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Rain Volume Estimation Over Areas Using Satellite and Radar Data

Period Covered: 1 January 1985 - 30 June 1985

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This is a summary of the work accomplished during the first half of 1985 (including the month of July).

1. The principal goal of the project is to investigate the feasibility of rain volume estimation over fixed and floating areas using rapid scan satellite data following a technique recently developed with radar data, called the Area Time Integral (ATI) technique. To accomplish this task, case studies were continuously selected (during the first half of 1985 as well as during 1984) on the basis of existing radar and satellite data sets which match in space and time.

The radar and rapid scan GOES satellite data were collected during the Cooperative Convective Precipitation Experiment (CCOPE) and North Dakota Cloud Modification Project (NDCMP). Six multicell clusters and cells were analyzed to the present time. The small mesoscale areas of Austin and Houze (1972) or the mesoscale cloud systems described by Super and Heimbach (1980) as cells bigger than a cumulus cloud but smaller than a typical mesoscale convective complex were considered "clusters". Three clusters were selected on each day, 12 June and 2 July, as illustrated in Table 1. The 12 June clusters occurred during the daytime, while the 2 July clusters during the nighttime. A total of 86 time steps of radar and 79 time steps of satellite images were analyzed. There were approximately 12-min time intervals between radar scans on the average.

The radar data were on hand at the Institute of Atmospheric Sciences, South Dakota School of Mines and Technology. Magnetic tapes of digital satellite data were acquired by the Department of Atmospheric Science, Colorado State University, from the Bureau of Reclamation, the University of Wisconsin through the National Environmental Satellite Data Information Service (NESDIS), and the GOES data archive at CSU. The satellite data were processed at the IRIS/DRSES facility located at CSU. The radar data were processed at SDSM&T. Details concerning data processing were described in the first and second semiannual reports.

The trends of the echo areas and of the temperature thresholds picked to match the radar return area are displayed in Fig. 1A, B, C, D, E, and F for the six cells, respectively. A visual inspection of these graphs emphasizes a general similarity of evolution and a tendency for satellite products to lag that of radar (Fig. 1A, 1B, and 1E). A two-cycle oscillation emphasizing the multicell character of the clusters is demonstrated, except for cell E. The cirrus spissatus debris is visible in two of the cells, 1B and X2. A hint of the first growing period is present in the satellite data trend (in Fig. 1A), primarily because the clusters initial stage was overlaid by debris from previous activity.

Figures 2A, B, C, D, E and F display the maximum radar reflectivity (Z), the temperature of infrared maximum count (T_{MX}), and the maximum echo height (H) for reflectivity values >20 dBz on an interpolated

TABLE 1

Characteristics of the Analyzed Clusters

No.	Cluster Ident.	Date 1981	Time Period (Radar) (GMT)	Time Steps Radar	Time Steps Satellite	Cluster Type	Satellite Data Type
1	1A	12 June	1657 - 1955	14	13	Multicell	Infrared, Visible
2	1B	12 June	1746 - 1955	10	12	Multicell	Infrared, Visible
3	E	12 June	1657 - 1930	11	12	One Cell	Infrared, Visible
4	X1	2 July	0103 - 0453	19	16	Multicell	Infrared
5	X2	2 July	0201 - 0434	13	10	Multicell	Infrared
6	A	2 July	0103 - 0453	19	16	One Cell	Infrared

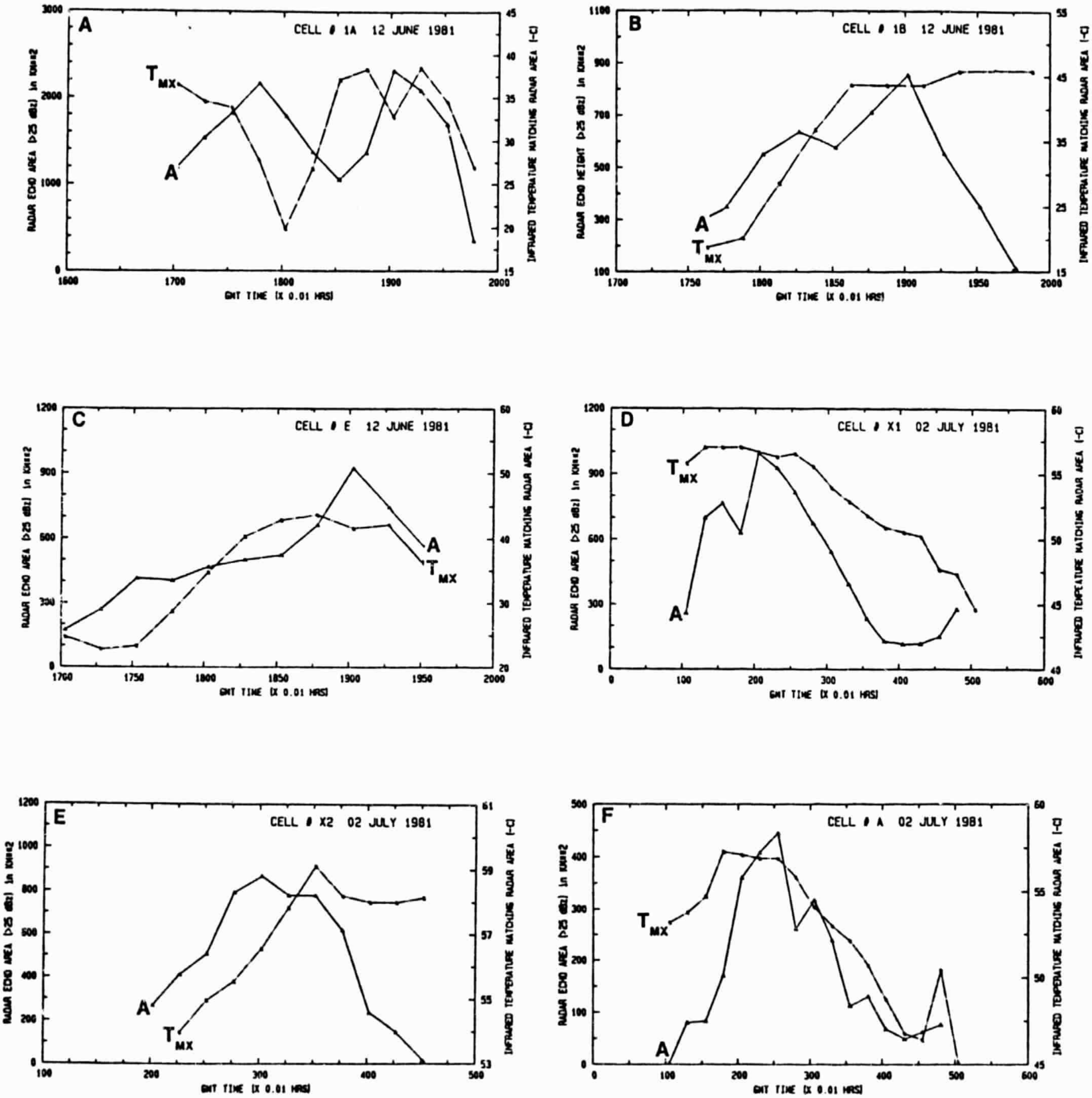

Fig. 1: Trends of radar echo area (A) and infrared temperature matching radar echo area (T_{MX}) for the six analyzed clusters.

