# N O T I C E

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# ASSESSMENT OF THE QUALITY OF 'GATE' AREA RAINFALL DATA FROM A NIMBUS-5 RADIOMETER

## Final Report Under NASA Grant NAG 5-14
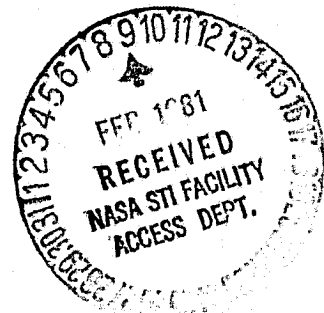
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# INTRODUCTION

The purpose of the present study is to evaluate the quality of rainfall intensity estimates derived from passive microwave measurements by the Electrically Scanned Microwave Radiometer (ESMR-5) aboard the Nimbus-5 satellite. The microwave measurements used are those coincident with the GARP (Global Atmospheric Research Program) Atlantic Tropical Experiment (GATE). ESMR-5 derived rainfall intensity estimates are compared with hourly averaged GATE radar rainfall measurements. Using the radar measurements as ground truth it is determined that with the transfer curves derived herein the ESMR-5 derived data consistently over estimates rainfall by a factor of approximately 1.4.

# RESEARCH PLAN

The ESMR-5 data set used herein consists of computer printouts of microwave brightness temperature measurements for seventy-nine (79) Nimbus-5 overpasses coincident with GATE radar rainfall measurements. The following tasks were completed in assessing the quality of these data:

1.  Collect and verify computer printouts of ESMR-5 GATE coincident data.

2.  Convert ESMR-5 brightness temperatures to rain intensity estimates for the two-degree square of the earth's surface centered at ($23.5^{\bullet}$ W, $8.5^{\bullet}$ N).

3.  Compare ESMR-5 derived rain intensity estimates with coincident GATE radar measurements of rainfall.

## METHODOLOGY

### 1. Data Collection and Preparation

The ESMR-5 data are available on computer tape at Goddard Space Flight Center. A search was made of the ESMR-5 data catalogues to locate GATE coincident data. Their references are given in Table 1. Computer printouts of these data were provided by Dr. Paul W. Hwang of Goddard. The printouts indicate brightness temperatures with their latitude-longitude locations and beam positions.

Those data points coincident with the GATE are located and plotted on a grid representing the two degree square centered at $(23.5^{\circ} \text{ W, } 8.5^{\circ} \text{ N})$. Beam position, brightness temperature, and scan angle are recorded for each. Then a correction of the brightness temperature is carried out. This correction scheme is given by Wilheit [3, Table 5-3] and is a function of beam position.

GATE radar rainfall data are available on both magnetic tape and microfilm from the GATE World Archives. Also, a GATE Radar Rainfall Atlas [2] is available. Among the data sets contained in the Atlas are tables indicating one hour, three hour, six hour, twelve hour, and twenty-four hour mean area precipitation rate for the fifteen geographic areas shown in Figure 1 [2]. GATE radar derived hourly rainfall intensity estimates for the entire GATE area on a grid of $0.25^{\circ} \times 0.25^{\circ}$ were obtained on microfilm from the GATE World Archives. See Figure 4.

Figure 3 indicates the four one-degree square regions into which the two-degree square region centered at (23.5°W, 8.5°N) was divided. Mean ESMR-5 derived rainfall intensity estimates for the entire region and for each of the four subregions were computed for GATE coincident Nimbus-5 overpasses. These means were also computed for corresponding GATE radar rain rate estimates.

## 2. Conversion of ESMR-5 Brightness Temperatures to Rain Rates

Rain intensity for each data point is determined via an appropriate brightness temperature/rain rate relation. In the present study two such relations are used.

Using ESMR-5 data for September 2, 1974, GMT 12:57-13:04, when Nimbus-5 was directly over the GATE area, arithmetically averaged brightness temperatures for areas 1 through 12 in Figure 1 were determined. A brightness temperature/rain rate relation was determined using a least squares linear fit of these temperatures plotted against hourly precipitation rates for corresponding areas [2]. The resulting relation has the equation

$$R = 0.031T - 4.258.$$

Where R denotes rain rate and T denotes brightness temperature.

