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ATTACHMENT B

ESTIMATION OF CONVECTIVE RAIN VOLUMES UTILIZING THE AREA-TIME-INTEGRAL TECHNIQUE

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1. INTRODUCTION

Interest in the possibility of developing useful estimates of convective rainfall with Area-Time Integral (ATI) methods is increasing (Smith et al., 1990; Atlas et al., 1990). In practice, the rainfall volume V from a convective system over a time interval can be identified as:

$$V = \overline{R} \sum_i A_i \, \Delta t_i \quad . \qquad (1)$$

Here A_i represents the area over which some measured quantity exceeds a specified threshold during the (centered) time interval Δt_i between observations. The measured quantity can be gage rainfall rate, but radar reflectivity factor or satellite infrared temperature can also be used. The summation extends over the duration $T = \sum \Delta t_i$ of the rainfall event of interest. The quantity $\overline{R}$ represents the average rainfall rate over the identified area for the case under study. The summation in (1) is identified as the ATI.

The basis of the ATI technique is the observed strong correlation between rainfall volumes and ATI values. This means that rainfall can be estimated by just determining the ATI values, if previous knowledge of the relationship to rain volume is available to calibrate the technique. The ATI's can be determined from rain gage data, if the gage density and time resolution are sufficient (Doneaud et al., 1979, 1981); from radar data (Doneaud et al., 1981, 1984; Lopez et al., 1989); or from satellite infrared observations (Doneaud et al., 1987; Smith et al., 1990). The respective thresholds involve the minimum measurable amount of rainfall, a minimum radar reflectivity factor, or a maximum IR brightness temperature. Correlations found between ATI values determined from any of these sources and rainfall amounts determined either from gages or radar data have been 0.9 or greater in every case studied thus far. For radar ATI's in particular, the correlation is typically 0.98.

This paper provides examples of the application of the ATI approach to gage, radar, and satellite measurements. For radar data, the degree of transferability in time and among geographical areas is examined. Recent results on transferability of the satellite ATI calculations will be presented at the conference.

2. APPLICATION TO RAIN GAGE DATA

With a dense network of recording gages, ATI values can be calculated from (1) by considering each gage that receives a threshold amount of rain during the specified time interval. The area A_i can be established using a method such as Thiessen polygons. A rough estimate of the ATI can be obtained by assuming each gage to represent an equal area, if the network is not too far from uniform.

Such an analysis was made for McKenzie County, North Dakota, in the summer of 1972 (Doneaud et al., 1979). There were 22 recording gages distributed over an area of 7374 km^2, and the readings were reduced to hourly data which were used to obtain the gage ATI values. The results were compared with estimates of 12-hr rainfall over the area obtained from a separate network of 65 non-recording gages (read twice daily) over the same area. Figure 1 shows the results of this comparison for the 18 rain days having at least 3 gage-hours of recorded data. (The synoptic classification in the figure is not of concern here.)

The slope on this log-log plot is about 1.16. It was recognized that even 65 gages might not give a good estimate of the areal rainfall, especially for the smaller events, so a similar analysis was done using radar to estimate the area rainfall. That analysis yielded a slope of about 1.03 (agreeing better with those in Table 1 below).

To place an absolute scale on the abscissa, note that 1% of the possible gage-hour rain events ($x = 0.0$ in Fig. 1) would correspond to an ATI of about 885 km^2·hr. On the ordinate in the figure, $y = 0.0$ corresponds to a rain volume of 10^3 kt = 10^3 km^2·mm. The regression lines for the gage and the radar estimates of the area rainfall would intersect at about $x = 1.0$ (ATI = 8850 km^2·hr), $y = 1.5$ (rain volume = 3.16×10^4 km^2·mm); at that point, the average rainfall rate over the rainy area would be 3.6 mm hr^{-1}. This compares favorably with the average rates obtained using a reflectivity threshold of 25 dBz to calculate the ATI from radar data. This fact suggested that we were on the right track, even though much concern has recently been expressed about the selection of the proper threshold (Atlas et al., 1990).

