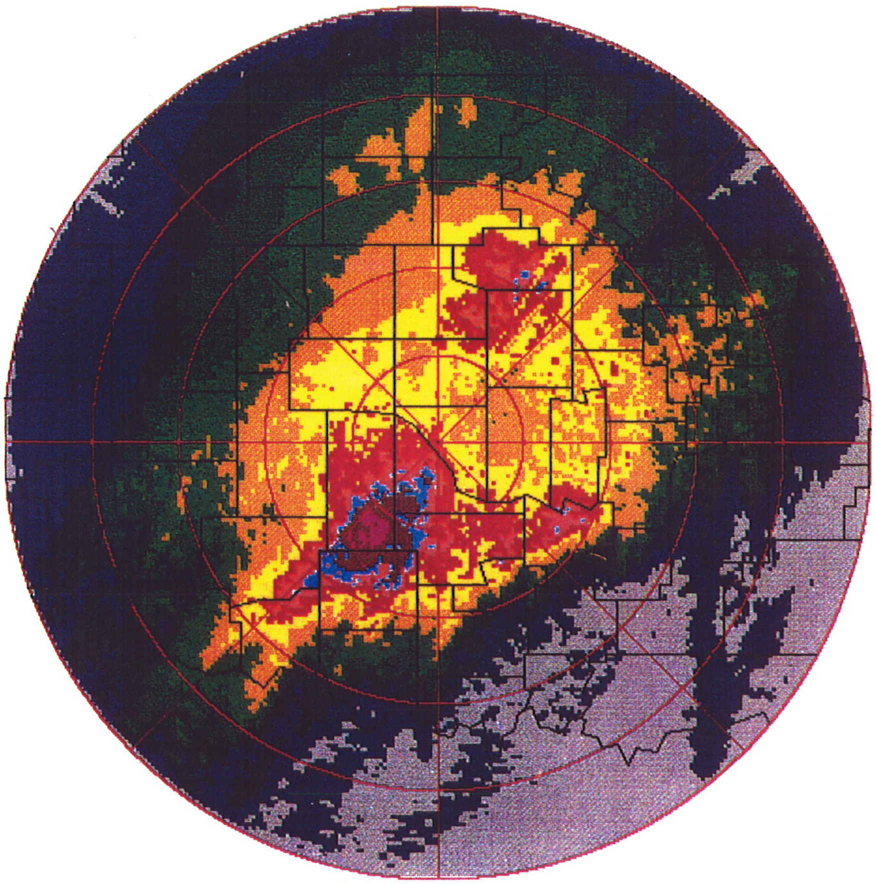
NEXRAD

Hydrometeorological Processing



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NEXRAD HYDROMETEOROLOGICAL PROCESSING

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1. INTRODUCTION

One of the most important steps in the process of making river forecasts is an accurate precipitation analysis. Precipitation is one of the primary inputs to the National Weather Service's River Forecast System. Accurate precipitation analyses are also extremely important to the meteorologist faced with a flash-flood situation. A rain gage network, even a fairly dense one, can miss significant rainfall, especially rainfall associated with intense convective storms. Another significant problem with rain gage networks is the inability to determine patterns of precipitation or to identify the heaviest amounts. Thus, there is a strong need for real-time precipitation analysis that is not totally dependent upon rain gage observations. This is especially important for remote areas where it is difficult to establish and maintain surface observing stations. In the early 1970's an effort was begun to use the established National Weather Service (NWS) radar network to provide areal precipitation analysis. Development of procedures for using radar as a tool to measure precipitation has progressed from manual techniques, to semi-automatic techniques, to the fully automatic techniques employed by The Next Generation Weather Radar (NEXRAD).

NEXRAD is a joint Department of Commerce, Department of Defense and Department of Transportation effort to develop and procure a Doppler weather radar system. It is a nationwide network of weather radars designed to meet the weather mission needs of the United States into the twenty-first century. All told, the three agencies will acquire approximately 175 radars, 413 workstations and associated equipment. For the Continental United States, NWS currently plans to replace the existing weather radar network with 113 of the approximately 175 NEXRAD's. Deployment of the NEXRAD's is scheduled to begin in the spring of 1990 and continue into the mid 1990's. NEXRAD is a totally integrated system and consists of a 10 cm Doppler Radar, a powerful computer to process the data and develop products, and a graphical workstation to display products.

The hydrometeorological software comprises four stages of processing. The first stage is complete and will be performed within NEXRAD. Processes for stages two through four occur externally. Testing and evaluation of the Stage I hydrometeorological processing have been conducted by the Hydrologic Research Laboratory (HRL) in collaboration with the NEXRAD Operational Support Facility (OSF) in Norman, Oklahoma, and the Prototype Regional Observing and Forecasting Service (PROFS) located in Boulder, Colorado. Testing and evaluation of Stages II - IV are well underway at HRL. The four stages of hydrometeorological software were developed by HRL and a schematic is shown in diagram 1. The following sections will discuss the four stages of hydrometeorological processing.

2. THE FOUR STAGES OF HYDROMETEOROLOGICAL PROCESSING

2.1 Stage I

The Stage I processing within NEXRAD contains two major components: a Precipitation Processing System (PPS) and a Flash Flood Potential (FFP) System. In Stage I the data are processed to a level of refinement that can be achieved relatively cheaply (with respect to computer resources), yet provide an accuracy that make the precipitation estimates useful for local real-time applications.

2.1.1 Precipitation Processing System (PPS)

PPS generates one-hour running, three-hour running, and running storm total precipitation accumulations. Five functional steps are performed to develop the best estimate of precipitation:

(1) Development of Sectorized Hybrid Scan
(2) Conversion to Precipitation Rate
(3) Precipitation Accumulation
(4) Adjustment using Rain Gages
(5) Product Update

Since radar only indirectly measures precipitation rates, an emphasis on quality control of the data has been built into the processing steps of the PPS.

