University of Nevada, Reno

Spatial Distribution of Convective Activity in the Las Vegas Valley and its Relation to the Urban Growth Boundary

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in
Geography

by

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ABSTRACT

Spatial Distribution of Convective Activity in the Las Vegas Valley and its Relation to the Urban Boundary (August 2010)

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Urban areas have a large influence on the environment due to the effects urbanization has in regards to land use and land cover change. Since the land and atmosphere are coupled within the hydrologic cycle the conversion of land from its natural state, to an urban surface, can alter the microclimatology of a city and its adjoining regions. Past research has shown that cities can manipulate regional convection and precipitation. This is a product of several factors such as: increased temperatures and lift caused by the urban heat island effect (UHI), alteration of the land use and land cover (this consists of surface roughness changes, surface albedo, and the change in natural vegetation), pollution, and the design of the urban surface (which causes augmented friction and convergence). This study analyzed if the rapid growth and transformation of the natural landscape in the Las Vegas Valley (LVV) has had any effect upon the climatology of the region. This research created a convective climatology and then analyzed the spatial distributions of the convective patterns occurring in the LVV to determine if there have been any changes in the patterns that coincide with the rapid urbanization of this arid regime.

Radar composite reflectivity data was used to create a convective climatology for the LVV covering the period from 1995 to 2008. The LVV study region was divided into six directional sections: northwest (NW), west (W), southwest (SW), northeast (NE), east (E), and southeast (SE). Through the creation of a convective climatology for the LVV the storm patterns and trends were analyzed. The activity during the study period revealed three key areas of high convective activity. The western LVV along the Spring Mountains, the Black Mountain area in the SE section, in the McCullough Range, and around the Gass Peak area in the north-central valley in the NE section.

The mean 700mb wind direction during the study period was 197°, a south-southwesterly wind direction. This mean wind direction makes part of the SE, the E, and the NE sections the downwind areas of the study region. The eastern sections demonstrated statistically significant increases in the daily percentage of convective activity during storm events days. Also the urban area showed a statistically significant enhancement in convective activity. The overall trend in the LVV has been a decrease in the average strength of the 30+ dBZ values in the valley as a whole. When those trends are analyzed on a sectional basis four of the six sections exhibit the same trend; the NW, W, SW, and NE. The SE trend displays no change in average dBZ level. The E section displays a slight increase of the average dBZ value over the span of this study, this further supports what has been observed in other urban-modification climate studies; an enhancement of convective activity over and downwind of the urban area.

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CHAPTER 1

INTRODUCTION

In the past 50 years Clark County, and its main city Las Vegas, NV, have gone from a relatively small community to an ever expanding metropolitan center within the arid southwest. Las Vegas is not only one of the top tourist destinations in the world, but is also a key source of revenue for the entire state of Nevada due to its influx of tourism and earnings of the gaming industry. Besides being a tourist hot-spot, Las Vegas has also been one of the fastest growing cities in the United States for several decades. According to the U.S. Census Bureau, the Las Vegas - Paradise, NV Metropolitan Statistical Area (MSA), which contains a majority of the population for Clark County, NV, has grown by over 38% in the past decade; since 1990 it has grown by over 156%, and since 1970 it has grown by more than 596%. The population in the Las Vegas – Paradise MSA in 1970 was just 273,288; the estimate for 2009 from the U.S. Census Bureau put that number at 1,902,834 making it the 30th largest MSA by population. These population numbers only account for the resident population. Las Vegas also has a visitor population that, on a monthly total, outnumbers the resident population. In 2009, the monthly average number of visitors to Las Vegas numbered over 3,000,000, over 40 million people enplaned/deplaned into Las Vegas in 2009, the average daily automobile traffic at the Nevada / California border heading to Las Vegas numbered over 39,000 (LVCVA, 2010). The visitor volume was actually down by 3%, probably due to the economic environment, but these numbers are still quite large and should be noted when discussing the population of the LV - Paradise MSA.

Up until the 1960’s, Las Vegas’ development was influenced by the construction of the Hoover Dam and the district known as ‘The Strip’; this being the area along Highway 91 that housed most of the casino resorts. In the late 1960’s the growth of Las Vegas, promoted by tourism, the nation’s migration to the desert southwest, and an improved network of roads, led to a dispersion of housing, employment, and services away from the urban core and into the suburbs (Wheeler, 2008).

As more lands in the Las Vegas Valley are developed, or urbanized, the impact this is having on its physical environment need to be explored. One such effect urbanization has been shown to have on its environment, climatologically, is the urban heat island (UHI). The meaning of a heat island is simply the observance of hotter air temperatures in a built-up urban environment as compared to its rural surroundings (EPA, 2008). This effect can be noticed at any time during the day, but it is most pronounced, and has the greatest impact at night. The UHI affects people at multiple levels. It creates a higher energy demand for summer air conditioning cost, increases air pollution and greenhouse gas emissions, heart-related illnesses and deaths, and water quality (EPA, 2010).

Besides affecting the comfort, financial, and health aspects of life the UHI has also been shown to have an effect on weather patterns around urban areas. The UHI and its affect on weather patterns have been well studied in several eastern and mid-western cities of the United States. Much of the UHI research has focused on how it is affecting precipitation around the urban area. It has been observed that urban-induced precipitation has increased in several large cities, with the increase occurring directly over the urban center to 80 km downwind of the urban center (Dixon and Mote, 2003). Yet one area that has been somewhat underexplored has been the rapidly expanding southwestern cities. Since arid regions lack substantial precipitation, researchers have not studied the interaction of human endeavors and rainfall patterns (Shepherd, 2006). Shepherd describes three reasons why arid cities make ideal candidates for studying human affects on urban climate; first he notes that many areas in the arid southwest have rapidly grown in the past 20-30 years allowing for the assessment of pre- and post-urban growth and precipitation data using the abundance of ground and satellite data sources, secondly, he points out that the aridity of the southwest minimizes the chance of precipitation contaminants from large-scale events such as fronts or low pressure systems allowing the focus to be convective-regionally based processes linked to urbanization, last he describes how arid cities rely heavily on irrigation and how that can lend to a moister than typical environment which may support or enhance the precipitation process.

It has been shown through analysis of impervious surface area (ISA) using Landsat TM and ETM+ images that within the LVV the urban land use and land cover (LULC) creates a daytime cooling effect in the low- to medium-density urban areas and a UHI in the high-density urban areas (Xian and Crane, 2006). The reasoning Xian and Crane gave for the daytime cooling effect in the low- to medium-density ISA was accredited to the vegetation canopy cover that was planted and not naturally occurring in the LVV. This study will attempt to determine if the rapid growth and transformation of the natural landscape in the LVV is having any effect upon the climatology of the valley. This research will create a convective climatology and then analyze the spatial distributions of the convection patterns occurring in the LVV to attempt to determine if there has been any change in the patterns that coincide with the rapid urbanization of this arid regime.

CHAPTER II

LITERATURE REVIEW

Urban areas have been shown to be influencing weather patterns in studies dating back nearly two centuries (Dixon and Mote, 2003). Horton (1921) observed that some northeastern United States cities appeared to be generating thunderstorm activity. In the 1970's the Metropolitan Meteorological Experiment (METROMEX) study found higher precipitation values downwind of urban areas (Mote et al, 2007). The urban caused increases in precipitation are attributed to such factors as the urban heat island effect, pollution, turbulence from urban obstructions, and the change in low-level moisture due to land conversion (Huff and Changnon, 1973). After discussing these influences, along with the use of NEXRAD radar data in analyzing weather events, it will be demonstrated how this research adds to the existing scientific knowledge.

2.1 Urban Impacts on Weather Systems

As urban centers expand they tend to develop an urban heat island (UHI). An urban heat island is present when the urban area displays higher temperature readings than its surrounding rural area. A prominent feature of the UHI is the reduced cooling in the late afternoon and evening hours. One reason given for this is the decreased sky-view factor from the buildings. The urban buildings have less of their surface area exposed to the open air and have more of their area facing the other warm building surfaces, as opposed to the open horizontal surface in the rural areas. This reduces the radiative loss of heat leading to higher nocturnal minimum temperatures in the urban area as compared to the rural. The urban-rural difference in temperatures grow quickly just past sunset and are most pronounced three to five hours after sunset (Dixon and Mote, 2003). A study based on 28 United States cities showed that the greatest urban-rural temperature differences occur during the summer months of July and August (Gallo and Owen, 1999).

A key factor in the development of the UHI is wind speed. Several studies have demonstrated that wind speeds, coupled with cloud cover, are the most important weather parameters that affect not only the development, but also the intensity of the UHI (Dixon and Mote, 2003). UHI intensity is conversely related to cloud cover on calm nights because increased cloud cover reduces the release of heat over the rural areas. On calm nights, wind speeds in the urban area may be stronger than the rural area due to the horizontal surface temperature and pressure gradients between the two. The warmer urban center creates low air pressures that cause the cooler air from the rural area to converge towards the urban center (Oke, 1988). When surface winds hit the increased roughness of the urban setting the horizontal speeds decrease. Hence, the urban areas cause surface winds to decrease under significant synoptic flow and decrease under weak synoptic flow (Dixon and Mote, 2003).

Research has shown that the UHI has an influence on precipitation that falls near urban centers. The UHI does not appear to create more rainfall but it does appear to enhance rainfall that already occurs. Huff and Changnon (1973) observed enhanced precipitation in six of the eight cities they studied. Their study indicated not only that all days with rainfall were enhanced, but that the days with moderate to heavy rainfall was the most enhanced. They credited this enhancement to the increased roughness of the city surface, instability of the urban heating, and increased pollution over the city. Shepherd et al. (2002), when studying Atlanta, Georgia, observed an increase of over 19% in precipitation downwind of the metropolitan area during the warm seasons from 1998-2000. Shepherd (2006) also found a significant increase in precipitation in the arid climate of Phoenix, Arizona, 12-14%, when comparing pre-urbanized years (1895-1949) to post-urbanized years (1950-2003). Wescott (1995) used lightning strike data as a proxy for convective activity. She studied 16 major urban centers in the Midwestern United States. She found that although the urban areas may initiate new cloud growth, their effect on the thunderstorm activity behaves as shown in the other studies; the urban centers appear to enhance the existing thunderstorms that pass over the cities, along with the activity downwind.

In past studies pollution was credited as being one possible factor in affecting the increase in precipitation due to urbanization. More recent studies have indicated that pollution, or the increase of condensation nuclei, shows little to no increase in precipitation. The increased condensation nuclei create a larger number of small droplets but less coalescence and drop formation. The urban pollution may create more droplets but they do not grow large enough to fall as precipitation. They might actually form regions of reduced rainfall downwind of the pollution source (Dixon and Mote, 2003).

2.2 NEXRAD Radar Use

Studies in regards to the urban modification of local climates have used a variety of data sources. This study will use surface station data to establish the mean wind direction in the LVV, and will use Next Generation Radar (NEXRAD) Level III data from the National Climatic Data Center (NCDC) archives. Due to the location of the radar stations at higher elevations in the Western United States forecasters in the West must use data from high levels in the atmosphere to infer what sort of weather is occurring at the ground level (Maddox et al., 2002). So in this study the composite reflectivity data product (NCZ) was used since this product returns the highest observation in the entire column, instead of using base reflectivity which only reports to reflectivity at one elevation in the column.

Several studies have used radar reflectivity data, along with a geographic information system (GIS), when analyzing the occurrence and distribution of weather events (Dixon and Mote, 2003; Mote et al., 2007; Hocker and Basara, 2008). Dixon and Mote (2003) used these two resources to study the patterns and causes of UHI-induced rainfall around the Atlanta Metropolitan area. They chose the NEXRAD data because it covered their entire study region at 15 minute intervals at 2km pixel resolution. Mote el al. (2007) used the radar-estimated precipitation product to better quantify the urban influenced precipitation around Atlanta, GA. They chose the NEXRAD radar product because an earlier study (Austin, 1987) pointed out that radar measures, quite accurately, the aerial distribution of rainfall amounts. Austin's study also pointed out that radar may be the most reliable data source to obtain rainfall amounts that occur during summertime convection. Mote el al. (2007) used the hourly precipitation product (N1P) to estimate precipitation accumulation at a spatial resolution of 4km by 4km. Hocker and Basara (2008) used NEXRAD level II and III data in their analysis of the temporal and spatial characteristics of supercells across Oklahoma. By using the radar data they were able to establish thresholds that enabled them to classify and track supercell storms.

Most of the previous research that has been on urban influenced weather patterns has taken place in more humid climates. This study will be one of the few that focuses on an arid region. As with the previous studies, the expectation is that there will be an increase in convective activity over, and downwind from, the Las Vegas Metropolitan area. As the rate of growth has been extreme in this region it is expected that the anthropogenic induced signal will have become larger.

CHAPTER III

DATA AND METHODS

3.1 Study Area

The area of study is the Las Vegas Valley (LVV) (Figure 3.1). This valley is located in the very southern tip of the state of Nevada, in Clark County, and contains the state's largest urban center, Las Vegas. The LVV is a water basin within the Colorado River Basin; it can also be delineated by four predominant mountain ranges, the Sheep Range to the north that reaches over 9900ft, the Spring Mountains to the west which top out at 11,910ft, the McCullough Range to the south that is up to 7000ft, and the Frenchman Range to the east that is much lower, reaching only 2600ft.

The LVV is located at the southwestern edge of the Great Basin and the northeastern edge of the Mojave Desert, therefore the climate is arid with sparse precipitation. Precipitation in the LVV is fairly evenly spread throughout the year but it is delivered in distinctly different methods. There are two drivers of precipitation in the

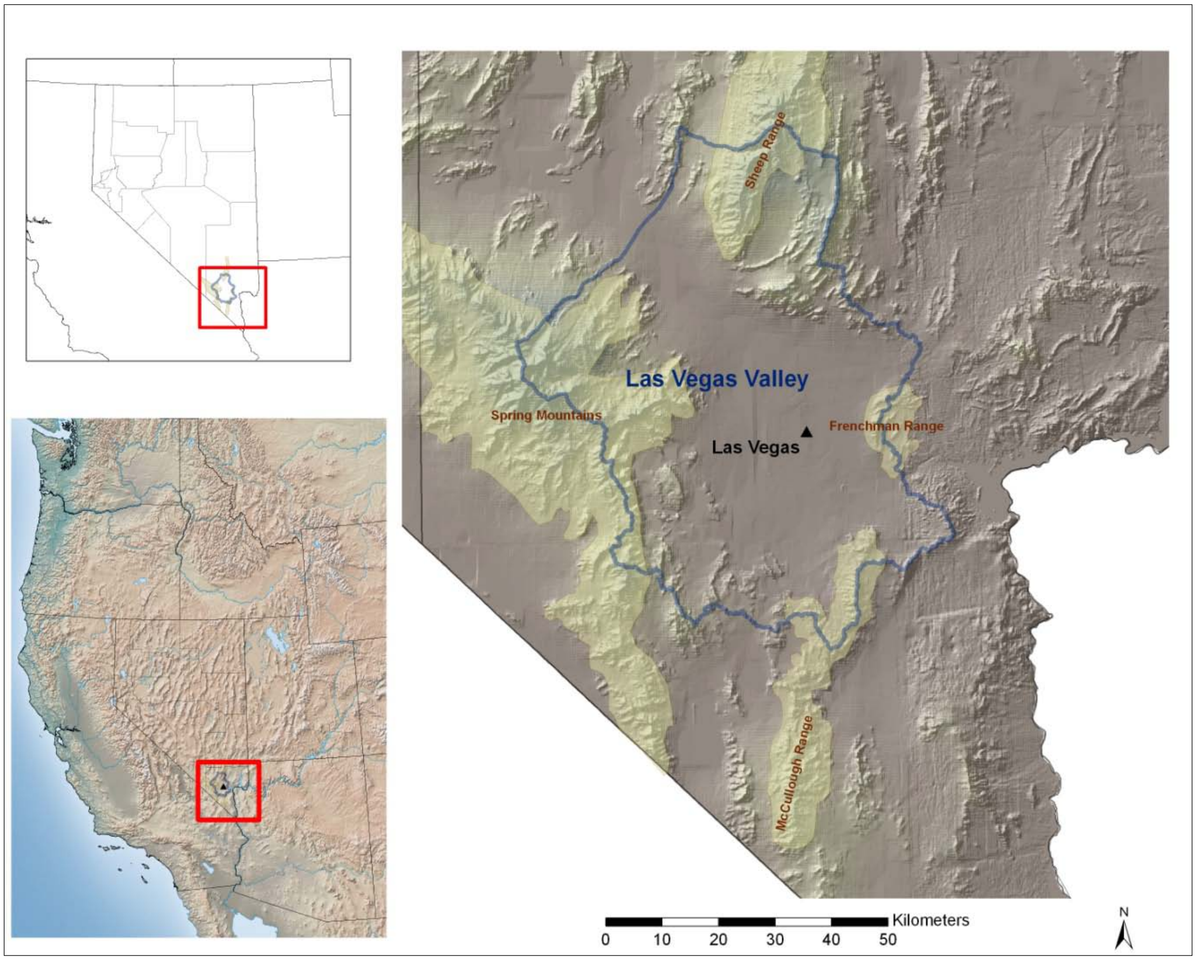


Figure 3.1. The Las Vegas Valley. The valley is defined in hydrologic terms as a water basin within the Colorado River basin. It is defined spatially as the valley that is bordered by four mountain regions; the Sheep Range to the north, the Spring Mountains to the west, the Frenchman Range to the east, and the McCullough Range to the south.

LVV region; mid-tropospheric cyclones in the winter months and convective events in the warm season. Summer is the time of year the LVV receives thunderstorm activity, Las Vegas averages 13.3 thunderstorm days each year, with 10.4 occurring from June to September (Gorelow, 2005). Most of the thunderstorm events occur in July and August when the region is influenced by the low-level moisture that ventures up from the Gulf of California during the surges of the North American Monsoon (Randerson and Sanders, 2000).

The normal climate values of this arid environment are based on the years 1971 to 2000 using data from the Las Vegas National Weather Service Forecasting Office. Table 3.1 shows the normal monthly mean precipitation, mean temperature, minimum temperature, and maximum temperature values. The mean precipitation ranges from a low of 0.08 inches in June to a high of 0.69 inches in February. The mean temperature varies from just 47 °F in December and January, to a sweltering 91.2 °F in July.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
$\mathbf{P_{mean}}$	0.59	0.69	0.59	0.15	0.24	0.08	0.44	0.45	0.31	0.24	0.31	0.40
$\mathbf{T_{mean}}$	47.0	52.2	58.3	66.0	75.4	85.6	91.2	89.3	81.3	68.7	55.0	47.0
$\mathbf{T_{min}}$	36.8	41.4	47.0	53.9	62.9	72.3	78.2	76.7	68.8	56.5	44.0	36. 6
$\mathbf{T_{max}}$	57.1	63.0	69.5	78.1	87.8	98.9	104.1	101.8	93.8	80.8	66.0	57.3

Table 3.1. Normal monthly mean precipitation (inches), minimum temperature (°F), maximum temperature (°F), and mean temperature (°F) for the Las Vegas Valley (1971-200) as measured at the Las Vegas/McCarran Airport.

The topography of the LVV also plays a role by influencing precipitation events. Mountain ranges not only alter precipitation patterns, but at the mesoscale they can create thermally driven convergence zones that increase thunderstorm development. It has been established that thunderstorm initiation and evolution are connected to and modified by boundary layer convergence zones (Runk, 1996). Runk describes such a convergence zone in the low-level wind field within the LVV which he has named the Las Vegas Convergence Zone (LVCZ). He discovered that the LVCZ is related to an interaction between the background wind field and the mountain-valley solenoid that is generated by differential heating.

