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POST-WILDFIRE FLASH FLOODING: AN ANALYSIS OF COLORADO WILDFIRES AND THE NORTH AMERICAN MONSOON FROM 1995-2002

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1. INTRODUCTION

The National Center for Atmospheric Research (NCAR) reports that flash flooding in Colorado accounts for losses of approximately 37 million dollars annually. The spatial and temporal distribution of flash flooding in the western United States, including Colorado, is controlled to a great extent by two factors. 1) disturbance regimes in mountain drainage basins, and 2) the distribution of intense (usually convective) rainfall (Montgomery and Dietrich 1994). A seasonally prevalent disturbance regime in the western U.S. is wildfire. In the post-wildfire environment slopes become much more susceptible to erosion processes, debris flows, and flash flooding during intense rainfall episodes (Cannon et al. 2001).

Post-wildfire flash floods in the Rocky Mountains become a threat during the summer season, when wildfires burn mountain slopes. According to the National Weather Service (NWS) the wildfire threat in Colorado increases significantly in the later part of June, peaks in early July and remains high throughout August. July and August also see an increase in the frequency of thunderstorms in Colorado. The increased convective activity can be attributed to the influence of the North American Monsoon (NAM) across the Colorado Plateau.

The NAM is a period of increased rainfall (primarily convective) over northwestern Mexico and the southwestern portion of the U.S. The monsoon region is defined as those areas that receive at least fifty percent of their annual rainfall in the months of July, August, and September. (Douglas et al. 1993). The NAM is realized most prominently in the western foothills of the Sierra Madre Occidental in northwestern Mexico. Portions of Arizona and New Mexico also received substantial summer season precipitation as a result of NAM circulation patterns. Colorado is north of the core monsoon area, but portions of the state receive more than 30 percent of annual precipitation during July, August, and September (Douglas et al. 1993).

NAM circulation is characterized by convective *bursts* and short lived *breaks* when convective activity is dramatically reduced. Bursts may last for upwards of twenty days (Watson et al. 1994a). Colorado, which is on the periphery of the NAM core, experiences monsoon bursts in the late summer months (Reap 1986). Potential instability in central and western Colorado is enhanced during NAM bursts by pulses of low and mid-level moisture from the Gulf of California and the Gulf of Mexico (Hales 1972; Brenner 1974; Douglas et al. 1993). During NAM bursts the moisture boundary can push as far north as southern Wyoming (Watson et al. 1994a).

This research assesses the relationship between wildfire burn parameters and the NAM influence in Colorado. To accomplish this assessment the project will use data collected from the summer season, defined as 1 June through September 30 for the period 1995-2002.

2. DATA AND METHODS

Wildfire data was collected from *Daily Situation Reports* made available on-line by the Colorado Office of Emergency Management. The monthly wildfire parameters for the study consisted of number of fires and cumulative acres burned. Flash flood information was obtained from the National Climatic Data Centers on-line version of *Storm Data*. An event was identified if the *Storm Data* description of a flash flood confirmed that the hydrological event occurred in an area recently burned by a wildfire. An index to measure the strength of the NAM over Colorado was calculated by normalizing the monthly precipitation totals using a z-value. The NAM-Z follows:

$$\text{NAM-Z}_i = \text{PPT}_i - \textit{ppt}_i \ / \ s_i$$

Where PPT_i is the monthly precipitation total for month (i), $\textit{ppt}_i$ is the 30-year mean monthly precipitation for month (i), and s_i is the standard deviation calculated from the 30-year record for month (i). Precipitation data for this calculation were obtained from the Western Regional

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Climate Center's *Colorado Climate Summary*. Data from 45 stations across Colorado were used to generate regional precipitation parameters. The regions, with 15 precipitation stations each, were partitioned using the NWS forecast operation areas in Colorado. The NWS forecast offices representing each of the areas are Grand Junction (west), Denver-Boulder (north east), Pueblo (southeast), and Goodland, KS (far east) (Figure 1.). The area in the Goodland, KS forecast area is excluded from this analysis.

