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DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

A COMPARISON OF INFRARED IMAGERY AND VIDEO PICTURES IN THE ESTIMATION OF DAILY RAINFALL FROM SATELLITE DATA

Walton A. Follansbee and Vincent J. Oliver

Washington, D.C.
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National Environmental
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ABSTRACT. An Empirical method of estimating 24-hr rainfall in the Tropics and subtropics using both satellite video pictures and infrared imagery was tested to determine whether comparable results could be obtained. This method was tested for Alabama, Georgia, and South Carolina for the months of July, August, and September 1973. The infrared data set provided approximately the same degree of accuracy as the video data set, and the mean of the estimates from the two data sets provided additional accuracy. Seven-day-running totals of these mean estimates coincided closely with 7-day-running totals of observed rainfall.

The rainfall estimation technique applies best to humid tropical convective storm areas. For use in mountainous dry climates, a modification of the procedure, which takes into account the known differences between rain in the mountains and rain in the valleys, is suggested.

I. APPLICABILITY OF THE TECHNIQUE TO INFRARED NIGHTTIME DATA

An empirical method of estimating 24-hr rainfall in the Tropics and subtropics using satellite cloud pictures has been described by Follansbee (1973). This method used afternoon pictures because convective activity over land areas is greater then than earlier in the day. In fact, there is generally a negative correlation between morning cloudiness and afternoon and evening thunderstorms (Purdom 1973, Purdom and Gurka 1974). A subsequent test has shown that infrared imagery obtained at 9 p.m. local time provides accuracy about equal to that of the video data. The experiment took place in Alabama, Georgia, and South Carolina during July, August, and September 1973.

The formula for 24-hr-rainfall estimates, R_e, for a given area is

$$R_e = \frac{K_1C_1+K_2C_2+K_3C_3}{100} \qquad (1)$$

where C_1, C_2, and C_3 are the percentages of the area respectively covered by cumulonimbus, nimbostratus, and cumulus congestus and K_1, K_2, and K_3 are empirically derived coefficients for these three cloud types. Through testing, it was determined that when the estimated rainfall (R_e) is given in inches of rain, then K_1=1.0, K_2=0.25, and K_3=0.02. Since K_3 is small in magnitude, cumulus congestus coverage normally can be ignored. Little or no nimbostratus was observed in the satellite pictures over Alabama, Georgia, and South Carolina during the period July 1-September 30, 1973. The test, therefore, was conducted using cumulonimbus clouds only; thus the formula became

$$R_e = \frac{C_1}{100} . \tag{2}$$

Daily rainfall estimates were obtained by estimating the percentage of each State covered by cumulonimbus clouds appearing in the ATS-3 geostationary satellite picture taken nearest to 2000 GMT (3 p.m. EST) and in the NOAA-2 night infrared image taken at 9 p.m. EST (0200 GMT).[1] These estimates were verified by computing the mean of all observed 24-hr-rainfall amounts for reporting locations in the State; these observations are measurements of the 24-hr rainfall made within 2 hr of 1200 GMT. For example, the mean of 24-hr-rainfall amounts measured at all Alabama stations reporting between 5 a.m. and 9 a.m. EST on July 2 was compared with the estimated 24-hr amounts for Alabama using the ATS-3 picture taken near 3 p.m. EST on July 1 and the NOAA-2 infrared image taken at 9 p.m. EST on July 1.

Generally, the mean of the values derived from the two satellite data sets for a given day coincides more closely with the observed amount than either data set value alone. The mean algebraic error of estimates for the three States during the 3-mo period was +0.06 in., using the afternoon pictures; +0.01 in., using the night infrared (IR) imagery; and +0.03 in., using the mean estimates. The mean absolute error for the entire sample, using data from each satellite separately, was identical (i.e., 0.12 in.); however, when the mean of the two estimates was used, the mean absolute error reduced to 0.09 in. This suggests that not only is either data set equally usable but also that both can be combined to obtain even greater accuracy. Tables 1 through 8 support this conclusion.

Table 1 shows the algebraic and absolute errors by State and month. Tables 2 through 4 are contingency tables relating observed rainfall to estimated rainfall based on the afternoon ATS-3 pictures (table 2), the NOAA-2 night IR imagery (table 3), and the mean of the two sets (table 4). The percentages for the various differences in class interval are comparable, but table 4 shows the greatest skill. The estimates based on video tend to overestimate rainfall, estimates based on the infrared tend to underestimate, and the mean of the two sets of estimates tends to overestimate slightly.