For this study the LVV region was divided into six study sections (Figure 3.2). These sections are equal area regions of 768 square kilometers each. The regions bisect the urban footprint of Las Vegas and divide the valley into northwest, west, southwest, northeast, east, and southeast sections. By establishing these six directional sections a convective climatology can be established based on placement within the valley. Then any directionality in the change over time of the storm events can be analyzed by the possible shift of, along with an increase or decrease in, event activity between the sections.

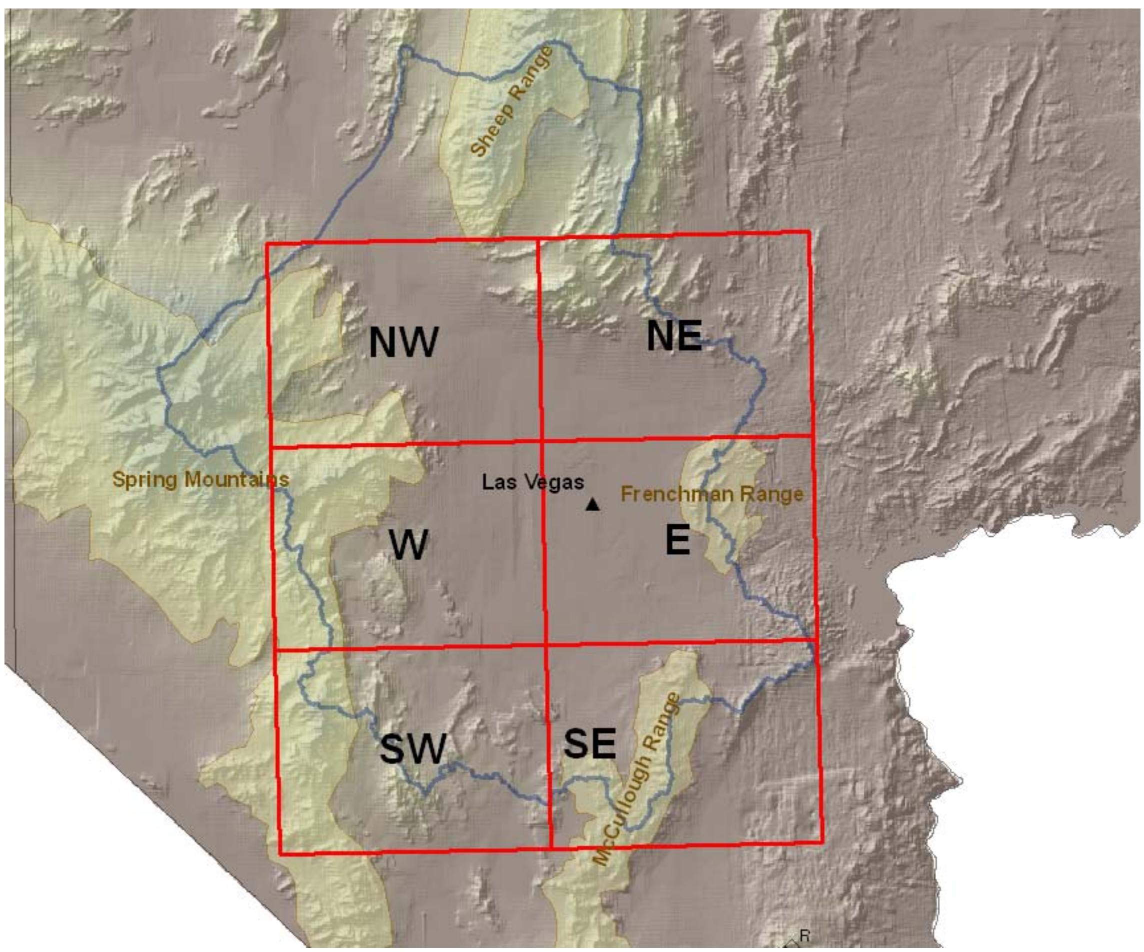


Figure 3.2. Locations of the six directional study sections in the Las Vegas Valley, each section is 768 km^2.

The possible influence upon the convective climatology that the development of the LVV has had will also be explored. An urban growth boundary was used to compare the number of events occurring over the urban setting versus the number of events occurring outside the urban growth boundary within the six study sections. The boundary that was used to represent the extent of the urban growth was the Bureau of Land Management Bureau of Land Management Las Vegas Valley Disposal Boundary (Bureau of Land Management, 2004). This boundary covers the area within the LVV that is allotted for the conversion from federal lands to private lands (Figure 3.3). The boundary contains the developable lands for urban growth in the LVV, with the current urbanization nearly filling the entire boundary, and with the projected continual growth of the LVV, one can assume that the boundary will either be completely filled, or will be expanded to accommodate the rapid expansion of the Las Vegas metropolitan area. Therefore the BLM LVV Disposal Boundary served as an ideal delineator for the developed versus undeveloped lands within the LVV study area.

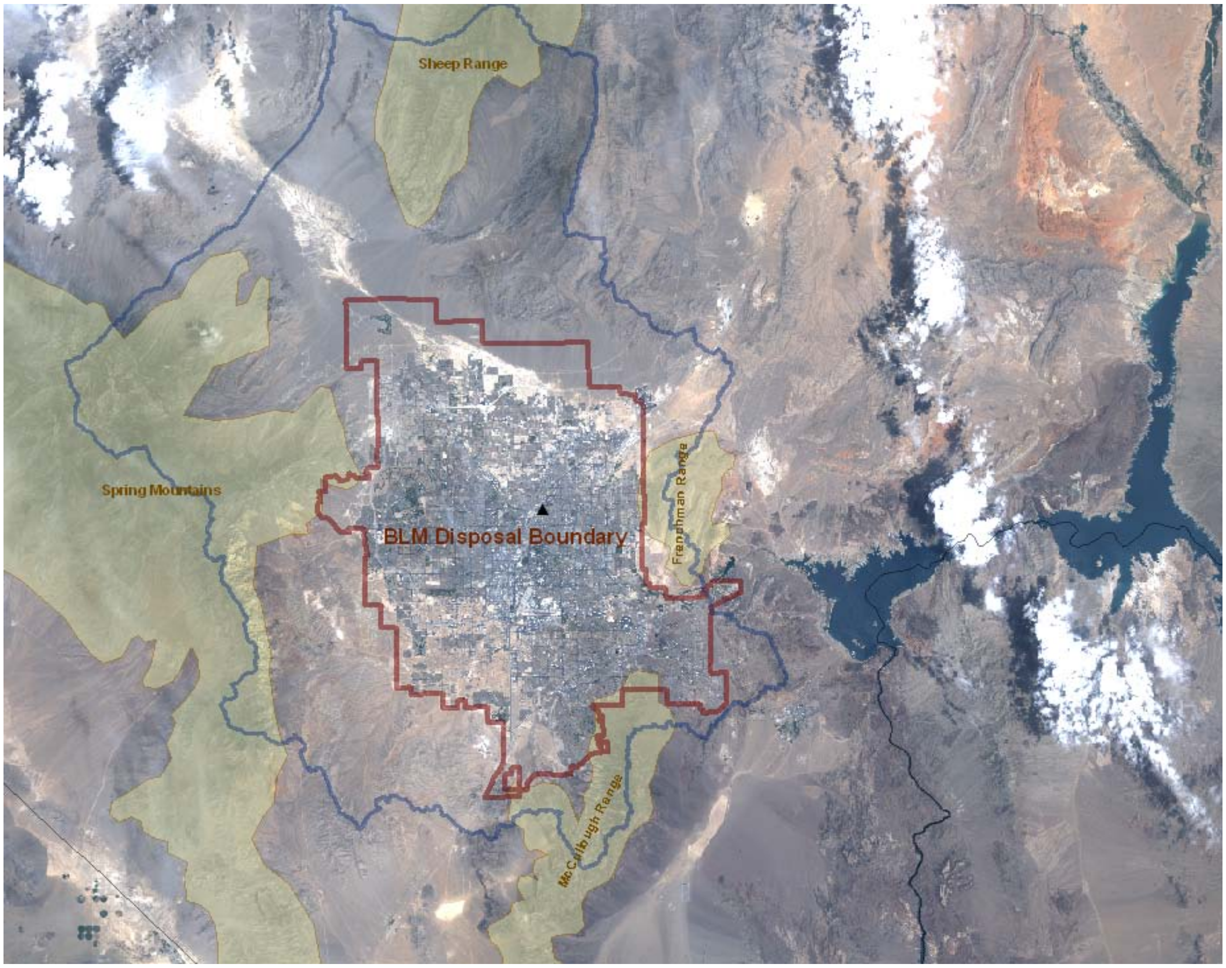


Figure 3.3. BLM Las Vegas Disposal Boundary. The satellite imagery is a LandSAT image from July 4, 2008.

3.2 Data

3.2.1 National Climatic Data Center (NCDC) Storm Events Database

One aspect of this study was to create a convective event climatology for the LVV. The LVV is a relatively mild location in regards to severe weather events; as compared to the Midwest or Eastern states so in order to pinpoint days that had such incidences the NCDC Storm Events database, along with the Storm Prediction Center's

(SPC) Severe Plot program, were used. The NCDC database compiles all severe storm events that have occurred in the United States since 1959 to the present. The events recorded have caused loss of life, injuries, significant property damage, and/or a disruption of commerce. The database obtains its data from the National Weather Service (NWS), who in turn gathers their records from several sources, some of which are county, state, and federal emergency management officials, local law enforcement, skywarn spotters, damage surveys, newspaper clipping services, the insurance industry, and the general public (NCDC, 2010). This database has been a primary source of information for studies in regards to hazardous weather events by atmospheric and hazard scientists (Ashley and Gilson, 2009).

The Severe Plot program from the SPC takes the Storm Events database data and plots it on a map that can be queried at a user-defined geographic extent. It displays the hail, wind, and tornado events, which can also be filtered based on various desired parameters related to those types of events. Severe Plot was queried to identify any possible events that were not reported in the NCDC database.

Several past studies that have used this data source have pointed out some of its shortcomings. Ashley and Gilson (2009) listed the following reasons: 1) the NWS's reliance on media and newspaper clipping services, which may not include all the events that have occurred; 2) the media and clipping services application has not been standardized, leading to inequalities in its usage by NWS offices; 3) some events involve one, or a small number, of individuals making them less likely to be reported; 4) in regards to lightning events in the database, and possibly others, the medical examiners and doctors sometimes list the event as a secondary cause of death, rather than the primary cause. Despite these weaknesses in the database it has been the only consistent dataset in use for hazardous storm events since 1959 (Curran et al., 2000). The underreporting in the database was noticeable in this study by just comparing the climatic norms of the number of thunderstorm events per year in the warm season, 10.4, to the actual number reported in the database (Table 3.2). Another drawback in this database is that the storm event is not simply listed as a thunderstorm. Since the database is prone to underreporting, and all the types of events listed in Table 2 could be attributed to a type of event that can take place during a thunderstorm, all unique days with an event occurring were considered as a thunderstorm day. Even by doing this only 4 of the 13 years examined either met, or exceeded, the climatic norm.

Year	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**
Tstm Wind Events	0	7	8	8	0	2	0	1	1	2	2	6	2	3
Lightning Events	0	2	1	2	0	0	0	0	0	0	1	0	2	3
Hail Events	0	4	4	4	1	0	0	0	1	1	4	3	0	2
High Wind	1	0	0	0	0	0	1	0	0	0	0	0	1	3
Flash Flood	0	1	5	10	5	2	3	0	1	0	2	3	4	7
Heavy Rain	0	1	0	1	0	0	0	0	0	0	0	0	1	0
Whirlwind	0	2	0	0	0	0	0	0	0	0	0	0	0	0
sml Stream Flood	0	0	3	0	1	0	0	0	0	0	0	0	0	0
Funnel Cloud	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Tornado	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Total Events	1	17	21	27	7	4	4	1	3	3	9	12	10	18
Unique Days	**1**	**11**	**10**	**16**	**5**	**3**	**4**	**1**	**2**	**2**	**6**	**9**	**7**	**10**

Table 3.2. Number of storm events reported in the NCDC Storm Events database per each of the observed years in this study

The Severe Plot program listed four additional days of events that were not reported in the NCDC database. There were three wind events and one hail event, all occurring in 1995.

3.2.2 Atmospheric Sounding Data

To analyze the upper atmosphere, radiosonde data was acquired for all the thunderstorm event days selected from the NCDC Storm Event database. Each day at 0000 and 1200 Coordinated Universal Time (UTC), which is 1700 Pacific Daylight Time (PDT) on the previous date and 0500 PDT of the same date respectively during the warm season, a weather balloon is launched at the Desert Rock airport in Mercury, Nevada. This station is located approximately 50 miles to the northwest of downtown Las Vegas (Figure 3.4). This data is used locally to predict the weather for the southern Nevada region, as well as the Las Vegas metropolitan area.

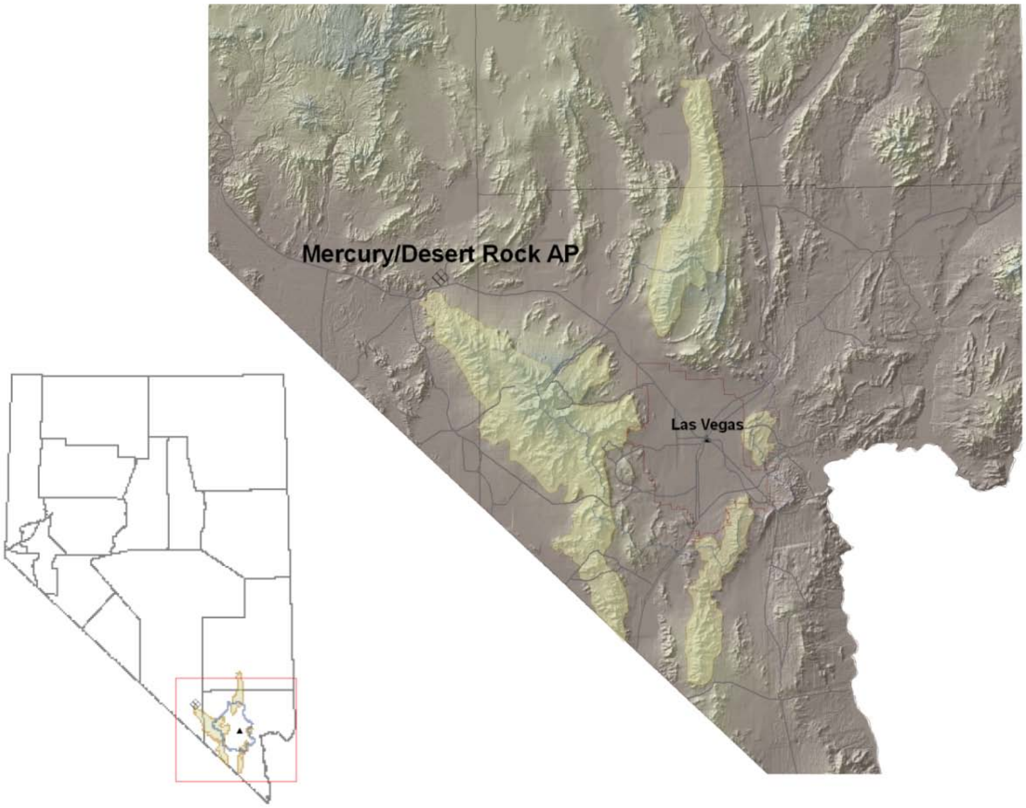


Figure 3.4. Location of Mercury / Desert Rock AP station for atmospheric sounding data collection.

The atmospheric sounding data was accessed through the University of Wyoming, Department of Atmospheric Science's Soundings website located at http://weather.uwyo .edu/upperair/sounding.html. The 1200 UTC and 0000 UTC of the next date observations were obtained for each day. The variables collected from each sounding was the equivalent potential temperature (Theta-e) at the surface, 700mb, and 500mb levels, the wind direction and speed at the 700mb and 500mb levels, the convective available potential temperature computed using virtual temperature (CAPV), total totals (TT), K index (KINX), and lifted index (LI). The Theta-e is a measurement of the temperature and moisture content of the air at a particular level in the atmosphere, in this study the levels used were the surface, 700mb, and the 500mb level, which is roughly 1000m, 3000m and 5500m in elevation. The CAPV, TT, KINX, and LI are stability indices and are used to give an estimate of the atmospheric static stability. If the atmosphere is unstable, with moisture available at the lower-levels along with a triggering mechanism to elevate the air and create some motion, convective weather and precipitation can develop (Peppier, 1988). Based on the level of the indices, and thus the level of the instability, a forecaster can predict what sort of weather may occur for the particular day.

The indices are calculated from several of the variables collected by the radiosonde. The LI is the temperature difference between a lifted parcel and the surrounding air at the 500mb level. The parcel is lifted dry adiabatically (-9.8 °C / 1000m) from the surface to the lifted condensation level (the point at which the parcel becomes saturated), and then moist adiabatically (~-5 °C / 1000m) to the 500mb level. The LI is negative when the parcel is warmer than its environment (DeRubertis, 2006). The formula for the LI is:

$$LI = T\,(500\text{mb environment}) - T\,(500\text{mb parcel})$$

The KINX is used as a predictor for thunderstorm events. The index is high when abundant moisture is present throughout the midlevels (850mb to 500mb) along with a strong lapse rate. High KINX indicates that intense rainfall is likely (DeRubertis, 2006). Notice in the formula for the KINX that when the dewpoint depression (ΔT 700mb) is small, the index increases:

$$KINX = (T850mb - T500mb) – T_d\ 850mb – (T700mb - T_d\ 700mb)$$

The TT is a combination of two other indices, the vertical totals (VT) and the cross totals (CT). It is used as another indicator of thunderstorm activity. The index is a valuable predictor of spring and summer 12-36 hour probability forecast of thunderstorms as well as conditional probability forecast of local severe storms (Peppier, 1988). The formula for TT is:

$$TT = (T850mb-T500mb) + (T_d850mb-T500mb)$$

The CAPE is used to evaluate the convective potential of the environment. CAPE is a more complex assessment of the energy available in the atmosphere, it is a vertically integrated index whereas the other indices assess a single-level (Blanchard, 1998). It measures the cumulative buoyant energy in the free convective layer from the level at which the parcel temperature exceeds the ambient temperature and the parcels are unstable relative to their environment (the level of free convection) to the level at which the ambient temperature and parcels are stable relative to their environment (the equilibrium level) (Blanchard, 1998). The formula for CAPE is:

$$CAPE = \int_{ZLFC}^{ZEL} \left(\frac{Tvp - Tv\theta}{Tv\theta}\right)$$

where Tvp is the virtual temperature of the parcel and Tvθ is the virtual temperature of the environment, ZEL is the height of the equilibrium level, ZLFC is the level of free convection, and g is gravity (Blanchard, 1998).

Numeric scales have been developed for the four indices for predicting possible thunderstorm activity (Table 3.3). These scales are generally valid for the eastern two-thirds of the United States (Peppier, 1988). Since this study is in the arid west these scales may not be completely applicable to the LVV, in a study by DeRubertis (2006) she analyzed trend changes in stability indices nationwide. In her study, in order for the western U.S. to register extreme weather days, she had to lower the threshold of three indices; the LI, KINX and SWEAT (not used in this study). In an online article by Dana Wagner (www.theweatherprediction.com), a broadcast meteorologist for KVBC in Las Vegas, he pointed out that in the LVV values of CAPE above 1000 j/kg and an LI in the negative range are valid values that may indicate that thunderstorm activity can occur. The indice used in this study to determine if a sounding indicated a potentially stable atmosphere versus an unstable one was the LI. Any values less than zero were considered to be indicative of an unstable sounding for the LVV.

