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AN OPERATIONAL EVALUATION OF THE SCOFIELD/OLIVER TECHNIQUE FOR ESTIMATING PRECIPITATION RATES FROM SATELLITE IMAGERY

Richard Ochoa

National Weather Service Forecast Office
Phoenix, Arizona
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UNITED STATES
DEPARTMENT OF COMMERCE
Philip M. Klutznick, Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
Richard A. Frank, Administrator

National Weather
Service
Richard E. Hallgren, Director

This Technical Memorandum has been reviewed and is approved for publication by Scientific Services Division, Western Region.

L. W. Snellman

L. W. Snellman, Chief
Scientific Services Division
Western Region Headquarters
Salt Lake City, Utah

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AN OPERATIONAL EVALUATION OF THE SCOFIELD/OLIVER TECHNIQUE FOR ESTIMATING PRECIPITATION RATES FROM SATELLITE IMAGERY

Richard Ochoa
Weather Service Forecast Office
Phoenix, Arizona

ABSTRACT. A technique for estimating rainfall rate quantitatively from satellite imagery, the Scofield/Oliver technique, was tested in Arizona during the summer of 1978. Although the number of cases is small, some interesting cases illustrating potential weaknesses of the technique in the western United States are discussed and recommendations for eliminating these weaknesses are given.

I. INTRODUCTION

The Scofield/Oliver technique was developed as an objective means of estimating precipitation from satellite imagery (1977a). The scheme is based on cloud-top temperature over a point (or area) of interest and the variation in size of the coldest cloud top. Simply stated, higher (and therefore colder) convective cloud tops correlate with greater rainfall rates. Similarly, greater expansion rates of the coldest cloud top with time correlate with greater rainfall rates.

Cloud-top temperature and expansion are determined by analyzing infrared (IR) imagery. By assigning distinct grey shades to specific temperature intervals, a contoured effect, referred to as grey-shade enhancement, is produced. As an example, cloud-top temperatures from -32°C to -41°C might be displayed as a medium grey. Figure 1 shows an example of a thunderstorm depicted by grey-shade enhancement. The grey shade to temperature relationship, referred to as an enhancement "curve", is shown in Figure 2.

Enhanced IR imagery provides the user with a simple and rapid interpretation of the picture. From enhanced imagery, like that shown in Figure 1, an analyst can quickly ascertain the upwind portion (tightest IR gradient) and cirrus blow-off debris. In addition to enhanced IR imagery, one-half mile resolution visible pictures are used to locate precipitation amplifiers such as overshooting tops, merging thunderstorms, and convective cloud-line mergers.

Cloud-top temperature, rate of expansion of the coldest cloud tops, and the precipitation amplifiers mentioned above are used in a decision flowchart in the Scofield/Oliver technique to produce an estimate of rainfall rate. The decision flowchart is reproduced in full as an Appendix to this paper.

Relationships between cloud features and rainfall estimates presented in the Scofield/Oliver decision flowchart were derived primarily from samples taken from the central part of the United States (Scofield and Oliver, 1977a). Case studies of heavy precipitation events in Missouri (Craig, 1977), Pennsylvania (NOAA/NWS, 1977, and Scofield, 1978), Texas (Scofield, 1976, and Belville, 1977), and other areas in the United States east of the Continental Divide have shown that the technique is reliable and generally provides estimates that are sufficiently accurate enough to be used as a basis for heavy rain warnings.

Prior to the summer of 1978 no case studies had been done in the western United States, however, and many questions were raised with regard to the use of a technique, which was developed for thunderstorms generating in air masses characterized by deep moisture over generally flat terrain, in the western United States where high-based thunderstorms with dry, lower layers and increased terrain effects were more common. To answer some of these questions, an evaluation of the technique was planned and implemented at the Phoenix (PHX) WSFO during the summer of 1978. The Quantitative Precipitation Estimation (QPE) test was designed to assess the utility of the Scofield/Oliver scheme of estimating rainfall amounts operationally in Arizona. Satellite imagery received operationally at PHX WSFO was used to generate area rainfall estimates. Afterwards, actual rainfall amounts from the observational network were used to verify the rainfall estimates.

II. PROCEDURES

Procedures during the test followed the Scofield/Oliver technique except that hourly picture pairs (consecutive IR pictures one-hour apart) were used as opposed to half-hourly picture pairs used by Scofield/Oliver. Grey-shade enhancement used for evaluating the imagery was similar to temperature-grey shade relationship shown in Figure 2.

All rainfall estimates, except for the Whiteriver case study, were performed by the author. Transparent grids with verification sites were placed directly over the satellite photograph while making the rainfall estimate. Verification sites are shown in Figure 3. For each study, a worksheet as shown in Figure 4 was completed. The worksheet was basically Step 4 of the decision flowchart with the rainfall rates doubled to account for hourly estimates. The worksheet expedited the technique and placed all information on one sheet. Some estimates were made in real time while others were completed shortly thereafter. Due to the speed and objectiveness of the Oliver/Scofield scheme, the estimates would be comparable to those made by a forecaster at a typical forecast office. Very little subjectivity entered the estimate.

Verification sites were composed of Arizona's NWS offices and substations. Verification data consisted of only hourly rainfall values. No daily rainfall amounts were included in the verification data.

III. SELECTED CASE STUDIES

a. July 24, 1978 - Phoenix

On July 24, 1978, an upper level ridge was centered over Nevada and Utah with moist, unstable SE flow over Arizona. An easterly wave which caused some light morning showers at PHX was over NW Arizona at 00Z, July 25, 1978. The average morning surface dew point in Arizona was 58°F at 14Z, July 24. Phoenix reported a 69°F dew point, up 3°F from the previous day. At 0103Z, July 25, Phoenix surface and radar observations reported a thunderstorm to the southeast moving toward the north at 10 mph. At 0145Z, enhanced IR imagery showed Phoenix located in an area where grey levels were tightly packed (Figure 5a) with cloud tops colder than -70°C. At 0245Z Phoenix was located within an area of repeat grey levels (Figure 5b). At first glance, merging thunderstorms over Phoenix might have been suspected. However, further scrutiny showed the thunderstorm system NE of Phoenix had decreased in intensity while the intensity of the system over the station had remained approximately constant. Since the length of the axis of the coldest contour (white) remained the same during the time period, the estimate of 0.60 inches/hour was made (refer to decision tree in the Appendix). Phoenix WSFO recorded 0.68 of an inch of rain between 0152Z and 0255Z, and a peak gust of 64 mph at 0201Z.

b. August 1, 1978 - Payson and Clifton

An example of a large discrepancy between the Quantitative Precipitation Estimate (QPE) and actual rainfall amounts occurred at Payson, Arizona, on August 1, 1978. Between 2315Z August 1 and 0015Z August 2, a developing thunderstorm was located near Payson, Arizona (Figure 6a-c). The QPE technique gave a value of 0.80 inches/hour which verified poorly against the 0.04 inches actually observed at the station between 2300Z and 0100Z.

