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# RADCOMP, A REAL-TIME RADAR DATA COMMUNICATIONS AND PROCESSING SYSTEM

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## 1. INTRODUCTION

Hydrologic forecasts are limited by the accuracy of the rainfall-estimates which are available in sufficient time for input to the forecasting models and procedures. Therefore, it is of vital importance in issuing reliable forecasts and warnings of floods and flash floods, that rainfall data be made available as quickly as is feasible. Unfortunately, the data collection systems currently being employed often are inadequate to describe the timing, duration, and rainfall amounts occurring in the storm systems presenting the flooding problems. It has been shown that timely radar and satellite data can improve the accuracy of areal rainfall estimates (see Greene and Saffle, 1978; and Scofield and Oliver, 1977). This especially should be true if data from rain gages, radar, and satellites can be combined to produce optimum rainfall-estimates.

This problem is being addressed by the Hydrologic Rainfall Analysis Project (HRAP) being conducted by the National Weather Service (NWS) Hydrologic Research Laboratory. Through cooperation with other elements of the NWS, other research laboratories of the National Oceanic and Atmospheric Administration (NOAA), and the National Environmental Satellite Service (NESS), and using contractual support when feasible, HRAP is directed toward developing objective techniques for preprocessing, quality controlling, and optimally merging rainfall data from multi-radars, rain gages, and satellites into data bases that may be accessed by any user having access to the NOAA central computer files. The results from this research will provide improvements in the accuracy and timeliness of flood forecasts prepared by the NWS River Forecast Centers (RFC's), and should improve the inputs to and the evaluation of quantitative precipitation forecasts. Flash flood warnings issued by the Weather Service Officers also will be enhanced by the use of objectively analyzed rainfall data from digital radars — data which can be acquired in near real time (Greene, Hudlow, and Farnsworth, 1979).

One of the principal multi-sensor data inputs to the computerized rainfall analyses system, being developed in HRAP, are high resolution digital radar-rainfall estimates. Such data are available currently at the five existing Digitized Radar Experiment (D/RADEX) sites. However, one of the main problems encountered in the past in the hydrologic application of these digital radar data has been the lack of timely and efficient transmission of them to a central site for additional processing and subsequent input to hydrologic models. As the NWS plans for the Next Generation Weather Radar (NEXRAD) and the use of enormous volumes of digital data from multiple radars for hydrometeorological forecasting applications, the requirements for efficient data handling and communication procedures becomes even more acute. It had been hoped that when Automation of Field Operations and Services (AFOS) become operational, this communications problem would be solved; but because of other data loading requirements, this may not be true with the present AFOS communications capabilities. One alternative to transmitting digital radar rainfall estimates to the central processing site via regional and national AFOS circuits, is to use the RFC's as data interface and relay points utilizing the RFC "Gateway" terminal and data link over dedicated lines to the NOAA 360/195 computer system. However, it is estimated that it will require a minimum of one year to complete the implementation of the hardware and to develop, test, and implement the software required for this option. One interim solution has been obtained with the development of the RAdar Data COMmunications and Processing system (RADCOMP) which automatically polls data from the D/RADEX sites and relays these data to a centralized hydrologic file. This paper gives a detailed description of the current configuration of this real-time data communications and processing system and includes an example analysis of rainfall data provided by it. It is planned that the basic technology comprising RADCOMP will be transferred to the "Gateway" system for one or more RFC's in the near future.

## 2. DIGITAL RADAR-RAINFALL ESTIMATES

HRAP is currently configured to collect radar-rainfall estimates from four NWS D/RADEX sites: Jackson, Ky.; Monett, Mo.; Oklahoma City, Okla.; and Pittsburgh, Pa. These D/RADEX sites, with the exception of Jackson, Ky., were established in late 1971 and early 1972 and consist of WSR-57 weather radars with digital interface and processing systems added. At the Jackson site a WSR-74S radar, along with a D/RADEX type processor, was installed in 1981.

In the D/RADEX system, software has been developed for the NOVA 1200 minicomputer, located at the radar sites, which converts reflectivities into rainfall rates. The average rainfall accumulated during discrete 3-hour periods is available in map form on a 3 x 5 nmi grid, centered on the radar site, and extending outward to a range of 125 nmi (230 km) (Figure 1).

The map for the previous 3-hour period is available until replaced by a new 3-hour average accumulated rainfall map 3 hours later. The maps are available about 1 minute after their period of coverage ends. Radar-

OKC AVERAGE ACCUMULATED RAINFALL MAP CONVECTIVE RATES USED
1800Z, MAY 28, 1981 TO 2100Z, MAY 28, 1981

| CODE VALUE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RAIN(100TH IN) | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 |