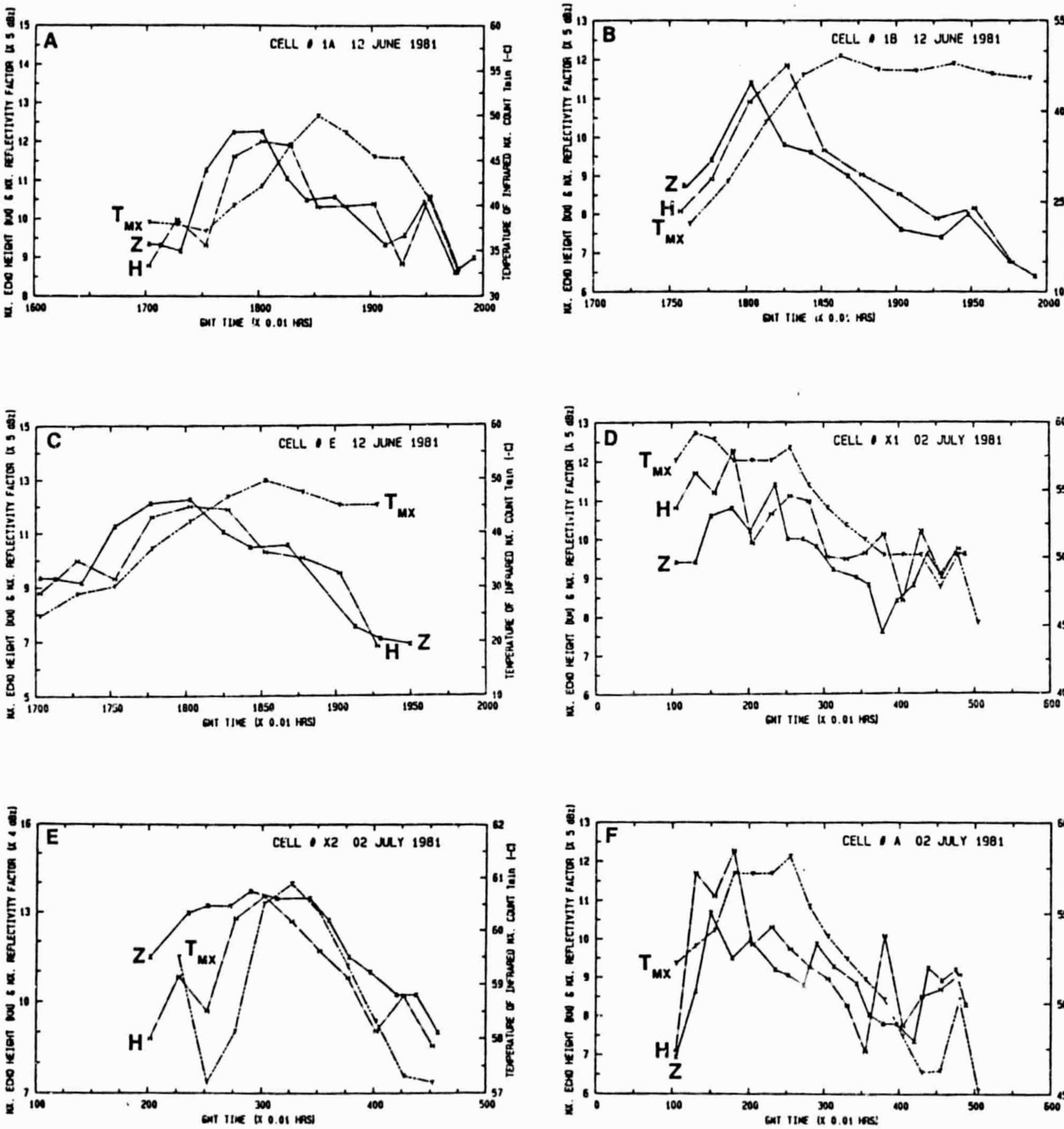

Fig. 2: Trends of radar maximum echo height (H), maximum reflectivity (Z), and temperature of infrared maximum count (T_{MX}) for the six analyzed clusters.

step-by-step basis for all six cells. Again, as in Fig. 1, the similarity of the cluster evolution, the 30 minute time lag between radar and satellite peaks, and the cirrus debris problem are evident. It is important to note that during the presence of cirrus debris, the minimum cloud top temperature remains lower than initially.

A summary of radar and satellite products for the six analyzed clusters is presented in Table 2. Columns (2) to (5) represent radar products, column (7) to (10) independent satellite products, while column (11) to (13) satellite products matching radar quantities. Columns (11) to (13) were computed for the storm lifetime using histograms. Two of such histograms are presented in Attachment A, Fig. 4.

A visual inspection of both radar and satellite products (Table 2) emphasizes variable geometries (physical appearance) of the six considered clusters. The 2 July clusters are more extended in the vertical than the 12 June as viewed by satellite. The radar products are roughly the same for both days. The MEH (column 3) average is only slightly higher (.196 km) for 2 July. The cluster with the largest MEH (X_2, MEH = 14.4 km) did not generate the greatest amount of rain.

The main purpose of this work is to reach to compute convective rain volumes over areas by application of the ATI technique based only on satellite data. The key element is to determine ATI from independent satellite data without consideration of radar reflectivities. This is possible if trends of satellite products generated independently (Table 2, columns 7-10) are similar to those of satellite based upon radar observations as done here. For instance regression curves correlating satellite digital count thresholds to satellite IR maximum count values, or satellite IR maximum count values averaged over the duration of the cell have to be identified. Such a linear regression relating the satellite IR maximum count value averaged over the duration of the cluster to the satellite IR temperature which matches the radar ATI is displayed in Fig. 5 of Attachment A. Certainly this finding is based only on a very limited sample size. Investigations are to further test and refine these results.

Descriptive models representing the structure of the radar reflectivities and the minimum temperature of infrared digital counts as a function of surface area and time have a similar appearance above a given satellite threshold (Fig. 6A, B; Attachment A). This correspondence is emphasized by the -50°C and the 35 dBz curves. These models were computed by averaging the six analyzed cluster products. For warmer thresholds, the multicell structure of the clusters generates multimode digital count trends. The multicell structure of the cluster appears to be more evident on the satellite products.

Adjustments of the radar and satellite data on a step-by-step basis were performed on 2-3 May 1985 during a joint SDSM&T and CSU meeting at Rapid City. Participants were T. H. Vonder Haar and P. Laybe from CSU and A. A. Doneaud, J. R. Miller, Jr., and L. R. Johnson from SDSM&T.

TABLE 2

Characteristic Products of Bowman Radar and GOES Satellite Data for Six Clusters (or Cells) of Summer 1981

RADAR DATA					SATELLITE DATA							
Cell No. and Duration (hrs)	Max dBz	Max Echo Height km	ATI km^2 hr	Rain Vol km^2 mm	λ	Maximum Digital Count	Temp of IR Max Count T_{MX} (-°C)	Average* Temp of IR Max Count T_{AMX} (-°C)	Averaged* Vis Max Count	Digital Count Thresh Matching Radar ATI	Temp Matching Radar ATI T_{MA} (-°C)	ATI (Satellite)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1A / 2.96	61	12.2	4,625	16,119	IR VIS	195 66	50.2	41.5	62.8	178.70 57.73	33.0	4,534 4,534
1B / 2.50	57	12.1	1,117	4,082	IR VIS	194 65	49.2	45.1	63.0	189.09 59.36	45.0	1,169 1,169
E / 2.55	61	12.2	1,302	6,831	IR VIS	195 64	50.2	43.6	61.0	185.68 57.85	41.0	1,221 1,221
X1 / 3.83	57	12.5	1,897	11,001	IR	204	59.2	53.5		201.21	56.4	1,876
X2 / 2.55	55	14.4	1,338	1,027	IR	207	61.2	58.6		202.47	58.0	1,243
A / 3.83	53	12.5	704	4,268	IR	204	59.2	53.8		201.39	56.5	722

*Averaged over the cell lifetime.

