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RAINFALL ESTIMATIONS FROM GEOSYNCHRONOUS SATELLITE IMAGERY

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ABSTRACT

A method to estimate rainfall from visible geosynchronous satellite images is outlined. The two component relationships, derived from ATS-3 and WSR-57 radar data, are discussed. Calculations are made on two days with this method and compared with ground truth rainfall. Satellite estimates on both days are within a factor of two of ground truth.

Sources of error in the component relationships are ennumerated. Several planned refinements, such as stratification of the data by synoptic condition and origin of convection, are presented.

INTRODUCTION

The satellite rain estimation method to be outlined arose out of the need to measure rainfall over two large areas: the Florida peninsula and surrounding waters in the context of the Experimental Meteorology Laboratory's weather modification experiments, and portions of the Atlantic ocean during the Global Atmospheric Research Project's Atlantic Tropical Experiment (GATE). Of the two conventional methods to monitor rainfall, gages and radar, the difficulty of maintaining a sufficiently dense gage network over an adequately large area is prohibitive. Radars also have problems, most notably anomalous propogation, a variable Z-R relation, a varying calibration and again coverage over a finite area. The only platform, from which large areas could be observed appeared to be that of a satellite.

METHOD

Since 1972 scientists of the Experimental Meteorology Laboratory (EML) of the National Oceanographic and Atmospheric Administration, and of the Space Science and Engineering Center (SSEC) of the University of Wisconsin - Madison have collaborated on a method to estimate rainfall from satellite visible imagery. A data set, consisting of summer 1972 and 1973 ATS-3 images (both digital tapes and hard-copy negatives), radar reflectivities (on either microfilm, digital tape or both) and raingage data from a number of dense (3-10 km^2/gage) networks covering a total of 825 km^2, is being used to derive the component relationships. Derivation of the method is being accomplished on the Man Computer Interactive Data Access System (McIDAS) at SSEC; derivation as well as use is also possible employing ATS-3 transparencies or negatives in conjunction with a scanning densitometer capable of false color enhancement.

A previous study by Woodley, et al. (1971) showed a relationship between mean 10 min. echo area and rain volume per 10 min. This relationship, Figure 1, has been stratified according to the time behavior of echo area. Thus an echo which is in its growing stage will produce more rain than an echo of the same area, which is decaying. Since the radar used was the S-band (10 cm wavelength) radar of the University of Miami, which if anything underestimates rainfall (Herndon et al. 1973), every point in Figure 1 corresponds to precipitating cloud.

Utilizing this echo area-rain volume relationship, it then remains to link some quantity, measurable by satellite, to echo area. We have related normalized cloud area to normalized echo area, where the maximum cloud area during the life cycle of each cloud has been used as the normalization factor. A preliminary cloud-echo relationship is shown in Figure 2. Similar to the relationship in Figure 1, the data of Figure 2 have been classified according to the time behavior of cloud area. The upper half of the graph pertains to cloud areas which are increasing with time; the lower to those decreasing with time. Since the data comprising Figure 2 are presently minimal (22 clouds from four days in 1972), they have been averaged over normalized cloud area intervals of 10%. The curve shown is an "eyeball" fit to the averaged data. The seemingly spurious point in the lower portion of the curve corresponds to a cloud which had, for this data set, an anomalously large echo associated with it throughout its life cycle.

The echo areas in Figure 2 were defined by the 2.5 mm/hr rain rate of the Miami WSR-57 radar. Cloud area, representing a given precipitation probability, was defined by a threshold brightness using Figures 3, 4 and 5. Figure 3 shows the percentage of clouds having associated echoes in each 10 digital count interval. Figures 4 and 5 are cumulative plots in which the lower digital count portions of each curve are overestimates because only those dimmer clouds, which eventually had echoes, were analyzed. On the basis of these three figures, cloud area was defined by a brightness contour of 80 digital counts, out of a possible 255. (Digital counts on the image tapes and density units, as measured by a densitometer from hard-copy, are both proportional to cloud brightness.) Thus, Figure 4 indicates that almost 50% of the clouds which reached 80 digital counts or higher are precipitating, whereas, according to Figure 5, less than 10% of those clouds which did not attain 80 digital counts actually produced precipitation.