The second is a freezing level dependent ralation derived from the Wilheit curves [4] shown in Figure 2. This relation is an interpolation of the 4km and 5 km freezing level curves

to correspond to a freezing level of 4.7 km which more closely approximates GATE conditions.[+] The formula for the relation is

$$R = \begin{cases} 0 & , \ 0 \leq T \leq 185 \\ 0.101T - 18.643, & 186 \leq T \leq 217 \\ 0.116T - 21.962, & 218 \leq T \leq 247 \\ 0.217T - 46.829, & 248 \leq T \end{cases}$$

where R denotes rain rate and T denotes brightness temperature.

## RESULTS AND CONCLUSIONS

The relation (*)$R = 0.031T - 4.258$ was used to calculate rain intensity for each ESMR-5 data point. Of the twelve areas in Figure 1, only area 11 is entirely within the two-degree square centered at $(23.5^\circ$ W, $8.5^\circ$ N). Thus, in this instance, ESMR-5 rain intensity estimates for area 11, derived using the relation (*) were compared with GATE radar derived hourly mean precipitation rates [2] for this area. Table 3 is a summary of the results and shows that the relation (*) leads to an over estimation of rainfall. However, consistency in the estimations is evident.

Since the relation

$$R = \begin{cases} 0 & , \ 0 \leq T \leq 185 \\ 0.101T - 18.643, & 186 \leq T \leq 217 \\ 0.116T - 21.962, & 218 \leq T \leq 247 \\ 0.217T - 46.829, & 248 \leq T \end{cases}$$

is derived from theoretically sound curves, a more comprehensive
+[1]

analysis was carried out on rain rate estimates derived via this formula. Of the 78 available GATE coincident ESMR-5 sensings only 68 could be matched with coincident GATE radar derived hourly rainfall intensity measurements. Using these data, for each matched overpass, mean rain intensity estimates (ESMR-5 and radar) were computed for each of the five regions (I, II, III, IV, and G) shown in figure 3.

Mean rain rate estimates (ESMR-5 and radar) were computed for the five regions for the entire GATE experiment and for each phase of GATE. For Region I and Region G 14 day and 7 day means were computed. In each instance the ratio ESMR-5 rainfall/radar rainfall was computed. The following is a listing of the results. Rain rates are in mm/hr.

## GATE

| REGION | ESMR-5 | RADAR | RATIO |
|--------|--------|-------|-------|
| I | 0.73 | 0.42 | 1.74 |
| II | 0.74 | 0.41 | 1.80 |
| III | 0.72 | 0.67 | 1.07 |
| IV | 0.67 | 0.79 | .85 |
| G | 0.72 | 0.54 | 1.33 |

Mean ratio 1.36
Standard derivation of ratio 0.41

## PHASE I

| REGION | ESMR-5 | RADAR | RATIO |
|--------|--------|-------|-------|
| I | 0.50 | 0.45 | 1.11 |
| II | 0.36 | 0.46 | 0.78 |
| III | 0.54 | 0.61 | 0.89 |
| IV | 0.56 | 0.54 | 1.03 |
| G | 0.49 | 0.64 | 0.77 |

Mean of ratio 0.91
Standard deviation of ratio 0.15

## PHASE II

| REGION | ESMR-5 | RADAR | RATIO |
|--------|--------|-------|-------|
| I | 0.87 | 0.24 | 3.63 |
| II | 0.85 | 0.12 | 7.08 |
| III | 0.90 | 0.76 | 1.18 |
| IV | 1.14 | 1.00 | 1.14 |
| G | 0.94 | 0.53 | 1.77 |

Mean of ratio 2.96
Standard deviation of ratio 2.52

## PHASE III

| REGION | ESMR-5 | RADAR | RATIO |
|--------|--------|-------|-------|
| I | 0.82 | 0.52 | 1.58 |
| II | 0.94 | 0.53 | 1.77 |
| III | 0.75 | 0.66 | 1.14 |
| IV | 0.52 | 0.94 | 0.96 |
| G | 0.76 | 0.56 | 1.36 |

Mean of ratio 1.36
Standard deviation of ratio 0.33

## FOURTEEN DAY MEANS REGION I

| PERIOD | ESMR-5 | RADAR | RATIO |
|--------|--------|-------|-------|
| 1 | 0.27 | 0.26 | 1.04 |
| 2 | 0.78 | 0.62 | 1.26 |
| 3 | 1.14 | 0.28 | 4.07 |
| 4 | 0.85 | 0.53 | 1.60 |