Reasons for the discrepancy at Payson are not certain but difficulties associated with making an estimate for a point rather than over some integrated area are suspected. In other words, precipitating cells may occupy only a small portion of the total area within the cloud boundaries as seen from the satellite. Thus, a grid error of only a few miles could mean the difference between a few hundredths or three-fourths of an inch of precipitation.

A few miles to the southeast, during the same time period, precipitation estimates agreed well with amounts observed at Clifton, Arizona. The Clifton case involved one of the precipitation amplifiers cited by Scofield and Oliver (1977a) overshooting tops. For the period between 2215Z and 0115Z, total QPE for Clifton was 0.76 inches. Included in this estimate was 0.50 inches for overshooting tops near the station at 0045Z (Figure 6c). The satellite estimate was very close to the actual 0.80 inches reported at Clifton between 2230Z and 0130Z.

c. July 11, 1977 - Whiteriver

Though not occurring during the 1978 period of evaluation, a case which occurred the previous summer has been included because it apparently involved enhancement of precipitation as a result of orographic lifting. On July 11, 1977, the 0245Z - 0345Z QPE for Whiteriver was 0.02 inches/hour (Figure 7a-b). Between 0245Z and 0345Z Whiteriver reported 1.55 inches of rain along with local flooding of roads and homes. Considering Whiteriver lies in a valley oriented north/south and very moist south to southeast flow was occurring, orographic lifting was probably a significant contributing factor in the rainfall amount recorded. This type of precipitation amplifier could be a significant factor at many mountain locations.

IV. INTERPRETATION OF DATA

Results (Figure 8) show that in 11 of the 26 cases (42%) of the QPE and observed values were within 0.10 inch. Fifteen (58%) of the estimates verified within 0.20 inch. The K index was included in the QPE test to see if moist (dry) cases correlated to high (low) K values. From this study, the K index shows no correlation to the accuracy of the QPE. This is probably due to the non-representativeness of using K values taken normally 12 hours or more before the rainfall began. No further statistical analyses were performed due to the small sample size and problems of verification.

Several problems, including hourly picture pairs, verification and satellite picture gridding plague the estimation scheme. One of the most serious problems is that of hourly picture pairs. Considering the lifetime of a thunderstorm, the hourly time interval between picture pairs is too long. Thus, the ability of the forecaster to issue timely flash-flood statements is severely hampered. The time element is crucial during severe weather.

Another problem is verification of rainfall estimates with a single point due to the sparsity of rainfall reporting stations and even fewer with hourly rainfall observations. Compounding the problem is the variation of rainfall amounts due to localized precipitation from thunderstorms. Nonrepresentativeness of the verification data was the largest problem in this study.

Inaccuracies in gridding the satellite imagery created another handicap. The task of manually gridding the picture was often made difficult by the lack of identifiable terrain features.

V. CONCLUSIONS

Despite difficulties in working with the QPE scheme as described in the preceding section, the results seem encouraging. Orographic effects appear to be an important factor, not included in the technique. The author agrees with Scofield and Oliver (1977b) in that no fine tuning of the estimations should take place until further testing is carried out.

During 1978, no opportunity to test the Scofield/Oliver technique during flash-flood situations arose. Even though accuracy of the technique in Arizona is unproven at present, simplicity and quickness of the technique make it a powerful tool in alerting the forecaster to potential flash-flood situations. The scheme can be augmented by radar and surface observations. By using all of these data sources in a complementary way, the problems of locating potentially dangerous heavy precipitation areas are eliminated. The technique was very valuable in areas where radar coverage is limited.

The main conclusion is that the greatest benefit would be obtained if the National Environmental Satellite Service (NESS) field offices performed the scheme, since they receive enhanced IR and high-resolution visible imagery every half hour as opposed to the hourly picture pairs received by the National Weather Service Forecast Offices (WSFOs). Radar and/or surface observations often pinpoint the rainfall location. This information could be combined with the NESS estimate of the rainfall rate to provide a reliable indicator of flash-flood potential.

VI. RECOMMENDATIONS

Further study of the use of the Scofield/Oliver system in the southwestern states needs to be accomplished in order to accumulate a representative sample for fine tuning the precipitation estimates. Orographic and high-level thunderstorm influences must be incorporated into the scheme for use in Arizona. Until such research is completed, no modifications of the scheme should be attempted. The feasibility of NESS satellite field offices providing rainfall estimates to the WSFOs on a routine basis should be investigated.

VII. ACKNOWLEDGMENTS

The author sincerely thanks Mr. Richard Wagoner, Scientific Services Division, National Weather Service Western Region Headquarters, for his assistance in the QPE experiment; Mr. Michael Franjevic, Phoenix WSFO, for his Whiteriver, Arizona, case study, and Mr. Frank Gift, Boise WSFO, for the K index analyses. The support of the staff of Phoenix WSFO is appreciated.

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Scofield, Roderick A., 1978: Using satellite imagery to estimate rainfall during the Johnstown rainstorm. Proceedings of Conference on Flash Floods: Hydrometeorological Aspects, Los Angeles, California, AMS, Boston, Massachusetts.

