12A.7 INITIATION AND EVOLUTION OF SUMMERTIME STORMS IN CENTRAL ARIZONA

P. L. MacKeen[1,2], K. W. Howard[1], and D. M. Schultz[1,2]
[1]National Severe Storms Laboratory, Norman, Oklahoma
[2]Cooperative Institute for Mesoscale Meteorological Studies

1. INTRODUCTION

Traditionally, summertime precipitation in Arizona is characterized in terms of 'breaks' and 'bursts' in the North American Monsoon (e.g., Carleton 1986; Watson et al. 1994; Mullen et al. 1999). Breaks denote relatively dry conditions, whereas bursts denote relatively wet conditions. The diurnal climatology elucidates the tendency for storms to initiate first (near noon) over the Mongollon Rim and White Mountains, followed by initiation over the Southeast Highlands. During the afternoon, the storms move southwestward down the central Arizona terrain gradient, and westward from the eastern terrain, culminating within the Sonoran Desert near sundown. This diurnal evolution is ubiquitous, appearing in climatologies using precipitation gauges (Balling and Brazel 1987), lightning, (Watson et al. 1984), and radar mosaic (MacKeen and Zhang 2000) data.

Although this diurnal cycle is well known, individual days can depart markedly from this climatology. The goal of this study is to explore this variability in central Arizona precipitation by examining the role of terrain and associated synoptic conditions on preferred storm initiation locations and storm evolution.

2. DATA

To document 1999's varied summertime storm evolution and associated synoptic regimes, the WSR-88D 1-km resolution radar reflectivity mosaics, digital 1-km elevation data, and 12 UTC upper-air data collected in Phoenix and Flagstaff are analyzed. Although these radar data are available from 1996 onward, the 1999 dataset is examined first because it is the most complete. The majority of studies that analyze Arizona's precipitation climatology avoid using radar data primarily due to beam blockage by mountainous terrain. This data-sampling limitation is addressed by mosaiking, or mapping radar data from two WSR-88D's onto a common Cartesian grid using objective analysis techniques (Zhang et al. 2000). Level 2 data collected by the Phoenix (KIWA) and Flagstaff (KFSX) WSR-88D's during July and August 1999 (61 of the 62 days) are used to examine summertime precipitation over central Arizona. The mosaic technique is performed on a 440 km x 440 km domain with 1-km grid spacing, over 10-minute time increments. The domain (Fig. 1) includes Phoenix, the most populated city in Arizona, and mountainous terrain features that affect the area's precipitation variability.

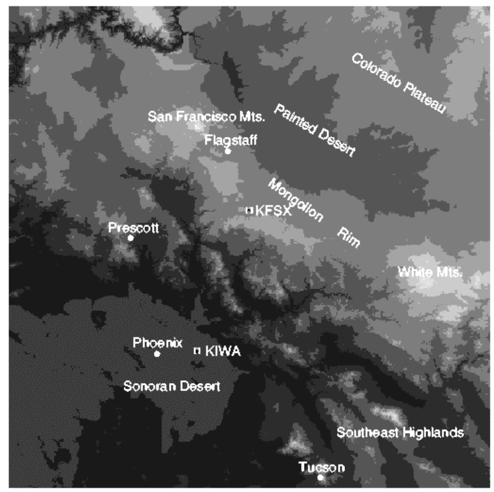

Figure 1. Domain of mosaiked radar data, including Phoenix (KIWA) and Flagstaff (KFSX) radar locations and major terrain features.

3. STORM EVOLUTION TYPES

Precipitation events are categorized into four storm evolution types by examining the radar mosaic loops. Below the four types and associated synoptic regimes are described. The 12 UTC soundings collected in Phoenix and Flagstaff are used to describe the local atmospheric conditions, and 700-mb and 500-mb maps are used to discern synoptic regime.