Some other 4-6 clusters are scheduled to be processed and analyzed next.

2. A contribution entitled, "The Area-Time-Integral Technique to Estimate Convective Rain Volumes Over Areas Applied to Satellite Data -- A Preliminary Investigation" coauthored by André A. Doneaud, James R. Miller, Jr., and L. Ronald Johnson of the Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, South Dakota, and Thomas H. Vonder Haar and Patrick Laybe, of the Department of Atmospheric Sciences, Colorado State University, Fort Collins, Colorado, has been accepted for presentation at the Sixth Conference on Hydrometeorology of the American Meteorological Society 29 October - 1 November 1985, Indianapolis, Indiana. A copy of the Preprint Volume Paper is attached as Attachment A.

3. A 15 minute presentation was given by A. A. Doneaud at the Panel Review Meeting of the Global Scale Atmospheric Research Program, 8-11 July 1985, Columbia Inn, Columbia, Maryland. A trip report is attached as Attachment B. An abstract of the presentation was included in an "Abstract Digest" volume published by Science and Technology Corporation. The abstract is attached as Attachment C.

4. A 50 minute seminar was given by A. A. Doneaud at the NASA/GSFC on the afternoon of 11 July. The subject was related to the progress made up to date on Grant No. NAG 5-386.

5. A journal manuscript to be submitted for possible publication to the Monthly Weather Review or to the Journal of Climate and Applied Meteorology is under work and will be ready in 1-2 months.

ATTACHMENT A

THE AREA-TIME-INTEGRAL TECHNIQUE TO ESTIMATE CONVECTIVE RAIN VOLUMES OVER AREAS APPLIED TO SATELLITE DATA - A PRELIMINARY INVESTIGATION

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1. Introduction

The main emphasis of this study is to investigate the feasibility of rain volume estimation using satellite data following a technique recently developed with radar data, called the Area-Time-Integral (ATI) technique. The basis of the method is the existence of a strong correlation between the radar echo area coverage integrated over the lifetime of the storm and the radar estimated rain volume. It provides a means of estimating total rain volumes over fixed and floating target areas of the order of 1,000 to 100,000 km^2 for clusters lasting >40 min (Doneaud et al., 1981, 1984a). The technique does not require the consideration of detailed interior structure measured by radar or other means to generate rain volumes; only the area covered by rain events. Simplicity of the approach, if applied successfully to satellite data, holds the promise of reducing sources of error by minimizing required data input in comparison to other methods.

Some of the satellite methods used to estimate rain volumes over areas considered cloud histories in the calculation process (i.e., Griffith et al., 1976). Negri et al. (1984) found the Griffith-Woodley Technique (GWT) quite complicated as it necessitates different conversion factors for each stage of cloud development for a given climate. The cited authors suggested a simplified version of the technique. Griffith et al. (1981) showed that special precautions should be used to adjust the magnitude of the estimates when using the GWT technique in a much drier climate. Scofield and Oliver (1977) have developed rainfall estimation methods for use in forecast offices primarily for flash flood prediction (large and long-lasting storms). Negri and Adler (1981) and Adler and Mach (1984) found cloud height-rainfall rate relations by considering only the period of maximum development of the convective system. The ATI technique considers cloud histories and requires only one conversion factor to convert the ATI to total rain volume. The proposed method limits input to only satellite variables in estimating rain volumes. Relations between digital count thresholds which yield areas that match areas >25 dBz used to determine the ATI's have to be found to extend the technique. Other satellite quantities such as cloud top minimum temperature or thermodynamic profiles may also be useful to better understand selection processes that occur.

2. Data and data processing

Radar and rapid scan satellite data were collected during the summer season of 1981. The radar data were collected in Bowman (western North Dakota) as a part of the North Dakota Cloud Modification Project (NDCMP) and the rapid scan satellite data were collected as a part of the Cooperative Convective Precipitation Experiment (CCOPE). The radar data were processed at the South Dakota School of Mines and Technology and the satellite data at the Colorado State University.

The Bowman radar was an Enterprise Electronics Corporation WR-100, 5.4-cm system equipped with a digital video integrator and processor and a magnetic tape recorder. The data tapes were processed following procedures similar to those described by Schroeder and Klazura (1978). The rain volume for every cluster was computed using an optimized Z-R relationship, $Z = 155\ R^{1.88}$ (Smith et al., 1975) based on data from this region. Details concerning the processing of the radar data can be found in Doneaud et al. (1984c). Digital printouts of the dBz values at low tilt angle were prepared and converted from spherical to a rectangular coordinate system.

Digital Visible and Infrared Spin Scan Radiometer (VISSR) data from both the east and west GOES were used. GOES-West was in the rapid scan (high frequency imaging) mode during the days analyzed. Rapid scan imagery from GOES-West was used to match as close as possible the satellite image times to the radar scan times. When a close match was not possible with GOES-West imagery, GOES-East imagery was employed. The satellite data were processed at the IRIS/DRSES (Interactive Research Imaging System/Direct Readout Satellite Earth Station) facility located at CSU. The satellite imagery was remapped into a Lambert conformal projection so that the radar PPI data and the satellite imagery are in the same perspective. The resultant image resolution is ≈ 2.47 km^2 per image pixel. The visible satellite data was normalized for solar zenith angle. The infrared satellite data has a calibration stability of ±5° at 295°K. The remapped infrared imagery was modifed by a routine which smoothes the sharp contrast between pixels by averaging.

A radar sector of interest was defined to delineate specific radar echo clusters for each radar time throughout the radar echo cluster lifetime. The radar sector of interest was used to locate the convective cluster responsible for the rainfall in the remapped satellite data. The radar echo clusters within the defined sectors of interest were identified by drawing a "box" using axes and radials around the cluster. The cluster echo areas of >25 dBz reflectivity threshold and the corresponding radar ATI and rain volume are calculated.

Next, a satellite sector of interest was defined by applying small adjustments to the radar sector using a manual processing technique. This was done to avoid cloud features suspected of not being detected by the radar. It is one of the most delicate tasks of this investigation because of several considerations: a) satellite and radar systems respond to different characteristics of clouds at different atmospheric levels; b) time differences between satellite and radar data sets can vary by as much as 10 min; c) spatial positioning of the satellite observations relative to the radar location necessitate error inclusion due to limited accuracy of geometric corrections; d) vertical wind shear advects the cloud tops downwind from the location of the radar echo area; and e) in the definition of the matching satellite sector of interest, the inclusion or exclusion of cirrus spissatus debris is a very important decision. If the cirrus debris appeared to be completely detached horizontally from the radar echo cluster, the cirrus cloud cover was excluded from the satellite sector of interest.

Six clusters lasting 2-4 hours are analyzed for which both digital satellite and radar data existed. These storm events occurred on 12 June and 2 July. Table 1 describes some characteristic quantities of these clusters. The 12 June clusters occurred during the daytime, while the 2 July clusters occurred during the nighttime. A total of 86 time steps of radar and 79 time steps of satellite images were analyzed. There were approximately 12-min time intervals between scans on the average. The 12 June clusters were analyzed using both infrared and visible data. For the 2 July clusters, only infrared data were available. The small mesoscale areas of Austin and Houze (1972), or the mesoscale cloud systems described by Super and Heimbach (1980) as cells bigger than a cumulus cloud but smaller than a typical mesoscale convective complex were considered "clusters" in this work.