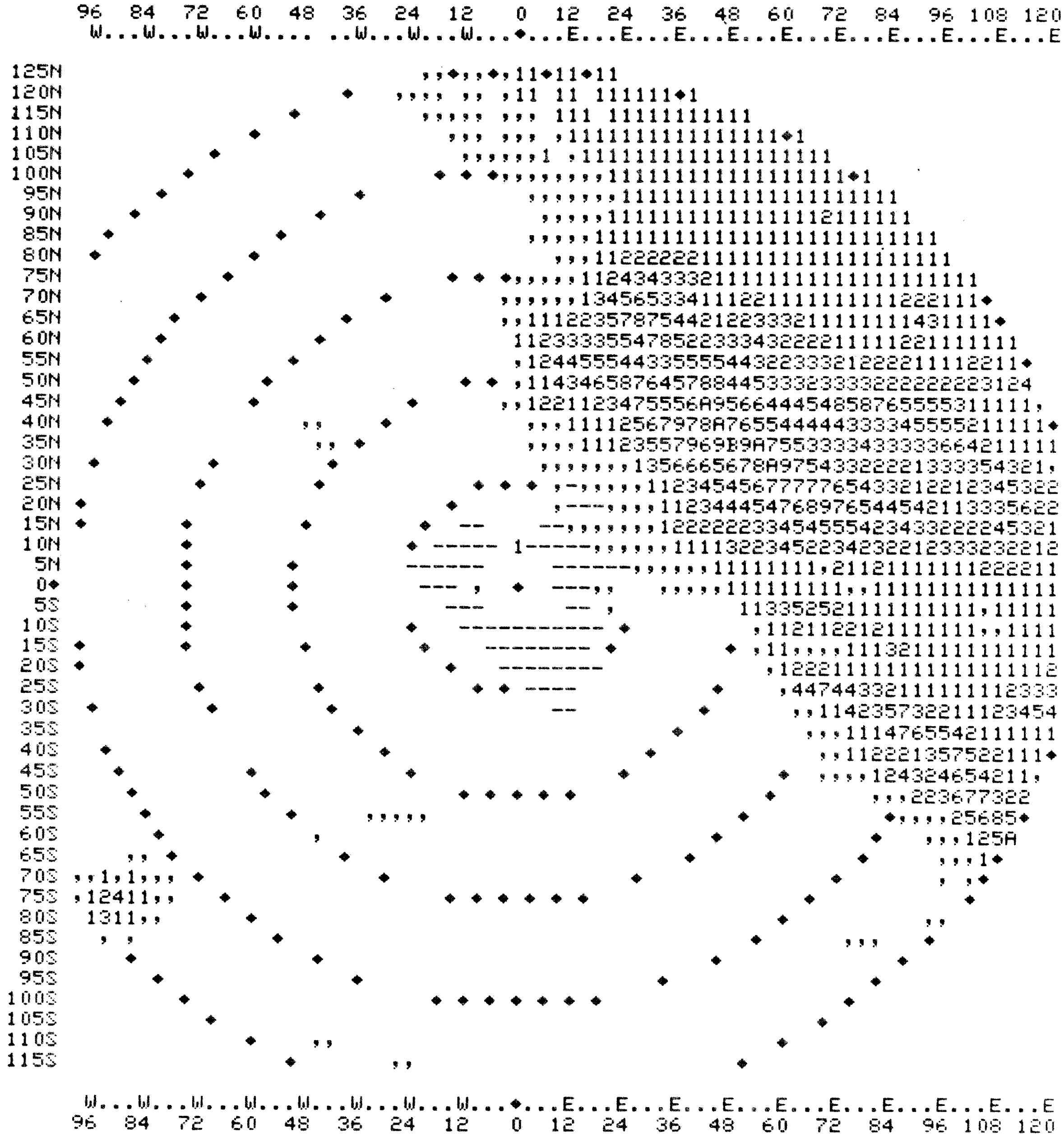


Figure 1. Oklahoma City digital radar-rainfall map for 18Z to 21Z on May 28, 1981. Codes used are listed underneath header. Commas stand for less than 0.2 inches. The abscissa and ordinate are labeled in units of nautical miles.

rainfall estimates have been found to be in general agreement with gages under the radar umbrella but the anomalous propagation (AP) problems remain to be solved. It is hoped that the addition of available gage and satellite data as proposed in the HRAP analyses system will be of significant value in reducing the contamination of the rainfall-estimates by AP. We also feel that it may be possible with the new NEXRAD system currently undergoing development to devise better methods of identifying AP by use of clutter suppression techniques. Even so, the chances of AP occurrences and other data deficiences will always exist. Therefore, until a very comprehensive multivariate data processing and analysis system has been perfected which includes objective quality control procedures, it is extremely important that all users of radar-rainfall estimates be attuned to the possibility of encountering bad data.

A new D/RADEX rainfall product will soon replace the coarse 3 x 5 nmi data as input to RADCOMP. A full resolution, 2 degree azimuth x 1 nmi range, polar grid will be used and maps will be for a 1-hour period rather than 3 hours providing a significant increase in both spatial and temporal resolution. It has already been demonstrated that the current system can be modified to handle the full resolution data without the addition of new hardware, except for the addition of 1200 baud modems at the D/RADEX sites.

## 3. RADCOMP

A major effort within HRAP has been directed toward developing a system to get digital radar-rainfall estimates into the operational environment during this interim period until the Gateway assumes this communications function. This effort led to the development of RADCOMP. The system development, hardware, and software required for RADCOMP are discussed in this section.

### 3.1 System Development

Through the use of an Apple II microprocessor coupled with a D.C. Hayes micromodem, a system was developed to automatically collect, via dial-up telephone, radar-rainfall estimates from the D/RADEX sites and to relay these data to the NOAA IBM 360/195 system through the Time Share Option (TSO). This system underwent operational testing for three months (Summer 1980) and the results proved the feasibility of automatically collecting and relaying radar-rainfall estimates to a central site for additional processing and input into hydrologic forecasting models.