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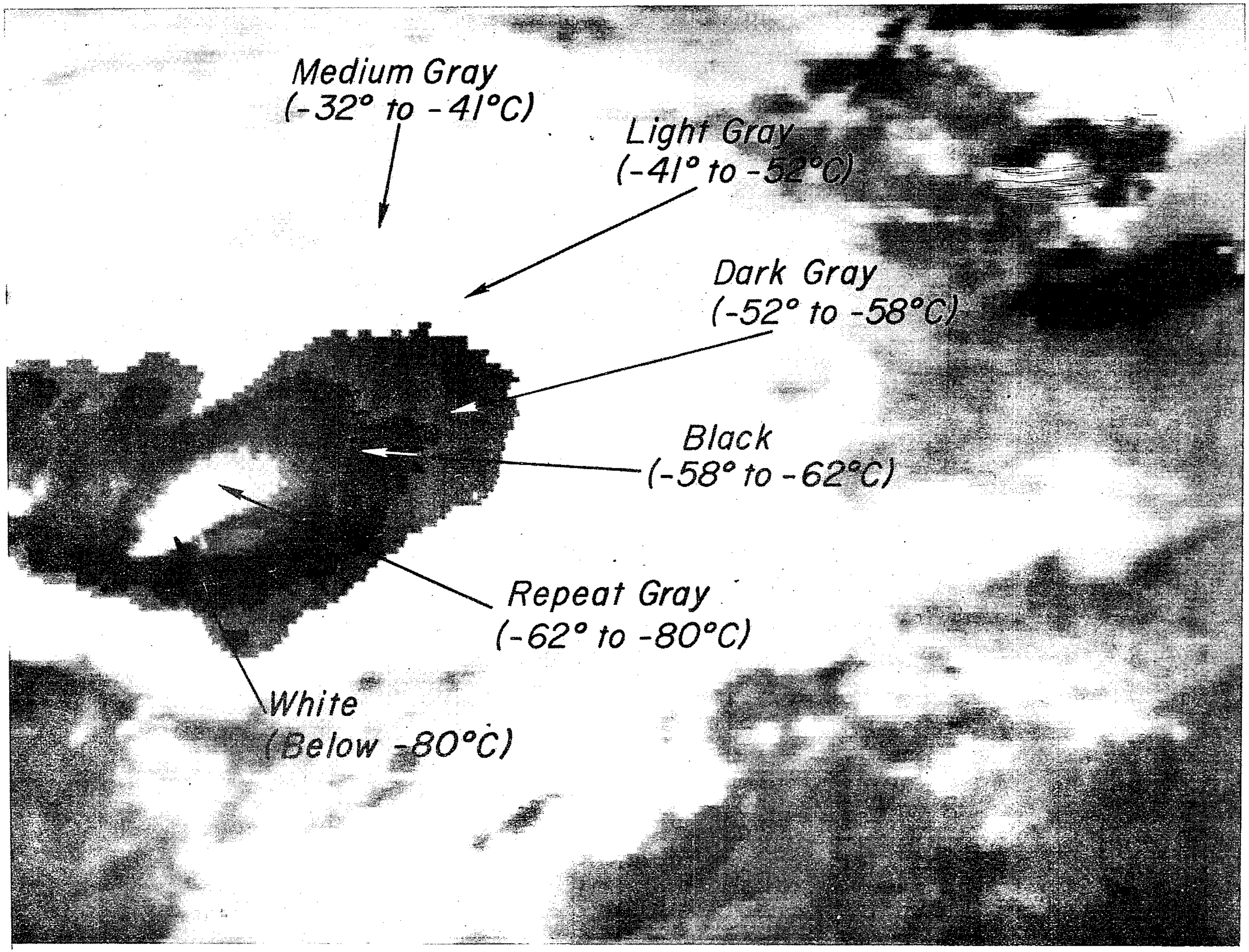
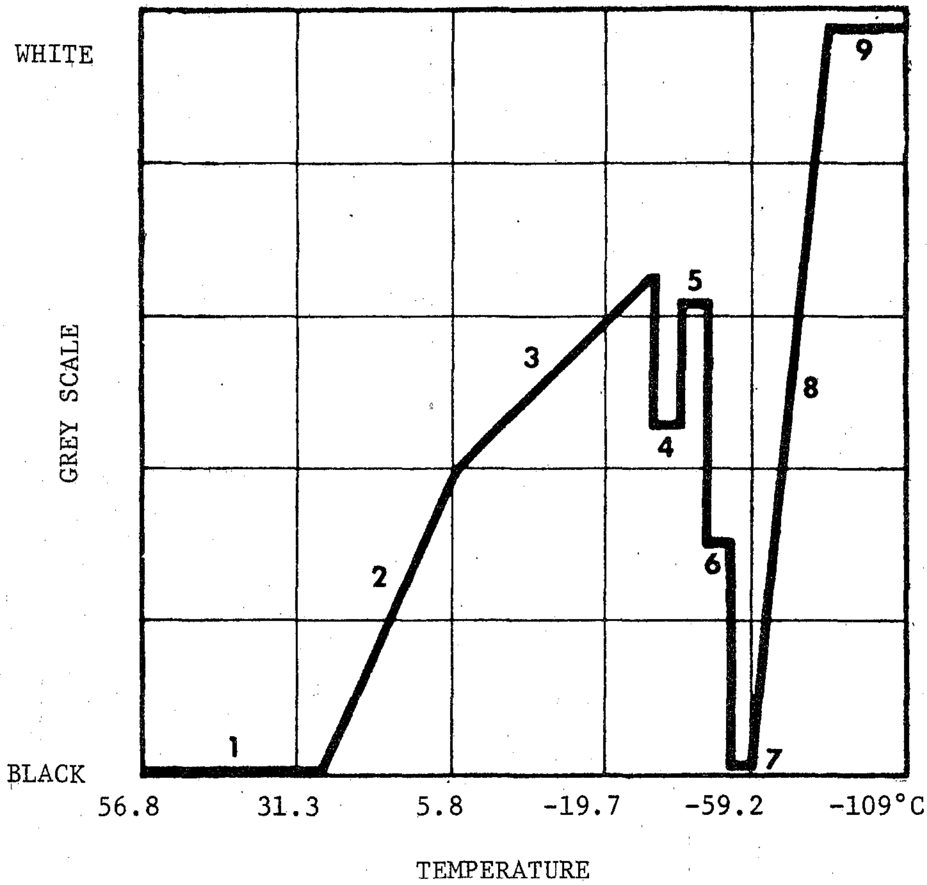


Figure 1. Enhanced Infrared (IR) Satellite Image Showing Different Grey Shades Associated with a Mature Thunderstorm. Compare to Temperature/Grey Shade Relationship shown in Figure 2.



SEGMENT NUMBER	°C TEMPERATURE TO	COMMENTS REASON FOR SEGMENT ENHANCEMENT
1	+58.8 to +28.2	Little or no useful Met Data (Black)
2	+28.8 to + 6.8	Low Level/Sea Surface Difference
3	+ 6.8 to -31.2	Middle Level - No Enhancement
4	-32.2 to -41.2	First Level Contour (Med Grey)
5	-42.2 to -52.2	Thunderstorm Enhancement (Light Grey)
6	-53.2 to -58.2	(Dark Grey)
7	-59.2 to -62.2	(Black)
8	-63.2 to -80.2	Overshooting tops Enhancement
9	-80.2 to -109.0	(White)

Figure 2. Temperature/Grey-Shade Relationship used to Produce IR Image shown in Figure 1.

