The Population Bias of Severe Weather Reports West of the Continental Divide

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November 2005

Abstract

Many severe storms in the West may go unreported or unobserved, and therefore the severe weather climatology is not fully understood. But as the population has increased in the West so has the number of severe weather reports. To check if a population bias exists, correlation coefficients are calculated with respect to population for tornadic and nontornadic severe storm activity. The sample size for tornadic storms is too small to draw any conclusion. To calculate the correlation coefficients for nontornadic severe storms, population and severe weather data are used for every county in each western state between the years 1986-1995 and 1996-2004. The calculated correlation coefficients reveal that population and the number of nontornadic severe storms are significantly correlated, and this indicates that a population bias does exist for several western states.

1. Introduction

The number of severe weather reports for the western United States is considerably less than for other parts of the country. The lack of moisture, lift, and instability limits convective potential in the West; therefore, the number of severe storms is less than what occurs in other parts of the country. But there may be non-meteorological reasons that limit the number of severe weather reports. These reports may be limited to urban centers, and therefore severe weather data likely exhibit a population bias. Severe storms in rural areas may go unobserved, and hence unreported.

Severe weather does occur in the west and occasionally grabs national media attention, like the 11 August 1999 Salt Lake City tornado that struck downtown. The Teton-Yellowstone F4 tornado of 21 July 1987 (Fujita 1989) may be a better example of western U.S. severe weather (i.e., it occurs in a remote area and there are no known witnesses to the storm). However, it's conceivable that many severe storms are observed, but may have gone unreported. One example is a storm observed by the author's late uncle who was a caretaker at a Boy Scout camp (Camp Pico Blanco south of Monterey, California). On 31 July 1977, he observed a severe thunderstorm and estimated wind gusts reached 80 mph and also noted that the sky turned green (his observation was not reported to the National Weather Service and does not appear in Storm Data). Severe thunderstorms near the central California coastline in late July are rare, but this storm occurred and had significant consequences. Lightning from thunderstorms that afternoon sparked the Marble Cone fire, several miles south of Camp Pico Blanco that burned 177,866 acres, the third largest wildfire in California's history (California Department of Forestry and

Fire Protection 2004).

The aforementioned cases illustrate the challenges of establishing a relevant severe weather climatology for the western U.S. Since no one knows how many severe storms go unreported or unobserved, there's uncertainty on how many severe storms actually do occur. People have been gradually moving into areas that were once unpopulated, and are now observing severe storms that would not have been observed beforehand. To provide a better understanding on how often severe weather occurs, trends for tornadic and nontornadic severe storms will be examined. The area of concern will be limited to the continental United States that reside west of the Continental Divide. Hawaii and Alaska are not included since both states have vastly different climates compared to the western U.S.

2. Earlier Research

Early research with respect to tornadic and severe storms has been concentrated in the Midwest, but in the past 10 to 15 years, there has been more research to document severe and tornadic storms in the western United States. Fujita (1989) examined in detail the F4 tornado that tracked across western Wyoming, including Yellowstone National Park. Evenson and Johns (1995) looked into synoptic weather patterns that lead to severe weather outbreaks in the Pacific Northwest. Similarly, Maddox et al (1995) compiled several types of weather patterns that generate severe thunderstorms in central Arizona. Bluestein (2000) studied a supercell storm that formed over elevated, complex terrain and produced a tornado and large hail north of Divide, Colorado. Dunn and Vasiloff (2001) used WSR-88D and Terminal Doppler Weather

Radar data and showed that the Salt Lake City tornado developed rapidly upward along a boundary layer convergence line and reached downtown with less lead time than the average Midwest tornadic storm.

