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A PROTOTYPE OPERATIONAL 0-1 HOUR RADAR-BASED FLASH FLOOD POTENTIAL ALGORITHM

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1. INTRODUCTION

The National Weather Service (NWS) is currently implementing within AWIPS (Advanced Weather Interactive Processing System) a nationwide operational capability termed Flash Flood Monitoring and Prediction (FFMP) to monitor and predict the potential for flash flooding using WSR-88D-derived rainfall estimates and other information (Smith et. al. 2000, Glaudemans 1999). The Hydrologic Research Laboratory has developed a prototype algorithm, Flash Flood Potential (FFP), that compares WSR-88D rainfall estmates with “flash flood guidance” (FFG) rainfall that is computed daily by the NWS River Forecast Center’s operational hydrologic models. These FFG rainfall amounts depend on the soil moisture state and represent the approximate threshold basin-average rainfall depth over a given duration that would cause small streams to begin flooding. Wet soils are characterized by relatively low FFG (and therefore high flood threat), and vice-versa. Comparison of these thresholds with radar-estimated rainfall provides information on flood threat.

The FFP computes gridded radar rainfall estimates for a given WSR-88D radar domain and compares them with corresponding gridded FFG for durations of one, three, and six hours to assess the potential for flash flooding. In addition, it produces a 0-1 hour quantitative precipitation forecast (QPF) based on extrapolation of radar rain rate fields forward in time using a local pattern matching technique. This forecasted rainfall field is also compared with FFG to determine future flood threat. The algorithm ultimately produces a probabilistic forecast of the likelihood that radar rainfall estimates will exceed FFG called the Critical Rainfall Probability.

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2. HISTORY OF THE FFP ALGORITHM

The Flash Flood Potential algorithm was originally developed and tested by HRL beginning in 1984 with the intention of implementing it operationally within the NEXRAD system (Walton et. al. 1985, Walton and Johnson 1986, Walton et. al. 1987). The NEXRAD Interim Operational Test Facility (later to become the WSR-88D Operational Support Facility, OSF) performed additional tests on the algorithm and recommended improvements necessary before deployment (O’Bannon 1987). The NOAA Forecast Systems Laboratory (FSL) also implemented and tested the algorithm beginning in 1988 (Kelsch and Walker 1989, Kelsch 1990). FFP products were made available in real time on FSL’s early AWIPS prototype system to forecasters at the Denver, Colorado NWS forecast office beginning in 1990 using radar data from NCAR’s Mile High radar. Favorable reviews were received from forecasters (Tunnel 1990). However, when the radar was decommissioned, the FFP ceased running operationally in Denver.

In 1992 the NWS requested that the FFP be implemented on the WSR-88D radar to provide flash flood warning capability at the forecast offices, however due to the processing power and disk space limitations of the radar, the OSF recommended in 1994 that the algorithm be implemented within AWIPS.

3. ALGORITHM INPUTS

There are two primary input data sources: WSR-88D reflectivity factor data every volume scan and flash flood guidance rainfall depth over the radar domain.

The algorithm computes radar-derived rainfall accumulation over three durations (1, 3, and 6 hours) consistent with the durations of the FFG. Despite the fact that the existing rainfall algorithm resident on the WSR-88D already generates rainfall accumulations updated every volume scan using reflectivity measurements (Fulton et. al. 1998), there are currently no full-data-resolution (i.e., non-quantized) rainfall products on the polar grid that are available outside of it (such a product will be available in the next software build). Since AWIPS is external to the WSR-88D, it is therefore necessary within the FFP to regenerate the rainfall accumulations from the raw reflectivity data using the WSR-88D Digital Hybrid Scan Reflectivity (DHR) product that is available on the polar grid (1 deg by 1 km) every volume scan and contains the full reflectivity data resolution (0.5 dBZ). Following the logic of the WSR-88D rainfall algorithm, reflectivity is transformed to rain rate using a Z-R relationship such as $Z=300\ R^{1.4}$, and the rain rates are then summed over time to produce accumulations updated every volume scan on the polar grid. If rain gauge data are available, corrections to the radar estimates can be applied. When the gauge-adjusted digital rainfall product on the polar grid is available from the WSR-88D in the next software build, this reflectivity-rainrate-accumulation processing step will no longer be needed.

