"NON-REVIEWED"

SIMULTANEOUS CLOUD COMPARISONS USING DIGITAL RADAR AND SATELLITE MEASUREMENTS

Michael R. Poellot

Department of Aviation
University of North Dakota
Grand Forks, North Dakota

and

David W. Reynolds

Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado

ABSTRACT

Results are presented from a comparison of digital radar and satellite cloud climatological studies for 12 days during the 1976 High Plains Cooperative Project (HIPLEX). Both observation systems observed on each day cloud numbers, sizes and locations with respect to Miles City, Montana, one of the HIPLEX field sites. The results point out the limitations of using but one measurement system in trying to determine natural convective activity. Problems are discussed in both the processing techniques used and in the limitations of both the radar and satellite data if used separately. The impact of the results of these kinds of studies are important to answering such questions as "extra-area" effects, etc.

1.0 INTRODUCTION

During the summer of 1976 the Bureau of Reclamation carried out an extensive field program as part of Project Skywater in a effort to understand convective processes on the High Plains of the U.S. This program, called HIPLEX (High Plains Cooperative Project), is an ongoing study consisting of many interdisciplinary meteorological studies to observe and measure the convective cloud systems which develop on the High Plains in order to determine their potential seedability.

As part of the observing systems, both digital 5 cm radar data as well as digital SMS/GOES VISSR (Visible and Infrared Spin Scan Radiometer) data were recorded during parts of the May, June and July 1976 field season. One of the main purposes of both measurements was to determine the number, size, location, etc. of naturally developing cumulus within the target area (150 km radius from target). For this study, the Miles City, Montana target area has been used. During twelve days of the 1976 season both digital radar and satellite data were available for comparison. This paper will describe the types of processing performed on each of the different data sets. Results of the comparisons will show that each system measured its own particular signatures from these clouds. These signatures are dependent on resolution of the measurement system and the cloud's physical properties. Thus, a comparison of the two independent data sets will help explain any problems or limitations in each of the systems. Such things as the number of precipitating versus non-precipitating clouds may be examined from these comparisons as well. This parameter can be extremely important to a weather modification program which needs to know the number of potentially seedable clouds available.

Also discussed will be methods of overlaying digital radar ("ground truth") and satellite data into a common map base for particular studies of interest. These comparisons can be extrapolated in space and time to help identify any "extra-area" effects caused by seeding. An example of radar-satellite composites as displayed on the Colorado State University ADVISAR (All Digital Video Imaging System for Atmospheric Research) will be shown.

2.0 SATELLITE DATA PROCESSING

For this study, digitally recorded VISSR data were used from the SMS-2 geosynchronous satellite. SMS-2 (hereafter GOES-W for Western GOES) has a subpoint of 0^0N, 135^0W. This satellite scans the earth at a quarter after and at a quarter of the hour. Thus, data are available on a half-hourly basis. The data were recorded at full spatial resolution with nominal spot sizes of 1.0 km north-south by 1.0 km east-west for the visible sensor and 8 km N-S by 4 km E-W for the infrared sensor. The data were recorded on computer compatible 9-tract tape at the GOES Direct-Readout Groundstation (DRGS) based at the White Sands Missile Range (Step 1 on Fig. 1). A sector was recorded for an area bounded by 50^0N to 30^0N and 115^0W to 95^0W. Once the data were on 9-tract tape, the next step was to convert the satellite line-element arrays into absolute earth coordinates. This was done in Step 2 of Fig. 1. Using one landmark measurement per day and imputing this to an analytic navigation model developed by Phillips and Smith (1973) (resides on the NCAR computer), a set of satellite-earth transformations could be produced for carrying out this study.

In 1976, 35 days of satellite data were collected. Of these, 12 had corresponding radar data available for comparison. Examination of the number, size, location, and temporal frequency of clouds was performed. Figure 2 shows the area around MLS for which the satellite cloud climatology was performed. The configuration of the area was caused by the way the satellite scans the earth. The size of the area was determined by representing 512 lines and 1024 elements of data on the C.S.U. ADVISAR CRT (Smith, et al., 1978). The array limit of the ADVISAR memories are 512 x 512. We display 512 lines and sample every other visible element. At this latitude, 46^0N, a "pixel" of satellite data has dimensions of 1.54 km (in the north-south) by 1.02 km (in the east-west). By sampling every other element in the east-west, the final study resolution is 1.54 km north-south by 2.04 km east-west near Miles City. Thus, the minimum size cloud detectable with the visible data is 3.14 km^2. Due to noise and low brightness levels of small clouds, the minimum size cloud actually used is 10 km^2. The cloud statistics analyzed for this study are for the area immediately around MLS (150 km radius) for comparison with the radar.