Mean of ratio 1.99
Standard deviation of ratio 1.40

## FOURTEEN DAY MEANS REGION G

| PERIOD | ESMR-5 | RADAR | RATIO |
|--------|--------|-------|-------|
| 1 | 0.47 | 0.66 | 0.71 |
| 2 | 0.72 | 0.59 | 1.22 |
| 3 | 1.16 | 0.53 | 2.18 |
| 4 | 0.68 | 0.46 | 1.48 |

Mean of ratio 1.38
Standard deviation of ratio 0.61

## SEVEN DAY MEANS REGION I

| PERIOD | ESMR-5 | RADAR | RATIO |
|--------|--------|-------|-------|
| 1 | 0.07 | 0.19 | 0.58 |
| 2 | 0.47 | 0.40 | 1.18 |
| 3 | 0.90 | 0.76 | 1.18 |
| 4 | 0.66 | 0.49 | 1.40 |
| 5 | 1.19 | 0.02 | 59.5 * |
| 6 | 1.09 | 0.54 | 2.02 |
| 7 | 1.21 | 0.35 | 3.46 |
| 8 | 0.50 | 0.70 | 0.71 |
| 9 | 0.39 | 0.39 | 1.0 |

Mean of ratio 7.89
Standard deviation of ratio 19.37

* When 59.5 is removed we have:
Mean of ratio 1.44
Standard deviation of ratio 0.93

## SEVEN DAY MEANS REGION G

| PERIOD | ESMR-5 | RADAR | RATIO |
|--------|--------|-------|-------|
| 1 | 0.33 | 0.70 | 0.47 |
| 2 | 0.60 | 0.63 | 0.95 |
| 3 | 0.68 | 0.64 | 1.06 |
| 4 | 0.76 | 0.53 | 1.43 |
| 5 | 1.15 | 0.43 | 2.67 |
| 6 | 1.16 | 0.63 | 1.84 |
| 7 | 1.00 | 0.46 | 2.17 |
| 8 | 0.38 | 0.46 | 0.83 |
| 9 | 0.42 | 0.41 | 1.02 |

Mean of ratio 1.38
Standard deviation of ratio 0.71


Observe that the mean of the ratio

ESMR-5 rain rate/radar rain rate

hovers consistently about 1.4. It is known that during Phase II
of the GATE, the operation of ESMR-5 was anomalous. For this
reason, data from only 15 GATE coincident overpasses were retrie-
vable. The results presented here indicates that these, too, may
not be true readings. When the ratio for the Phase II estimates
of rain rate are removed from the computations the mean ratio is
1.4 to the nearest hundredth.

These results indicate that oceanic rain rate estimates de-
rived from ESMR-5 data are very consistent when compared to radar
estimates.

## OTHER PERTINENT QUESTIONS

Several analyses suggested in the grant proposal could not be performed in the allotted time. They are as follows:

1. Compare the quality of ESMR-5 measurements at scan angles less than or equal to $30^\circ$ with that of angles greater than $30^\circ$.

2. Compare the quality of ESMR-5 measurements at scan angles less than or equal to $40^\circ$ with that of angle greater than $40^\circ$.

3. Approximate the fraction of rain during the GATE that was such that ESMR-5 saturation affected rain intensity measurement.

# REFERENCES

[1] Austin, P. and S. Geotis; 1978: 'Evaluation of the Quality of Precipitation Data from a Satellite-Borne Radiometer', Final Report under NASA Grant NSG 5024.

[2] Hudlow, M. D. and V. L. Patterson; 1979: Gate Radar Rainfall Atlas, Center for Environmental Assessment Services, NOAA, Washington, D. C.

[3] Wilheit, T. T.; 1972: 'The Electrically Scanning Microwave Radiometer (ESMR) Experiment', The Nimbus-5 Users Guide, NASA Goddard Space Flight Center, Greenbelt, Maryland.