Indice	**Stable**	**Marginally Stable**	**Moderately Stable**	**Very Unstable**	**Extremely Unstable**
CAPE	0	0 to 1000	1000 to 2500	2500 to 3500	< 3500
LI	0-3	0 to -3	-3 to -6	-6 to -9	< -9

Thunderstorm Probability	**0**	**20%**	**20 to 40%**	**40 to 60%**	**60 to 80%**	**80 to 90%**	**near 100%**
KINX	<15	15 to 20	21 to 25	26 to 30	31 to 35	36 to 40	> 40

Convection Probability	**Not Likely**	**Likely Tstms**	**Isolated Tstms**	**Widely Scattered Tstms**	**Scattered Severe Storms**
TT	<44	44-50	51-52	53-56	>56

Table 3.3. Stability Indice Values and Storm Probabilities

3.2.3 Radar Data

To analyze the convective activity for the observation days selected from the NCDC Storm Events database Next Generation Radar (NEXRAD) Level III data was used. This data was acquired from the NCDC Mass Storage System (HAS: http://has.ncdc.noaa.gov). In order to view and export the data into a usable format the NCDC Weather and Climate Toolkit, a Java-based software freely distributed by NOAA, was used to export the radar files into shapefiles so they could be analyzed in the ESRI ArcGIS software. The radar station that covers the LVV (KESX) has been in operation since June 1995, it is located about 35 miles southeast from downtown Las Vegas and is at an elevation of 4867 feet (Figure 3.5).

NEXRAD gathers weather information by using returned energy to the station. The radar emits a pulse of energy, if that energy comes into contact with an object, such as rain, a portion of that energy is returned to the emitting source. The radar operates in two modes; clean air and precipitation. In clean air mode the radar updates every ten minutes and sweeps at a tilt of 0.5° to 4.5°, in precipitation mode the radar updates every six minutes and sweeps up to 19.5°. When precipitation is present it is desirable to see more of the vertical structure of the storms, so in precipitation mode the radar completes 14 different elevation scans in a matter of five minutes (Cain and Kirkwood, 2004). The amount of transmitted power returned to the radar, or reflectivity, is measured in decibels of Z (dBZ), where Z represents the energy returned from the contact with an object. The dBZ values are also used as measurements of the intensity of rainfall. The dBZ value is representative of the amount of rainfall that is falling per hour (Table 3.4). Maddox et al.

(2002) pointed out that in the West weather forecasters must use radar data from the high levels to infer the weather threat at the ground level. Therefore the data product used in this study was the composite reflectivity (NCZ), which displays the maximum reflectivity value within a scan from any of the elevation angles. Since the NCZ returns the highest dBZ from the whole volume scan it does not necessarily represent actual precipitation that is hitting the ground, but it can indicate precipitation higher up in the atmosphere, which is a common occurrence in severe thunderstorms where the updraft is strong enough to keep the moisture aloft (Cain and Kirkwood, 2004). A level of 30 dBZ and higher was used in this study as an indicator of convective activity, from the scale in Table 3.4, 30 dBZ and higher indicates rainfall is present. Also, according to Cain and Kirkwood (2004), there is a chance of clutter, or false readings, that can appear with <30 dBZ readings in the radar data from birds or even insects within 34 miles of the station.

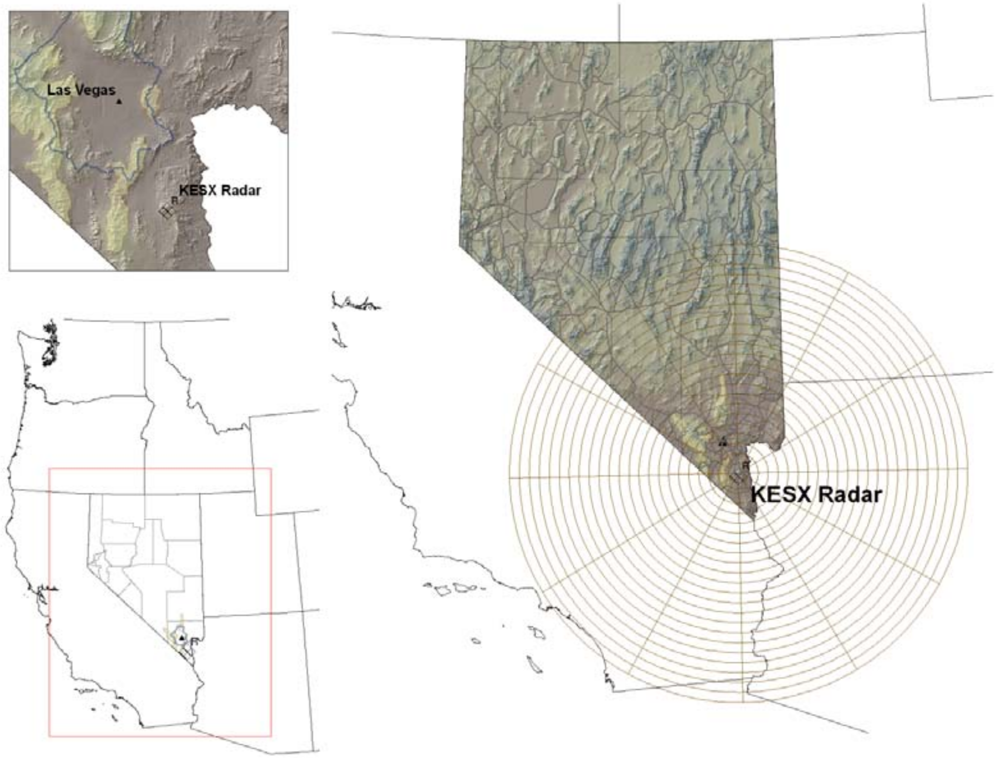


Figure 3.5. Location of KESX radar station and the area it covers (286 miles from station).

dBZ	20	30	36	41	47	52	55	60	65
PPT/hr	trace	0.10	0.25	0.5	1.25	2.50	4.00	8.00	16+

Table 3.4. dBZ Scale showing amount of precipitation (ppt) per hour based on reflectivity

3.2.4 Surface Weather Station Data

To analyze the weather conditions in the LVV at the surface several variables were gathered from the National Weather Service (NWS) station located at McCarran International Airport (KLAS) in Las Vegas, Nevada. Wind speed, wind direction, temperature maximum, and temperature minimum from 1973 to 2008 were collected from the KLAS station through the NOAA National Data Center Surface Data, Hourly Global database. The station is 7 miles southwest of downtown Las Vegas, is at an elevation of 2131 feet, and has a period of record spanning from January 1973 to present (Figure 3.6).

Figure 3.6. Location of Las Vegas / McCarran AP (KLAS) NWS Station.

3.3 Methods

This study examines the regional changes in the location of the convection within the LVV and the established study sections. Also, in order to determine if the urbanization of the LVV is having any affect on the occurrence of the convection, a land surface comparison was performed. To determine if urbanization is having an impact, similar to earlier studies in other regions, it is expected that the areas downwind from the urban setting will have an increase in convective activity. The objectives of this study are:

(1) To establish a convective climatology of the LVV from NEXRAD data

(2) And determine if any change in the convective patterns has occurred in the LVV since the radar data came online in 1995.

If the convective activity trends show a change in the six study regions, as well as within the urban boundary, over the time span of the study, then it would appear that the explosive urbanization of the LVV may have an influence on its storm patterns.

3.3.1 Determination of Storm Event Dates

In order to analyze thunderstorm activity in the LVV the days that had convective activity are needed. The resource used to identify the active days was the NCDC Storm Events database. This dataset is accessed through the NOAA website: http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms. The data was queried for all events that occurred in Clark County, Nevada. The data was then pared down to the warm season events that occurred from 1995 to 2008 to correlate with the time span that the radar dataset was available for. The database lists certain days as thunderstorm events but due to reasons mentioned in the Data section all days with any event type were analyzed. From 1995 to 2008, 87 event days were identified to have occurred during the warm season (June to September).

3.3.2 Establish Convective Climatology

The surface weather observations at the KLAS station were used to establish the mean wind direction for Las Vegas, at the surface. Once the mean wind direction within the LVV was determined the six study regions could be classified as upwind or downwind in relation to the urbanized area.

With the storm event days determined the radar and atmospheric sounding data was acquired for those dates. The sounding data is accessed from the University of Wyoming Atmospheric Soundings website. The interface is a clickable map of North America with all the available stations that collect upper atmospheric radiosonde data. The data cannot be queried for a particular time span; it has to be gathered on a day-by-day basis. The date desired is filled in, the station clicked, and then a text file is displayed in a new browser window with all the data observed from the radiosonde for that date and time. The desired upper atmospheric variables for both the morning (12Z prior date) and afternoon (00Z of observation date) soundings were transcribed for each observation day.

The morning and afternoon data was then analyzed and four day-type profiles were established. The four day-types were based on the LI values for observed time. A negative LI value was considered an unstable atmosphere and a positive value a stable atmosphere. The four day-types were: 1) stable AM – stable PM (PosAM/PosPM), 2) stable AM – unstable PM (PosAM/NegPM), 3) unstable AM – stable PM (NegAM/PosPM), and 4) unstable AM – unstable PM (NegAM/NegPM).

The radar data comes from NCDC as compressed files that contain numerous data products. The data was uncompressed and then viewed using the NCDC Weather and Climate Toolkit. This freely distributed software from NOAA allows one to not only view radar data on a U.S. map, but also export the data into numerous formats. The software to be used in the analysis of this data is ESRI ArcGIS so the radar data was exported to a polygon shapefile. The NCZ data product, upon export to the shapefile, has a spatial resolution of $4km^2$, is in geographic coordinate system North American 1983, and temporally is in UTC. Since the data is in UTC the date of, and prior, must be downloaded in order to cover the entire observation date in local standard time (LST). The radar data is collected as frequently as every six minutes per hour, so the daily data, when exported, can have an individual shapefile for every six minutes of the day, if there is data present at that time of day. The data was merged on an hourly basis using ArcGIS which resulted in an hourly shapefile for each observation date. Due to their being upwards of ten files contained in each hourly merged file, each spatial location could potentially have ten dBZ values in each hour.

The only attributes that are contained in the radar polygon shapefiles are dBZ values and a color index that is related to those values. For each hourly file a date and hour field was added and filled. The polygon data was then converted to point data in order to perform counts within the study regions. The merged radar files cover a distance up to 286 miles away from the radar station location. In order to analyze the reflectivity that occurred within the LVV the data was clipped to the extent of the study area (Figure 3.2). After clipping to the study extent the dBZ values that were 30 or greater were selected out. In order to get a reflectivity climatology that covered the entire study period, 1995 to 2008, for the six study regions all the daily point files were merged to one file and then a spatial join and sum with the six regions was performed.

3.3.3 Perform Regional Comparisons

To compare the changes that have occurred between the six study regions during the study period, the 30 plus dBZ points were joined spatially, and then summed per each of the six study sections for each observation date. The next step was to calculate the percentage of events that occurred in each section for the particular observation day. A linear regression analysis was run on the daily observation percentages for each study section. Visual Data, a statistical software package created by Dr. James Carr at the University of Nevada, Reno, was used for the regression analysis.

The other area of interest in this study is the occurrence of 30 plus dBZ over the urban area. A spatial join and sum of the 30 plus dBZ points that took place within the urban boundary, as well as outside the urban boundary, but contained by the overall study boundary, was created for each observation date. As with the six study sections; a percentage of events that occurred during each observation day inside, along with outside, the urban boundary was computed. A regression analysis was also performed on this data set using Visual Data.

CHAPTER IV

CONVECTIVE CLIMATOLOGY RESULTS

The analyses in this chapter were performed to establish baseline climate parameters that occur in the LVV. In order to determine if any change has taken place due to the rapid growth of the LVV during the time frame of this study (1995 to 2008) this baseline is needed. A standard climatology is generally expected to contain at least 30 years worth of data, but due to constrictions on availability of the desired radar data set a shorter temporal period was used. The NCDC radar data set was available at the KESX station from June 1995 to present. This study spanned the warm seasons from 1995 to 2008. Therefore the convective climatology that was established for the LVV spanned 14 warm seasons. Another aspect of this study is linking the urban growth within the valley and how it may be affecting the local climatology. Although this 14 season time span is not the most ideal, the amount of growth that has occurred in the LVV during this period warrants the need to examine the possible affects it may be having. Per the Nevada State Demographer, the population in Las Vegas, in 1995, was 1,055,435 and in Clark County as a whole, 1,611,593. By 2008 the population expanded to 1,967,716 in Las Vegas and 2,738,733 for Clark County (NSBDC, 2010), this is a growth rate of 86% and 70% respectively.

4.1 Surface Wind Results

Several parameters were analyzed to establish a convective climatology in the LVV. The first variable examined was the surface winds in order to establish the mean wind direction. The KLAS surface station data was available for a much longer period (1973 to 2008) than the radar data so a proper climatologic wind parameter could be established. The overall average wind direction for the LVV, at the surface, was 197°, or a south-southwest (SSW) direction. When looking at the winds as the day develops the winds begin in the morning hours before sunrise coming from the SSW, 221° in the 6th hour, then as the day warms until the 16th hour they shift slightly more to the SSW, up to 228°. Then at the 17th hour the winds shift more southerly, and then southeasterly, at 150° in the 19th hour. As the night cools the winds shift back to the south and then southwesterly by the 4th hour (Table 4.1). In Table 4.1 the hourly wind averages for the storm dates are also tallied and compared to the overall averages. Overall the surface winds on storm dates, as reported at the McCarran International Airport, are more southerly (-15.4°) and a bit slower (-0.39 mph). The most distinct difference comes in the active hours of the 16th to 18th; the surface winds are southeasterly on storm days during these hours.

Hr	All Dates: Avg Dir	All Dates: Avg Spd	Storm Dates: Avg Dir	Storm Dates: Avg Spd	Diff Dir	Diff Spd
1	172.94	4.71	168.13	4.61	4.81	0.11
2	181.65	4.68	185.38	4.88	-3.73	-0.20
3	193.38	4.58	186.99	4.61	6.39	-0.02
4	207.93	4.41	188.89	4.27	19.04	0.14
5	217.63	4.35	188.41	3.99	29.22	0.36
6	220.56	4.29	193.41	4.24	27.15	0.06
7	218.29	4.08	190.51	3.53	27.78	0.55
8	218.40	4.13	194.08	3.39	24.32	0.75
9	218.29	4.05	191.85	3.35	26.44	0.71
10	219.07	3.95	196.32	3.01	22.76	0.94
11	220.76	3.84	199.87	3.05	20.89	0.79
12	222.48	3.75	212.38	3.17	10.11	0.58
13	223.83	3.54	211.35	2.68	12.48	0.86
14	227.36	3.60	210.00	2.82	17.36	0.78
15	228.16	3.47	212.92	2.53	15.24	0.95
16	223.08	3.31	188.98	2.14	34.10	1.17
17	200.42	3.25	133.86	2.42	66.56	0.84
18	168.15	3.40	137.83	2.66	30.32	0.74
19	149.66	3.61	140.00	3.29	9.66	0.32
20	150.55	3.96	134.78	3.51	15.77	0.45
21	154.45	4.19	152.37	4.11	2.07	0.08
22	161.15	4.38	164.20	4.37	-3.06	0.02
23	164.77	4.51	193.29	5.24	-28.52	-0.73
24	169.78	4.54	187.80	5.48	-18.02	-0.94
Avg	197.20	4.02	181.82	3.64	15.38	0.39

Table 4.1. Hourly Wind Averages in the LVV. Surface wind climatology for the LVV from the KLAS station at the Las Vegas/McCarran Airport for the years spanning 1973 to 2008.

4.2 Upper Atmosphere Results

Moving up from the surface, the upper atmosphere was analyzed and a climatology was established based on atmospheric sounding data obtained at the KDRA site in Mercury, Nevada. By analyzing the sounding data the atmospheric conditions that contribute to storm genesis can be examined; some of these being the stability and moisture availability of the atmosphere. Sounding data was compiled from the AM and PM radiosonde balloon launches for the storm event dates. Not every morning, and/or afternoon, balloon launch results in a successful reading of the upper atmosphere. During the time span analyzed in this study there were four dates with only a PM sounding, seven days with only an AM sounding and eight days with no sounding data at all. This resulted in 68 days that had both an AM and a PM observation. The theta-e, wind, and stability values were studied along with the stability indices. The LI stability indice was used to categorize the sounding as being indicative of an unstable, or stable, atmosphere. A positive LI means a stable environment, and a negative LI indicates an unstable environment. From this classification four types of days were formed; PosAM/PosPM, PosAM/NegAM, NegAM/PosPM, and NegAM/NegPM. The percentages of days, by type, along with their amount of activity are shown in Table 4.2.

Day Type	Percent of Observations	Percent of Activity
NegAMNegPM	44.12%	39.86%
PosAMNegPM	20.59%	30.92%
NegAMPosPM	10.29%	9.54%
PosAMPosPM	25.00%	19.68%

Table 4.2. Percent of Days and Activity by Day Type.

The upper atmospheric variables compiled were the theta-e at the surface, 700mb and 500mb levels, along with the wind speed and direction at the 700mb and 500mb levels. In the upper level the 700mb winds are indicative of the direction that convective events will follow (Shearman, 1977), so by looking at the wind direction at that level the direction from where the storms are coming from can be determined. This parameter was needed in order to determine which study regions in the LVV would be considered upwind and downwind. This was important because of the earlier studies mentioned in

Chapter 2, in regards to urbanization affecting and/or enhancing the weather downwind of the urban setting.

The average wind direction at the surface for all the storm days was 182°, or due south, for both the daytime and the nighttime. At the 700mb level the average winds are from a more south-southwesterly (199° to 192°) direction on storm event days (Table 4.3). Another observation of note is that the times of day that were indicated as being stable, or having a positive LI, had increased wind speeds at the higher levels. This supports the observation made by Runk (1999) in regards to the Las Vegas Convergence Zone (LVCZ). He pointed out that the ideal wind speeds needed to be between 5-7 m/s, or 9.7 – 13.6 knots, in the 1-4 km level (surface to roughly above 700mb) for the formation of the LVCZ to take place. The observations shown in Table 4.3 demonstrate that the times of day with a positive LI are above this ideal threshold.

Day Type	**Hr**	**Theta E Sfc**	**Theta E 700mb**	**Theta E 500mb**	**DRCT deg 700mb**	**SKNT 700mb**	**DRCT deg 500mb**	**SKNT 500mb**
All Days	5	333.4	334.19	330.2	199.39	12.43	188.03	17.29
All Days	17	343.17	335.56	331.28	192.1	13.21	206.46	16.85
NegAM NegPM	5	340.4	336.83	331.59	205.13	9.5	183.5	12.73
NegAM NegPM	17	346.81	338.89	333.01	194.33	10.43	183	14.4
PosAM NegPM	5	330.16	333.75	329.32	173.21	11.29	176.43	19.43
PosAM NegPM	17	346.19	338.29	332.02	187.86	12.29	208.93	15.29
NegAM PosPM	5	336.63	336.47	328.76	210	13.57	195.71	15.43
NegAM PosPM	17	341.47	333.96	329.66	217.86	15.57	230.71	18.43
PosAM PosPM	5	323.74	328.26	328.32	207.06	16.35	204.12	21.71
PosAM PosPM	17	336.01	329.12	328.39	197.41	18.59	239.41	21.35

Day Type	Hr	CAPV	TT	K Index	L Index
All Days	5	219.07	47.76	27.05	0.39
All Days	17	343.97	48.24	28.53	-0.68
NegAMNegPM	5	418.58	51.5	34.28	-2.02
NegAMNegPM	17	628.27	51.49	34.62	-2.68
PosAMNegPM	5	2.41	46.67	25.23	1.78
PosAMNegPM	17	256.69	50.46	29.95	-1.74
NegAMPosPM	5	177.61	50.4	33.1	-0.98
NegAMPosPM	17	25.69	45.14	25.54	1.25
PosAMPosPM	5	5.85	41.2	13.34	4.21
PosAMPosPM	17	19.97	42.64	17.19	2.55

Table 4.3. Average values from the atmospheric soundings on the storm event days.