The technique used was to load the full resolution visible image for the area shown in Fig. 2 onto the ADVISAR CRT for each time period available. Bad data lines would then be eliminated from the data using a special software program. A sequence of 8 images could be loaded onto the ADVISAR memories at any one time. Thus, 4 hours of images could be sequenced to denote cloud growth and movement. These data were then transferred to a video cassette to provide a hard copy of the data for future analysis and to provide a quick check of subsequent cloud statistics found from both satellite and radar.

As each image was placed on the ADVISAR the joystick-cursor capability of the system allowed a determination of a brightness threshold discriminating between cloud - no cloud (Step 3, Fig. 1). An actual contour was drawn around each cloud for the entire array until the operator was satisfied that this threshold optimized the delineation of the clouds. Once this was performed the operator could choose only those areas with convective clouds to be written to a 7-track data tape which would then contain the array of data for which the software program CLDPOP would be run(see Reynolds and Vonder Haar, 1976) (Step 4, Fig. 1). These data tapes could then be transferred to the C.S.U. computer center for processing. This also allowed the statistics to be run on the data and the results plotted on mocrofilm.

The normal operating day for the satellite data reception was from 1745 GMT to 2415 GMT. The processing of radar data was thus limited to this period. The sizes of the clouds observed were categorized into class intervals at 20 km^2 each for areas up to 100 km^2. From 100-1000 km^2 the intervals were 100 km^2 and then clouds greater than 1000 km^2 to 100,000 km^2 were grouped together. For cloud locations, the target area was divided into four sections: NE, SE, SW, NW and clouds were tabularized as to which quadrant their centroid was located in. Because the satellite processing actually looked at a much larger area than the 150 km radius, only those clouds whose centroids were located within 150 km of Miles City were used in this study. The importance of this will be mentioned when the radar and satellite results are compared.

3.0 RADAR DATA PROCESSING

The HIPLEX experimental area in Montana is defined by the 150 km range circle of the weather radar located in Miles City. A complete description of this Project Skywater radar is given by Harrison (1978). Briefly, it is a 5 cm weather radar system, manufactured by Enterprise Electronics Corporation, configured with a digital recording capability. The characteristics of the radar are summarized in Table 1. Data are digitized by a digital video integrator and processor (DVIP) and recorded on 9-track, 800 cpi magnetic tape recorders.

The resolution of this system is one data bin which is 1 km in range

TABLE 1. CHARACTERISTICS OF HIPLEX SWR-75 RADARS.

Peak transmitter power	250 kW
Pulse duration	2.0 μs
Antenna type	circular parabolic
Horizontal half-power beamwidth	0.9^0
Vertical half-power beamwidth	1.0^0
Effective system gain	43.7* dB
Wavelength	5.4 cm
Pulse repetition frequency	207/414 pps
Receiver noise	2 dB
Receiver	logarithmic
Receiver bandwidth	0.6 MHz
Receiver dynamic range	80 dB
System noise figure	<3 dB

*This figure incorporates all waveguide mismatch and similar losses beyond the directional couplers as well as radome loss. (from Schroeder and Klazura, 1978)

by 1^0 in azimuth. The radar is capable of detecting minimum equivalent reflectivities (Z_e) of -10 dBz at 25 km and +5 dBz at 150 km. A complete calibration of the system is performed at the beginning and end of each field season, including measurement of the antenna system gain and antenna position errors. Other calibrations are performed weekly and daily.

Data are collected for HIPLEX by operating the radar in a volume scan mode. This consists of a single antenna sweep at a base tilt of 1^0 elevation followed by eleven sweeps at antenna elevations of 2^0 to 12^0. In this mode the atmosphere within the target area is sampled once every five minutes. Project aircraft are tracked simultaneously with a secondary (IFF) radar system and the aircraft positions are recorded for each sweep. Data recording procedures and the subsequent processing routines are described in detail by Schroeder and Klazura (1978).

The processing of the recorded digital data is done in three steps (Fig. 3): edit and error correction; automatic tracking; and data conversion and output. Raw data tapes are sent to UND and all of the processing through the Archive File (A-file) is done on the UND Interdata 7/32 and 8/32 computer systems.

The Interdata 7/32 system is comparable in power to an IBM 370-135 computer while the 8/32 system is comparable in power to an IBM 370-158 computer. Both systems support the standard set of peripheral equipment, such as console, printer, and terminals. In addition, the 7/32 system supports a 300 MB disc drive for storage of the large radar data files, as well as two 800 cpi tape drives. The 8/32 system also supports a 300 MB disc drive, as well as two 800/1600 cpi tape drives. Both systems currently process Skywater radar data 24 hours/day and seven days/week.