[4] Wilheit, T. T., A. T. C. Chang, M. S. V. Rao, E. B. Rogers, and J. S. Theon; 1977: 'A Satellite Technique for Quantitatively Mapping Rainfall Rate Over Oceans', Journal of Applied Meteorology, 16, 551-560.
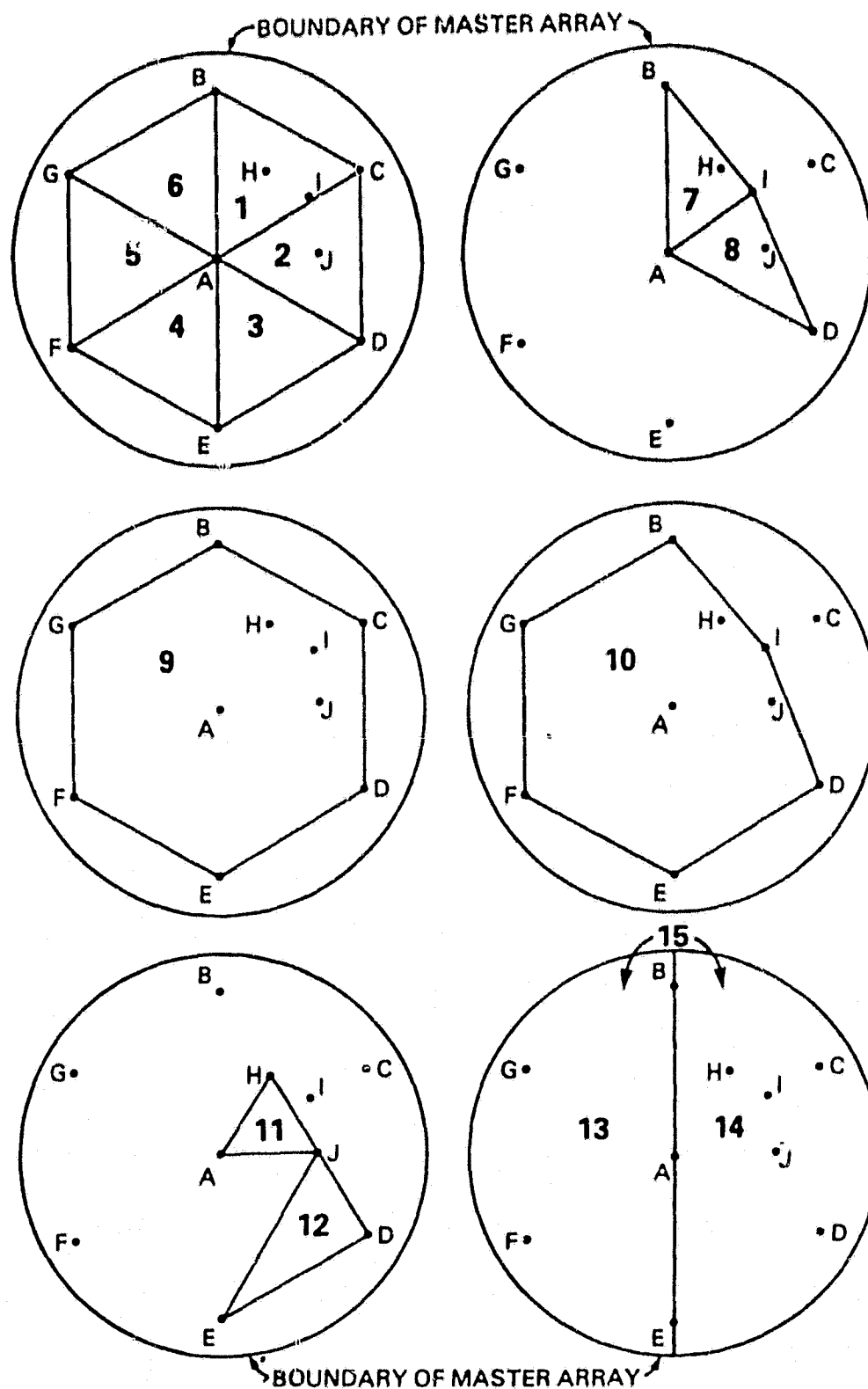
Figure 1. Key giving geometric areas corresponding to the area numbers appearing above the columns of the daily rainfall tabulations. Letters designate ship positions.