3. Analysis of the data

3.1 Time Step Analysis

Using the technique described in Section 2, satellite brightness and temperature pixel counts above defined thresholds within the satellite sector of interest were counted and converted to area. Histograms of area versus brightness counts were produced for each satellite time step for each data type for the lifetime of the storm. These histograms and the computed radar area (multiplied by the radar time interval) were used to determine thresholds for satellite data (matching the radar area multipled by time) by

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4	X1	2 July	0103 - 0453	19	16	Multicell	Infrared
5	X2	2 July	0201 - 0434	13	10	Multicell	Infrared
6	A	2 July	0103 - 0453	19	16	One Cell	Infrared

forcing the areas multiplied by time for satellite to be equal to radar. Both satellite and radar time series were reduced to a constant 15-min time increment by linear interpolation such that functional time dependence is comparable. The echo areas >25 dBz (multiplied by time), as well as the corresponding threshold count values, exhibit a large spectrum of variations during the storm lifetime. No relationship has been found between these variations and the stages of the storm lifetime.

The trends of the echo areas and of the temperature thresholds picked to match the radar return area are displayed in Fig. 1A, B, C, D, E, and F for the six cells, respectively. A visual inspection of these graphs emphasizes a general similarity of evolution and a tendency for satellite products to lag that of radar (Fig. 1A, 1B, and 1E). A two-cycle oscillation emphasizing the multicell character of the clusters is demonstrated, except for Cell E. The cirrus spissatus debris is visible in two of the cells, 1B and X2. The cirrus debris make the definition of the end of a cluster (as a convective entity) from the satellite images difficult. A hint of the first growing period is present in the satellite data trend (in Fig. 1A), primarily because the clusters initial stage was overlaid by debris from previous activity. Again remnants of previous activity preclude initial observations in Fig. 1D (Cluster X1) and Fig. 1F (Cell A).

Figure 2A, B, C, D, E, and F display the maximum radar reflectivity (Z), the temperature of infrared maximum count (T_{MX}), and the maximum echo height (H) for reflectivity values >20 dBz on an interpolated step-by-step basis for all six cells. Again, as in Fig. 1, the similarity of cluster evolution and the time lag between radar and satellite is evident.

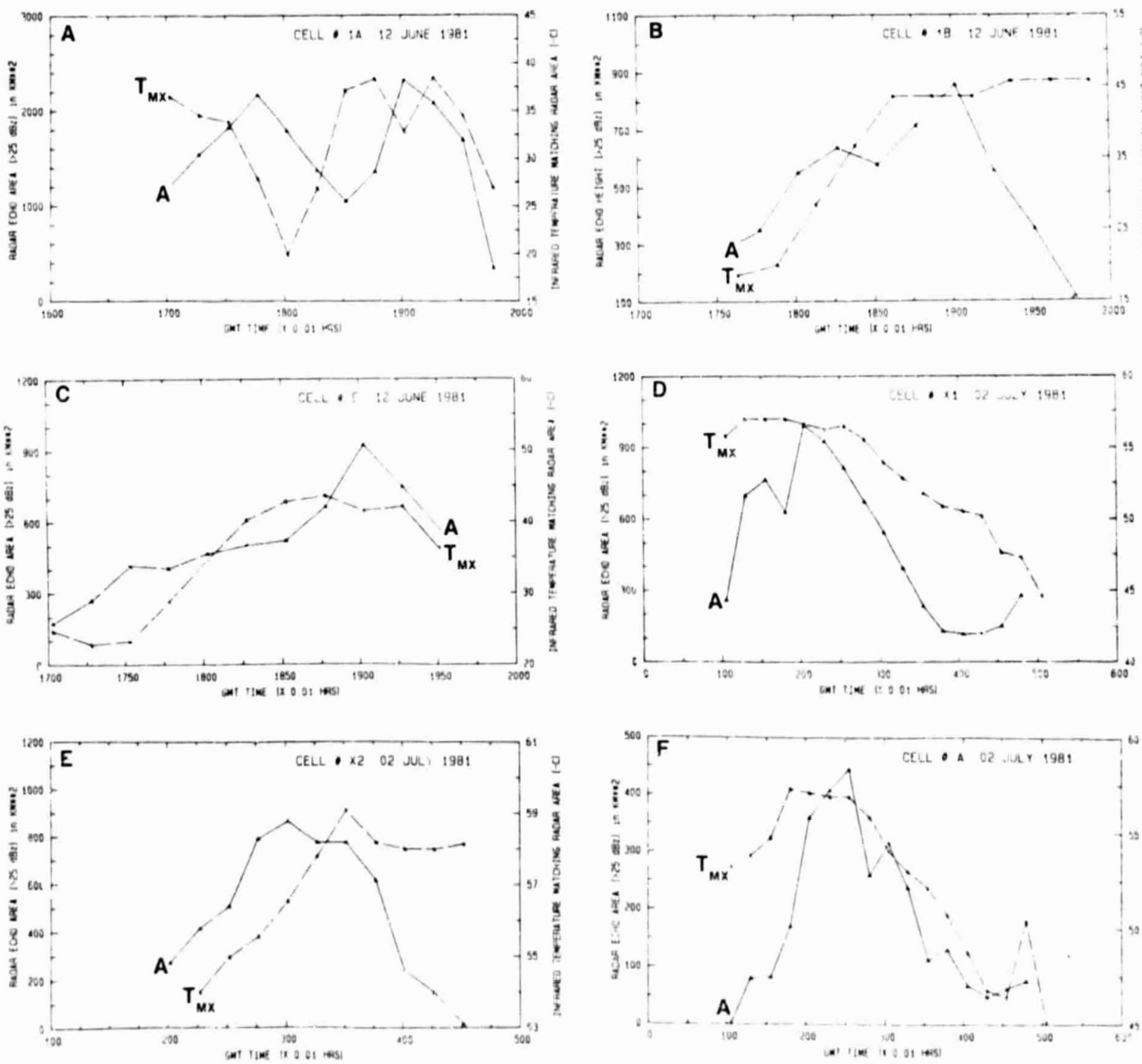

Fig. 1: Trends of radar echo area (A) and infrared temperature matching radar echo area (T_{MX}) for the six analyzed clusters.