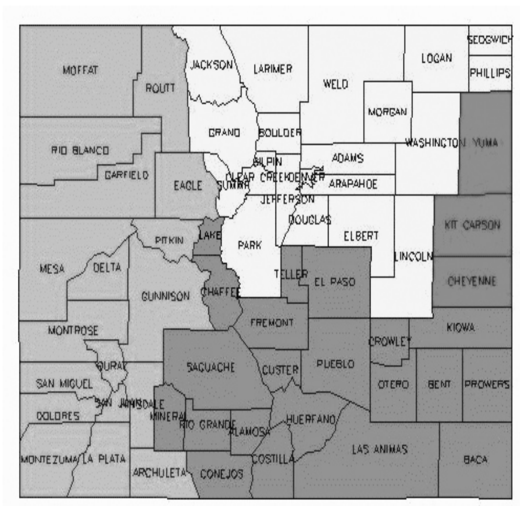

Figure 1. NWS forecast regions in Colorado. (western portion is Grand Junction; northeast portion Denver-Boulder; southeastern portion less the three northeastern-most counties is Pueblo).

3. ANALYSIS

For the three NWS forecast areas (Denver-Boulder, Grand Junction, and Pueblo) there were a total of 352 wildfires over the eight year period of record (POR). The total acreage burned during this period, according to daily situation reports, was 647,440. For a NAM reference the mean percentage of precipitation falling from June through September was 27.4% for Boulder, 29.2% for Grand Junction, and 40.6% for Pueblo.

3.1 Denver-Boulder Region

Figure 2 is a plot of the monthly accumulated acreage burned in a particular year and the NAM-Z precipitation normalization index for the Boulder NWS region. NAM-Z values above zero indicate a month that is contributing a higher percentage to the annual precipitation total. A NAM-Z value less than zero indicates a month with a contribution to annual precipitation that is less than the 30-year normal. For the purposes of this study a positive NAM-Z value will be interpreted as a stronger monsoon effect, and a negative NAM-Z value, a weaker than normal monsoon effect. The Denver-Boulder region has two significant wildfire years, 2000 and 2002. Both of these high burn periods have NAM-Z values that are below normal for the early summer (June and July in 2000; and June, July, and August for 2002). In both cases the late summer exhibits above normal precipitation. The plot in Figure 3 reveals that during 2000 there were 10 floods reported in the Boulder region (5 in July and 5 in August). In 2002 there were a total of 21 floods in the region, occurring during all four months even though precipitation was below normal in three of these months. The lowest monthly flood total was actually realized in September, the only month with above normal precipitation during the summer of 2002. The large wildfire numbers in the summer of 2002 seem to suggest that burn parameters may be an important element in the flood hydrology in this region even if rainfall is below normal. A Pearson' Product Moment correlation analysis confounds this assertion however. The correlation between the monthly number of floods and burned acreage as revealed by a correlation coefficient (CC) was 0.19, and this result was not significant at the 0.05 test level. The CC for number of floods and NAM-Z was 0.24 and again was not significant.

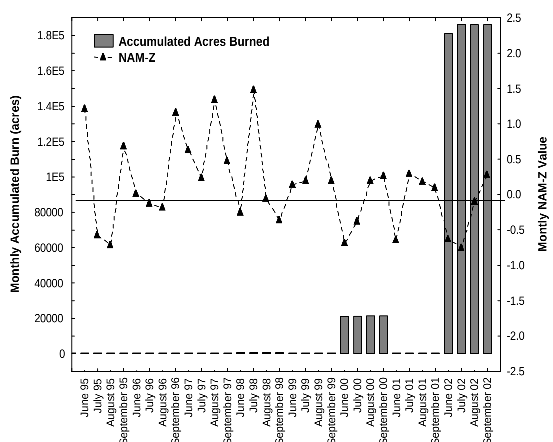

Figure 2. Summer season wildfire and NAM analysis for years 1995-2002, Denver-Boulder Region.