The first step is to produce a "sectorized hybrid scan", which is a scan comprised of reflectivity data from the four lowest tilts of the radar volume scan. There is a four-fold reason for this multiple tilt processing rather than using a single tilt:

(1) to minimize ground clutter and clear mountains or man made obstacles,
(2) to reduce effects of abnormal beam refractions and losses,
(3) to improve range performance, and
(4) to result in the use of data from a more uniform altitude versus range.

The choice of tilt is based on range and topography. It is desirable to use the lowest tilts at the furthest ranges.

The reflectivity data are preprocessed prior to development of the hybrid scan to remove as much erroneous data as possible. One source of error results from partial or complete beam blockages, generally from man-made objects (such as water towers). The form of the blockage correction depends upon the percent of the beam blocked and the radial width of the blockage. Reflectivity outliers can occur when the beam strikes high reflectivity objects such as planes. These data points are corrected using neighboring data points.

The final quality control check is to determine whether or not data from the lowest tilt will be used in building the hybrid scan. The low tilt is the one most likely to be contaminated by anomalous propagation (AP), ground clutter and other noise. The vertical echo continuity check rejects the lowest tilt when more than a given percent of the echos at the lowest angle disappear at the second elevation angle.

Following construction of the hybrid scan, the reflectivity data are converted to rainfall rates using an empirical relationship, in the form $Z_e = aR^b$ where Z_e is the equivalent reflectivity factor, which is the output from the Hydrid Scan step, and R is the rainfall rate. Two quality control procedures are performed in the Rate algorithm. First, temporal continuity of the total field volumetric water is checked to insure that spurious data have not introduced physically unreasonable rates of echo development or decay. Range effects resulting from signal degradation and partial beam filling may also unduly reduce precipitation estimates at further ranges; therefore, a range-dependent, site-varying correction will be applied to the precipitation rate data.

The next step is to perform precipitation accumulations. Two types of accumulations are generated. The first is a scan-to-scan accumulation which measures the precipitation accumulation from one instantaneous rate scan to the next. The second is a running hourly accumulation which is updated every volume scan. A temporal continuity test checks the data for missing periods which might result from system malfunction or rejection of scans. If too much data are missing, no running hourly accumulation is performed.

An outlier check is performed on the hourly accumulations. This check is made in addition to the instantaneous reflectivity outlier check because clutter which passes the reflectivity test could, if it remains at a high level, produce impossibly large accumulations.

The fourth functional step is adjustment of the accumulations based on available rain gage data. In spite of efforts to maintain a high level of quantitative accuracy in estimating precipitation from radar data, there are sure to be errors in these estimates. In fact, errors of a factor of 2 or more can occur due to a wide variety of causes including hardware calibration, anomalous propagation, wet radome attenuation, inappropriateness of Z-R relationship for the particular storm system, etc. While some of these errors will be localized or perhaps range dependent, most will produce a generally uniform multiplicative bias in the radar estimated precipitation. In order to correct for these errors, a procedure has been developed to compare hourly precipitation from rain gages to associated radar values and to estimate the mean-field radar bias.

The adjustment procedure is based on a discrete Kalman filter (Ahnert et al, 1986). The bias update is performed once per hour when sufficient real-time gage reports are available. If not enough gage reports are available the previous estimate of the bias is propagated forward.

In the final step of processing in the PPS, two basic types of products, graphical and digital, are generated from the adjusted running hourly (or clock hour) and adjusted scan-to-scan accumulation scan sets generated above. Graphical products will be displayed at forecast offices. Digital products will be used for subsequent numerical processing and input to forecast models.

The precipitation graphics products are displayed on a 2 km x 2 km grid out to a range of 230 km from the radar site and have up to 16 color levels. These products are briefly described below:

(1) The Hourly Precipitation Product (figure 1) provides the running hourly total or clock hour totals and is updated approximately once every 5 minutes.
(2) The Three Hour Precipitation Product (figure 2) gives the three hour total over the past three clock hours and is updated up to once per hour. This product is not generated if more than one of the clock hours to be used in computing the totals is missing.
(3) The Storm Total Precipitation Product (figure 3) depicts the total accumulations since the last one-hour break in significant precipitation and is updated approximately once every 5 minutes. This product is generated even when missing periods occur.

Also produced is a digital array product of the running hourly accumulations. The product, updated every volume scan (approximately five minutes) will be mapped onto a 1/40th Limited-area Fine Mesh (LFM) grid (approximately 4 km x 4 km). Although the product has somewhat degraded spatial resolution it will provide the same temporal resolution and far greater data resolution (100 data levels). In addition, supplemental data such as instantaneous area averaged precipitation rates over a 1/4 LFM Grid, bias estimate value, missing periods, and gages polled, are appended to the digital array product. The supplemental data serves as part of the information for performing additional quality control and data adjustment steps in subsequent hydrometeorological procedures.

Despite all the quality control procedures in PPS, the products will not be perfect. PPS does not, for example, directly account for changes in the phases of precipitation from liquid to frozen or vice versa. The PPS products will, however, be of the highest quality possible given current technology and available resources. Ongoing and future research and development will enhance the performance of the PPS.

2.1.2 Flash-Flood Potential (FFP) System

The Stage I NEXRAD FFP System produces short-term forecasts of precipitation accumulations and flash-flood potential. Technically, the flash-flood potential is presented in the form of "critical rainfall probabilities" which are defined below. The NEXRAD FFP System consists of a precipitation projection procedure and a flash-flood potential assessment procedure. The precipitation projection procedure forecasts precipitation accumulation up to one hour into the future. The forecasts are updated every volume scan (approximately every five minutes). The procedure also produces projected total precipitation accumulations and associated error variances. The projected total accumulation is composed of the previously observed accumulation and the projected accumulation. The observed precipitation data used by the FFP comes from the NEXRAD Precipitation Processing Subsystem (PPS). These projections, accumulations, and error variances are the basic input for the flash-flood potential assessment procedure.

