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UNDERSTANDING THE MESOSCALE PROCESSES OF FLASH FLOODS: IMPACTS ON PREDICTION AND RESPONSE

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1. INTRODUCTION

Dangerous flash floods are often storm-scale events with the most violent episodes occurring over a few to tens of square miles and within a few hours of the causative rainfall. A qualitative definition from a North American Treaty Organization (NATO) Advanced Study Institute describes a flash flood as a flood in which the causative rainfall and the runoff are occurring on the same time and space scale (NATO, 2000). Such events are very similar to severe weather phenomena in terms of the localized and potentially life-threatening consequences.

However, flash floods are not defined by objective measures like severe weather (i.e. 3/4–inch hail, 58 mph wind). Objective flash flood guidance related to rainfall amount or stream rises does not exist due to the complex relationship between precipitation intensity, amount, and its impact on fast-response basins. The National Weather Service (NWS) definition of a flash flood requires that it should occur within six hours of the rainfall (NWS, 1997). However, even the NWS definition does not offer sufficient specificity since many flash floods occur less than two hours from the causative rainfall. The spatial and temporal coverage of flash flood "warnings" will sometimes be more comparable with a "watch" in severe weather. This is reflective of the state-of-the-art in flash flood forecasting.

Current tools such as Flash Flood Monitoring and Prediction (FFMP) will assist with the need for merging high-resolution rainfall information with detail basin information (Filiaggi, et al. 2002). FFMP guidance is currently limited by the limitations of gridded rainfall data and flash flood guidance (FFG).

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2. STORM-SCALE PROCESSES

There are many contributing mechanisms involved in flash flood development. The most important factors are those affecting precipitation intensity as well as those related to runoff. The balance between basin response and the precipitation intensity is very delicate. Previous studies have looked at the importance of precipitation efficiency and other contributing factors to anomalously high rainfall rates (Kelsch, 2002; Kelsch, et al. 2000). Other studies have looked at basin characteristics, including size, common to major flash flood episodes (Baeck and Smith, 1998; Davis, 2001). Small basins, ≤50 km^2 (≤20 mi^2), are much more prone to flash flooding. Particular problems occur in areas of steep terrain or in basins that have been altered through processes such as urbanization or fire.

Although anomalously high rainfall rates are often characteristic of flash flood episodes, these are not necessarily the product of high precipitation efficiency. Large amounts of moisture processed by strong, organized convection can result in extreme, localized precipitation rates even when the storm system as a whole may be somewhat inefficient at converting available moisture into precipitation. It is also important to remember that flash flooding can occur when the precipitation rate is enough to overwhelm the basin's ability to accommodate that rate. Thus, the hydrologic response of a given basin can be the most important physical process resulting in a flash flood. For example, a heavily urbanized basin may experience flash flooding from convective rainfall rates that are not considered particularly extreme.

Figure 1 depicts the relationship between the size of the intense precipitation area to that of the basin. In Fig. 1a the intense precipitation area is small with respect to the basin. Thus, the risk of flash flooding at the outlet of this basin is small. In figure 1b, although the intense precipitation area is rather small, the basin is very small and thus the intense precipitation covers almost the entire basin. The basin response to the precipitation poses a greater flash flood risk than the situation in Fig. 1a. Small basins like that in Fig. 1b are typical of steep terrain areas and in urban areas (even gently sloped ones) where human development essentially breaks natural basins into numerous small sub-basins. Fig 1c depicts a large area of intense precipitation that could present a flash flood risk even in somewhat larger basins. Situations with high precipitation efficiency may not only increase the potential precipitation rate, but can also increase the area covered by the intense precipitation.