3.2 Grand Junction Region

The Grand Junction NWS forecast area is represented in Figure 4. This region has seen more active fire seasons compared to Denver-Boulder and to Pueblo as will be seen in section 2.3. The years 1996, 2000, and 2002 all have more than 100,000 acres burned over the respective summers. Fire year 2002 was by far the most extensive with a total of 210,150 acres damaged by wildfire. In each of the three above mentioned fire years at least one of the summer months exhibited a strongly positive NAM-Z index value. The months are September 1996, August 2000, and September 2002. In each of these months at least one flood was reported in *Storm Data* in this region. In September 2002 a total of

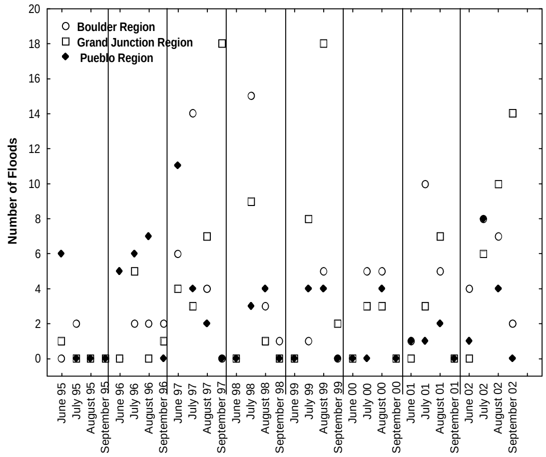

Figure 3. Summer season flood records for each of the three analysis regions for the period 1995-2002.

14 floods occurred in this analysis region. The statistical analysis between monthly flood numbers, burn area, and NAM-Z confirms that in the Grand Junction NWS forecast area a significant relationship exists between flood occurrence and the NAM-Z index (CC=0.65). Additionally, the CC for accumulated acreage and monthly flooding is 0.28.

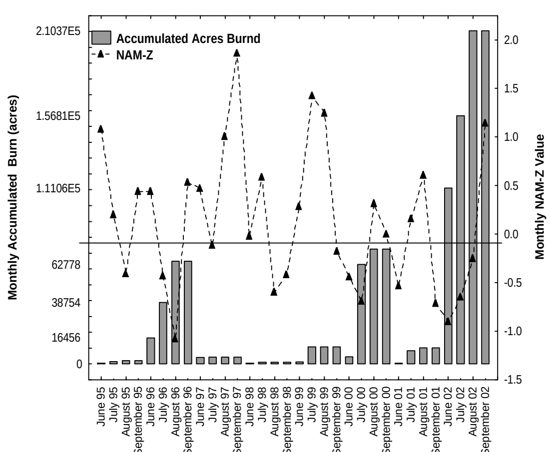

Figure 4. Summer season wildfire and NAM analysis for years 1995-2002, Grand Junction Region.

3.3 Pueblo Region

Figure 5. is the plot of the Pueblo NWS forecast region. In this region the link between the variables tested in the study were the weakest. The only significant fire season in this region was 2002 and not surprisingly the strong fire season coincided with dryer than normal conditions (negative NAM-Z values). Breaking this trend the month of September 2002 had a strongly positive NAM-Z value. There were, however, no floods reported in the Pueblo region for September 2002 (Figure 3). The most prolific flooding in the region was recorded in the summer of 1996. This season coincided with a full summer of above normal precipitation as revealed by the NAM-Z index. There were no wildfires during 1996 however.

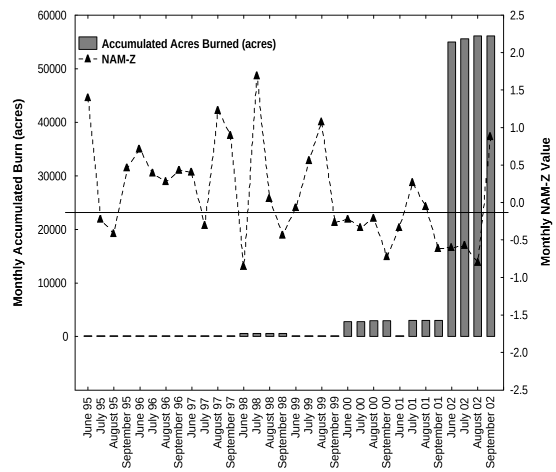

Figure 5. Summer season wildfire and NAM analysis for years 1995-2002, Pueblo Region.