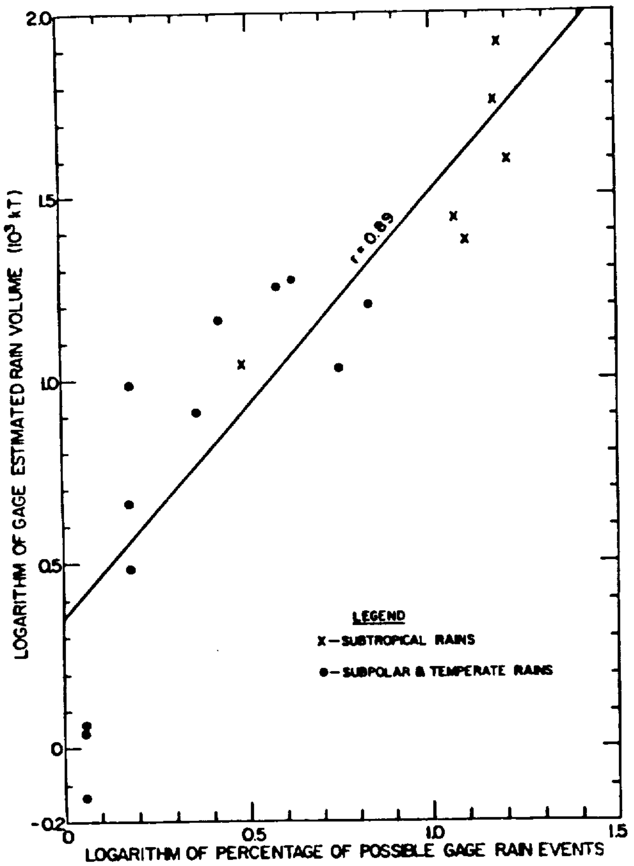

Fig. 1: Log-log plot of gage-estimated daily rain volume for McKenzie County, North Dakota vs. the percentage of possible gage-hours which actually had rain. The abscissa can be converted into an ATI as indicated in the text.

3. APPLICATION TO RADAR DATA

The most extensive uses of the ATI concept to date have involved radar observations. For example, during the Cooperative Convective Precipitation Experiment (CCOPE) that occurred in 1981 in southeastern Montana, radar volume-scan data were recorded continually during declared "go" days by a C-band radar system with 1° beamwidth. An extensive study of the CCOPE radar echo clusters was accomplished (Johnson and Hjelmfelt, 1990). Since the life history of each cluster was known, calculation of the Area-Time Integrals for these clusters was straightforward. Calculation of rainfall amounts using a Z-R relationship developed for the region ($Z = 155 R^{1.8}$, Smith et al., 1975) was accomplished at the same time.

Figure 2 compares the resultant radar-estimated rainfall to the Area-Time Integral for 865 clusters for which time histories are available. The log-log plot indicates extremely good correlation over a range that exceeds five orders of magnitude in rainfall. Regression analysis demonstrates a correlation coefficient of 0.988, with y-intercept of 0.326 log (km² mm) and slope of 1.088. The root-mean-square logarithmic error of 0.145 translates to a factor 1.4. Given any radar ATI that is computed using the same reflectivity threshold of 25 dBz, a straightforward rainfall estimate can be produced using Fig. 2.