Table 1.  ESMR-5 GATE DATA

| Day | Time Span | Tape-File | Day | Time Span | Tape-File |
|-----|-----------|-----------|-----|-----------|-----------|
| 179 | 0107-0117 | L9697-17  | 211 | 0008-0017 | L5349-6   |
| 179 | 1252-1300 | L9679-1   | 211 | 0157-0204 | L5349-4   |
| 180 | 1207-1215 | L9679-9   | 211 | 1340-1349 | L5349-10  |
| 181 | 1309-1315 | L9679-17  | 212 | 0110-0119 | L5349-16  |
| 182 | 1223-1232 | L5308-10  | 212 | 1255-1304 | L5349-21  |
| 183 | 0142-0153 | L2441-4   | 222 | 0047-0054 | L5362-4   |
| 183 | 1325-1332 | L5308-18  | 222 | 1230-1237 | L5362-15  |
| 184 | 0054-0105 | L5308-24  | 223 | 0149-0156 | L5362-7   |
| 186 | 0110-0119 | L5326-20  | 224 | 1245-1253 | L5368-9   |
| 186 | 1256-1304 | L5228-3   | 225 | 0021-0026 | L5368-17  |
| 187 | 0027-0035 | L5228-8   | 227 | 0035-0041 | L5381-10  |
| 187 | 1210-1218 | L5228-14  | 227 | 1216-1224 | L5381-15  |
| 188 | 1313-1319 | L5225-4   | 242 | 0143-0150 | L5399-11  |
| 188 | 0130-0137 | L5228-22  | 242 | 1325-1333 | L5399-16  |
| 189 | 1227-1238 | L5225-7   | 243 | 0100-0108 | L5399-22  |
| 190 | 0145-0157 | L5225-13  | 243 | 1241-1248 | L6861-4   |
| 193 | 0117-0125 | L1599-20  | 244 | 0013-0021 | L6861-12  |
| 193 | 1300-1307 | L5327-2   | 244 | 0200-0209 | L6861-11  |
| 194 | 0033-0040 | L5327-14  | 244 | 1154-1202 | L6861-17  |
| 194 | 1213-1223 | L5327-11  | 244 | 1344-1350 | L6861-18  |
| 195 | 1316-1324 | L5360-4   | 245 | 1257-1304 | L6896-3   |
| 196 | 0048-0055 | L5360-11  | 246 | 1210-1219 | L6896-16  |
| 196 | 1230-1237 | L5360-16  | 247 | 0133-0139 | L9661-1   |
| 197 | 0150-0157 | L5360-22  | 247 | 1313-1321 | L9661-6   |
| 197 | 0005-0012 | L5360-23  | 248 | 0043-0053 | L9661-18  |
| 197 | 1332-1340 | L5359-6   | 248 | 1228-1235 | L9661-16  |
| 209 | 0140-0150 | L5269-4   | 249 | 0147-0155 | L5255-6   |
| 209 | 1325-1332 | L5269-10  | 249 | 1330-1337 | L5255-4   |
| 210 | 0053-0103 | L5269-16  | 250 | 1243-1252 | L5255-18  |
| 210 | 1237-1245 | L5269-21  | 251 | 0015-0023 | L5276-1   |

Table 1 (continued)