The original radar data may contain an assortment of errors due to factors like incorrect switch settings or problems with the radar system. The data is first run through an edit routine REDIT. If numerous parity errors are encountered, a special program is employed to salvage data from these tapes. A considerable amount of data has been salvaged from otherwise unprocessable tapes through the use of this program. In the edit routine all uncorrectable erroneous information and non-echo data bins are deleted, and all errors in the data are flagged. This produces a compressed file containing data for those bins which exceed the noise level of the system, and it results in a storage reduction of about 10:1.

RERRCOR is then used to correct the compressed file and the data is re-edited to ensure that all errors have been properly corrected. The final phase of the edit step is RAPPEND which builds a single data file (the A-file) from individual contiguous data tapes. Copies of the A-files are maintained at UND, and at the Bureau of Reclamation offices for use on the CYBER computer system in Denver.

The second step of the processing is the automatic identification and tracking of separate echo entities. This objective scheme was developed to eliminate the subjective influence of the analyst and make the tracking more consistent (Brady, et al., 1978).

The automatic cell tracking algorithm consists of three separate programs run sequentially. The radar cloud identification program (RADCID) defines and contours individual echo entities based on a specified dBz level. RADBOX accepts the definitions of these contoured clouds and generates a circumscribing Θ,r polar rectangle for each entity. These entities are then automatically tracked and annotated by RTRACK through their lifetime in the radar coverage area. Composite PPI (CPPI) and composite B-scan (CBSCAN) displays are an output product of the tracking phase.

In the final processing step the data are converted in RADPROC from DVIP units to meteorological units using a version of the Probert-Junes (1962) radar equations. Two magnetic tape files are generated by RADPROC. The U-file contains location, area, volume, rain, motion, and morphology information for each defined echo entity. The D-file consists of equivalent reflectivity data in a compressed form.

UND has developed numerous programs to access and utilize the data in support of HIPLEX. In order to compare the radar and satellite observations for this investigation, volume scan data was obtained from the study day U-files. The radar climatology was developed from the echoes observed at times corresponding to the satellite pictures.

4.0 INTERCOMPARISON OF RADAR AND SATELLITE CLIMATOLOGIES

The intercomparison presented here is based on the digital radar and satellite data that were available for twelve days of the 1976 field season. The clouds and echoes appearing during this study period were counted, sized, and located directionally from the Miles City radar site. It should be noted that the satellite climatology includes only those clouds which appeared to be convective in nature; the radar echoes were required to exist for at least two consecutive volume scans, or approximately 10 minutes before entering into the statistics.

4.1 Summary of the Total Data Set

The relative frequencies of occurrence of the visible clouds and echoes by time of day are plotted in Fig. 4. The mid-afternoon peak of activity indicated by the satellite observations is typical for the summer season around Miles City. However, this is not accompanied by a similar peak in the number of radar echoes. The reason for this is not clear when viewing the data set as a whole, but a possible explanation will be discussed in a later section as the data are examined on a daily basis.

The total number of satellite convective clouds observed for the twelve days was 1937 while the total number of radar echoes was 383. Although there were approximately five times as many visible clouds as echoes, Fig. 5 shows that both distributions are strongly skewed toward the small clouds. The 0-100 km^2 category contains more than 80% of the total clouds and echoes.

If the populations are broken down further in the 0-100 km^2 range, (Fig. 6) we find the relative frequency of radar echoes to be skewed even more. One reason for this is that the minimum size cloud observed by the satellite system is 10 km^2, while the radar system resolves echoes on the order of 1 km^2. A breakdown of the 0-20 km^2 echo category shows that 60% of the echo areas are less than 10 km^2, thus skewing the distribution toward the small end. However, the visible clouds less than 10 km^2 in area are not included in the satellite climatology. In addition, the radar echo will always be smaller than the visible boundary of the cloud, so a 50 km^2 visible cloud may contain only a 10 km^2 radar echo.

A classification of the activity by quadrant of the target area (Fig. 7) shows that, although there are some differences, both observation platforms indicate a maximum of activity in the northwest quadrant. A conclusion that may be drawn from this distribution is that the same percentage of clouds were echoing in all quadrants.

4.2 Summary of the Data on a Daily Basis

In order to compare the statistics on a day-by-day basis, additional sources of information were consulted. A daily weather description for the 1976 Miles City field season by Hartzell (1977) was used to obtain the overall weather picture. Satellite loops on video tape and radar PPI's on microfiche were also viewed for each day. The daily cloud comparisons were made using the same stratifications as for the total data set: time of day, area, and direction. These comparisons showed differences in all of these categories for a variety of reasons.