There have been many studies on severe weather climatology, such as tornadic storms (Kelly et al 1978; Doswell and Burgess 1988; Raddatz and Hanesiak 1991), nontornadic severe thunderstorms (Kelly et al 1985), and severe thunderstorm wind reports (Weiss et al 2004). Blier and Batten (1994) did a climatological analysis of tornado occurrence in California, and they stated that the frequency of tornadic storms in the south coastal region of California is 3.19 x 10^{-4} tornadoes km^{-2} yr^{-1}, a number that is qualitatively comparable to that of Oklahoma, 2.86 x 10^{-4} tornadoes km^{-2} yr^{-1}. Earlier research in the central Plains compared population density with tornado reports. Schaefer and Galway (1982) found lack of support for a population bias in the western Plains from Oklahoma and Kansas, except for counties with high populations. But Grazulis (1991) noted there was a higher percentage of unreported tornadoes in less populated western Kansas, compared to eastern Kansas. Raddatz and Hanesiak (1991) speculated that tornadoes have been under-reported in parts of Manitoba with sparse population.

But none of these articles examined severe storm climatologies that are specific to the Western states as a whole, or attempted to correlate severe weather data with population, a subject that will be studied in this paper.

3. Severe Weather Data and Population in the Western United States

The western states have experienced the fastest growth in the U.S. for many years; the top five fastest growing states, on a percentage basis from 1990 to 2000, are in the West: Nevada, Arizona, Colorado, Utah, and Idaho (U.S. Census Bureau 2001). In 1950, the population of the eleven western states was 20 million. By 2000, this number had risen to 60 million, and by 2025 the projected population by the U.S. Census Bureau is 85 million. But most of the population in the West is crowded into urban centers; 13 of the top 20 urbanized areas ranked by density (500,000 people or more) reside in the West (Table 1). The West is the most urbanized region of the country, where more than four out of five westerners live in urbanized areas; for the rest of the country, nearly two in three live in urban areas. By way of contrast, six of the ten states with the lowest population density are in the West.

Coinciding with the population increases has been the steady rise of severe weather reports. As the correlation coefficients will show in the following tables, an association can be made between increasing population and the number of severe weather reports. Questions regarding these associations may include:

* How frequent is severe weather in the western U.S.?

* Is there a relationship between population and observed severe weather?

* Do severe storms in the western U.S. pose different risks and hazards compared to severe storms in other parts of the country?

* Why is this information important?

To answer these questions, trends of observed severe weather and population will be studied, despite the limited data set. Tornadic storm data go back to 1950, but there are considerably less data for severe nontornadic storms and only available since 1986. Even with this limited data set (19 years), correlation coefficients can be calculated between nontornadic storms and population trends (shown in section 3b.).

a. Tornadic Storms

Tornado data spanning from 1950 through 1999 will be used in this study. Figure 1 charts the total number of reported tornadoes for all western states in each decade. The population data (U.S. Census Bureau 1995) at the beginning of each decade were used for each corresponding decade. Referring to Figure 1, each decade showed an increase of population and observed tornadoes. From these two data sets between number of reported tornadoes and population for each decade, a correlation coefficient is calculated, where 0 means no correlation, and +1 and -1 means one data set can be predicted from the values of the other data set. The calculated correlation coefficient is 0.96, suggesting there is a strong correlation between population and reported tornadic storms. This data supported Brooks (2004) comments that part of the reason for the dramatic increase of F0 and F1 tornadoes nationwide was likely from increasing population in the western United States. However, due to the lack of the data sample size, the strong correlation may be a coincidence as there could be other unknown factors that could account for the strong correlation.

Figure 1 shows that tornadic storms in western states that exceed F1 on the Fujita scale are rare, with an annual mean of only 1. F3 and F4 tornadoes are extremely rare, but do occur, with one such event every six years. There have been no reports of F5 tornadoes for this period of observation. Since 1950, the data from Figure 1 do not indicate any trend and shows a negative correlation with population, -0.77. Therefore the increase of reported tornadic storms consisted of F0 and F1 storms, similar to the national trend of the past 30 years (McCarthy and Schaefer 2004). Despite the low number of F2 or greater storms, they account for most of the injuries, deaths, and property damage. According to the National Climatic Data Center (2005) from 1950 to 1999, F2 tornadoes or higher have caused 499 of the 634 injuries, 10 of 11 fatalities, and $308.7 millions dollars of the $391.7 million dollars worth of property damage. Overall, Table 2 shows that tornadic storms account for 12.7 injuries per year and $7.8 million dollars of property damage per year (National Climatic Data Center 2005).

b. Nontornadic severe thunderstorms

For nontornadic severe thunderstorms, data availability only goes back to 1986. While this time period is relatively short, the information is valuable and shows that significant changes have occurred during this time period. These data are broken up in two parts, 1986-1995 and 1996-2004. The five year average of the 1986-1995 period can be compared with the 1996-2004 period to establish a trend (Fig. 2). Incidentally, 1995 was the year that many WSR-88Ds became operational in the West, and the number of NWS forecast offices increased. Therefore, splitting apart the data set at 1996 becomes very convenient for this research.

