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INTERACTIVE PRECIPITATION PROCESSING FOR THE MODERNIZED NATIONAL WEATHER SERVICE

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1. INTRODUCTION

The National Weather Service (NWS) is about to undergo an extensive modernization program which will involve new radar systems and new communications and computational equipment to aid in weather forecasting. One of the key pieces of data that the NWS requires is estimates of precipitation. Precipitation data is used by the meteorological forecasters for the issuance of flash flood forecasts and is crucial to the hydrologic forecaster preparing main stem river forecasts. The NWS Office of Hydrology (OH) has been leading the efforts to upgrade the precipitation estimation procedures.

The NEXRAD (Next Generation Weather Radar) program, which will be providing over 110 new radars, referred to as WSR-88D radars, provides the opportunity to greatly increase the spatial and temporal resolution for precipitation estimation. The radar characteristics have been defined such that the WSR-88D will provide quantitative estimates of precipitation far exceeding in utility the qualitative estimates available from the current radar network.

The AWIPS (Advanced Weather Interactive Processing System) will allow greater flow of data between offices than is currently possible while providing the forecaster interactive processing capabilities to analyze the data in ways not previously possible. AWIPS workstations will be located at every WFO (Weather Forecast Office) and RFC (River Forecast Center) in the NWS.

The subject of this paper is the combining of these two new technologies to provide improved precipitation estimates for the NWS. These precipitation estimates will be used as input for hydrologic models for both main stem river forecasts and flash flood forecasts. In addition, the estimates will be the basis for national precipitation summaries which are used for long term precipitation forecasts and for calibration of hydrometeorological models.

2. THREE STAGES OF PRECIPITATION PROCESSING

OH has been working for a decade now preparing its three stages of precipitation processing. Stage 1 processing, also referred to as the NEXRAD Precipitation Processing Subsystem (PPS) will be run on the WSR-88D computer located at the WFOs, as shown in Figure 1. Stage 1 will incorporate a limited amount of rain gage data in order to perform a mean field bias computation while performing a number of quality control procedures to remove erroneous radar data (Ahnert et al., 1983). Stage 2 processing will also be performed at the WFO but on the AWIPS computer. Stage 2 will use additional rain gage data as well as satellite data for quality control to produce a multi-sensor field, merging the radar and gage information through an objective analysis procedure, and a 'gage-only' field. Stage 3 processing, the focus of this paper, will be run at the RFCs, mosaicking the Stage 2 products from all the WFOs in the RFC area of responsibility in order to develop the best possible estimate of precipitation. Stage 3 is the only stage that is interactive and therefore the only stage in which the forecaster will have an opportunity to affect the precipitation field. Significant effort has been made in Stages 1 and 2 to minimize data contamination through various automated quality control procedures. However, not all bad data will be able to be removed automatically. The human eye is still better at pattern recognition requiring the use of these interactive techniques to correct the data. Further description of the three stages of processing can be found in Hudlow et al.(1983; 1989), and Hudlow, (1990).

3. PROTEUS

As part of the NWS modernization activities, a number of risk reduction plans have been developed to ease the transition activities in preparation for the AWIPS environment. OH has participated in these plans with a project referred to as PROTEUS (Prototype RFC Operational, Test, Evaluation and User Simulation) to demonstrate modernization activities at the RFC. As part of PROTEUS, OH has acquired scientific workstations running a UNIX environment for software development and testing of prototype interactive hydrologic and precipitation processing application programs at selected RFCs. A companion paper in this volume discusses other aspects of PROTEUS and NWS Hydrology modernization plans (Fread et al., 1991). The Stage 3 precipitation processing software is part of this PROTEUS risk reduction activity. A preliminary version of the Stage 3 software has been written in C; it uses a commercial off-the-shelf graphics interface running under the X Window System. A more complete description of this environment is provided by Adams (1991).

4. STAGE 3 PROCESSING

At the workstation, the forecaster will be presented a menu of options, one of which will be for Stage 3 precipitation processing. Within this option shall be three sub-options: Regular Hourly Operations, Daily Post Analysis, and Interactive Parameter Editing.