To illustrate the use of this method, assume that the normalized areas of a cloud of interest have been determined from a sequence of satellite images spanning the cloud's lifetime. Assume further that the cloud's maximum area is 500 km^2, and the normalized cloud area on the first picture is 0.30. Since the cloud is increasing in area at the time of the first picture, the normalized echo area is 0.06 from Figure 2, and thus the echo area is 30 km^2 (i.e. 500 km^2 x 0.06). From Figure 1, the rain volume produced by a 30 km^2 echo, which is increasing with time, is 75×10^3 m^3 per 10 min. Similar calculations can be made for the remaining pictures.

RESULTS

The preceding type of calculation has been made over a 13,000 km^2 area in central Florida on two days. Volumetric rain estimates were made by satellite method, utilizing ATS-3 negatives and a color densitometer. These rain estimates were compared with radar rain estimates which had been adjusted by rain gages. (Several gage networks are contained in the area analyzed.) The radar-gage adjustment is described in Herndon, et al. (1973).

The results of the two days' estimates are summarized in Figure 6. Each day was divided into periods of 1 to 1 1/2 hrs., corresponding to two to three pictures. Daily totals have been tabulated. It can be seen from Figure 6 that the satellite daily estimates are within a factor of two of ground truth. These are encouraging results for two reasons. First the cloud-echo relationship is hardly in a definitive form at this time. Secondly, there is currently a factor of two variability in the echo-rain relationship.

REFINEMENTS

Several improvements to this method need to be made. The cloud-echo relationship of Figure 2 will be finalized. Also, the echo-rain relationship of Figure 1 will be rederived using WSR-57 radar data adjusted by gages. Gage adjusted radar rain volumes will decrease the variability due to measurement errors, but will not affect scatter due to natural variability. To be of maximum utility the method must be adapted to the entire day. We are presently confined to the 3 1/2 hours either side of local noon due to radiation geometry effects. Our collaborators are working on the possibility of extending calculations to all daylight hours by applying a normalization scheme. With the launch of geosynchronous satellites having infrared sensors, rain estimations at night will be possible. The method will also be adapted to include infrared, as well as visible, information in the daytime estimations.

Additionally, several refinements are planned. The final version of the cloud-echo relationship will be stratified by maximum digital count within the cloud. This should reduce the scatter in Figure 2. The finalized plots of both Figures 1 and 2 will be stratified by synoptic condition, time of day, and origin of convection-continental or maritime. Each of these conditions should significantly affect the stratification.

CONCLUSION

The estimation of rainfall from a satellite platform appears to be feasible, judging by the calculations made from very preliminary relationships. If so, this method will have applications in areas where conventional rain measuring techniques are unavailable or impossible to use. Two such examples are estimations on the several GATE space scales over the Atlantic Ocean and estimations for hydrological purposes in developing South American countries.