Tables 5 through 7 are categorical rain-no rain verifications of the estimates using the afternoon video pictures, the night IR, and the mean of the two data sets, respectively. In these verifications, the video pictures show more skill than the IR data; however, the

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[1] Advanced Technology Satellite (ATS)

mean of the two data sets illustrates the greater skill as compared to their individual contributions. Categorical rain-no rain scores are given in table 8.

Figures 1 through 9 show a daily comparison of the estimates, based on each data set, their mean, and the observed rainfall, for each of the three States during July, August, and September 1973.

For computing crop yield, agricultural interests have need of 7-day-rainfall summations. Seven-day-running totals of the daily rainfall estimates for Alabama, Georgia, and South Carolina during July, August, and September 1973 were compared with the corresponding totals of daily observed rainfall. As seen in figure 10, the agreement is very close.

So far, all of the discussion has been based on rainfall estimates done in humid tropical or subtropical areas where the method works reasonably well. In other climates, some important modifications are needed. We find that, for mountainous dry regions, nearly all of the convective season rain falls on the mountains. The valleys often get only a light sprinkle or no rain at all; therefore, rainfall estimates from cumulonimbus clouds that cover both the mountains and the valleys must be made using a different coefficient for the mountains than for the valleys. We suggest as a starter that, for a very small area just at the peak of the mountain range, the coefficient of 1.00 be used just as is done over flat humid areas. For the valleys, zero is appropriate; the slopes will be in-between. If monthly climatology of the rainfall is available, the rainfall estimate coefficients should be lines exactly parallel to the normal rainfall isohyets for the appropriate month. If the normal monthly rainfall is not available, make the assumption that the coefficients are parallel to the contours of equal altitude and proceed to make the estimates using these new coefficients.

II. CONCLUSIONS

In the use of the technique, approximately equal accuracy is obtainable using either the video pictures or the night IR imagery. Somewhat greater accuracy is possible using the mean of the estimates from the two data sets. On the other hand, morning pictures cannot be used, at least over land, because of the negative correlation between morning cloud cover and afternoon and evening convective rain.

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Table 1.--Mean of daily errors in rainfall estimates

Period	Area	Absolute error			Algebraic error		
		Video	Infrared	Mean	Video	Infrared	Mean
July	Alabama	0.08	0.17	0.09	+0.05	+0.03	+0.04
	Georgia	.12	.15	.10	+ .05	+ .02	+ .04
	South Carolina	.12	.12	.10	+ .02	+ .01	+ .02
August	Alabama	.12	.09	.07	+ .09	+ .04	+ .07
	Georgia	.10	.08	.07	+ .08	+ .02	+ .05
	South Carolina	.09	.10	.06	+ .05	+ .01	+ .02
September	Alabama	.11	.14	.10	+ .07	+ .07	+ .07
	Georgia	.16	.14	.14	+ .05	- .03	.00
	South Carolina	.17	.11	.13	+ .05	- .06	.00
Three-mo mean	Alabama	.10	.13	.09	+ .07	+ .05	+ .06
	Georgia	.14	.13	.10	+ .06	.00	+ .03
	South Carolina	.13	.11	.09	+ .04	- .01	+ .01
	Three-State mean	.12	.12	.09	+ .06	+ .01	+ .03

Table 2.--Contingency table relating observed daily rainfall to estimated daily rainfall using afternoon video pictures from ATS 3

		Estimated								
		0	0.01-0.10	0.11-0.20	0.21-0.30	0.31-0.50	0.51-1.00	1.01-2.00	2.01-5.00	Total
Observed	0	15	17	1	1	1				35
	0.01-0.10	10	66	27	13	2	3			121
	.11- .20	2	13	13	15	16	4			63
	.21- .30		1	4	6	4	5			20
	.31- .50		2	3	4	7	7			23
	.51-1.00			1	1	1	3			6
	1.01-2.00						1			1
	2.01-5.00						1			1
	Total	27	99	49	40	31	24			270

Estimated versus observed rainfall

Difference in class interval	No. of cases	Percent of cases	Cumulative percent of cases
0	110	41	
1	103	38	79
2	43	16	95
3	10	4	99
4	4	1	100
Total	270		

Table 3.--Contingency table relating observed daily rainfall to estimated daily rainfall using night IR imagery from NOAA 2

		Estimated								
		0	0.01-0.10	0.11-0.20	0.21-0.30	0.31-0.50	0.51-1.00	1.01-2.00	2.01-5.00	Total
Observed	0	24	9		1					34
	0.01-0.10	41	53	9	4	6	4			117
	.11- .20	5	26	12	2	8	7			60
	.21- .30	1	11	2	1	2	3			20
	.31- .50	1	2	4		6	6			19
	.51-1.00			1		2	3			6
	1.01-2.00			1		1				1
	2.01-5.00						1			1
	Total	72	101	28	8	25	24			258