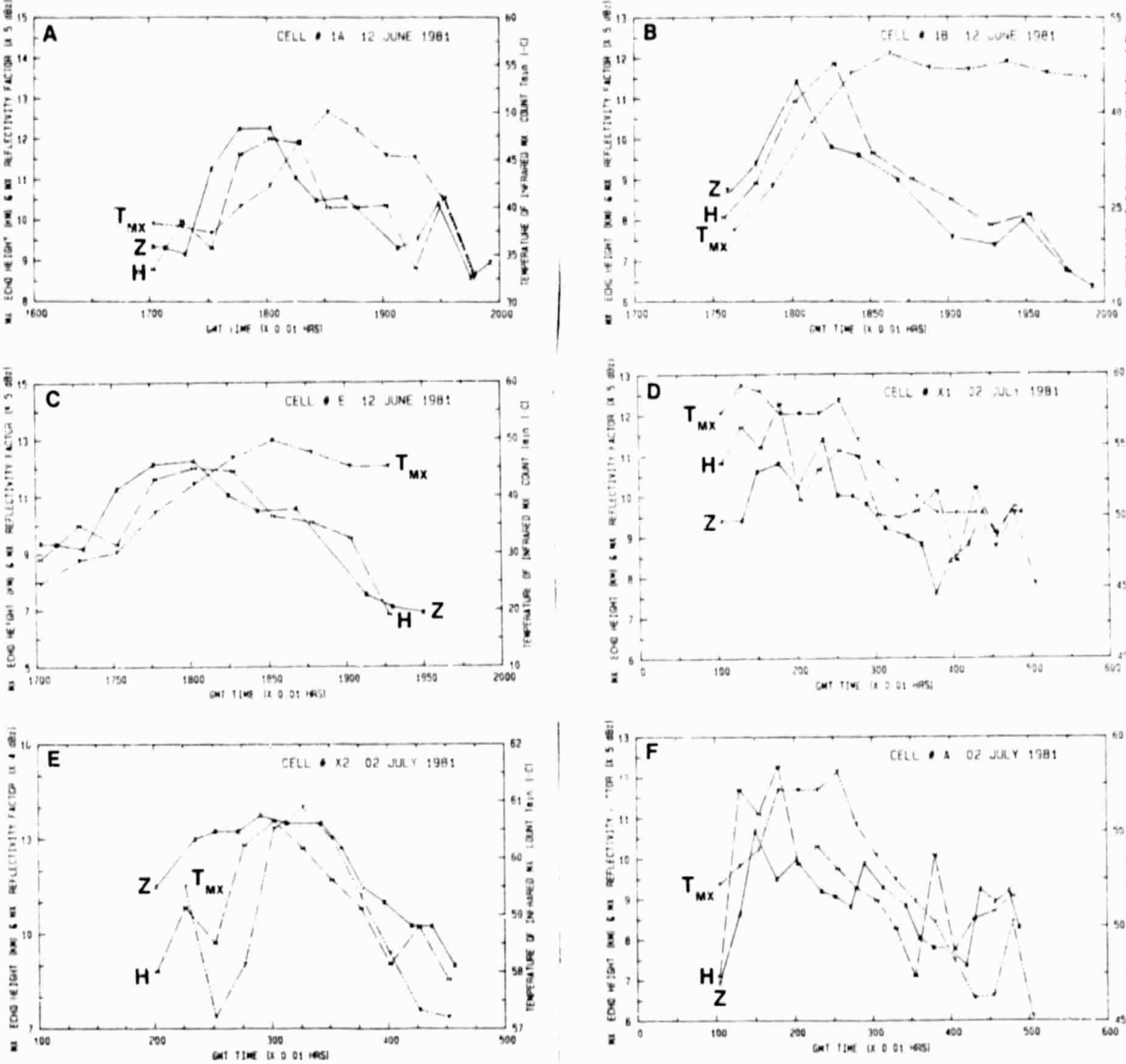

Fig. 2: Trends of radar maximum echo height (H), maximum reflectivity (Z), and temperature of infrared maximum count (T_{MX}) for the six analyzed clusters.

In Fig. 1A, a 30-min lag between the maximum echo height and maximum reflectivity as radar products and the minimum temperature by satellite is evident. That again demonstrates the multicell character of this cluster (1A). An identical 30-min lag is also visible in Figs. 2B and 2C. In the same two figures, the cirrus debris is evident. It is important to note that during the presence of cirrus debris, the minimum cloud top temperature remains lower than initially. Remnants of previous activity precluded definitive initial observations for Cells X1 and X2 (Figs. 2D and 2E). For Cell X2, only the infrared maximum count trend converted to temperature is available.

The step-by-step radar reflectivites for >25 dBz on a 10-dBz step interval for the 2 July 1981 clusters, as well as the corresponding satellite IR features, are presented in Fig. 3. The radar sectors used to delineate the echo clusters are displayed on each radar PPI image, while the satellite subjective sectors are displayed on the satellite images. The IR contours represent -4°C temperature steps with the first contour representing a fixed temperature. The multicellular structure of Cluster X1 is evident. Cluster X2 starts as a single cell and develops into a multicellular structure as it matures. In the satellite images as well as in the radar PPI, Cell X1 grows until 0128 GMT (two consecutive time steps); it slowly decays until 0241 GMT, and more rapidly until the end at 0503 GMT. Cell A is a part of Cluster X1, which grew until 0241 GMT, then slowly decayed two consecutive time steps. The evolution of Cell X2 is best followed by the radar PPI. The data suggest that the development of Cell X2 is in the outflow region of a previous cluster, well extended horizontally and vertically. The maximum vertical extension of all clusters occurs during the first half of their lifetime.

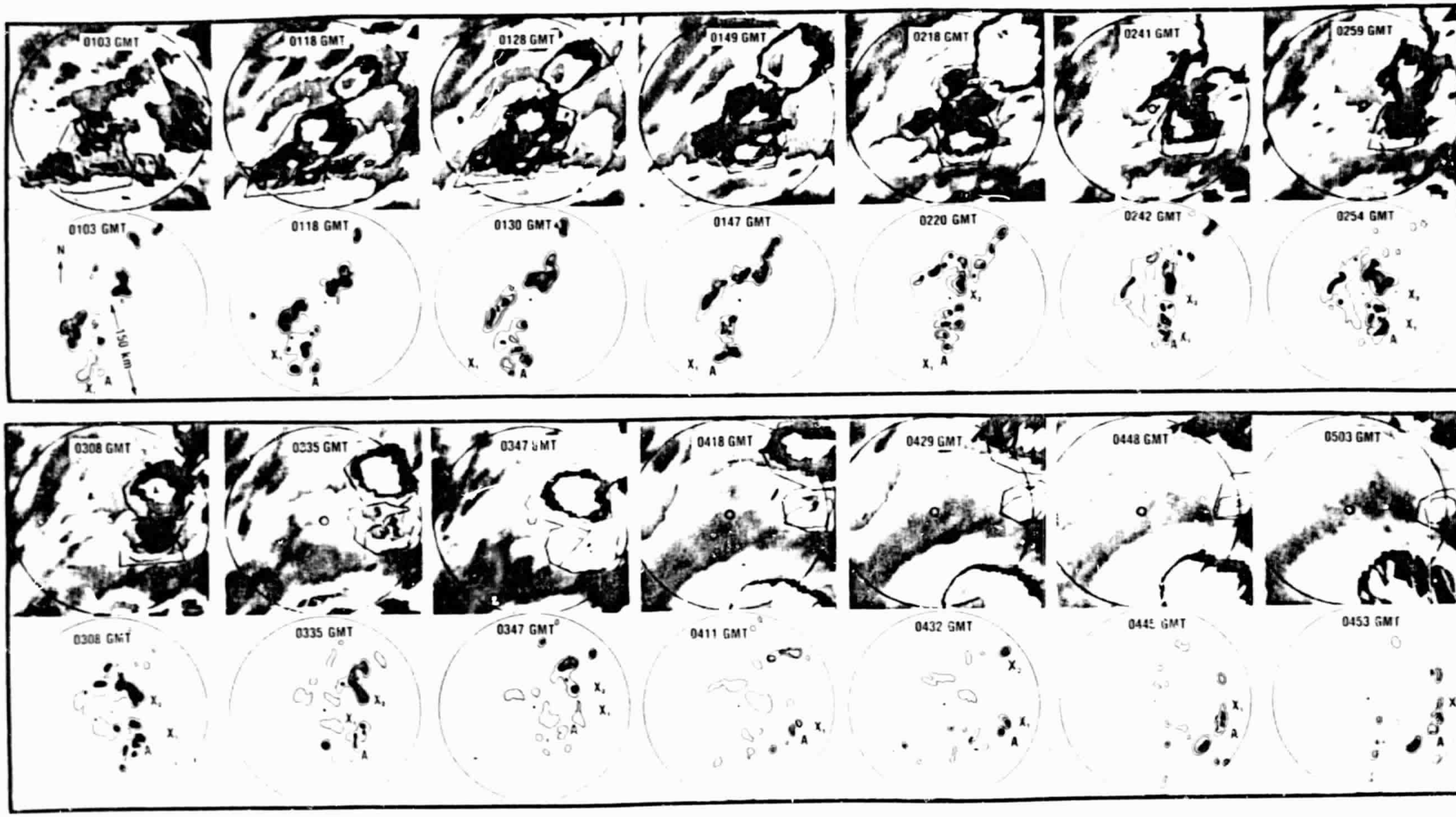

Fig. 3: Sequences of GOES rapid scan satellite pictures and radar reflectivities for the lifetime of the 2 July clusters.