The dependence upon TSO for entry of data into the IBM 360/195 proved to be the "weak link" in this data collection system. The NOAA Office of Management and Computer Systems (OMCS) runs TSO for research and program development, not for operational use. Some problems that were encountered in attempting to use TSO as part of a real-time operational data collection system are:

(a) TSO is not in operation 24 hours a day and is sometimes dropped when computer resources are reduced.

(b) Delays of up to 3 hours were experienced in logging onto TSO on some days when TSO was running.

Based on the TSO experiment, alternative means of getting radar-rainfall estimates from the Apple II to the 360/195 files were explored. It was found that the problems associated with TSO could be eliminated by use of a 1200 baud dial-in line to the Interdata 50 computer maintained by the NWS Computer Communications Center at Suitland, Maryland. The Interdata 50 would automatically receive radar-rainfall data transmitted to it from the Apple II and relay these data via the IBM 360/40 communications computer to the IBM 360/195 data files. At the time of this data transfer, operational processing and/or analyses programs can be automatically triggered to run on the IBM 360/195.

Some advantages of using the Interdata 50 Communications port instead of TSO for entry of data into the IBM 360/195 system are:

(a) Reliable and continuous access to the IBM 360/195, making radar data available for hydrologic applications in near real-time.

(b) Automatic triggering of operational analysis programs on the IBM 360/195 system.

(c) Elimination of the need for extra disk storage in the Apple II system for holding data while waiting to log on TSO.

(d) Increased data transmission rates.

(e) Enhanced capability to collect high resolution radar data at hourly intervals from several radar sites.

The use of the 1200 baud port to the Interdata 50 required the addition of a 1200 baud converter, modem, auto-dialer, and data access arrangement to the Apple II. A Racal-Vadic modem with accessories was purchased for this use because of its compatability with the Apple II system and equipment in the NWS Computer Communications Center. This 1200 baud modem was delivered in late November 1980 and new software development began at that time.

We found that having the Apple system automatically call the D/RADEX sites, rather than waiting for the radar site to call, allowed for more control of the data transfer process. Therefore in the current version of RADCOMP, which is now operational, the radar sites are called automatically via an FTS (Federal Telecommunications Service) line approved for data transfer. Data flow in RADCOMP is illustrated in Figure 2.

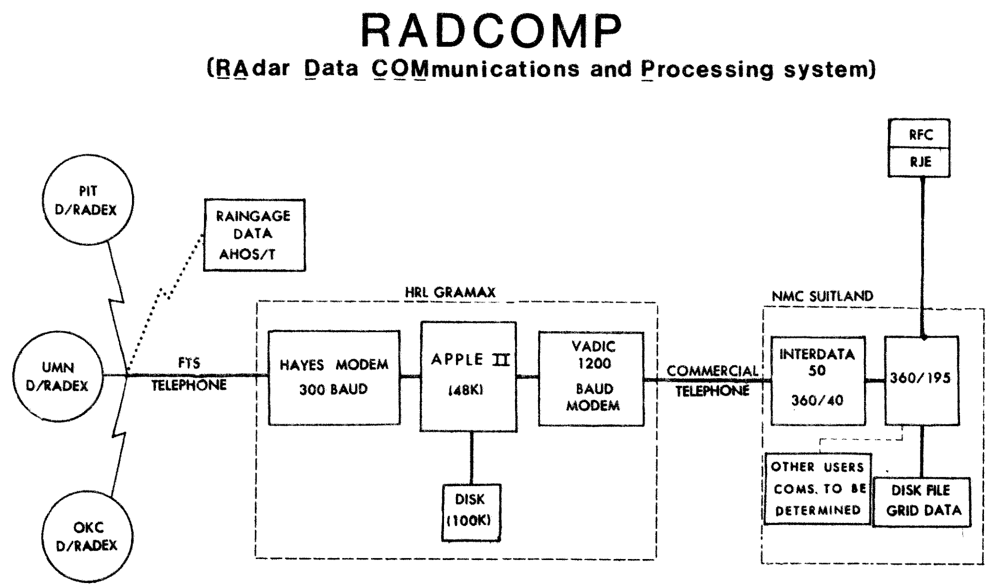


Figure 2. RADCOMP data flow.

3.2 HARDWARE

The hardware used in RADCOMP is comprised of:

(a) An Apple II Plus microprocessor with video display,

(b) an Apple Disk II,

(c) a D.C. Hayes Micromodem II,

(d) a Racal Vadic 801 autodialer and 3415 modem,

and

(e) a Texas Instrument (TI) Silent 700 printer

3.2.1 Apple II Plus. Manufactured by Apple Computer Inc. and equipped with 48K bytes of memory, a real time clock, and a video display, the Apple II Plus has proven itself over the past year to be both highly reliable and adaptable. In fact, during the past year of almost round-the-clock operation it has required maintenance only once, when one of the RAM's (random access memory) went bad and had to be replaced. Although some software changes will be required to collect and transfer the full resolution radar-rainfall data, the Apple II Plus contains adequate memory for the full resolution data (21K), the RADCOMP software (10-12K), and the Apple II Disk Operating System (D.O.S.) and Basic system (13K). In the current version of RADCOMP the 3 x 5 nmi resolution data requires only 8K memory. The Apple Clock is a real time calender clock used to control RADCOMP timing. This clock switches to battery power whenever power to the microprocessor is lost. System messages pertaining to the operations currently being undertaken are displayed on a Sanyo 9-inch video monitor.