1. Some days had many more visible clouds than radar echoes. This may be explained by the fact that small convective clouds such as stratocumulus and small towering cumulus do not produce echoes which are detectable by a 5 cm radar.

2. Other days unexpectedly had more echoes than clouds. This was determined to be primarily a result of counting radar echoes from non-convective clouds which were not included in the subjective satellite climatology. There were also two instances where a subjective interpretation of the radar data indicated that a number of the objectively identified echoes were probably noise or interferences and should not have been included in the statistics. In addition, one visible cloud may contain several radar echoes.

3. The radar and satellite indicate different times of maximum convective activity on most days. On certain days this is apparently due to the radar including non-convective echoes in the echo count. Differences will also result from the ability of the satellite to observe the early stage of convective development a half hour or more before the clouds produce echoes.

4. The distributions of cloud and echo areas differed as in the total daily summary. As explained earlier, this is due to system resolutions and natural cloud characteristics. In addition, the satellite processing was initially done over an area larger than the radar coverage. These results were then classified as to the location of the clouds centroid within or outside the 150 km range. Thus some of the centroids for visible clouds detected by the satellite fall outside the target area even though the corresponding radar echoes would be partially seen within the 150 km range and thus included in the climatology.

5. Classification of the activity by quadrant on a daily basis gives good agreement between data sets with the exception of time periods when non-convective clouds were producing radar echoes.

5.0 SUMMARY AND FUTURE STUDIES

Clearly, it is important to use satellite observations to verify and interpret radar data and to use radar data as ground truth for the satellite. This study showed how the cloud signatures differ between these two systems and that each system has certain problems and limitations. For example, the satellite may be better able to distinguish convective from non-convective clouds, and it gives a broader picture of the activity. On the other hand, the radar can "see" what is occurring under a cirrus shield and has higher spatial and temporal resolution. The satellite data, then, is basically not affected by attentuation in the horizontal plane, and the radar is essentially not attenuated in the vertical.

Results from this study show that more detailed cloud by cloud comparisons are needed to interpret such things as visible cloud lifetime versus echo lifetime, cloud visible size versus echo size, and number of echoes within a visible cloud. Smith and Reynolds (1978), have succeeded in combining digital radar and satellite data into a common reference frame using analytic mapping techniques and solid state video refresh technology. In the mapping procedure selected for study the polar sterographic radar projection is used as the common reference base to tie the radar scan projection to the earth coordinate system. Figure 8 is a schematic of the mapping procedure. Once the two data sets are spatially and temporally consistent the two data channels can be stored in digital video refresh memories used by the C.S.U. ADVISAR. The two separate memories are then composited on a color television monitor using separate color input channels. In this fashion, the composite imagery blends together and self-enhances the composite scene. For example, when a bright (red) cold (blue) cloud overlays a radar echo (green), the addition of these three primary colors produces white, a distinct signature. By having a series of these composites, the time evolution of the precipitation features associated with the cloud top features can be studied. It should also be stated that once the satellite data has been transformed into the radar coordinate system, it may be input into the UND cell tracking program. Unfortunately, no color image can be displayed in this volume so we show Fig. 9, a composite image in black and white and point out the salient features.

A direct application of the above technique is in using the satellite signatures within the radar-satellite overlap area and sensing the same signatures in the satellite data outside the radar field of view. This has direct impact to the extended area or "downwind" effects problem in cloud seeding programs. Both data sets will thus be essential for this type of study. This problem is an issue of growing concern in weather modification and UND is deeply involved in the extended area studies of the HIPLEX project. The satellite will be very useful in this effort because of its large field of view, and it may be the most cost effective observation platform. There are still uncertainties, however, about its scientific effectiveness in this application. The attempts being made to improve and verify the satellite data and integrate them with radar and other observations is thus an important one and work will continue in this area.

REFERENCES

Brady, P., M. Schroeder, and M. Poellot, 1978: Automatic identification and tracking of radar echoes in HIPLEX. Preprints, 18th Conference on Radar Meteorology, Atlanta (28-31 March), Amer. Meteor. Soc., pp. 139-143.

Harrison, W., 1978: Project Skywater SWR-75 radars. Preprints, 18th Conference on Radar Meteorology, Atlanta (28-31 March), Am. Meteor. Soc., pp. 391-394.

Hartzell, C., 1977: Final report on meteorological support services provided to the High Plains Cooperative Program at Miles City, Montana. Western Scientific Services, Inc., Report FR-849-71, December, 133 pp.