Type 1 (26 days or 43%) comprises events where precipitation is limited mostly to mountainous terrain, although occasionally precipitation is present also just north of Tucson. Such events are subcategorized into days comprised mostly of Mongollon Rim-initiated storms (19 days), Southeast Highlands and White Mountains-initiated storms (5 days), and New Mexico initiated-initiated storms that move into eastern Arizona only (2 days). The potential for storms along the Mongollon Rim vs. the Southeast Highlands and White Mountains is distinguished best by the vertical moisture profile at Flagstaff. Days where storms initiate over the Southeast Highlands and White Mountains, dewpoints throughout the troposphere are lower and wind profiles are more consistently southwesterly at Flagstaff. These 5 events occur within

Corresponding author address: Pamela MacKeen, NSSL, 1313 Halley Circle, Norman, OK 73069. E-mail: Pam.MacKeen@nssl.noaa.gov

1–2 days following shortwave trough passage. Storm occurrence is limited to eastern Arizona because the westerly winds following trough passage advect substantially drier air into Arizona.

In contrast, on Mongollon Rim-only days the vertical moisture and wind profiles are more variable at Flagstaff. The 500-mb winds during twelve of the 19 events are southwesterly (7 days), westerly (4 days), or northwesterly (1 day) with tropospheric-deep moisture punctuated by a 100-mb deep dry layer center at 500 mb. During the other seven events, 500-mb winds are southerly or southeasterly, due to the summertime subtropical ridge, and the tropospheric-moisture is deep.

Type 2 (18 days or 30%) comprises wide-spread convection over central Arizona. Moisture is abundant throughout the troposphere at both Phoenix and Flagstaff on these days, and, with the exception of one day experiencing westerly winds, winds are almost equally divided between southwesterly (4 days), southerly (4 days), and southeasterly (5 days) with height. The four days with southwesterly winds are associated with an approaching shortwave trough, which indicates the presence of synoptic forcing. In contrast, the day with westerly winds follows the passage of a shortwave trough, and, two previous days experiencing widespread precipitation. The 9 days with either southerly or southeasterly winds are associated with the presence of the summertime subtropical ridge. Type 2 days associated with the summertime subtropical ridge differ from Type 1 days associated with the summertime subtropical ridge in that the winds are stronger and more unidirectional with height, and the troposphere is moister.

Type 3 (13 days or 21%) comprises precipitation evolutions similar to the precipitation evolution depicted by the diurnal precipitation climatology. Thus, storms initiate over the Mongollon Rim and the Southeast Highlands and eventually move into Phoenix. At Phoenix, the 500-mb wind tends to have an easterly wind component, distributed as southeasterly (4 days), easterly (2 days), or northeasterly (1 day). However, 500-mb winds are southwesterly on the four remaining days. In contrast, at Flagstaff, the 500-mb wind direction tends to be southwesterly (6 days). Southeasterly winds at 500-mb occur on three days, and easterly and southerly winds on one day each. Interestingly, moisture and wind conditions are similar to those on Type 1 Mongollon Rim-only days. Characteristics shared between Type 1 and Type 2 events include wind direction variation mostly from southwesterly to southeasterly, depending on the position of the summertime subtropical ridge, and moisture profiles that are either moist with height or punctuated by an 100-mb deep dry layer at 500 mb. The strikingly similarity between sounding-profiles associated with Type 1 and Type 3 events make it difficult to anticipate future convective evolution. This challenge is discussed further in Section 4.

Type 4 (4 days or 6%) comprises days experiencing no precipitation. One day is associated with a northwesterly wind profile, and the remaining three days occur consecutively in mid-August, just prior to, and then following, the passage of a strong shortwave trough.

4. EVOLUTION UNDER SOUTHWEST OR SOUTHEAST FLOW

The similarity between wind profiles for Type 1 and Type 3 events provides a challenge for distinguishing these two types. In order to address this challenge, 500-mb winds at Phoenix and Flagstaff are examined for days having similar wind direction, namely either southwesterly or southeasterly. For this study, 13 (11) events are associated with southwesterly (southeasterly) winds at Phoenix and Flagstaff.