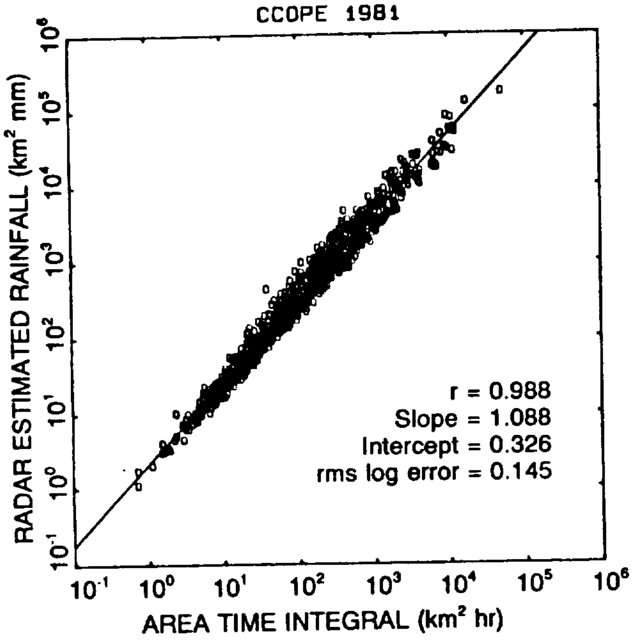

Fig. 2: Log-log scatter plot of ATI vs. radar estimated rain volume for echo clusters from CCOPE. Solid line shows the regression result.

Such comparison of area-time integral values to radar-estimated rain volumes using an appropriate Z-R relationship has been accomplished for several projects; the results are presented in Table 1. Each regression relationship like that established in Fig. 2 results in a power-law relation of the form

$$V = K \times ATI^{b} \quad , \qquad (2)$$

where V is rain volume; K and b are constants determined by regression. Specifically, b is the slope and K is the antilog of the intercept.

TABLE 1

ATI-Radar Rainfall Parameters Determined by Regression for Several Projects and Different Radars

PROJECT (YEAR)	K	b	RADAR (Type, Beamwidth)
NDPP (1972)	2.62	1.09	S-band, 2°
NDCMP (1980)	3.68	1.01	C-band, 2°
NDCMP (1981)	3.07	1.08	C-band, 2°
NDCMP (1982)	3.74	1.02	C-band, 2°
NDCMP (1984)	3.57	1.03	C-band, 2°
CCOPE (1981)	2.12	1.09	C-band, 1°
FACE (78, 79, 80)	3.40*	1.00	S-band, 2°
COHMEX (1986)	6.01	1.05	S-band, 2°

*18-dBz threshold used for ATI.

The first six entries of the table are for data from the western portion of North Dakota and eastern Montana, which represent similar geographic locations. For those six entries, the b parameter varies only from 1.01 to 1.09, while the K parameter varies from a low of 2.12 for CCOPE to a maximum of 3.74. Thus, we see small year-to-year variations as well as some differences (especially in K between Montana and North Dakota in the same year, 1981) that may be partly due to differences in radar characteristics.

The COHMEX data from the southeastern U.S. have a similar b parameter but the K parameter is substantially larger. This increase may be a climatological difference or only an artifact of the data. The WSR-57 RADAP data for COHMEX were recorded out to ranges of 250 km versus only 150 km for the ND/MT data. At ranges >150 km, with a 2° beamwidth, the sampling volume becomes rather large. Using the criterion that the reflectivity factor for the sampling volume has to exceed 25 dBz requires that a significant storm event must be taking place at the larger ranges before its inclusion in this study. Therefore, the larger coefficient may simply reflect greater rain amounts from these more mature events.

On the other hand, a similar radar was used in southern Florida during the FACE project for 1978, 1979, and 1980. Lopez et al. (1989) presented a composite figure for the three years comparing integrated radar echo area to radar-estimated rain volume. Their figure is similar to Fig. 2 except that linear scales were used. Scatter was evident about a line of slope 1 (which would have the same slope on a log-log plot); parameter K for 1-hr integration steps at a threshold of only 18 dBz is the reported average rain rate of 3.4 mm hr^{-1}. This value compares rather well with the K values from the High Plains observations with 2° beamwidths, but raising the threshold to 25 dBz would yield a higher value. The instrumented region of the project was within 170 km range of the radar.

