (as received from NMC via autodial) is stripped down to the minimum size which still covers the entire state. Next, each pixel in the reduced data set is converted from temperature to rainfall amount in subroutine QUICK (the Q method) using the temperature to rainfall conversion table generated in subroutine LOOKUP. This new data set is then added to the total rainfall data set in subroutine RAINSM. After all 24 hours of IR imagery have been processed the sum in the total rainfall file is the 24-hour satellite estimate - the Q method estimate for the day.

The final estimation program consists of the main driver routine MAIN and 7 subroutines: GNDTRU, FILSIA, SORT, INTERP, NXTPNT, RANGE, and WEIGHT. The final rainfall estimate is computed by MAIN as follows: The satellite estimate, computed previously in the first program, and the gage readings for each reporting ground station are entered in subroutine FILSTA. Subroutine INTERP then computes the interpolated rainfall and error values for each control station in the system using these values at each analysis station. Subroutines SORT, NXTPNT, RANGE, and WEIGHT are used in the interpolation scheme which will be described later. Once the interpolated rain and error values have been computed for each control station, the five preliminary estimates are computed. G is simply the interpolated rainfall field; Q is the satellite estimate computed previously; Qa is the satellite estimate (Q) plus the interpolated error value (the error value adjusts the satellite estimate); Qm is the mean of the interpolated rainfall field and the satellite estimate; and Qam is the mean of Qa and the interpolated rainfall field. From these values an error is computed for each of the five estimates and the absolute value summed for all control stations. The method with the lowest total error is proclaimed the official method or "winner" for the day. Once the winner has been found, the control station gage readings are incorporated into the winning method and the final estimate is computed. When G wins, subroutine INTERP computes the interpolated rainfall field for the entire state using both control and analysis stations. When Q wins, the previously computed satellite estimate is the field estimate (but all observed gage readings override the satellite in their cells.) When Qa wins, INTERP computes the interpolated error field for the entire state, which is then added to the satellite estimate, producing the final estimate. When Qm wins, INTERP computes the interpolated rainfall field and the final estimate is the mean of this field and the satellite estimate. When Qam wins, INTERP computes both the interpolated rain and error fields, the satellite estimate is added to the error field (Qa field) and the final estimate is the mean of this field and the interpolated rain field. See Figure 3-1 for general flow diagrams.

The curve first used in automated technique relating cloup top temperature to hourly precipitation actually consists of two linear curves with different slopes. -32°C corresponds to 0.01 inch and -56°C corresponds to 0.25 inch; that is, rain increases by 0.01 inch for each 1°C decrease in temperature. Thereafter rain increases by 0.05 inch for each 1°C decrease in temperature of the cloud top. Thus -83°C corresponds to 1.60 inches of rain per hour, and the atmosphere should seldom become colder than this.

For the storm of August 15-16, 1980, the first storm analyzed by the new automated technique, a number of stations which report hourly precipitation amounts were compared with the corresponding cloud top temperature in the pictures at the beginning and end of the hour. A new curve was generated from the resulting scatter diagram. For this curve, -24°C corresponds to 0.01 inch, and -56°C corresponds to 0.17 inch, for an increase of 0.01 inch for each 2°C decrease in temperature. Thereafter rain increases 0.06 inch for each 1°C decrease in temperature, reaching 1.80 inches at -83°C. (See Figure 3-2.)

Both curves have been applied to each of the 1980-81 storms studied. The verifications are listed in Tables 5-1 through 5-22. As a result, the old curve has been adopted as official.

The stations used in analysis and verification of 1978 storms (Figure 2-1) are not uniformly distributed, but these were the only available stations which report at or near 7 a.m. EST (1200Z.) By August 1980 several of these stations had been discontinued, while a considerable number had been added. Figure 3-3 shows the location of stations used in analyzing and verifying the storms of 1980 and 1981. Twelve Nationwide Agricultural Touchtone System (NATS) stations, recruited by VPI&SU, are included. The distribution still leaves eastern Virginia and the southwestern counties under populated. These gaps are to be filled with NATS stations in the near future. Also the delayed stations, which report in the CDS several months late, will have to be replaced unless the observer can be induced to report in real time via NATS.

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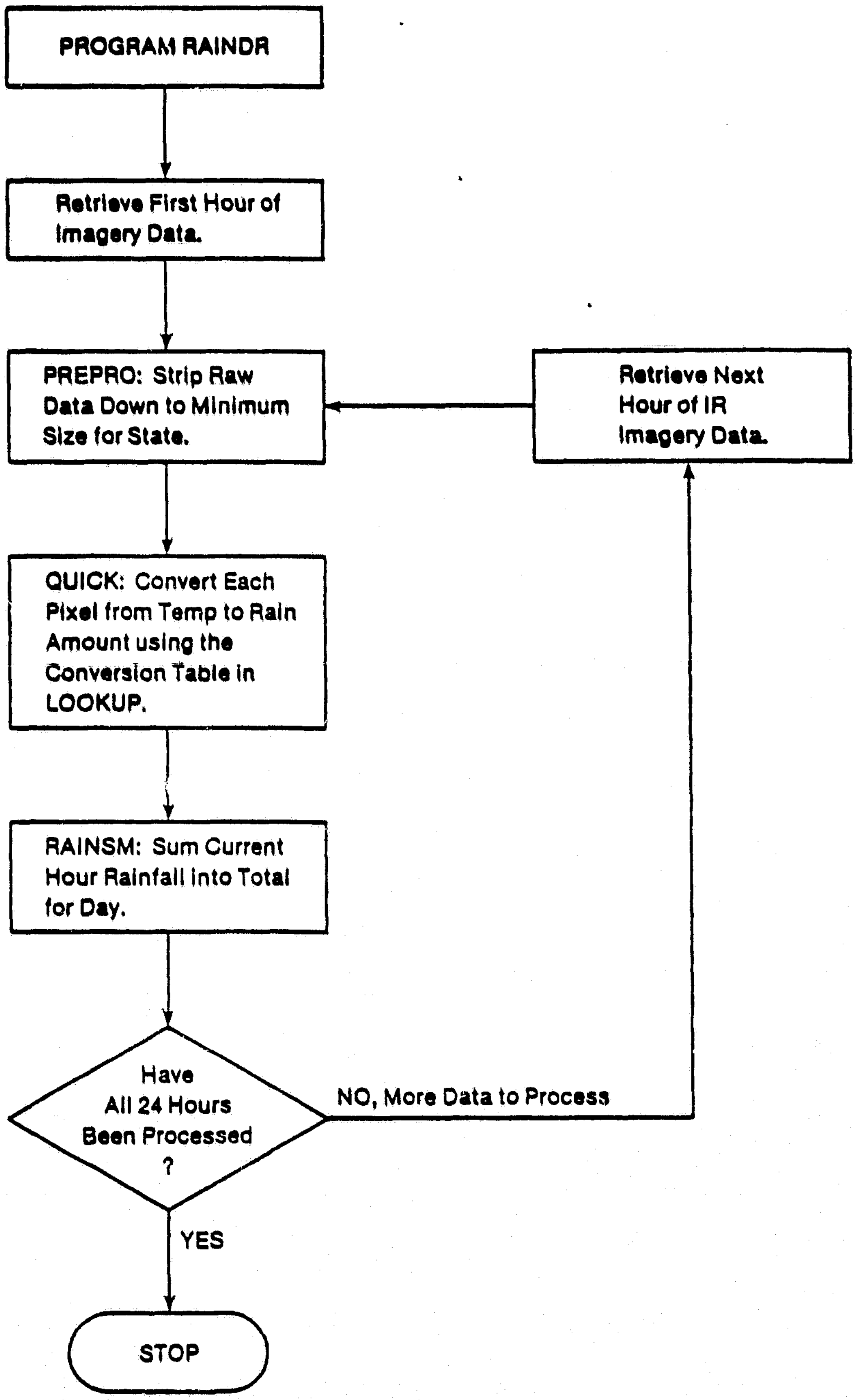

Figure 3-1. Program RAINDR

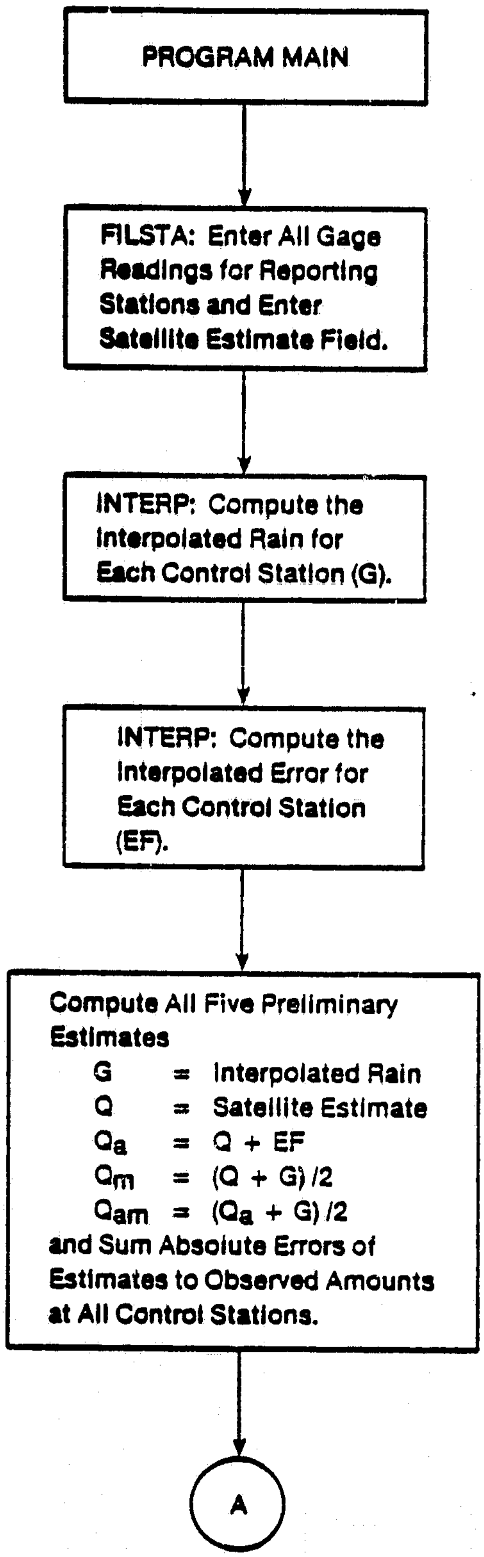

Figure 3-1. Program MAIN

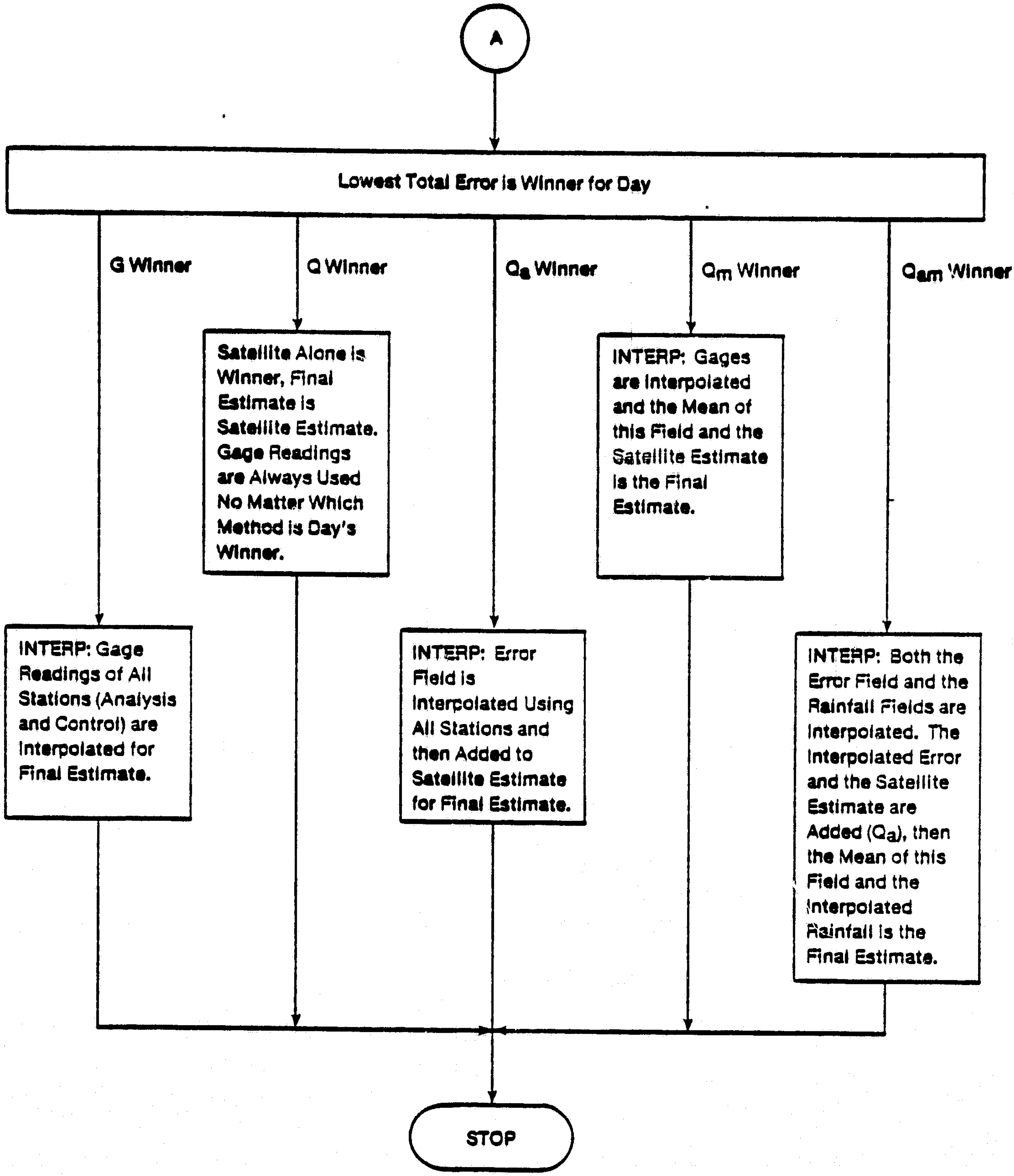

Figure 3-1. Lowest Total Error

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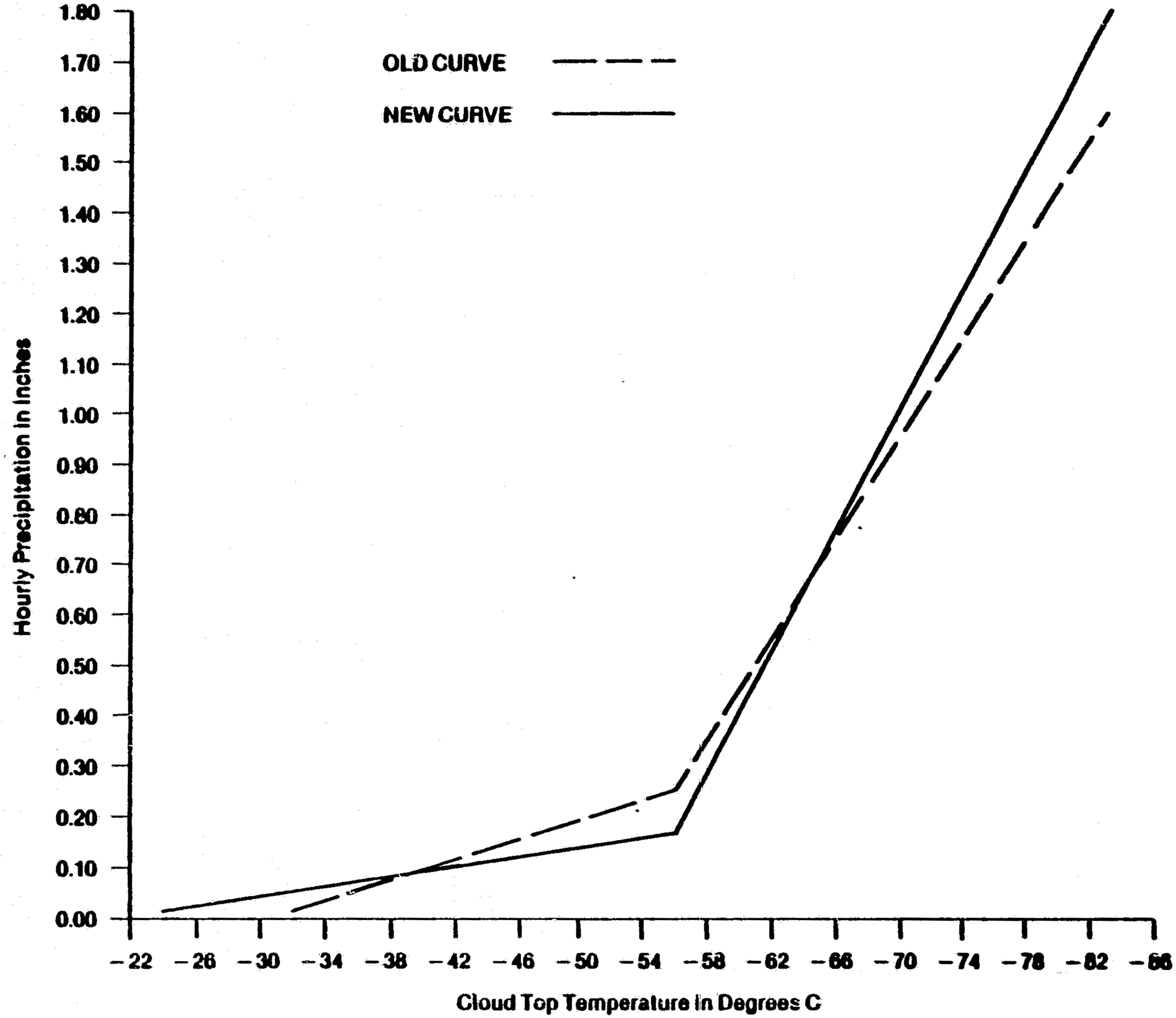

Figure 3-2. Cloud Top Temperature vs Precipitation - Old and New Curves Used in 1980-81 Storms

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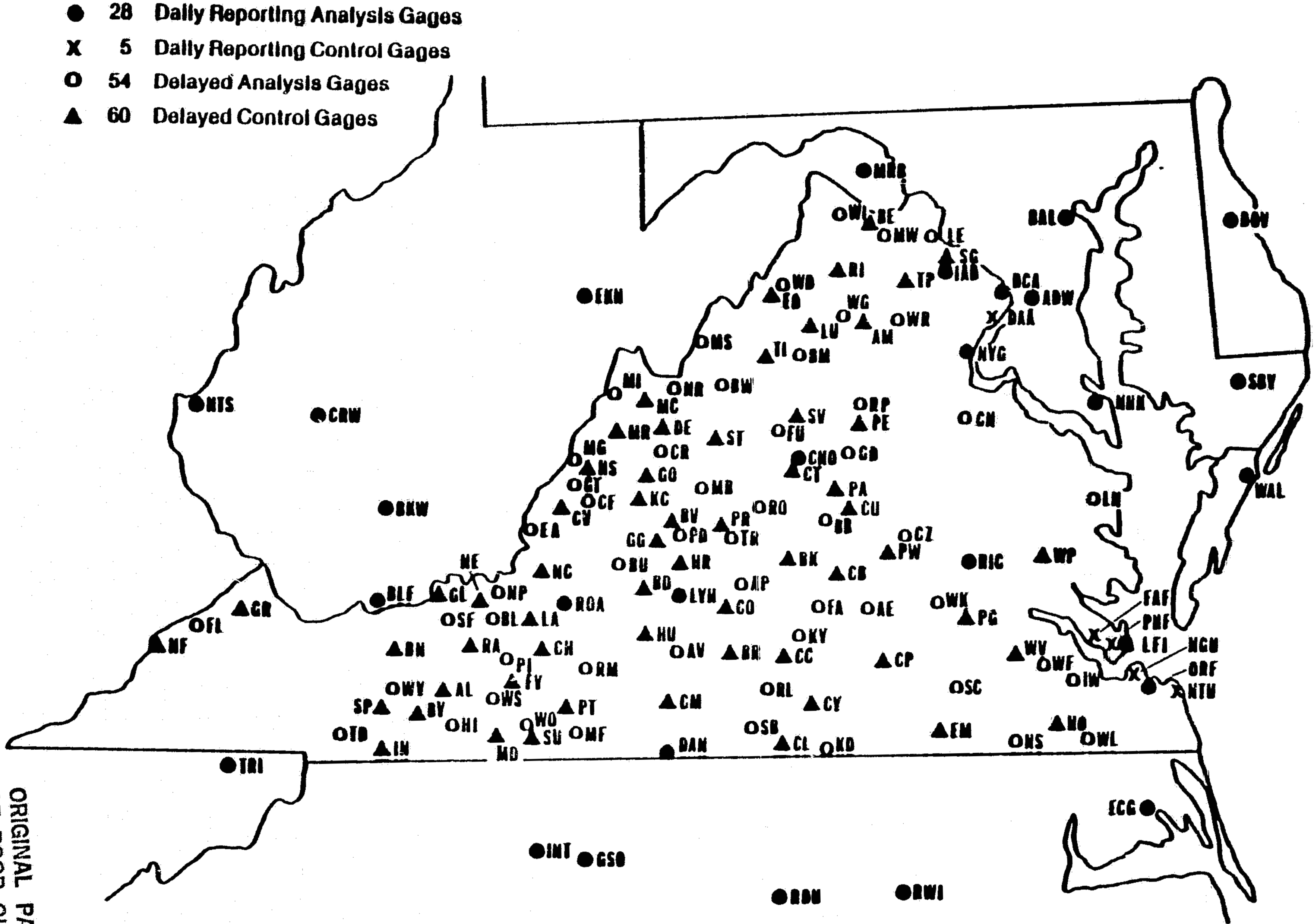

Figure 3-3. Stations Used in Analysis and Verification in 1980-81 Storms

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The automated technique generates five fields of 24-hour precipitation estimates for the state of Virginia, tests each field against control data, and chooses (for the day in question) the field which makes the best score. The fields, designated G, Q, Qm, Qa and Qam, may be subdivided into preliminary and final fields as the technique proceeds. Each field consists of 2885 rectangular cells which cover the state.