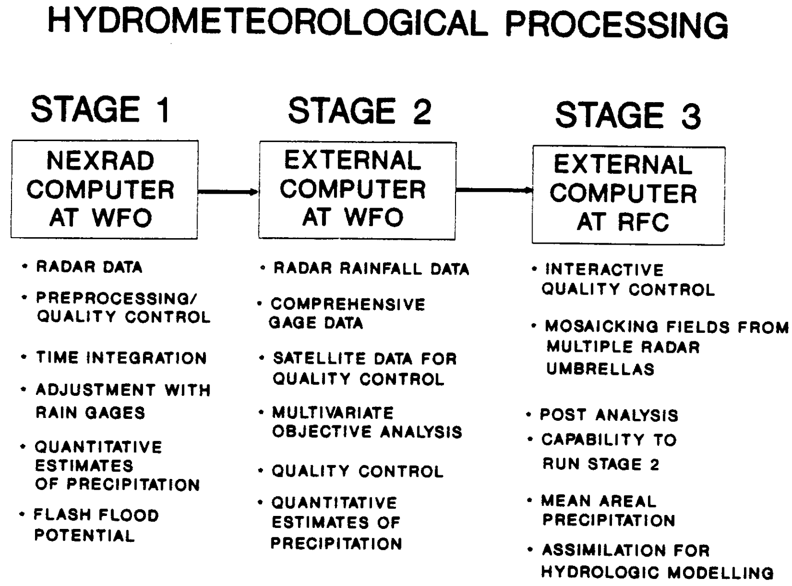

Fig. 1. Three Stages of Precipitation Processing.

4.1 Regular Hourly Operation

Stage 3 hydrometeorological processing will occur at the RFCs. Data is combined from each of the WFO Stage 2 analyses within the area of responsibility to generate a mosaicked precipitation field for the RFC. Each RFC will be receiving data from between 12 and 25 WFO sites. The RFC located in Tulsa is shown in Figure 2 showing the coverage from the NWS WSR-88D within the RFC area of coverage. Stage 3 is the only step of the precipitation processing in which the forecaster can interactively determine the appearance of the precipitation field. A Stage 3 flow diagram is found in Figure 3.

The forecaster has two quality control decisions that can be made within Stage 3. The first is a decision on the quality of the individual Stage 2 multi-sensor fields, which is the merged field of radar and rain gage data. Stage 3 has the capability of displaying side by side on the workstation monitor the multi-sensor and gage only fields generated in Stage 2. If it is believed that the multi-sensor field is excessively contaminated by anomalous propagation or other errors which will be generally apparent to the eye, the forecaster can elect to remove the multi-sensor field from further analysis, and the gage only field will be included in the precipitation mosaic. This decision can be made on a radar by radar basis.

If the multi-sensor field is thought to be only partially contaminated it will be possible to draw a polygon on the workstation to remove a section of erroneous data. This polygon of data will be filled in with the corresponding gage-only field data.

The second quality control decision the forecaster can make regards the quality of the gage data used in the Stage 2 analysis. Within Stage 3 is an option to display the hourly gage accumulation along with corresponding radar accumulations. The forecaster may flag a gage (or multiple gages) from the database, if it is believed that a gage report is in error; and Stage 2 runs for the affected radars will be automatically re-submitted from the RFC, excluding the questioned gage value(s) from its analysis. Following completion of the Stage 2 runs, Stage 3 would be restarted.

In addition to those mentioned, Stage 3 has a few other options to aid in the precipitation analysis. One is the capability to zoom into a small portion (approximately 100-km by 100-km) of the RFC coverage area to view the precipitation field in greater detail. A time lapse feature will also be available to show an animation of the previous six hours of mosaicked data. A number of map overlays will also be provided to assist in locating the heavy precipitation areas. These include states, cities, rivers, and RFC-defined river basin boundaries.

The result of these interactive quality control steps is a precipitation mosaic for the RFC area of coverage. For areas of overlapping radar coverage, the mosaicked value will consist of the average of the non-zero precipitation accumulations. Earlier studies have shown this simple method to be an effective averaging scheme with a minimal processing load. (Hudlow et al., 1979; Patterson et al. 1979).

4.2 Daily Post Analysis

One of the vast sources of data used by the NWS is the network of cooperative observers who report daily precipitation at approximately 12 GMT each day. While this data obviously cannot be incorporated into the hourly Stage 3 products, it is considered that they are essential information to be included for calibration and hydrologic forecasting purposes. Therefore a daily post-analysis option has been included with the Stage 3 software to incorporate this data. The 24 hourly mosaicked fields will be summed up to produce a 24-hour multi-sensor accumulation. In addition, a 'gage-only' field using the cooperative network gages will also be generated, using the radar to indicate the location of precipitation, and the gage data will be weighted to determine the quantitative estimates of precipitation at each grid location. Similar quality control procedures as described for the regular Stage 3 operation will be employed to verify the quality of the cooperative gage network. Any bad gage accumulation values can be removed from the data base. The multi-sensor and gage-only fields will then be merged to produce a final gridded mosaic for the entire RFC. The merging process will, for each grid bin, determine a weighted sum of the daily multi-sensor and gage-only fields. The weight assigned to the gage-only field will be a function of the distance to the nearest gage location and the spatial variability of the storm.

When a satisfactory 24-hour multi-sensor accumulation is obtained, the daily product will be time distributed based on the hourly products previously developed to generate new hourly products for the past 24 hours. These products should be the highest quality precipitation data produced by the three stage processing.