3.2.2 Apple Disk II. This 5 inch diameter floppy disk system with 103K byte storage capacity is used to permanently store the RADCOMP software as well as data when necessary. The system is set up so that after a power failure the complete system software is automatically reloaded into memory and run. Data are stored on disk temporarily whenever a problem is encountered trying to transfer the data to the Interdata 50 computer at Suitland, Maryland.

3.2.3 D.C. Hayes Micromodem II. The modem, with its Microcoupler forms a complete low speed (300 baud/30 char. per sec) data communications subsystem for the Apple II Plus. It combines a modem which is compatible with the Bell System 103 type modem, the Microcoupler data access arrangement which permits direct connection to the FTS telephone line, and the firmware required for its operation in an on-board ROM (read only memory). This system can be instructed to automatically call or automatically answer using commands from within a Basic program running on the Apple II Plus.

3.2.4 Racal-Vadic Autodialer and Modem. The VA3415 modem is a highly versatile device which transmits and receives asynchronous or synchronous data at speeds up to 1225 baud. Racal-Vadic's Data-Access-Arrangement permits direct connection to a commercial telephone line. A California Computer System (CCS) serial interface card is used to connect the Racal-Vadic equipment to the Apple II via an RS232 interface. The pulse autodialer includes such features as positive dial tone detection, positive answer tone detection, as well as invalid digit detection. Both the modem and autodialer include complete diagnostics display for testing and system troubleshooting.

3.2.5 Texas Instrument (TI) Silent 700 Printer. The 300 baud printer is used to keep a permanent record of RADCOMP system operation as well as for data display and program listings when required. An Apple II asynchronous serial interface card enables the system to send messages to the TI Silent 700 for printing.

### 3.3 Apple Software

The framework of the Apple real-time operating system is written in Integer BASIC, a high level interpretative language, which calls various routines, some of which are written in a more time efficient machine oriented language, to perform specific functions. A general flowchart of the Apple real-time software is presented in Figure 3. As shown in figure 3, the Apple operating system is comprised of three basic modules or loops: CONTROL, CALLSITE, and DISKSEND.

Timing of the Apple operating system functions is controlled by the actual time obtained from the Apple clock. The CONTROL loop is executed once each minute until it directs execution of a program task. Once the task has been performed, or at least attempted, command is returned to the CONTROL loop.

The first task performed each time the CONTROL loop is executed is to compare the current time and the time the radar sites were last called for data to a schedule of the discrete 3-hour collection periods. If a new collection period has begun since the sites were last called GETSITE flags are set for each site to indicate that it is time to collect data for the next time period. Other tasks are performed only during specific minutes of CONTROL loop execution. The CALLSITE routine is called at 4 and 34 minutes past the hour. It checks the GETSITE flags and if data have not been successfully obtained from one or more of the sites an attempt is made to call those sites, get the radar-rainfall estimates, and transfer these data to the Interdata 50. The routine is called once every 30 minutes in order to limit the number of long distance calls, whenever problems occur getting data from one or more sites. Waiting until 4 minutes past the hour to call the sites allows for the processing time required at the D/RADEX site to produce the new radar-rainfall map. Lastly, whenever the one's digit of the minutes is equal to 4 (i.e. every 10 minutes) the CONTROL loop transfers commandto the DISKEND routine. This routine checks whether data have been stored on the Apple Disk II. A radar-rainfall map is stored on the disk whenever a problem occurs while trying to send data to the Interdata 50. If data have been stored onto disk an attempt is made to send it to the Interdata 50. Following completion of the complete CONTROL loop a WAIT routine is executed which pauses before allowing the CONTROL loop to repeat until the minute digit changes from its current value.

Whenever the CONTROL loop, described above, executes the CALLSITE routine and data from the period have not been collected from all sites, RADCOMP instructs the Micromodem II to call the missing site. The modem dials the number and awaits a carrier from the Bell 103J auto-answer modem at the radar site. RADCOMP monitors the Micromodem II's status register to check whether a carrier was detected from the site. If a connection is made, the GETDATA routine is executed.

First, the GETDATA routine must instruct the D/RADEX computer using a sequence of seven command codes to indicate the D/RADEX product being requested. Following the transmission of each command code to the site, the RESPONSE1 routine is called which checks for the correct response from the site. The response is stored as a sequence of integers whose values correspond to the ASCII codes of the characters received. The RESPONSE1 routine checks the Micromodem II status register constantly within a loop. If the status shows the receive register to be full the register is read and stored. Also, the status loop counter is reset to 0. If no response is received, or an incorrect response is received, the loop counter will increase beyond a pre-set value at which time an error flag is set and the Micromodem II is instructed to hang-up the phone line. If at any time during execution of RESPONSE1 the radar site carrier is lost, the status register will indicate this and RESPONSE1 will set the error flag and instruct the Micromodem II to hang-up also.