Estimated versus observed rainfall

Difference in class interval	No. of cases	Percent of cases	Cumulative percent of cases
0	99	38	
1	99	38	77
2	37	14	91
3	18	7	98
4	5	2	100
Total	258		

Table 4.--Contingency table relating observed daily rainfall to the mean of daily estimates from afternoon video and night IR imagery

		Estimated							
			0.01-0.10	0.11-0.20	0.21-0.30	0.31-0.50	0.51-1.00	1.01-2.00	2.01-5.00	Total
Observed	0	13	18	2	1					34
	0.01-0.10	5	81	16	6	6	1			115
	.11- .20		14	14	15	13	3			59
	.21- .30		1	7	5	5	1			19
	.31- .50		2		3	9	6			20
	.51-1.00			1		1	4			6
	1.01-2.00						1			1
	2.01-5.00						1			1
	Total	18	116	40	30	34	17			255

Estimated versus observed rainfall

Difference in class interval	No. of cases	Percent of cases	Cumulative percent of cases
0	126	49	
1	91	36	85
2	24	9	94
3	13	5	99+
4	1	1-	100
Total	255		

Table 5.--Categorical rain-no rain verification of daily estimates using afternoon video pictures from ATS 3

		Estimates		
		Rain	No rain	Total
Observed	Rain	223	12	235
	No rain	20	15	35
	Total	243	27	270

Table 6.--Categorical rain-no rain verification of daily estimates using night IR imagery from NOAA 2

		Estimates		
		Rain	No rain	Total
Observed	Rain	176	48	224
	No rain	10	24	34
	Total	186	72	258

Table 7.--Categorical rain-no rain verification of the mean of daily estimates from afternoon video and night IR imagery

		Estimates		
		Rain	No rain	Total
Observed	Rain	216	5	221
	No rain	21	13	34
	Total	237	18	255

Table 8.--Categorical rain-no rain scores for Alabama, Georgia, and South Carolina

Verification element	Estimates based on ATS-3 video	 NOAA-2 IR	 Mean, video & IR
Total estimates*	270	258	255
Total correct	238	200	229
Percent correct	88	78	90
Expected correct by chance	215	171	208
Skill score	0.42	0.33	0.45
Threat score	.87	.75	.89
Post agreement	.92	.95	.91
Prefigurance	.95	.79	.98
Bias	1.03	.83	1.07

*See table 9 for explanation of elements.

Table 9.--Explanation of categorical rain-no rain verification elements (data from table 5)

		Estimates Rain	 No rain	 Total
Observed	Rain	223(a)	12(b)	235($a+b$)
	No rain	20(c)	15(d)	35($c+d$)
	Total	243($a+c$)	27($b+d$)	270($a+b+c+d$)

Total estimates = $T = a+b+c+d$ = 223+12+20+15 = 270.

Total correct = $R = a+d$ = 223+15 = 238.

Percent correct = R/T = 88%.

Expected correct by chance = E

$$= \frac{(a+b)(a+c)+(c+d)(b+d)}{a+b+c+d} = \frac{(235)(243)+(35)(27)}{270} = 215.$$

$$\text{Skill score} = \frac{R-E}{T-E} = \frac{238-215}{270-215} = \frac{23}{55} = 0.42.$$

$$\text{Threat score} = \frac{a}{a+b+c} = \frac{223}{223+12+20} = \frac{223}{255} = 0.87.$$