4.3 Interactive Parameter Editing

The Stage 3 procedures include a number of adaptable parameters. The interactive workstation environment allows for easy manipulation of these parameters through a menu driven system. This operation allows the forecaster to edit the parameters without requiring his/her knowledge of the operating system command language and also allows for error checking of the input parameters by imposing a limitation on the allowable values to use. This requirement will be especially important as additional radars are installed since one of the parameters is the number and location of existing radar sites.

5. PRODUCT USAGE

The Stage 3 analysis will result in the production of a gridded array of precipitation. The grid size will be approximately 4-km on a side, varying with latitude. The size of the array will vary for each RFC to allow for a rectangle of data surrounding the boundaries of the RFC. The Stage 3 analysis will be used in two ways. First, it will be used as input to the Mean Areal Precipitation (MAP) preprocessor of the hydrologic models in use at the RFCs. The MAP preprocessor accumulates and averages hourly rainfall estimates to the time and space resolutions required for hydrologic forecasting. The MAP time step required by the RFC may vary from one to twenty-four hours. The MAP time series that are generated are used as input to the RFC hydrologic modelling, including the Interactive Forecast Program described in companion papers by Page (1991), and Wiele and Smith (1991). Second, it will be transmitted to the National Meteorological Center where it could be combined with the precipitation fields from each of the RFCs to develop a national precipitation map and will be able to be used for calibration of the hydrometeorological models. In addition, it would be possible to provide this information to outside users interested in water resources management. In time, these products should produce a historical archive of precipitation information for use with numerous water management programs.

6. CURRENT AND FUTURE STATUS OF STAGE 3 SOFTWARE

A preliminary version of Stage 3 software has been developed and sent to the Tulsa RFC for initial testing and operations. Stage 3 has been tested in a demonstration mode during development using radar data acquired from the Doppler radar located at the National Severe Storms Laboratory in Norman, Oklahoma and the WSR-88D prototype, also in Norman. In the late summer of 1990, the Tulsa RFC began receiving data from the WSR-57 RADAP (RAdar DAta Processor) located in Oklahoma City in a real-time mode. This data was re-mapped to the appropriate grid for use by Stage 2 and 3 processing and these packages have been used in test operations by the RFC since that time. The implementation of the first operational WSR-88D in Oklahoma City in the spring of 1991 and completion of the new MAP processor will result in routine operation of the Stage 3 precipitation processor. In time, Stage 3 will be available at all 13 RFCs within the United States and should allow for enhanced precipitation analysis for the NWS hydrologic forecaster.

7. SUMMARY

The Stage 3 Precipitation Processor has been developed by the National Weather Service Office of Hydrology for use at the River Forecast Centers. It is designed to produce the highest quality precipitation data available to the forecasters at spatial and temporal scales not previously achievable. The modernization activities of the NWS -- the introduction of the WSR-88D radars, and AWIPS, along with new processing capabilities such as the Stage 3 software -- should result in improved precipitation estimation and thereby improved hydrologic forecasting.

8. ACKNOWLEDGEMENTS

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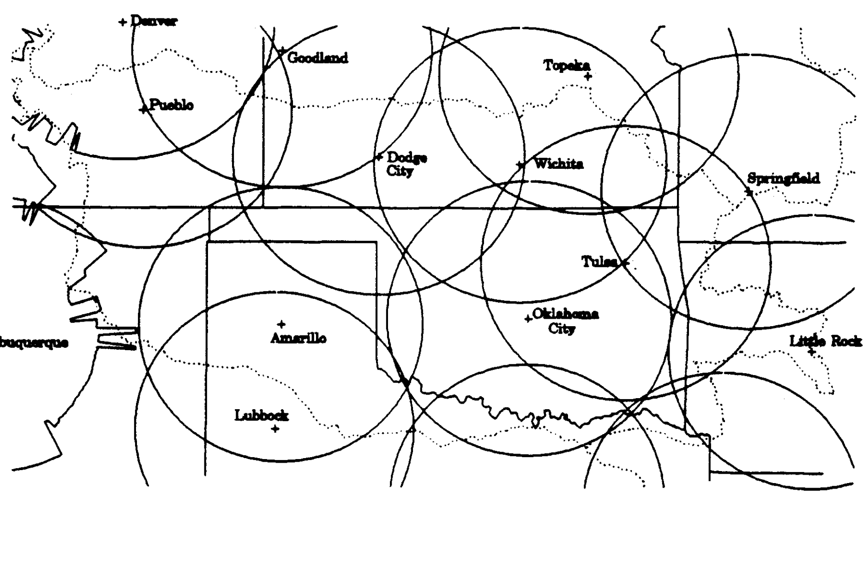

Fig. 2. Tulsa River Forecast Center boundary (dotted line) showing locations and coverage extent of WSR-88D network. Not shown are three Defense Department radar sites which will provide coverage for the RFC.