4. CASE STUDY:GRAND JUNCTION REGION

During the summer of 2002 in the Grand Junction NWS forecast region heavy rainfall produced eight flash flood episodes at sites burned by two major wildfires (Coal Seam in the north central portion of the region; and Missionary Ridge in the southwest of the region). Of these eight flood events six produced prodigious amounts of cloud-to-ground lightning and were confirmed to be embedded in major NAM bursts.

At the Coal Seam wildfire site two major flooding episodes were identified. The first on 5 August was embedded in the strongest burst sequence of the summer. This event produced a two-hour rainfall total of 17mm. Peak 15-minute rainfall intensity was recorded at 9.4mm. The second flood event at the Coal Seam site occurred on 12 September 2002.

There were four distinct flood producing rainfall events identified in the post-wildfire environment at Missionary Ridge. The dates of the events were 23 July, 3 August, 29 August, and 12 September. The 29 August event had the strongest convective signature with a storm total 630 cloud-to-ground lightning flashes within an area of 7850km^2. The flash flood that occurred at 1945UTC produced storm total rainfall of 8.4mm and had a peak 15-minute rate of 4.0mm.

Each of the six flood producing rainfall events can be classified as classic NAM induced thunderstorms. A synoptic composite analysis of these events identified the mean 700hPa 335°K θ_e isotherm extending across the western portion of Colorado. Watson et al. (1994) suggest that a 700hPa θ_e value of 334°K is an effective delineation of the NAM boundary. In three of the flood events (23 July, 3 August, and 5 August) the 700hPa θ_e ridge extended beyond the northern boarder of Colorado. Additionally, each of the six events coincide with a large subtropical high pressure ridge building from the east. The center of this high varies in position (between events) from the middle portion of Kansas to central New Mexico.

5. SUMMARY AND CONCLUSIONS

The NAM impact on flooding in the state of Colorado has been analyzed in terms of the frequency of a disturbance regime (wildfire). The state of Colorado was divided into four regions based on NWS forecast responsibility. These regions were used to compare the number of floods occurring during the summer months with the accumulated acreage burned by wildfire each summer season. Both the Denver-Boulder and Pueblo NWS forecast regions show little correspondence between the two variables. The Grand Junction region, however, exhibits a strong positive correlation between flood occurrence and NAM-Z, and a somewhat weaker relationship between flood occurrence and acreage burned by wildfire. The summer of 2002 provided six thunderstorms of NAM origins that generated flash floods at the Coal Seam and the Missionary Ridge wildfire sites.

This work reveals some basic climatological understanding of the environment in which flash floods occur after wildfires in complex terrain.

6. REFERENCES

Brenner, I.S., 1974: A surge of maritime tropical air—gulf of California to the southwestern United States, *Monthly Weather Review*, **102**, 375-389.

Cannon, S.H., E.R. Bigio, and E. Mine, 2001: A process for fire-related debris flow initiation, Cerro Grande fire, New Mexico, *Hydrological Processes*, **15**, 3011-3023.

Douglas, M.W., R.A. Maddox, K. Howard, and S. Reyes, 1993: The Mexican monsoon, *Journal of Climate*, **6**, 1665-1677.

Hales, J.E., 1972: Surges of maritime tropical air northward over the gulf of California, *Monthly Weather Review*, **100**(4), 298-306.

Montgomery, D.R., and W.E. Dietrich, 1994: A physical based model for the topographic control on shallow landsliding, *Water Resources Research*, **30**(4), 1153-1171.

Reap, R.M., 1986: Evaluation of cloud-to-ground lightning data from the western United States for the 1983-84 summer seasons, *Journal of Applied Meteorology*, **25**, 785-799.

Watson, A.I., R.L. Holle, and R.E. Lopez, 1994: Cloud-to-ground lightning and upper-air patterns during bursts and breaks in the southwest monsoon, *Monthly Weather Review*, **122**, 1726-1739, 1994.