$$\text{Post agreement} = \frac{a}{a+c} = \frac{223}{243} = 0.92.$$

$$\text{Prefigurance} = \frac{a}{a+b} = \frac{223}{235} = 0.95.$$

$$\text{Bias} = \frac{a+c}{a+b} = \frac{243}{235} = 1.03.$$

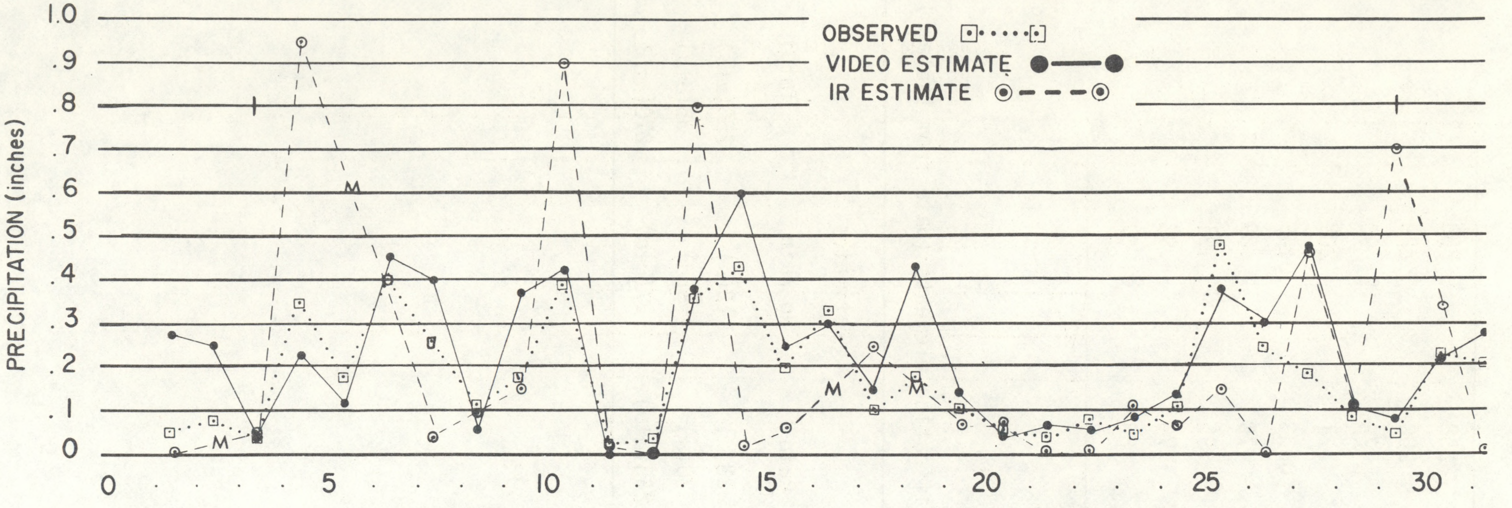

Figure 1.--Average daily rainfall, Alabama, July 1973