Transferability of these relationships can be tested by using one relationship (like Fig. 2) to estimate rainfall amounts for other data sets. For example, during the 1984 North Dakota Cloud Modification Project, echo clusters were determined as in the CCOPE study. For each cluster, the same Z-R relationship was used to produce an estimate of rainfall. In Fig. 3, these estimates are compared to rainfall amounts estimated by using the observed ATI values with the CCOPE relationship presented in Fig. 2. Here we are comparing 1984 radar data to an ATI-rain volume relationship determined from 1981 data obtained with a different radar beamwidth. Yet, Fig. 3 demonstrates that the two different estimation schemes are similar. The ATI-estimated rainfall amounts do tend to be lower than those obtained from the Z-R relationship. This is consistent with the lower K parameter for the CCOPE relationship, as indicated in Table 1.

In another attempt to determine geographical transferability of the ATI relationships, the data secured by the RADAP system at Nashville, Tennessee, during the COHMEX project were similarly analyzed. The results are demonstrated in Fig. 4. Again, the ATI-estimated amounts tend to be lower than those obtained using a Z-R relationship developed specifically for the project (Peterson et al., 1990). The scatter is larger than that seen for North Dakota in the previous figure, and the degree of underestimate is a little greater. That is also consistent with the differences in the K values in Table 1.

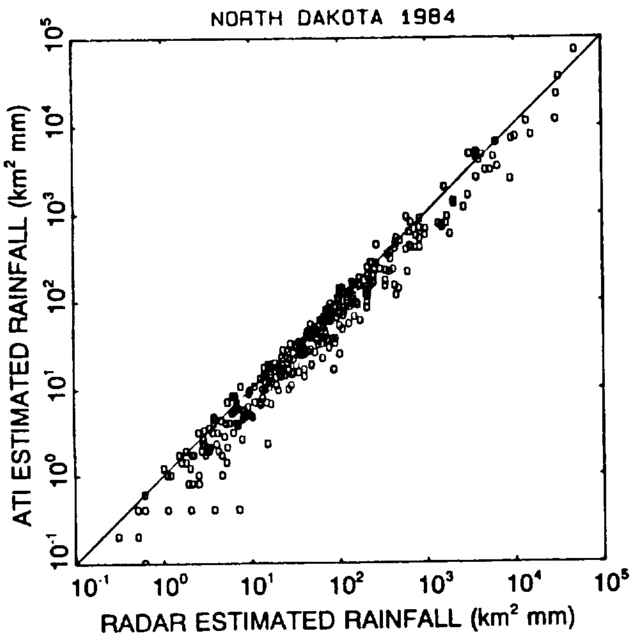

Fig. 3: Log-log scatter plot of rain volumes determined from the radar ATI using the CCOPE relationship (Fig. 2) for echo clusters from North Dakota 1984 vs. their direct radar-estimated rain volumes. The ideal 1:1 comparison line is shown.

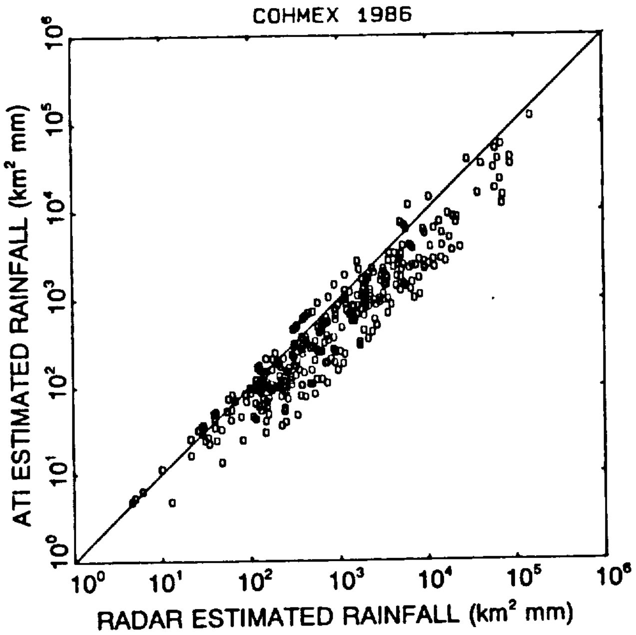

Fig. 4: Log-log scatter plot of rain volumes determined from the radar ATI using the CCOPE relationship (Fig. 2) for echo clusters from COHMEX 1986 vs. their direct radar-estimated rain volumes. The solid line shows the ideal 1:1 correspondence.