Figure 2 reveals a noteworthy increase of reported nontornadic severe thunderstorms between the period of 1996-2004 compared to the 10 year period of 1986-1995. Adjusting for the annual average, California, Washington, western New Mexico, Oregon, Nevada, and Arizona showed at least a 100% increase for the latter 9 year period versus the initial 10 year period. Western Colorado had the largest increase in severe weather reports by more than a factor of 3. Overall, the percentage change for the entire western continental U.S. was +87%.

Nineteen years of data is not a sufficient period of time to correlate nontornadic severe storms with decadal changes of population. Another method is used instead; the correlation coefficient is computed by using population and the number of severe weather reports for each county. For example, 20 Colorado counties reside west of the continental Divide, so the sample size would be 20 to calculate the correlation coefficient between reported severe weather and county population. The correlation coefficients are calculated for two time periods (Table 3), 1986-1995 and 1996-2004, using the census data of 1990 and 2000 respectively (U.S. Census Bureau 2002).

Despite overall changes in the number of severe weather reports between each time period, the correlation coefficients remained remarkably steady for each state, with the notable exception of western New Mexico. The two states in the Pacific Northwest (Washington and Oregon) showed near zero correlation with population and observed severe weather. But if both states are separated into western and eastern halves, using the Cascade Mountains as the separation line, the numbers become better correlated (Table 4). The larger population centers for both states are in the western half, but the eastern portions accounts for more reported severe storm reports.

What's notable about these numbers is that the correlation between the two time periods have stayed remarkably similar (with the exception of western New Mexico, western Washington, and possibly Utah) for each state. Given an increase of observed severe weather events, one might expect changes in the correlation coefficients with a lower value suggesting a lesser population bias. Instead, the rise in severe weather reports has primarily occurred in urban areas, and as a result, the correlation coefficients have remained similar. Therefore, western NWS forecasts offices have shown a significant improvement in retrieving severe weather reports from urban areas. Collecting storm data from rural areas remain a challenge, hence the climatology of severe weather in these areas is not well understood, or unknown!

The above conclusion is somewhat similar to the results of statistical interpolation used by Ray et al (2003) who estimated the true number of tornadoes in the central Plains is about 60% higher. They also concluded that there is a positive correlation between tornado occurrence with population density and radar location, as well as a significant correlation with the existence of a tornado warning.

4. Why Western Severe Storms Pose Unique Challenges to Operational Forecasters

Severe storms in the western states do pose unique problems that need to be addressed. A better understanding of the severe weather climatology is required for many reasons.

- Population shifts to the western U.S., and inhabitation of areas that were once unpopulated.

- Increased recreational use. Some of these areas may be uninhabited or sparsely populated, but may be frequently used by outdoor enthusiasts.

- Improved communications. People in rural areas may have wireless communication devices with instant messaging capabilities that alert for weather warnings, including severe weather. More people may have such devices in the future.

- Lack of ground truth. McCarthy (2002) stated that timely ground-truth reports played a critical role during the 3 May 1999 Oklahoma tornado outbreak. In rural areas, retrieving ground truth in a timely manner can be difficult; therefore, the warning decision-making process can be negatively impacted and severe warnings lack detail.

- The western states have perceived favorable weather and people expect persistence. The western U.S. is considered to have ideal climate by many people, and perhaps is one of the reasons people move to the West. But this benign weather may lull people into believing that this will persist day to day. Severe and deadly weather does occur, but it's infrequent, and this infrequency makes people more vulnerable to the hazards of severe weather. To increase public awareness, the accuracy of forecasting severe weather becomes very important, especially when the environment is such that severe weather probability is above, or much above, climatology.