Immediately following the seventh instruction to the D/RADEX system the radar-rainfall map is sent from the D/RADEX Computer to the Apple II. The data are read using the RESPONSE1 routine described above. An ASCII "$" signals the end of the message from the site, and when this character is received a return to the GETDATA routine takes place. The Micromodem II is instructed to hang-up and then, if the error flag has not been set, the data are checked for a valid header. This is done by checking for a "PIT", "JKL", "OKC", or "UMN" (indicating the Pittsburgh, Jackson, Oklahoma City, or Monett D/RADEX sites respectively) in the data header. If one of the above is present in the header its position is marked, the header is printed on the TI Silent 700 printer, and the SENDDATA routine is called.

Because the data received by the Interdata 50 must be transmitted in blocks of no more than 3500 characters, the SENDDATA routine first calculates the number of blocks which will be required to send the data. Then, by transmitting control codes and the telephone number through the California Computer Systems (CCS) serial interface to the Racal-Vadic 801 auto-dialer and 3415 modem, the auto-dialer is instructed to call the Interdata 50 port and await the carrier. Determining whether a proper connection is made with the Interdata 50 is accomplished through use of the CCS serial interface status register. Two critically timed checks of this register, one just following the completion of dialing (status register should be equal to 2 indicating: no errors, receive register empty, and transmit register empty) and one just following the detection of a carrier by the Racal-Vadic modem (status register should be equal to 3 indicating: no errors, receive register full, and transmit register empty), are used to check for a good connection. Once connected, the header, which includes an identifi-

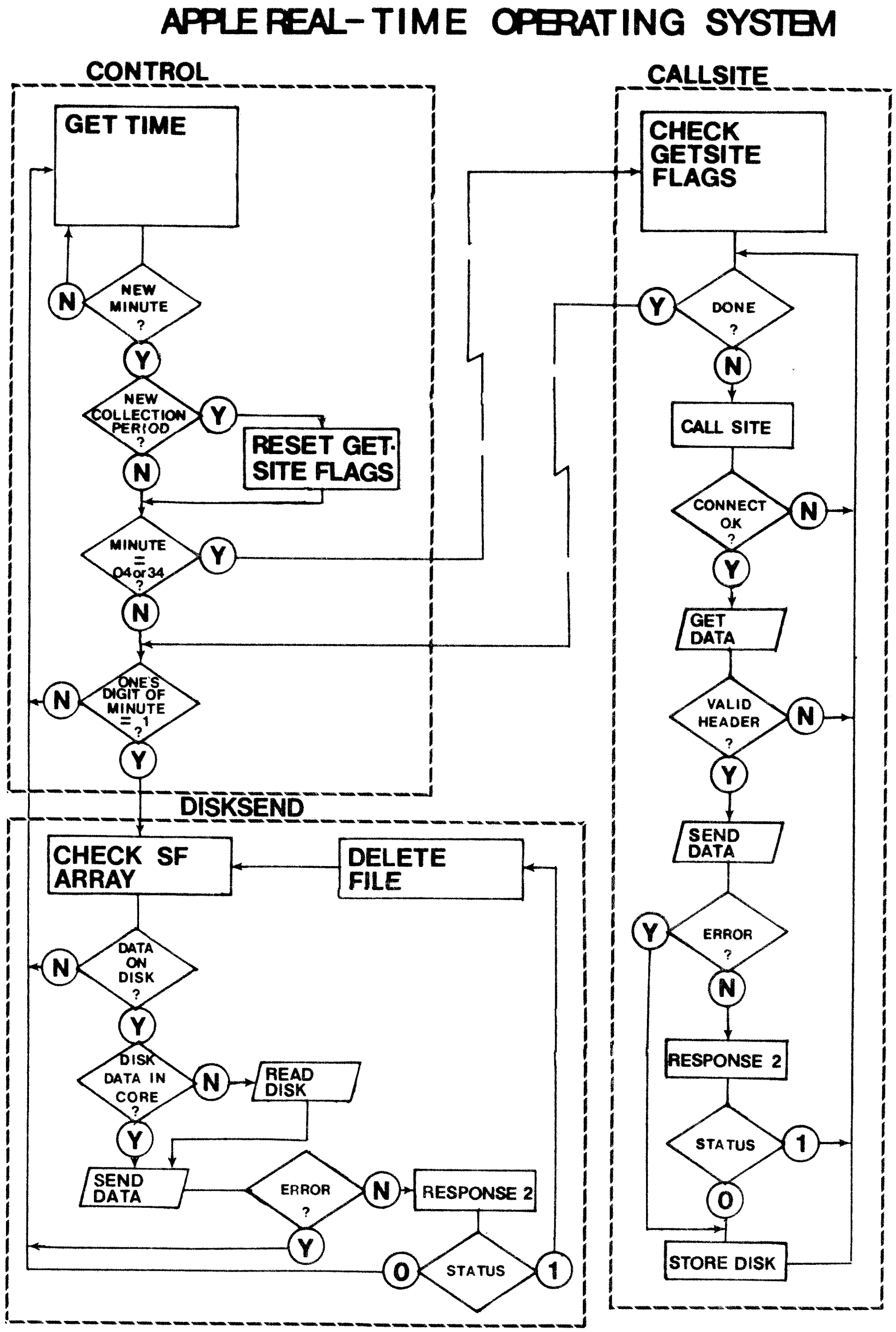


Figure 3. Flowchart for the Apple real-time operating system.