All 24-hour rain gage readings taken at or near 7 a.m. EST (noon GMT) are ingested by the mini-computer, which interpolates between the analysis stations to get the preliminary G field. The control gage readings are stored by the computer for future use. The preliminary G field provides a 24-hour estimate of precipitation for each cell in the state for the period from 7 a.m. to 7 a.m. EST (1200Z to 1200Z.)

Hourly digital IR imagery for the 24-hour period is received via auto-dial from the NMC data tank. The mini-computer assigns an hourly precipitation estimate to each cell in Virginia, using the curve relating cloud top temperature to precipitation. The hourly precipitation estimates are summed by the comptuer to provide a 24-hour total for each cell. This is the preliminary Q field.

Each observed gage measurement is considered ground truth for the 9.7 by 6.2 km cell in which the gage is located. This observed value overrides any estimate based on the satellite data in that cell. Therefore the computer compares the observed amount at each analysis station with the satellite (Q) estimate for that cell, the difference being the error in the Q field in that cell. An error field for Q is then obtained by interpolation between all analysis stations, but not the control stations. This error field is used to modify all cells in the Q field. These modified cells comprise the Qa field, or the adjusted satellite field.

For example, suppose that cell A lies somewhere between cells B, C, D and E, which contain analysis stations (see Figure 3-4.) To obtain the probable error in the Q field at cell A, the Q field errors at B, C, D and E are given weights in proportion to the inverse (reciprocal) of their respective distances from A. Distances between cells are measured from cell center to cell center. Say that B lies 50 km southwest of A; C lies 40 km westnorthwest of A; D is 70 km north of A; and E is 60 km east of A. We'll assume that no other analysis station lies within 100 km of A (the technique's arbitrary cut-off distance for influence.) The influence B exerts on A

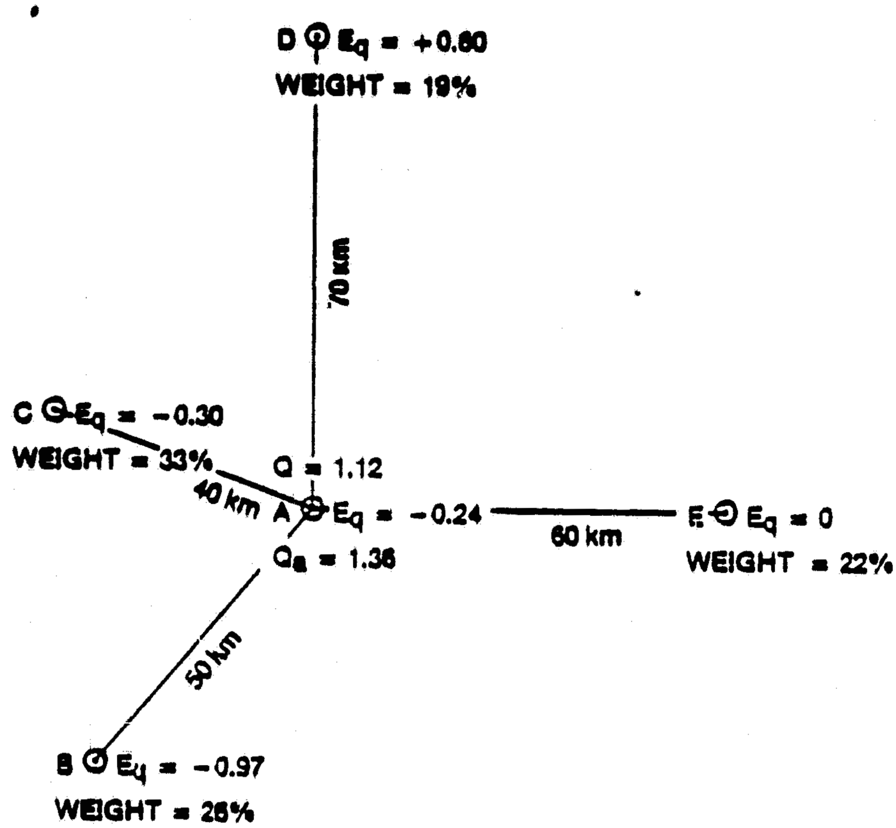

Figure 3-4. Interpolation Procedure as used to Derive Q Error Field

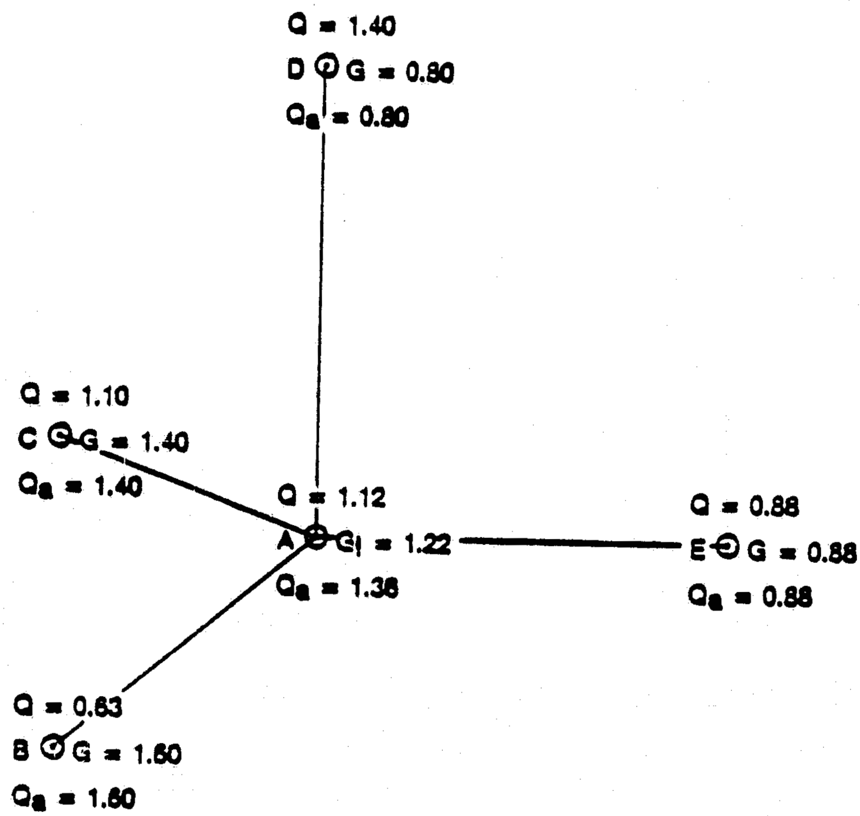

Figure 3-5. Interpolation Procedure as used to Derive G Field

is proportional to the inverse of the distance from A to B; that is, the reciprocal of 50, or 0.02. C's influence is the reciprocal of 40, or 0.025. D's influence is 0.014, and E's influence is 0.017. The total influence is their sum, which is 0.076. This assigns B 26% of the weight, C 33%, D 19% and E 22%. If the Q error at B is, say, -0.97, at C is -0.30 inch, at D is +0.60 inch, and at E is zero, then B will contribute -0.252 inch to the error at A, C will contribute -0.099 inch, D will contribute +0.114 inch, and E will contribute zero. The algebraic sum is -0.237, or -0.24 inch, the probable error in the Q field at A. If the Q value at A is, say, 1.12 inches, then the Qa value at A will be 1.36 inches.

At this point the computer could perform this adjustment of the Q estimates for each cell in the state to derive the Qa field, but in practice it now makes the adjustment at the control station only. Note that the Qa value at each analysis station will equal the observed gage measurement, but that Qa will rarely equal the gage measurement at each control station.

The next step is to derive the Qm field. The computer performs this task by taking the mean of G and Q values in each cell. However, at each analysis station the gage reading will override any differing Q value in that cell. That is, in each analysis gage cell, G=Q=Qm.

The Qam field is derived in the same way, by determining the mean between the G and Qa values in each cell in that state.

For verification, an error is computed for each field at each of the control stations. The errors for each field are summed, and the field with the least absolute error is chosen as the "best" precipitation field for the 24-hour period in question. This is sti a preliminary field. It must now be adjusted by means of a control gage readings, which up to this point have not been used in any of the analyses, to get the final official precipitation field for the day.

The example in Figure 3-4 is further expounded in Figure 3-5. Hypothetical G and Q values have been entered at points B, C, D and E, and are compatible with the errors in Q shown in Figure 3-4. Multiplying the G values, i.e. 1.60, 1.40, 0.80 and 0.88 by 26%, 33%, 19% and 22%, respectively, and summing, we get an interpolated G estimate, G_i, of 1.22 inches at A. The Qm estimate at A is the mean of the G and Q values, or 1.17 inches. The Qam estimate is the mean of the G and Qa values, or 1.29 inches. (Note that G and Qa do not have the same value at A, since G is merely interpolated, not ground truth. Also note that Q at point A is not an interpolation of the Q values at B, C, D and E, since it has been derived directly from the satellite imagery.)

Assume that point A is a control station. In this event, the measured amount at A is ground truth and will be used to determine the error at A of each estimate field. The estimates, of course, will have no influence on the observed amount. In our example, if the observed precipitation at A is 1.32 inches, then the errors are G=-0.10, Q=-0.20, Qm=-0.15, Qa=+0.04, and Qam=-0.03 inch.

The computer compares the estimate obtained by each of the five methods at each control point with the corresponding gage measurement and computes the correlation coefficient, R, for each method. Normally the method with the smallest total absolute error will have the highest correlation coefficient, but when two methods are virtually equal in least total absolute error, R may be used as a tie-breaker.

SECTION 4 - CRITIQUE OF AUTOMATED TECHNIQUE

The temperature of cloud tops depicted in infrared satellite imagery accounts for some of the variability in precipitation under those clouds. A scheme which attempts to estimate precipitation from cloud top temperature alone suffers from great over-simplification and can attain only limited success. Alternatively, the inclusion of other parameters (not including observed rainfall) complicates the procedure, necessitating either more complex computer modelling or the services of an on-the-job satellite meteorologist. The meteorologist would take cognizance of the following rules, among others:

(1) Shields of cirrus and cirrostratus are cold, but taken alone produce no precipitation.

(2) In the convective regimes of warm weather, thunderstorms and heavy rain tend to be concentrated in the sharply defined upwind (at cirrus level) portion of the cold cloud mass rather than in the filmy ill-defined downwind portion.

(3) Convective cells are often embedded in synoptic-scale systems, particularly in colder months, but are detected only with difficulty by the satellite meteorologist.

(4) Heavier precipitation generally occurs in the comma cloud, in areas of maximum positive vorticity advection, and near the inflection point of the jet stream over or near a front as delineated in the satellite imagery.

(5) On occasion the coldest clouds over the state will be non-precipitating debris from old systems, while somewhat warmer clouds are producing copious rain or snow.

The expertise of a trained satellite meteorologist on a continuing basis is required to recognize and cope with situations such as those referred to in the above examples. It is with this in mind that we should evaluate any shortcomings of the automated technique, which does have the decided advantage of requiring no expert input.

Missing data, and garbled data received by auto-dial from the NMC computer, have plagued the investigation and may well plague operations in future. (Fifteen out of 24 hours of data were missing during the storm of March 5-6, 1981, and 14 hours were missed during the September 17-18, 1980 storm. (see Table 4-1) Interpolation algorithms are fairly reliable when a <u>single</u>

Table 4-1: Pixel Shift, Observed Storm Total (Precipitation), and Number of Control Stations, Analysis Stations and Missing Hours of Satellite Data for Storms of 1980 and 1981

Storm Date	Pixel Shift	Storm Total#	Control Stations	Analysis Stations	Missing Hours
1980					
Aug 15-16	3S 1E	7.61	47	63	11
Sep 9-10	3S 2E	4.75	51	61	12
Sep 16-17	2S 0	0.24	52	66	10
Sep 17-18	5S 1E	20.36	56	73	14
Sep 24-25	2S 2W	27.12	56	69	10
Sep 25-26	2S 1W	3.61	53	68	7
Oct 24-25	0 1E	41.13	49	63	3
Nov 15-16	4S 0	5.71	48	59	5
Nov 17-18	1S 1W	39.75	52	71	4
Dec 9-10	2S 0*	11.24	53	80	7
1981					
Mar 4-5	1S 0	25.56	57	68	6
Mar 5-6	1S2W	2.23	54	68	15
Mar 16-17	2S 0*	4.85	50	62	7
Mar 22-23	2S 0*	25.26	53	67	12
Mar 29-30	2S 0*	9.99	51	64	4
Mar 30-31	1S 2W	22.20	51	58	7
Apr 14-15	2S 0*	12.40	53	74	6
May 15-16	2S 0*	5.08	53	62	7
May 18-19	2S 0*	31.66	53	66	9
May 19-20	2S 0*	26.47	53	64	9
Jul 21-22	1N 2W	2.69	17	32	6

Inches. *Overall mean shift.

hour of data is missing. A particularly unsatisfactory situation is several hours of missing data at the very beginning or end of the day, with no anchor point for the interpolation. Recently reception has improved, but three or four missing hours per day is not uncommon. Garbling, a very serious problem in the early stages of the investigation, has been nearly eliminated.

The digital imagery received via auto-dial consists of an array of 129 by 129 pixels. The picture center (the 65th pixel of the 65th row) is supposed to be at 37° north latitude, 79° west longitude, about five kilometers southwest of Brookneal, Virginia. Cloud features in actual satellite EIR photographs (Figure 4-1) were carefully compared with the corresponding features in the digital imagery accessed by auto-dial (Figure 4-2.) In 13 storms occurring between August 1980 and March 1981, geographical location of the clouds was somewhat different in the two types of imagery. In general it was necessary to shift the digital pixels to the north to bring cloud patterns into line with their counterparts in the EIR photographs. Put another way, it was necessary to examine pixels to the south of the 65th pixel of the 65th row to find clouds over 37° north, 79° west (picture center). The actual shift of the stations varied from storm to storm, and even from hour to hour, but averaged two pixels south and almost one-half pixel east for all cases. That is, instead of looking for the cloup top temperature over Richmond at the 88th pixel in the 59th row (the nominal position for Richmond) we should expect it in the 88th pixel (or perhaps the 89th) in the 61st row. We have not found the reason for this shift, but NMC is aware of it and is attempting to solve the problem.

Figure 4-1 is the EIR photograph taken by the geostationary satellite at 0300Z August 16, 1980, showing cloud features in relation to geographical landmarks. Figure 4-2 is the corresponding digital imagery for 0300Z August 16, 1980, accessed by auto-dial. Careful examination of clouds in relation to landmarks shows that corrections in registration must be made in the digital product to bring it into alignment with the EIR photograph (which has been quite accurately registered by the National Environmental Satellite Service). These corrections are indicated in Table 4-2. The shift column shows the direction of the error. The correction must be made in the opposite direction.

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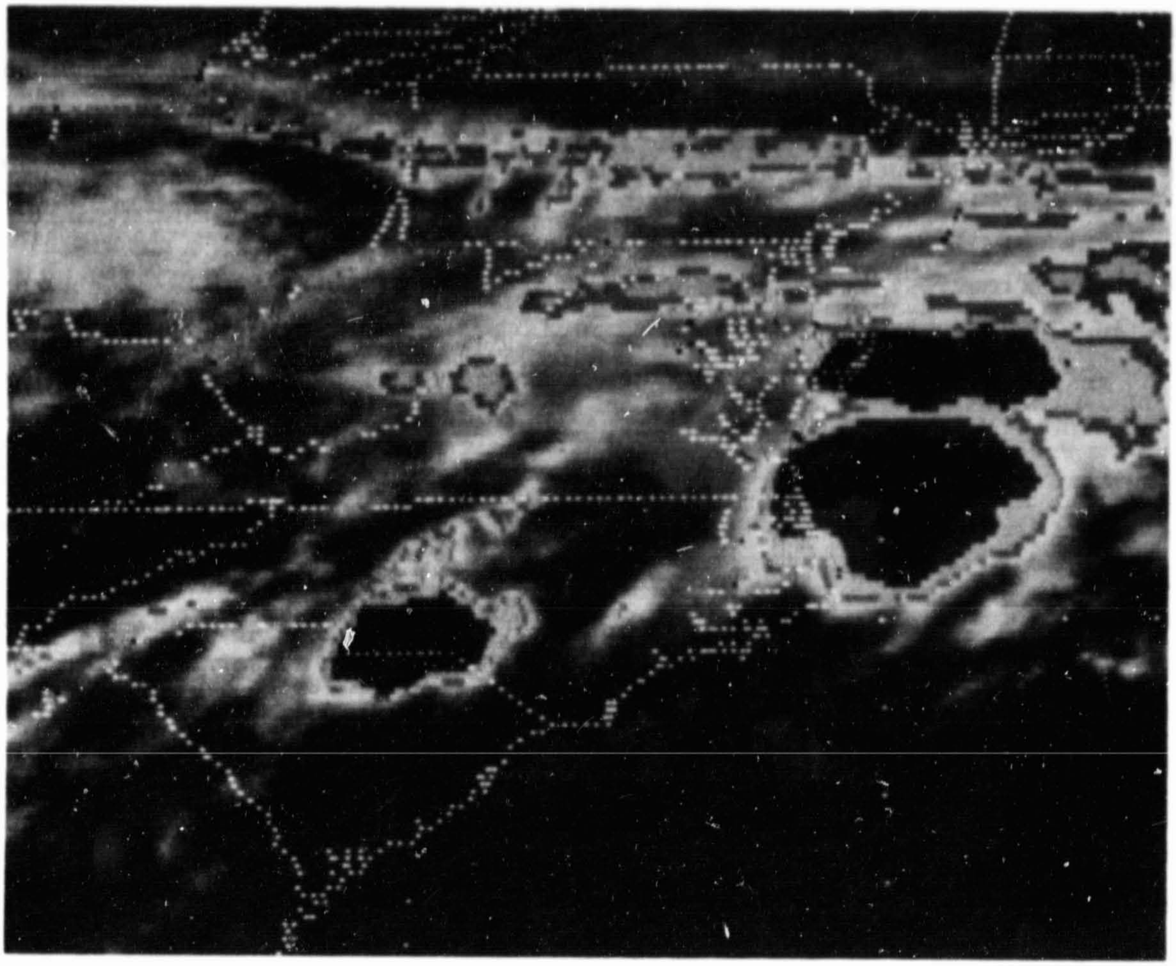

Figure 4-1. EIR Photograph taken at 0300Z August 16, 1980
showing Cloud Features in Relation to Landmarks