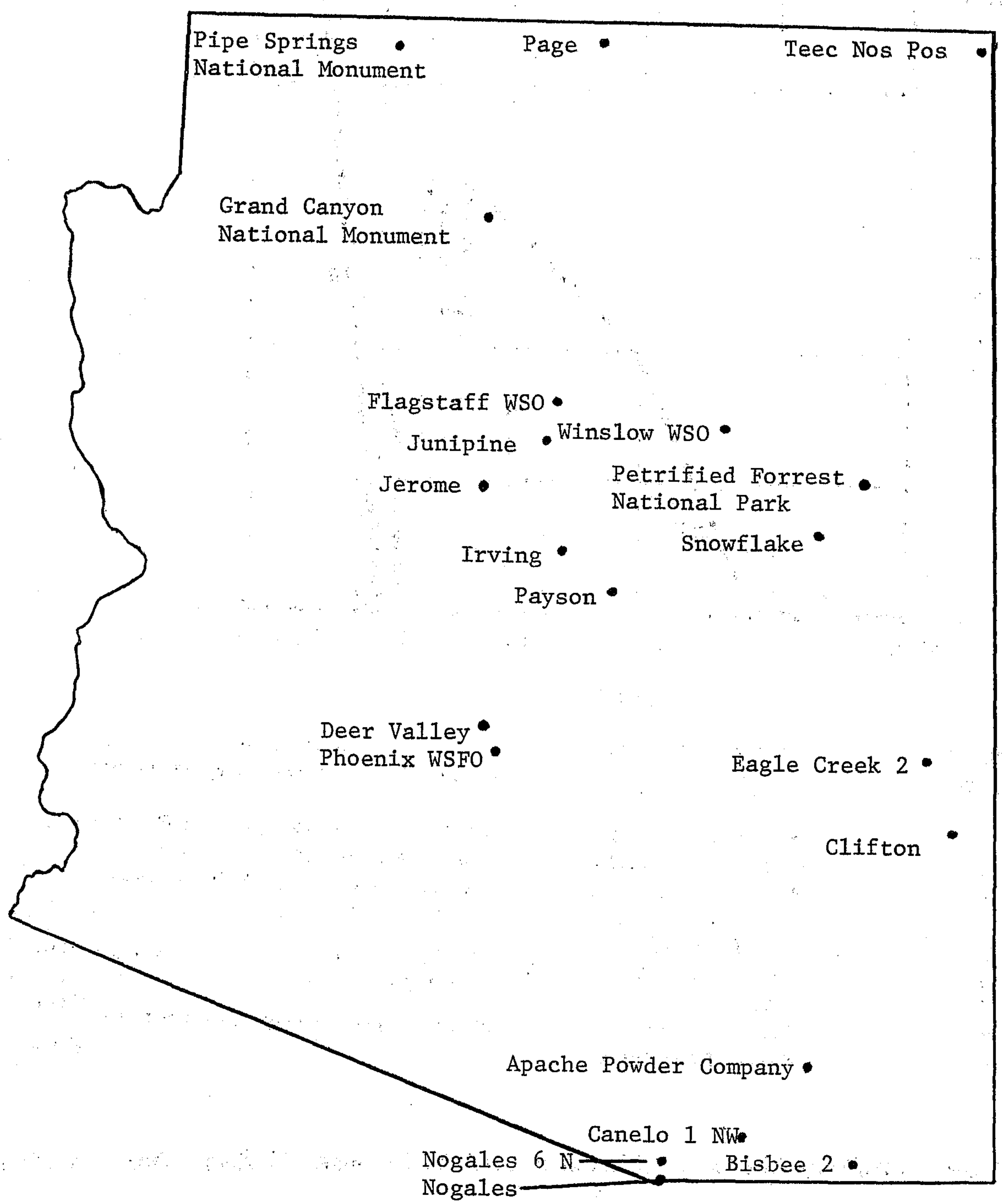


Figure 3. Verification Sites used in QPE Evaluation.

QPE WORKSHEET

STN ______________ Date __________ Time Interval __________ Z- __________ Z

Change in coldest contours of Cb system affecting station   Increase ______ Same ______ Decrease ______

Amount that coldest tops increased

	Increase: >2/3°	Increase: >1/3≤2/3	Increase: ≤1/3	Same	Decrease
Medium Gray	0.50	0.30	0.20	0.05	T
Light Gray	1.00	0.40	0.30	0.20	0.02
Dark Gray	1.50	0.80	0.40	0.30	0.06
Black	2.00	1.20	0.60	0.40	0.05
Repeat Gray Levels	3.00	1.50	0.80	0.60	0.08
White	4.00	2.00	1.00	0.80	0.20

Overshooting tops over station? NO_____ YES_____ (Add 0.50 in) *

Merging thunderstorms over station? NO_____ YES_____ (Add 0.50 in) *

Convective cloud line merger over station? NO_____ YES_____ (Add 0.50 in) *

Total QPE (in/hr) ______________ Verifying Precipitation ______________

Synopsis: ____

____

____

____

Comments: ____

____

____

____

*If amplification factor occurs during entire hour, add 1.00 in.

Figure 4. Worksheet used in QPE Evaluation.

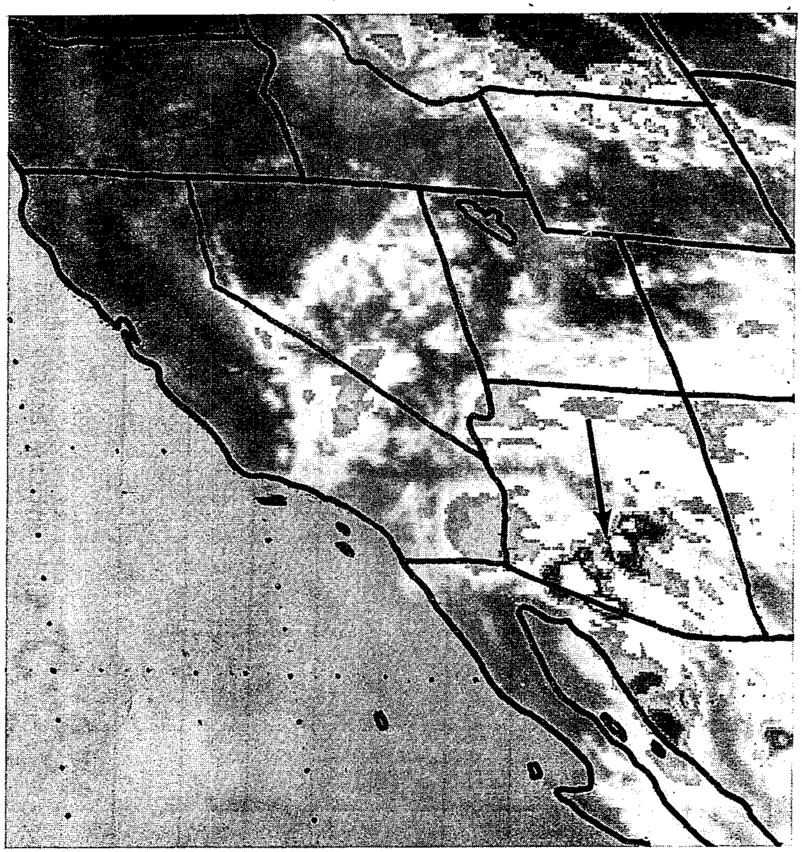


Figure 5a.