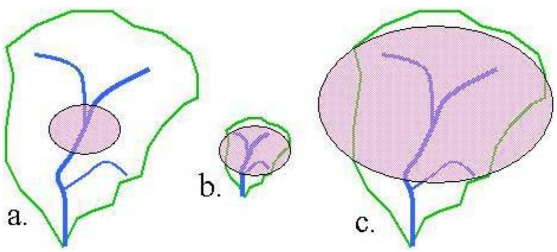

Figure 1: Three basins are depicted and assumed to have the same hydrologic characteristics except "b" is the smaller than the other two. The ovals depict the area of intense precipitation which is a) small with respect to the basin, b-c) large with respect to the basin.

Fig. 2 shows an isohyet analysis of the 5.5-hour rainfall (Kelsch, 1998) for Fort Collins, Colorado on the evening of 28 July 1997. Although the area covered by the 150-mm (6-in) isohyet was rather large for this semi-arid location due to the unusual presence of deep, tropical moisture, it was still a rather small area of intense rainfall. However, the severely impacted Spring Creek (blue line in Fig. 2) drained only 32 km^2 (13 mi^2) between its headwater and the railroad embankment by the red X's in the figure. Severe flood damage was experienced at the red X's in Fig. 2 just downstream of a detention pond along Spring Creek. Although the impact on the small, upper Spring Creek basin was devastating, the total volume of water is not particularly extreme with respect to larger basins and thus the impact on the larger streams a little further downstream was minimal. This event can be reviewed further with a webcast listed in section 6 called *Urban Flooding: It Can Happen in a Flash*.

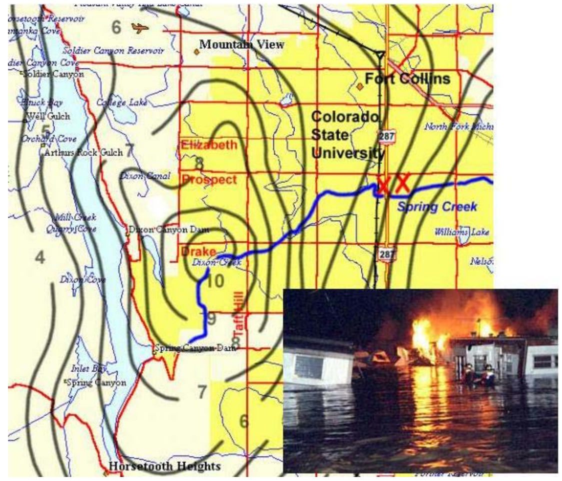

Figure 2: Isohyetal analysis (1-in intervals beginning with 3 in) for the 28 July 1997 Fort Collins storm with Spring Creek in blue and the red X's located just downstream of a detention pond. Insert shows the scene at the left X.

Fig. 3 depicts a situation where regenerative convection repeatedly impacts the same area. These situations are most likely in areas of the central United States that can experience quasi-stationary MCS's and are described as frontal or mesohigh events by Maddox, et al. 1979. In these situations the intense precipitation keeps reforming in a common area and moving along a quasi-stationary axis as shown by the shaded pink ovals in the Fig. 3. Sometimes the axis can shift or pivot with time as shown with the tan-colored ovals in Fig. 3. The intense rains can impact many small basins and even some relatively large ones (>60 km^2).

A real situation like that depicted in Fig. 3 is shown with the isohyetal analysis in Fig. 4. This record rainfall event during the night of 17-18 July 1996 occurred near Chicago and produced a 24-h state rainfall record of 431 mm (16.96 in) in the Chicago suburb of Aurora, Illinois. Much of that rain fell in only six hours. The 150-mm (6-in) area is shaded in Fig. 4 and the red oval shows the 6-inch area of the Fort Collins storm for comparison. The large amounts of moisture processed by regenerative MCS's in the central states can result in very widespread intense rainfall impacting many small basins and perhaps a few that are somewhat larger.