3.2 Cluster Lifetime Analysis

A summary of radar and satellite products for the six analyzed clusters is presented in Table 2.

Columns (2) to (5) represent radar products, while columns (7) to (13) are satellite products. The digital count thresholds matching radar ATI's, and the respective minimum temperatures, as well as the satellite ATI (columns 11-13) were computed for the storm lifetime using histograms. Two of the histograms are presented for Cluster 1A (VIS and IR); Fig. 4A, B. The dashed-dotted line represents the satellite determined ATI (on a step-by-step basis) and its respective digital count. The columns on Table 2 displaying satellite products could be divided in columns representing independent satellite products [columns (7), (8), (9), (10)], and columns representing satellite products obtained as a combined radar versus satellite analysis [columns (11), (12), (13)].

A visual inspection of both radar and satellite products (in Table 2) emphasizes variable geometries (physical appearance) of the six considered clusters. The 2 July clusters are more extended in the vertical than on 12 June as viewed by satellite. The satellite products (columns 7-12) are always greater for 2 July than 12 June. The radar products are roughly the same for both days. The MEH (column 3) average is only slightly higher (0.96 km) for 2 July. The cluster with the largest MEH (X2, MEH = 14.4 km) did not generate the greatest amount of rain.

The six clusters exhibit a large spectrum of ATI values ranging from 704 km^2 hr for Cell A to 4,625 km^2 hr for cluster 1A. The rain volume varies from 4,082 km^2 mm (1B) to 16,119 km^2 mm (1A). A large diversity in cluster size is not demonstrated by this data set.

The main purpose of this investigation is to compute convective rain volume over a moving targeted area by application of the ATI technique based only on satellite data. As such, the key element is to determine ATI from independent satellite data without consideration of radar data. This is possible if trends of satellite products (Table 2, columns 7, 8, 9, and 10) generated independently are similar to those of satellite products based upon radar observatons as done here. An independent satellite quantity which defines the most appropriate digital count that matches the radar ATI for a given cluster would be a solution. For instance, regression curves correlating satellite digital count thresholds to satellite IR maximum count values, or satellite IR maximum count values averaged over the duration of the cell have to be identified. Such a linear regression relating the satellite IR maximum count value averaged over the duration of the cluster to the satellite IR temperature which matches the radar ATI is displayed in Fig. 5. The correlation coefficient is .93. Certainly this finding is based only on a very limited sample size. Investigations are anticipated to further test and refine these findings.

Encouraging is the fact that descriptive models representing the structure of the radar reflectivities and the minimum temperature of infrared digital counts as a function of surface area and time have a similar appearance above a given satellite threshold (Fig. 6A,B). This correspondence is emphasized by the -50°C and the 35-dBz curves. These models were computed by averaging the six analyzed cluster products. For warmer thresholds, the multicell structure of the clusters generates multimode digital count trends. The multicell structure of the cluster appears to be more evident in the satellite products.

TABLE 2

Characteristic Products of Bowman Radar and GOES Satellite Data for Six Clusters (or Cells) of Summer 1981

RADAR DATA					SATELLITE DATA							
Cell No. and Duration (hrs)	Max dBz	Max Echo Height km	ATI km^2 hr	Rain Vol km^2 mm	λ	Maximum Digital Count	Temp of IR Max Count T_{MX} (-°C)	Average* Temp of IR Max Count T_{AMX} (-°C)	Averaged* Vis Max Count	Digital Count Thresh Matching Radar ATI	Temp Matching Radar ATI T_{MA} (-°C)	ATI (Satellite)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1A / 2.96	61	12.2	4,625	16,119	IR VIS	195 66	50.2	41.5	62.8	178.70 57.73	33.0	4,534 4,534
1B / 2.50	57	12.1	1,117	4,082	IR VIS	194 65	49.2	45.1	63.0	189.09 59.36	45.0	1,169 1,169
E / 2.55	61	12.2	1,302	6,831	IR VIS	195 64	50.2	43.6	61.0	185.68 57.85	41.0	1,221 1,221
X1 / 3.83	57	12.5	1,897	11,001	IR	204	59.2	53.5		201.21	56.4	1,876
X2 / 2.55	55	14.4	1,338	1,027	IR	207	61.2	58.6		202.4[illegible]	58.0	1,243
A / 3.83	53	12.5	704	4,268	IR	204	59.2	53.8		201.39	56.5	722

*Average over the cell lifetime.

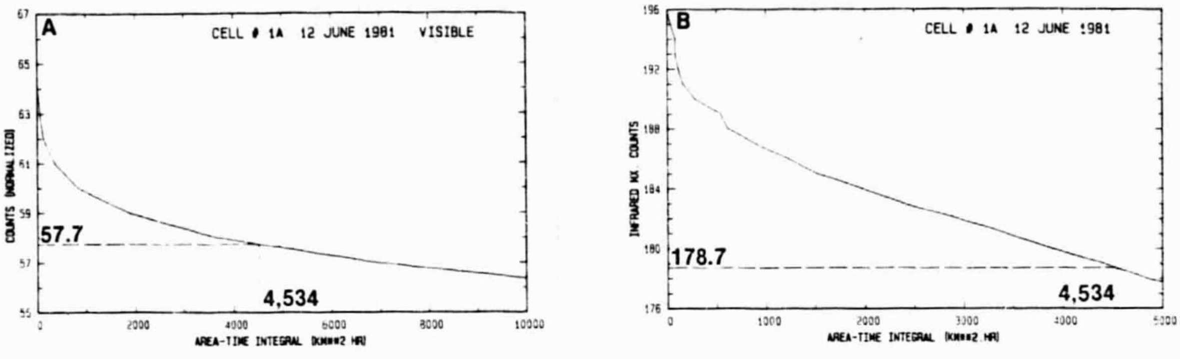

Fig. 4: Histograms of VIS (A) and IR (B) digital counts vs. satellite ATI's for cell 1A; the radar ATI and the correspondent digital count are also displayed.

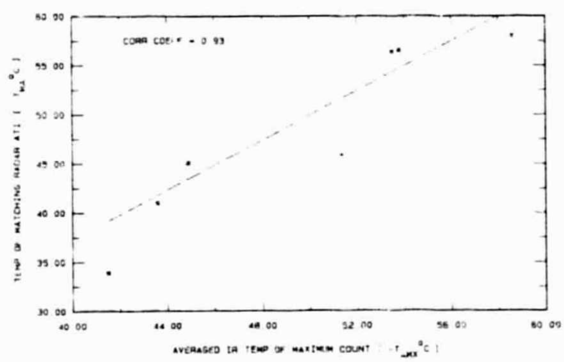

Fig. 5: Scatter and linear regression of temperatures matching radar ATI and average (over the cell duration) temperatures of IR maximum count. Every star represents a cluster.

4. Concluding remarks

This analysis of six convective clusters suggests that the extension of the ATI technique to the use of satellite data holds promise. The differences of the internal structure of the radar reflectivity features (taken close to the cloud base) and of the satellite features (taken near the top of the cloud) give rise to differences in estimating rain volumes by delineating area; however, by focusing upon the area integrated over the lifetime of the storm, the investigations suggest that some of the errors produced by the differences in the cloud geometries as viewed by radar or satellite are eliminated.

Models describing the structure of radar reflectivities and minimum temperatures by infrared digital counts as a function of surface area and time are similar above given satellite and radar thresholds. By averaging the six analyzed cluster products, these thresholds were found to be -50°C and 35 dBz for satellite and radar data, respectively.