Similar wind direction at these sites is a potential tool for differentiating types because such winds provide a method for discerning the tendency for different initiation locations and storm evolutions associated with 500-mb southwesterly vs. southeasterly winds. This is accomplished by calculating the relative frequency of radar reflectivity values between 23-40 dBZ_e associated with each wind direction over 3-hr periods, hereafter referred to as relative frequency. Figures 2 and 3 show the relative frequencies associated with mid-day (17–19 UTC; 11am–1pm MST) and early evening (23–1 UTC; 4–6 pm MST) under southwesterly and southeasterly flow.

Under southwesterly flow, high mid-day relative frequencies are located mostly downwind of mountain peaks and ridges (Fig. 2a), which indicates that lee-side convergence is likely the dominant forcing mechanism. By comparing the spatial distribution of mid-day relative frequencies (Fig. 2a) with the spatial distribution of early-evening relative frequencies (Fig. 2b), we deduce that storm movement tends to be northeastward under southwesterly flow. Thus, when storms move mostly northeastward, the potential for secondary convective initiation toward the southwest, and eventually into the Sonoran Desert, is low.

Under southeasterly flow, high mid-day relative frequencies are located mostly over the mountain ridges (Fig. 3a). By comparing the spatial distribution of mid-day relative frequencies (Fig. 3a) with the spatial distribution of early-evening relative frequencies (Fig. 3b), we deduce that storm movement tends to be southwestward for Mongollon Rim storms, and westward for Southeast Highland storms. Analyses of radar mosaic-loops show that outflow boundaries moving down the mountainous terrain toward and into Phoenix provide the lift necessary for secondary initiation. This result agrees with Wilson and Schreiber's (1986) finding that convergence boundaries from mountain storms are responsible for storm initiation east of the Colorado Rocky Mountains. Furthermore, although we recognize

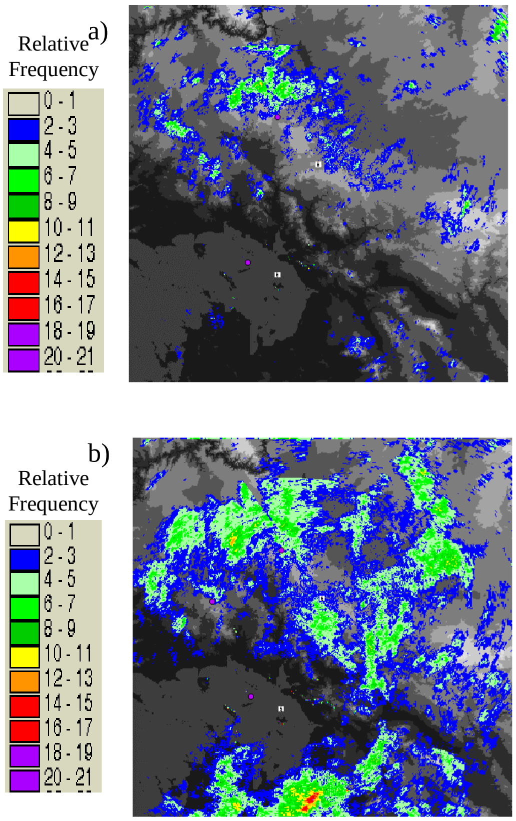

Figure 2. Relative frequency (%) of radar reflectivity echo values between 25–40 dbz_e during a) 17–19 utc (11 am–1 pm MST) and b) 23 utc–01 utc (4–6 pm MST) for the 13 days experiencing southwesterly 500-mb winds at both Phoenix and Flagstaff.

that not all outflow boundaries (including intersecting ones) initiate new storms, *for this study, storms initiate over Phoenix only on days when mountain-storm outflow boundaries intersect near Phoenix.*

5. FUTURE WORK

This study finds that topography and synoptic regime play a crucial role in regulating four storm evolution types. Although storm evolution types are distinct, variations within each type exist. To understand such variations better, additional upper-air sounding characteristics (e.g., stability) and terrain-forcing mechanisms will be investigated. Also, yearly seasonal variability based on 1996–1998 events will be examined to determine the viability of forecasting storm evolution type.