Phillips, D. R. and E. A. Smith, 1973: Geosynchronous satellite navigation model. SSEC Final Report (NAS5-27794), Univ. of Wisc., Madison, Wisconsin.

Probert-Jones, J., 1962: The radar equation in meteorology. Quart. J. Roy. Meteoro. Soc., 88, 485-495.

Reynolds, D. W. and T. H. Vonder Haar, 1976: Satellite support to the HIPLEX activities for 1976. Annual Report to the Bureau of Reclamation under contract 6-07-DR-20020.

Smith, E. A., T. A. Brubaker, and T. H. Vonder Haar, 1978: "All Digital Video Imaging Systems for Atmospheric Research (ADVISAR)". Atmospheric Science Report, Colorado State University, Fort Collins, Colo. 80523.

Smith, E. A. and D. W. Reynolds, 1978: The generation and display of digital radar-satellite composites using analytic mapping techniques and solid-state refresh technology. Preprints of Conference on Weather Forecasting and Analysis and Aviation Meteorology, Oct. 16-19, Silver Springs, MD

Schroeder, M., and J. Klazura, 1978: Computer processing of digital radar data gathered during HIPLEX. J. Appl. Meteorology. 17:4, pp. 498-507.

ACKNOWLEDGEMENTS

The research was sponsored by the Bureau of Reclamation under Contracts 6-07-DR-20020 and 14-06-D-7581. Partial computer support was provided by the National Center for Atmospheric Research which is sponsored by NSF.

FIGURE CAPTIONS

Fig. 1 Flowchart showing satellite data reception, navigation and processing for cloud climatological studies.

Fig. 2 Geographical area over which the satellite cloud climatologies were performed. The 150 km radius area around Miles City is shown.

Fig. 3 Flowchart of digital radar data processing steps.

Fig. 4 Relative frequency of cloud numbers versus time of day for the 12 days studied.

Fig. 5 Relative frequency of cloud numbers versus size for the class intervals shown.

Fig. 6 Relative frequency of cloud numbers versus size for the class intervals shown.

Fig. 7 Number of clouds in relative frequency versus location for the Miles City target area.

Fig. 8 Mapping technique used for mapping satellite digital data into the radar polar sterographic projection.

Fig. 9 Illustration of the compositing of digital radar and satellite data into a common map projection for analysis.