The flash-flood potential assessment procedure uses flash-flood guidance values developed by NWS River Forecast Centers (RFC), and observed and projected precipitation accumulations from the precipitation projection procedure to produce observed and projected Critical Rainfall Probabilities (CRP). The CRP is an estimate of the probability that the actual precipitation for some time during the rainfall event has exceeded (for observed CRP) or will exceed (for potential CRP) the flash-flood guidance value. The flash-flood guidance values are based on hydrologic models run by the RFC's. These guidance values are estimates of how much rainfall would be required over specified durations to produce flooding, given the current hydrologic conditions, at one or more locations within a zone or county.

The FFP system generates digital, graphic, and alphanumeric products. The digital products are intended for numerical use at computer facilities external to the NEXRAD system itself. The digital data maintain the full dynamic range and full precision of the data used to generate the product. Just like the PPS, the digital data are on a "universal" grid so that data from multiple sites are immediately compatible for rapid mosaicking.

After compaction to further reduce communication loadings, the digital data will be transferred to other computer facilities at the RFC's and forecast offices for use in automated forecasting models and procedures. The digital products are:

(1) The Digital Projected Precipitation provides, in compressed form, the projected precipitation on a 131 x 131 1/40th LFM grid (approximately 4 km x 4 km).

(2) The Digital Precipitation Variance provides, in compressed form, the projected and observed error variance on a 131 x 131 1/40th LFM grid. Selected supplemental data are also included and may consist of the following:

- Projection parameter
- Storm velocity parameters
- Storm "dynamics"

The precipitation graphics products will be displayed on a 4 km x 4 km grid out to a range of 230 km from the radar site and have up to 16 color levels. These products are briefly described below:

(1) The Projected Precipitation Product will provide the projected precipitation for up to 1 hour into the future and will be updated every scan (figure 4).

(2) The Maximum Observed Critical Rainfall Probability Product will provide the maximum observed critical rainfall probability and will be updated every scan.

(3) The Maximum Projected Critical Rainfall Probability Product will provide the maximum projected critical rainfall probability and will also be updated every scan (figure 5).

The alphanumeric products will provide flash-flood probability information in a form suitable for display on both graphic and alphanumeric display devices and are described below:

(1) The Flash-Flood Guidance Summary Product will provide, in an alphanumeric table: the guidance value, zonal maximum observed

precipitation accumulation, and zonal maximum total storm (observed and projected) precipitation accumulation for each guidance-value duration in each flash-flood guidance zone. This product will be updated every scan.

(2) The zonal maximum Critical Rainfall Probability Product will provide, in an alphanumeric format, the zonal maximum observed and projected flash-flood probabilities. This product will also be updated every scan.

The products produced by the FFP System should be viewed by the user as useful guidance, but not as definitive identification of flash flooding until interpreted together with other available information. The products generated, using the projection procedure, do not explicitly take the following conditions into account:

- Storm systems moving faster than approximately 50 km/hr.
- Curvilinear storm motions.
- Individual cell dynamics other than that accounted for by the current residual field.
- Initiation of precipitation other than due to the motion of existing precipitation areas.
- Orographic effects.

Other limitations arise from the use of flash flood guidance values which presently:

- Do not reflect criteria for urban areas.
- Are not currently calculated the same way at all RFC's.
- Are calculated from data bases that may not allow the RFC's hydrologic models to accurately reflect soil moisture conditions for all areas within a zone or county.
- Are updated only once a day and do not have an updating procedure to reflect changes brought about by multiple rainfall events.

It is important that the user be aware of these limitations when interpreting and using products from the FFP System.

2.2 Stage II

The Stage II Precipitation Processor program (Stage II) is used to compute hourly precipitation on a 4 kilometer by 4 kilometer grid for the area covered by a single NEXRAD system. Input to Stage II includes hourly digital precipitation data from Stage I processing, GOES infrared satellite data, rain gage data, and eventually other hydrometeorological information. Ultimately the Stage II program will run at the National Weather Service Warning and Forecast Office (WFO) colocated with the NEXRAD system. In the interim time, a combination of Stage II and III processing will be done at several of the RFC's. Stage II precipitation analyses are used by the WFO in providing forecast guidance during periods of severe weather and as input to Stage III precipitation processing at NWS River Forecast Centers.

Stage II precipitation processing differs from Stage I in several ways. Additional quality control steps are carried out in Stage II processing. Satellite and rain gage data are used to detect and eliminate errors in NEXRAD data associated with clear-air anomalous propagation or other data contamination not detected or eliminated during Stage I processing. From the satellite data it can be determined whether clouds are contained in a 1/4 LFM grid box (40 kilometer by 40 kilometer region). If radar observations of rainfall are contained in a 1/4 LFM grid box for which satellite data indicate no clouds are present and for which no rain gages record rainfall, then the radar data are replaced by zero values.

In Stage II processing, radar and rain gage data are "merged" to form an optimal multisensor estimate of the rainfall field. The merging procedure accounts for strengths and weaknesses of the two measurement systems. To estimate rainfall at a given location, a rain gage observation will be heavily weighted only if it is close to the location. The weight that a rain gage receives will also depend on characteristics of the rainfall field. For rainfall fields with large spatial variability (as is typically the case with convective storms) rain gage observations will generally receive lower weights than for more uniform rainfall fields (associated, for example, with stratiform rainfall).

The Stage II program will also produce estimates of rainfall based largely on rain gage data. In the "gage-only" rainfall analysis, radar data are used only to delineate regions receiving no rainfall from precipitating regions. This product is used in Stage III precipitation processing when forecasters determine that errors remain in the amount of rainfall measured by radar.

Graphical products will allow display of Stage II precipitation estimates at the WFO. Summary information, such as mean rainfall over the field and maximum point rainfall, will also be displayed by the Stage II program.

2.3 Stage III

The Stage III Precipitation Processing program (Stage III) provides two products. It provides hourly estimates of rainfall on a 4 kilometer by 4 kilometer grid for the entire area of responsibility of a River Forecast Center. At a River Forecast Center it is necessary to combine information from a number of NEXRAD radars. The program also provides mean areal precipitation (MAP) values for basins specified by the River Forecast Center. MAP time series are provided at the time step required by the River Forecast Center (1 hour, 2 hours, 3 hours, 6 hours, or 24 hours) for operational hydrologic forecasting.