- Biases of the F-scale. Another issue is that F-scale is a damage scale, rather than an intensity scale; this is attributed to a population bias and the lack of structures (Guyer and Moritz 2002). Schaefer and Galway (1982) noted a population bias of F-scale rating in the western Plains; tornadoes that strike higher populated areas tend to have a higher rating than those in open country. Possibly, this may be true of western tornadic storms, where some tornadic storms rated F1 in open land may have been assigned F2 if they struck a populated area.

5. Conclusions

With population expected to continue to increase in the West, more severe weather reports can be expected. But there needs to be improvement in retrieving such reports in sparsely populated and remote areas. Not only would this provide a better severe weather climatology, but would provide forecasters with an improved baseline to interpret radar data. Also, while people may not live in remote areas, they have access to these areas, and these people may carry wireless communication devices to receive and report weather information.

People that live in the western U.S. need to be aware that severe storms, although infrequent, do occur. Forecasters need to recognize the weather patterns that generate these storms as soon as possible (e.g., Evenson and Johns 1995; Maddox et al. 1995), then increase public awareness. With Ray et al. (2003) stating a positive correlation between tornado warnings and observance of tornadic storms, increasing public awareness of any severe weather may increase the chances of retrieving reliable storm reports. This would accomplish two goals: increase the forecaster's knowledge of severe weather climatology and lower the bias between population and severe weather reports.

Acknowledgments

The author wishes to thank Ron Miller, Dr. Michael Meyers, and Jeffrey Manion who reviewed earlier versions and provided valuable input to the manuscript. Reviewers, including Matthew Bunkers, made many suggestions that were incorporated and significantly improved the manuscript. Jeff Colton helped to retrieve the storm data. Thanks also to Mary Cairns for providing initial ideas for this paper.

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Table 1 – 2000 Urbanized Areas of the U.S. Ranked by Density

(Population > 500,000)

Rank	Urbanized Areas	Population	Sq._Miles	Pop. Density
1	Los Angeles--Long Beach--Santa Ana, CA	11,789,487	1,668	7,068
2	San Francisco--Oakland, CA	2,995,769	428	7,004
3	San Jose, CA	1,538,312	260	5,914
4	New York--Newark, NY--NJ--CT	17,799,861	3,353	5,309
5	New Orleans, LA	1,009,283	198	5,102
6	Honolulu, HI	718,182	154	4,660
7	Las Vegas, NV	1,314,357	286	4,597
8	Miami, FL	4,919,036	1,116	4,407
9	Fresno, CA	554,923	139	4,003
10	Denver--Aurora, CO	1,984,887	499	3,979
11	Chicago, IL-IN	8,307,904	2,123	3,914
12	Mission Viejo, CA	533,015	137	3,894
13	Salt Lake City, UT	887,650	231	3,847
14	Sacramento, CA	1,393,498	369	3,776
15	Phoenix--Mesa, AZ	2,907,049	799	3,638
16	Riverside--San Bernardino, CA	1,506,816	439	3,434
17	San Diego, CA	2,674,436	782	3,419
18	Washington, DC--VA--MD	3,933,920	1,157	3,401
19	Portland, OR--WA	1,583,138	474	3,340
20	San Antonio, TX	1,327,554	408	3,257

Table 2: Casualties and Property Damage from Tornadic Storms (1950-1999)

	Tornadoes	Injuries	Deaths	Loss $(mil.)

Arizona	180	139	3	46.3
California	287	87	0	105.2
W. Colorado	17	0	0	0.1
Idaho	137	7	0	5.4
W. Montana	13	0	0	0.1
Nevada	61	2	0	1.6
W. New Mexico	20	3	1	1.0
Oregon	69	2	0	28.8
Utah	92	91	1	172.6
Washington	74	303	6	28.0
W. Wyoming	25	0	0	2.6
Total	975	634	11	391.7
Per Year	19.5	12.7	0.2	7.8