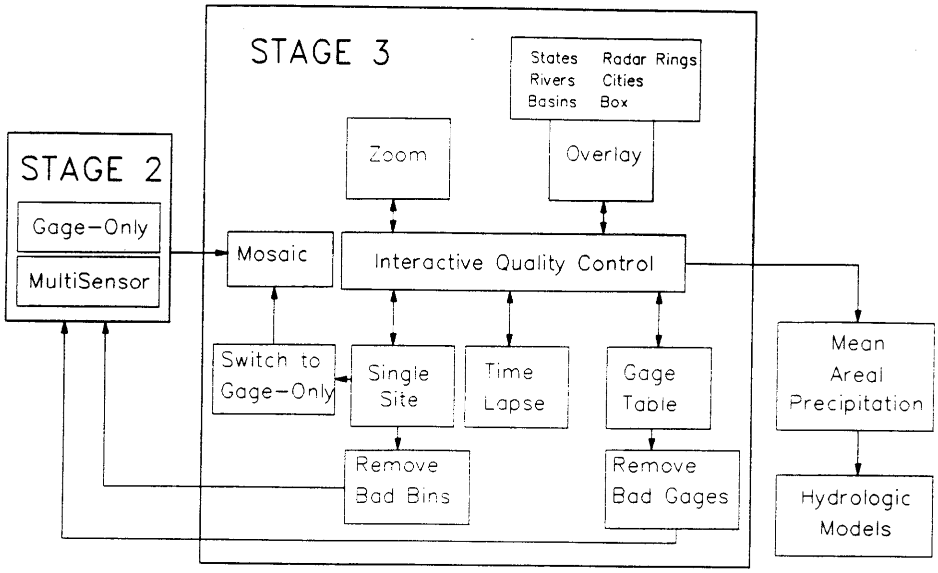

Fig. 3. Flow Diagram for Stage 3 Precipitation Processing (Regular Hourly Operation).

9. REFERENCES

Adams, T.E., 1991: Graphical User Interface Concepts for hydrologic Forecasting in the Modernized Weather Service *Preprints, 7th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology*, AMS, New Orleans, January 13-18, 1991.

Ahnert, P.R., Hudlow, M.D, Johnson, E.R., Greene, D.R. and Dias, M.P.R.,1983: Proposed 'On-Site' Precipitation Processing System for NEXRAD, *Preprints, 21st Conference on Radar Meteorology*, American Meteorological Society, Edmonton, Alberta, Canada, September 19-23, 1983, pp. 378-385.

Fread, D.L., G.F. Smith, and G.N. Day, 1991: Role of Real-Time Interactive Hydrologic Processing in Support of Water Resources Forecasting in the Modernized Weather Service *Preprints, 7th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology*, AMS, New Orleans, January 13-18, 1991.

Hudlow, M.D., R. Arkell,, V. Patterson, P. Pytlowany, and F. Richards, 1979: Calibration and Intercomparison of the GATE C-Band Radars, *NOAA Technical Report EDIS 31*, US Department of Commerce, 98 pp.

Hudlow, M.D., Greene, D.R., Ahnert, P.R., Krajewski, W.F., Sivaramakrishnan, T.R., Johnson, E.R., and Dias, M.P.R.,1983: Proposed Off-Site Precipitation Processing System for NEXRAD, *Preprints, 21st Conference on Radar Meteorology*, American Meteorological Society, Edmonton, Alberta, Canada, September 19-23, 1983, pp. 394-403.

Hudlow, Michael D., Smith, James A., Walton, Mark L., and Shedd, Robert C.,1989: NEXRAD - New Era in Hydrometeorology in the United States, *Preprints of the International Symposium on Hydrological Applications of Weather Radar*,University of Salford, Salford, England, August 14-17, 1989, paper B-1.

Hudlow, Michael D., 1990: Modern Era of Rainfall Estimation, *International Symposium on Remote Sensing and Water Resources*, Enschede, Netherlands, August 20, 1990.

Page, D. 1991: The Interactive NWS River Forecast Program *Preprints, 7th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology*, AMS, New Orleans, January 13-18, 1991.

Patterson, V.L., Hudlow, M.D., Pytlowany, P.J., Richards, F.P., Hoff, J.D., 1979: GATE Radar Rainfall Processing System *NOAA Technical Memorandum EDIS 26*, Center for Environmental Assessment Services, NOAA, 34pp.

Wiele, S. and G.F. Smith, 1991: Improved Hydrologic Forecasting with the Interactive NWS River Forecast Program *Preprints, 7th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology*, AMS, New Orleans, January 13-18, 1991.