The Stage III program contains two basic steps: 1) quality control/mosaicking, and 2) MAP computation. The first step is an interactive quality control step in which the forecaster can replace rainfall estimates by rain gage estimates (for the area covered by a specified radar). The forecaster will base his decision on displays of preliminary mosaicked radar/gage and gage fields for the entire forecast area. From these displays it should normally be clear to the forecaster if anomalous propagation errors (or certain other errors) are still present in the radar/gage rainfall estimates. The product of the first step is an hourly mosasicked rainfall field for the entire River Forecast Center area of coverage. Figure 6 shows a mosaicked 6 hour rainfall field for the Arkansas River basin. In the MAP calculation, hourly rainfall estimates on a 4 kilometer by 4 kilometer spatial grid are accumulated and averaged to the time and space resolutions required for hydrologic forecasting.

2.4 Stage IV

The final step in precipitation processing is Stage IV. In Stage IV a national map of hourly rainfall is produced. The spatial scale for which the national map will likely be implemented is 4 kilometer by 4 kilometer, that is the scale at which Stage II and Stage III computations are carried out. The input data for Stage IV is the hourly 4 kilometer by 4 kilometer data from Stage III.

3. SUMMARY

The four stages of hydrometeorological processing will provide high-quality precipitation estimates over the entire conterminous U.S. The first stage will take place within NEXRAD and be used for real-time graphical displays and input to forecast procedures at the local forecast offices and river forecast centers. Data from this first stage of processing will be made available to other governmental users and the private sector through the NEXRAD Information Dissimination Service (NIDS). Data will also be available on a regional basis through cooperative agreements with RFC's. Processing in stages two through four will further improve quality of precipitation estimates using satellite, additional gage data, and eventually other hydrometeorological information. The final optimal precipitation estimates will be input to hydrologic models and allow the user to monitor the accumulated precipitation for various durations up to the current time, evaluate precipitation forecasts for short periods into the future and assess flood potential. Using data from NEXRAD, combined with additional raingage and satellite data, it should be possible to realize large improvements in the accuracy of estimating areal precipitation. These improvements should, in turn, lead to large economic benefits and better management of our increasingly precious water resources.

4. ACKNOWLEDGEMENTS

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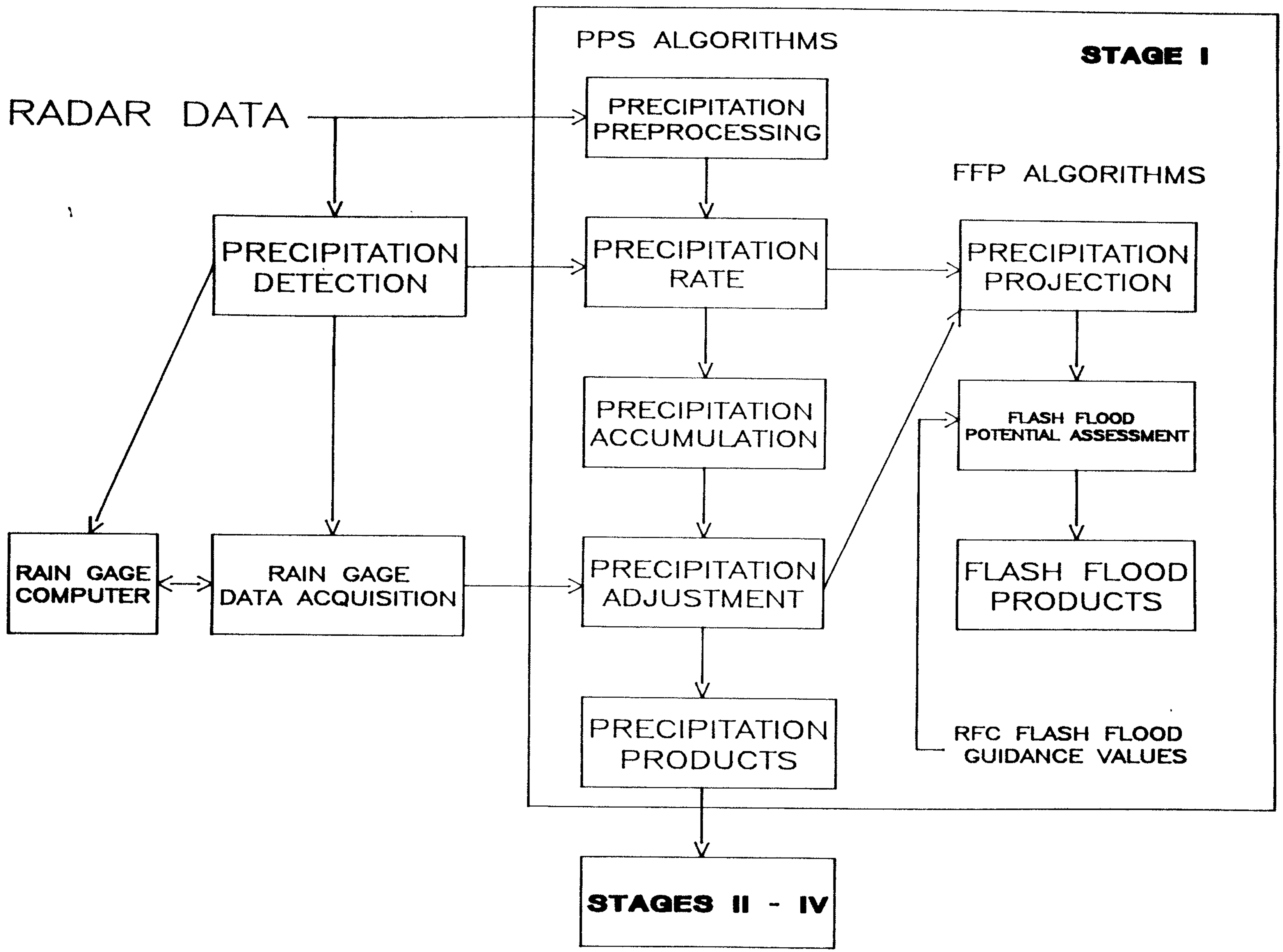