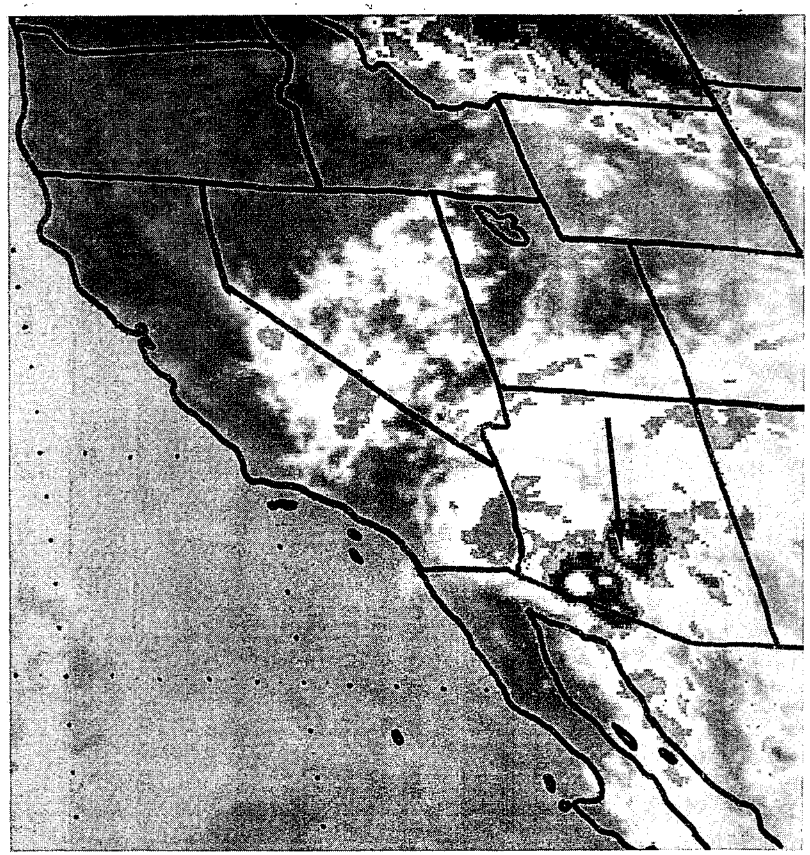


Figure 5b.

Figure 5. Enhanced IR Imagery valid 0145Z July 25, 1978 (a); and 0245Z July 25, 1978 (b).

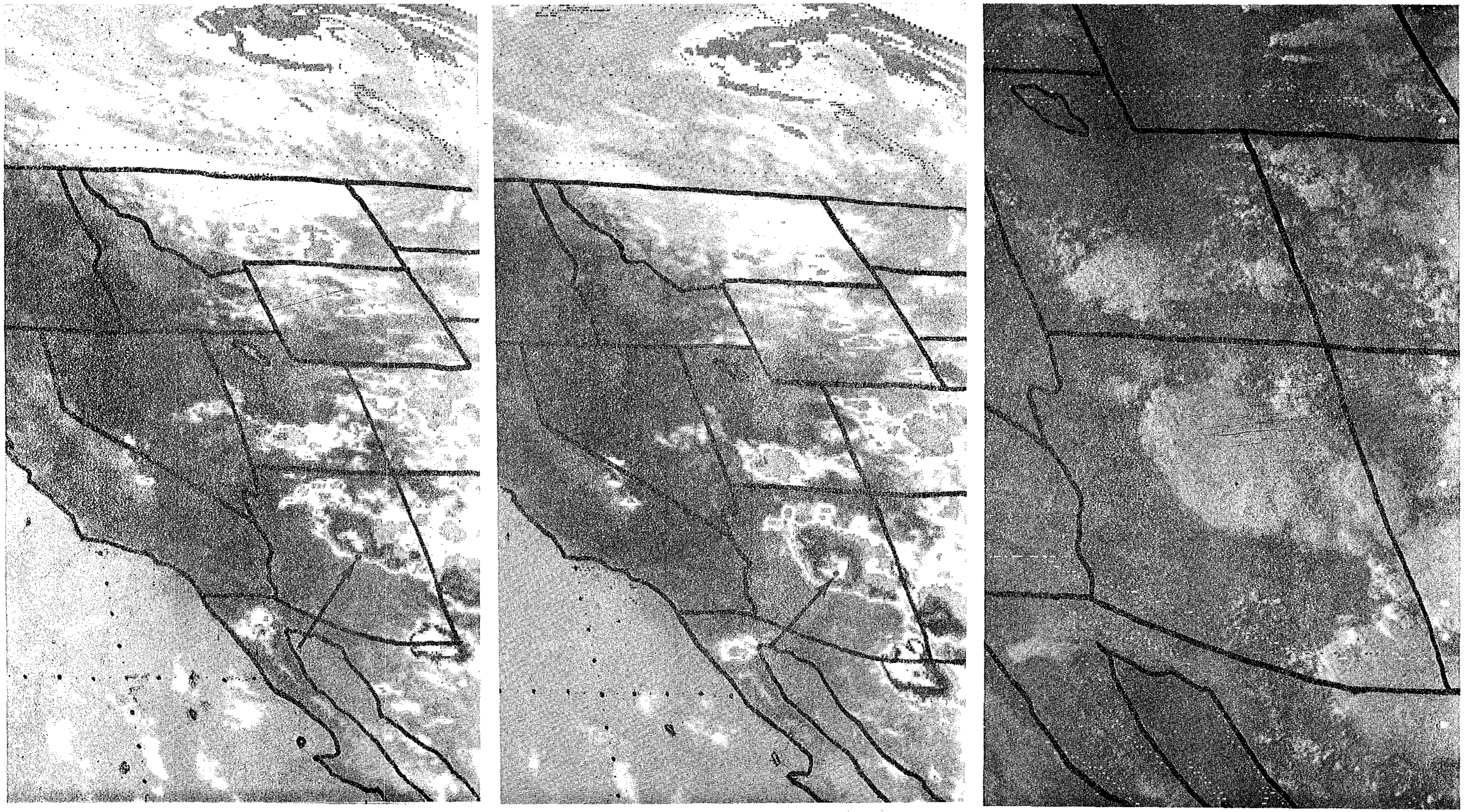


Figure 6a. Figure 6b. Figure 6c.