ACKNOWLEDGMENTS

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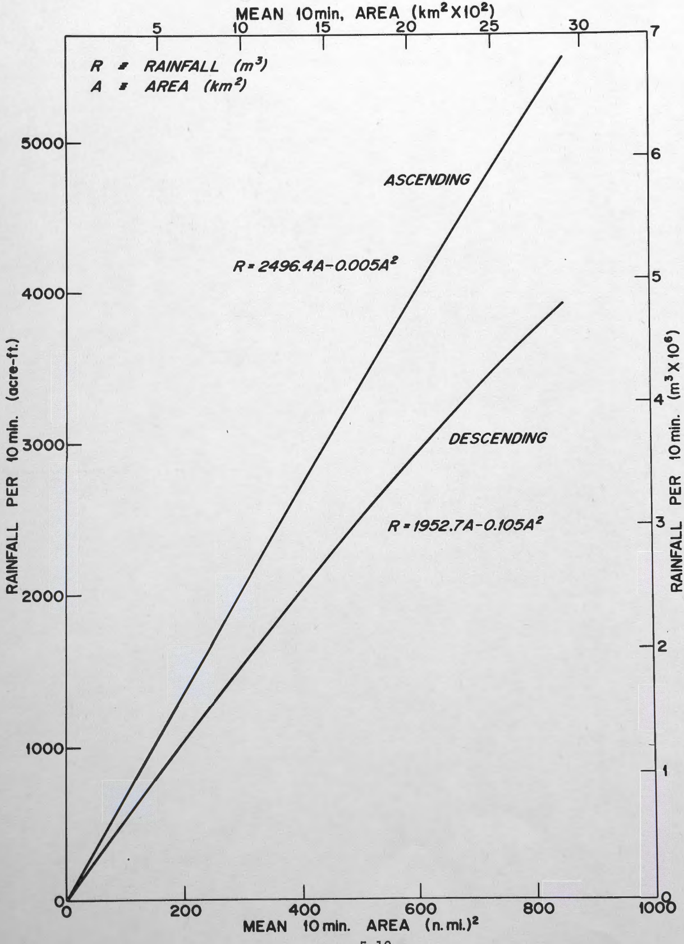
REFERENCES

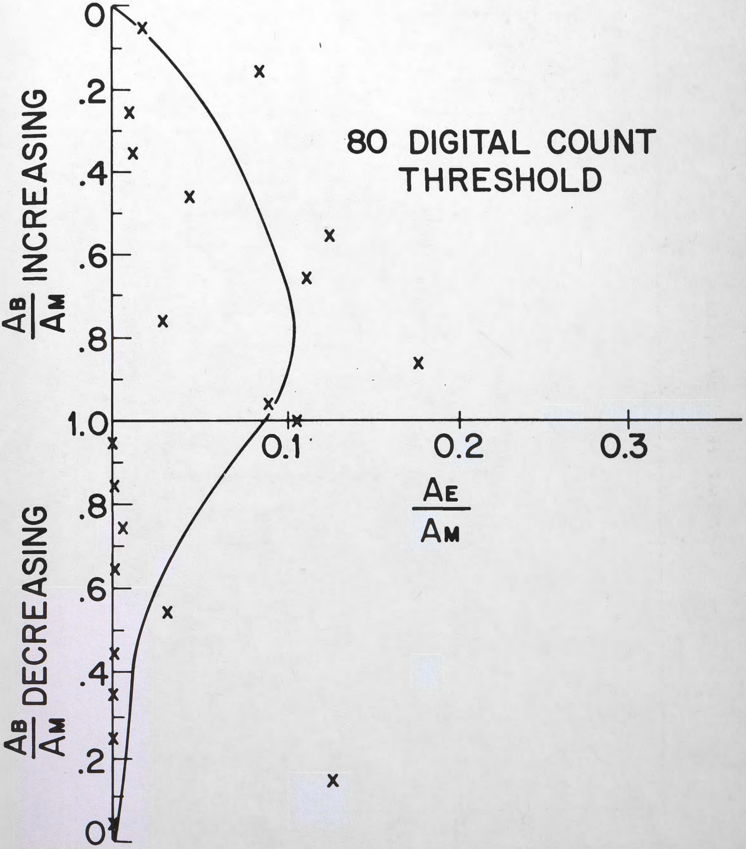
(1) Herndon, A., W. L. Woodley, A. H. Miller, A. Samet and H. Senn, 1973: Comparison of gage and radar methods of convective precipitation measurement, NOAA Tech Memo ERL OD-18, 67 pp.