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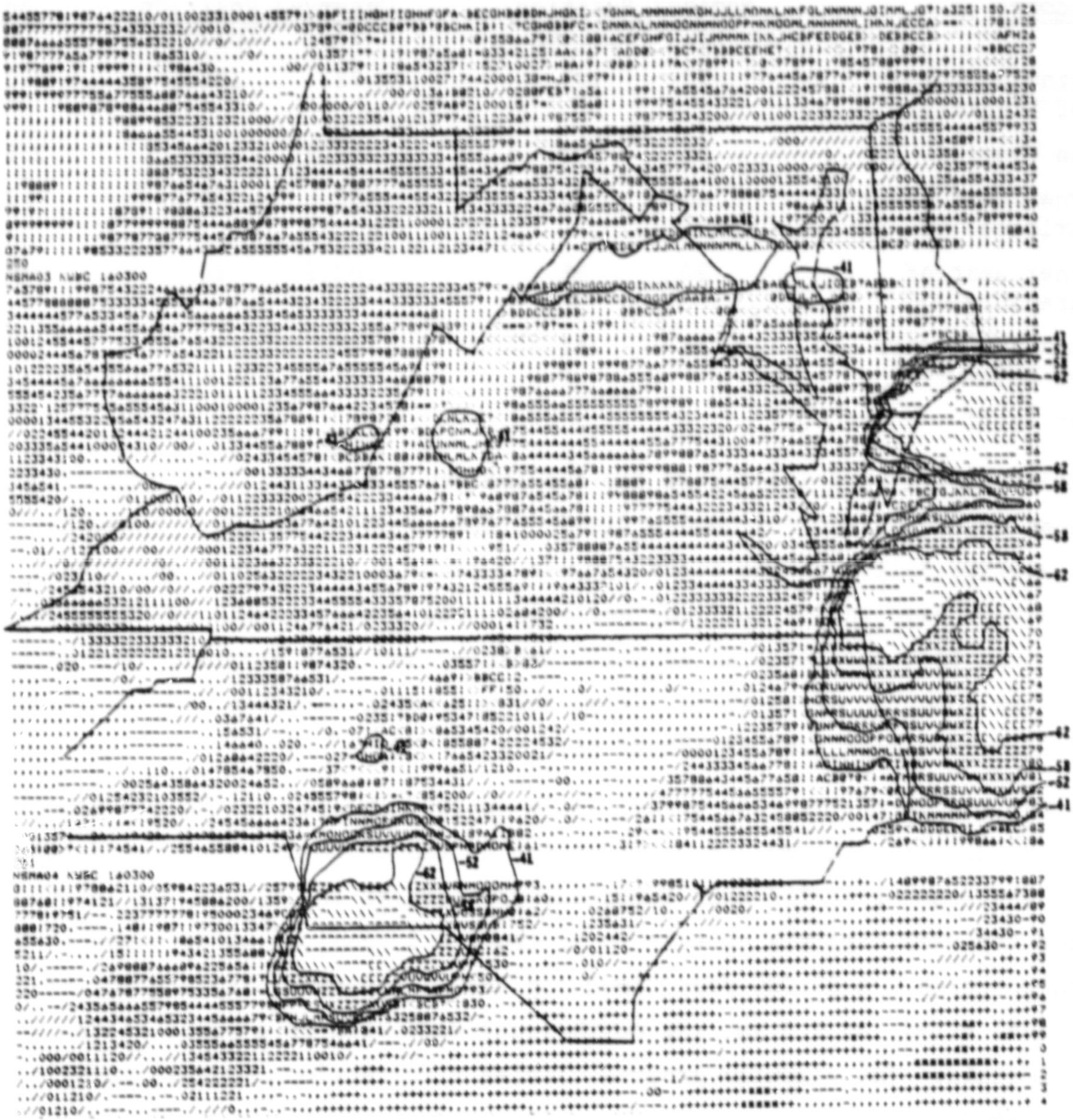

Figure 4-2. Digital Imagery Accessed by Auto-dial at 0300Z August 16, 1980 showing Cloud Features in Relation to Landmarks

Table 4-2. Apparent Shift in Landmark Positions in Digital Imagery for 0300Z August 16, 1980

Landmark	Nominal Position Row	Nominal Position Column	Observed Position Row	Observed Position Column	Shift
Southeast corner of Virginia	70	109	73	108.5	3S 0.5W
Cape Charles	63	108	65.5	107	2.5S 1W
Corner west of Charlotte, NC	85	35	87	38	2S 3E
Corner west of Laurenburg, NC	90	55	92.5	56	2.5S 1E
Southwest corner of Delaware	48	112	48	110	0 2W
Mean Shift					2S 0.1E

Similar shifts were determined for the imagery for 2000Z, 2100Z and 2200Z of August 15, 1980, and for 0000Z, 0100Z, 0200Z, 0400Z and 0600Z of August 16, 1980. The average shift for the storm day was 3 south 1 east. Four additional landmarks were used in the full day analysis: the southwest tip of Maryland (row 39/column 58); the junction of Ohio, Kentucky and West Virginia (row 48/column 13); the junction of Virginia, Tennessee and North Carolina (row 69/column 26); and Picture Center (row 65/column 65).

Another source of possible error, which applies equally to the EIR photographs and the digital imagery, is parallax due to the angle at which the satellite over the equator at 75° west longitude photographs the clouds. A 40,000 foot cloud top over Virginia appears to be about 6.5 nautical miles north of its true position. A 30,000 foot cloud top has an apparent displacement of 5.3 nautical miles, or 9.8 km, the north-south dimension of a pixel in the latitude of Virginia. The computer program carries a correction for this parallax phenomenon.

SECTION 5 - ANALYSIS OF EXPERIMENTAL STORMS OF 1980-81

The automated technique was tested on 21 storms which occurred in 1980 and 1981. Composite scores for these storms are shown in Table 5-1. The scores attained by each of the five methods are tabulated in Tables 5-2 through 5-22. Table 5-23 shows how frequently each method had the highest correlation coefficient (estimated vs observed precipitation), the least mean absolute error, and the least mean algebraic error (overestimates and underestimates). The G method makes the highest scores overall, somewhat better with the old curve (cloud top temperature vs precipitation) than with the new curve. The Qam method does well in least mean absolute error, particularly with the new curve. Qa scores well in bias (mean algebraic error), leading on six storms (29 percent) with each curve.

While the technique is designed primarily to estimate growing season rain, most of it convective in nature, only five of the 21 storms in the study were typical airmass storms. The remaining 16 were associated with fronts and synoptic-scale low pressure systems. Appendix B gives a brief description of the synoptic situation for each of the storms.

The original computer program was completed and the link with NMC's computer was established in August 1980. Four summer storms were accessed and analyzed between August 15 and September 21, 1980. Among these the "storm" of September 16-17 produced very little rain. Subsequently six storms in autumn, three in winter and seven in spring were studied. Storms over Virginia were scarce in the summer of 1981, and the storm of July 21-22, 1981 alone was accessed and analyzed. Only 17 control stations and 29 analysis stations were available for this storm; the results therefore should be viewed with caution.

In view of the scarcity of summer airmass storms during the experimental period from August 1980 to July 1981, the uniform rainfall patterns observed should not be surprising. A good example of uniform distribution is the weak storm of April 14-15, 1981. (See Figure 5-1.) Heaviest rain in Virginia (one-half to three-quarters of an inch) occurred in an eliptical area extending between Trout Dale and Hillsville in the southwest part of the state. Most other sections had between 0.1 and 0.4 inch, and only three reporting points had no rain. Whenever such uniformity prevails the interpolation algorithm incorporated into the program makes the "gages only" routine hard to beat by any satellite method.

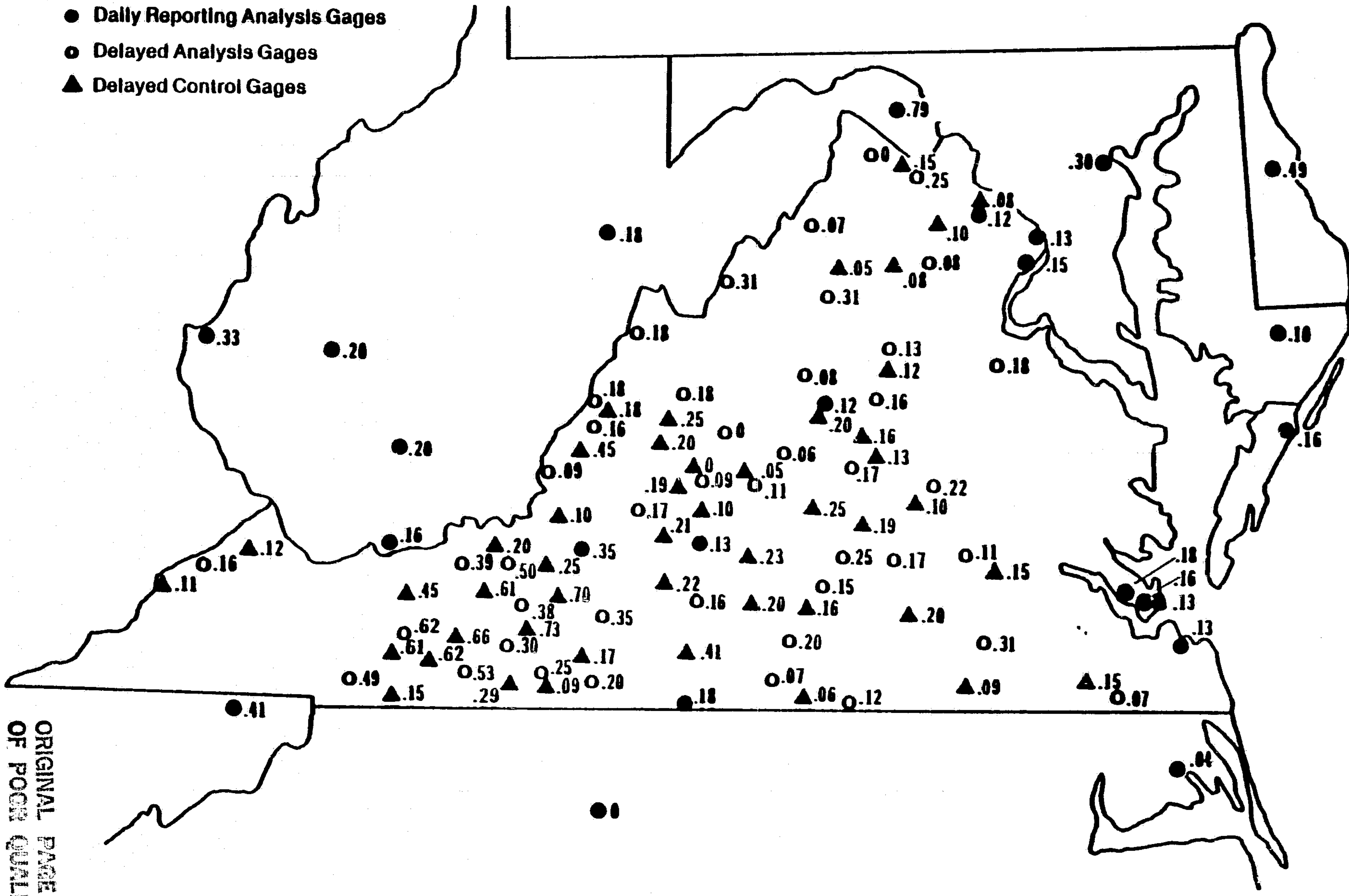

Figure 5-1. Precipitation Pattern on April 14-15, 1981

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Table 5-1. Composite Scores for each Method for 21 Storms in 1980-81

	Q	G	Qa	Qm	Qam
Old Curve					
Mean Absolute Error (inches)	0.525	<u>0.123</u>	0.181	0.295	0.145
Mean Algebraic Error (inches)	+0.310	+<u>0.004</u>	+0.043	+0.157	+0.024
New Curve					
Mean Absolute Error (inches)	0.547	<u>0.123</u>	0.172	0.311	0.143
Mean Algebraic Error (inches)	+0.428	+<u>0.004</u>	+0.042	+0.216	+0.023

N=1062. Best scores underlined.

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Table 5-2. Scores for Storm August 15-16, 1980

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.687	0.836	0.800	0.768	0.863
Mean Absolute Error*	0.259	0.093	0.110	0.159	0.089
Mean Algebraic Error*	+0.206	-0.001	+0.037	+0.103	+0.018
New Curve					
Correlation Coefficient	0.715	0.836	0.771	0.788	0.853
Mean Absolute Error*	0.411	0.093	0.116	0.229	0.091
Mean Algebraic Error*	+0.403	-0.002	+0.025	+0.201	+0.010

N=47. Mean Rain at Control Station: 0.162 inch. *Inches.

Table 5-3. Scores for Storm September 9-10, 1980

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.466	0.832	0.624	0.687	0.770
Mean Absolute Error*	0.214	0.056	0.089	0.125	0.065
Mean Algebraic Error*	+0.170	-0.020	+0.001	+0.075	-0.010
New Curve					
Correlation Coefficient	0.490	0.832	0.647	0.718	0.773
Mean Absolute Error*	0.240	0.056	0.077	0.141	0.060
Mean Algebraic Error*	+0.201	-0.020	-0.007	+0.090	-0.014

N=51. Mean Rain at Control Stations: 0.093 inch. *Inches.

Table 5-4. Scores for Storm September 16-17, 1980

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	-0.087	0.452	0.077	-0.020	0.193
Mean Absolute Error*	0.024	0.006	0.013	0.015	0.010
Mean Algebraic Error*	+0.015	-0.002	+0.004	+0.006	+0.001
New Curve					
Correlation Coefficient	-0.161	0.452	-0.086	-0.118	0.075
Mean Absolute Error*	0.072	0.006	0.014	0.039	0.010
Mean Algebraic Error*	+0.065	-0.002	+0.005	+0.032	+0.002

N=52. Mean Rain at Control Station: 0.005 inch. *Inches.

Table 5-5. Scores for Storm September 17-18, 1980

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.183	0.619	0.642	0.605	0.637
Mean Absolute Error*	0.351	0.227	0.232	0.260	0.229
Mean Algebraic Error*	-0.307	-0.051	-0.060	-0.179	-0.055
New Curve					
Correlation Coefficient	0.276	0.619	0.637	0.609	0.631
Mean Absolute Error*	0.316	0.227	0.229	0.251	0.228
Mean Algebraic Error*	-0.246	-0.051	-0.057	-0.148	-0.054

N=56. Mean Rain at Control Stations: 0.364 inch. *Inches.

Table 5-6. Scores for Storm September 24-25, 1980

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.009	0.501	0.326	0.298	0.425
Mean Absolute Error*	0.397	0.252	0.280	0.287	0.262
Mean Algebraic Error*	-0.293	-0.031	-0.027	-0.162	-0.029
New Curve					
Correlation Coefficient	-0.026	0.501	0.405	0.384	0.462
Mean Absolute Error*	0.323	0.252	0.265	0.270	0.258
Mean Algebraic Error*	-0.112	-0.031	-0.022	-0.071	-0.026

N=56. Mean Rain at Control Station: 0.484 inch. *Inches.

Table 5-7. Scores for Storm September 25-26, 1980

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	-.00002	0.263	0.057	0.032	0.152
Mean Absolute Error*	1.014	0.071	0.115	0.512	0.089
Mean Algebraic Error*	+1.013	+0.010	+0.037	+0.512	+0.024
New Curve					
Correlation Coefficient	0.015	0.263	0.205	0.062	0.252
Mean Absolute Error*	1.154	0.071	0.089	0.582	0.078
Mean Albebraic Error*	+1.154	+0.010	+0.022	+0.582	+0.016

N=53. Mean Rain at Control Stations: 0.068 inch. *Inches.

Table 5-8. Scores for Storm October 24-25, 1980

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.429	0.575	0.575	0.556	0.583
Mean Absolute Error*	0.504	0.268	0.288	0.316	0.268
Mean Algebraic Error*	-0.282	+0.054	+0.075	-0.114	+0.064
New Curve					
Correlation Coefficient	0.456	0.575	0.590	0.578	0.588
Mean Absolute Error*	0.377	0.268	0.275	0.289	0.266
Mean Algebraic Error*	-0.106	+0.054	+0.077	-0.026	+0.066

N=49. Mean Rain at Control Station: 0.839 inch. *Inches.

Table 5-9. Scores for Storm November 15-16, 1980

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.111	0.530	0.240	0.148	0.288
Mean Absolute Error*	0.457	0.060	0.304	0.247	0.177
Mean Algebraic Error*	+0.340	+0.002	0.237	+0.171	+0.120
New Curve					
Correlation Coefficient	0.093	0.530	0.225	0.125	0.268
Mean Absolute Error*	0.884	0.060	0.337	0.446	0.194
Mean Algebraic Error*	+0.884	+0.002	+0.269	+0.443	+0.135

N=48. Mean Rain at Control Stations: 0.119 inch. *Inches.

Table 5-10. Scores for Storm November 17-18, 1980

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.363	0.682	0.506	0.591	0.606
Mean Absolute Error*	0.477	0.186	0.221	0.280	0.202
Mean Algebraic Error*	-0.428	+0.018	+0.031	-0.205	+0.025
New Curve					
Correlation Coefficient	0.425	0.682	0.551	0.608	0.625
Mean Absolute Error*	0.286	0.186	0.210	0.221	0.196
Mean Algebraic Error*	-0.135	+0.018	+0.018	-0.058	+0.018

N=52. Mean Rain at Control Station: 0.764 inch. *Inches.

Table 5-11. Scores for Storm December 9-10, 1980

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	-0.089	0.197	0.078	-0.056	0.129
Mean Absolute Error*	1.663	0.096	0.213	0.836	0.136
Mean Algebraic Error*	+1.663	+0.009	+0.061	+0.836	+0.035
New Curve					
Correlation Coefficient	-0.136	0.197	0.006	-0.081	0.077
Mean Absolute Error*	1.638	0.096	0.170	0.824	0.120
Mean Algebraic Error*	+1.638	+0.009	+0.041	+0.824	+0.025

N=53. Mean Rain at Control Stations: 0.212 inch. *Inches.

Table 5-12. Scores for Storm March 4-5, 1981

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	-0.027	0.726	0.207	0.063	0.297
Mean Absolute Error*	1.112	0.087	0.494	0.560	0.274
Mean Albebraic Error*	+1.112	+0.007	+0.315	+0.559	+0.161
New Curve					
Correlation Coefficient	-0.018	0.726	0.210	0.066	0.291
Mean Absolute Error*	1.205	0.087	0.533	0.606	0.289
Mean Algebraic	+1.205	+0.007	+0.362	+0.606	+0.184

N=57. Mean Rain at Control Station: 0.448 inch. *Inches.

Table 5-13. Scores for Storm March 5-6, 1981

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.257	0.532	0.545	0.564	0.539
Mean Absolute Error*	0.041	0.046	0.045	0.033	0.045
Mean Algebraic Error*	-0.038	+0.027	+0.025	-0.005	+0.026
New Curve					
Correlation Coefficient	0.030	0.532	0.495	0.386	0.524
Mean Absolute Error*	0.149	0.046	0.051	0.094	0.047
Mean Algebraic Error*	+0.134	+0.027	+0.026	+0.081	+0.026

N=54. Mean Rain at Control Stations: 0.041 inch. *Inches.

Table 5-14. Scores for Storm March 16-17, 1981

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.059	0.658	0.482	0.510	0.587
Mean Absolute Error*	0.107	0.059	0.082	0.079	0.069
Mean Algebraic Error*	-0.004	-0.005	+0.005	-0.005	-0.00045
New Curve					
Correlation Coefficient	0.289	0.658	0.604	0.559	0.643
Mean Absolute Error*	0.308	0.059	0.067	0.164	0.060
Mean Algebraic	+0.299	-0.005	-0.005	+0.147	-0.005

N=50. Mean Rain at Control Station: 0.097 inch. *Inches.

Table 5-15. Scores for Storm March 22-23, 1981

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	-0.062	0.805	0.762	0.411	0.803
Mean Absolute Error:	1.652	0.148	0.182	0.862	0.154
Mean Algebraic Error:	+1.647	+0.062	+0.051	+0.854	+0.057
New Curve					
Correlation Coefficient	-0.022	0.805	0.799	0.598	0.809
Mean Absolute Error:	1.330	0.148	0.150	0.699	0.145
Mean Algebraic	+1.330	+0.062	+0.051	+0.696	+0.056

N=53. Mean Rain at Control Stations: 0.477 inch. *Inches.

Table 5-16. Scores for Storm March 29-30, 1981

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.432	0.714	0.392	0.552	0.616
Mean Absolute Error*	1.022	0.113	0.161	0.499	0.130
Mean Algebraic	+1.012	-0.052	+0.004	+0.480	-0.024
New Curve					
Correlation Coefficient	0.437	0.714	0.555	0.587	0.671
Mean Absolute Error*	1.058	0.113	0.137	0.517	0.123
Mean Algebraic Error*	+1.054	-0.052	-0.020	+0.501	-0.036

N=51. Mean Rain at Control Stations: 0.196 inch. *Inches.

Table 5-17. Scores for Storm March 30-31, 1981

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.170	0.498	0.445	0.456	0.484
Mean Absolute Error:	0.475	0.174	0.203	0.298	0.184
Mean Algebraic Error:	+0.413	-0.016	-0.034	+0.199	-0.025
New Curve					
Correlation Coefficient	0.284	0.498	0.493	0.523	0.500
Mean Absolute Error*	0.388	0.174	0.182	0.260	0.177
Mean Algebraic Error*	+0.312	-0.016	-0.026	+0.148	-0.021

N=51. Mean Rain at Control Stations: 0.435 inch. *Inches.

Table 5-18. Scores for Storm April 14-15, 1981

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.274	0.565	0.434	0.450	0.543
Mean Absolute Error*	0.213	0.112	0.144	0.142	0.116
Mean Albebraic Error*	+0.039	-0.012	-0.008	+0.014	-0.010
New Curve					
Correlation Coefficient	0.067	0.565	0.448	0.304	0.539
Mean Absolute Error*	0.268	0.112	0.131	0.176	0.115
Mean Algebraic Error*	+0.204	-0.012	-0.013	+0.096	-0.012

N=53. Mean Rain at Control Station: 0.234 inch. *Inches.

Table 5-19. Scores for Storm May 15-16, 1981

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.683	0.620	0.732	0.741	0.689
Mean Absolute Error*	0.067	0.067	0.059	0.055	0.059
Mean Algebraic Error*	-0.062	+0.003	-0.005	-0.029	-0.001
New Curve					
Correlation Coefficient	0.624	0.620	0.716	0.718	0.674
Mean Absolute Error*	0.064	0.067	0.057	0.058	0.060
Mean Algebraic Error*	-0.051	+0.003	-0.008	-0.024	-0.003

N=53. Mean Rain at Control Stations: 0.096 inch. *Inches.