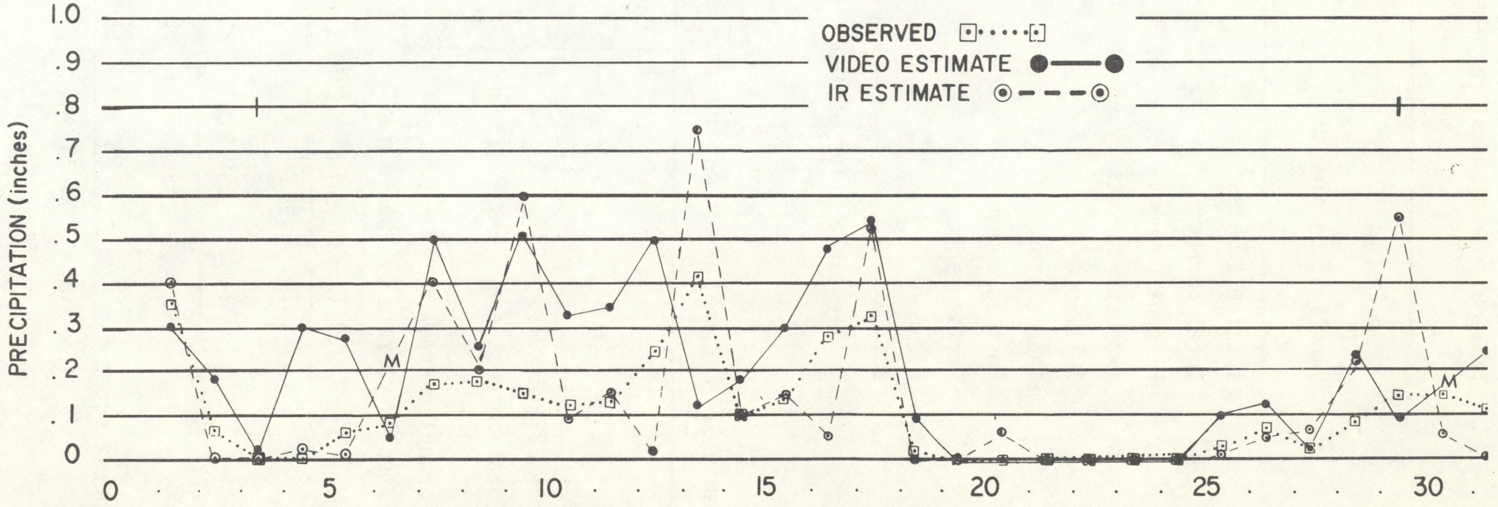

Figure 2.--Average daily rainfall, Alabama, August 1973

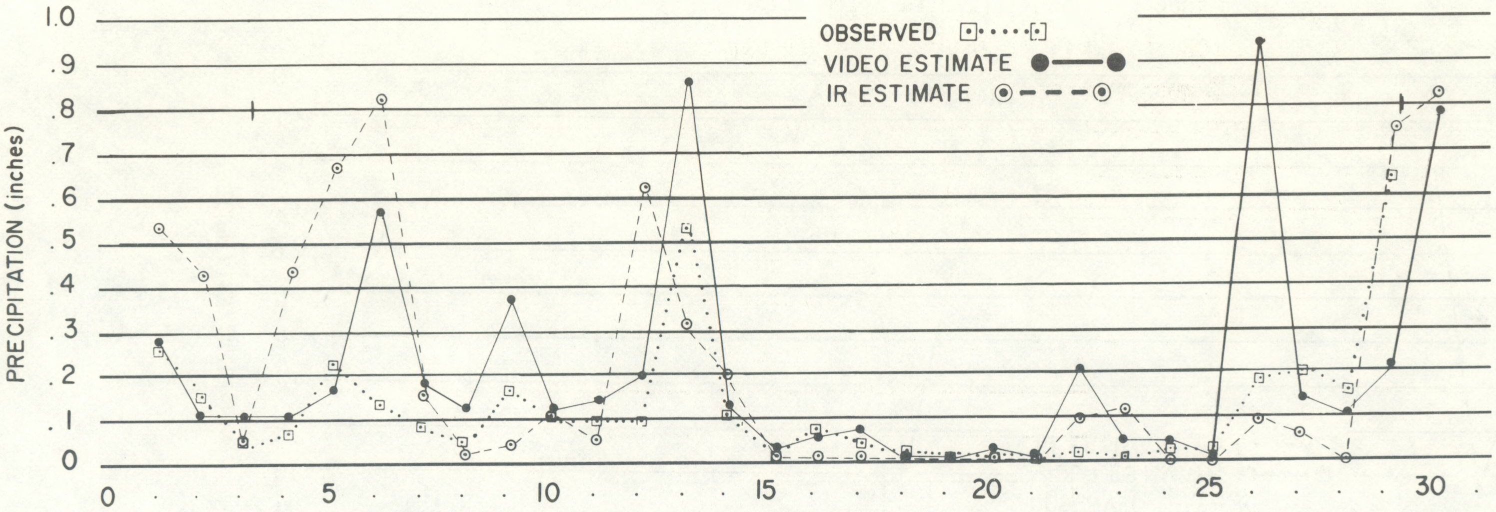

Figure 3.--Average daily rainfall, Alabama, September 1973

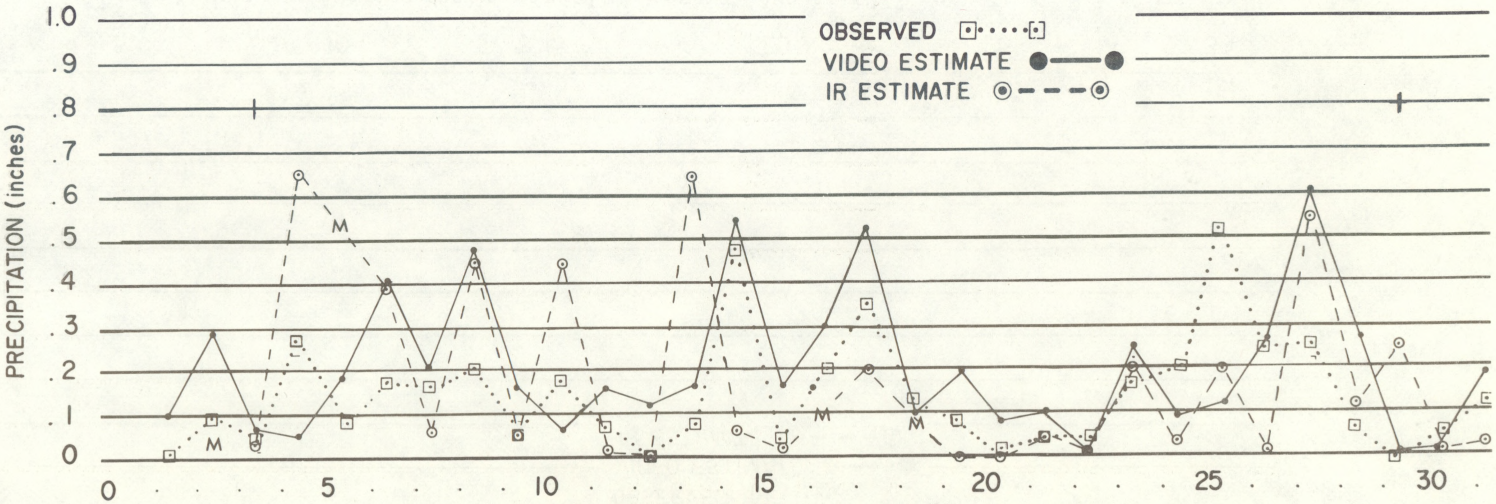