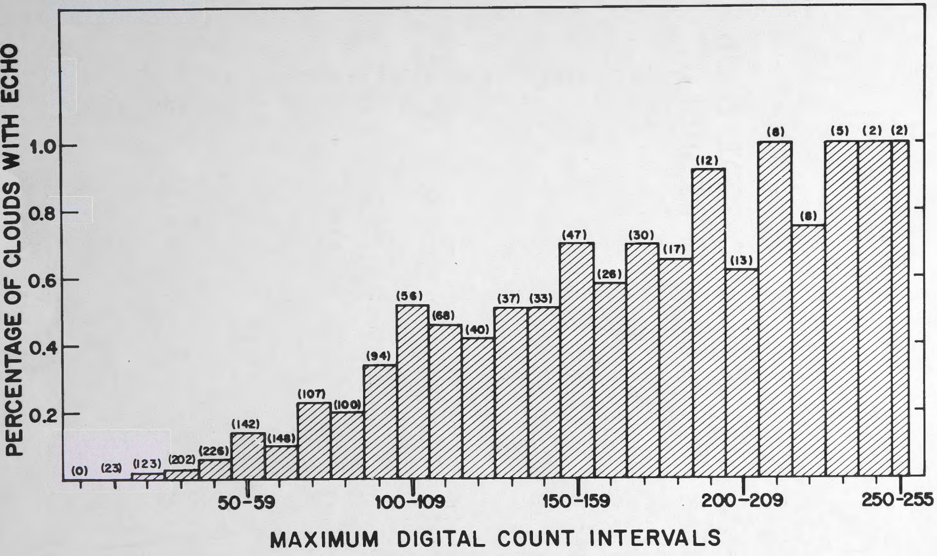
(2) Woodley, W. L., B. Sancho and J. Norwood, 1971: Some precipitation aspects of Florida showers and thunderstorms, Weatherwise, Vol. 24, 106-119.