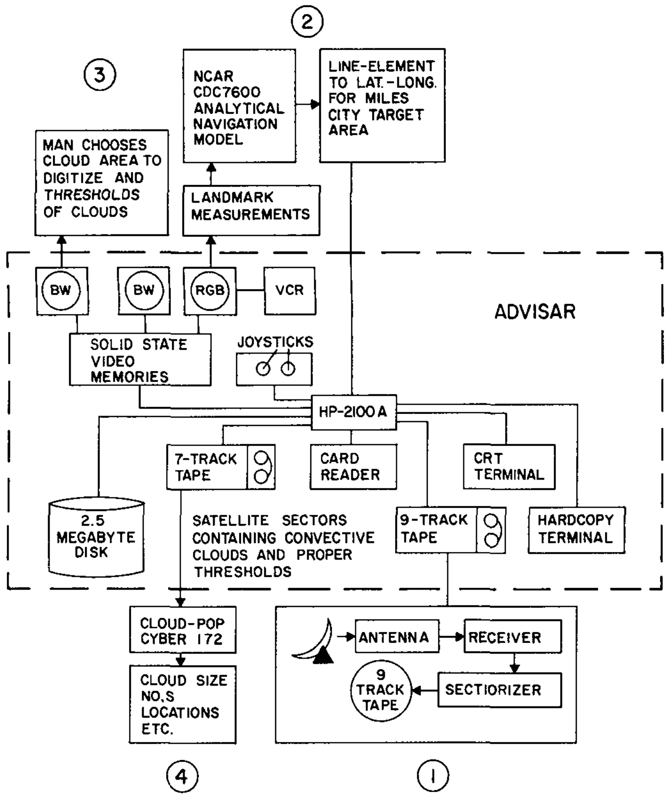


FIGURE 1

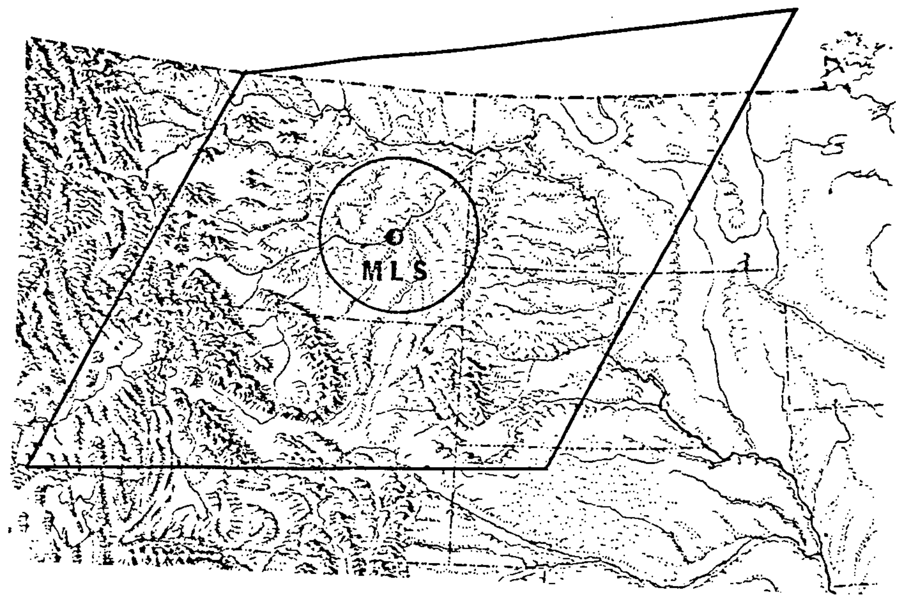
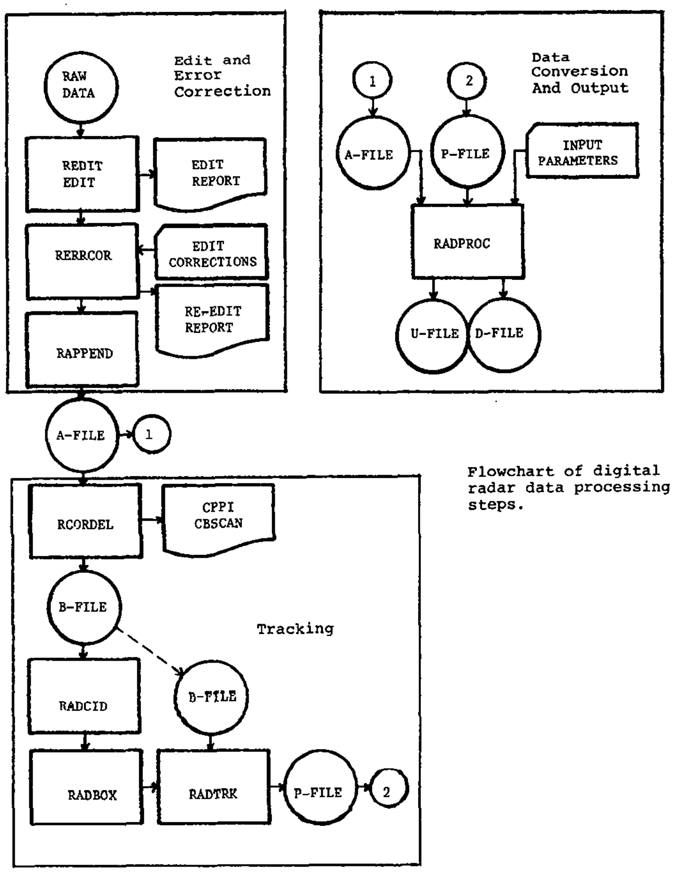


FIGURE 2

"NON-REVIEWED"



Flowchart of digital radar data processing steps.