Diagram 1. Four Stages of Hydrometeorological Processing

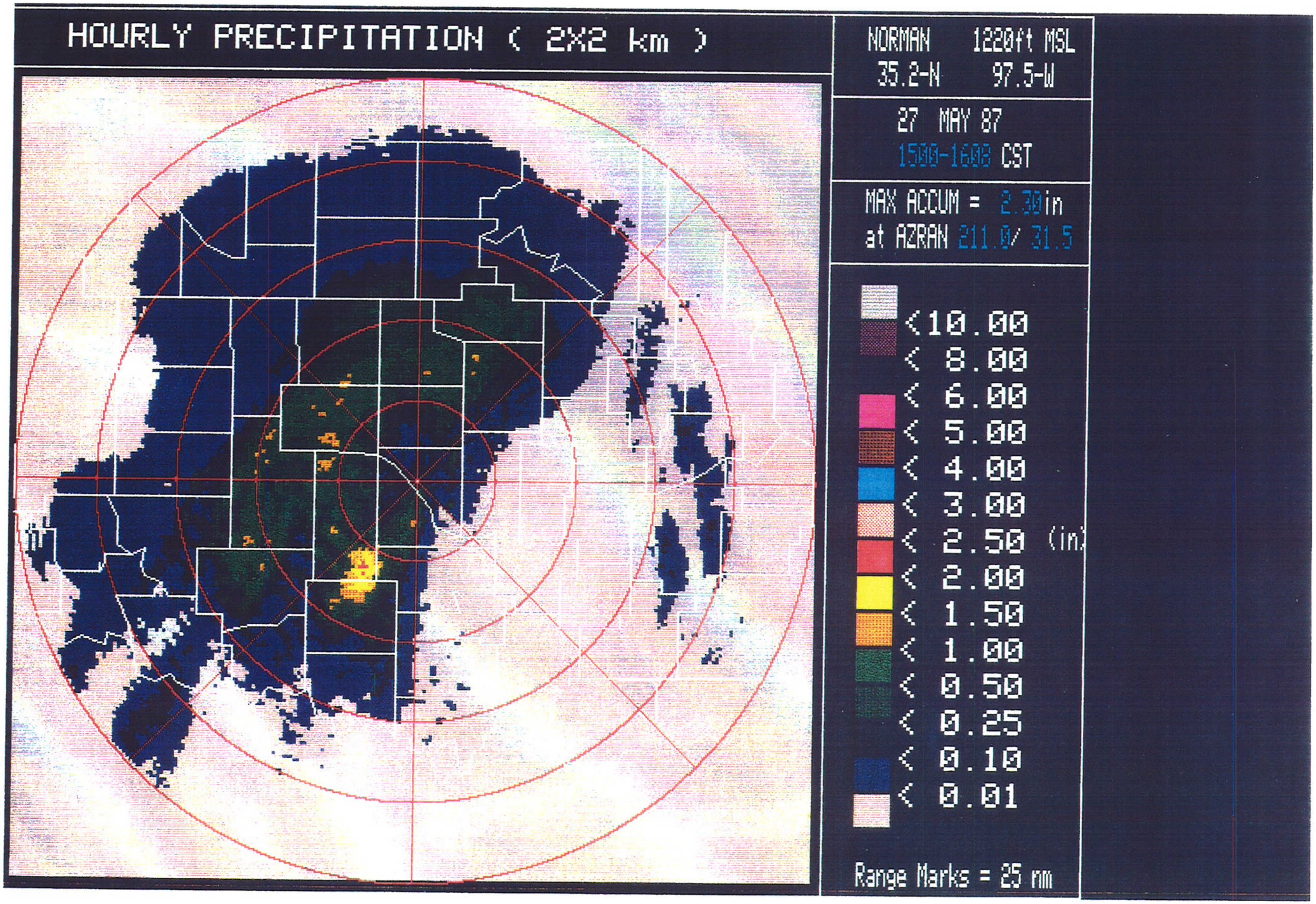

Figure 1. One Hour Total Rainfall for the period 1500 to 1600 CST, May 27, 1987.