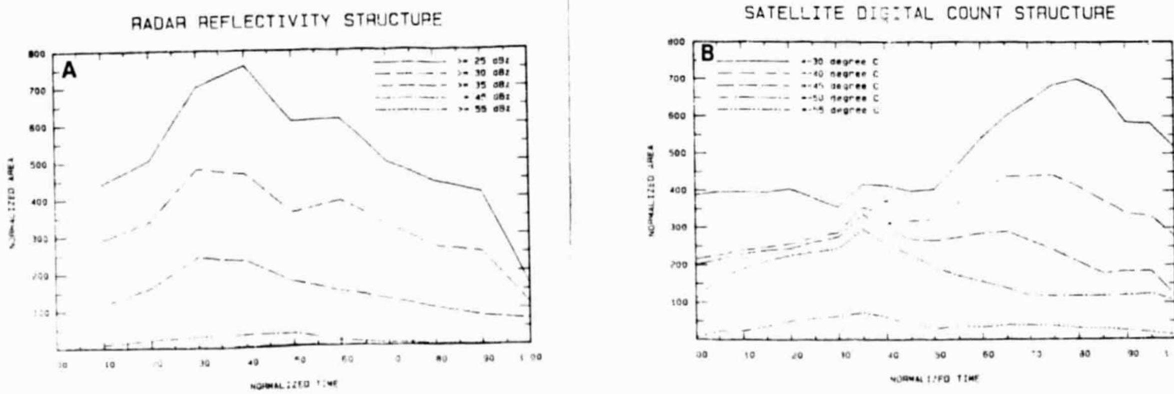

Fig. 6: Structures of radar reflectivities (A) and minimum temperature of IR digital counts (B) as functions of normalized area and time.

It is of crucial importance in this type of analysis to be able to determine accurately the start and the end times of the convective events. The starting time can easily be determined when the first cluster's echo is visible in the radar data. Yet, the cirrus debris makes the definition of the end of the cluster (as a convective entity) from the satellite images difficult. This inconvenience can be overcome if the maximum development of the cluster is taken as the ending time of the analysis. The ATI technique also works if only the growing part of the cluster lifetime is considered (Doneaud et al., 1984b). The maximum development of the cluster can be defined using radar data as the maximum echo height, the maximum reflectivity, or the echo area >25 dBz. Satellite data definition of maximum development could be based on the maximum count value or the minimum temperature. Investigations are anticipated to further illuminate such a procedure.

In some of the graphs presented (Figs. 1 and 2), time lags as great as 30 min were observed. Maximum echo height, maximum reflectivity, and maximum echo area were found to occur before the IR temperature threshold matching echo areas >25 dBz and the minimum temperature of infrared maximum count. These time lags do not generate problems in considering the maximum development of the cluster as the ending time of the analysis.

Samples of radar and satellite products averaged over the six analyzed clusters were compared. A linear regression relating the satellite IR maximum count value (as an independent satellite product) to the satellite IR temperature matching the radar ATI (dependent on radar) showed a high correlation (.93). This would indicate that definition of the ATI's value could be based on independent satellite data. The regression is based only on a very limited sample size, making concluding remarks hazardous. Investigations are anticipated to further test and develop these findings.

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ATTACHMENT B

31 July 1985

MEMORANDUM FOR THE RECORD

FROM: A. A. Doneaud

SUBJECT: Trip Report to Attend the Panel Review Meeting of the NASA Global Scale Atmospheric Research Program, Washington, DC

I traveled to Washington, DC, by private auto between 5-20 July 1985 to attend the panel review meeting of the Global Scale Atmospheric Research Program. The panel review meeting was scheduled to be held at the Columbia Inn, Columbia, Maryland. The logistics of this review were handled by Science and Technology Corporation (STC) under the chairmanship of Dr. Karl Johannessen, STC.

In addition to the participation at the panel review meeting I gave a seminar at the NASA Goddard Space Flight Center on the afternoon of 11 July and I visited NSF offices the afternoon of 9 July and the morning of 12 July.

The panel review was conducted in an open forum similar to an AMS topical meeting. Since the Global Scale Atmospheric Research Program covers 60 tasks and each task was initiated by an individually identifiable project, presentations were not combined and each presenter had 15 minutes to show his objectives, results and future work.

The panel members were Dr. Richard Anthes (NCAR), Dr. David Burridge (ECMWF), Dr. John Hovermale (NEPRF), Dr. Karl Johannessen (STC, Panel Moderator), Dr. Donald Johnson (University of Wisconsin), Dr. Peter Webster (Penn State University), and Dr. Axel Winn-Nielsen (Danske Meteorologiske Institut). The Moderator's goal was to let the panel look at the progress made in each individual task and assess how that progress contributes to the overall balance of the program. In such a way redundant or nonproductive research could be removed and new tasks in research areas more beneficial to the program could be initiated.

The technical program for the panel review was organized in three sessions: Session A-Satellite Data Retrieval and Objective Analyses, Chairperson K. R. Johannessen, ETC; Session B-General Circulation, Modeling and Global Diagnostic, Chairpersons E. Kalnay, NASA/GSFC and G. H. Fichtl, NASA/MSFC; Session C-Theoretical Studies with Special Models, Regional Diagnostic Studies, Teleconnections, Chairpersons R. K. Kakar, Jet Propulsion Laboratory and S. H. Melfi, NASA/GSFC.

An opening session was chaired by Dr. K. R. Johannessen. Dr. J. S. Theon presented the NASA Headquarters viewpoint and Dr. Robert J. Curran (The Program Manager) presented the Program (of the Global Scale

Atmospheric Processes Research) Orientation. Dr. Johannessen introduced the panel members. Following E. Kalnay (NASA/GSFC), G. Fichtl (NASA/MSFC), and R. K. Kakar (NASA/JPL) presented overviews of their institution program.

Session A was dominated by papers dealing with retrievals of wind, temperature, moisture, and pressure fields. Most of the presentations were given by NASA/GSFC scientists. The GLAS (Goddard) retrieval model uses three major components: analysis/forecast/retrieval. Several significant developments, including the use of "significant height" orography, higher resolution and improved parameterization of super-saturation precipitation have been implemented. The GLAS Analysis System (Baker, 1983) has also undergone significant improvements, mainly the replacement of the two-dimensional by a three-dimensional scheme. The Goddard Temperature Retrieval System (Susskind et al., 1984) determines atmospheric and surface parameters which, when substituted in the radiative transfer equations, match the infrared and microwave observations within a specified amount. This physically based retrieval system determines, together with atmospheric temperature soundings several other weather and climate parameters. Significant recent improvements include the development of accurate sea surface temperature determination (Susskind and Reuter, 1985) and of humidity soundings. The goal of this Goddard Research Group Projects is to include in addition to the customary atmospheric fields available from the four-dimensional analysis (pressure, temperature, humidity, and winds) other fields like estimates of cloud cover, cloud top pressure and temperature, atmospheric heating rates, snow and ice cover, surface fluxes of heat, and others. Besides Goddard scientists, some University scientists presented their progress. G. L. Achtemeier et al. (Illinois) presented Variational Objective Analyses for Cyclone Studies; G. Wahba and D. R. Johnson (Wisconsin-Madison) described some Mathematical Methods for Variational Objective Analysis; and M. J. Munteanu (Maryland) showed applications of Clustering Techniques and Total Ozone Data to Satellite Soundings. Our presentation, The ATI Technique (To Estimate Convective Rain Volumes Over Areas) Applied to Satellite Data, was included in Session A and was well received.