Table 5-20. Scores for Storm May 18-19, 1981

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.498	0.544	0.588	0.585	0.611
Mean Absolute Error*	0.310	0.208	0.213	0.221	0.196
Mean Algebraic Error*	+0.049	+0.040	+0.045	+0.045	+0.043
New Curve					
Correlation Coefficient	0.556	0.544	0.625	0.634	0.617
Mean Absolute Error*	0.326	0.208	0.197	0.237	0.195
Mean Algebraic Error*	+0.268	+0.040	+0.052	+0.154	+0.046

N=53. Mean Rain at Control Station: 0.597 inch. *Inches.

Table 5-21. Scores for Storm May 19-20, 1981

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.483	0.559	0.570	0.628	0.594
Mean Absolute Error*	0.143	0.119	0.148	0.108	0.119
Mean Algebraic Error*	-0.063	+0.020	+0.067	-0.022	+0.043
New Curve					
Correlation Coefficient	0.327	0.559	0.572	0.585	0.580
Mean Absolute Error*	0.182	0.119	0.128	0.124	0.118
Mean Algebraic Error*	+0.137	+0.020	+0.040	+0.078	+0.030

N=53. Mean Rain at Control Stations: 0.499 inch. *Inches.

Table 5-22. Scores for Storm July 21-22, 1981

	Q	G	Qa	Qm	Qam
Old Curve					
Correlation Coefficient	0.389	<u>0.788</u>	0.575	0.531	0.695
Mean Absolute Error*	0.278	<u>0.138</u>	0.168	0.183	0.153
Mean Algebraic Error*	+0.174	+0.062	+<u>0.056</u>	+0.118	+0.059
New Curve					
Correlation Coefficient	0.359	<u>0.788</u>	0.486	0.509	0.649
Mean Absolute Error*	0.281	<u>0.138</u>	0.183	0.185	0.161
Mean Algebraic Error*	+0.171	+0.062	+<u>0.058</u>	+0.117	+0.060

N=17. Mean Rain at Control Station: 0.158 inch *Inches.

Table 5-23. Best Score Frequencies, Storms of 1980-1981

	Q	G	Qa	Qm	Qam
Old Curve					
Highest Correlation Coefficient	0	14	1	3	3
Least Mean Absolute Error	0	16	0	3	2
Least Mean Algebraic Error	0	11	6	1	3
New Curve					
Highest Correlation Coefficient	0	13	2	4	2
Least Mean Absolute Error	0	15	1	0	5
Least Mean Algebraic	0	11*	6*	1	3*

* Includes ties

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Precipitation for the storm of March 4-5, 1981 was more than double that for April 14-15. Again the distribution was quite uniform. (See Figure 5-2.) The G method easily beat the satellite methods in this storm.

The storm of October 24-25, 1980 was fairly uniform, but there were definite exceptions. (See Figure 5-3.) Deerfield (0.05 inch) is surrounded by stations with 0.54, 0.54 and 1.22 inches. Free Union (0.10 inch) is surrounded by stations with 0.54, 1.27, 0.91, 1.10, 1.33 and 2.08 inches. Qam verified best in this storm.

The storm of August 15-16, 1980 demonstrates the irregular patterns of summer. (See Figure 5-4.) Thunderstorms in southeastern Virginia and the Eastern Shore brought more than an inch in many places, and 4.13 inches to Norfolk. A gage near Virginia Beach received six inches in less than two hours. Significant rain occurred in irregular patterns in northern and north central Virginia, but most of the James River Basin above Richmond got no rain. The highest scores in this storm were made by Qam. Thus, as the rainfall patterns become more irregular, the satellite's contribution to the technique increases significantly.

Overall the highest correlations were obtained in the summer storm of August 15-16, but R was also relatively high in the storms of September 9-10, 1980 and May 15-16, 1981. The poorest correlations occurred on December 9-10, September 16-17, and September 25-26 (all 1980). Significantly, the mean of all correlation coefficients for Q, Qa, Qm and Qam for the colder period from September 16 to March 17 is a poor 0.300, while for the warmer period from March 22 to September 10 the mean is 0.560 (not that these dates are ideal cutoffs between warm and cold weather, but they do dramatically separate the lower scores from the higher.) These statements hold true regardless of which temperature vs precipitation curve is used. For the G method, however, $\overline{R}$ = 0.520 during the colder period, and $\overline{R}$ = 0.675 during the warmer period. In the colder period the G method has the highest R value in 73 percent of the storms when the old curve is used, and in 82 percent of the storms when the new curve is used. In the warmer period G has the highest R in 60 percent of the storms with the old curve, and only 40 percent with the new curve. In other words, the G method appears to be fairly reliable throughout the year, while the methods involving satellite data are competitive in the warmer months but suspect in the colder.

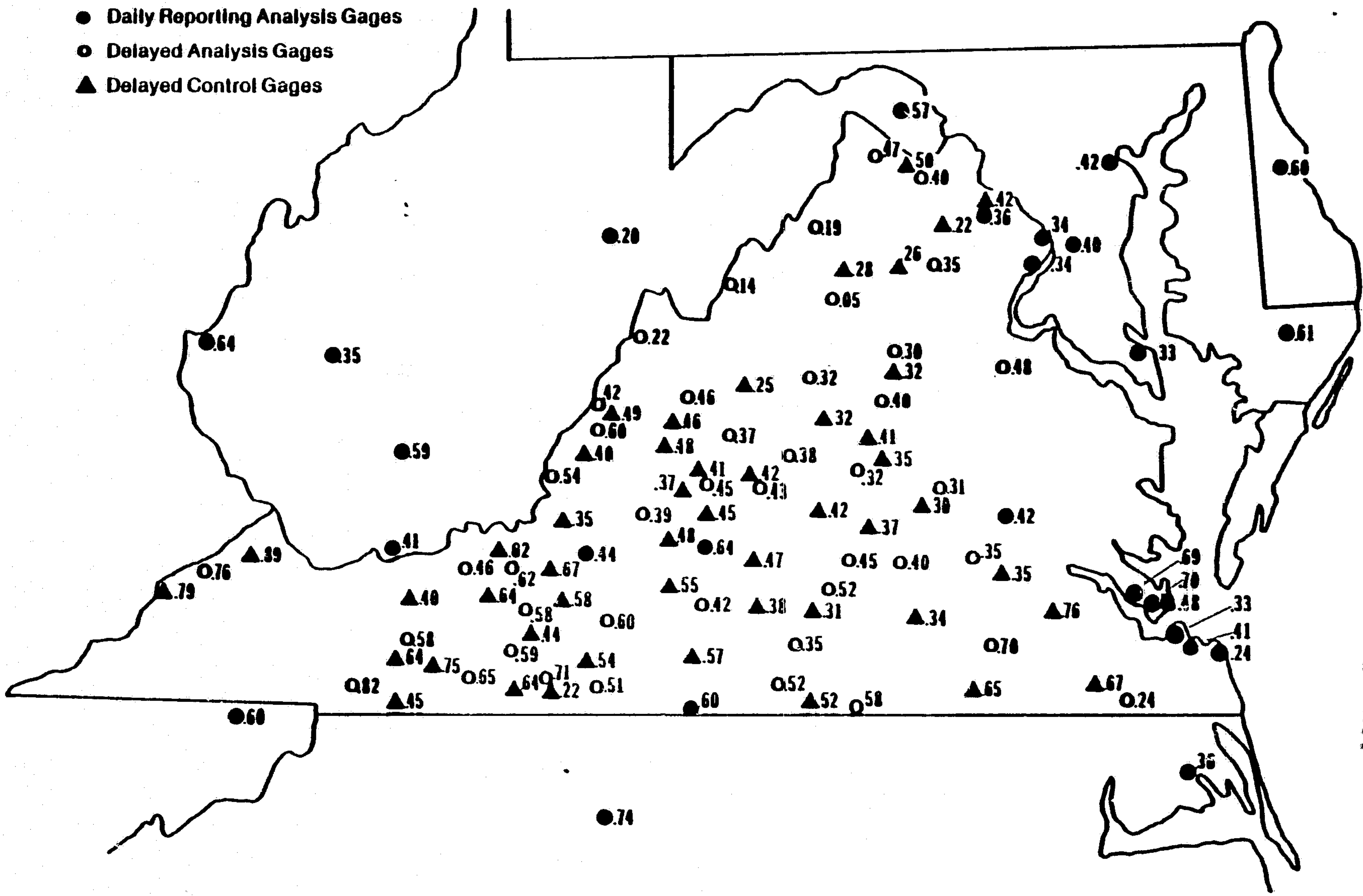

Figure 5-2. Precipitation Pattern on March 4-5, 1981

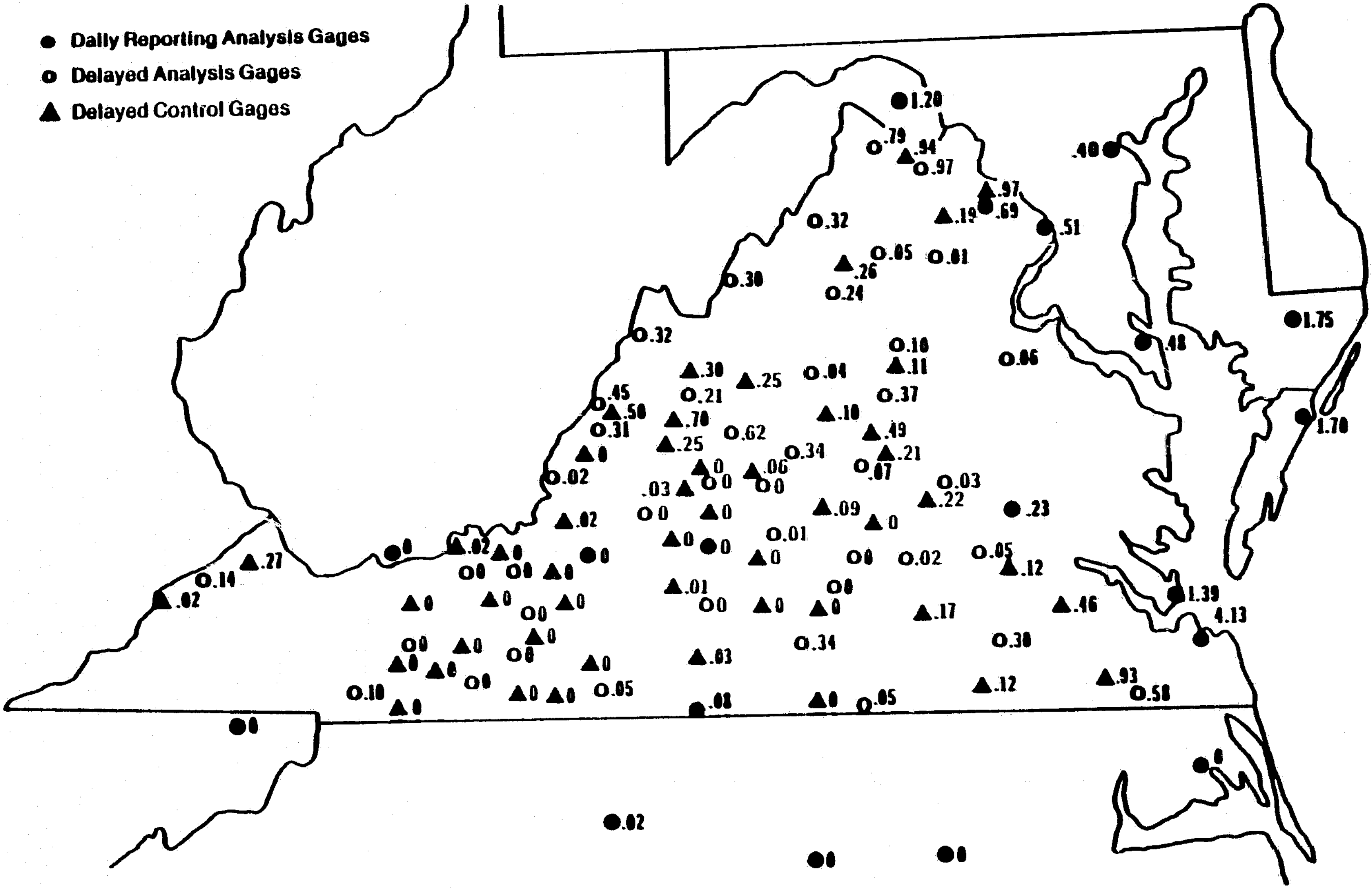

Figure 5-4. Precipitation Pattern on August 15-16, 1980

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All methods overestimated rainfall in 1980 and 1981, while all methods underestimated the rain in 1978. Yet a comparison of Table 2-1 and Figure 3-2 would suggest the opposite. That is, the cloud top temperature vs. precipitation relationship used in 1978 should produce slightly higher estimates than either curve used in 1980 and 1981. The answer to this apparent paradox is that the period March to August 1978 had above normal.precipitation while June 1980 to April 1981 was unusually dry.

In regions with very dry environments (deserts and temporary drought areas) disappointingly scant rain is produced as a rule by the occasional cumulonimbus that does occur, even when the convective chimney is quite large and tall. In very wet environments, on the other hand, rather innocuous appearing build-ups may bring surprisingly heavy rain. There is usually a lag of several months from the onset of the below normal rainfall which initiates the drought condition to the inhibiting effect on such cumulonimbus as do occur. A similar lag occurs in the excessively wet periods.

Departures from normal in precipitation for stations representing six geographical areas of Virginia are presented in Tables 5-24 and 5-25. Table 5-24 shows well above normal rainfall for the period March 1978 through August 1978, and below normal for the following two months. Table 5-25 shows large deficits for the period March 1980 through April 1981. The cumulative deficit ranges from -2.28 inches at Wytheville to -16.37 inches at Norfolk. Under these circumstances any predictive curve based on normal precipitation will underestimate in the wet periods and overestimate in the dry. However, an examination of the scores in Tables 2-2 through 2-9 , and 5-1 through 5-22 , will show that Q and Qm are the only methods that are seriously affected by these anomalous situations.

For the seven storms of 1978 taken together, the mean underestimate for Q is -0.20 inch, for Qm is -0.11 inch, and for G, Qa and Qam a negligible -0.01 inch. The worst score for a single storm is -0.69 inch for Q, -0.38 inch for Qm, -0.20 inch for G, -0.19 inch for Qam, and -0.17 inch for Qa. The large underestimates for Q and Qm occurred on May 4-5, 1978; those for G, Qam and Qa on July 31-August 1, 1978.

For the 21 storms of 1980-81 taken together, the mean overestimate for Q is +0.31 inch (old curve) and +0.43 inch (new curve); for Qm it is +0.16 inch (old curve) and +0.22 inch (new curve). Qa and Qam show negligible over-

Table 5-24. Departure from Normal in Precipitation, 1978 (inches)

1978	RIC	WY	LYH	ROA	ORF	IAD
March	+2.29	+0.90	+0.38	+2.59	+4.38	+2.85
April	+1.54	+1.90	+2.60	+4.74	+0.19	-1.34
May	+0.50	+0.26	+3.47	+1.38	+2.30	+1.37
June	+1.74	-1.45	-0.07	-1.46	+4.22	+0.75
July	-1.39	-0.27	+0.78	+0.93	-1.51	+0.40
August	+0.87	+4.13	-0.16	+2.18	-4.26	+0.04
Cumulative March-August	+5.55	+5.47	+7.00	+10.36	+5.32	+4.07
September	-3.32	-2.90	-3.28	-2.97	-3.03	-2.51
October	-1.73	-1.87	-1.76	-2.41	-1.56	-1.95
Cumulative September-October	-5.05	-4.77	-5.04	-5.38	-4.59	-4.46

Legend:
RIC = Richmond, Eastern Piedmont
WY = Wytheville, Southwestern Mountain
LYH = Lynchburg, Western Piedmont
ROA = Roanoke, Central Mountain
ORF = Norfolk, Tidewater
IAD = Dulles International Airport, Northern

Table 5-25. Departures from Normal in Precipitation, 1980-1 (inches)

1980	RIC	WY	LYH	ROA	ORF	IAD
June	-3.14	-1.06	-2.78	-1.70	-2.23	-1.72
July	-0.45	+2.93	-0.44	+1.44	-3.85	+0.29
August	-2.91	-2.25	-2.71	-1.28	-1.38	-2.58
September	-1.21	+0.27	-1.51	-1.76	-2.73	-0.59
October	+4.02	+0.67	-0.25	-0.89	+1.15	+0.03
November	-1.02	-0.65	+0.19	-0.70	-0.93	+0.36
December	-2.82	-1.98	-2.65	-2.51	-0.47	-2.79
1981						
January	-2.22	-1.47	-2.28	-2.45	-2.30	-2.44
February	-0.25	-0.05	+1.02	-0.66	-1.05	+1.49
March	-1.86	-1.14	-1.65	-1.03	-1.54	-2.49
April	+0.19	-0.36	-0.29	-1.05	-0.45	+0.09
Cumulative June-April	-11.67	-5.09	-13.35	-12.59	-15.78	-10.35

Legend:
RIC = Richmond, Eastern Piedmont
WY = Wytheville, Southwestern Mountain
LYH = Lynchburg, Western Piedmont
ROA = Roanoke, Central Mountain
ORF = Norfolk, Tidewater
IAD = Dulles Internationl Airport, Northern

estimates of +0.04 and +0.02 inch for each curve, and G has zero bias. The largest overestimates for Q are +1.66 inches (old curve) and +1.64 inches (new curve) on December 9-10, 1980. The largest for Qm are +0.85 inch (old curve, March 22-23, 1981) and +0.82 inch (new curve, December 9-10, 1980). Largest for Qa are +0.31 inch (old curve) and +0.36 inch (new curve) both on March 4-5, 1981. Largest for Qam are +0.16 inch (old curve), and +0.18 inch (new curve) both on March 4-5, 1981. G has no bias larger than ±0.06 inch in any of the 21 storms, an excellent record. These statistics show that the automated method has a built-in protection against bias.

Neither the old nor the new curve of cloud top temperature vs. precipitation shows decided superiority. The frequencies in Table 5-23 give a slight edge to the new curve. Tables 5-2 through 5-22 indicate that Q was improved in only 38 percent of the cases when the new curve replaced the old, and Qm in only 33 percent of the cases. On the other hand, Qa improved in 67 percent of the cases, and Qam improved in 71 percent of the cases. However, the composite scores in Table 5-1 show much larger mean errors for Q and Qm under the new curve than under the old, but very small improvements in Qa and Qam under the new curve. This tends to swing the verdict in favor of the old curve.

Since neither curve has demonstrated marked superiority when tested in 21 storms, it is fortunate that both curves are now integral parts of the computer program. The user may adopt either or both curves for each rainy day, at his discretion.

SECTION 6 - THE FUTURE

This report completes the research and development phase of the project. The automated technique is now ready for the operational phase for which it was designed. In presenting reliable precipitation estimates for every cell in Viginia in near real time on a daily on-going basis, the technique requires on the order of 125 to 150 daily gage readings by dependable, highly motivated observers distributed as uniformly as feasible across the state.

Appendix C lists the stations used in the various stages of the investigation. These include official weather stations which report daily over national teletype and facsimile circuits; NATS stations recruited by VPI&SU, also reporting daily; cooperative observers whose reports are difficult to obtain prior to publication two months or more after the fact; and a handful of stations no longer reporting. Observation time for all these stations is, of necessity, between 6 a.m. and 9 a.m. local time. For best results with the automated technique, the cooperative observers should either be induced to assume NATS status or be by-passed with nearby recruits. The cooperative observers are in general a dedicated breed, yet their reports are of little value to the program if delayed more than 24 hours past observation time.

The motivation of volunteer observers depends largely on the "human approach", on convincing the observer that his contribution is important, and maintaining that conviction by frequent feedback of positive results achieved by the system. The NATS observers, recruited mainly from the agricultural community, no doubt have a stake in the economic benefits of the program, but pride in having a worthwile impact on their neighbors' management problems and programs also looms large.

John F. Moses (Moses[16]) has computerized the most time-consuming and laborious aspects of the Scofield/Oliver scheme and developed an interactive man-machine technique. Tests of his model are very promising; particularly good scores were made in a heavy thunderstorm regime over a high-density network of rain gages in northern Illinois. This interactive tehnique is still used almost exclusively for heavy rain situations, but it is hoped that eventually it can be applied to weaker storms, as required by agricultural users.

Project AGRISTARS, funded by Congress to devise a comprehensive program to estimate precipitation on a world-wide, year-round basis, has been examining all existent methods to attain this end. The Applications Laboratory of NESS, Washington, D. C. is developing meteorological satellite derived products in support of AGRISTARS. The users of the automated technique might find it advantageous to maintain contact with the Applications Lab in order to benefit by its findings.

In order to exploit new breakthroughs, the software of the system described in this report is adaptable and open-ended. The hardware, unlike many systems designed for short-range research projects, has been provided by NASA for a permanent operation, and is generally of highest quality and durability.