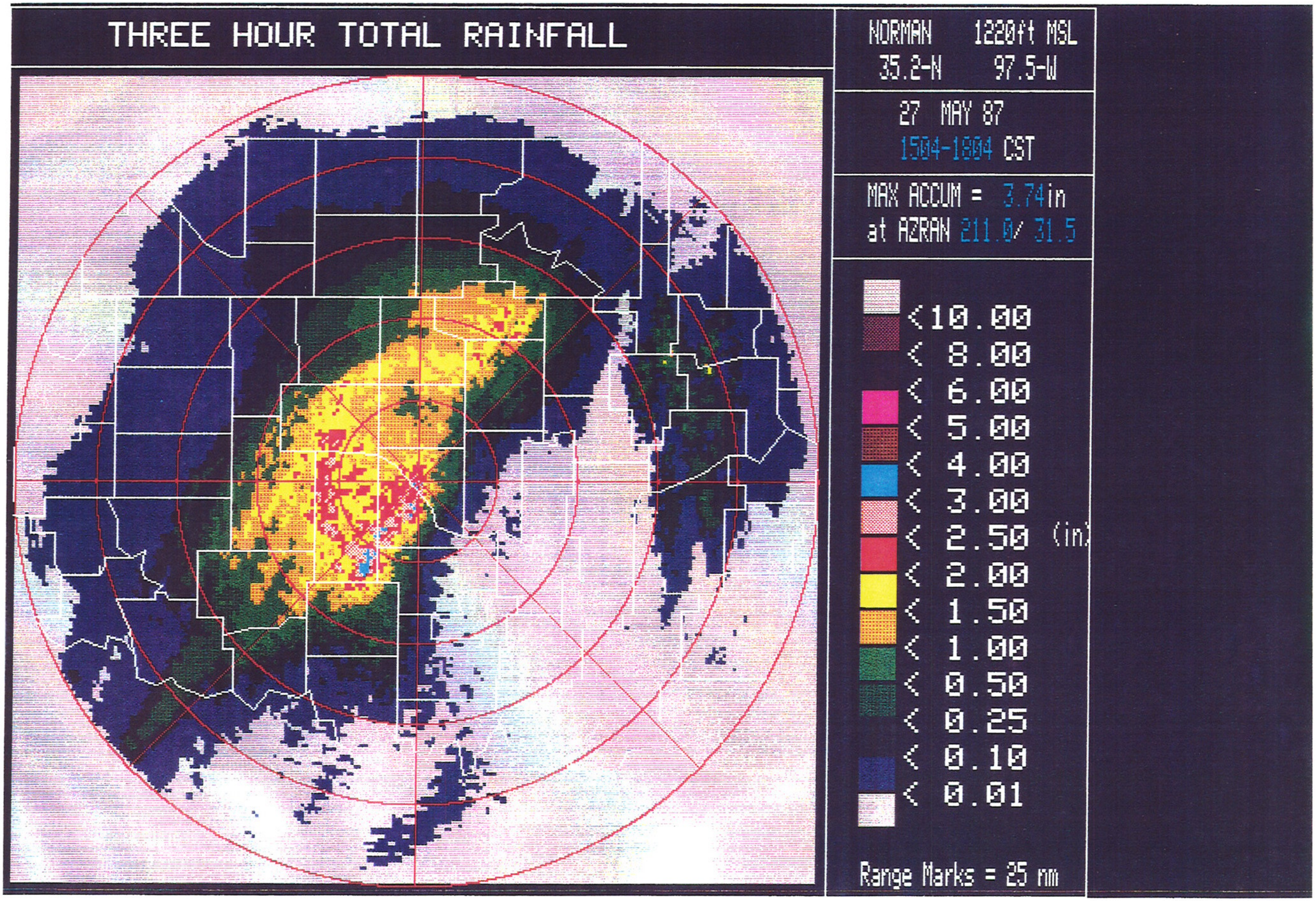

Figure 2. Three Hour Total Rainfall for the period 1504 to 1804 CST, May 27, 1987.

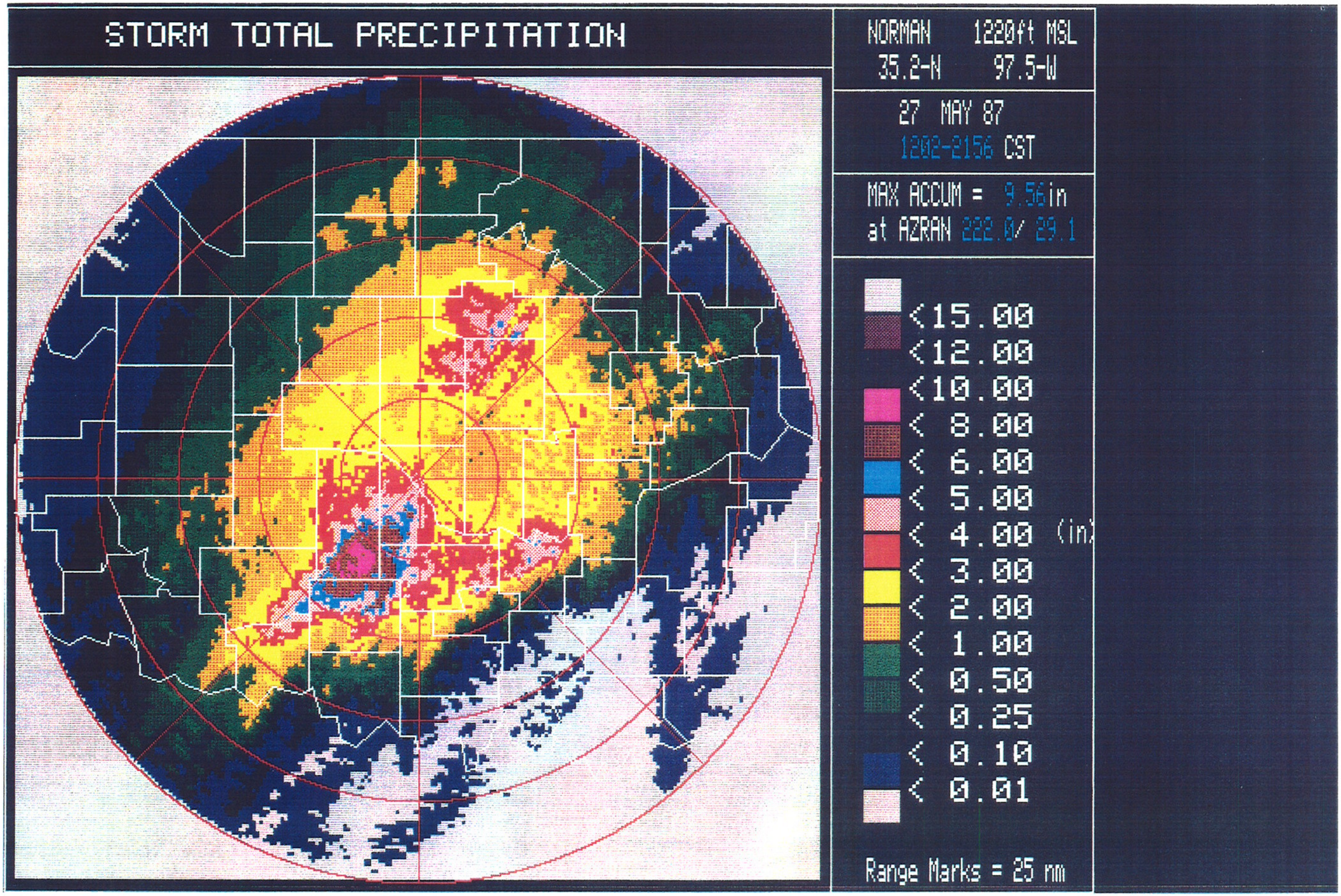

Figure 3. Storm Total Rainfall for the period 1202 to 2156 CST, May 27, 1987.