FIGURE 3

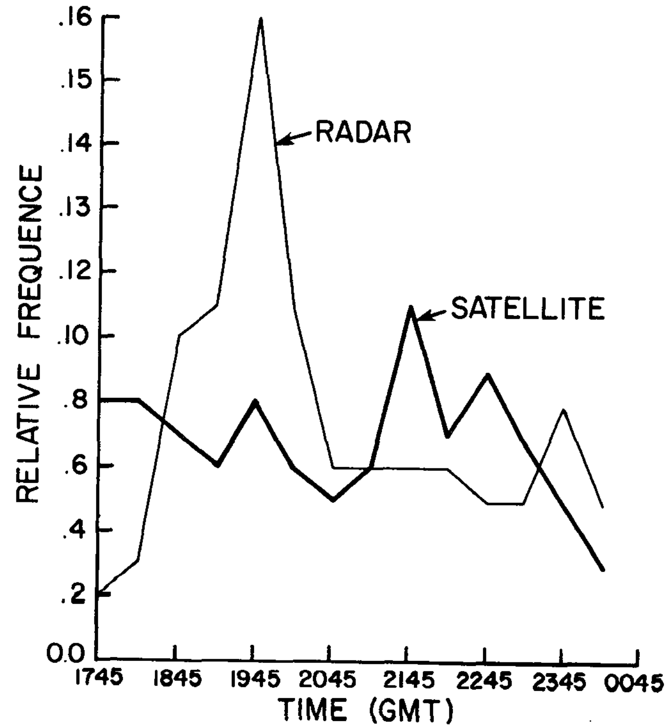


FIGURE 4

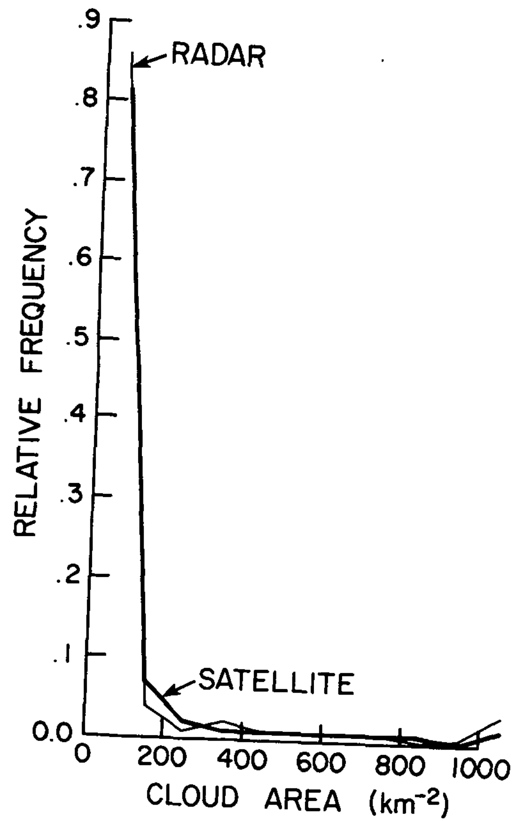


FIGURE 5

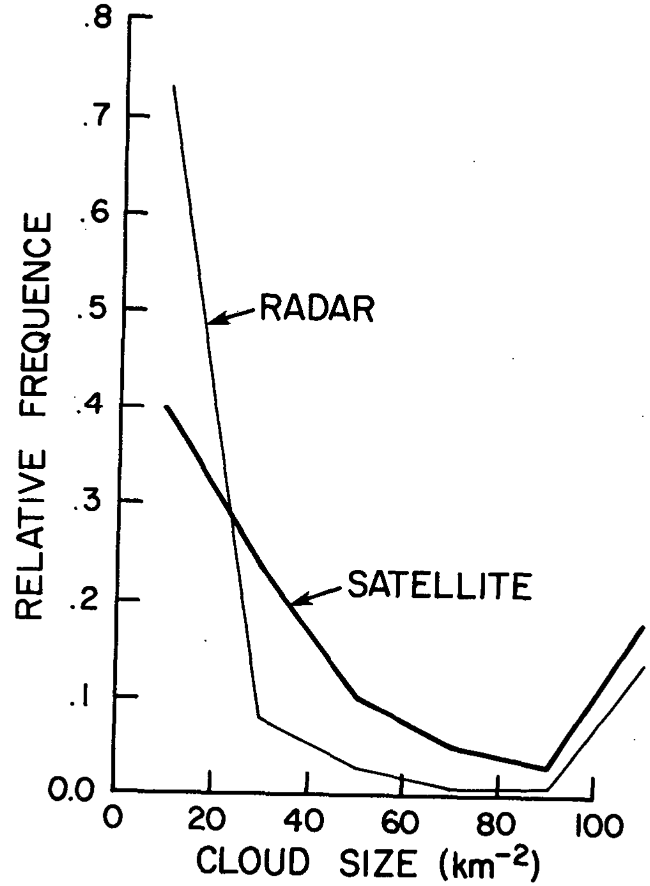


FIGURE 6

"NON-REVIEWED"