Figure 6. Enhanced IR Imagery valid 2315Z August 1, 1978 (a); 0015Z August 2, 1978 (b); and High-Resolution Visible Imagery valid 0045Z August 2, 1978 (c).

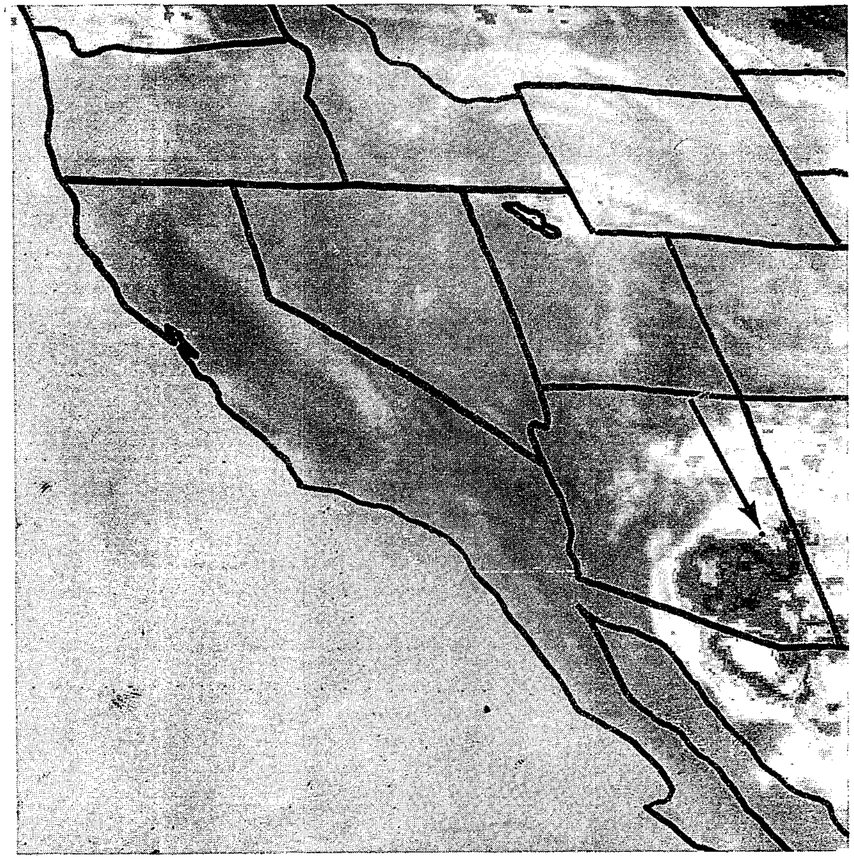


Figure 7a.

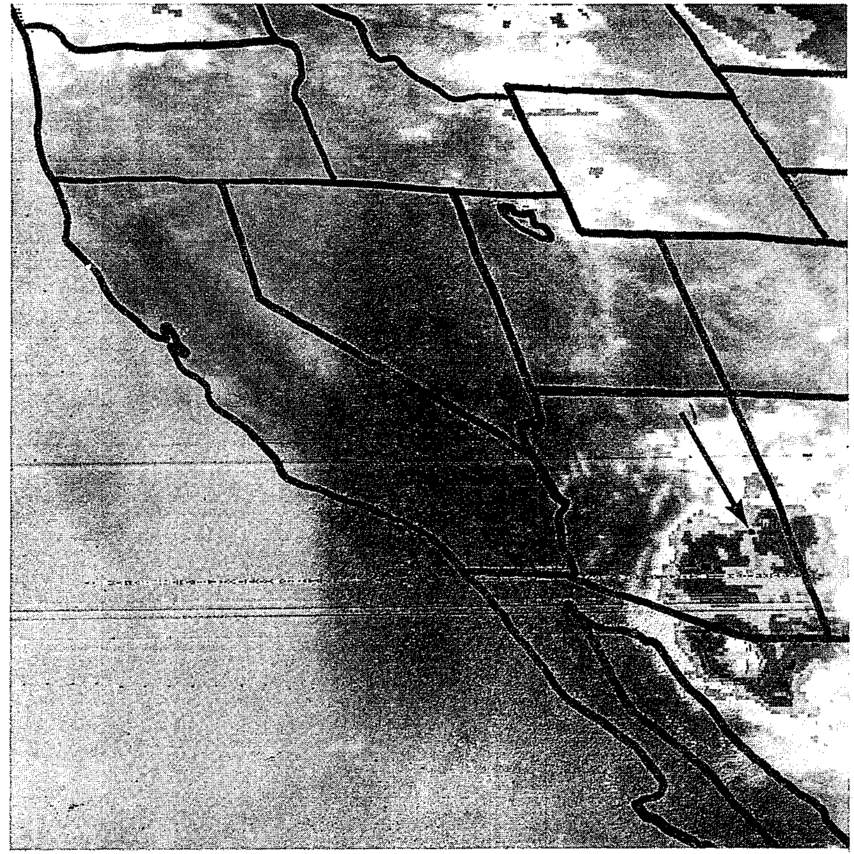


Figure 7b.

Figure 7. Enhanced IR Imagery valid 0245Z July 11, 1977 (a); and 0345Z July 11, 1977 (b).

FIGURE 8

VERIFICATION OF QPE ESTIMATES
(26 Cases)

DATE	TIME INTERVAL (GMT)	STATION	ELEVATION (feet)	PRECIPITATION (inches) QPE	OBSERVED	K INDEX
7/17	1915-2015	Grand Canyon National Park	6748	.40	.10*	31
7/17	1915-2215	Pipe Springs National Monument	4920	.08	.25	31
7/17	1915-2215	Snowflake	5642	.22	.23	28
7/17	2015-2115	Page	4270	.02	.03	30
7/18	2015-2115	Winslow WSO	2890	.10	Trace	29
7/19	2215-2315	Nogales	3808	.80	.53	34
7/20	1915-2015	Petrified Forest National Park	5425	.20	Trace	18
7/24	0145-0245	Deer Valley	1257	.20	.46	30
7/25	0145-0245	Phoenix WSFO	1110	.60	.68	35
7/25	0245-0345	Phoenix WSFO	1110	.10	Trace	35
7/25	0345-0445	Phoenix WSFO	1110	.01	.01	35
7/25	2115-2315	Eagle Creek 2	4870	.60	.27	34
7/25	2115-2215	Junipine	5134	.30	.34	33
7/25	2115-2215	Nogales 6 N	3560	.60	.41	38
7/31	2315-0246	Teec Nos Pos	5290	.76	1.32	24
8/1	0215-0246	Nogales	3808	.50	.70	38
8/1	2115-2215	Flagstaff WSO	7006	.40	.07	25
8/1	2115-0015	Jerome	5245	.90	.83	26
8/1	2115-0015	Junipine	5134	1.30	.19	25
8/1	2215-0015	Apache Powder Company	3690	.70	.34	38
8/1	2215-0015	Bisbee 2	5430	1.60	.29	38
8/1	2215-0015	Clifton	3460	.76	.80	34
8/1	2315-0115	Irving	3795	.90	.33	30
8/1	2315-0015	Payson	4913	.80	.04	30
8/2	2015-2115	Flagstaff WSO	7006	.30	.26	19
8/2	2115-2215	Canelo 1 NW	5010	.30	.35	32