Figure 4.--Average daily rainfall, Georgia, July 1973

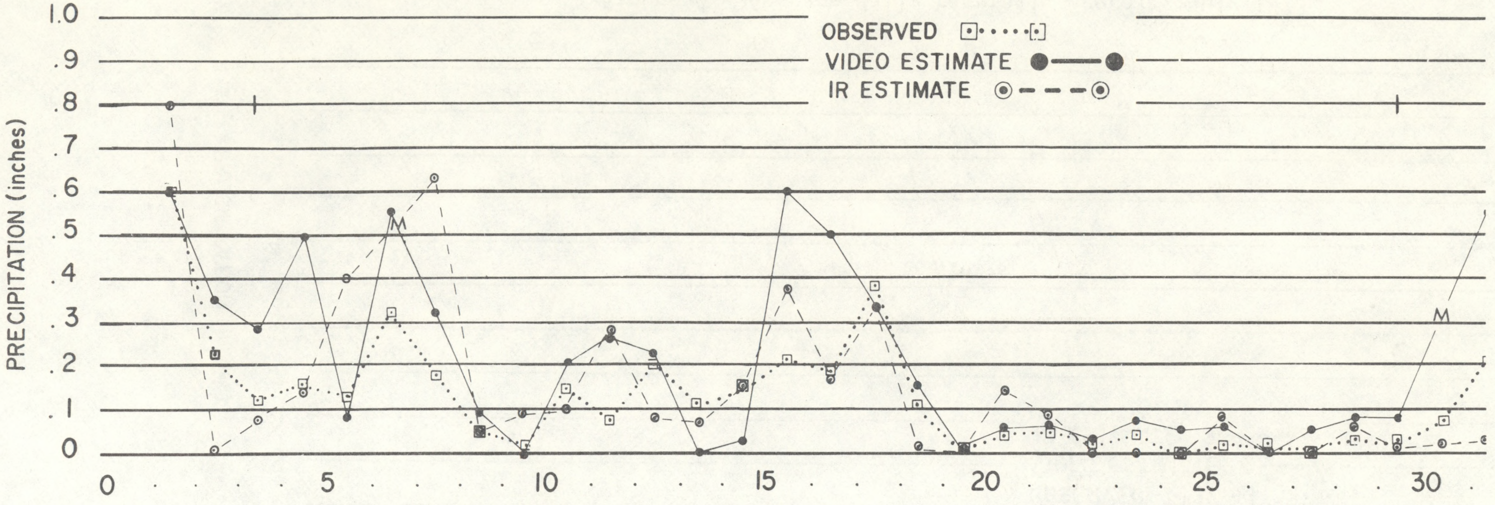

Figure 5.--Average daily rainfall, Georgia, August 1973

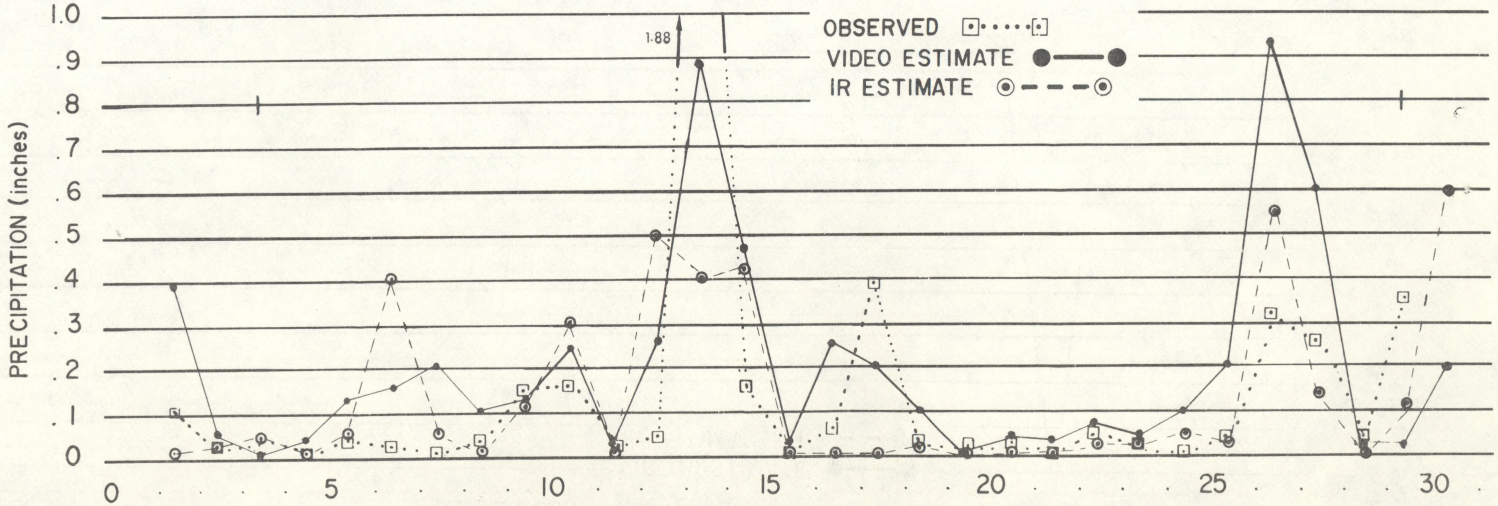

Figure 6.--Average daily rainfall, Georgia, September 1973

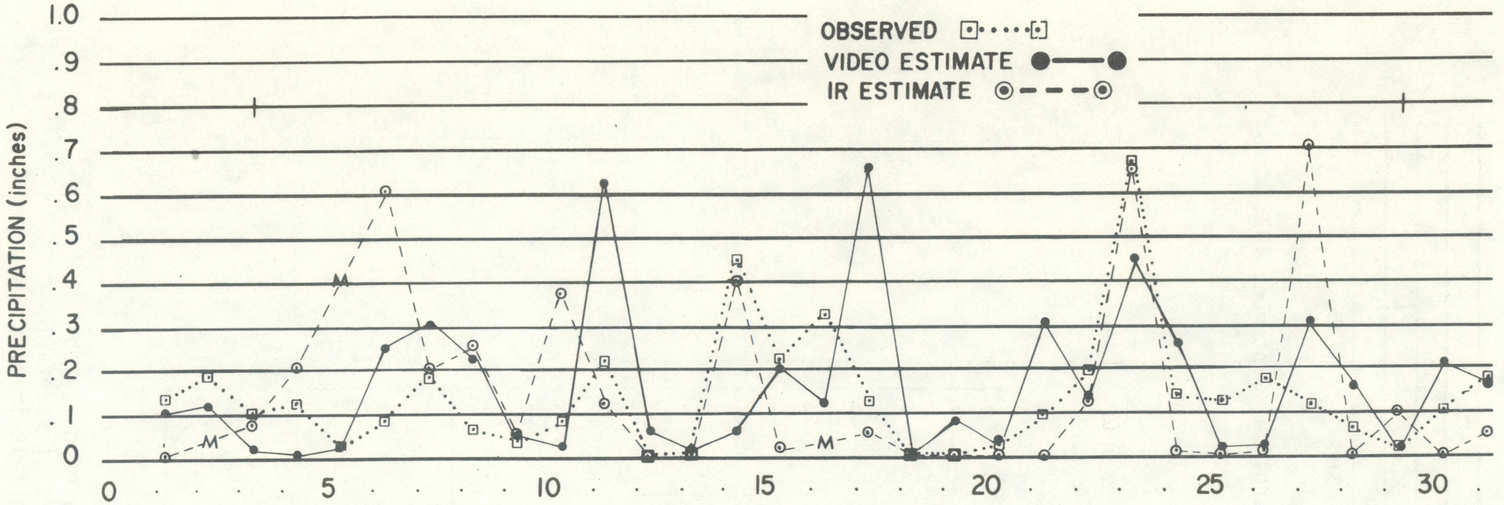