| Day | Time Span | Tape-File | | Day | Time Span | Tape-File |
|-----|-----------|-----------|--|-----|-----------|-----------|
| 251 | 0203-0210 | L5276-2 | | 257 | 1250-1258 | L6872-6 |
| 251 | 1159-1205 | L5276-6 | | 258 | 1202-1210 | L6872-13 |
| 252 | 0116-0125 | L5276-14 | | 259 | 0123-0129 | L6872-21 |
| 252 | 1300-1308 | L5276-20 | | 259 | 1305-1311 | L9649-3 |
| 253 | 0032-0040 | L5343-9 | | 260 | 0037-0044 | L9649-10 |
| 253 | 1215-1223 | L5343-3 | | 260 | 1219-1228 | L9649-15 |
| 254 | 1316-1324 | L5343-15 | | 261 | 0138-0145 | L5268-17 |
| 255 | 1232-1240 | L6842-3 | | 261 | 1321-1327 | L5268-3 |
| 256 | 1333-1340 | L6842-14 | | 262 | 0053-0100 | L5268-9 |
| | | | | 262 | 1235-1243 | L5268-15 |
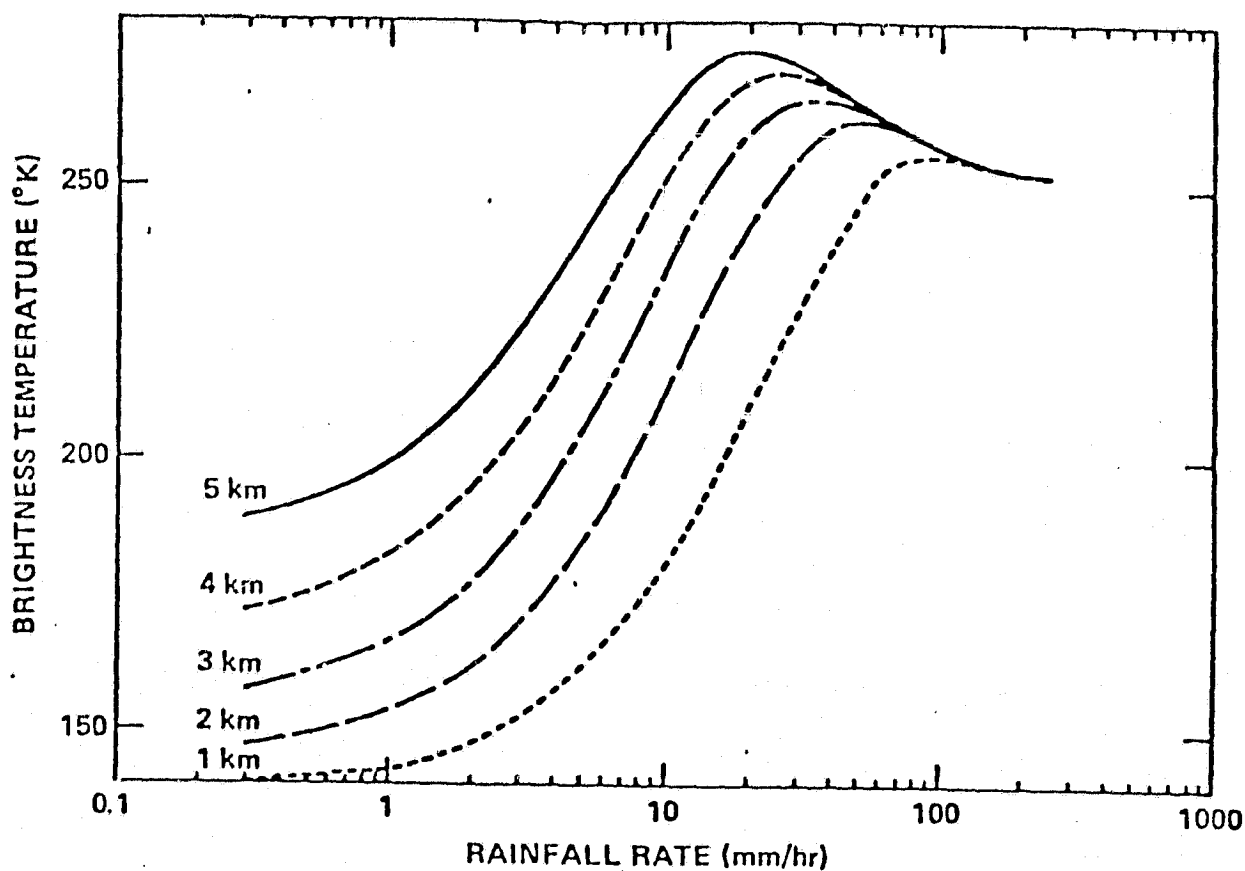


Fig. 2. Calculated brightness temperature at 1.55 cm as a function of rain rate for melting levels of 1, 2, 3, 4 and 5 km (from Wilheit et al, 1977).

## TABLE 2: DERIVATION OF THE LINE $R = 0.031\ T_B - 4.258$

T = Brightness Temperature

R = Rain Rate

| Region | T | R | R estimate | Residual |
|---|---|---|---|---|
| 1 | | | | |
| 1 | 171 | 0.64 | 0.98 | -.34 |
| 2 | 175 | 1.08 | 1.10 | -.02 |
| 3 | 181 | 1.09 | 1.28 | -.19 |
| 4 | 165 | 0.43 | 0.79 | -.36 |
| 5 | 172 | 1.04 | 1.01 | +.03 |
| 6 | 174 | 1.86 | 1.07 | +.79 |
| 7 | 171 | 0.82 | 0.98 | -.16 |
| 8 | 175 | 0.98 | 1.10 | -.12 |
| 9 | 173 | 1.02 | 1.04 | -.02 |
| 10 | 173 | 1.05 | 1.04 | +.12 |
| 11 | 172 | 1.51 | 1.01 | +.5 |
| 12 | 191 | 1.46 | 1.59 | -.13 |

Table 3. Comparison of ESMR-5 rain intensity estimates via the relation R = 0.031T - 4.258 with GATE radar derived hourly mean precipitation rates for area 11 of Figure 1.