We cannot resolve the transferability question, with the data analyzed thus far. Using the same radar in the same location gives repeatable results (e.g., Doneaud et al., 1984). All our geographical comparisons also involve other differences, in wavelength, beamwidth, or range coverage. Thus we are not yet certain which are the more important factors, or whether they outweigh geographic differences.

4. APPLICATION TO SATELLITE INFRARED DATA

A special study with the major goal of establishing a satellite ATI method that could be used to estimate rain volumes is in progress. The initial analysis used radar data from the CCOPE and North Dakota-81 field projects as ground truth for comparison to satellite infrared rapidscan data. By optimization, it was determined that the ATI calculated using the area enclosed by the -23°C isotherm was most closely correlated to the radar-estimated rainfall. The results are presented in Fig. 5 and are discussed in Smith et al. (1990).

This satellite-identified ATI is significantly different from the ATI determined by radar or rain gages. The satellite ATI does not represent just the rainy portion of the storm, but, in fact, is many times greater. The slope in Fig. 5 is substantially less than unity, indicating that the satellite ATI grows more rapidly than the corresponding rain volume. Yet the optimization shows the area enclosed by the -23°C isotherm to be most closely related to the rain volume. Thus we expect to obtain good estimates of storm rain volumes, although accurate positioning of the rainfall on the surface will not be possible.

5. CONCLUSIONS

Application of the Area-Time Integral technique to estimate rain volume is very successful with comparable radar data. The same correlations appear in gage data where the gage network is sufficiently dense. The technique also appears promising using satellite infrared data.

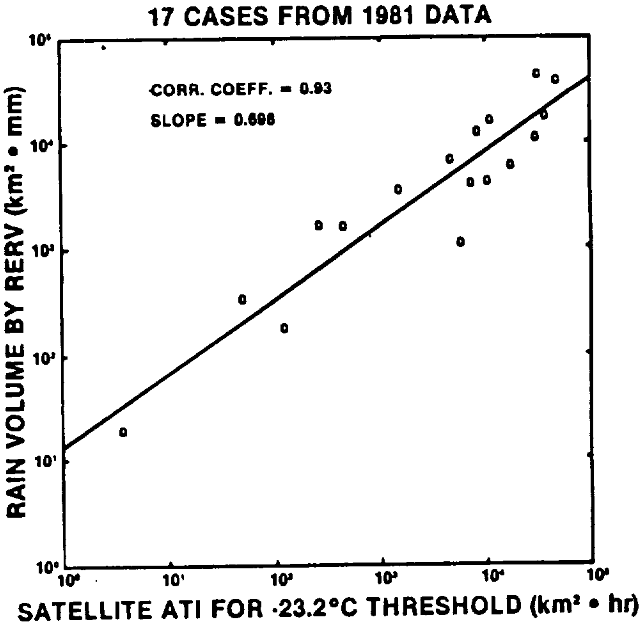

Fig. 5: Scatter plot and linear regression of cloud cluster rain volume (estimated by radar) vs. satellite ATI, for the optimized infrared threshold temperature of -23°C.

Still, many questions need to be answered. It is obvious that a radar-determined relationship for the northern Great Plains may not be applicable to the more moist environments of the southeastern United States. Signs of such differences appear in our results, but other equipment or analysis variations muddy the picture at this time. We need more direct comparisons with similar radars in different geographic areas to resolve the transferability issue.

Using satellite data requires better identification of rain-producing events before application of the ATI method. The satellite ATI calculation does not insure a raining event, but can reasonably estimate the amount of rainfall given that rain is occurring. We need more extensive testing of the method with satellite data to determine how to circumvent this concern as well as to investigate geographic transferability.

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