Table 3: Nontornadic Severe Weather and Population Correlation

	# Counties	1986-1995	1996-2004
Nevada	17	.81	.85

Western Colorado	20	.88	.89
Arizona	15	.97	.87
Western Montana	11	.83	.83
Utah	29	.84	.62
Western New Mexico	9	.07	.30
Western Wyoming	4	.80	.79
Idaho	44	.55	.43
California	58	.36	.42
Washington	39	.02	-0.04
Oregon	36	.06	-0.12

Table 4: Nontornadic Severe Weather and Population Correlation for Washington and Oregon

Forecast Office	1986-1995	1996-2004
Western Washington – 19 counties		
Population/Severe Weather Correlation	0.75	0.32

Number of Reported Severe Storms	4	7
Eastern Washington – 20 counties		
Population/Severe Weather Correlation	0.59	0.68
Number of Reported Severe Storms	58	138
Western Oregon – 19 counties		
Population/Severe Weather Correlation	0.31	0.14
Number of Reported Severe Storms	42	51
Eastern Oregon – 17 counties		
Population/Severe Weather Correlation	0.65	0.76
Number of Reported Severe Storms	89	224

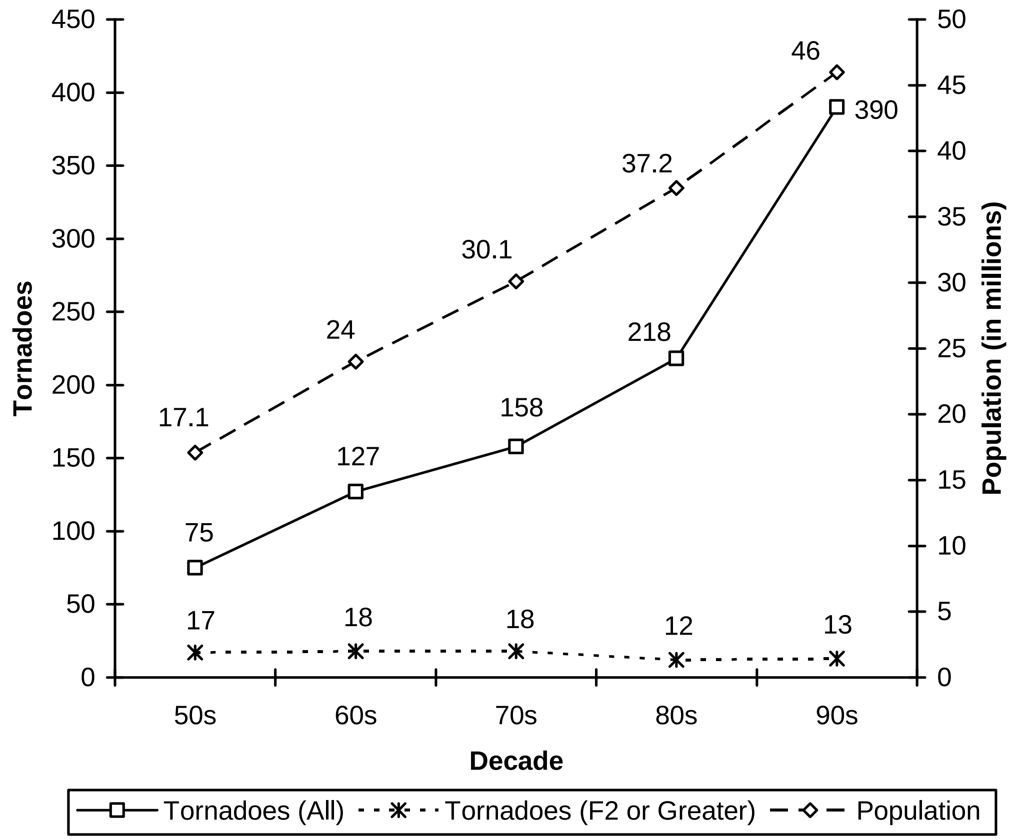

Figure 1. Graph of all tornadoes, F2 and greater tornadoes, and population per decade for the western states west of the continental Divide, not including Hawaii and Alaska.