APPENDIX A

COMPUTER PROGRAMS #1 & #2

COMPUTER PROGRAM #1

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      PROGRAM RAINDR
C*************************************
C   THIS IS THE MAIN DRIVER ROUTINE FOR THE SATELLITE RAINFALL
C   ESTIMATION PROGRAM. COMPUTE RAINFALL ESTIMATE FOR EACH HOUR
C   FROM 1200 ZULU THROUGH 1100 ZULU THE NEXT DAY (24 HOURS).
C   THE TOTAL DAYS ESTIMATE IS THE SUM OF EACH HOURLY ESTIMATE.
C*************************************
      LOGICAL*1 FILNAM(15),ANS,IFILNM(16)
      LOGICAL*1 ISTA,ISTATN(8),NAME(24),ICA
      INTEGER IROW,ICOL,ID
      REAL STATN(13)
      INTEGER NOGOOD,THRESH,IYR(2),IMO(2),IDAY(2),HOURS(24),IHR
      REAL ZERO(120),CHRAIN(120),LHRAIN(120),FILE(4)
      DATA ZERO/120*0.0/,THRESH/24/,FILE/' DY1','IDAT','12. ','.'    0'/
      DATA HOURS/'12','13','14','15','16','17','18','19',
     1          '20','21','22','23','00','01','02','03',
     2          '04','05','06','07','08','09','10','11'/
      EQUIVALENCE (STATN(1),ISTATN(1)),(ISTATN(1),ID),(ISTATN(3),ICA),
     1          (ISTATN(5),IROW),(ISTATN(7),ICOL),(STATN(13),NAME(1))
      EQUIVALENCE (FILE(1),IFILNM(1)),(IFILNM(3),IHR),
     1          (FILNAM(1),IFILNM(2))
      WRITE(5,*)'ENTER YEAR,MONTH,DAY OF FIRST 12 HOURS ',
     1          '(1200 ZULU TO 2300 ZULU) AS YY,MM,DD'
      READ(5,*)IYR(1),IMO(1),IDAY(1)
      WRITE(5,*)'ENTER YEAR,MONTH,DAY OF LAST 12 HOURS ',
     1          '0000 ZULU TO 1100 ZULU) AS YY,MM,DD'
      READ(5,*)IYR(2),IMO(2),IDAY(2)
      ISTA=.FALSE.
      WRITE(5,*)'DO YOU WANT HOURLY STATION ESTIMATES PRINTED (Y OR N)?'
      READ(5,180)ANS
      IF(ANS.NE.1HY)GO TO 20
      ISTA=.TRUE.
      WRITE(6,10)IYR(1),IMO(1),IDAY(1)
   10 FORMAT('1HOURLY STATION ESTIMATES FOR DATE ',I2,'/',I2,'/',I2)
   20 NBAD=0
      NMISS=0
C
C   SET LHRAIN TO ZERO INITIALLY
C   SET TRAIN TO ZERO INITIALLY ALSO
C
      WRITE(5,*)'BEGIN EXECUTION'
      WRITE(5,*)'ZERO FILLING LAST HOUR AND TOTAL RAIN FILES'
      OPEN(UNIT=4,NAME='DY0:LHRAIN.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAULHR,MAXREC=42)
      OPEN(UNIT=10,NAME='DY0:TRAIN.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAUTRA,MAXREC=42)
      IAUTRA=1
      IAULHR=1
      DO 100 I=1,42
      WRITE(4'IAULHR)ZERO
  100 CONTINUE
      DO 150 I=1,42
      WRITE(10'IAUTRA)ZERO
  150 CONTINUE
      CLOSE(UNIT=10)
      CLOSE(UNIT=4)
C
C   PROCESS ALL 24 HOURS OF DATA
C   HOUR LOOP
C
      II=1
      DO 1000 N=1,24
      IF(N.NE.13)GO TO 200
      WRITE(5,*)'REPLACE DATA DISK WITH 0000Z TO 1100Z DISK'
      WRITE(5,*)'TYPE RETURN WHEN READY TO CONTINUE'
      READ(5,180)ANS
  180 FORMAT(20A1)
      II=2
  200 DECODE(2,205,HOURS(N))IHOUR
  205 FORMAT(I2)
      IHR=HOURS(N)
      IF(ISTA)WRITE(6,201)IHR
  201 FORMAT('0HOUR ',A2/
     1          ' ID  C/A  ROW  COL   ESTIMATE',8X,'NAME')
      WRITE(5,*)
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      WRITE(5,*)'PROCESS NEXT HOUR OF DATA'
      WRITE(5,330)(FILNAM(I),I=1,10)
  330 FORMAT(1X,'FILE NAME THIS HOUR ',10A1)
      OPEN(UNIT=2,NAME=FILNAM,TYPE='OLD')
      OPEN(UNIT=3,NAME='DYO:CHSAT.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=30,ASSOCIATEVARIABLE=IAVSAT,MAXREC=42)
      ICHDAT=ILUN(2)
      IUSAT=3
      CALL PREPRO(IYR(II),IMO(II),IDAY(II),IHOUR,
     1         ICHDAT,IUSAT,IAVSAT,NOGOOD)
      CLOSE(UNIT=3)
      WRITE(5,*)'PREPRO COMPLETED'
      IF(NOGOOD.EQ.0)GO TO 300
C
C   BAD HOUR/MISSING DATA
C
      WRITE(5,*)'BAD HOUR OF DATA'
      NBAD=NBAD+1
      NMISS=NMISS+1
      CLOSE(UNIT=3)
      IF(NBAD.LT.THRESH)GO TO 1000
      WRITE(5,*)'TOO MANY HOURS MISSING/BAD, THRESH EXCEEDED'
      GO TO 1500
C
C   GOOD DATA SET
C
  300 OPEN(UNIT=4,NAME='DYO:LHRAIN.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAVLHR,MAXREC=42)
      OPEN(UNIT=8,NAME='DYO:CHRAIN.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAVRAI,MAXREC=42)
      IURAI=8
      IULHR=4
      CALL QUICK(IUSAT,IURAI,IAVSAT,IAVRAI)
      CLOSE(UNIT=3)
      WRITE(5,*)'QUICK COMPLETED'
C
C   STORE HOURLY STATION VALUES FOR PRINTING IF DESIRED
C
      IF(.NOT.ISTA)GO TO 390
      OPEN(UNIT=12,NAME='DYO:STAFIL.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=18,ASSOCIATEVARIABLE=IAVSTA,MAXREC=200)
      DO 380 I=1,200
      READ(ISTAFL'I)STAIN
      IF(ID.LT.0)GO TO 390
      IF(IROW.GT.MXROW.OR.IROW.LT.MNROW)GO TO 380
      IF(ICOL.GT.MXCOL.OR.ICOL.LT.MNCOL)GO TO 380
      READ(IURAI'IROW)CHRAIN
      WRITE(6,310)ID,ICA,IROW,ICOL,CHRAIN(ICOL),NAME
  310 FORMAT(1X,I2,3X,I1,3X,I3,2X,I3,3X,F6.2,5X,24A1)
  380 CONTINUE
      CLOSE(UNIT=12)
C
C   ANY MISSING HOURS?
C
  390 INTERP=0
      IF(NMISS.EQ.0)GO TO 600
      OPEN(UNIT=11,NAME='DYO:INTERP.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAVINT,MAXREC=42)
      IUINT=11
      INTERP=1
C
C   COPY CHRAIN HEADER TO INTERP FILE
C
      READ(IULHR'1)LHRAIN
      READ(IURAI'1)CHRAIN
      WRITE(IUINT'1)CHRAIN
C
C   MISSING DATA, HOW MANY?
C
      WRITE(5,*)NMISS,' HOURS MISSING DATA'
      IF(NMISS.NE.2)GO TO 500
C
C   2 HOURS MISSING, INTERPOLATE
C
      DO 450 K=2,42
      READ(IURAI'K)CHRAIN
      READ(IULHR'K)LHRAIN
      DO 400 I=1,112
      CHRAIN(I)=LHRAIN(I)+2.0*CHRAIN(I)
  400 CONTINUE
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      WRITE(IUINT'K)CHRAIN
 450  CONTINUE
      WRITE(5,*)'INTERPOLATION COMPLETED'
      CLOSE(UNIT=9)
      GO TO 600
C
C   NOT 2 MISSING,1 OR GREATER THAN 2 MISSING,SEMI-INTERPOLATE
C
 500  DO 580 K=2,42
      READ(IURAI'K)CHRAIN
      READ(IULHR'K)LHRAIN
      DO 550 I=1,119
      CHRAIN(I)=0.5*LHRAIN(I)+1.5*CHRAIN(I)
 550  CONTINUE
      WRITE(IUINT'K)CHRAIN
 580  CONTINUE
      WRITE(5,*)'INTERPOLATION COMPLETED'
      CLOSE(UNIT=9)
C
C   SUM RAIN FOR THIS HOUR INTO TOTAL FOR DAY
C
 600  CLOSE(UNIT=4)
      OPEN(UNIT=10,NAME='DY0:TRAIN.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAUTRA,MAXREC=42)
      OPEN(UNIT=9,NAME='DY0:TEMRRA.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAUTEM,MAXREC=42)
      IUTEM=9
      IUTRA=10
      IF(INTERP.EQ.0)GO TO 650
      CALL RAINEM(IUINT,IUTEM,IUTRA,IAUINT,IAUTEM,IAUTRA)
      CLOSE(UNIT=11)
      GO TO 660
 650  CALL RAINEM(IURAI,IUTEM,IUTRA,IAURAI,IAUTEM,IAUTRA)
      CLOSE(UNIT=8)
 660  CLOSE(UNIT=9)
      CLOSE(UNIT=10)
      WRITE(5,*)'RAINEM COMPLETED'
      NMISS=0
C
C   COPY CHRAIN TO LHRAIN FILE
C
      OPEN(UNIT=4,NAME='DY0:LHRAIN.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAULHR,MAXREC=42)
      OPEN(UNIT=8,NAME='DY0:CHRAIN.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAURAI,MAXREC=42)
      DO 700 K=1,42
      READ(IURAI'K)CHRAIN
      WRITE(IULHR'K)CHRAIN
 700  CONTINUE
      CLOSE(UNIT=4)
      CLOSE(UNIT=8)
      WRITE(5,*)'COPYING CHRAIN TO LHRAIN COMPLETED'
 1000 CONTINUE
C
C   END OF HOUR LOOP
C
C
C   PROCESSING COMPLETED FOR ALL HOURS, CHECK FOR MISSING LAST HOUR
C
      IF(NMISS.EQ.0)GO TO 1500
C
C   SEMI-INTERPOLATE FOR MISSING FINAL HOURS
C
      OPEN(UNIT=4,NAME='DY0:LHRAIN.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAULHR,MAXREC=42)
      OPEN(UNIT=10,NAME='DY0:TRAIN.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAUTRA,MAXREC=42)
      OPEN(UNIT=11,NAME='DY0:INTERP.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAUINT,MAXREC=42)
      IUINT=11
      IUTRA=10
      IULHR=4
C
C   COPY TRAIN HEADER TO INTERP
C
      READ(IULHR'1)LHRAIN
      READ(IUTRA'1)CHRAIN
      WRITE(IUINT'1)CHRAIN
C
C   SEMI-INTERPOLATE
```

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```
C
      DO 1200 K=2,42
      READ(IULHR'K)LHRAIN
      READ(IUTRA'K)CHRAIN
      DO 1100 I=1,119
      CHRAIN(I)=CHRAIN(I)+0.5*LHRAIN(I)
 1100 CONTINUE
      WRITE(IUINT'K)CHRAIN
 1200 CONTINUE
      WRITE(5,*)'INTERPOLATION FOR LAST HOUR COMPLETED'
      CLOSE(UNIT=4)
C
C     COPY INTERP TO TRAIN
C
      DO 1300 I=1,42
      READ(IUINT'I)CHRAIN
      WRITE(IUTRA'I)CHRAIN
 1300 CONTINUE
      CLOSE(UNIT=10)
      CLOSE(UNIT=11)
      WRITE(5,*)'PROCESSING COMPLETED FOR DAY'
 1500 WRITE(5,*)'PROGRAM TERMINATED'
      CALL EXIT
      END
```

```
      SUBROUTINE PREPRO(IYR,IMO,IDAY,IHOUR,ICHDAT,IUSAT,IAUSAT,NOGOOD)
C*********************************
C     THIS ROUTINE STRIPS RAW DATA DOWN TO MIN SIZE, FILLS IN FOR
C     MISSING RECORDS, FLAGS FOR MISSING HOURLY DATA SETS IF NECESSARY.
C     OUTPUT IS SMALLEST USEABLE DATA SET WHICH STILL COVERS ENTIRE
C     STATE AREA (WITH LEAST AMOUNT OF EXTRA SPACE). FOR IR, 120
C     CHARACTERS PER RECORD, TOTAL OF 42 RECORDS WITH A HEADER RECORD
C     OF 120 CHARACTERS CONTAINING DATE,TIME,FILE NAME,MISSING DATA
C     SET FLAG,BAD DATA FLAG,ETC. NOGOOD SET TO 1 WHEN DATA SET BAD
C       NOTE: CURRENTLY PROCESSING ONLY IR DATA.
C*********************************
      LOGICAL*1 FIRST,ITEMP(120),ITEST
      LOGICAL*1 IREC(120),HEADER(120),DATIME(4),YYMM(4),KEY(12)
      LOGICAL*1 CUREC(131),LAREC(120),IBAD,EMPTY,NAME(5),NAME4(2)
      INTEGER IROW,LROW,IBLK,NREC,NCHRS,THRESH,BAD
      REAL*4 RKEY(3)
      EQUIVALENCE (RKEY(1),KEY(1)),(CUREC(1),IREC(1))
      EQUIVALENCE (HEADER(1),YYMM(1)),(HEADER(5),DATIME(1))
      EQUIVALENCE (HEADER(9),NAME(1)),(HEADER(14),EMPTY)
      EQUIVALENCE (HEADER(15),IBAD),(NAME(4),NAME4(1))
      DATA RKEY/'NSMA','01 K','WBC '/
      DATA NAME/'D','A','T','0','0'/,THRESH/26/
      NOGOOD=0
C
C     SET UP HEADER RECORD
C
      ENCODE(4,10,YYMM)IYR,IMO
   10 FORMAT(2I2)
      ENCODE(4,10,DATIME)IDAY,IHOUR
      ENCODE(2,10,NAME4)IHOUR
C
C     REPLACE ANY LEADING BLANKS WITH ZEROS
C
      IF(IYR.LT.10)YYMM(1)='0'
      IF(IMO.LT.10)YYMM(3)='0'
```

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```
      IF(IDAY.LT.10)DATIME(1)='0'
      IF(IHOUR.LT.10)DATIME(3)='0'
      IF(IHOUR.LT.10)NAMEA(1)='0'
      EMPTY='0'
      IBAD='0'
      IAUSAT=1
C
C   WRITE OUT HEADER RECORD
C
      WRITE(IUSAT'IAUSAT,ERR=8000)HEADER
C
C   PROCESS DATA SET
C
      BAD=0
      LROW=34
      IBLK=0
      FIRST=.TRUE.
      NREC=0
100   CALL RDATA(CUREC,NCHRS,IERR,ICHDAT,IBLK,FIRST)
      FIRST=.FALSE.
      IF(IERR.LT.0)GO TO 3000
      NREC=NREC+1
      IF(NCHRS.EQ.131)GO TO 200
C
C   CHECK FOR NSMA & KWBC RECORD
C
      IF (NCHRS.NE.13) GO TO 100
      DO 110 I=1,4
      IF(KEY(I).NE.CUREC(I))GO TO 100
      IF(KEY(I+7).NE.CUREC(I+7))GO TO 100
110   CONTINUE
C
C   CHECK TIME DATE RECORD
C
      DO 120 I=13,16
      IF(CUREC(I).NE.DATIME(I-12))GO TO 2900
120   CONTINUE
      GO TO 100
C
C   131 CHARACTERS. CHECK ROW NUMBER FOR POSITIONING
C
200   DECODE(2,210,CUREC(130),ERR=500)IROW
210   FORMAT(I2)
C
C   MAKE SURE IROW IS VALID
C
      IF(IROW.LE.0.OR.IROW.GE.100)GO TO 500
C
C   CHECK IROW INSIDE STATE BOUNDARIES
C
      IF(IROW.LE.34.AND.LROW.EQ.34)GO TO 100
      IF(IROW.LE.34.OR.IROW.GE.76)GO TO 100
C
C   GOOD DATA ROW. CHECK FOR SKIPS IN DATA
C
      IDELTA=IROW-LROW
      IF(IDELTA.LT.1)GO TO 100
      IF(IDELTA.EQ.1)GO TO 300
C
C   FILL IN FOR MISSING DATA BY WEIGHTED AVERAGING
C
      IREC(120)=CUREC(131)
      JJ=LROW+1
      KK=IROW-1
      N=IDELTA
      J=1
      K=N-1
      IF(LROW.GE.75)GO TO 230
      DO 220 II=JJ,KK
      WRITE(IUSAT'IAUSAT,ERR=8000)IREC
220   CONTINUE
      GO TO 300
230   DO 250 II=JJ,KK
      DO 240 I=1,119
      ITEMP(I)=FLOAT(K)*FLOAT(LAREC(I))/FLOAT(N) +
     1          FLOAT(J)*FLOAT(IREC(I))/FLOAT(N)
240   CONTINUE
      ITEMP(120)=LAREC(120)
      WRITE(IUSAT'IAUSAT,ERR=8000)ITEMP
      J=J+1
```

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```
      K=K-1
250   CONTINUE
C
C   FILL IN COMPLETE, GO WRITE CURRENT RECORD
C
C   WRITE CURRENT RECORD, MOVE CURRENT RECORD INTO LAST REC,
C   AND UPDATE LROW
C
300   IREC(120)=CUREC(131)
C
C   CHECK CHARACTERS IN ROW FOR SATURATION ERROR.
C   THIS OCCURS WHEN ALL CHARACTERS IN ROW ARE THE SAME.
C   THIS CONDITION IS IMPOSSIBLE IN GOOD DATA AND IS
C   GROUNDS FOR THROWING OUT THE ROW AS BAD DATA.
C
      ITEST=IREC(1)
      DO 315 MM=2,119
      IF(ITEST.NE.IREC(MM))GO TO 320
315   CONTINUE
C   SATURATED ROW, THROW OUT AS BAD DATA
      GO TO 500
320   WRITE(IUSAT'IAUSAT,ERR=8000)IREC
      DO 350 I=1,120
      LAREC(I)=IREC(I)
350   CONTINUE
      LROW=IROW
      GO TO 100
C
C   ROW OUT OF STATE BOUNDARIES
C
400   IF(IROW.LT.74)GO TO 500
      IF(LROW.GE.75)GO TO 1700
C
C   SOME ROWS MISSING AT END, FILL BY REPEATING LAST RECORD
C
      JJ=LROW+1
      DO 450 I=JJ,75
      WRITE(IUSAT'IAUSAT,ERR=8000)LAREC
450   CONTINUE
      GO TO 1700
C
C   BAD RECORD ENCOUNTERED, COUNT #BAD AND THEN GO READ ANOTHER RECORD
C
500   BAD=BAD+1
      GO TO 100
C
C   CHECK FOR #BAD RECORDS AGAINST THRESHOLD
C
1700  IF(BAD.LE.THRESH) RETURN
C
C   SET BAD FLAG, REWRITE HEADER WITH FLAG
C
      NOGOOD=1
      IBAD='1'
      IF(FIRST.GT.35)EMPTY='1'
      WRITE(IUSAT'1,ERR=8000)HEADER
      RETURN
C
C   ERROR WRITING OUT FILE
C
8000  WRITE(6,*)' ***ERROR WHILE WRITING OUTPUT FILE - SET EMPTY'
      WRITE(5,*)' ***ERROR WRITING FILE'
      GO TO 9900
C
C   ERROR READING INPUT FILE
C
9000  WRITE(6,*)' ***ERROR WHILE READING INPUT FILE - SET OUTPUT EMPTY'
      WRITE(5,*)' ***ERROR READING FILE'
9900  EMPTY='1'
      IBAD='1'
      NOGOOD=1
      WRITE(6,*)IERR,ICHDAT,NREC,NGHNG,IDAY,IHOUR
      WRITE(IUSAT'1)HEADER
      RETURN
      END
```