| PHASE I | ESMR | RADAR | PHASE II | ESMR | RADAR | PHASE III | ESMR | RADAR |
|---|---|---|---|---|---|---|---|---|
| June 28 N + | 0.59 | 0.00 | July 28 N | 1.28 | 1.38 | Aug. 30 N | 2.67 | 2.16 |
| 28 D # | 1.18 | 1.03 | 28 D | 1.75 | 0.00 | 30 D | 1.60 | 0.11 |
| 29 D | 1.88 | m- | 29 N | 0.71 | 1.20 | 31 N | 0.70 | 0.01 |
| 30 D | 1.52 | m | 29 D | 1.14 | 0.69 | 31 D | 0.75 | 0.00 |
| July 1 D | 1.43 | 0.01 | ∫ 00:00 30 N | 2.23 | 0.27 | Sept. | | |
| 2 N | 1.47 | 0.03 | 30 D | 1.96 | 0.07 | 00:22 1 N | 2.16 | 0.06 |
| 3 D | 2.55 | 0.08 | 02:01 30 N | 1.39 | 0.00 | 02:10 1 N | 1.40 | 0.04 |
| 3 N | 0.76 | 0.00 | 31 N | 1.05 | m | 12:03 1 D | 2.03 | 0.42 |
| 5 D | 0.63 | 0.03 | Aug. 1 D | 0.81 | m | 13:51 1 D | 2.01 | 0.47 |
| 5 N | 0.80 | 0.32 | 10 N | 2.54 | 4.95 | 2 D | 1.05 | 1.51 |
| 6 N | 1.31 | 0.03 | 10 D | 2.39 | 0.14 | 3 D | 1.72 | 0.03 |
| 6 D | 1.40 | 0.00 | 11 N | 1.23 | 0.00 | 4 N | 1.26 | 0.00 |
| 7 D | 1.92 | 1.33 | 13 N | 2.57 | 0.00 | 4 D | 1.13 | 0.01 |
| 7 N | 1.19 | 0.12 | 15 N | 1.06 | 0.00 | 5 N | 1.88 | 0.84 |
| 8 D | 2.08 | 1.04 | 15 D | 1.25 | 0.00 | 5 D | 1.97 | 2.53 |
| 9 N | 1.24 | m | | | | 6 N | 1.29 | m |
| 12 N | 1.12 | 0.00 | | | | 6 D | 2.39 | 1.17 |
| 12 D | 0.71 | 0.00 | | | | 7 D | 0.72 | 0.09 |
| 13 N | 1.75 | 0.10 | | | | 8 N | 2.22 | 0.36 |
| 13 D | 2.01 | 0.77 | | | | 9 N | 1.37 | 0.10 |
| 14 D | 2.01 | 1.36 | | | | 9 D | 1.27 | 3.49 |
| 15 N | 1.87 | 2.65 | | | | 10 N | 1.52 | 0.18 |
| 15 D | 1.24 | 0.10 | | | | 10 D | 1.39 | 0.02 |
| 16 N | 1.17 | 0.00 | | | | 11 D | 1.30 | 0.00 |
| 16 D | 1.54 | 0.00 | | | | 12 D | 2.50 | 3.00 |
| | | | | | | 13 D | 2.32 | m |
| | | | | | | 14 D | 1.34 | 2.83 |
| | | | | | | 15 D | 1.67 | 0.10 |
| | | | | | | 16 N | 1.52 | 0.33 |
| | | | | | | 13:05 16 D | 1.77 | 3.21 |
| | | | | | | 00:37 17 N | 1.66 | 0.64 |
| | | | | | | 17 D | 2.05 | 0.54 |
| | | | | | | 18 N | 1.43 | 0.03 |
| | | | | | | 18 D | 1.53 | 0.02 |
| | | | | | | 19 N | 0.95 | 0.22 |
| | | | | | | 19 D | 1.80 | 1.61 |

PHASE I    AVERAGE: ESMR - 1.41, RADAR - 0.41; RATIO - 3.44
PHASE II   AVERAGE: ESMR - 1.56, RADAR - 0.67; RATIO - 2.33
PHASE III  AVERAGE: ESMR - 1.61, RADAR - 0.79; RATIO - 2.08
GATE       AVERAGE: ESMR - 1.53, RADAR - 0.64; RATIO - 2.40