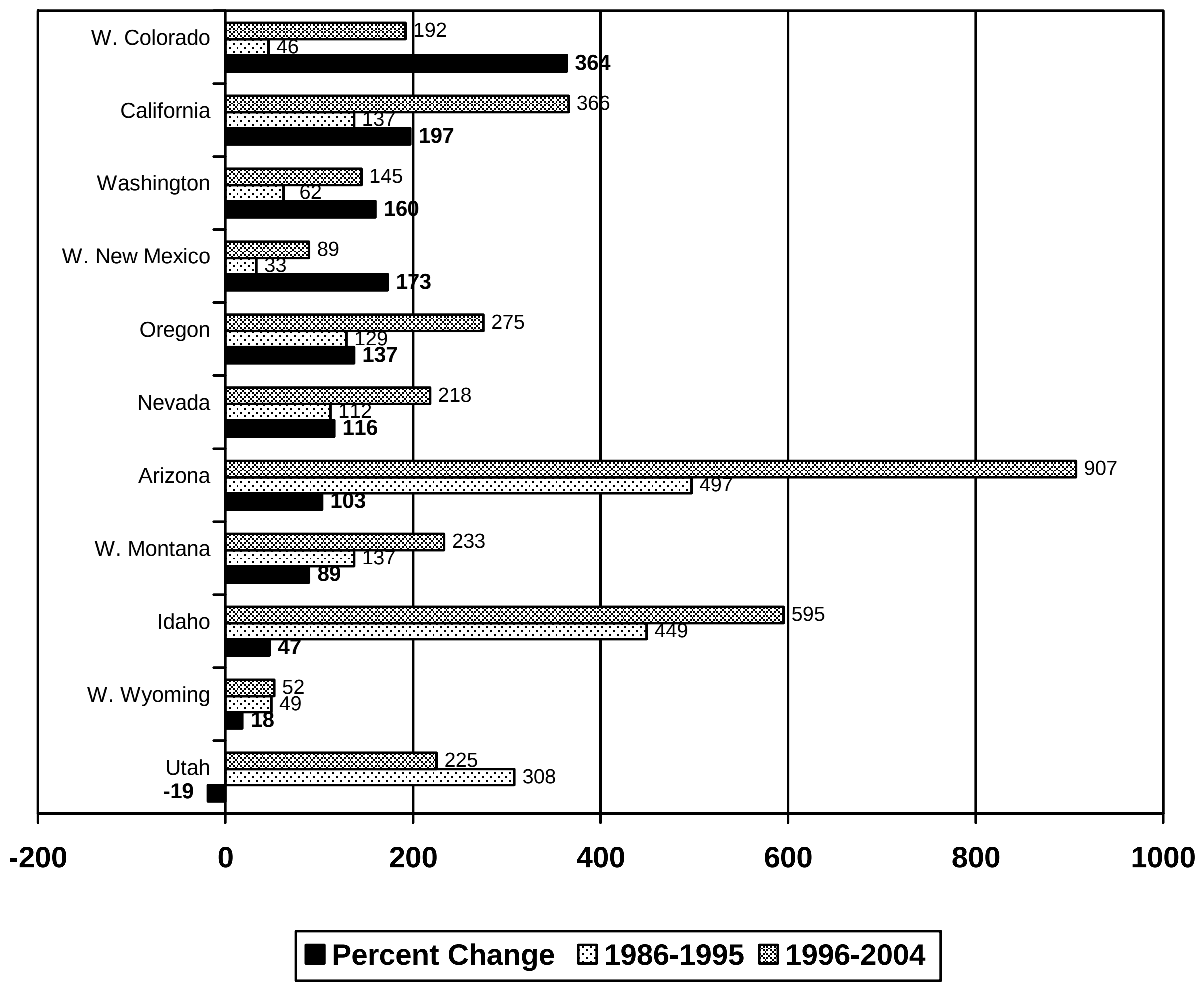

Figure 2. Number of nontornadic severe storms in the West for each state. The percent change is calculated by using the annual average from 1986-1995 to 1996-2004.

Figure Captions

Figure 1. Graph of all tornadoes, F2 and greater tornadoes, and population per decade for the western states west of the continental Divide, not including Hawaii and Alaska.

Figure 2. Number of nontornadic severe storms in the West for each state. The percent change is calculated by taking the annual average from 1986-1995 to 1996-2004.