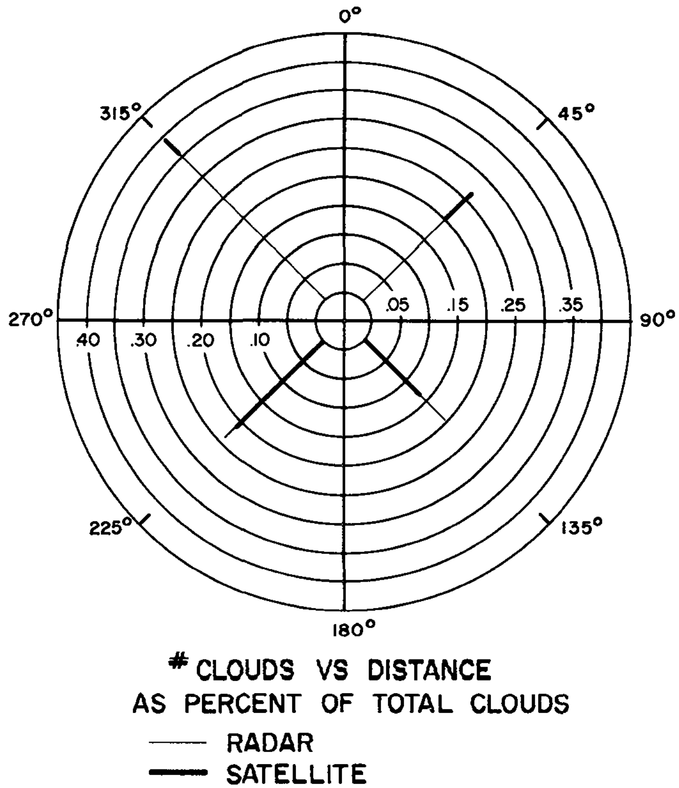


FIGURE 7

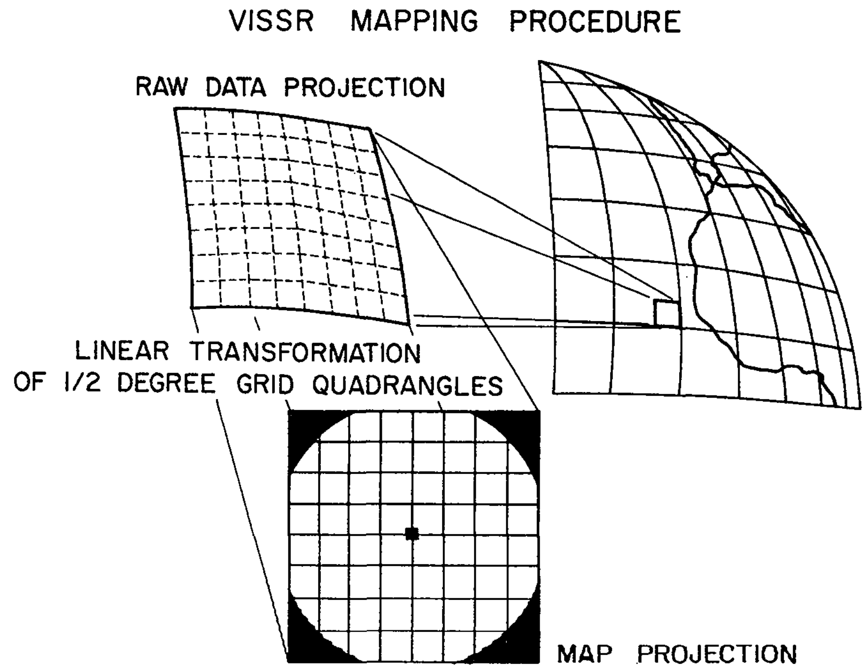


FIGURE 8

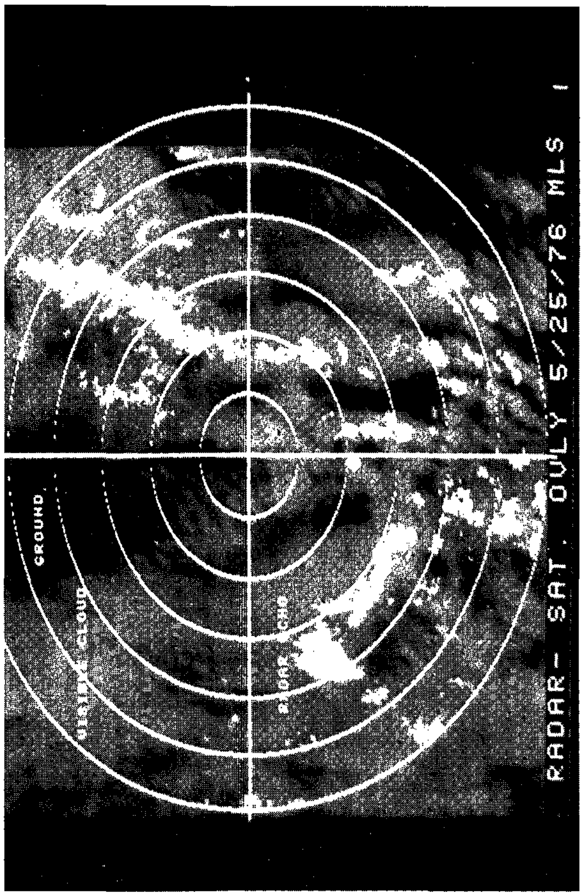


FIGURE 9