*1800Z-0000Z

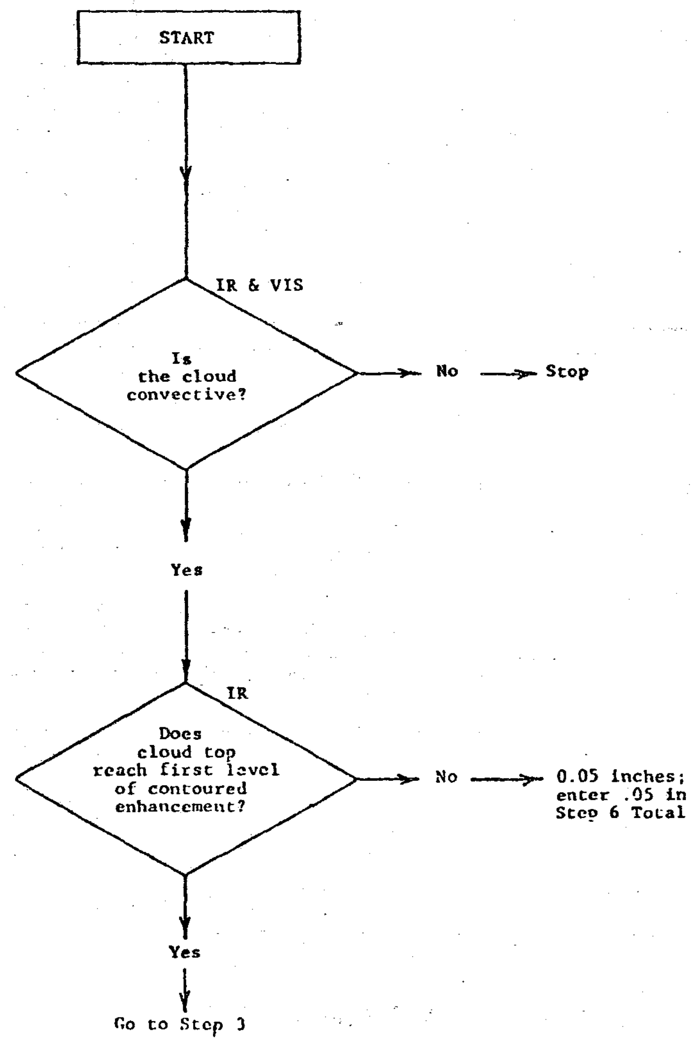
APPENDIX

Flow diagram for assessing Quantitative Precipitation Estimates (QPE) from satellite imagery (after Scofield and Oliver, 1977a).

APPENDIX

Half-hourly convective rainfall estimation scheme (in inches) at a station; enhanced IR and high resolution visible imagery used as input.

DECISION TREE



STEP 1.
Examine shape of cloud to determine if convective (round, oval, carrot-shaped, triangular).
USE VIS AND IR.

STEP 2.
Determine if convection is deep.
USE ENHANCED IR.

STEP 3.
Identify the active portion of the convective cloud system. Use enhanced IR and VIS. VIS (underlined) means that visible imagery is the best data for making that decision.

A. Upwind portion of anvil locates the active area of the convective system:

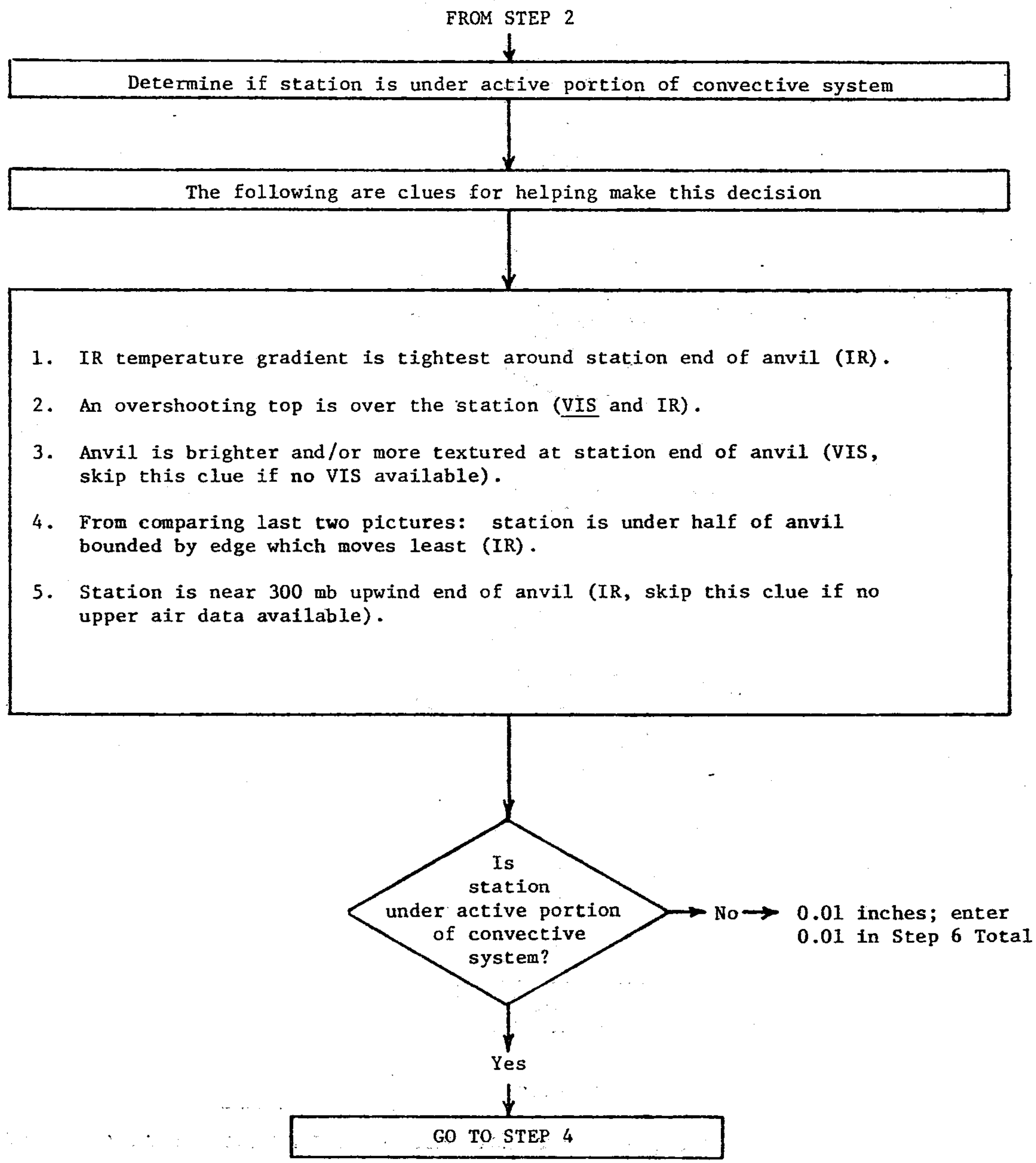
IR gradient is tightest around upwind end of anvil.