The assumption going into the study was that a typical storm event day in southern Nevada would begin with a stable morning, then through the process of daytime heating, turn into an unstable afternoon which would promote the development of convection that would lead to afternoon/evening storm activity, or instability would be indicated for the entire day from both sounding observations. The hourly convective activity within the LVV supported this claim but this occurred in just 65% of the cases. The hourly counts of 30+ dBZ activity for all the observation days show that minimal activity occurs in the predawn and through the remaining AM hours but as the day heats the activity has a maximum at the 15th hour, elevated activity through the evening hours through the 19th, and then as the evening cools the activity follows suit (Figure 4.1).

The NegAMNegPM 30+ dBZ activity per hour behaves similar to the overall trend, but these days display a 15th and a 19th hour maximum, and then a drop off of activity in the nighttime hours after 20th through the morning hours (Figure 4.2).

The PosAMNegPM 30+ dBZ activity behaves as the soundings imply; low activity in the morning hours and then strong activity in the afternoon. These days exhibit afternoon activity that gets carried through the evening hours (Figure 4.3).

For 25% of the dates a completely stable day was observed, a PosAM/PosPM day, according to the sounding data. Though all the soundings indicated that the atmosphere was stable on these dates, the Storm Event database listed that activity did occur in Clark County. On these dates the activity follows the overall trend by having a peak during the 15th hour, but the bulk of the activity only lasts for four hours in the afternoon from the 15th through 18th (Figure 4.4).

The remaining 10% of the dates had an unstable morning and then a stable afternoon (NegAM/PosPM). Even though the sounding data for the NegAMPosPM dates indicated that the morning would be more active than the afternoon, by looking at the counts of 30+ dBZ activity within the LVV, on an hourly basis, this was not the case (Figure 4.5). The NegPMPosAM days displayed activity throughout the day but had peak hours from 1200-1600 local time, with 1500 being the maximum of activity.

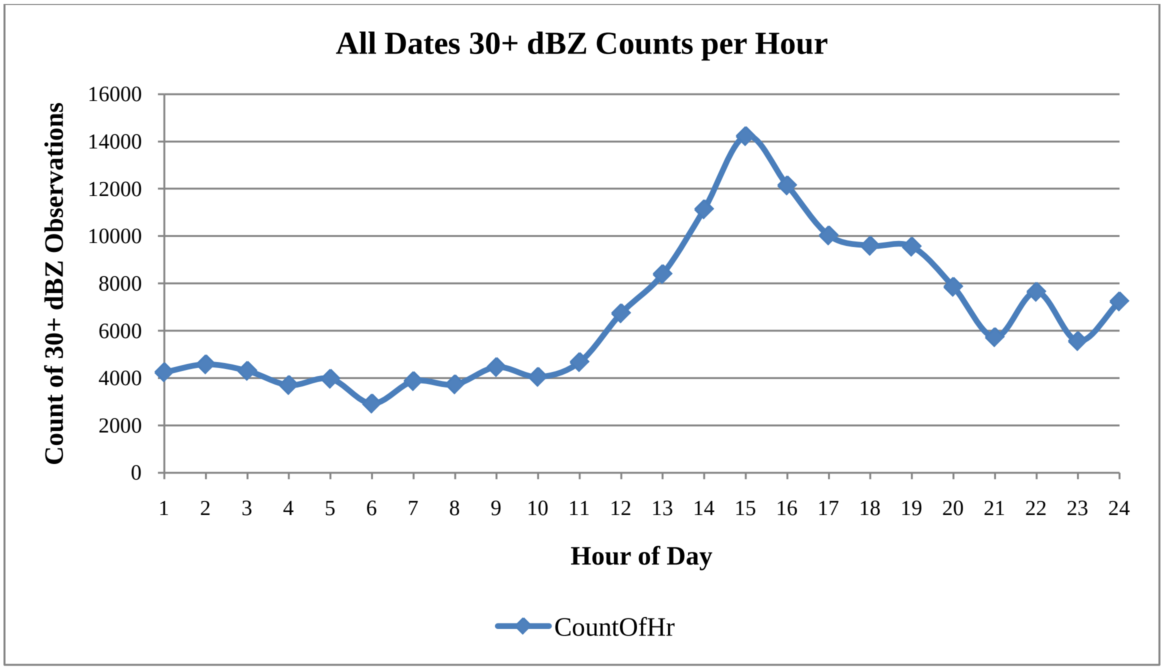


Figure 4.1. Hourly 30+ dBZ Activity for All Observation Days

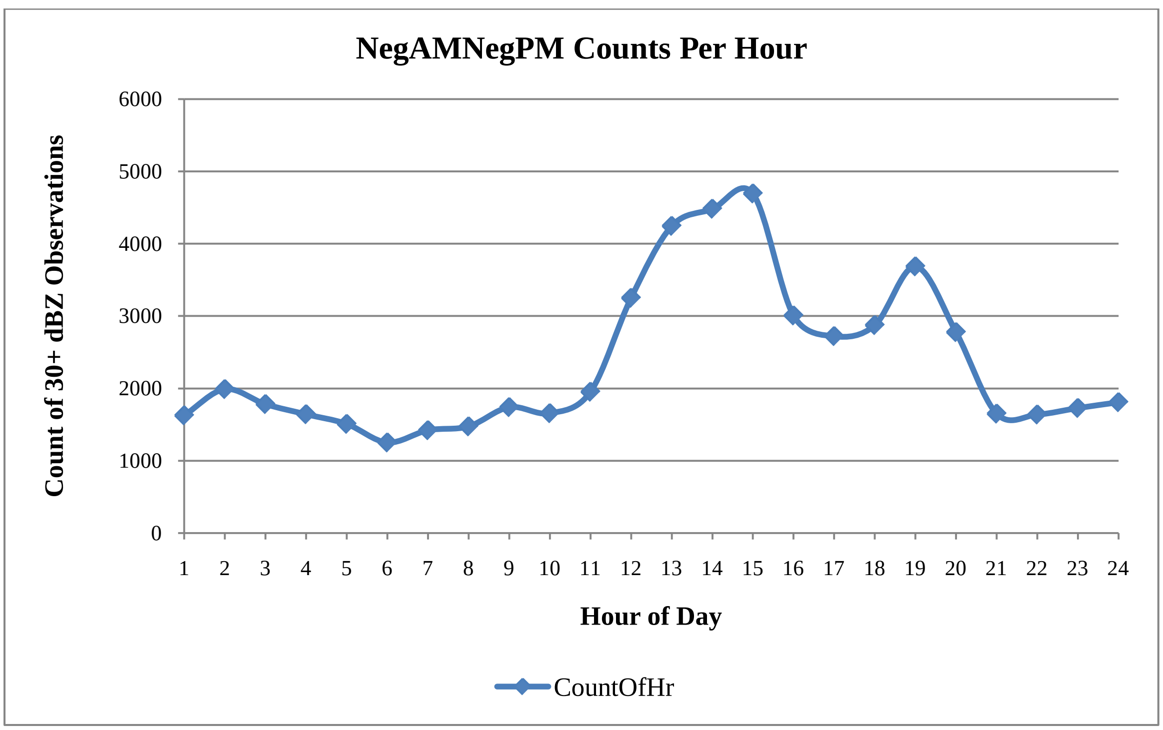


Figure 4.2. Hourly 30+ dBZ Activity for NegAMNegPM Days.

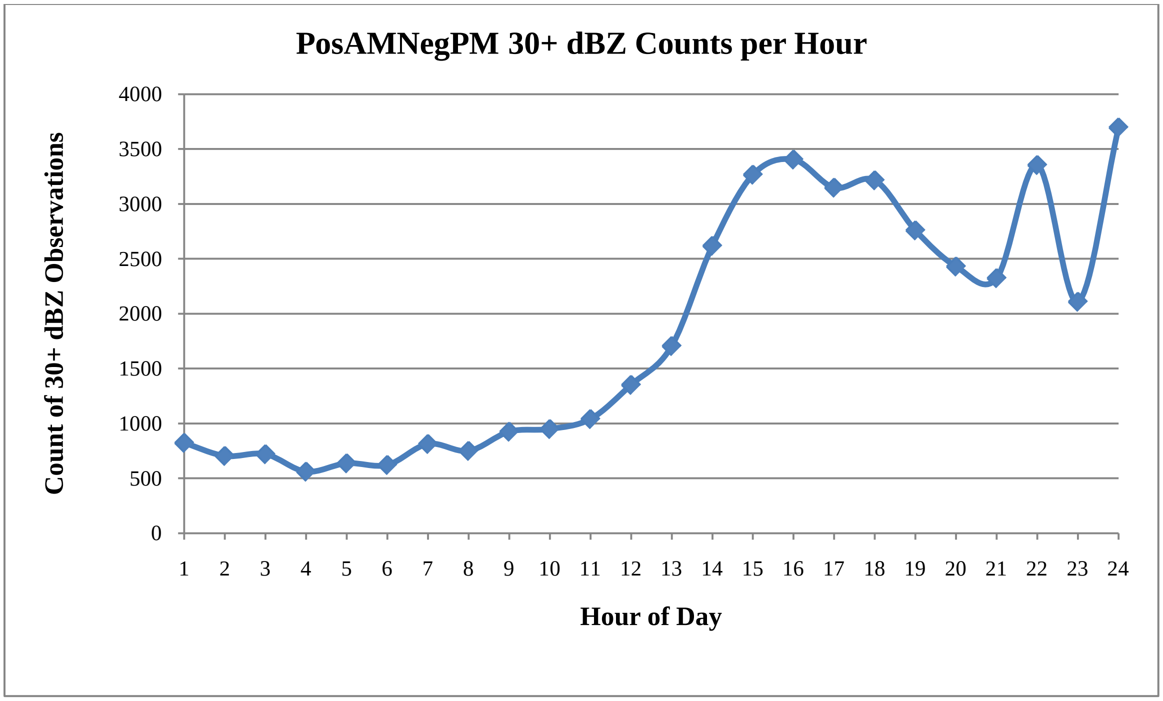


Figure 4.3. Hourly 30+ dBZ Activity for PosAMNegPM Days.

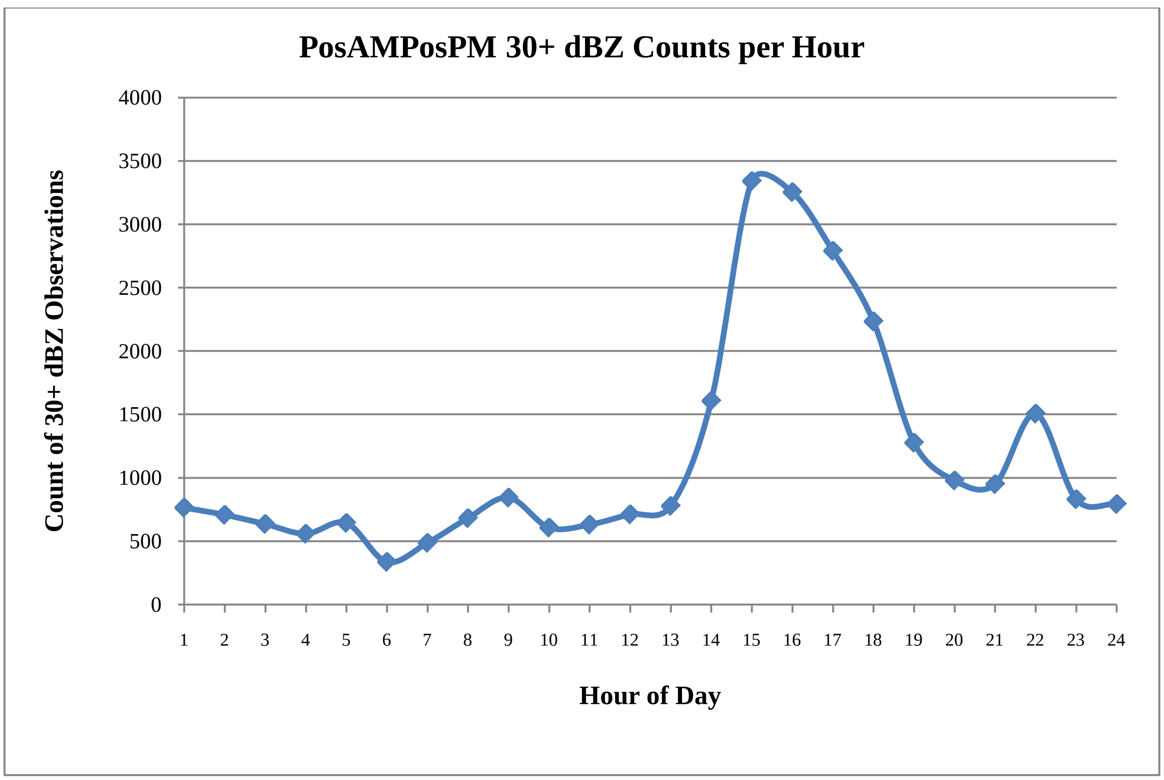


Figure 4.4. Hourly 30+ dBZ Activity for PosAMPosPM Days.

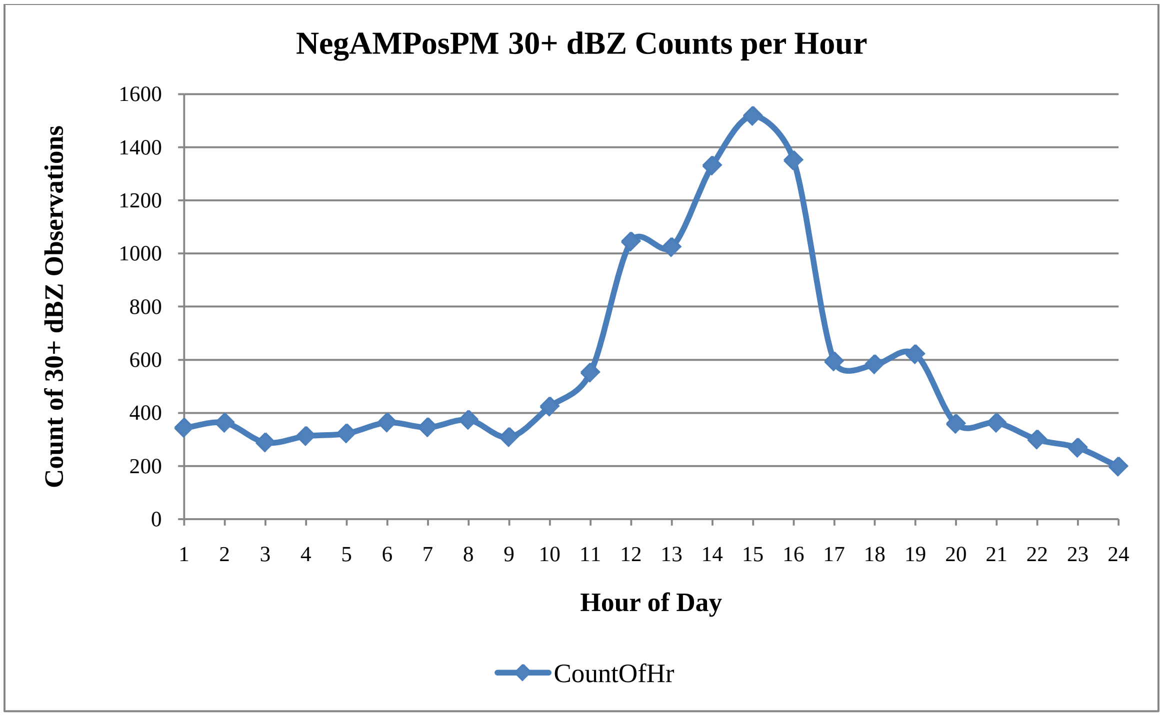


Figure 4.5. Hourly 30+ dBZ Activity for NegAMPosPM Days.

4.3 Spatial Distribution of Convection

The LVV was divided into six study sections; NW, W, SW, NE, E, and SE. The NEXRAD data was converted to points in order to obtain a count of the 30+ dBZ activity in each study section. Since the resolution of the NEXRAD data is 4km by 4km, each point represents the 16km^2 polygon it was converted from. The data was originally merged to hourly files, and then to a daily file. To create the overall convective climatology layer all the daily files were merged into one file. All the points could then be summed per each study section and a percentage of activity could be calculated. The most active areas are in the west (37,669) and southwest (37,598) sections, which contain the Spring Mountains. These two regions are nearly equal in activity; the next most active region is the southeast (22,055), which is bisected by the McCullough Range. The remaining three regions, the east (16,966), northeast (16,577), and the northwest (16,329), have lower, but nearly equal, activity levels (Figure 4.6). A gridded layer was also created to show the 30+ dBZ activity in the same resolution that the data is delivered from NCDC (Figure 4.7). This map shows the hot spots of the Spring Mountains in the western valley, Black Mountain area in the southeastern McCullough Range, and in the higher elevations, Gass Peak area, of the north-central valley.

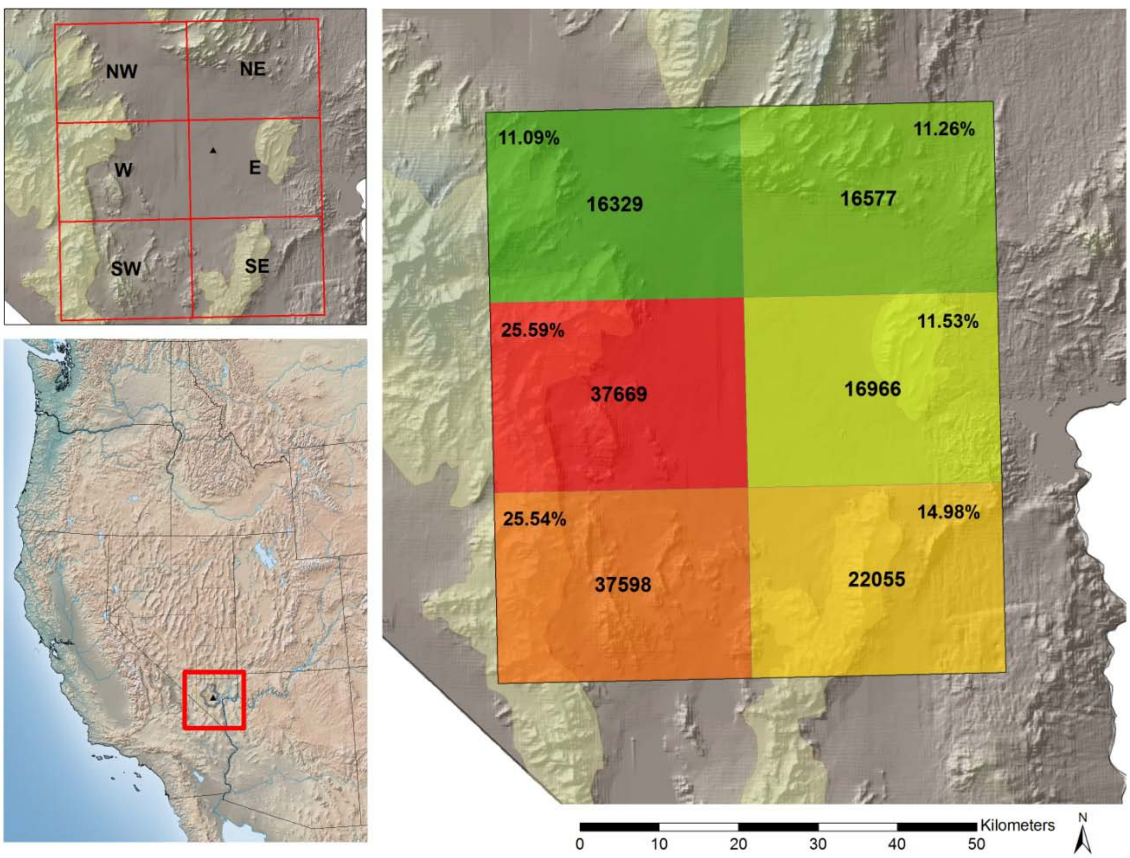


Figure 4.6. Convective Activity in Six Regions of the LVV.