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```
      SUBROUTINE RDATA(IDATA,NCHRS,IERR,ICHAN,IBLK,FIRST)
C     THIS ROUTINE READS DATA FROM THE DISK FILE (ICHAN) IN BLOCKS
C     OF 512 CHARACTERS AND RETURNS THIS DATA LINE BY LINE TO THE CALLING
C     PROGRAM VIA IDATA, WITH THE NUMBER OF CHARACTERS IN THE LINE IN
C     NCHRS, AND ANY ERROR CONDITIONS IN IERR AS FOLLOWS:
C
C           IERR = 0   GOOD READ
C                = -1  END OF FILE ON DISK (NCHRS=0)
C                < -1  ERROR READING BLOCK (NCHRS=0)
C     IBLK IS THE BLOCK # TO BE READ NEXT (0 REFERENCED), AND SHOULD
C     BE SET TO 0 BY THE CALLING PROGRAM ON THE FIRST CALL, BUT NOT
C     CHANGED UNTIL THE ENTIRE FILE HAS BEEN READ.
C
C     NOTE: MAX OF 131 CHARACTERS PER LINE RETURNED TO CALLING PROGRAM
C     ******************************************************************
      DIMENSION INBUF(256)
      LOGICAL*1 IBUF(512),IDATA(131),FIRST
      EQUIVALENCE (INBUF(1),IBUF(1))
      IF(FIRST)I=512
C
C     I = CHARACTER POSITION IN IBUF
C     J = CHARACTER POSITION IN IDATA
C
      NCHRS=0
      J=1
      IF(I.LT.512)GO TO 100
C
C     READ IN A NEW BLOCK OF DATA
C
10    IERR=IREADW(256,INBUF,IBLK,ICHAN)
      IBLK=IBLK+1
      IF(IERR.LT.0) RETURN
      I=0
C
C     MOVE CHARACTERS FROM IBUF TO IDATA
C
100   I=I+1
      IF(I.GT.512) GO TO 10
C
C     CHECK FOR CARRIAGE RETURN
C
      IF(IBUF(I).NE.'15) GO TO 200
C
C     CHECK FOR NO DATA YET
C
      IF(J.EQ.1)GO TO 100
      NCHRS=J-1
      RETURN
C
C     CHECK FOR ILLEGAL OR CONTROL CHARACTER TO SKIP
C
200   IF(IBUF(I).LT.'40) GO TO 100
C
C     TRANSFER CHARACTER TO IDATA. MAX OF 131 CHARACTERS RETURNED IN IDATA
C
      IF(J.LE.131)IDATA(J)=IBUF(I)
      J=J+1
      GO TO 100
      END
```

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```
      SUBROUTINE QUICK(IUSAT,IURAI,IAUSAT,IAURAI)
C*************************************
C   THIS ROUTINE CONVERTS THE SATELLITE DATA TO RAINFALL
C   RATE FOR EACH HOURS DATA.
C*************************************
      LOGICAL*1 IDATA(120)
      REAL RAIN(120),HEAD(120)
      EQUIVALENCE (IDATA(1),HEAD(1))
C
C   READ HEADER RECORD
C
      IAUSAT=1
      IAURAI=1
      READ(IUSAT'IAUSAT)IDATA
      WRITE(IURAI'IAURAI)HEAD
C
C   CONVERT DATA TO RAINFALL
C
      DO 500 I=2,42
      READ(IUSAT'IAUSAT)IDATA
      CALL LOOKUP(IDATA,RAIN)
      WRITE(IURAI'IAURAI)RAIN
  500 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LOOKUP(IDATA,RDATA)
C**********************************************
C   THIS ROUTINE CONVERTS THE SATELLITE TEMPERATURE DATA
C   TO RAINFALL RATE VIA A LOOKUP TABLE DEVELOPED BY
C   WALT FOLLANSBEE.
C**********************************************
      REAL RAIN(94),RDATA(120)
      LOGICAL*1 IDATA(120),IFIRST
      DATA RAIN/94*0.0/,IFIRST/.TRUE./
C
C   ON FIRST CALL, GENERATE TABLE
C
      IF(.NOT.IFIRST) GO TO 50
      IFIRST=.FALSE.
      CON=0.0
      DO 10 I=30,54
      CON=CON+0.01
      RAIN(I)=CON
   10 CONTINUE
      DO 20 I=55,94
      CON=CON+0.05
      RAIN(I)=CON
   20 CONTINUE
C
C   CONVERT DATA TO RAINFALL AMOUNTS FROM LOOKUP TABLE
C
   50 DO 100 I=1,119
      RDATA(I)=RAIN(IDATA(I)-31)
```

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```
  100   CONTINUE
C
C   MOVE ROW NUMBER INTO REAL ARRAY
C
        DECODE(1,150,IDATA(120)) RDATA(120)
  150   FORMAT(F1.0)
        RETURN
        END
```

```
        SUBROUTINE LOOKUP(IDATA,RDATA)
C**********************************************
C   THIS ROUTINE CONVERTS THE SATELLITE TEMPERATURE DATA
C   TO RAINFALL RATE VIA A LOOKUP TABLE DEVELOPED BY
C   WALT FOLLANSBEE.
C**********************************************
        REAL RAIN(96),RDATA(120)
        LOGICAL*1 IDATA(120),IFIRST
        DATA RAIN/96*0.0/,IFIRST/.TRUE./
C
C   ON FIRST CALL, GENERATE TABLE
C
        IF(.NOT.IFIRST) GO TO 50
        IFIRST=.FALSE.
        CON=0.005
        DO 10 I=33,54
        CON=CON+0.005
        RAIN(I)=CON
   10   CONTINUE
        DO 20 I=55,96
        CON=CON+0.06
        RAIN(I)=CON
   20   CONTINUE
C
C   CONVERT DATA TO RAINFALL AMOUNTS FROM LOOKUP TABLE
C
   50   DO 100 I=1,119
        RDATA(I)=RAIN(IDATA(I)-31)
  100   CONTINUE
C
C   MOVE ROW NUMBER INTO REAL ARRAY
C
        DECODE(1,150,IDATA(120)) RDATA(120)
  150   FORMAT(F1.0)
        RETURN
        END
```

```
        SUBROUTINE RAINSM(IURAI,IUTEM,IUTRA,IAVRAI,IAVTEM,IAVTRA)
C********************************************
C   THIS ROUTINE SUMS THE CURRENT HOURS RAINFALL INTO THE TOTAL
C   ESTIMATE FOR THE DAY, USING A TEMP FILE.
C********************************************
        REAL RAIN(120),TEMP(120),TOTAL(120),HEADER(120)
```

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```
      IAUTEM=1
      IAUTRA=1
      IAURAI=1
C
C   UPDATE HEADER TO LATEST HOUR
C
      READ(IUTRA'IAUTRA,ERR=8000)HEADER
      READ(IURAI'IAURAI,ERR=8000)HEADER
      WRITE(IUTEM'IAUTEM,ERR=9000)HEADER
      DO 100 I=2,42
      READ(IUTRA'IAUTRA,ERR=8000)TOTAL
      READ(IURAI'IAURAI,ERR=8000)RAIN
      DO 50 J=1,119
      TEMP(J)=TOTAL(J)+RAIN(J)
   50 CONTINUE
      TEMP(120)=RAIN(120)
      WRITE(IUTEM'IAUTEM,ERR=9000)TEMP
  100 CONTINUE
C
C   COPY TEMP TO TOTAL RAINFALL FILE AFTER SUMMING
C
      IAUTEM=1
      IAUTRA=1
      DO 200 I=1,42
      READ(IUTEM'IAUTEM,ERR=8000)TEMP
      WRITE(IUTRA'IAUTRA,ERR=9000)TEMP
  200 CONTINUE
      RETURN
C
C   READ ERROR WHILE SUMMING HOURS DATA AND TOTAL
C
 8000 WRITE(6,*)'*** ERROR READING FILE WHILE SUMMING HOURLY ',
     1 'RAINFALL - TERMINATED'
      CALL EXIT
 9000 WRITE(6,*)'*** ERROR WRITING FILE WHILE SUMMING HOURLY ',
     1 'RAINFALL - TERMINATED'
      CALL EXIT
      END
```

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COMPUTER PROGRAM #2

```
      PROGRAM MAIN
C*****************************************************************
C     THIS IS THE MAIN DRIVER ROUTINE FOR THE OVERALL
C     RAINFALL ESTIMATE SYSTEM.  THIS ROUTINE COMPUTES
C     THE INTERPOLATED RAIN AND ERROR VALUES FOR THE
C     CONTROL STATIONS IN THE SYSTEM, COMPUTES THE FIVE
C     ESTIMATES (THE SATELLITE ALONE ESTIMATE IS READ FROM
C     THE SATELLITE ESTIMATE FILE ASSUMED TO BE EXISTING
C     PRIOR TO RUNNING THIS ROUTINE.  THE FILE MAY BE EMPTY
C     HOWEVER, INDICATING THAT THE SATELLITE ESTIMATE WAS
C     NOT AVAILABLE FOR THAT DAY) AND THEIR ASSOCIATED
C     TOTAL ERRORS, DETERMINES WHICH OF THE FIVE METHODS
C     IS THE WINNER FOR THE DAY, AND COMPUTES THE FINAL
C     RAINFALL ESTIMATE FOR THE DAY USING THE WINNING METHOD.
C*****************************************************************
C
      REAL RNDAT(120),ERDAT(120),STAIN(18),RAIN(120),SATEST(120)
      INTEGER ALLSTA(200,5)
      LOGICAL*1 ANS,TITLE(24)
      EQUIVALENCE (STAIN(6),Q),(STAIN(7),G),(STAIN(8),QA),
     1            (STAIN(9),QM),(STAIN(10),QAM),(STAIN(12),SE),
     1            (STAIN(5),OBS)
C     DEFINE STATEMENT FUNCTION TO COMPUTE CORRELATION COEFFICIENT
      COREL(N,SX,SY,SXY,SXSQ,SYSQ)=(N*SXY-SX*SY)/
     1            SQRT((N*SXSQ-SX*SX)*(N*SYSQ-SY*SY))
C
      OPEN(UNIT=2,NAME='DY0:STAFIL.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=13,ASSOCIATEVARIABLE=IAUSTA,MAXREC=200)
      OPEN(UNIT=3,NAME='DY0:TRAIN.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAUSAT,MAXREC=42)
      WRITE(5,*)'ENTER STORM DATE INFORMATION (UP TO 24 CHARACTERS)'
      READ(5,1)TITLE
    1 FORMAT(24A1)
C
C     FILL STATIONS REPORTING WITH OBS,SATEST,ERR 0-3,FLAG IF GAGES
C     NOT AVAIL OR SAT NOT AVAIL,STOP IF BOTH NOT AVAIL
C
      ISTAFL=2
      ISATFL=3
      CALL FILSTA(ISTAFL,ISATFL,ISAT,IGAGE)
      WRITE(5,*)'FILSTA COMPLETED'
      CLOSE(UNIT=ISATFL)
C
C     CHECK FOR NO GAGES TODAY
C
      IF(IGAGE.GT.0)GO TO 1000
C
C     GAGES PRESENT, SORT FOR INTERPOLATION
C
      CALL SORT(ISTAFL,ALLSTA)
      WRITE(5,*)'SORT COMPLETED'
C
C     CHECK FOR NO SAT EST AVAIL
C
      IF(ISAT.GT.0)GO TO 2000
C
C     SAT AND GAGES BOTH AVAIL , COMPUTE VARIOUS COMBINATIONS
C
C     COMPUTE INTERPOLATED RAIN AND ERROR FOR CONTROL STATIONS
C
      CALL INTERP(1,ISTAFL,0,ALLSTA)
      WRITE(5,*)'INTERP COMPLETED FOR RAIN AT CONTROLS'
      CALL INTERP(2,ISTAFL,0,ALLSTA)
      WRITE(5,*)'INTERP COMPLETED FOR ERROR AT CONTROLS'
C
C     COMPUTE QM,QA,QAM,CORRELATION SUMS,
C     AND ERROR SUMS FOR EACH AT CONTROL STA
C
      EQ=0.
      EG=0.
      EQA=0.
      EQM=0.
      EQAM=0.
      SMOBS=0.
      SSOBS=0.
      SMQ=0.
      SSQ=0.
      SQOBS=0.
```


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```
      SMQ=0.
      SSQ=0.
      SQOBS=0.
      SMQA=0.
      SSQA=0.
      SQAOBS=0.
      SMQM=0.
      SSQM=0.
      SQMOBS=0.
      SMQAM=0.
      SSQAM=0.
      SQAMOB=0.
      N=0
      DO 100 I=1,200
C
C     CHECK FOR MORE STATIONS
C
      IF(ALLSTA(I,1).LT.0)GO TO 200
C
C     CHECK FOR CONTROL STATION
C
      IF(ALLSTA(I,4).NE.0)GO TO 100
      ID=ALLSTA(I,1)
      READ(ISTAFL'ID)STATN
      QM=(G+Q)/2.0
      QA=Q+EF
C     RAIN ESTIMATE CANNOT BE NEGATIVE
      IF(QA.LT.0.0)QA=0.0
      QAM=(QA+G)/2.0
      WRITE(ISTAFL'ID)STATN
      EQ=EQ+ABS(OBS-Q)
      EG=EG+ABS(OBS-G)
      EQA=EQA+ABS(OBS-QA)
      EQM=EQM+ABS(OBS-QM)
      EQAM=EQAM+ABS(OBS-QAM)
      N=N+1
      SMOBS=SMOBS+OBS
      SSOBS=SSOBS+OBS*OBS
      SMQ=SMQ+Q
      SSQ=SSQ+Q*Q
      SQOBS=SQOBS+Q*OBS
      SMG=SMG+G
      SSG=SSG+G*G
      SGOBS=SGOBS+G*OBS
      SMQA=SMQA+QA
      SSQA=SSQA+QA*QA
      SQAOBS=SQAOBS+QA*OBS
      SMQM=SMQM+QM
      SSQM=SSQM+QM*QM
      SQMOBS=SQMOBS+QM*OBS
      SMQAM=SMQAM+QAM
      SSQAM=SSQAM+QAM*QAM
      SQAMOB=SQAMOB+QAM*OBS
  100 CONTINUE
C
C     COMPUTE WINNER FOR DAY
C
  200 ISMALL=1
      SMALL=EQ
      IF(EG.GT.SMALL)GO TO 210
      ISMALL=2
      SMALL=EG
  210 IF(EQA.GT.SMALL)GO TO 220
      ISMALL=3
      SMALL=EQA
  220 IF(EQM.GT.SMALL)GO TO 230
      ISMALL=4
      SMALL=EQM
  230 IF(EQAM.GT.SMALL)GO TO 240
      ISMALL=5
      SMALL=EQAM
  240 WRITE(5,241)TITLE
      WRITE(6,241)TITLE
  241 FORMAT(1X,80A1)
      WRITE(5,*)'TOTAL OBSERVED RAINFALL AT CONTROL STATIONS = ',
     1          SMOBS
      WRITE(6,*)'TOTAL OBSERVED RAINFALL AT CONTROL STATIONS = ',
     1          SMOBS
      WRITE(5,*)'ABSOLUTE ERRORS FOR Q,G,QA,QM,QAM = '
      WRITE(5,*)EQ,EG,EQA,EQM,EQAM
```

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```
      WRITE(6,*)'ABSOLUTE ERRORS FOR O,G,OA,OM,OAM = '
      WRITE(6,*)EO,EG,EOA,EOM,EOAM
      WRITE(5,*)'TOTAL ESTIMATES FOR O,G,OA,OM,OAM = '
      WRITE(5,*)SMO,SMG,SMOA,SMOM,SMOAM
      WRITE(6,*)'TOTAL ESTIMATES FOR O,G,OA,OM,OAM = '
      WRITE(6,*)SMO,SMG,SMOA,SMOM,SMOAM
      WRITE(5,*)'ALGEBRAIC ERRORS FOR O,G,OA,OM,OAM = '
      WRITE(5,*)SMO-SMOBS,SMG-SMOBS,SMOA-SMOBS,SMOM-SMOBS,
     1          SMOAM-SMOBS
      WRITE(6,*)'ALGEBRAIC ERRORS FOR O,G,OA,OM,OAM = '
      WRITE(6,*)SMO-SMOBS,SMG-SMOBS,SMOA-SMOBS,SMOM-SMOBS,
     1          SMOAM-SMOBS
C     COMPUTE CORRELATION COEFFICIENTS
      CCO=COREL(N,SMOBS,SMO,SOOBS,SSOBS,SSO)
      CCG=COREL(N,SMOBS,SMG,SGOBS,SSOBS,SSG)
      CCOA=COREL(N,SMOBS,SMOA,SOAOBS,SSOBS,SSOA)
      CCOM=COREL(N,SMOBS,SMOM,SOMOBS,SSOBS,SSOM)
      CCOAM=COREL(N,SMOBS,SMOAM,SOAMOB,SSOBS,SSOAM)
      WRITE(5,*)'CORRELATION COEFFICIENTS FOR O,G,OA,OM,OAM = '
      WRITE(5,*)CCO,CCG,CCOA,CCOM,CCOAM
      WRITE(6,*)'CORRELATION COEFFICIENTS FOR O,G,OA,OM,OAM = '
      WRITE(6,*)CCO,CCG,CCOA,CCOM,CCOAM
      WRITE(5,*)'WINNER FOUND'
      WRITE(5,*)'WANT TO PROCEED WITH FINAL ESTIMATE COMPUTATION?'
      READ(5,250)ANS
  250 FORMAT(80A1)
      IF(ANS.NE.1HY)GO TO 9000
      WRITE(5,*)'COMPUTING FINAL ESTIMATE'
C
C     GO TO THE WINNING METHOD FOR FINAL COMPUTATION
C
      GO TO (1000,2000,3000,4000,5000),ISMALL
C
C     SATELLITE ALONE IS WINNER (MAYBE NO GAGES FOR DAY)
C
 1000 WRITE(5,*)'SATELLITE ALONE IS WINNER'
      OPEN(UNIT=3,NAME='DYO:TRAIN  ',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAUSAT,MAXREC=42)
      OPEN(UNIT=8,NAME='DYO:RAINFL  ',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAURAI,MAXREC=42)
      IRAIFL=8
C
C     COPY SATEST TO RAIN FILE
C
      DO 1100 I=1,42
      READ(ISATFL'I)SATEST
      WRITE(IRAIFL'I)SATEST
 1100 CONTINUE
C
C     CHECK FOR GAGES TO FILL IN FINAL EST
C
      IF(IGAGE.GT.0)GO TO 1500
C
C     GAGES PRESENT , PUT GROUND TRUTH IN FINAL EST
C
      CALL GNDTRU(ISTAFL,IRAIFL,ALLSTA)
 1500 CLOSE(UNIT=ISATFL)
      CLOSE(UNIT=IRAIFL)
      CLOSE(UNIT=ISTAFL)
      WRITE(6,*)'SATELLITE ALONE METHOD IS WINNER TODAY'
      GO TO 2000
C
C     GAGES ONLY WINNER (MAYBE NO SAT EST AVAIL)
C
 2000 WRITE(5,*)'GAGES ALONE IS WINNER'
      OPEN(UNIT=8,NAME='DYO:RAINFL  ',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAURAI,MAXREC=42)
C
C     INTERP FOR ENTIRE FIELD USING ALL STATIONS
C
      IRAIFL=8
      CALL INTERP(3,ISTAFL,IRAIFL,ALLSTA)
C
C     NEED CODE HERE TO GET DATE ON FINAL FILE
C
      CLOSE(UNIT=IRAIFL)
      CLOSE(UNIT=ISTAFL)
      WRITE(6,*)'GAGES ONLY METHOD IS WINNER TODAY'
      GO TO 9000
C
```