Figure 7.--Average daily rainfall, South Carolina, July 1973

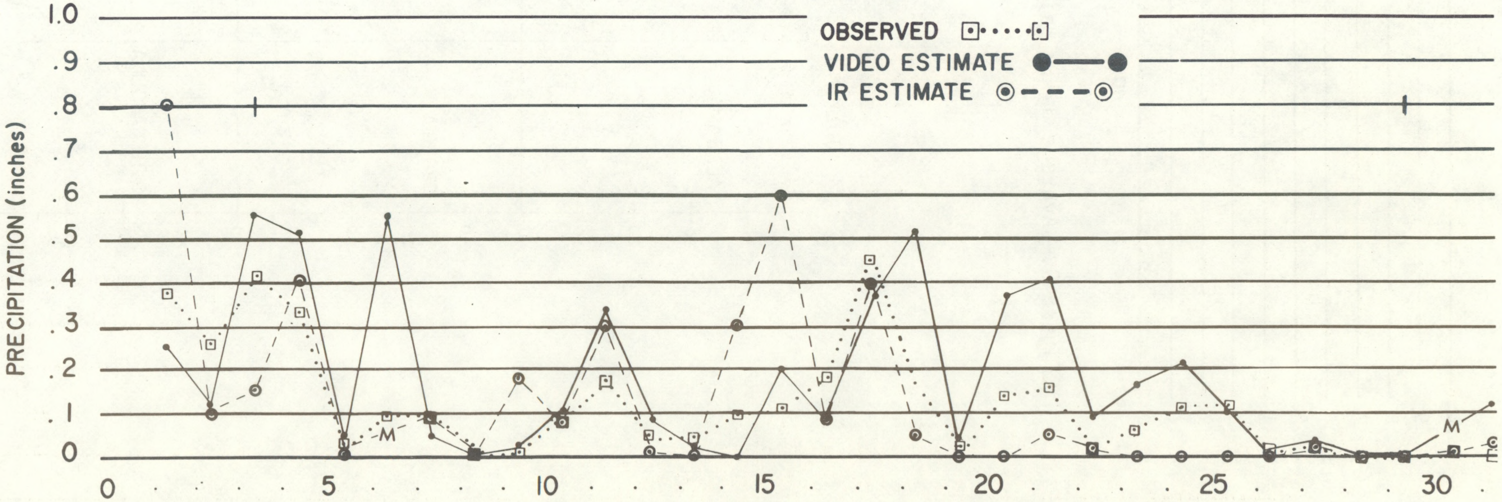

Figure 8.--Average daily rainfall, South Carolina, August 1973

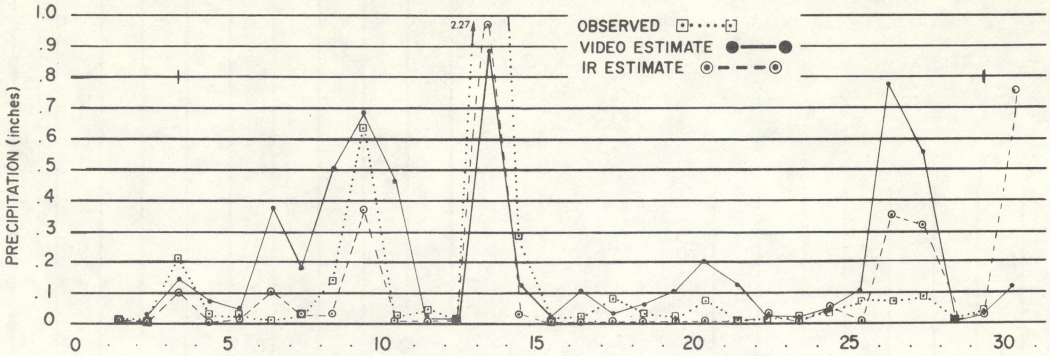

Figure 9.--Average daily rainfall, South Carolina, September 1973