cation for RADCOMP data, the time of transmission (from Apple Clock), the block number of the block being transmitted, and the 3 letter radar site identifier, is sent out followed by the first block of data which is terminated by an ASCII "ETX". If more than one block is required to send the map, successive blocks are sent each preceded by a new header including the block number and ended by an "ETX". The header and data are sent out by first checking the CCS serial interface status register for a value of 2. An error flag is set if the status register doesn't return to 2 for a few seconds in which case the data are saved on disk for transmission at a later time. After the status register has been checked and has been found to have value 2, the ASCII code is put in the transmit register of the CCS serial interface which gets it to the Racal-Vadic modem for sending to the Interdata 50. After sending the entire map, an ASCII "EOT" is sent to the Interdata to indicate the completion of the message.

Immediately after the "EOT" is sent the SENDDATA routine calls the RESPONSE2 machine language routine. The RESPONSE2 routine is written in machine langauge in order to be fast enough to catch the 1200 baud response from the Interdata 50. The CCS serial interface status register is checked for about 30 seconds. If a response is received (status register 3) during this period, the variable STAT is set to 1 and control returns to the SENDDATA routine. If no response is received during this period, indicating the data transfer attempt was unsuccessful, the STAT variable is set to 0, and a return to the SENDDATA routine is executed. The register containing the variable STAT is then checked from the Integer BASIC SENDDATA routine and a message is printed on the TI Silent 700 to indicate whether transfer was a success or failure. Control then returns to the CALLSITE or DISKEND routine depending on which called the SENDDATA routine.

If SENDDATA was called by CALLSITE and data were transfered successfully the other sites are called if they haven't been already. If transfer was unsuccessful, data are stored onto disk.

The STOREDISK routine stores the data in character format on the Apple Disk II, whenever trouble is encountered in transferring data to the Interdata 50. Each line is written as a single record and ends with a carriage return. Up to 10 files (maps) may be stored on disk at the same time. Pointers are used to indicate the first and last file filled so that the 10 most recent maps are kept on disk if the Interdata 50 is down for an extended period of time. With four sites being called each 3 hours, data will be lost by RADCOMP only if the Interdata 50 port is down for more than 6 hours. By adding another floppy disk drive or a hard disk pack to the Apple II, additional radar sites and/or more data from the current four sites could be saved.

The SENDDATA routine may also have been called by the DISKSEND routine. This routine, executed by the control loop as described earlier, first checks the disk file status (SF) integer array. If an element of this array has value 1 then there is a corresponding data file on disk containing data which needs to be sent to the Interdata 50. If no data is currently on disk a return is made to the control loop. If the data from the file found on disk hasn't been stored in core, the READDISK routine is executed.

The READDISK routine reads the data file off the Apple II Disk one line at a time into a string. Then, character by character, this string is converted into an ASCII integer array and stored until the integer array contains the entire map.

Once the data on disk are stored in core, the DISKEND routine calls the SENDDATA routine which attempts to send the data to the Interdata 50. If the data are successfully transferred, the data file on disk is deleted, the SF array is updated, and a check is again made for more data on disk. If unsuccessful, execution of the DISKSEND routine is terminated and a return is made to the control loop.

### 3.4 Central Facility Processing

Digital radar-rainfall data that have been transmitted by the Apple real-time operating system to the Interdata 50 at the NWS Computer Communications Center are automatically relayed on a predetermined time schedule by the IBM 360/40 communications computer to a National Meteorological Center (NMC) temporary data file in the IBM 360/195 system. These data are then read from this file, decoded and reformatted, transformed to the HRAP grid, and stored in an HRAP hydrologic file for further application. The steps in this data processing scheme are outlined in Figure 4.

#### 3.4.1 Decoding and Reformatting

During the transmission process from the Apple II to the Interdata 50 and then to the IBM 360/195, the radar-rainfall maps are decomposed from the gridded array format to an unformatted character string spread over several computer data records in the NMC temporary data file. In addition, certain ASCII characters are converted or deleted. The NMC data file, into which these data are written, is cyclic with a period of approximately 12 hours (i.e. new data are written over old data after about 12 hours). The location of the next address that the computer will begin writing the next data record into is saved in a NMC "housekeeping" file. This address is called the file pointer.

A RADCOMP program triggered operationally by the Tulsa River Forecast Center (at a future date this program will be triggered automatically as radar-rainfall data are transferred from the IBM 360/40 to the IBM 360/195) retrieves the file pointer from the NMC housekeeping file, files this address as the point to begin processing in the next run, and backs off one location from the pointer address and uses that address as the point to stop processing data from the NMC temporary file in the current run. The decode program then