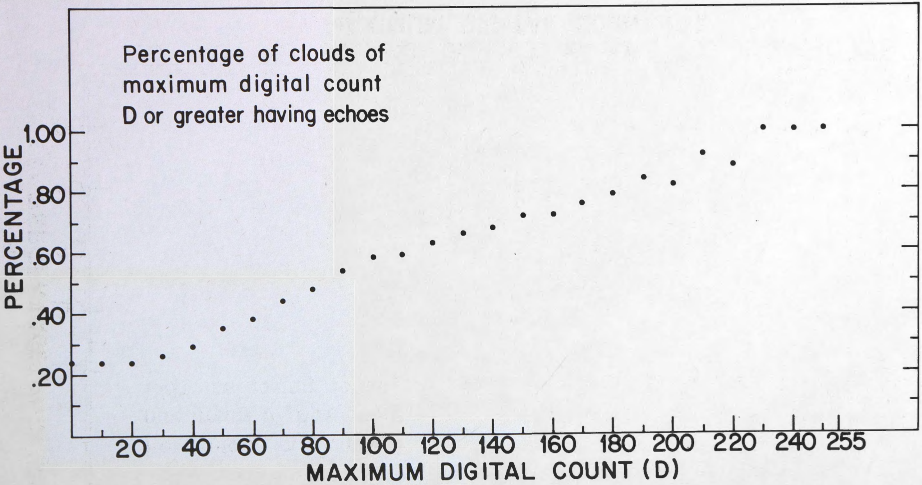
ILLUSTRATIONS

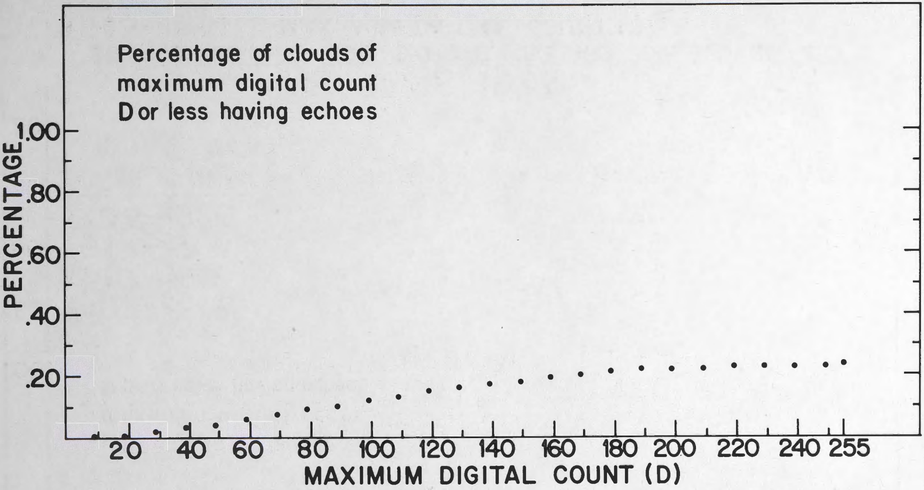
Figure 1	Echo area-rain volume relationship, derived using observations of the S-band radar of the University of Miami. Echo areas were defined by the minimum detectable signal (<0.2 mm/hr).
Figure 2	A preliminary cloud-echo relationship, in which both cloud areas (at the 80 digital count threshold), A_B, and echo areas (at the 2.5 mm/hr threshold), A_E, are normalized to maximum cloud area, A_M. Data from four days have been averaged over 10% intervals.
Figure 3	Echo frequency as a function of digital count intervals. The numbers in parentheses indicate total number of clouds in each interval.
Figure 4	Cumulative echo frequency as a function of digital count interval. These data have been accumulated from 255 digital counts and indicate what percentage of clouds, at a given digital count interval and above, have associated echoes.
Figure 5	Cumulative echo frequency as a function of digital count interval. These data have been accumulated from zero digital counts and indicate what percentage of couds, at a given digital count interval and below, have associated echoes.
Figure 6	Results of two satellite rainfall estimations.


MEAN 10 min. AREA (km² X 10²)
5
10
15
20
25
30
R = RAINFALL (m³)
A = AREA (km²)
ASCENDING
R = 2496.4A − 0.005A²
DESCENDING
R = 1952.7A − 0.105A²
RAINFALL PER 10 min. (acre-ft.)
0
1000
2000
3000
4000
5000
RAINFALL PER 10 min. (m³ X 10⁶)
0
1
2
3
4
5
6
7
MEAN 10 min. AREA (n. mi.)²
0
200
400
600
800
1000


80 DIGITAL COUNT THRESHOLD
$\frac{A_B}{A_M}$ INCREASING
$\frac{A_B}{A_M}$ DECREASING
$\frac{A_E}{A_M}$
0
.2
.4
.6
.8
1.0
.8
.6
.4
.2
0
0.1
0.2
0.3


PERCENTAGE OF CLOUDS WITH ECHO
1.0
0.8
0.6
0.4
0.2
(0)
(23)
(123)
(202)
(226)
(142)
(148)
(107)
(100)
(94)
(56)
(68)
(40)
(37)
(33)
(47)
(26)
(30)
(17)
(12)
(13)
(8)
(8)
(5)
(2)
(2)
50-59
100-109
150-159
200-209
250-255
MAXIMUM DIGITAL COUNT INTERVALS


Percentage of clouds of maximum digital count D or greater having echoes
PERCENTAGE
1.00
.80
.60
.40
.20
20
40
60
80
100
120
140
160
180
200
220
240
255
MAXIMUM DIGITAL COUNT (D)


Percentage of clouds of
maximum digital count
D or less having echoes
PERCENTAGE
1.00
.80
.60
.40
.20
20
40
60
80
100
120
140
160
180
200
220
240
255
MAXIMUM DIGITAL COUNT (D)

5 JULY 1972

TIME (Z)	EML — SSEC CALCULATED RAIN ($M^3 X 10^3$)	RADAR — GAGE DERIVED RAIN ($M^3 X 10^3$)	SAT. / GRND TRUTH
1400-1516	21	97	
1517-1610	179	252	
1611-1704	836	410	
1705-1826	3015	7350	
TOTAL 4.4hrs.	4050	8109	0.50
26 JUNE 1973			
1543-1614	1424	716	
1829-1923	1845	1564	
TOTAL 1.25hrs.	3269	2280	1.43