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```
C     QA (SATELLITE ADJUSTED) IS WINNER
C
 3000 WRITE(5,*)'SATELLITE ADJUSTED IS WINNER'
      OPEN(UNIT=3,NAME='DYO:TRAIN.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAVSAT,MAXREC=42)
      OPEN(UNIT=9,NAME='DYO:ERFILE.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAVERF,MAXREC=42)
      OPEN(UNIT=8,NAME='DYO:RAINFL.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAVRAI,MAXREC=42)
C
C     INTERP FOR ENTIRE FIELD ERROR (OBS-SAT EST) USING ALL STATIONS
C
      IERFFL=9
      IRAIFL=8
      CALL INTERP(4,ISTAFL,IERFFL,ALLSTA)
C
C     ADD ERROR FILE TO SAT EST FILE
C
      READ(ISATFL'1)SATEST
      WRITE(IRAIFL'1)SATEST
      DO 3100 I=2,42
      READ(ISATFL'I)SATEST
      READ(IERFFL'I)ERDAT
      DO 3050 J=1,119
      RAIN(J)=SATEST(J)+ERDAT(J)
 3050 CONTINUE
      RAIN(120)=SATEST(120)
      WRITE(IRAIFL'I)RAIN
 3100 CONTINUE
      CLOSE(UNIT=ISATFL)
      CLOSE(UNIT=ISTAFL)
      CLOSE(UNIT=IERFFL)
      CLOSE(UNIT=IRAIFL)
      WRITE(6,*)'SATELLITE ADJUSTED METHOD IS WINNER TODAY'
      GO TO 9000
C
C     QM (MEAN OF SAT EST AND INTERP RAIN FIELD) IS WINNER
C
 4000 WRITE(5,*)'MEAN OF SAT AND GAGES IS WINNER'
      OPEN(UNIT=3,NAME='DYO:TRAIN.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAVSAT,MAXREC=42)
      OPEN(UNIT=4,NAME='DYO:RNFILE.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAVRNF,MAXREC=42)
      OPEN(UNIT=8,NAME='DYO:RAINFL.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAVRAI,MAXREC=42)
      IRNFFL=4
      IRAIFL=8
C
C     INTERP FOR RAIN OVER ENTIRE FIELD USING ALL STATIONS
C
      CALL INTERP(3,ISTAFL,IRNFFL,ALLSTA)
C
C     COMPUTE QM = (RAIN+SATEST)/2.0 AND STORE ON FINAL FILE
C
      READ(ISATFL'1)SATEST
      WRITE(IRAIFL'1)SATEST
      DO 4100 I=2,42
      READ(ISATFL'I)SATEST
      READ(IRNFFL'I)RNDAT
      DO 4050 J=1,119
      RAIN(J)=(RNDAT(J)+SATEST(J))/2.0
 4050 CONTINUE
      RAIN(120)=SATEST(120)
      WRITE(IRAIFL'I)RAIN
 4100 CONTINUE
C
C     PUT GROUND TRUTH IN FINAL
C
      CALL GNDTRU(ISTAFL,IRAIFL,ALLSTA)
      CLOSE(UNIT=ISTAFL)
      CLOSE(UNIT=ISATFL)
      CLOSE(UNIT=IRNFFL)
      CLOSE(UNIT=IRAIFL)
      WRITE(6,*)'MEAN OF SATELLITE AND GAGES IS WINNER TODAY'
      GO TO 9000
C
C     QAM (MEAN OF QA AND GAGE INTERP FIELD) IS WINNER
C
 5000 WRITE(5,*)'MEAN OF SAT ADJUSTED AND GAGES IS WINNER'
      OPEN(UNIT=3,NAME='DYO:TRAIN.',TYPE='OLD',ACCESS='DIRECT',
```

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```
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAUSAT,MAXREC=42)
       OPEN(UNIT=4,NAME='DY0:RNFILE.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAURNF,MAXREC=42)
       OPEN(UNIT=9,NAME='DY0:ERFILE.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAUERF,MAXREC=42)
       IRNFFL=4
       IERFFL=9
C
C   INTERP FOR RAIN ALL STATIONS AND FOR ERROR ALL STATIONS
C
       CALL INTERP(3,ISTAFL,IRNFFL,ALLSTA)
       CALL INTERP(4,ISTAFL,IERFFL,ALLSTA)
       CLOSE(UNIT=ISTAFL)
C
C   COMPUTE GAM = (RAIN + ERROR + SATEST)/3.0
C
       OPEN(UNIT=8,NAME='DY0:RAINFL.',TYPE='OLD',ACCESS='DIRECT',
     1 RECORDSIZE=120,ASSOCIATEVARIABLE=IAURAI,MAXREC=42)
       IRAIFL=8
       READ(ISATFL'1)SATEST
       WRITE(IRAIFL'1)SATEST
       DO 5100 I=2,42
       READ(ISATFL'I)SATEST
       READ(IRNFFL'I)RNDAT
       READ(IERFFL'I)ERDAT
       DO 5050 J=1,119
       RAIN(J)=(SATEST(J)+RNDAT(J)+ERDAT(J))/3.0
 5050  CONTINUE
       RAIN(120)=SATEST(120)
       WRITE(IRAIFL'I)RAIN
 5100  CONTINUE
       CLOSE(UNIT=ISATFL)
       CLOSE(UNIT=IRNFFL)
       CLOSE(UNIT=IERFFL)
       CLOSE(UNIT=IRAIFL)
       WRITE(6,*)'MEAN OF SATELLITE ADJUSTED AND GAGES IS WINNER TODAY'
C
C   TERMINATE
C
 9000  CALL EXIT
       END
       SUBROUTINE GAGTRU(ISTAFL,IRAIFL,ALLSTA)
C*****************************************************************
C   THIS ROUTINE RESTORES THE GAGE READINGS TO THE
C   FINAL ESTIMATE FILE.  GAGE READINGS ARE ALWAYS
C
C   USED NO MATTER WHICH METHOD IS DAYS WINNER
C*****************************************************************
C
       REAL STAIN(19),RAIN(120)
       INTEGER ALLSTA(300,5)
       EQUIVALENCE (STAIN(5),OBS)
       I=1
C
C   CHECK FOR LAST STATION
C
  100  IF(ALLSTA(I,1).LT.0)RETURN
       NCOL=ALLSTA(I,3)
       NROW=ALLSTA(I,2)
       READ(IRAIFL'NROW-33)RAIN
       ID=ALLSTA(I,1)
       READ(ISTAFL'ID)STAIN
       RAIN(NCOL)=OBS
       WRITE(IRAIFL'NROW-33)RAIN
       I=I+1
       GO TO 100
       END
```

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```
      SUBROUTINE FILSTA(ISTAFL,ISATFL,ISAT,IGAGE)
C*****************************************************************
C   THIS ROUTINE FILLS REPORTING STATIONS WITH OBS,SAT EST,
C   ERR G-S,FLAGS ON/OFF. FLAGS FOR NO SATELLITE OR NO GAGES
C   OR NEITHER (WHEN NEITHER - TERMINATES).
C*****************************************************************
C
      REAL STATN(18),SATEST(120)
      LOGICAL*1 ANS
      LOGICAL*1 ISTATN(8),IONOFF
      EQUIVALENCE (STATN(1),ISTATN(1)),(STATN(5),OBS),(STATN(6),Q),
     $           (STATN(11),EGS),(ISTATN(4),IONOFF),(ISTATN(5),IROW),
     $           (ISTATN(7),ICOL)
      MXROW=75
      MNROW=35
      MXCOL=119
      MNCOL=1
      WRITE(5,*)'ARE ANY STATIONS AVAILABLE TODAY (Y OR N)?'
      READ(5,1)ANS
    1 FORMAT(80A1)
      IGAGE=0
      IF(ANS.NE.'Y')IGAGE=1
      WRITE(5,*)'IS THE SATELLITE ESTIMATE AVAILABLE TODAY (Y OR N)?'
      READ(5,1)ANS
      ISAT=0
      IF(ANS.NE.'Y')ISAT=1
C
C   CHECK FOR GAGE AVAIL
C
      IF(IGAGE.LT.1)GO TO 100
C
C  CHECK FOR SAT ONLY
C
      IF(ISAT.LT.1)RETURN
C
C   BOTH MISSING TERMINATE
C
      WRITE(6,*)'NEITHER SATELLITE NOR GAGES AVAILABLE - TERMINATE'
      CALL EXIT
C
C   GET GAGE READINGS
C
  100 WRITE(5,*)'HAVE ANY AVAILABLE STATIONS BEEN ENTERED ALREADY?'
      READ(5,1)ANS
      IF(ANS.EQ.1HY)GO TO 160
      DO 150 I=1,200
      READ(ISTAFL'I)STATN
      IONOFF=0
      WRITE(ISTAFL'I)STATN
  150 CONTINUE
      GO TO 190
  160 WRITE(5,*)'HAVE ALL AVAILABLE STATIONS BEEN ENTERED?'
      READ(5,1)ANS
      IF(ANS.EQ.1HY)GO TO 400
C
C   ENTER STATION READINGS IN ANY ORDER
C
  190 WRITE(5,*)'BEGIN ENTERING STATION OBSERVATIONS, TYPE -1,0 TO STOP'
  200 WRITE(5,*)'ENTER STATION ID AND OBSERVED VALUE AS ID,NNN.DD'
      READ(5,*)ID,OBSVD
      IF(ID.LT.0)GO TO 500
      IF(ID.LE.200)GO TO 210
      WRITE(5,*)'*** ID ERROR, TRY AGAIN'
      GO TO 200
  210 READ(ISTAFL'ID)STATN
      IONOFF=1
      OBS=OBSVD
C
C   CHECK FOR SATELLITE TOO
C
      IF(ISAT.GT.0) GO TO 300
      IF(IROW.GT.MXROW.OR.IROW.LT.MNROW)GO TO 240
      IF(ICOL.LE.MXCOL.AND.ICOL.GE.MNCOL)GO TO 250
  240 IONOFF=0
      GO TO 300
  250 READ(ISATFL'IROW-33)SATEST
      Q=SATEST(ICOL)
      EGS=OBSVD-Q
  300 WRITE(ISTAFL'ID)STATN
```

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      GO TO 200
  400 WRITE(5,*)'HAVE SATELLITE ESTIMATES BEEN ENTERED ALREADY?'
      READ(5,1)ANS
      IF(ANS.EQ.1HY)GO TO 500
C
C   READ IN AND STORE SATELLITE ESTIMATES FOR EACH REPORTING STATION
C
      DO 450 I=1,200
      READ(ISTAFL'I)STATN
      ID=ISTATN(1)
      IF(ID.LT.0)GO TO 500
      IF(IONOFF.EQ.0)GO TO 450
      IF(IROW.GT.MXROW.OR.IROW.LT.MNROW)GO TO 410
      IF(ICOL.LE.MXCOL.AND.ICOL.GE.MNCOL)GO TO 420
  410 IONOFF=0
      GO TO 440
  420 READ(ISATFL'IROW-33)SATEST
      Q=SATEST(ICOL)
      EOS=OBS-Q
  440 WRITE(ISTAFL'I)STATN
  450 CONTINUE
C   CHECK FOR ANY ERRONEOUS STATIONS
  500 WRITE(5,*)'WANT TO CHANGE STATUS OF ANY STATION FROM REPORTING TO'
      WRITE(5,*)'NOT REPORTING FOR THIS STORM?'
      READ(5,1)ANS
      IF(ANS.NE.1HY)GO TO 550
  510 WRITE(5,*)'ENTER ID OF STATION TO BE REMOVED FROM REPORTING'
      WRITE(5,*)'STATUS (-1 TO STOP)'
      READ(5,*)ID
      IF(ID.LT.0)GO TO 550
      READ(ISTAFL'ID)STATN
      IONOFF=0
      WRITE(ISTAFL'ID)STATN
      GO TO 510
C   CHECK FOR CORRECTION ENTRIES
  550 WRITE(5,*)'WANT TO CHANGE OBSERVED VALUE OF ANY STATION?'
      READ(5,1)ANS
      IF(ANS.EQ.1HY)GO TO 120
      WRITE(5,*)'DO YOU WANT TO CONTINUE WITH RAINFALL ESTIMATION?'
      READ(5,1)ANS
      IF(ANS.NE.1HY)CALL EXIT
      RETURN
      END
```

```
      SUBROUTINE SORT(ISTAFL,ALLSTA)
C*************************************************************
C   THIS ROUTINE SORTS THE REPORTING STATIONS BY COLUMN
C   INTO THE ALLSTA ARRAY USING A BUBBLE SORT
C*************************************************************
C
      REAL STATN(19)
      LOGICAL*1 ICA,IONOFF,ISTATN(8)
      INTEGER ALLSTA(200,5)
      EQUIVALENCE (ISTATN(1),STATN(1)),(ISTATN(1),ID),
     1         (ISTATN(4),IONOFF),(ISTATN(5),IROW),(ISTATN(7),ICOL),
     1         (ISTATN(3),ICA)
C
```

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```
C     STORE REPORTING STATIONS IN ALLSTA AND COUNT
C
            N=0
            DO 100 I=1,200
            READ(ISTAFL'I)STATN
            IF(ID.LT.0)GO TO 200
            IF(IONOFF.EQ.0)GOTO 100
            N=N+1
            ALLSTA(N,1)=ID
            ALLSTA(N,2)=IROW
            ALLSTA(N,3)=ICOL
            ALLSTA(N,4)=ICA
      100   CONTINUE
C
C     SORT ARRAY
C
      200   ALLSTA(N+1,1)=-1
C
C     BUBBLE SORT, ASSUME SORTED ALREADY
C
            J=N
      300   ISORT=1
            DO 400 I=2,J
            K=I-1
            IF(ALLSTA(K,3).LT.ALLSTA(I,3))GO TO 400
C     SWITCH ENTRIES
            ISORT=0
            DO 350 M=1,5
            ITEM=ALLSTA(K,M)
            ALLSTA(K,M)=ALLSTA(I,M)
            ALLSTA(I,M)=ITEM
      350   CONTINUE
      400   CONTINUE
            IF(ISORT.NE.0)GO TO 500
            ISORT=1
            J=J-1
            IF(J.GE.2)GO TO 300
C     ARRAY IS SORTED
      500   RETURN
            END
```

```
            SUBROUTINE INTERP(IOPT,IST  L,INFILE,ALLSTA)
C*****************************************************************
C     THIS ROUTINE INTERPOLATES FOR RAIN OR ERROR AT CONTROL STATIONS
C     ONLY (IOPT=1 OR 2) OR FOR ENTIRE STATE FIELD (IOPT=3 OR 4).
C     THE FORMULA USED IS BASED ON WEIGHTED INFLUENCE OF INVERSE
C     OF DISTANCE SQUARED FOR NEARBY STATIONS.
C*****************************************************************
C
            REAL ZERO(120),STATN(18),DATA(120)
            INTEGER ALLSTA(200,5)
            DATA ZERO/120*0.0/,INNPT/1/
C
C     CHECK FOR CONTROL STATIONS ONLY, OR ENTIRE FIELD
C
            IF(IOPT.GT.2)GO TO 1000
```


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```
C
C     CONTROL ONLY, SET WORD FOR RAIN OR ERROR(ERROR=11,IOPT=2)
C
      IWD=7
      IF(IOPT.GT.1)IWD=12
C
C     GET NEXT CONTROL STATION
C
  100 CALL NXTPNT(IOPT,NROW,NCOL,NSTA,ALLSTA)
C
C     CHECK FOR LAST ONE
C
      IF(NSTA.LT.0)RETURN
      READ(ISTAFL'NSTA)STATN
      CALL RANGE(IOPT,NROW,NCOL,ISTRT,NONE,ALLSTA,IRMNPT,IRMXPT,
     1          IMNPT,IMXPT,NRSF,NMAX)
C
C     CHECK FOR NO INFLUENCE
C
      IF(NONE.GT.0)GO TO 200
      CALL WEIGHT(IOPT,NROW,NCOL,RNER,ALLSTA,IRMNPT,IRMXPT,
     1          IMNPT,IMXPT,NRSF,NMAX,ISTAFL)
      STATN(IWD)=RNER
      GO TO 300
C
C     NO INFLUENCE, SET TO ZERO
C
  200 STATN(IWD)=0.0
  300 WRITE(ISTAFL'NSTA)STATN
      GO TO 100
C
C     INTERPOLATE FOR ENTIRE FIELD USING ALL STATIONS
C
 1000 DO 1100 I=2,42
      WRITE(INFILE'I)ZERO
 1100 CONTINUE
      NROW=34
 1200 NROW=NROW+1
C     ROW LOOP
      READ(INFILE'NROW-33)DATA
 1300 CALL NXTPNT(IOPT,NROW,NCOL,NSTA,ALLSTA)
C
C     CHECK FOR LAST COL IN ROW
C
      IF(NCOL.LT.0)GO TO 1900
C
C     ROW NOT COMPLETE, COMPUTE INTERP FOR POINT
C
      CALL RANGE(IOPT,NROW,NCOL,ISTRT,NONE,ALLSTA,IRMNPT,IRMXPT,
     1          IMNPT,IMXPT,NRSF,NMAX)
C
C     CHECK FOR POINT COINCIDENT WITH STATION
C
      IF(ISTRT.GT.0) GO TO 1400
C
C     NOT ON A STATION, INTERP
C
C     CHECK FOR NO STATION IN RANGE
C
      IF(NONE.GT.0)GO TO 1300
      CALL WEIGHT(IOPT,NROW,NCOL,RNER,ALLSTA,IRMNPT,IRMXPT,
     1          IMNPT,IMXPT,NRSF,NMAX,ISTAFL)
      DATA(NCOL)=RNER
      GO TO 1300
C
C     POINT ON A STATION
C
 1400 READ(ISTAFL'ISTRT)STATN
      DATA(NCOL)=STATN(5)
      IF(IOPT.GT.3)DATA(NCOL)=STATN(11)
      GO TO 1300
C
C     ROW COMPLETE
C
 1900 WRITE(INFILE'NROW-33)DATA
      IF(MOD(NROW,5).EQ.0)WRITE(5,*)'ROW ',NROW,' COMPLETED'
      IF(NROW.LT.75) GO TO 1200
C
C     ALL FINISHED
C
```

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```
      RETURN
      END
```

```
      SUBROUTINE NXTRNT(IOPT,NROW,NCOL,NSTA,ALLSTA)
C*****************************************************
C   THIS ROUTINE RETURNS THE NEXT COLUMN OR THE NEXT
C   STATION TO BE INTERPOLATED FOR (STATION WHEN IOPT
C   IS 1 OR 2, AND COLUMN WHEN IOPT IS 3 OR 4).
C*****************************************************
C
      INTEGER ALLSTA(200,5)
      INTEGER IELIM(41,2)
      DATA IELIM/74,73,73,72,72,71,69,68,64,63,62,54,53,52,51,50,
     1           50,49,48,47,46,45,45,20,17,15,13,11,10,9,8,6,3,1,1,1,
     1           1,1,1,1,1,
     1           74,76,78,86,88,88,90,92,93,93,92,92,91,94,96,98,100,
     1           102,117,117,117,117,117,117,117,117,117,117,117,117,
     1           117,117,117,117,117,117,117,117,117,117,117/
      DATA ICNTPT/1/,LASTPT/-1/
C
C   CHECK OPTION
C
      IF(IOPT.GT.2)GO TO 1000
C
C   STATION ONLY
C
  100 IF(ALLSTA(ICNTPT,1).LT.0)GO TO 500
      IF(ALLSTA(ICNTPT,4).EQ.0)GO TO 200
C  NOT A CONTROL STATION, GET NEXT ONE
      ICNTPT=ICNTPT+1
      GO TO 100
C
C   CONTROL STATION
C
  200 NSTA=ALLSTA(ICNTPT,1)
      NCOL=ALLSTA(ICNTPT,3)
      NROW=ALLSTA(ICNTPT,2)
      ICNTPT=ICNTPT+1
      RETURN
C
C  ALL STATION SENT,FLAG
C
  500 NSTA=-1
      ICNTPT=1
      RETURN
C
C   ENTIRE FIELD
C
 1000 IF(LASTPT.LT.0)GO TO 1500
C  NOT AT BEGINNING, SOMEWHERE IN MIDDLE OF ROW
      LASTPT=LASTPT+1
      IF(LASTPT.GT.IELIM(NROW-34,2))GO TO 1200
C  NOT PAST END,SEND BACK COL NUMBER
      NCOL=LASTPT
      RETURN
C  ROW COMPLETE,FLAG
 1200 NCOL=-1
      LASTPT=-1
      RETURN
C
C  START AT BEGINNING OF ROW
C
 1500 LASTPT=IELIM(NROW-34,1)
      NCOL=LASTPT
      RETURN
      END
```

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```
      SUBROUTINE RANGE(IOPT,NROW,NCOL,ISTPT,NONE,ALLSTA,IPMNPT,IPMXPT,
     1                IMNPT,IMXPT,NPSE,NMAX)
C*********************************************************************
C     THIS ROUTINE SETS THE POINTERS FOR INTERPOLATION OVER THE STATION
C     ARRAY AND COUNTS THE NUMBER OF STATIONS INFLUENCING POINT. FLAGS
C     IF NO STATION IN RANGE. FLAGS IF POINT COINCIDENT WITH STATION.
C*********************************************************************
C
      INTEGER ALLSTA(200,5)
      DATA NPRETH/4/,IPSEDL/5/,IMAXDL/10/,IANA/1/
      NONE=0
      ISTPT=0
C   SET STATION OPTION
      NOPT=-1
      IF(IOPT.LT.3)NOPT=0
C   SET UP MINS AND MAXS
      ICPMIN=NCOL-IPSEDL
      ICPMAX=NCOL+IPSEDL
      IRPMIN=NROW-IPSEDL
      IRPMAX=NROW+IPSEDL
      ICMIN=NCOL-IMAXDL
      ICMAX=NCOL+IMAXDL
      IRMIN=NROW-IMAXDL
      IRMAX=NROW+IMAXDL
C   SET UP POINTERS FOR COLUMN, MIN POINT FIRST
  100 IF(ALLSTA(IMNPT,3).GT.ICMIN)GO TO 150
C   NO, CHECK FOR EQUAL
      IF(ALLSTA(IMNPT,3).EQ.ICMIN)GO TO 200
C   NO, MOVE DOWN
C   CHECK FOR MORE STATIONS
  110 IF(ALLSTA(IMNPT+1,1).LT.0)GO TO 120
C   INCREMENT DOWN
      IMNPT=IMNPT+1
      IF(ALLSTA(IMNPT,3).GE.ICMIN)GO TO 200
      GO TO 110
C   LAST STATION REACHED, STOP HERE
  120 IMXPT=IMNPT
      IPMNPT=IMNPT
      IPMXPT=IMNPT
      GO TO 1000
C   TOO FAR DOWN, START OVER AT TOP
  150 IF(IMNPT.EQ.1)GO TO 200
      IMNPT=1
      GO TO 100
C
C   SET PREFERRED MIN
C
  200 IPMNPT=IMNPT
  205 IF(ALLSTA(IPMNPT,3).GE.ICPMIN)GO TO 300
C   NO, CHECK FOR NEXT STATION
      IF(ALLSTA(IPMNPT+1,1).LT.0)GO TO 210
C   NO, MORE STATIONS, INCREMENT
      IPMNPT=IPMNPT+1
      GO TO 205
C   NO MORE STATIONS, STOP HERE
  210 IMXPT=IPMNPT
      IPMXPT=IPMNPT
      GO TO 1000
C
C   SET PREFERRED MAX
C
  300 IPMXPT=IPMNPT
  310 IF(ALLSTA(IPMXPT,3).LE.ICPMAX)GO TO 320
C   NO, SEE IF BACKUP NEEDED
      IF(IPMXPT.GT.IPMNPT)IPMXPT=IPMXPT-1
      GO TO 400
C   MOVE DOWN, BUT CHECK FOR MORE STATIONS FIRST
  320 IF(ALLSTA(IPMXPT+1,1).LT.0)GO TO 330
C   MORE, INCREMENT
```