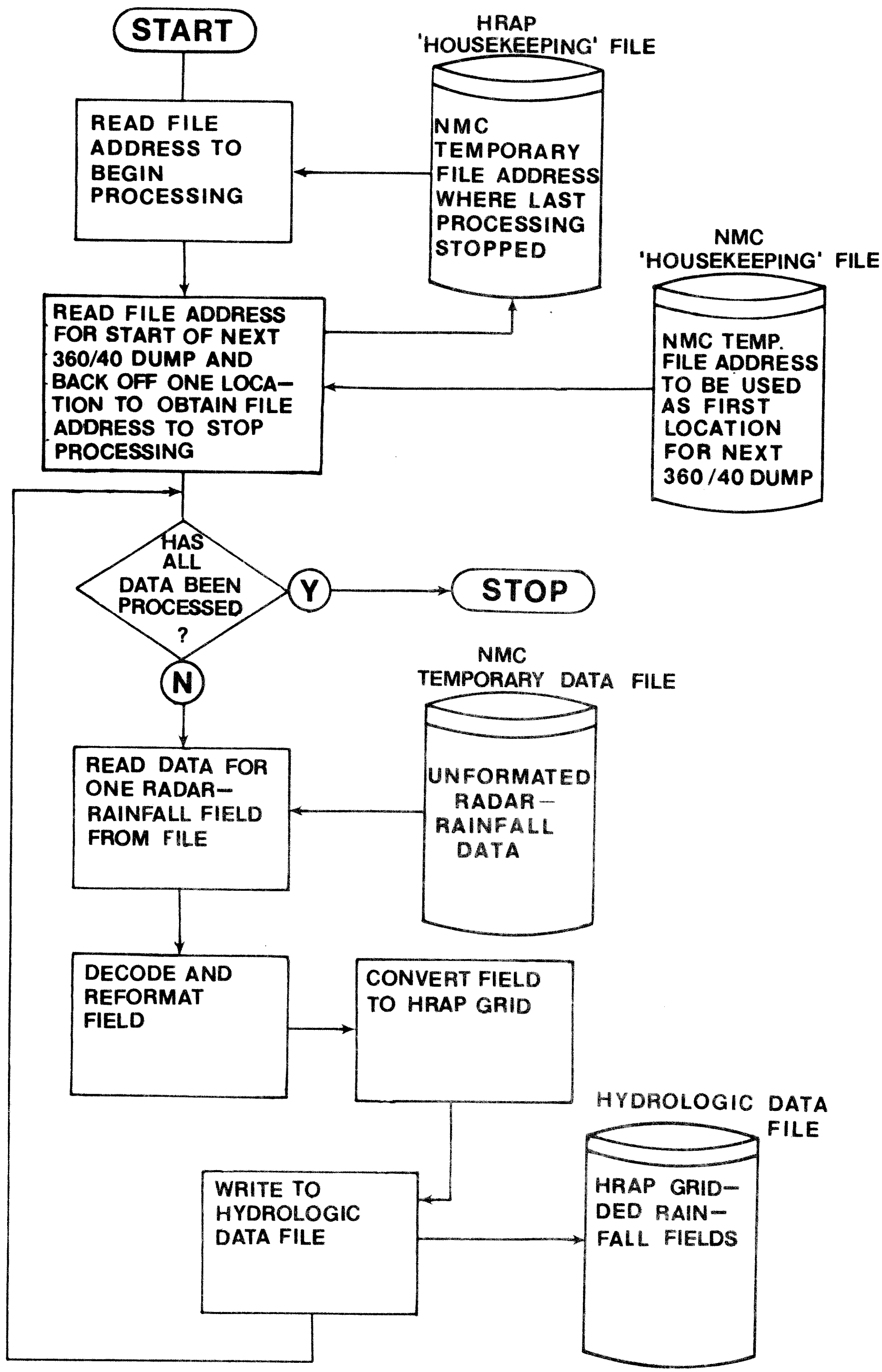


Figure 4. Steps in RADCOMP central facility data processing.

processes data character by character beginning with the start address (the file pointer of the previous run). This routine reformattes the data into the original radar-rainfall grid by keying upon control and/or identification characters in the data stream. Once the radar-rainfall field is reformatted, it is transformed to the HRAP grid and stored in the hydrologic disk file.

### 3.4.2 HRAP Grid

The HRAP grid is a "universal" grid that is formed by mapping the Earth coordinates (latitude, longitude) onto a polar stereographic map projection which is true at 60° North latitude and oriented so that 105° West longitude is parallel to the ordinate of the grid. For a detailed discussion of this grid system and the mapping or transformation equations see Greene and Hudlow (1981). Some characteristics of the grid are:

(a) Since the grid is based on a "conformal" projection, the shape of any small area on the map is the same as its corresponding shape on the earth. Also, on the grid all angles are preserved and the scale is the samein all directions at any point.

(b) The grid is "universal" in that for grid analyses of different regions which have common overlapping areas, the grid points within the overlapping area are coincident with one another. This grid also contains the NMC Limited Fine Mesh (LFM) grid as a subset.

(c) The grid mesh length varies betweeen 4 to 5 km depending upon latitude (at 60° North the mesh length is 4.7625 km).

Figure 1 shows an example of a digital radar-rainfall map received by the Apple real-time operating system from the Oklahoma City D/RADEX site for the period from 18Z to 21Z on May 28, 1981. The storm systems moving through the area that day resulted in heavy rainfall and numerous tornadoes. This map was automatically transferred to the IBM 360/195 and the data were decoded and reformatted using the procedure described above. The HRAP gridded rainfall estimates for the same data field as Figure 1 are shown in Figure 5.