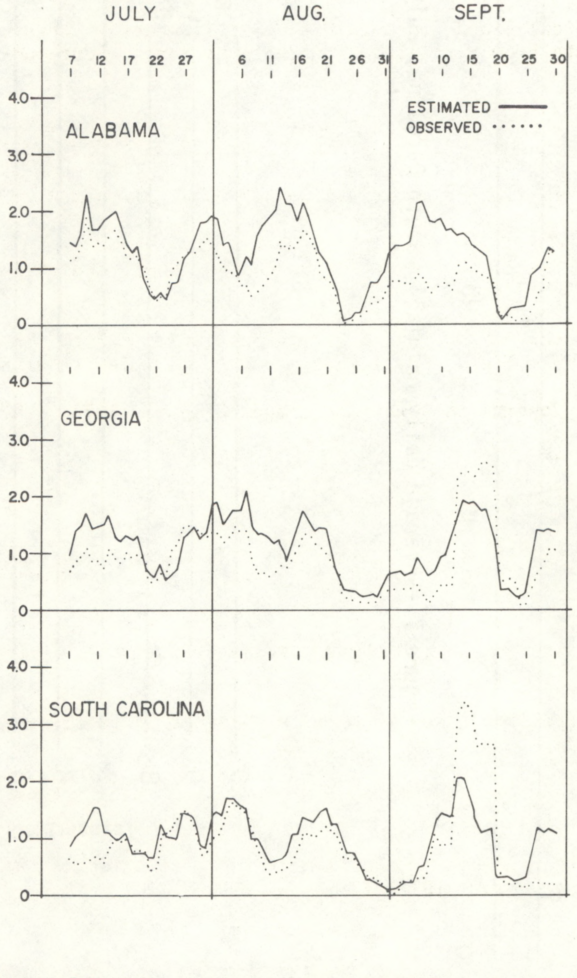

Figure 10.--Seven-day-running totals of daily observed rainfall and daily estimates of rainfall using both afternoon video and night IR imagery

(Continued from inside front cover)

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