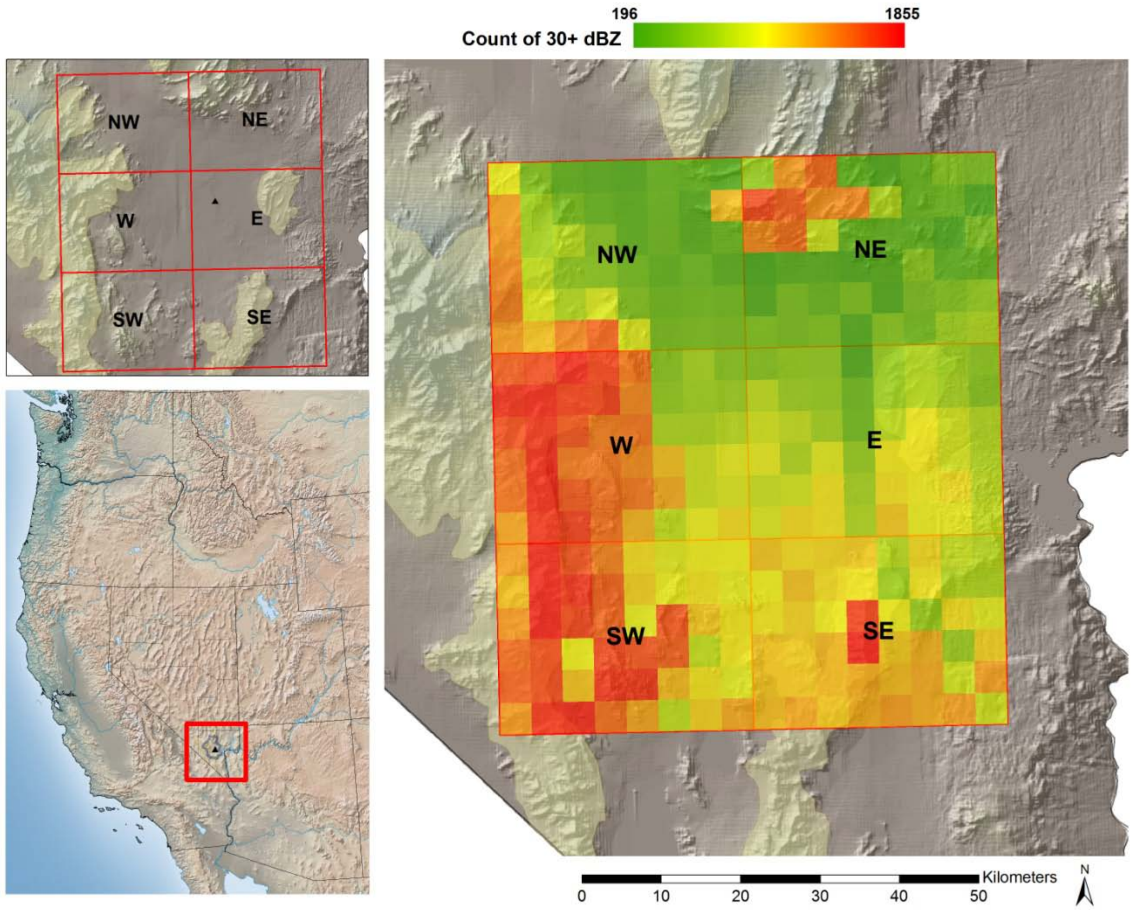
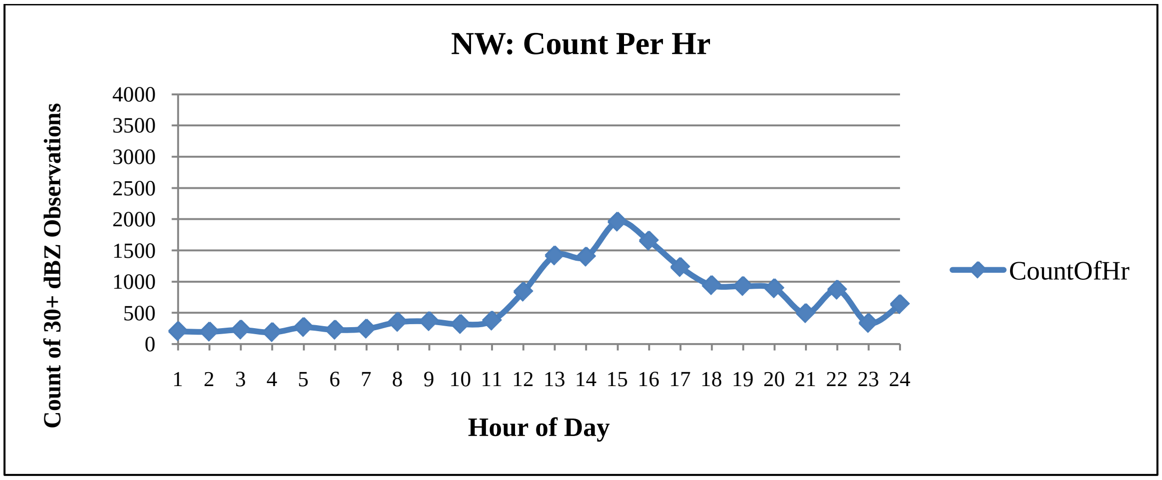
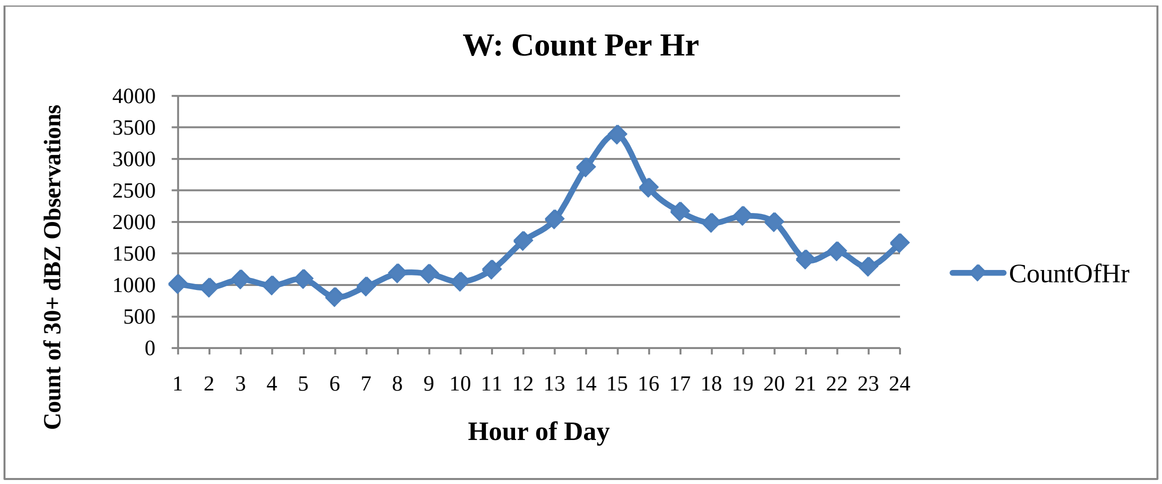
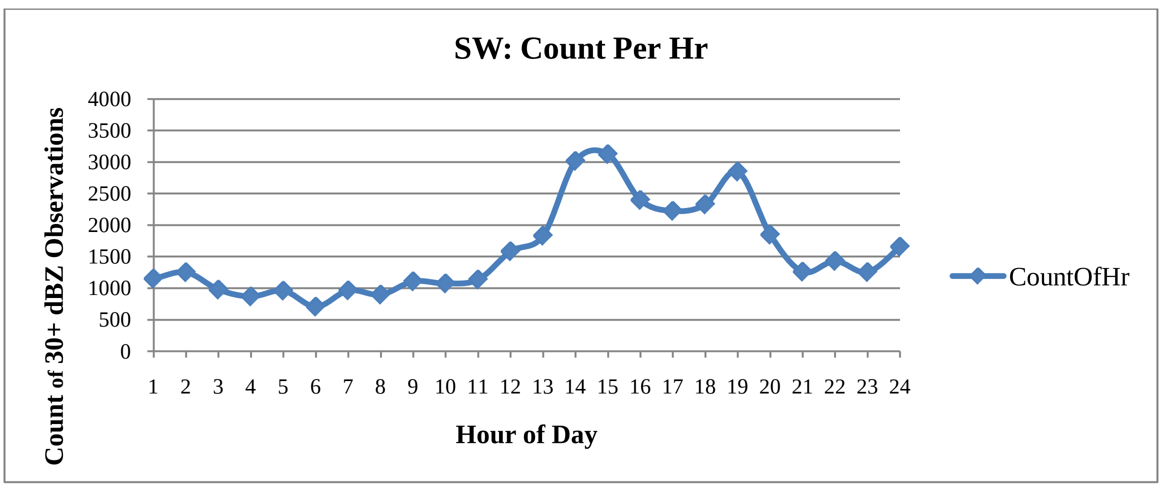


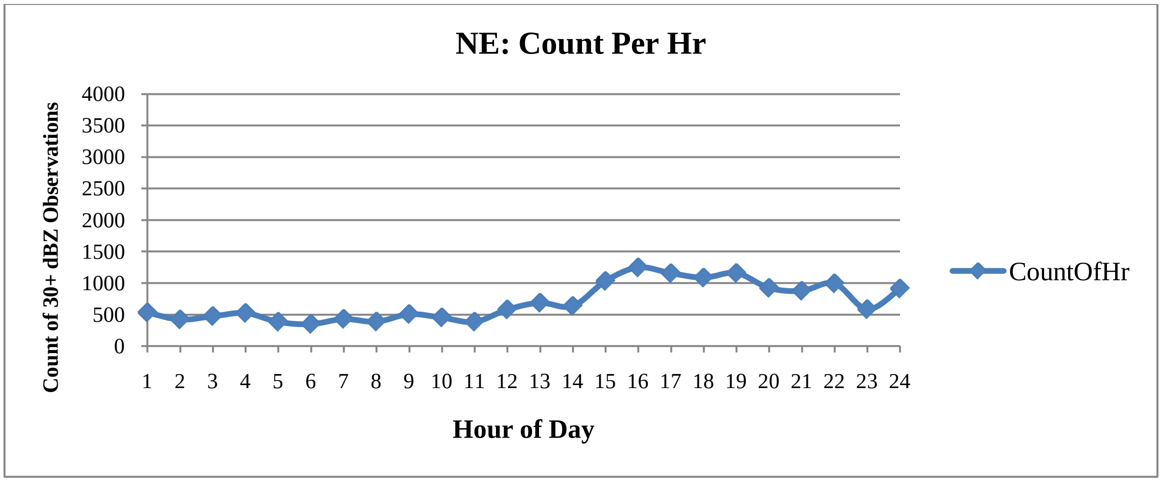
Figure 4.7. 16km^2 Gridded Layer of 30+ dBZ Activity in the LVV.

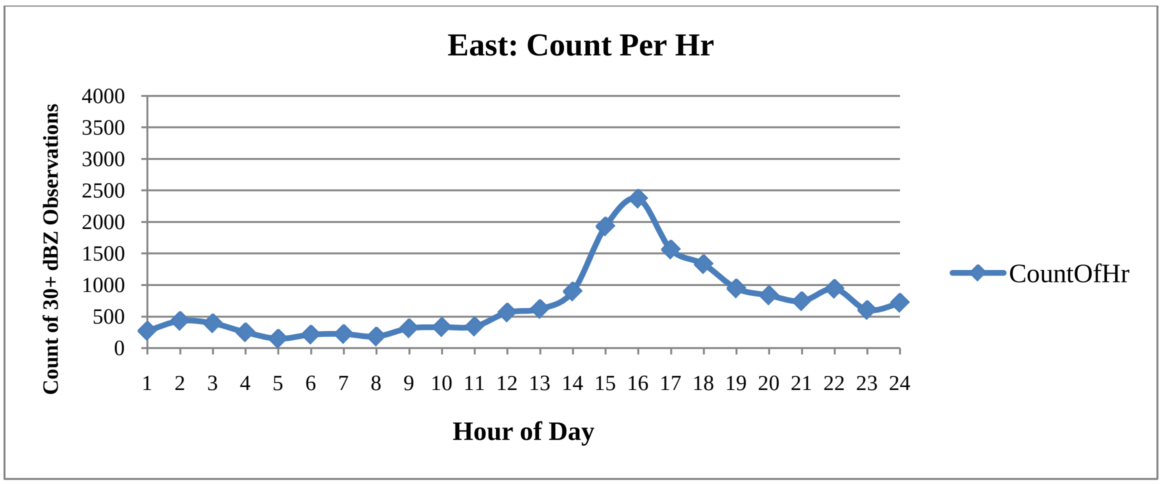
The time of day of the activity in each section was also analyzed. The NW, W, SE, and E show similar trends, activity grows as day warms, peaks around the 15th hour, then tapers off as the day cools. The SW and NE section display more evening activity than the others. The NE section shows a majority of late afternoon, evening activity. The SW section shows two peaks of activity, the 15th hour and the 19th hour, and then a sharp evening decline (Figure 4.8). A layer was also created to show the average hour of activity, on the 4km by 4km grid, throughout the study regions. The average hours span from a low of 13.24 (green) to a high of 16.88 (red). This map shows how the more active, high elevations have an earlier hour average, and it also demonstrates how the eastern and northwestern sections have a later hourly average of activity (Figure 4.9).











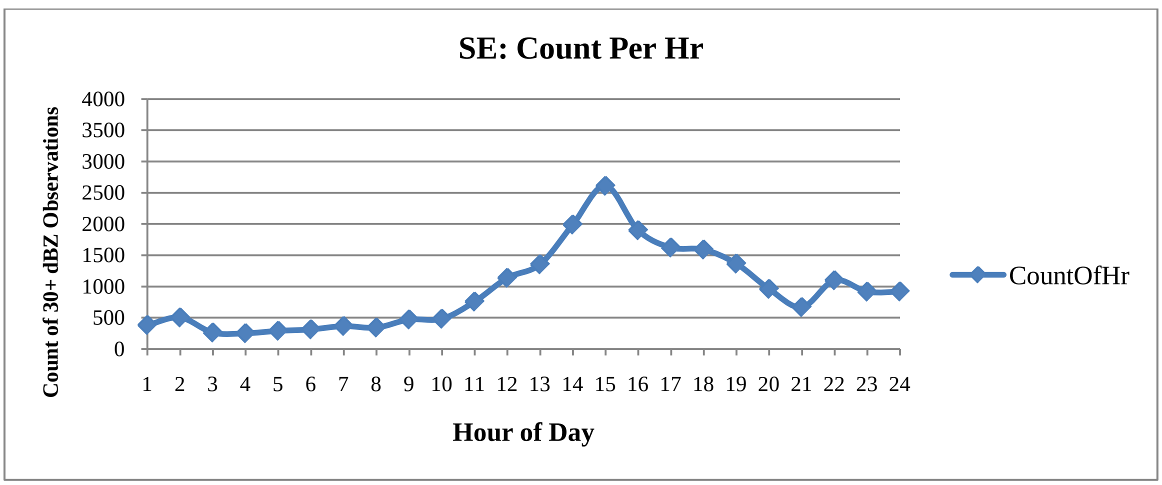


Figure 4.8. Hourly Counts of 30+ dBZ Activity Per Study Section

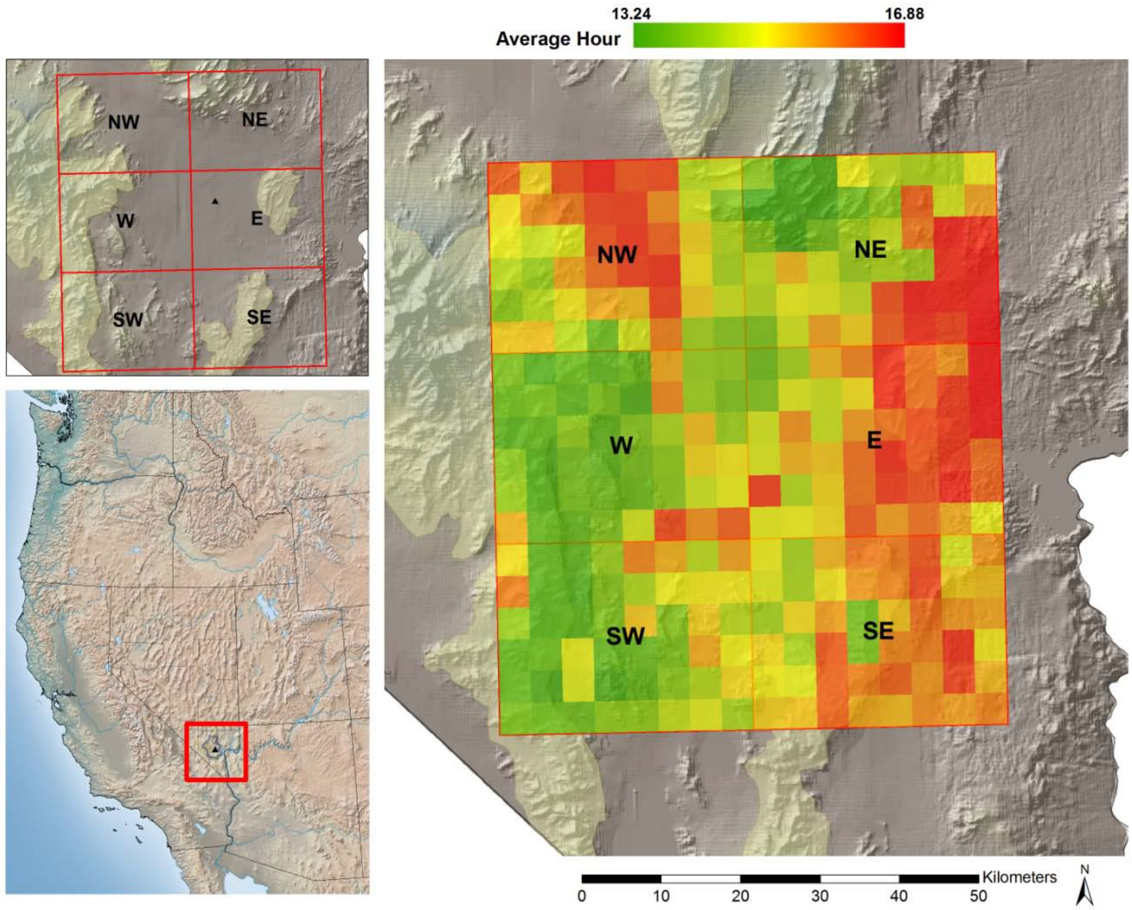


Figure 4.9. Hourly Average of 30+ dBZ Activity in the LVV. Greens are low, yellows mid, and reds are high values. The range is 13.24 to 16.88.

The final analysis performed in regards to convective climatology was the creation of an average dBZ layer, using all the observations that were 30 dBZ or higher. This layer shows that the high elevations in the west and northeast have the highest average values, but there is also a large portion over the southern half of the urban area that demonstrates large average dBZ values, between 38 and 39 in the darker red areas (Figure 4.10).