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      IPMXPT=IPMXPT+1
      GO TO 310
C  NO MORE, STOP HERE
  330 IMXPT=IPMXPT
      GO TO 1000
C
C   GET IMXPT
C
  400 IMXPT=IPMXPT
  410 IF(ALLSTA(IMXPT,3).LE.ICMAX)GO TO 420
C  OK,CHECK FOR BACKUP NEEDED
      IF(IMXPT.GT.IPMXPT)IMXPT=IMXPT-1
      GO TO 1000
C  MOVE DOWN, BUT CHECK FOR NEXT STATION FIRST
  420 IF(ALLSTA(IMXPT+1,1).LT.0)GO TO 1000
      IMXPT=IMXPT+1
      GO TO 410
C
C   ALL POINTERS SET,CHECK PREFERRED RANGE FOR DESIRED STATIONS
C   (BASED ON NOPT),CHECK FOR COINCIDENCE WITH STATION,CHECK
C   ROW RANGE, AND COUNT NUM IN PREFERRED RANGE.
C
 1000 NPRE=0
      DO 1500 I=IPMNPT,IPMXPT
      ALLSTA(I,5)=0
      IF(ALLSTA(I,4).LE.NOPT)GO TO 1500
C  STATION OK,CHECK ROW RANGE
      ICOL=ALLSTA(I,3)
      IROW=ALLSTA(I,2)
      IF(IROW.LT.IRPMIN.OR.IROW.GT.IRPMAX)GO TO 1500
C  ROW OK, CHECK FOR COINCIDENCE
      IF(IROW.EQ.NROW.AND.ICOL.EQ.NCOL)GO TO 2100
C  POINT IN RANGE, SET FLAG AND COUNT
      ALLSTA(I,5)=1
      NPRE=NPRE+1
 1500 CONTINUE
C
C   CHECK FOR ENOUGH IN PREFERRED RANGE
C
      IF(NPRE.GE.NPSETH)RETURN
C
C   NOT ENOUGH, CHECK MAX RANGE
C
      NPSE=0
      NMAX=0
      DO 2000 I=IMNPT,IMXPT
      ALLSTA(I,5)=0
      IF(ALLSTA(I,4).LE.NOPT)GO TO 2000
C  STATION OK,CHECK ROW RANGE
      ICOL=ALLSTA(I,3)
      IROW=ALLSTA(I,2)
      IF(IROW.LT.IRMIN.OR.IROW.GT.IRMAX)GO TO 2000
C  ROW OK,CHECK COINCIDENCE
      IF(IROW.EQ.NROW.AND.ICOL.EQ.NCOL)GO TO 2100
C  POINT IN RANGE,SET FLAG AND COUNT
      ALLSTA(I,5)=1
      NMAX=NMAX+1
 2000 CONTINUE
C  CHECK FOR NONE IN RANGE
      IF(NMAX.NE.0)RETURN
      NONE=1
      RETURN
C  POINT COINCIDENT WITH STATION,SET  FLAG
 2100 ISTPT=ALLSTA(I,1)
      RETURN
      END
```

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```
      SUBROUTINE WEIGHT(IOPT,NROW,NCOL,RNER,ALLSTA,IPMNPT,IPMXPT,
     1          IMNPT,IMXPT,NPRE,NMAX,ISTAFL)
C*********************************************************************
C   THIS ROUTINE COMPUTES THE INTERPOLATED VALUE FOR THE RAIN OR
C   ERROR BASED ON AN INVERSE DISTANCE WEIGHTING FORMULA USING
C   THE SURROUNDING GROUND STATION VALUES. RNER IS THE VALUE,
C   EITHER RAIN OR ERROR BASED ON THE OPTION IOPT.
C*********************************************************************
C
      REAL STATN(10)
      INTEGER ALLSTA(200,5)
C  SET WORD BASED ON OPTION
      IWD=11
      IF(IOPT.EQ.1.OR.IOPT.EQ.3)IWD=5
      IBEG=IPMNPT
      IEND=IPMXPT
      IF(NPRE.NE.0)GO TO 100
      IBEG=IMNPT
      IEND=IMXPT
C  COMPUTE INTERPOLATED VALUE
  100 SUMWG=0.0
      SUMW=0.0
      DO 500 I=IBEG,IEND
C  CHECK FOR IN RANGE
      IF(ALLSTA(I,5).EQ.0)GO TO 500
C  IN RANGE. COMPUTE WEIGHT AND SUM
      RDEL=IABS(NROW-ALLSTA(I,2))
      CDEL=IABS(NCOL-ALLSTA(I,3))
      DIS=SQRT((RDEL*8.7119)**2 + (CDEL*6.2235)**2)
      W=1.0/DIS
      SUMW=SUMW+W
      READ(ISTAFL'ALLSTA(I,1))STATN
      SUMWG=SUMWG+ W*STATN(IWD)
  500 CONTINUE
      RNER=SUMWG/SUMW
      RETURN
      END
```

APPENDIX B

OFFICIAL SYNOPSES BY NWS FORECAST OFFICE, WASHINGTON, D. C.

Official Synopses by NWS Forecast Office, Washington, D. C.

August 15-16, 1980: A cold front extension from Central New York to Indiana on the morning of August 15 moved southeastward across Virginia in the night and became stationary over the Carolinas on the 16th.

September 9-10, 1980: A strong cold front located in the Ohio Valley the morning of September 9 moved across the Appalachians by night reaching the north portion of Chesapeake Bay late at night. It moved east of the Bay and east coast early Wednesday (Sep. 10) morning, but trailed back across western North Carolina at 0939Z September 10.

September 16-17, 1980: No front in the area. Southeasterly winds of 10 to 15 knots in the afternoon becoming southerly 10 to 15 knots in the night.

September 17-18, 1980: A cold front moved eastward through the Ohio Valley on September 17 and stalled over the Appalachians late in the day, spreading showers and thunderstorms over Virginia. A warm front formed across southern Virignia during the afternoon, but weakened in the night. The cold front extended from eastern New England through southwest Virginia by 0939Z September 18. It moved southeastward off the coast by late in the day.

September 24-25, 1980: A stationary front extended east-west across the Carolinas near 35° north. Some rain developed across Virginia due to the nearness of the front.

September 25-26, 1980: A cold front extending from Ohio into Tennessee on the 25th moved rapidly eastward crossing Chesapeake Bay late on the night of September 25. A strong secondary cold front crossed the Appalachians on the morning of September 26 and moved offshore early in the afternoon.

October 1-2, 1980: A low center east of the Virginia capes moved slowly east northeastward on October 1 and early October 2. A cold front in the midwest moved eastward across the Appalachians late on October 2.

October 24-25, 1980: A deepening low off the Georgia coast on the morning of October 24 moved northward, reaching the North Carolina coast south of Hatteras at 3 a.m. (EDT) October 25. It continued to intensify as it moved northward into the southern Chesapeake Bay.

November 14-15, 1980: A slow-moving cold front crossed the Appalachians on the afternoon of November 14 and into central Virginia at night.

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November 15-16, 1980: The cold front moved across the Chesapeake Bay and southern Virginia the morning of November 15 and became stationary over the Carolinas by night. Late on the night of November 15 a low moved eastward off the North Carolina coast. High pressure dominated Virginia on the morning of November 16.

November 17-18, 1980: A frontal trough developed late the morning of November 17 near the Virginia capes and Carolina coastline, intensifying in the afternoon. A low pressure center formed offshore along the front near southeastern Virginia during the night and moved east northeastward at 30 knots, with a cold front trailing down across South Carolina by late on November 18.

December 9-10, 1980: A low over Kentucky on the morning of December 9 moved northeastward across West Virginia in the afternoon, across Pennsylvania in the night and off the New England coast on December 10. A cold front southward from the low crossed Virginia in the afternoon and night of the 9th. By 1200Z December 10 the front was in southeastern Virginia moving offshore.

March 4-5, 1981: An intensifying low over the plains states was moving eastward, but could not affect Virginia weather. Another intensifying low developed over South Carolina in the early morning of March 5 and began moving northeastward.

March 5-6, 1981: The intensifying low over South Carolina at 0939Z March 5 moved to northeastern North Carolina by 1539Z and off the Virginia capes by 2139Z and moved off to the east northeast thereafter. Virginia was dominated by strong northerly winds, with snow flurries.

March 16-17, 1981: A strong cold front moved southeastward across Virginia on March 16, and out over the Atlantic late in the day.

March 22-23, 1981: A weak high pressure ridge remained over Virginia on March 22, moving off the coast early in the morning of March 23. A developing low over Arkansas early on March 22 moved rapidly eastward and off the South Carolina coast by late in the morning of March 23.

March 29-30, 1981: A strong high off the Carolina coast moved slowly eastward. A cold front over the great plains moved rapidly eastward but was still west of the Appalachians early on the morning of March 30.

March 30-31, 1981: The cold front extending southward from Chicago on the morning of March 30 moved eastward across Virginia late in the afternoon and off the east coast at night. High pressure built up behind the front.

April 14-15, 1981: A warm front lying across southwest Virginia in the morning moved eastward across the state in the afternoon. A strong cold front followed in the wake of the warm front, moving east and south of Virginia shortly before midnight.

May 15-16, 1981: A cold front from Ohio to Georgia in the morning moved to a line from eastern Ohio to central South Carolina by evening. It crossed Virginia during the night reaching the coast shortly after daybreak.

May 18-19, 1981: High pressure dominated Virginia today, but a low moved into western Tennessee in the late afternoon with a warm front extending eastward from the low across the Carolinas. The front lay east-west across southern Virginia during the night, and became stationary across northern North Carolina in the early morning.

May 19-20, 1981: An east-west front across central North Carolina remained stationary today as a 1007-mb low in western Tennessee at 1200Z moved eastward along the front, reaching the North Carolina coast Wednesday morning. Early Wednesday morning (May 20) the front became a cold front and moved southward across South Carolina.

APPENDIX C

STATIONS USED IN INVESTIGATION

APPENDIX C - STATIONS USED IN INVESTIGATION

Name	Call	ID	Row	Col	Lat	Long	Status
Allisonia	AL	1	66	40	36.90	80.75	Control
Altavista	AV	2	63	60	37.10	79.30	Analysis
Amelia (see JE)	AE	153	61	78	37.30	78.03	Analysis
Amissville	AM	3	45	79	38.68	78.02	Control
Appomattox	AP	4	60	66	37.37	78.88	Analysis
Bedford	BD	5	60	57	37.35	79.52	Control
Berryville	BE	6	40	79	39.15	77.98	Control
Big Meadows	BM	7	47	73	38.52	78.43	Analysis
Blacksburg	BL	8	62	44	37.18	80.42	Analysis
Bland	BN	9	63	35	37.10	81.10	Control
Bremo Bluff	BB	10	56	74	37.70	78.30	Analysis
Bridgewater	BW	140	49	65	38.38	78.97	Analysis N
Brookneal	BR	11	64	65	37.03	78.93	Control
Buchanan	BU	12	58	55	37.53	79.68	Analysis
Buckingham	BK	13	58	71	37.55	78.55	Control
Buena Vista	BV	14	56	60	37.73	79.35	Control
Byllesby	BY	15	67	36	36.80	80.98	Control
Camp Pickett	CP	16	64	79	37.03	77.95	Control
Charlotte C. H.	CC	17	64	69	37.07	78.65	Control
Charlottesville	CT	18	53	71	38.03	78.52	Control
Charltsvl Airpt	CHO	117	52	72	38.13	78.45	Analysis
Chase City	CY	141	66	72	36.83	78.47	Control N
Chatham	CM	19	67	59	36.82	79.40	Control
Clarksville	CL	20	69	71	36.62	78.57	Control
Clifton Forge	CF	21	55	53	37.82	79.83	Analysis *
Columbia	CU	22	56	77	37.77	78.15	Analysis
Concord	CO	23	61	65	37.28	78.97	Control
Copper Hill	CH	24	63	48	37.10	80.13	Control
Corbin	CN	25	51	88	38.20	77.37	Control
Covington	CV	26	55	50	37.80	80.00	Control
Craigsville	CR	27	52	59	38.08	79.38	Control
Crozier	CZ	28	57	82	37.63	77.80	Analysis
Cumberland	CB	154	59	75	37.50	78.25	Control
Danville Arpt.	DAN	36	69	59	36.57	79.33	Analysis

Name	Call	ID	Row	Col	Lat	Long	Status	
Danville(Bridge)	DA	29	69	59	36.58	79.38	Analysis	
D.C. Nat'l Airpt.	DCA	95	43	93	38.85	77.03	Analysis	
Deerfield	DE	30	51	59	38.17	79.37	Control	*
Dulles Int. Arpt.	IAD	94	42	87	38.95	77.45	Analysis	
Earlehurst	EA	31	57	47	37.67	80.23	Analysis	
Edinburg	ED	166	43	70	38.85	78.60	Control	N
Emporia	EM	32	68	85	36.68	77.55	Control	
Farmville	FA	33	61	73	37.33	78.38	Analysis	
Floyd	FY	34	65	46	36.93	80.30	Control	
Fort Belvoir	DAA	114	45	90	38.72	77.18	Control	
Fort Eustis	FAF	118	63	98	37.13	76.62	Control	
Free Union	FU	35	51	71	38.15	78.57	Analysis	
Gathright Dam	GT	155	54	51	37.95	79.95	Analysis	
Glasgow	GG	37	57	58	37.62	79.43	Control	
Glen Lyn	GL	38	60	38	37.37	80.87	Control	#
Gordonsville	GD	39	52	76	38.08	78.18	Analysis	
Goshen	GO	40	53	57	37.98	79.50	Analysis	
Grundy	GR	41	61	21	37.27	82.08	Control	
Hillsville	HI	42	68	40	36.67	80.73	Analysis	
Holcombs Rock	HR	43	59	61	37.50	79.27	Control	
Holland	HO	44	68	96	36.68	76.78	Control	
Hot Springs	HS	45	53	53	38.00	79.83	Control	
Huddleston	HU	46	63	57	37.15	79.50	Control	
Independence	IN	47	69	34	36.65	81.17	Analysis	
Isle of Wight	IW	142	65	97	36.92	76.70	Analysis	N
Jetersville (AE)	JE	169	61	78				N
John Flannagan Lk	FL	48	62	17	37.23	82.35	Analysis	
John Kerr Dam	KD	49	69	75	36.60	78.28	Analysis	
Kerrs Creek	KC	50	55	56	37.87	79.57	Control	
Keysville	KY	156	63	71	37.17	78.52	Analysis	
Lafayette	LA	51	62	47	37.23	80.22	Control	
Lancaster	LN	167	55	100	37.80	76.52	Analysis	N
Langley AFB	LFI	52	64	102	37.08	76.35	Analysis	
Leesburg	LE	143	40	85	39.12	77.58	Analysis	N
Luray	LU	53	45	73	38.67	78.38	Control	
Lynchburg	LYH	54	61	62	37.33	79.20	Analysis	

Name	Call	ID	Row	Col	Lat	Long	Status
Martinsville Fil	MF	157	68	52	36.70	79.88	Analysis
McDowell	MC	55	49	57	38.33	79.50	Control
Meadows of Dan	MD	56	68	44	36.67	80.45	Control
Millgap	MI	57	49	54	38.35	79.72	Control
Mill Run Farm	MR	58	51	54	38.22	79.73	Control
Montebello	MB	60	54	63	37.88	79.13	Analysis
Mountain Grove	MG	61	52	52	38.10	79.88	Analysis
Mt. Solon	MS	158	49	63	38.35	79.08	Analysis
Mount Weather	MW	62	41	80	39.07	77.88	Analysis
NAS, Norfolk	NGU	151	65	103	36.93	76.28	Control
New Castle	NC	63	59	49	37.50	80.10	Control
Newport	NE	64	61	43	37.32	80.52	Control
Newport 6NE	NP	144	60	44	37.35	80.42	Analysis N
Newsoms	NS	145	69	91	36.63	77.12	Analysis N
Norfolk	ORF	65	66	104	36.90	76.20	Analysis
North Fork Lake	NF	66	63	13	37.13	82.63	Control
North River Dam	NR	67	49	61	38.37	79.27	Analysis *
Oceania	NTU	116	66	107	36.83	76.02	Control
Orange (PE)	PE	71	51	77	38.22	78.12	Control
Palmyra	PA	68	55	75	37.87	78.25	Control
Patrick Henry	PHF	152	63	100	37.13	76.50	Analysis
Pedlar Dam	PD	69	57	60	37.67	79.28	Analysis
Petersburg	PG	159	62	87	37.23	77.40	Control
Philpott Dam	PT	70	67	50	36.78	80.03	Control
Piedmont R.S.(OR)	PE	71	51	77	38.22	78.12	Control
Pilot	PI	72	64	45	37.07	80.35	Analysis
Piney River	PR	73	56	65	37.70	79.00	Control
Powhatan	PW	160	58	80	37.53	77.92	Control
Quantico Marine	NYG	113	47	89	38.50	77.30	Analysis
Radford	RA	74	63	42	37.13	80.55	Control
Randolph	RL	75	65	69	36.98	78.70	Analysis
Rapidan	RP	76	50	78	38.30	78.07	Analysis
Richmond	RIC	77	59	88	37.50	77.33	Analysis
Riverton	RI	78	42	76	38.93	78.20	Control *
Roanoke	ROA	79	61	51	37.32	79.97	Analysis
Rockfish	RO	80	55	68	37.80	78.75	Analysis

Name	Call	ID	Row	Col	Lat	Long	Status	
Rocky Mount (Va)	RM	81	65	52	37.00	79.90	Analysis	
South Boston	SB	161	68	66	36.70	78.88	Analysis	
Speedwell	SP	82	67	34	36.82	81.17	Control	
Staffordsville	SF	83	61	40	37.27	80.72	Analysis	
Stanardsville	SV	147	50	72	38.27	78.45	Control	N
Staunton S.P.	ST	84	51	64	38.15	79.03	Control	
Sterling	SG	85	42	86	38.98	77.47	Control	
Stony Creek	SC	86	66	87	36.90	77.45	Analysis	
Stuart	SU	162	69	46	36.63	80.27	Control	
The Plains	TP	87	43	82	38.90	77.75	Control	
Timberville 5E	TI	148	46	69	38.62	78.68	Control	N
Trout Dale	TD	88	68	30	36.67	81.40	Analysis	
Tye River	TR	89	57	65	37.63	78.93	Analysis	
Wakefield 6NE	WF	149	64	94	37.02	76.90	Analysis	N
Wallaceton	WL	90	69	101	36.60	76.43	Analysis	
Wallops Island	WAL	91	54	115	37.95	75.48	Analysis	
Warrenton	WR	92	45	82	38.68	77.77	Analysis	
Washington, Va.	WG	93	45	76	38.72	78.17	Analysis	
Waverly	WV	115	64	92	37.03	77.10	Control	
West Point	WP	150	59	95	37.52	76.83	Control	N
Willis	WS	163	66	43	36.85	80.48	Analysis	
Winchester	WI	96	39	76	39.20	78.17	Control	
Winterpock	WK	164	61	84	37.33	77.65	Analysis	
Woodstock	WD	97	43	71	38.88	78.52	Analysis	
Woolwine	WO	98	68	46	36.72	80.28	Analysis	
Wytheville	WY	99	65	35	36.93	81.08	Analysis	

Out of State

Andrews AFB, Md.	ADW	103	44	95	38.80	76.87	Analysis
Baltimore, Md.	BAL	100	40	98	39.18	76.67	Analysis
Beckley, W.Va.	BKW	119	56	34	37.78	81.12	Analysis
Bluefield, W.V.	BLF	106	61	33	37.30	81.22	Analysis
Bristol, Tenn.	TRI	107	70	16	36.48	82.40	Analysis
Charleston, W.V.	CRW	120	49	27	38.37	81.60	Analysis
Dover, Del.	DOV	137	40	115	39.12	75.45	Analysis
Elizabeth C.,N.C.	ECG	108	73	105	36.27	76.18	Analysis
Elkins, W. Va.	EKN	105	43	52	38.88	79.85	Analysis

Name	Call	ID	Row	Col	Lat	Long	Status
Greensboro, NC	GSO	110	75	51	36.08	79.95	Analysis
Huntington, WV	HTS	122	49	14	38.37	82.55	Analysis
Matinsburg, WV	MRB	104	37	79	39.40	77.98	Analysis
Patuxent, Md.	NHK	101	49	101	38.33	76.42	Analysis
Raleigh, N.C.	RDU	109	77	68	35.87	78.78	Analysis
Rocky Mount, NC	RWI	112	78	80	35.85	77.88	Analysis
Salisbury, Md.	SBY	102	49	114	38.33	75.52	Analysis
Winston-Salem NC	INT	111	74	47	36.13	80.23	Analysis

N - NATS Station

* - Station closed during later part of this study.

- Glen Lyn now takes observations at 6 p.m.

Due to closing of stations and resulting imbalance, the status of eight stations was changed midway through the study. Columbia, Goshen, Independence and Patrick Henry were changed from Control to Analysis; Corbin, Craigsville, Millgap and Winchester were changed from Analysis to Control.

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