+ Night
# Day
∫ GMT
- Missing

Figure 3. Subdivisions of the two-degree square region centered at (23.5° W, 8.5° N). The letter G denotes the entire region.
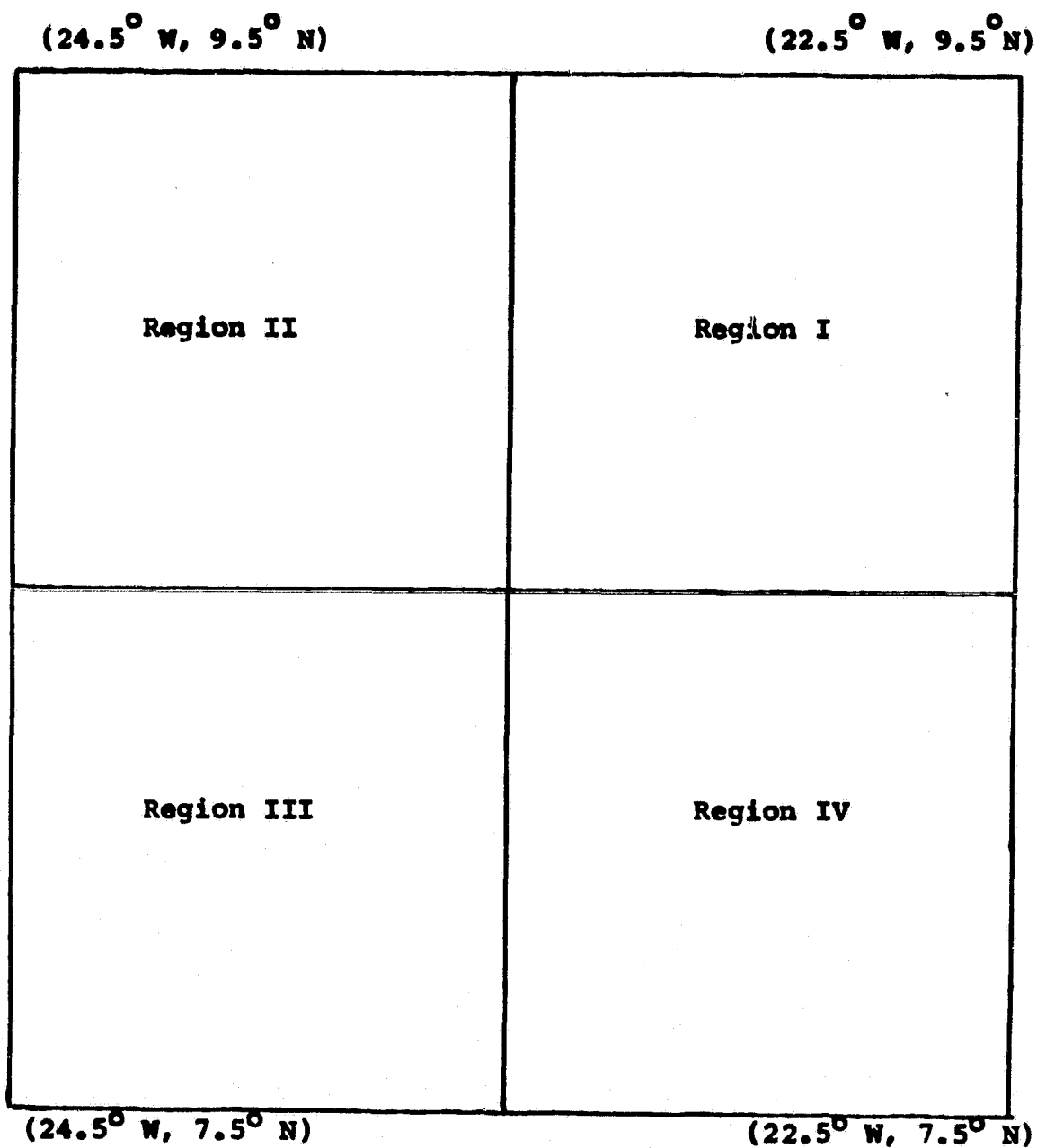
(24.5° W, 9.5° N)                                    (22.5° W, 9.5° N)

Region II                        Region I

Region III                       Region IV

(24.5° W, 7.5° N)                                    (22.5° W, 7.5° N)

**Figure 4    The GATE Area**