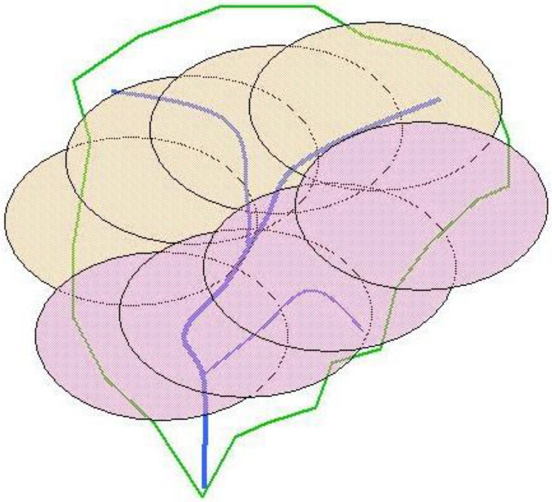

Figure 3: Shaded ovals depict intense precipitation areas that occur along an axis of regeneration. The tan ovals represent the axis of training echoes initially and the pink ovals represent a slight shift in the axis downstream over time.

Figure 4: Isohyetal analysis of the 18 July 1996 storm. The 6- and 10-inch isohyets are shown. The red oval near the top of the graphic represents the 6-inch area of the Fort Collins storm (Fig. 2) for comparison.

3. TRAINING ISSUES

The localized nature of flash flood events requires an approach to the forecasting challenge similar to that for severe weather. Unlike severe weather it will take more than knowing the meteorological indicators. Detailed knowledge and understanding of the hydrologic processes are necessary as well. There will not be objective criteria such as a given amount of rainfall, or a specific rise in a stream. These parameters will vary and be dependent on hydrologic conditions, stream volume, and rainfall rate. It is the delicate balance between the rainfall and the basins ability to accommodate that rainfall that determines the onset and severity of flash flooding.

The FFMP system (Filiaggi, et al. 2002) provides the ability to combine high-resolution multi-sensor rainfall data with high-resolution basin information. Currently the main input to the rainfall data is the radar network. All of the limitations of radar precipitation will affect the FFMP guidance. It is important that users of FFMP remain informed about radar performance and its future improvements.

Although the basin detail in FFMP provides information about basin size so that one can monitor small basins, there currently is not much other hydrologic information except what is inherent in the FFG generated by the River Forecast Centers (RFCs). The utility of the FFMP guidance will depend on the ability of FFG to represent the storm-scale hydrologic conditions. Thus, it is very important for users of FFMP to understand the limitations of FFG. Furthermore, customizing the basin information to establish hydrologic connectivity between basins and to identify locations with important hydrologic conditions (burn scars, urban areas, flood prone road crossings) is important.

Fig. 5 shows the radar-derived accumulation from the Ogallala, Nebraska flood of 6 July 2002. Interstate highway 80 (I-80) is depicted in the figure. The South Platte River (not depicted) runs along and just to the north of I-80. Thus, I-80 is between the area that received the most intense rainfall and the river. Heavy rainfall in a small, gently sloped rural area south of I-80 produced tremendous amounts of runoff that overwhelmed small creeks and agricultural ditches as the water made its way toward the South Platte River. Culverts under I-80 could not accommodate the flow, and the highway was washed out.

Although the Ogallala case did not involve the complexity of urbanization, rugged terrain, or fire scars, it still is a good example of the need for detailed and easily understood information about hydrologic processes during extreme precipitation events. To provide detail about which local areas and highways would be impacted, a forecaster needs fast and accurate information about the hydrologic connectivity of the small basins and where there may be a bottleneck in the flow toward the larger channels. FFMP is a start, but the evolution of the software and its input, and training of the users is very important.