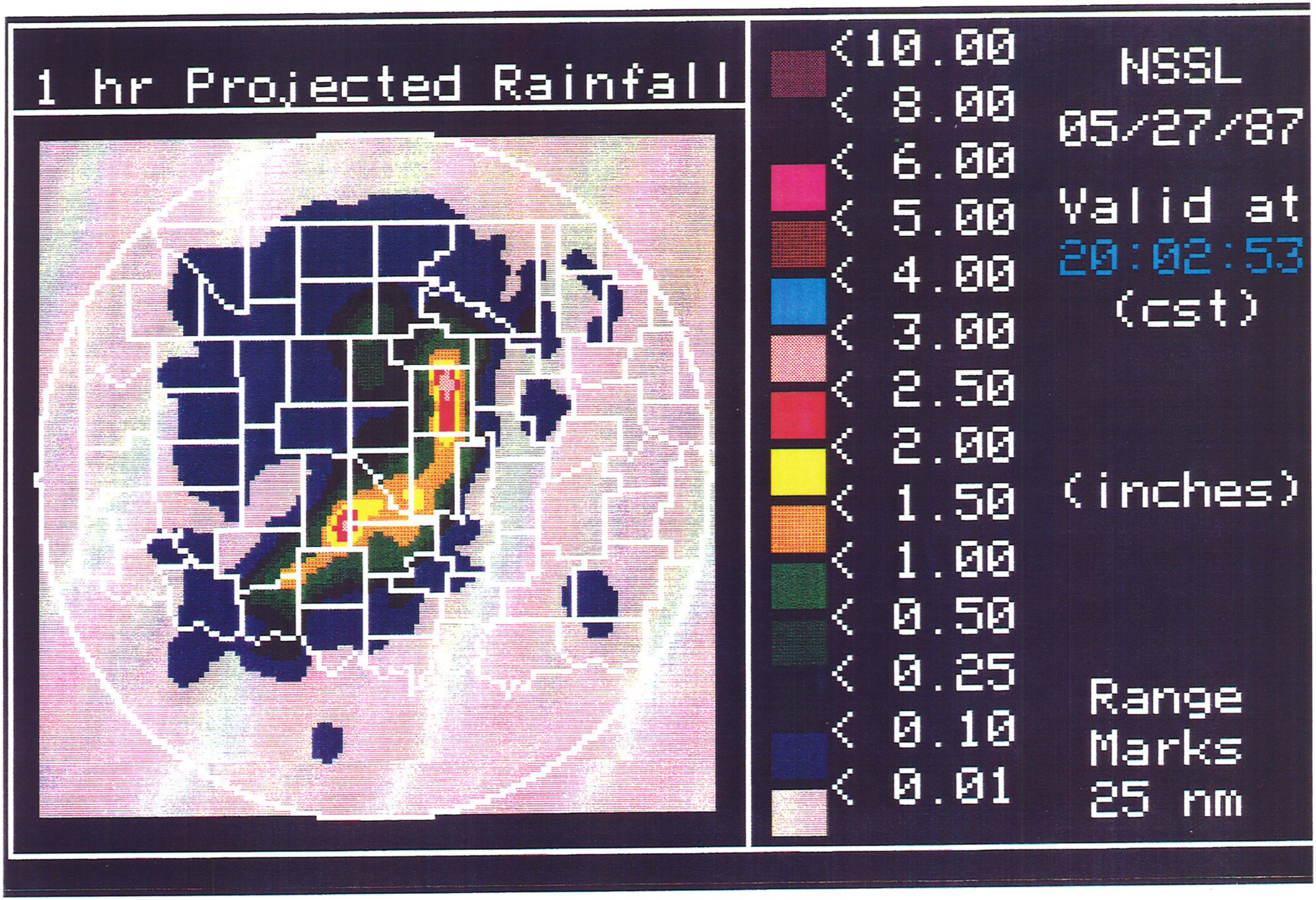

Figure 4. One Hour Total Projected Rainfall for the period 1902 to 2002 CST.