## 4. CONCLUDING REMARKS

With the expansion of the NWS digitized radar network will come the need for a larger system for the communication of digital radar-rainfall estimates to a central site for additional processing and input to hydrologic models. We believe that the RFC's will be able to act as data interface and relay points for these data, using the RFC "Gateway" terminal and data link to the NOAA 360/195, but that it will be at least a year before this system can become operational. Provisions also should be available at the RFC's to display the preliminary radar-rainfall estimates as they are being relayed to the central site for further processing. And, in the future, super minicomputers are planned for the RFC's which would enable processing at the RFC's as well as the central site. It is very likely that many of the techniques as well as some of the software used in RADCOMP will be applicable to the system using the "Gateway" terminal. RADCOMP has proven the feasibility of such a system. For the interim, RADCOMP will be providing radar-rainfall data from four digital radar sites in near real-time to anyone who has access to the NOAA 360/195 in Suitland, Maryland. These data, covering an area of over 600,000 square km., are already available to River Forecast Centers and their use should help to improve the accuracy and timeliness of flood forecasts and flash flood warnings issued by the National Weather Service in those areas covered by the digital radars.

## 5. ACKNOWLEDGEMENTS

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## 7. DISCLAIMER

Any reference to Manufacturer and model names in this paper should not be interpreted as general endorsement by the government of specific equipment for other applications beyond the limited scope described herein.

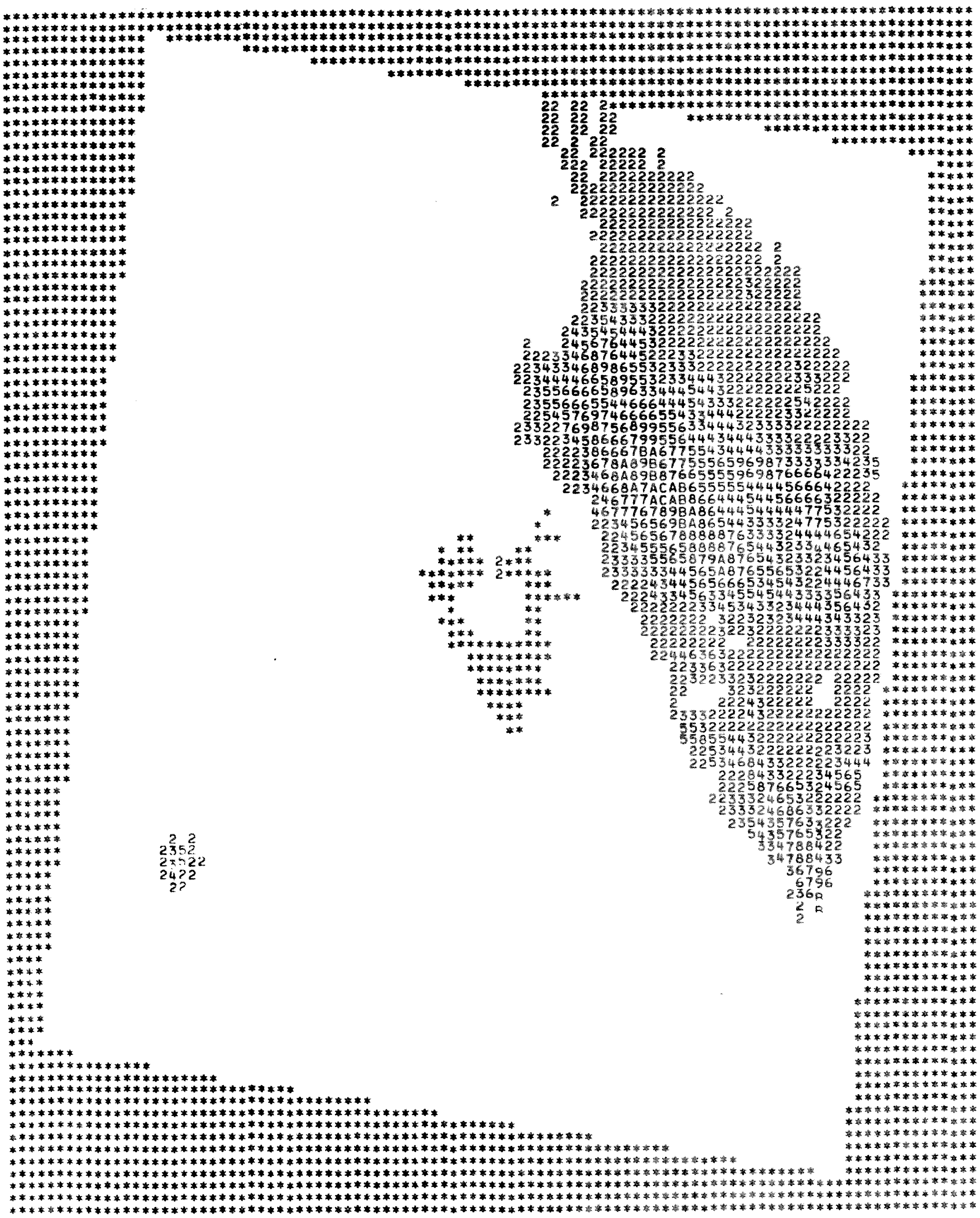

Figure 5. . HRAP gridded radar-rainfall estimates for 18Z to 21Z on May 28, 1981. Code values used are the same as those used in Figure 2 except they are incremented by 1. Amounts less than 0.2 inches (commas in Figure 2) are excluded.