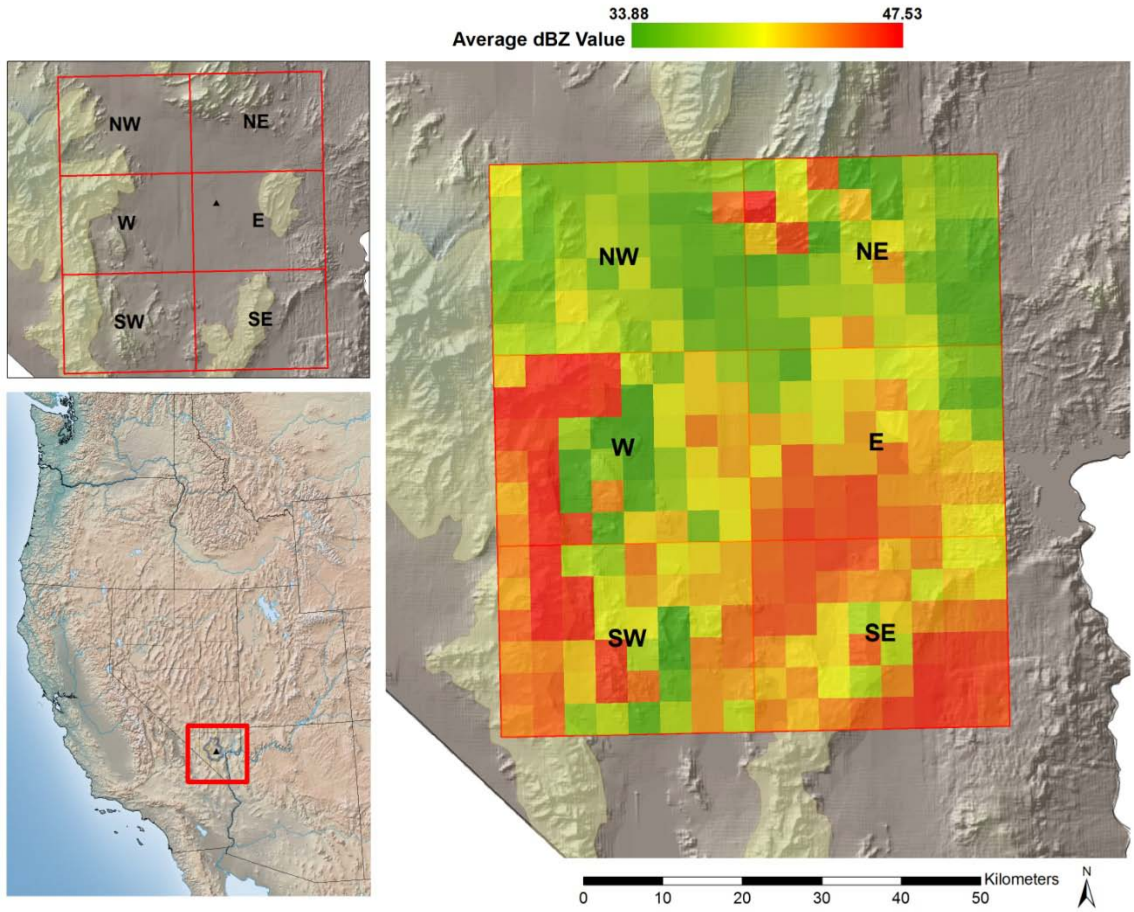


Figure 4.10. Average dBZ Values. Greens being low, yellows being mid, and reds being high values. The range is 33.88 to 47.53.

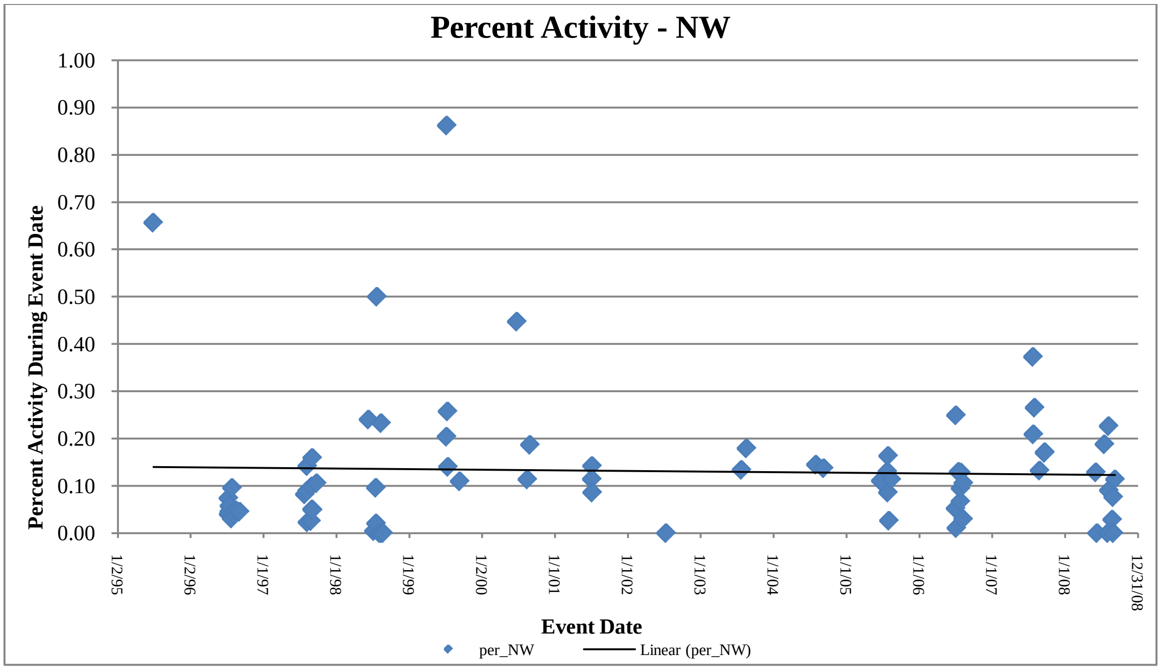
CHAPTER V

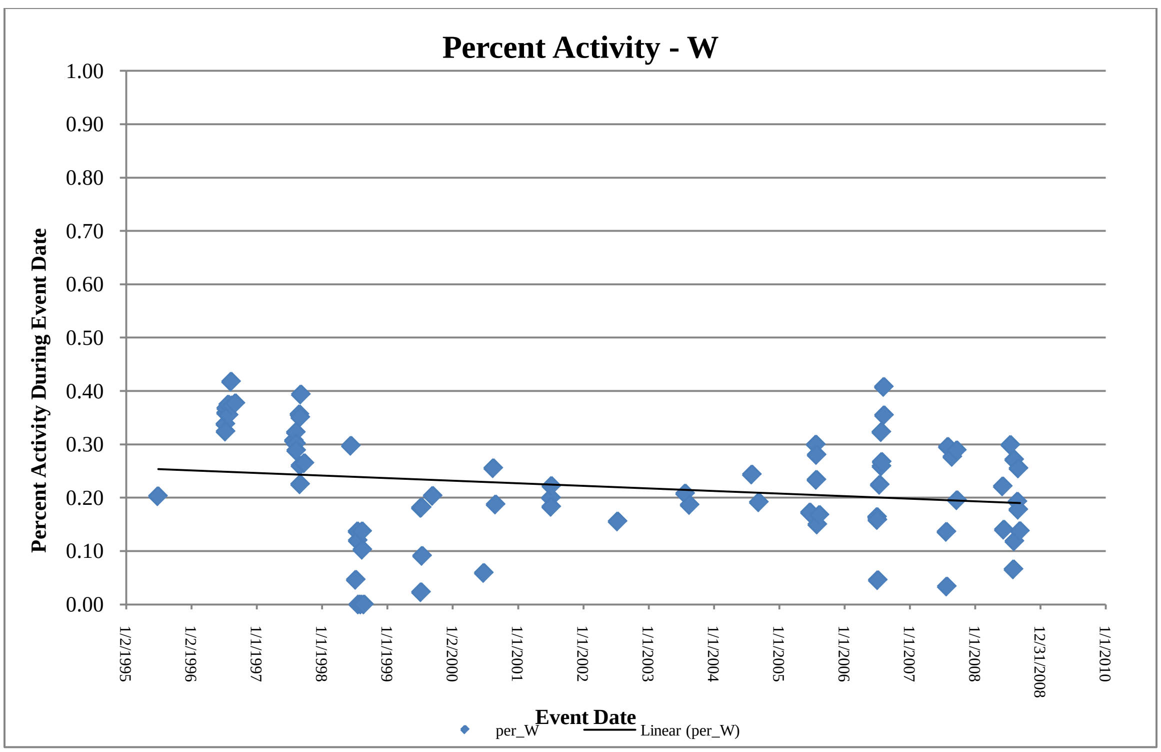
CHANGES IN CONVECTIVE PATTERNS

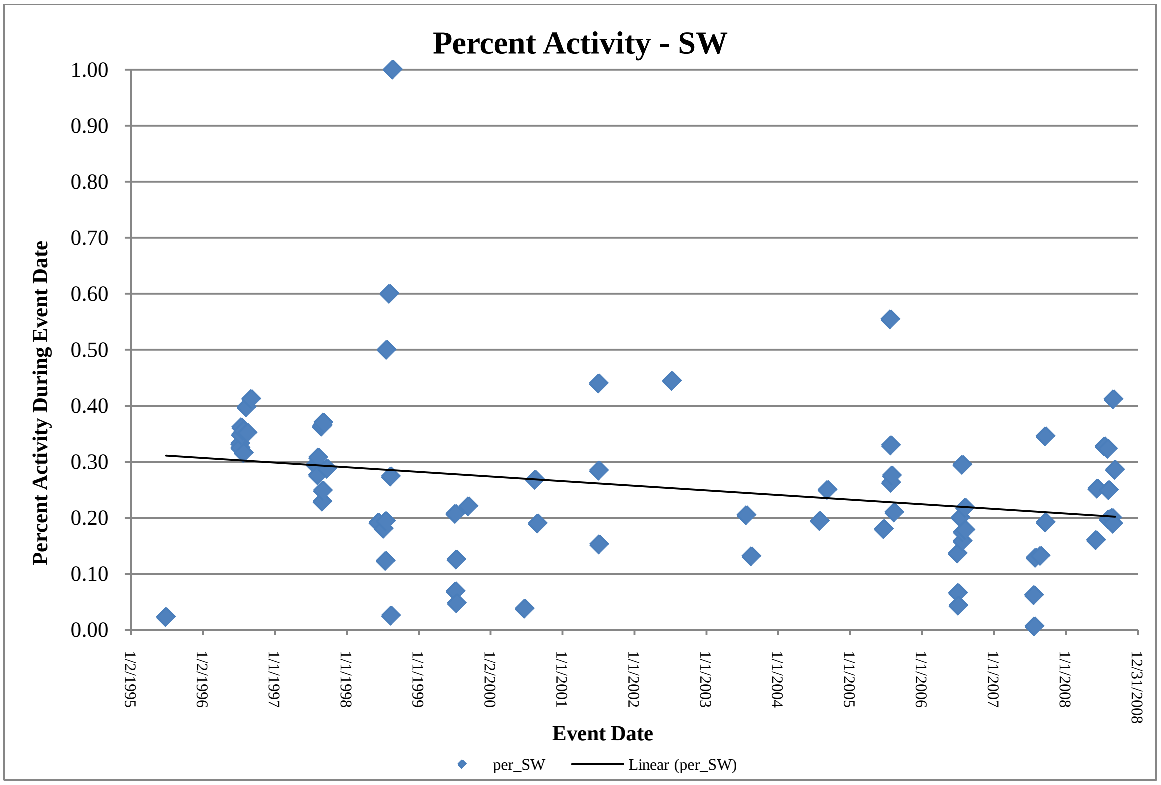
After establishing the climatic patterns for the convection in the LVV for the time period of study any changes in the patterns were analyzed. As mentioned in Chapter 3, the LVV was divided into six study regions; the NW, W, SW, NE, E, and SE. Each study section not only had the convective activity totaled, but also the percent of activity for each day, in each section, computed. From these daily percentages the change in activity, for the study period, was observed. Along with the six study regions the activity that occurred over the urban versus not over the urban area in the LVV had the same analysis performed.

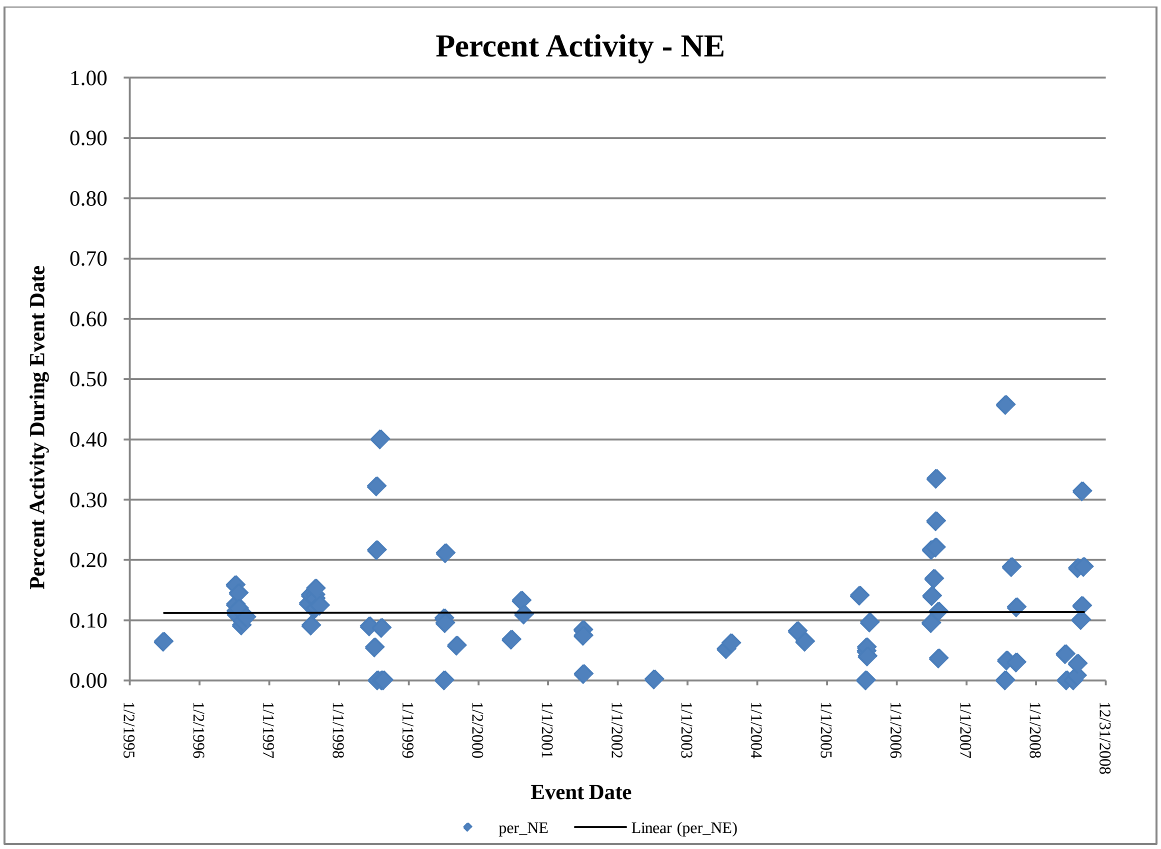
5.1 Directional Regions' Changes

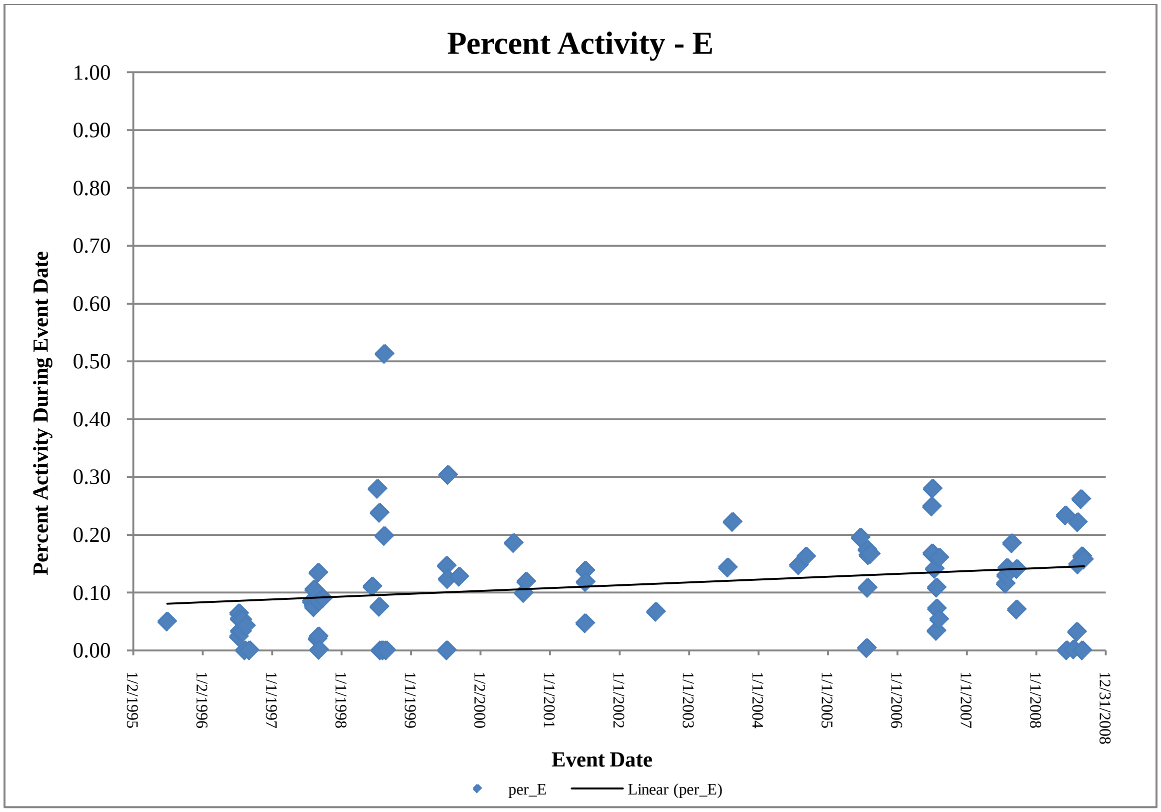
The percent of daily convective activity was computed for each storm day for each of the six study regions. The percent change over time was plotted to visually determine how the activity trended over the study period. The NW and NE sections showed little change, the W and SW sections showed a decrease, and the E and SE showed an upward trend (Figure 5.1). The next step was to run a linear regression analysis on all six regions to determine if the change over time was statistically significant. The software used for the analysis was Visual Data, a statistical software package created by Dr. James Carr at the University of Nevada, Reno. Of the six regions, four showed change over time that was significant (Table 5.1) per their F-statistic result.