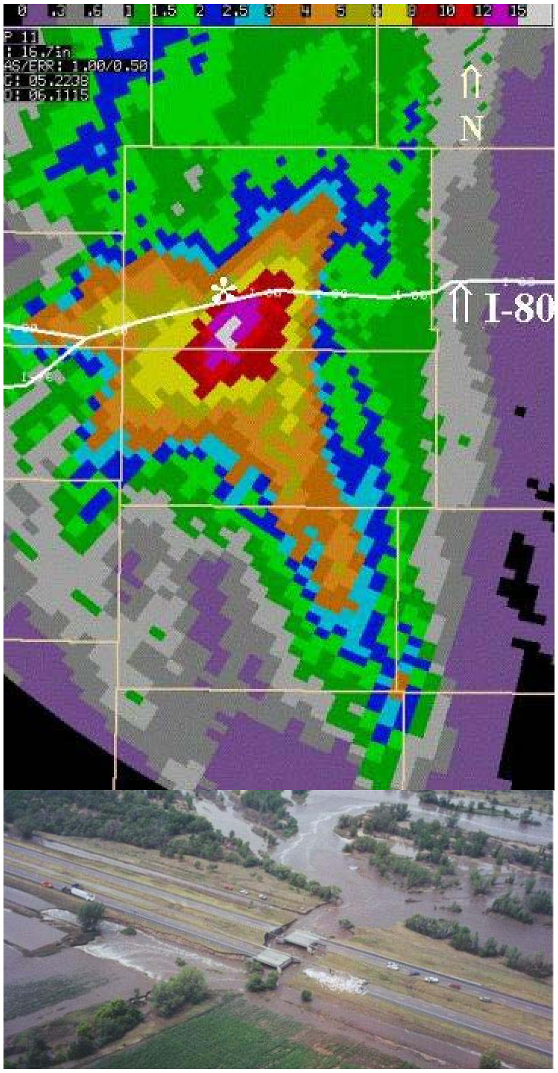

Figure 5: Storm total accumulation from the KLBF radar at 1600 UTC 6 July 2002 near Ogallala, Nebraska. Photo shows both sides of Interstate 80 washed out near the Ogallala exit (indicated by the asterisk on the radar image).

4. SUMMARY

The next big step in flash flood forecasting will be when the hydrologic information is improved to be representative of storm scale runoff and presented in a way that is easily assimilated into the forecast process. FFMP may very well be the avenue for these improvements. Without these improvements it will continue to be difficult to issue flash flood warnings with detail about specific drainages, urban areas, or highways.

For now training needs to focus on understanding both the meteorological and hydrologic input to the flash flood forecasting process. Training about radar limitations including physical processes that influence precipitation rate must continue in order to keep awareness high. Hydrologic information and the utility of FFG still has a long way to go. Training needs to help the forecasters understand the limitations of the current FFG and to make the most appropriate use of their basin information with other forms of Geographic Information Systems (GIS) data. In this way, users can make the best use the current tools and be prepared for the evolving utility of the next generation of flash flood tools (Davis, 2002). Many issues regarding flash flood forecasting are discussed in the *Flash Flood Operations and Awareness Teletraining (FLOAT)*. A recorded version of this training is listed in section 6.

Training and development issues that are above the forecaster level include; 1) prioritizing the need to understand and model warm-season precipitation processes, 2) advancing the understanding of flash flood hydrology so that FFG can be more representative of small, fast-response basins, and 3) developing more specific guidelines with respect to the definition of flash floods. In a recent flash flood meeting there was persuasive argument to remove the “flash flood’ heading and limit the heading to “flood” or “hydrologic” statements or warnings. While there is some merit to this argument, we need to realize that we still have a forecast problem with the short-fused end of the flood spectrum. The ability for forecasters to get the appropriate public response for rapid-onset floods will depend on the ability of the meteorological community to improve its data, understanding, and ultimately its forecasts of these elusive and localized events.

5. ACKNOWLEDGEMENTS

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6. WORLD WIDE WEB LINKS

From the COMET Computer-based Training Modules pages, http://www.comet.ucar.edu/modules/index.htm you can access the *Flash Flood Operations and Awareness Teletraining* material, http://www.comet.ucar.edu/class/FLOAT_2001/index.htm, and the Webcast titled *Urban Flooding: It Can Happen in a Flash,* http://www.comet.ucar.edu/modules/urbflood.htm.

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