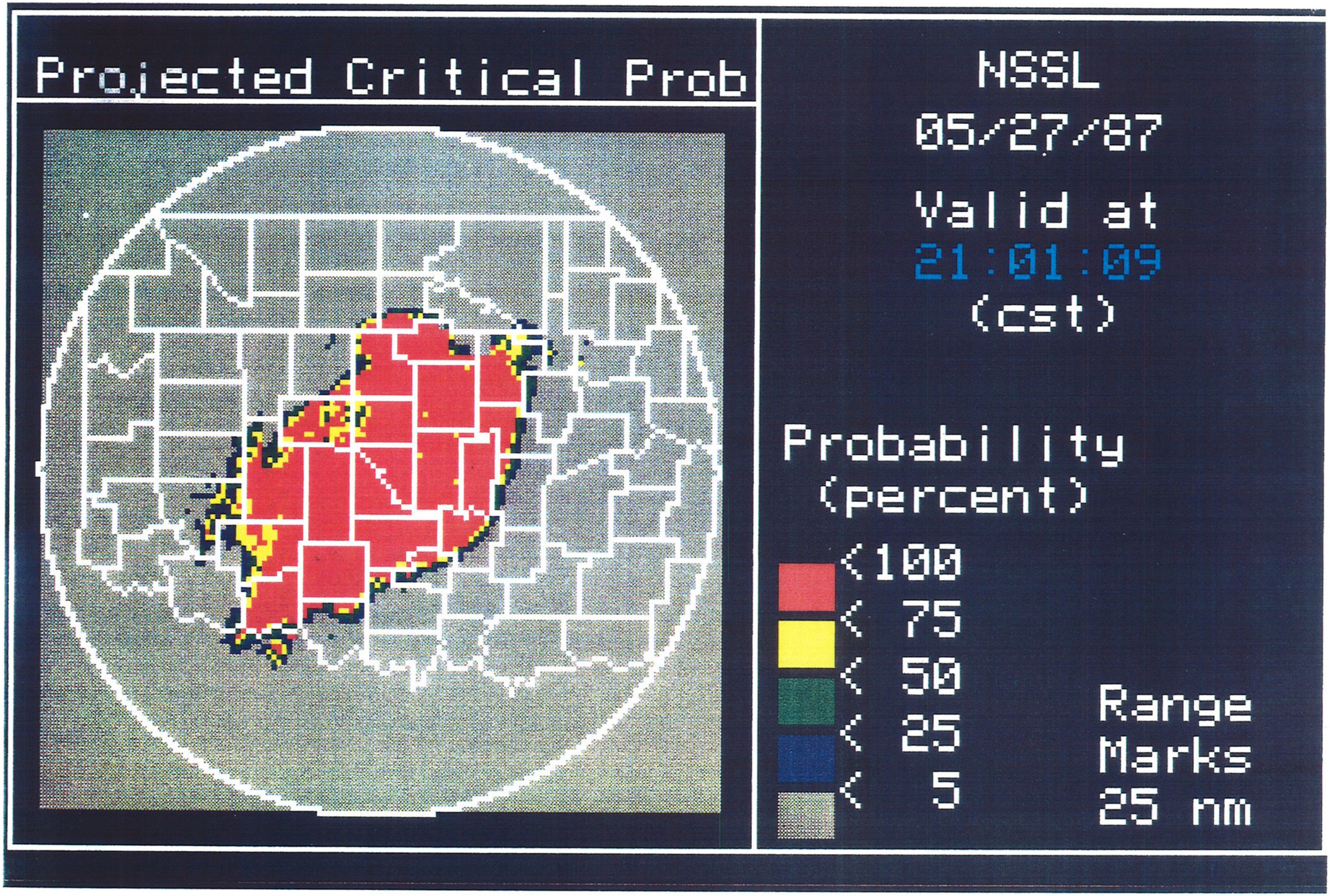

Figure 5. Projected Critical Rainfall Probability at 2001 CST projected for 2101 CST.

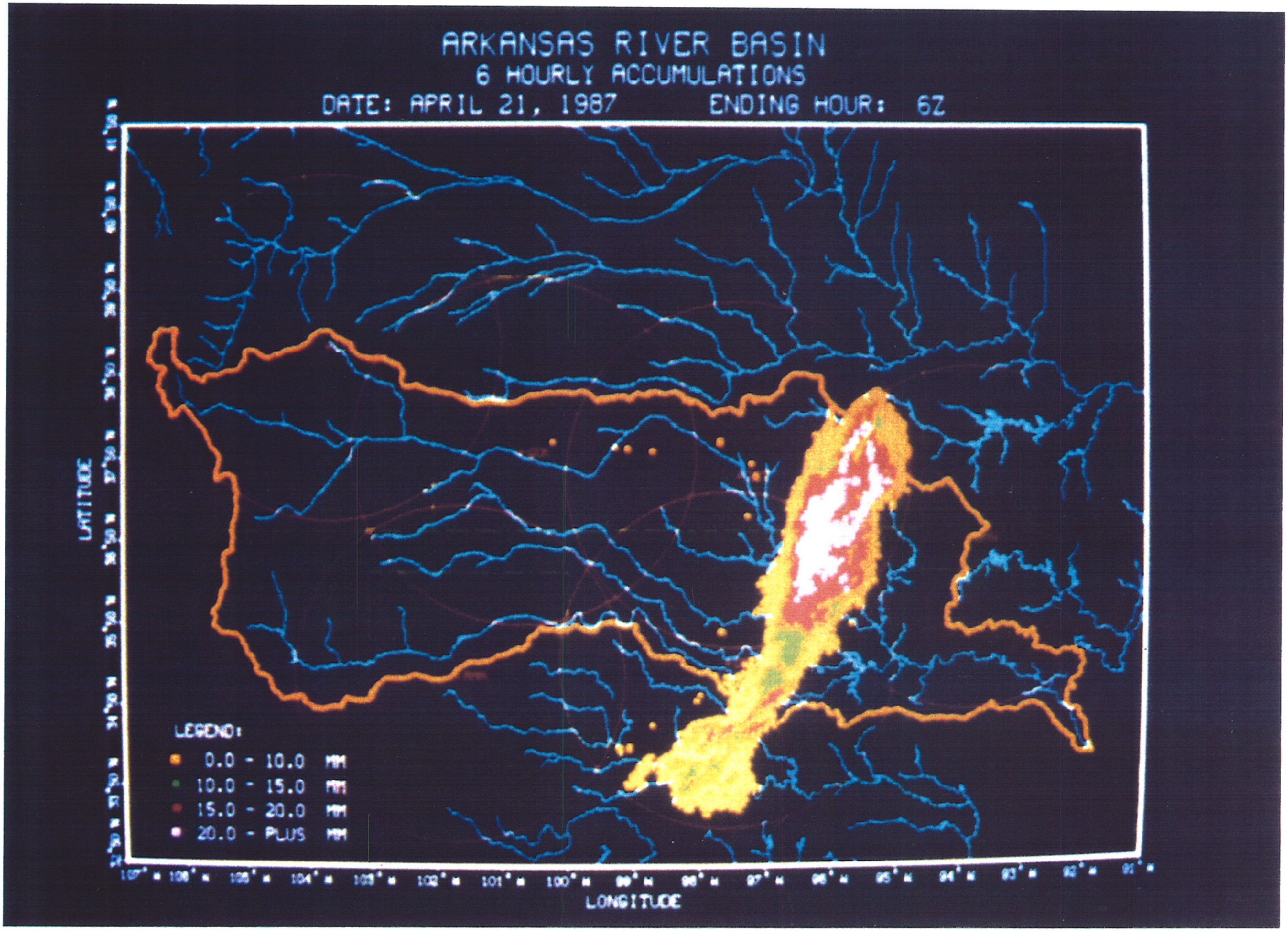

Figure 6. Mosaicked Six Hour Total Rainfall for the Arkansas River Basin.