Percent Activity - NW
Percent Activity During Event Date
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1/2/95
1/2/96
1/1/97
1/1/98
1/1/99
1/2/00
1/1/01
1/1/02
1/1/03
1/1/04
1/1/05
1/1/06
1/1/07
1/1/08
12/31/08
Event Date
per_NW
Linear (per_NW)


Percent Activity - W
Percent Activity During Event Date
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1/2/1995
1/2/1996
1/1/1997
1/1/1998
1/1/1999
1/2/2000
1/1/2001
1/1/2002
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
12/31/2008
1/1/2010
Event Date
per_W
Linear (per_W)


Percent Activity - SW
Percent Activity During Event Date
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1/2/1995
1/2/1996
1/1/1997
1/1/1998
1/1/1999
1/2/2000
1/1/2001
1/1/2002
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
12/31/2008
Event Date
per_SW
Linear (per_SW)


Percent Activity - NE
Percent Activity During Event Date
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1/2/1995
1/2/1996
1/1/1997
1/1/1998
1/1/1999
1/2/2000
1/1/2001
1/1/2002
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
12/31/2008
Event Date
per_NE
Linear (per_NE)



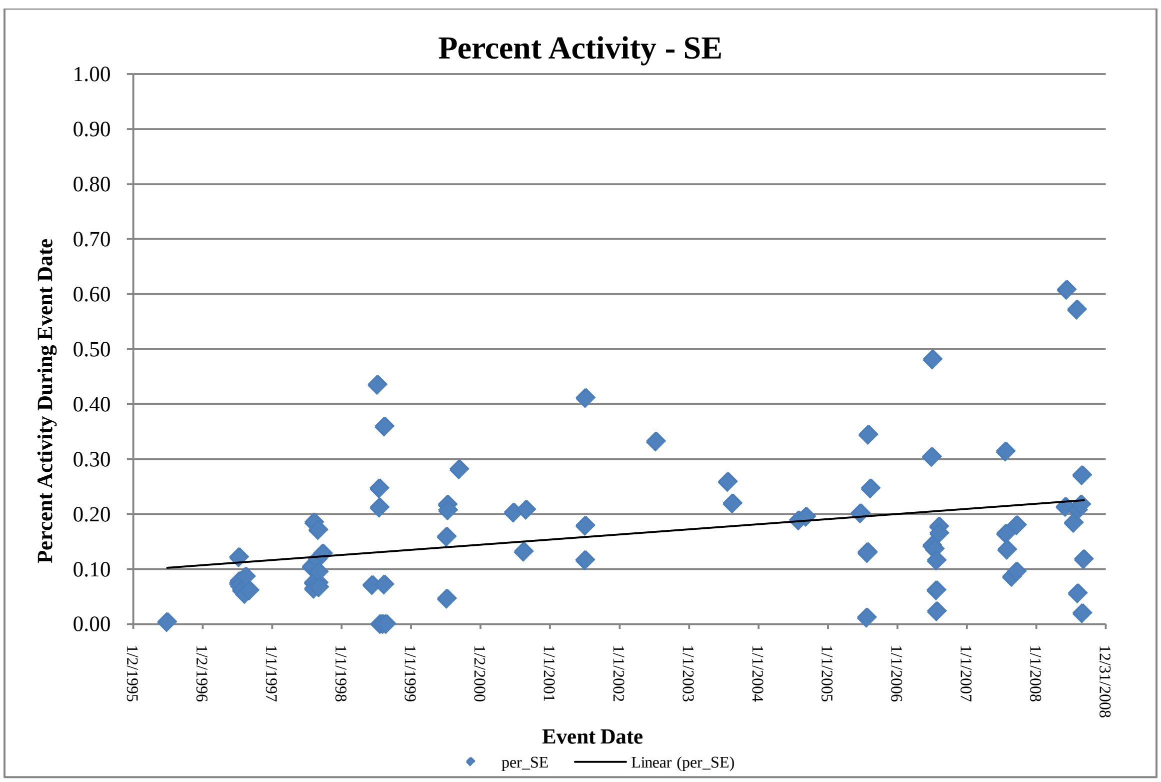


Figure 5.1. Percent Activity per Each Study Section.

Study Region	NW	W	SW	NE	E	SE
F Stat	0.02	6.85	4.46	0	5.76	10.23

Table 5.1. Linear Regression Results for Study Sections Using Visual Data

As the visual trends indicated the two northern section's changes were not statistically significant, and the remaining four sections did have significance in regards to their change. The results indicate that the convective activity, during this study period, has been shifting from the west-southwest sections to the east-southeast sections.

Another trend that was analyzed was the average dBZ level per storm day over the time period. The trend show that the average dBZ level overall is trending downward on storm days, so they appear to be lessening in their average intensity (Figure 5.2). The F-statistic was computed for this dataset in Visual Data and the result of 13.21 shows that this trend is statistically significant. When the average dBZ level is looked at in each section, similar results, a decreasing trend, are observed except in two sections, the E and SE (Figure 5.3). The SE trend suggest no change in the dBZ value over the study period, and the E trend suggest a slight increase in the dBZ intensity, however these two trends are not statistically significant when performing the regression analysis on the values. The other four sections display the decreasing 30+ dBZ intensity, and the NE (6.94), W (19.66), and SW (10.82) are statistically significant when running the regression analysis.

The final analysis done was to determine if convective activity has been affected over the urban landscape. The BLM Las Vegas Valley Disposal Boundary was used to delineate the urban events versus the non-urban events. The percentage of events occurring within the boundary versus outside the boundary was computed and plotted (Figure 5.4). The trend indicates that the amount of activity within the boundary has been increasing over the study period. The F-statistic was computed for these results and its value was 5.61, therefore this trend is also statistically significant.

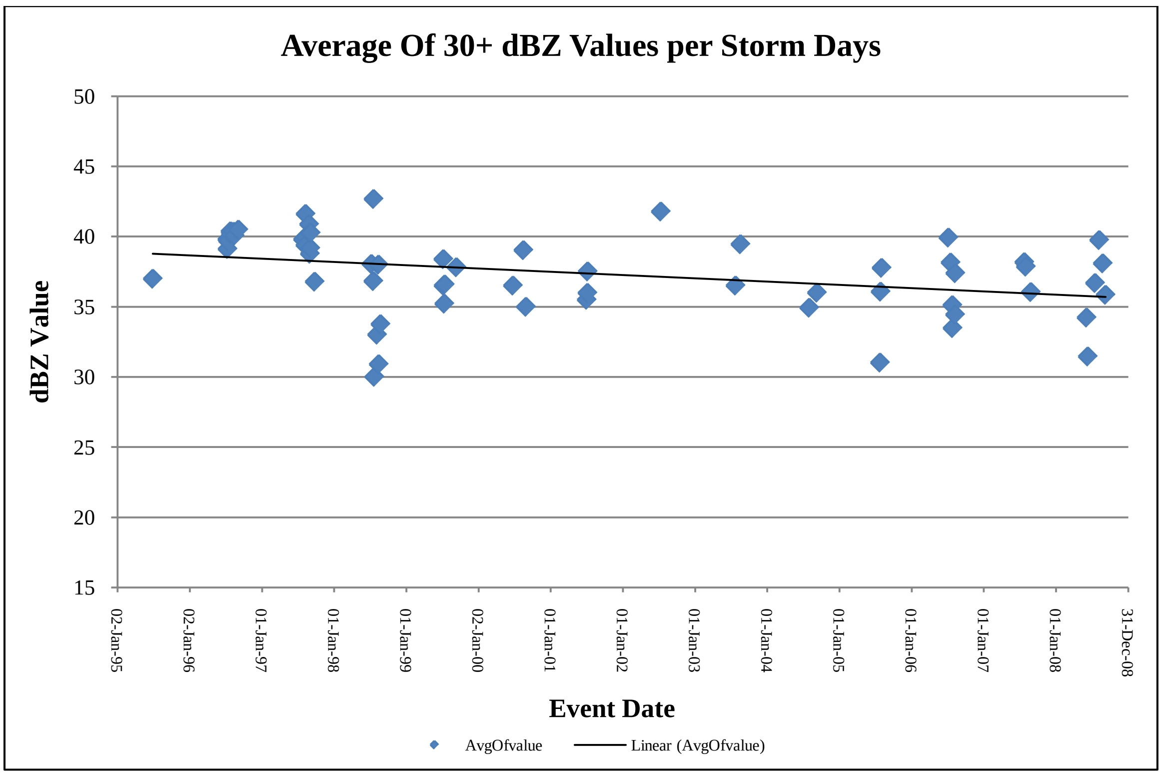
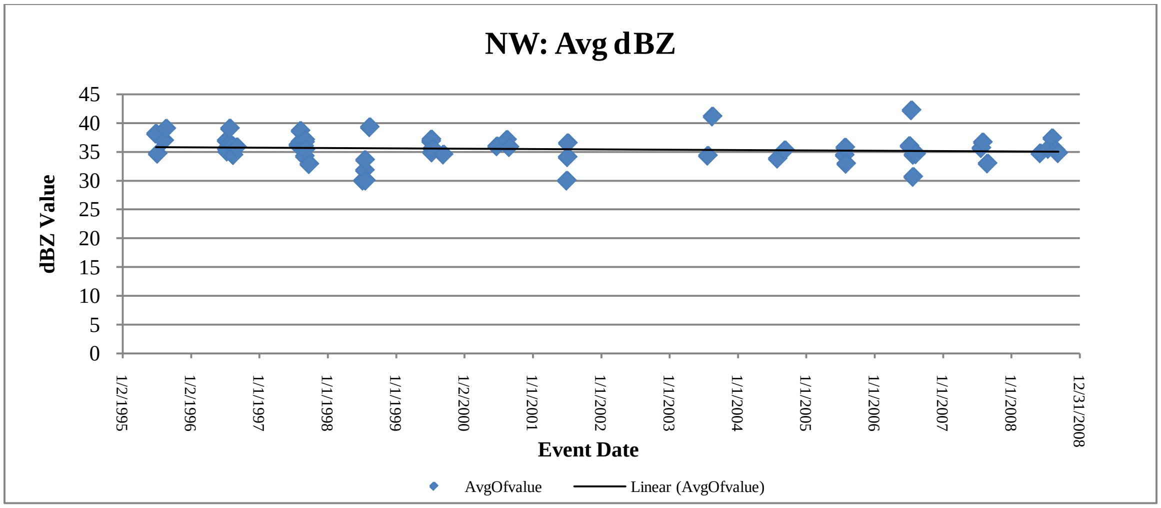
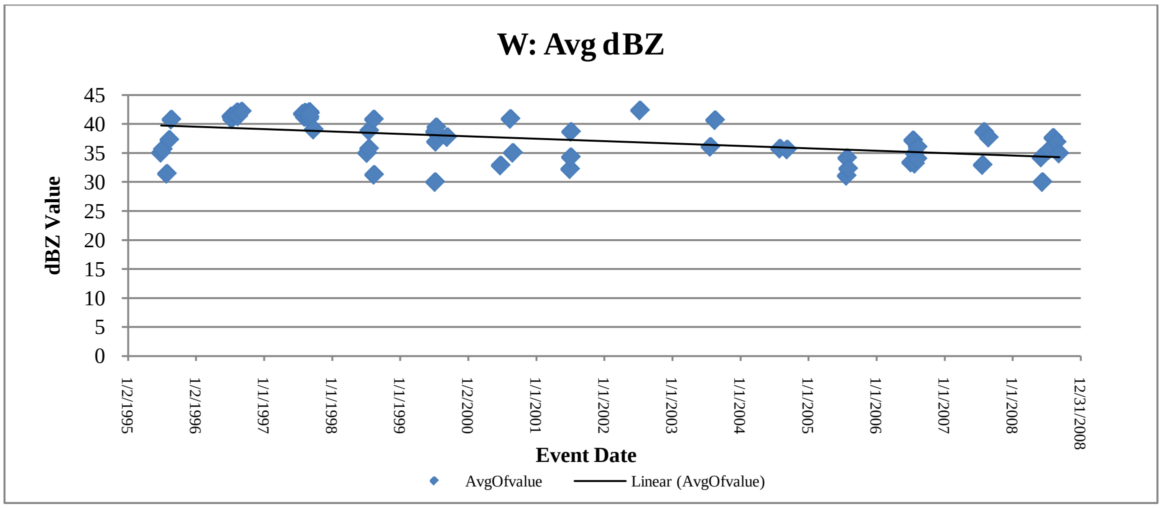
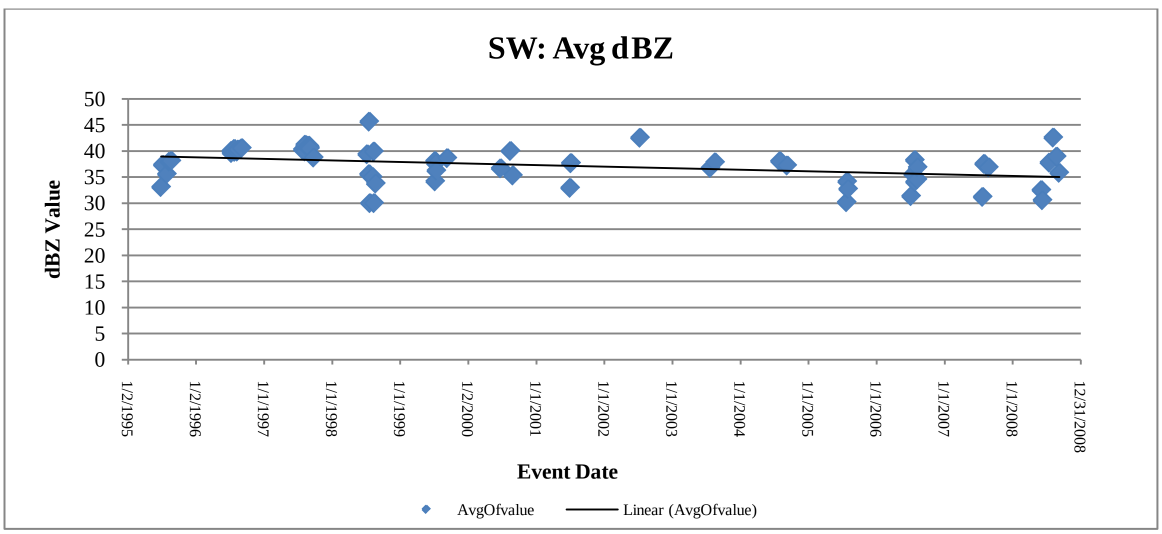
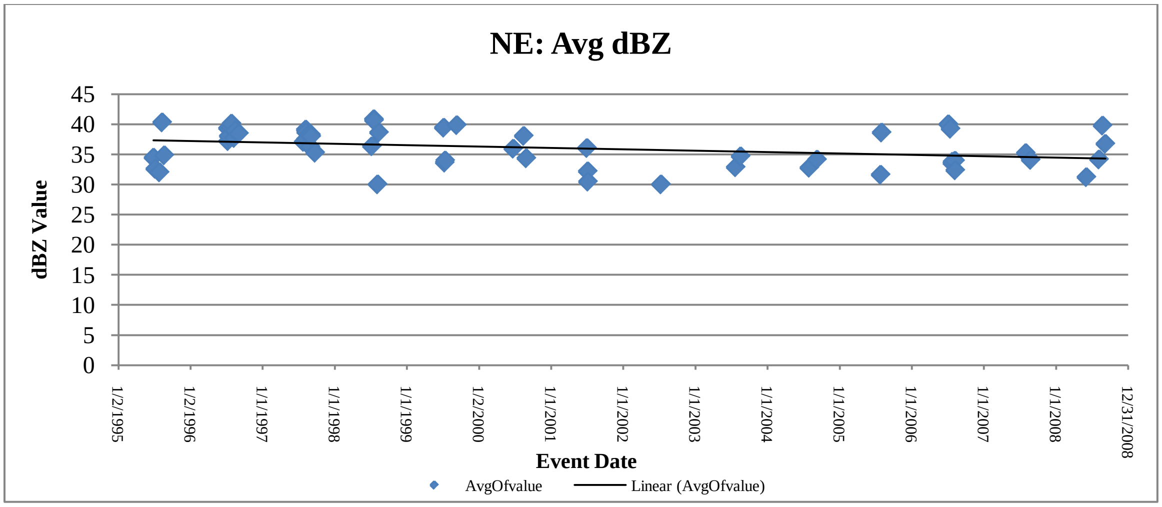


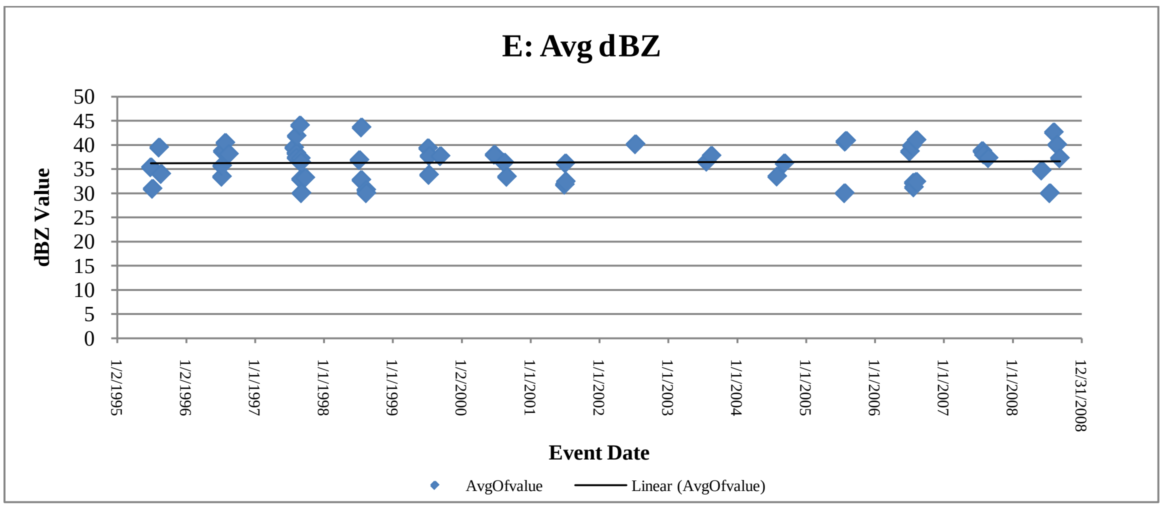
Figure 5.2 Average of 30+ dBZ Values per Storm Day. Graph shows a decreasing trend over the study period. F-stat from Visual Data is 13.21, making this trend statistically significant.


NW: Avg dBZ
45
40
35
30
25
20
15
10
5
0
dBZ Value
1/2/1995
1/2/1996
1/1/1997
1/1/1998
1/1/1999
1/2/2000
1/1/2001
1/1/2002
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
12/31/2008
Event Date
AvgOfvalue
Linear (AvgOfvalue)


W: Avg dBZ
45
40
35
30
25
20
15
10
5
0
dBZ Value
1/2/1995
1/2/1996
1/1/1997
1/1/1998
1/1/1999
1/2/2000
1/1/2001
1/1/2002
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
12/31/2008
Event Date
AvgOfvalue
Linear (AvgOfvalue)


SW: Avg dBZ
50
45
40
35
30
25
20
15
10
5
0
dBZ Value
1/2/1995
1/2/1996
1/1/1997
1/1/1998
1/1/1999
1/2/2000
1/1/2001
1/1/2002
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
12/31/2008
Event Date
AvgOfvalue
Linear (AvgOfvalue)





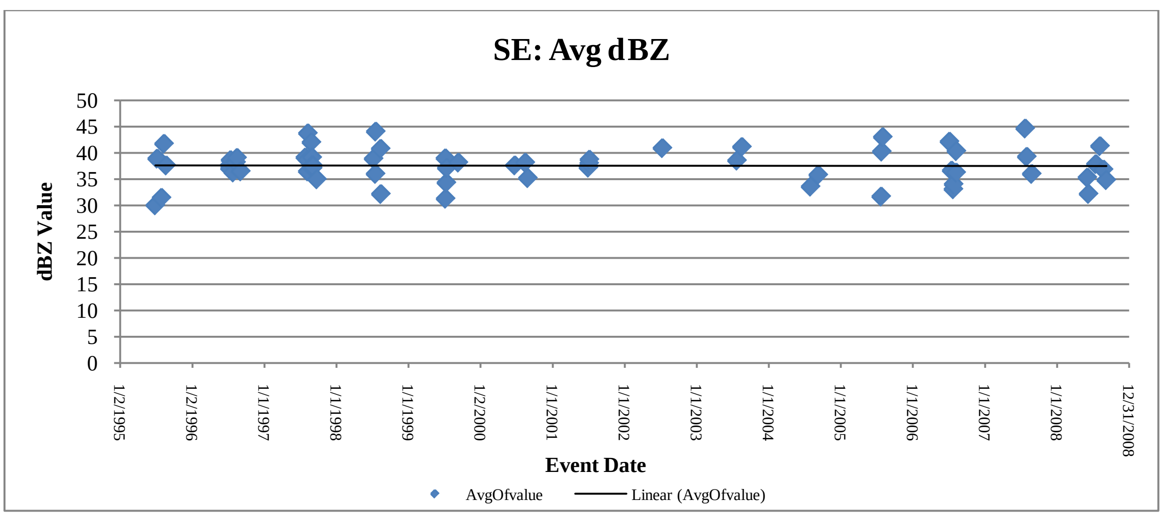


Figure 5.3. Sectional Averages of 30+ dBZ Activity. The NE, W, and SW decreases are statistically significant using the classical regression analysis. The NW suggests slight decrease. The E and SE are not significant either, but they visually suggest no change or a slight increase in dBZ intensity.