Acknowledgments. We thank Dr. Jian Zhang for use of her radar mosaic code and the Salt River Project of Phoenix, Arizona for funding this work.

REFERENCES

Balling, R. C., Jr., and S. W. Brazel, 1987: Diurnal variations in Arizona monsoon precipitation frequencies. *Mon.Wea. Rev.*, **115**, 342-346.

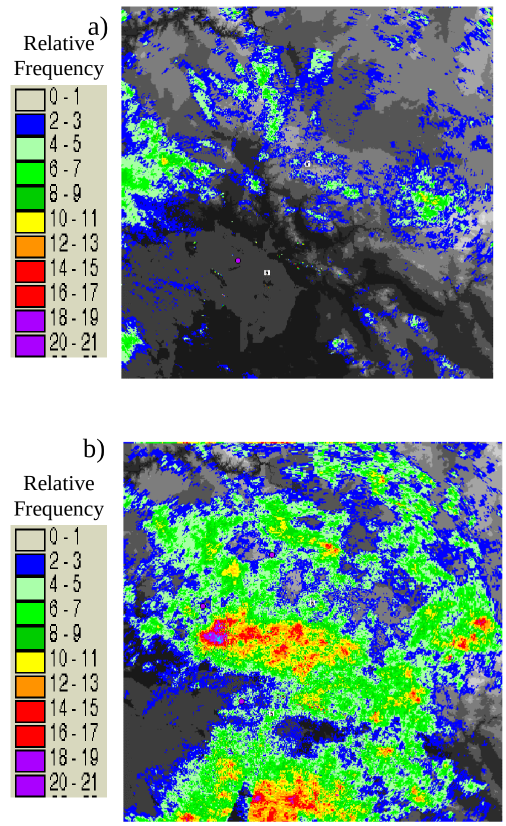

Figure 3. Same as Fig. 2 except for the 11 days experiencing southeasterly 500-mb winds at both Phoenix and Flagstaff.

Blanchard, D. O., 2000: Forecasting severe weather along the Mongollon Rim convergence zone. Preprints, *20th Conference on Severe Local Storms,* Orlando, FL, Amer. Meteor. Soc., 563–566.

Carleton, A. M., 1986: Synoptic-dynamic character of ‘bursts’ and ‘breaks’ in the south-west U.S. summer precipitation singularity. *J. Climatol*., **6**, 605–623.

Hales, J. E., 1977: On the relationship of convective cooling to nocturnal thunderstorms at Phoenix. *Mon. Wea. Rev.*, **105**,1609–1613.

MacKeen, P. L. and J. Zhang, 2000: Convective climatology for central Arizona during the 1999 monsoon. Postprints, *Southwest Weather Symposium,* Tucson, AZ, 64–67.

Mullen, S. L., J. T. Schmitz, and N. O. Renno, 1999: Intraseasonal variability of the summer monsoon over southeast Arizona. *Mon. Wea. Rev.,* **126**, 3016–3035.

Watson, A. I., R. E. Lopez, and R. L. Holle, 1994: Diurnal cloud-to-ground lightning patterns in Arizona during the southwest monsoon. *Mon. Wea. Rev.*, **122**, 1716–1725.

_____, R. E. Lopez, and R. L. Holle, 1994: Cloud-to-ground lightning and upper-air patterns during bursts and breaks in the southwest monsoon. *Mon. Wea. Rev.*, **122**, 1726–1739.

Wilson, J.W., and W.E. Schreiber, 1986: Initiation of convective storms at radar-observed boundary layer convergence lines. *Mon. Wea. Rev.,* **114**, 2516–2536.

Zhang, J., 2000: Three-dimensional mosaic displays of data from multiple WSR-88D Radars. Postprints, *Southwest Weather Symposium,* Tucson, AZ, 69–73.