The second primary input to the FFP algorithm is the flash flood guidance. The FFG is the approximate amount of rainfall depth over a basin that would cause small streams to reach bankfull (Sweeney 1992). It is computed using a lumped rainfall-runoff model in concert with a soil moisture accounting model within the NWS River Forecast

System running operationally at the River Forecast Centers and is updated generally once per day at 1200 UTC. FFG is computed for each RFC-defined basin and is then remapped onto the national HRAP grid (nominally 4 km rectilinear grid spacing). In the past, FFG had been spatially averaged to produce a single value over each county or forecast zone, but HRAP-gridded FFG is now becoming available operationally.

4. PROCESSING STEPS

There are two main statistically-based processing components of the FFP that will be briefly reviewed in this section: 1) the projection subalgorithm that computes the 0-1 hour rainfall forecast, and 2) the flash flood assessment subalgorithm that compares the observed and forecasted rainfall fields with the current FFG.

4.1 *Rainfall Projection*

To simplify the estimation of the 0-1 hour future rainfall, the polar arrays of rain rate (computed from reflectivity) are remapped to the rectilinear HRAP coordinate system. This grid system is exactly 1/40th the grid size of the Limited Fine Mesh (LFM) grid used in earlier atmospheric numerical models and extends across the conterminous U.S.

Pairs of adjacent rain rate arrays separated in time by typically 10-12 minutes are then used to estimate local radar echo motion vectors using a pattern matching technique similar to many well-known cross-correlation techniques (Wilson et. al. 1998). Every volume scan, local storm velocity vectors are computed every fifth HRAP grid cell (~20 km) by shifting a 5x5 group of grid cells in both orthogonal directions and finding the offset grid location of the minimum absolute rain rate difference over that 5x5 box between the first rate array and the second one. Once all storm motion vectors are computed and smoothed for a given volume scan, the rain rate array is advected forward in time, grid point by grid point, at 10 minute timesteps out to 60 minutes and the accumulations are computed. The rain rate array is first spatially smoothed each 10 minute timestep prior to advection, the details and motivation of which are beyond the scope of this paper.

Storm development and decay are not explicitly represented in this formulation, though it is somewhat more sophisticated than simple extrapolation of the latest rain rate fields. The output of this projection procedure is a one-hour gridded QPF on the HRAP grid. If desired, these projected accumulations can be easily converted to basin averages if basin boundary information is available.

4.2 *Flash Flood Assessment*

The last step is the assessment of the flash flood threat. The current observed and projected rainfall accumulations on the HRAP grid over 1, 3, and 6-hour durations are compared with the corresponding gridded flash flood guidances over the radar domain every volume scan to produce HRAP-gridded observed and projected flash flood probabilities. Additionally, basin maximum or basin average probabilities can be generated as well if desired by aggregating the HRAP grid cells that lie within each basin.

The flash flood probability is an estimate of the probability that the actual rainfall for some time during the rain event has exceeded (for the observed flash flood probability) or will exceed (for the projected flash flood probability) the flash flood guidance value. Even though the observed radar rainfall accumulations are deterministic, the 0-1 hour projected accumulations carry along statistical information associated with their uncertainty, and from that information flash flood probability can be computed.

If a rainfall event is in progress when the FFG values are updated by the River Forecast Centers (typically within a few hours after 1200 UTC each day), the algorithm properly takes this into account by only considering rain that has occurred *after* that time since rainfall occurring previously has already been incorporated into the updated FFG amounts. This will become more important of an issue when the RFCs eventually update the FFG twice per day at 0000 UTC in addition to 1200 UTC since flash flooding typically occurs more frequently in the evening hours.

5. VERIFICATION OF PROJECTION PROCEDURE

In order to evaluate the integrity of the rainfall projection procedure, we have begun a verification project using archived output products from runs of the algorithm. Archived data exists since early March 1999. Because the algorithm produces projected rain rate arrays at 10 minute intervals into the future out to 60 minutes for each volume scan as an intermediate step toward computing the projected accumulations, it is possible to compare these rate arrays with the corresponding observed rate arrays (considered "truth") on the HRAP grid for each of the six forecast lead times.

We are also generating verification statistics for the 1, 3, and 6-hour projected rainfall accumulations (note: the 3-hour rainfall accumulation projection is actually composed of a one-hour rainfall QPF and 2 hours of observed rainfall, and likewise for the 6-hour projection). This will provide guidance on how trustworthy these short-term QPFs are as a function of size of the forecast area, rainfall intensity or accumulation, forecast lead time, and the projection method.

In addition to the projection procedure described in the previous section, we are also evaluating a cross-correlation technique producing a single storm motion vector and then comparing these forecasts with one in which the radar fields are assumed to remain stationary over the one-hour forecast period to serve as a baseline for comparison.

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