Clouds are brightest and sometimes textured at upwind end.

Comparison of two successive pictures shows motion of anvil edge; greatest in downwind direction.

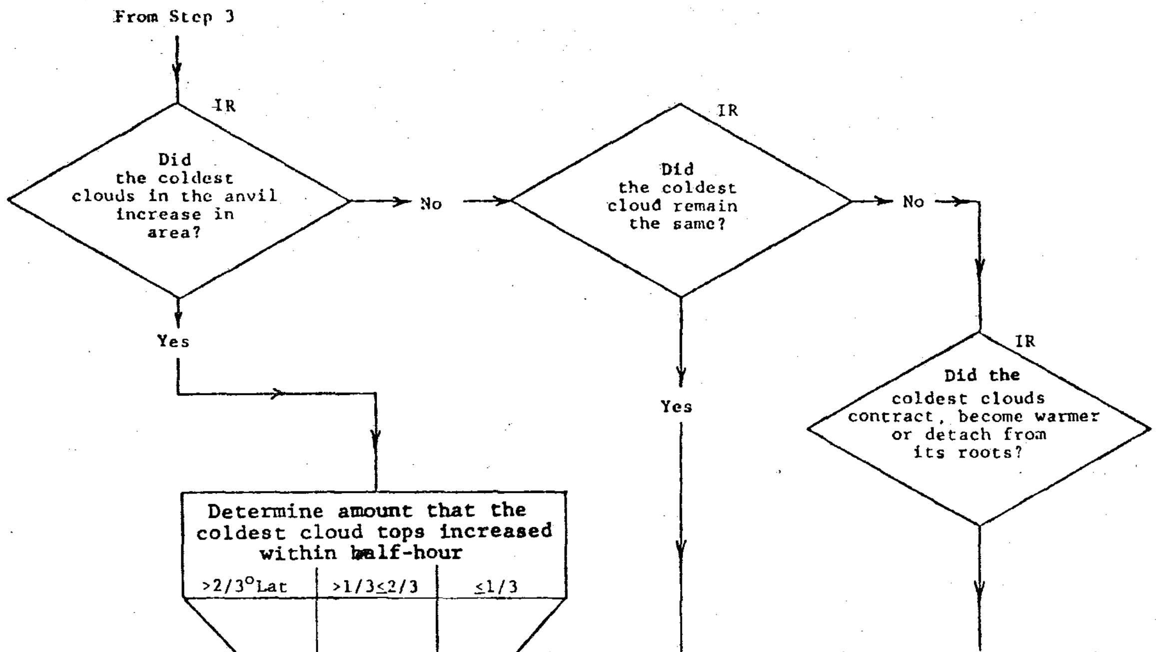
Winds aloft (usually best at 300 mb) used for determining upwind direction.

B. Overshooting tops show active area of anvil.



STEP 4.
Estimate half-hourly precip rates as a function of cloud top temperature and temperature change.
USE ENHANCED IR.

- Rainfall is heaviest when and where clouds are still getting colder and coldest area is growing.



CLOUD TEMPERATURE	>2/3°Lat	>1/3≤2/3	≤1/3	Remain the same	Contract, warmer or detach
Medium Gray (-32 to -41°C)	0.25	0.15	0.10	0.05	T
Light Gray (-41 to -52°C)	0.50	0.20	0.15	0.10	0.01
Dark Gray (-52 to -58°C)	0.75	0.40	0.20	0.15	0.03
Black (-58 to -62°C)	1.00	0.60	0.30	0.20	0.05
Repeat Gray Levels (-62 to -80°C)	1.50	0.75	0.40	0.30	0.08
White (Below -80°C)	2.00	1.00	0.50	0.40	0.10

First Guess Estimate → Enter First Guess in Step 6 and go to Step 5

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96 Map Type Precipitation Probabilities for the Western Region. Glenn E. Rasch and Alexander E. MacDonald, February 1975. (COM-75-10428/AS)
97 Eastern Pacific Cut-off Low of April 21-28, 1974. William J. Alder and George R. Miller, January 1976. (PB-250-711/AS)
98 Study on a Significant Precipitation Episode in Western United States. Ira S. Brenner, April 1976. (COM-75-10719/AS)
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102 A Set of Rules for Forecasting Temperatures in Napa and Sonoma Counties. Wesley L. Tuft, October 1975. (PB-246-902/AS)
103 Application of the National Weather Service Flash-Flood Program in the Western Region. Gerald Williams, January 1976. (PB-253-053/AS)
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114 Tropical Cyclone Kathleen. James R. Fors, February 1977. (PB-273-676/AS)
116 A Study of Wind Gusts on Lake Mead. Bradley Colman, April 1977. (PB-268-847)
117 The Relative Frequency of Cumulonimbus Clouds at the Nevada Test Site as a Function of K-value. R. F. Quiring, April 1977. (PB-272-831)
118 Moisture Distribution Modification by Upward Vertical Motion. Ira S. Brenner, April 1977. (PB-268-740)
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122 A Method for Transforming Temperature Distribution to Normality. Morris S. Webb, Jr., June 1977. (PB-271-742/AS)
124 Statistical Guidance for Prediction of Eastern North Pacific Tropical Cyclone Motion - Part I. Charles J. Neumann and Preston W. Leftwich, August 1977. (PB-272-661)
125 Statistical Guidance on the Prediction of Eastern North Pacific Tropical Cyclone Motion - Part II. Preston W. Leftwich and Charles J. Neumann, August 1977. (PB-273-155/AS)
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