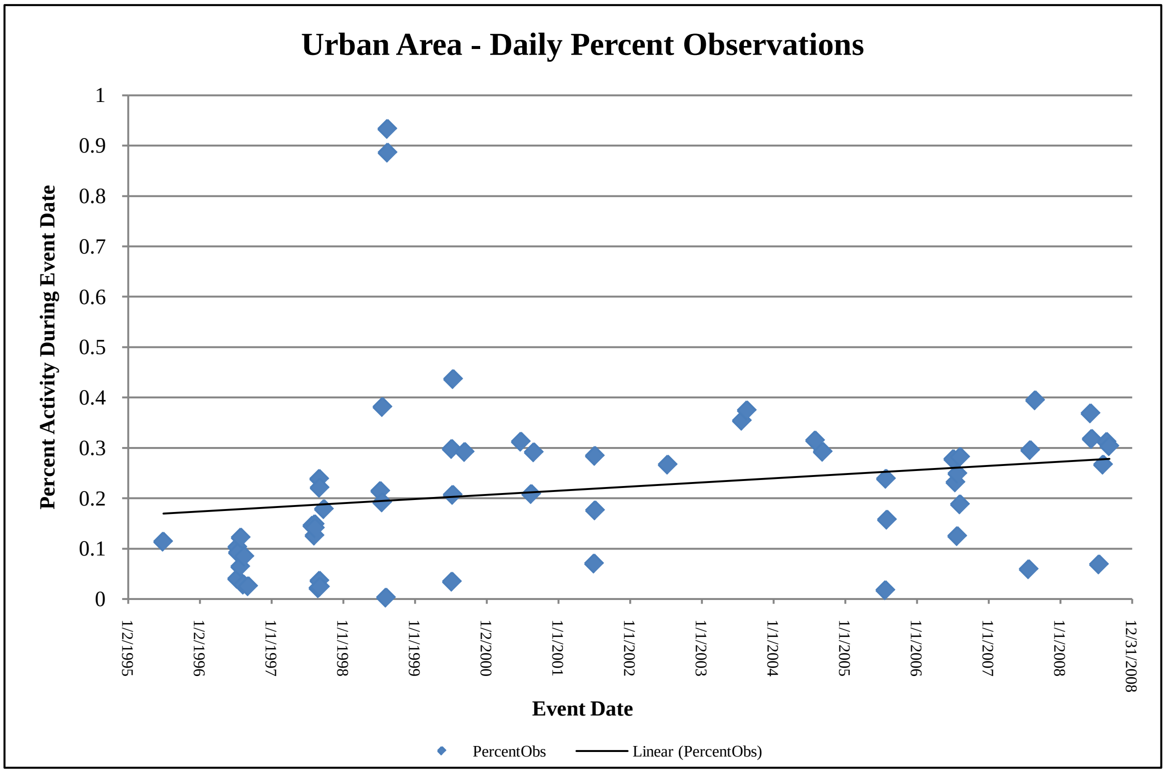


Figure 5.4 Percent of daily observations occurring over urban area show an upward trend. F-stat from Visual Data is 5.61, making this trend statistically significant.

CHAPTER VI

CONCLUSIONS

The main purpose of this research was to determine if the Las Vegas Metropolitan Area has changed the convective activity patterns in the Las Vegas Valley. This issue was answered by analyzing the following objectives: (1) to what extent has the LVV grown in population, (2) what is the convective climatology of the LVV on storm event days, and (3) how has the convective activity changed in the study regions within the LVV and over the urban area? In earlier urban climate studies it was found that the convection was enhanced downwind of the urban area. The majority of urban-enhanced climate studies have been done in relatively moist environments. The arid western United States has not been a focus of study, with the exception of Phoenix, Arizona. As in those studies, the urbanization of the LVV appears to have had an influence on the convective activity occurring over the urban landscape as well as areas downwind of the urban area.

6.1 Conclusions

This research covered the years from 1995 to 2008. The time frame of this study period was limited by the availability of the radar data collected at the KESX station. In 1995 the Las Vegas Metropolitan Area had a population of 1,055,435 and by the end of the study, 2008, the population of Las Vegas was 1,967,716, a growth of 86% (NSBDC, 2010). The rapid growth of this region can be expected to have an effect on the climate of the LVV. Due to its arid climate, the LVV and other urban centers in similar climate regimes have been mostly ignored in urban climate modification studies since there is such a minimum of rainfall in these areas. As expressed by Shepherd (2006), these regions should be analyzed because of their rapid growth, the ability to focus on regional convection, and the large use of irrigation that has added more moisture into the environment than would normally be present.

The analysis of the upper atmospheric data shows that a day with storm activity is not always reflected in the soundings in this arid region. The CAPE and K-Index values in this region are not nearly as high as they are on convective days in a humid climate. The average CAPE values on the storm event days in this region was just over 275, not very high but still a positive number. Yet one noticeable feature from the soundings is that, on average, storm event days start with a slight inversion in the AM sounding. This morning inversion, as mentioned by Runk (1996), aids in the development of the convective convergence zone in the LVV due to the replacement of the cool valley air by warmer air from above, forming a thermally forced mountain-valley solenoid. This then allows for moisture pooling that works to pre-condition the LVV for deep convection thus destabilizing the atmosphere.

Through the creation of a convective climatology for the LVV, using the NEXRAD level III data, the storm patterns and trends were analyzed. The activity during the study period, 1995 – 2008, revealed three key areas of high convective activity. The western LVV along the Spring Mountains, the Black Mountain area in the southeastern section, in the McCullough Range, and around the Gass Peak area in the north-central valley in the northeastern section. This map (Figure 4.7) also revealed how the convective activity spills out from the west and south stretching halfway up the valley and then tapering off to the north. The temporal component of the convection was also analyzed. The peak hour of activity in the LVV is during the 15th hour of the day. When looking at the average hour of the convective activity the higher elevation areas appear to have the activity first, in the 13th hour, and then the downwind, eastern sections, receive the average of their activity later in the afternoon, in the 16th hour.

The convective climatology led to results that follow the established Las Vegas Converge Zone (LVCZ) that Runk (1996) has described. He explained that the LVCZ forms along the leeside of the Spring Mountains in the western part of the valley, in a northwest to southeast direction spanning towards Lake Mead, in the late morning/early afternoon (Figure 6.1). The convergence boundary then moves across the valley in a northeasterly direction with the mean wind during the afternoon and early evening. The climatology established in this study follows this pattern. The early activity is identified in the west, Spring Mountains, and the late afternoon activity is clear in the east/northeast, with the eastern sections having their peak activity hours later than the west, and with the NE section having the majority of its activity in the late afternoon/evening hours.

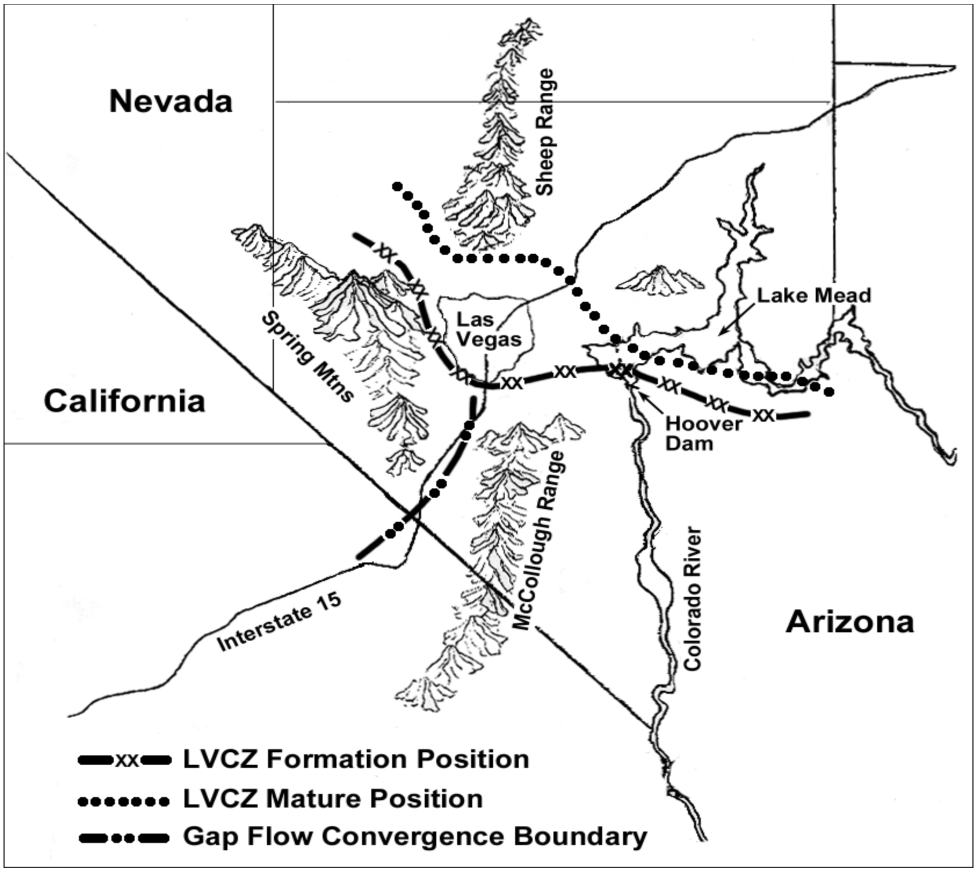


Figure 6.1. Diagram of the Las Vegas Convergence Zone Life Cycle. Described by Runk (1996). Source: Figure 7 from 'A Numerical Investigation of the Las Vegas Convergence Zone'.

In an earlier study performed by Westcott (1995), she demonstrated, using lighting strike data, that the urban area influenced the lightning strike activity. The lighting activity was enhanced during the afternoon hours, and the urban area appeared to enhance existing thunderstorms that passed over the city, and also downwind of most of the urban areas in her study. The upper atmosphere data was used to determine the mean 700mb wind in order to establish the upwind and downwind sections of the LVV. The mean 700mb during the study period was 197°, a south-southwesterly wind direction. This mean wind direction makes part of the SE, the E, and the NE sections the downwind areas of the study region. The analysis of the change in convective patterns in the LVV revealed similar trends as the Westcott study. The eastern sections demonstrated statistically significant increases in the daily percentage of convective activity during storm events days. Also the urban area has shown a statistically significant enhancement in convective activity. The overall trend in the LVV has been a decrease in the average strength of the 30+ dBZ values in the valley as a whole. When those trends are analyzed on a sectional basis four of the six sections exhibit the same trend; the NW, W, SW, and NE. The SE trend displays no change in average dBZ level. The E section displays a slight increase of the average dBZ value over the span of this study, this further supports what has been observed in other urban-modification climate studies; an enhancement of convective activity over and downwind of the urban area.

6.2 Implications

If the shift in convective activity continues as demonstrated in this study this could cause difficulties in urban planning and emergency management issues. With a shift of convective storms to the eastern parts of the valley, due to the sloping aspect of elevation towards Lake Mead in the LVV, the potential for increased erosion and sedimentary transport towards the lake could pose a threat to that area. Another issue that usually accompanies convective activity is lightning strike activity. In this arid environment lightning strikes can also spark fires, so if the trend continues as shown in this study fire activity may also increase in the eastern portions of the LVV. As prior research has shown, and confirmed in this study, urban areas can have an influence on their environment. This study has shown that convection has been increasing over the urban boundary, and has been increasing in the downwind portions of the LVV.

6.3 Future Research

Further research on the effects that urbanization has on convection patterns is needed to further support the main hypothesis. The research in this analysis of the LVV suggests that urbanization is having an influence on the convective activity in an often neglected arid study region, even though the study had a limited time span due to the availability of the NEXRAD radar data. The use of the NCDC Storm Events database has its weaknesses, as pointed out in previous studies, but it was useful in providing a basis of known storm event dates. The storm event dataset created in this study could be further expanded by using other data sources that cover a more continual temporal period. The U.S. National Lightning Detection Network (NLDN) Database would be an ideal source of data to expand this study. The NLDN dataset contains lightning strike data that could serve as a proxy for storm activity. The strike data gives temporal and spatial information on every lightning strike that occurs on a daily basis. Through the use of the NLDN dataset a more comprehensive thunderstorm dataset could be constructed, filling in any missing dates that were documented, or indicated in the data sources used in this study.

Based on previous research studies, it was expected that convective activity would be increased over the urban area, and downwind from the urban area. This research found that there are increases in activity over the urban boundary, as well as increases in the eastern and southeastern study sections, these results prove to be consistent with those earlier studies. If the urbanization of the LVV has had an influence on the convective patterns, then the projected continual growth in the region will further influence the convective activity. It is likely the anthropogenic signal will become even stronger if the projected growth trends of the Las Vegas Metropolitan area come to realization (Clark County Comprehensive Planning, 2009).

LITERATURE CITED

Ashley, W., & Gilson, C. (2009). A reassessment of U.S. lightning mortality. *Bulletin of the American Meteorological Society*, *90*(10), 1501-1518. doi:10.1175/2009BAMS276S.1.

Austin, P.M. (1987). Relation between measured radar reflectivity and surface rainfall, *Monthly Weather Review*, *115*(5), 1053-1071. Retrieved from Web of Science database.

Blanchard, D. (1998). Assessing the Vertical Distribution of Convective Available Potential Energy. *Weather & Forecasting*, *13*(3), 870. Retrieved from Academic Search Premier database.

Bureau of Land Management. (2004). *Las Vegas Disposal Boundary Environmental Impact Statement.* Las Vegas, NV: U.S. Department of the Interior. Retrieved from http://www.blm.gov/nv/st/en/fo/lvfo/blm_programs/planning/las_vegas_valley_disposal.html.

Cain, D. & Kirkwood, P. (2004). WSR-88D Radar FAQ's. *National Weather Service Radar Image.* Retrieved from http://weather.noaa.gov/radar/radinfo/radinfo.html.

Clark County Comprehensive Planning. (2009). *Population Forecast: 2009 Clark County Population Forecast: 2009 – 2050.* Clark County, NV. Retrieved from http://www.accessclarkcounty.com/depts/comprehensive_planning/demographics/Pages/Demographics.aspx

Curran, E., Holle, R., & Pez, E. (2000). Lightning Casualties and Damages in the United States from 1959 to 1994. *Journal of Climate*, *13*(19), 3448. Retrieved from Academic Search Premier database.

DeRubertis, D. (2006). Recent Trends in Four Common Stability Indices Derived from U.S. Radiosonde Observations. *Journal of Climate*, *19*(3), 309-323. Retrieved from Academic Search Premier database.

Dixon, P., & Mote, T. (2003). Patterns and Causes of Atlanta's Urban Heat Island–Initiated Precipitation. *Journal of Applied Meteorology*, *42*(9), 1273. Retrieved from Academic Search Premier database.

EPA. (2010). *Heat Island Effect.* Retrieved from http://www.epa.gov/heatisland/
Gallo, K., & Owen, T. (1999). Satellite-based adjustments for the urban heat island temperature bias. *Journal of Applied Meteorology*, *38*(6), 806. Retrieved from Academic Search Premier database.

Gorelow, A. (2005). A Climate of Las Vegas, Nevada. *NOAA Technical Memorandum NWS WR-271*, NOAA/ARL/SORD, Las Vegas, NV, 1-59. Retrieved from http://www.wrh.noaa.gov/wrh/techMemos/271.pdf.

Hocker, J., & Basara, J. (2008). A Geographic Information Systems–Based Analysis of Supercells across Oklahoma from 1994 to 2003. *Journal of Applied Meteorology & Climatology*, *47*(5), 1518-1538. doi:10.1175/2007JAMC1673.1.

Horton, R.E. (1921). Thunderstorm-breeding spots, *Monthly Weather Review, 49*(4), 193. Retrieved from http://journals.ametsoc.org/toc/mwre/49/4.
Huff, F. A. & Changnon S. A. (1973). Precipitation modification by major urban areas, *Bulletin of the American Meteorological Society*, *54*(12), 1220-1232. Retrieved from Web of Science database.

LVCVA (2010). 2009 Las Vegas Year-to-Date Executive Summary. *The Las Vegas Convention and Visitor's Authority*. Retrieved from http://www.lvcva.com/getfile/479/ES-YTD2009.pdf

Maddox, R., Zhang, J., Gourley, J., & Howard, K. (2002). Weather Radar Coverage over the Contiguous United States. *Weather & Forecasting*, *17*(4), 927. Retrieved from Academic Search Premier database.

Mote et al. (2007). Radar signatures of the urban effect on precipitation distribution: A case study for Atlanta, Georgia. *Geophysical Research Letters*, *34*(L20710), 1-4. doi:10.1029/2007GL031903.

NCDC. (2010). *Storm Data FAQ Page.* Retrieved from http://www.ncdc.noaa.gov/oa/climate/sd/sdfaq.html.
Nevada Small Business Development Center (NSBDC). (2010). *Data and Publications.* Retrieved from http://www.nsbdc.org/what/data_statistics/demographer/pubs/.

Oke, T. R. (1988). *Boundary Layer Climates.* (2nd ed.). Routledge.

Peppier, R. (1988). A review of static stability indices and related thermodynamic parameters. *Illinois State Water Survey Division.* Retrieved from http://www.isws.illinois.edu/pubdoc/MP/ISWSMP-104.pdf.

Randerson, D. & Sanders J. B. (2000). *Anomalous cloud-to-ground flash densities over Southern Nevada*. NOAA/ARL/SORD, Las Vegas, NV, 1-6. Retrieved from http://www.sord.nv.doe.gov/Lightning_research/lgtnconf1100A.pdf.

Runk, K. J. (1996). A numerical investigation of the Las Vegas Convergence Zone, *National Weather Service Forecast Office, Las Vegas Nevada*. Retrieved from http://www.wrh.noaa.gov/vef/projects/ni-lvcz.php.

Shearman, R.J. (1977). The speed and direction of movement of storm rainfall patterns with reference to urban storm sewer design / Vitesse et direction de la distribution de l'intensité de la pluie en ce qui concerne le dessin des égouts-déversoirs urbains. *Bulletin of the International Association of Scientific Hydrology*, *22*(3), 421-431. doi:10.1080/02626667709491735

Shepherd, J., Pierce, H., & Negri, A. (2002). Rainfall Modification by Major Urban Areas: Observations from Spaceborne Rain Radar on the TRMM Satellite. *Journal of Applied Meteorology*, *41*(7), 689. Retrieved from Academic Search Premier database.
Shepherd, J. (2006). Evidence of urban-induced precipitation variability in arid climate regimes. *Journal of Arid Environments*, *67*(4), 607-628. doi:10.1016/j.jaridenv.2006.03.022.

Westcott, N. (1995). Summertime cloud-to-ground lightning activity around major Midwestern urban areas, *Journal of Applied Meteorology*, *34*(7), 1633-1642. Retrieved from Web of Science database.

Wheeler, M. (2008). Why Here? A Short History of Las Vegas. *Planning*, *74*(2), 18-19. Retrieved from Academic Search Premier database.

Xian, G., & Crane, M. (2006). An analysis of urban thermal characteristics and associated land cover in Tampa Bay and Las Vegas using Landsat satellite data. *Remote Sensing of Environment*, *104*(2), 147-156. doi:10.1016/j.rse.2005.09.023.