Session B papers dealt mostly with accomplishments on general circulation modeling. Work on NASA/GSFC has been done mostly to improve and add new data to the fourth order G.C.M. available at NASA. Numerical diagnostic studies of major weather events were developed by R. Atlas. E. Kalnay et al. explored the existence of atmospheric predictability in the monthly to seasonal time scale by means of the use of comprehensive atmospheric models. The authors adapted the Lagged

Average Forecasting Techniques (LAFT) of Hoffman and Kalnay (1983, 1984) to 10 day operational forecasts. Y. Mintz et al. designed a biophysical numerical model of the vegetated surface of the earth which can be used with atmospheric general circulation models. H. M. Helfand developed the GLAS fourth order forecast model (Kalnay et al., 1983). The development included improvements to the model's horizontal and vertical resolution, design of better high-latitude and Shapiro filters, introduction of a nonlinear normal modes initialization scheme, enhancement of the model's orographic boundary data sets and creation of more sophisticated schemes for the parameterization of sub-grid scale physical processes. In addition to NASA scientists, some university people presented their results. S. E. Cohn et al. (Courant Institute of Mathematical Sciences) developed an implicit scheme for global numerical weather prediction. The method uses a large time step. Current primitive-equation models based on explicit and semi-implicit methods, must use a small time step to ensure numerical stability. D. A. Salstein and R. D. Rosen from Atmospheric and Environmental Research, Inc., Cambridge, Massachusetts, as well as Tsing-Chang Chen from Iowa State University determined physical processes generating the distribution of diabatic heating throughout the atmosphere. Knowledge of the distribution of diabatic heating throughout the atmosphere is vital to understanding the way in which the energy cycle of the atmosphere is maintained through the generation of Available Potential Energy (APE). Tsing-Chang Chen used the thermodynamic equation in the isobaric coordinates to estimate the diabatic heating. His results generally agree with other previous investigations, even though some differences occurred.

Session C was dominated by papers given by University scientists. B. Saltzmass (Yale University) developed models with nonlinear moist barotropic and barocolinic processes including viscosity and heating, and lower boundary orographic and thermal forcing. The authors related the dynamical activity in the atmosphere to satellite-derived infrared and visible radiation measurements in order to study atmospheric phenomena (i.e. hydrometeors). E. R. Reiter (Colorado State University) studied surface energy fluxes in complex terrain. J. A. Dutton et al. (Penn State University) studied global atmospheric dynamics in order to develop inverse methods that use dynamical criteria to convert satellite observations of phenomenological structure into quantitative observations. R. S. Lindzen (Massachusetts Institute of Technology) made a brief review of the studies carried out at MIT, studies of stationary waves, teleconnections, blocking, cumulus momentum transport, finite amplitude evolution of baroclinic instability, water vapor convergence due to temperature gradients and atmospheric free Rossby wave. J. P. McGuirk and A. H. Thompson (Texas A&M University) developed and implemented a statistical procedure for using TIROS N microwave data to infer infrared channel data for overcast conditions. The authors found that the satellite-sensed temperature and moisture signals vary differently, but consistently, within moisture bursts. In an empirical orthogonal function analysis over the tropical eastern Pacific, they found that a) the vertically oriented eigenfunctions could be interpreted in terms of typical meteorological events while b) the horizontal distribution of the eigenfunction amplitudes relate these meteorological signals to moisture bursts. D. G. Vincent (Purdue University) presented atmospheric circulation features in the southern hemisphere for the period 10-27 January 1979 using Global Weather Experiment (FGGE) data. The study focused on one of the major features in that period, the South Pacific Convergence Zone (SPCZ). K. B. Katsaros (University of Washington) described the structure of midlatitude cyclones observed with the atmospheric water channels of the scanning multichannel microwave radiometer. S. Mudrick (University of Missouri-Columbia) tested the quasi-geostrophic (QG) dynamics versus the primitive equation (PE) dynamics for modeling the effect of cyclone wave. By simulating a polar low possessing a wave length of 1200 km the authors found a quick development of that low the first day (with a maximum of the eddy kinetic energy) and then a decrease to a relative minimum kinetic energy on the third day.

The aforementioned papers were randomly selected without any technical or special considerations. A preprint volume containing all of the abstracts of the papers is available for consultation.

On the afternoon of 11 July I gave a seminar entitled "The ATI Technique and its Possible Application to Satellite Data" at the NASA/GSFC. The seminar was organized by Andrew Negri from the NASA/GSFC Laboratory for Atmospheric Science. Around 40 participants attended the seminar which was well received by the attendees.

I returned to Rapid City Saturday, 20 July, after taking three days of vacation.

AAD:cvb

ATTACHMENT C

THE AREA-TIME-INTEGRAL TECHNIQUE (TO ESTIMATE CONVECTIVE RAIN VOLUMES OVER AREAS) APPLIED TO SATELLITE DATA

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EXTENDED ABSTRACT

The main emphasis of the study is to investigate the feasibility of rain volume estimation using satellite data following a technique recently developed with radar data (collected in the northern High Plains), called the Area Time Integral (ATI) technique (Doneaud et al., 1981; 1984a; 1984b). The technique has been verified and proven to be efficient in Florida (Lopez, 1983) and South Africa. The basis of the method is the existence of a strong correlation between the area coverage (>25 dBz) integrated over the lifetime of the storm (ATI) and the rain volume. The technique does not require the consideration of the structure of the radar ntensities (as, for instance, the Z-R technique) to generate rain volume. This fact simplifies and may reduce some sources of error in applying the technique to satellite data. Similarly, it is suggested that once radiance thresholds matching ATI's are determined by using visible (VIS) and infrared (IR) information integrated over a storm's lifetime, the digital unit threshold should exhibit variation among storms only in relation to the geometry (i.e., vertical extension) of the convective cloud system; adjustments may be necessary for regional and seasonal differences. The ATI technique may also be used if only the growth part of the cluster is considered (Doneaud et al., 1984b). That eliminates the difficulties related to the definition of the end of the cluster's lifetime (as a result of cirrus debris) using satellite data. The new technique, if proven valid for satellite data, may be categorized as a simplified Woodley-Griffith technique adjusted for measurable characteristics of cloud systems (Negri and Adler, 1981).

Four multicell clusters were analyzed in 1984. Cells bigger than a cumulus cloud, but smaller than a typical mesoscale convective complex, were considered "clusters." The radar data were processed at the South Dakota School of Mines and Technology. The digital rapid scan satellite data were processed at the IRIS/DRSES facility located at Colorado State University. Different radar and satellite quantities for every time step for the selected clusters were computed. They reflect the multicell characteristic of the clusters, and yet still exhibit similar trends. Some preliminary results were presented at the 1984 Conference on Radar Meteorology (Doneaud et al., 1985). Six additional cells will be processed and analyzed in 1985.

The key element of this investigation is to determine an ATI from satellite data without using radar reflectivities. A satellite quantity defining the most appropriate digital count matching the radar ATI for a given cluster needs to be found: for instance, correlation studies between satellite digital count thresholds (matching radar ATI's), and satellite IR maximum cloud values (°C) are planned. The clusters analyzed show that the digital counts matching the radar ATI's are related to cluster characteristics and environment conditions. Twelve to fourteen clusters are scheduled to be analyzed through this grant (ending in December 1986).

A new proposal is intended to be submitted for the period 1987-89 to verify the applicability of the technique in regions with different climatic conditions using independent sets of data (i.e., data from the Oklahoma "Pre-STORM" Experiment). The objective of the new proposal should be twofold: to extend the validity of the technique in another region with possible extension to a global atmospheric scale, and to determine its accuracy using an independent data set. Sensitivity and accuracy tests will be proposed. The new cases will be finally added to the total number of cases describing the technique.

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