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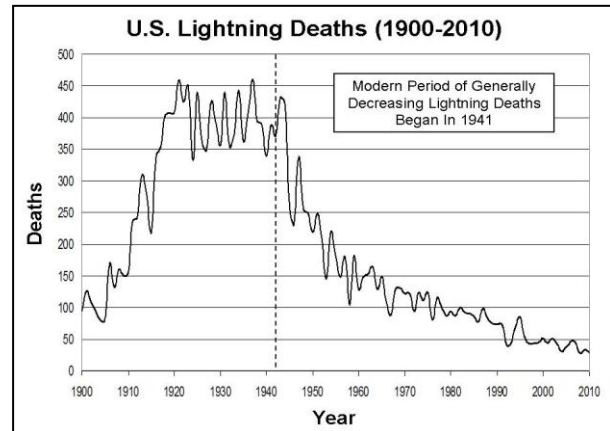
## 1. Introduction

The number of lightning deaths in the U.S. has been declining for many decades. As a result, the traditional 30-year mean used by National Weather Service for most climatological averages overestimates the current rate. The 30-year mean for lightning fatalities in the U.S. (1980-2009) is 57 deaths per year (National Weather Service, 2011a). However, the expected U.S. lightning fatality rate for 2011 is 32.8 deaths (see Table-2). The 10-year climatological mean is more representative with 41 deaths per year (2000-2009) (NWS, 2011a). However, such short period averages can be misleading, especially if skewed by a single extreme event. Others have tried to prove the impact of improved lightning safety public education since the early 1990s by showing that successive periods have smaller slopes (Lengyel, 2004). However, since the lightning fatalities are following a curve and started declining well before the 1990s, proving the impact of public education this way is difficult.

This paper provides a best-fit negative exponential curve for the U.S. annual lightning deaths since the early 1940s. This will allow estimating the expected number of lightning deaths for any year in the near future. The annual 95th percentile confidence interval for any year is also provided. This will allow estimating if the actual number of lightning deaths is statistically significant. Finally, estimates for the median, 25th percentile, and 75th percentile of the expected annual lightning deaths is also provided.

## 2. Statistical Analysis of Annual Number of U.S. Lightning Deaths

The number of annual lightning deaths in the U.S. from 1900-2010 is shown in Figure-1 and listed in Table-1. The data from 1900-1991 are from Lopez and Holle (1998), the data from 1992-2010 are from National Weather Service (2011b). Visual inspection shows three main sections: 1) generally increasing lightning deaths from 1900 to about 1920, 2) a plateau from about 1921 to 1940, and 3) generally decreasing lightning deaths from 1941-2010. The increasing period from 1900 to about 1920 is likely an artifact of poor reporting. The statistical analysis will deal only with the decreasing death rates from 1941 to 2010.



**Figure-1.** Annual lightning deaths in the U.S. from 1900-2010. The data from 1900-1991 are from Lopez and Holle (1998). The data from 1991-2010 are from National Weather Service (2011b). The lightning deaths have been generally decreasing since 1941.

Visual inspection of Figure-1 indicates that the lightning death rates began a general decline sometime between 1938 to 1944. With no evidence for which of these dates to refer as the start of the decline, the statistical analysis will use the middle of this period, 1941, as the start of the decline in U.S. lightning deaths.

The number of lightning deaths per year in the U.S. since 1941 is shown in Figure-2. The decrease appears to be following a negative exponential curve. Nine best-fit curves were tried including linear, polynomial curves of order two through six, exponential, power curves, and logarithmic curves. The negative exponential curve and logarithmic curves had the best correlation coefficient, being mathematically equivalent. The negative exponential curve is used since it is easier to visualize. The best-fit negative exponential curve is given by the following equation:

$$y = 1182.00e^{-0.0297(x - 1900)}$$

$$r^2 = 0.9166$$

where  $y$  = expected number of lightning deaths in the U.S.,  
and  $x$  = desired year.

**Table-1.**

Number of annual lightning deaths in the U.S. from 1900-2010. Data from 1900-1991 are from Lopez and Holle (1998) and data from 1992-2010 are from National Weather Service (2011b).

Year	Deaths	Year	Deaths	Year	Deaths
1900	95	1937	460	1974	112
1901	127	1938	396	1975	124
1902	108	1939	390	1976	81
1903	92	1940	340	1977	116
1904	81	1941	388	1978	98
1905	80	1942	372	1979	87
1906	169	1943	432	1980	94
1907	133	1944	419	1981	87
1908	161	1945	268	1982	100
1909	150	1946	231	1983	93
1910	156	1947	338	1984	91
1911	235	1948	256	1985	85
1912	243	1949	249	1986	78
1913	309	1950	219	1987	99
1914	279	1951	248	1988	82
1915	219	1952	212	1989	75
1916	337	1953	145	1990	74
1917	355	1954	220	1991	73
1918	402	1955	181	1992	41
1919	408	1956	149	1993	43
1920	408	1957	180	1994	69
1921	459	1958	104	1995	85
1922	425	1959	183	1996	53
1923	449	1960	129	1997	42
1924	333	1961	149	1998	44
1925	440	1962	153	1999	46
1926	364	1963	165	2000	51
1927	348	1964	129	2001	44
1928	425	1965	149	2002	51
1929	391	1966	110	2003	43
1930	358	1967	88	2004	31
1931	439	1968	129	2005	38
1932	355	1969	131	2006	47
1933	372	1970	122	2007	46
1934	442	1971	122	2008	28
1935	362	1972	94	2009	34
1936	409	1973	124	2010	29



**Figure-2.** Annual lightning deaths in the U.S. from 1941-2010. Data are same as in Figure-1.

A running 21-year 5th and 95th percentile was calculated for each year from 1951 to 2000 centered on each year  $\pm 10$  years. The analysis is limited to 1950 through 2000, to allow for the running  $\pm 10$  running years to 1941 and 2010, respectively. A best-fit negative exponential curve was chosen for both the 5th and 95th percentile curves (Figure-3). Each of these best-fit curves are given by the following equations:

$$y = 649.49e^{-0.0323(x - 1900)}$$

$$r^2 = 0.9178$$

where  $y$  = 5th percentile of lightning deaths,  
and  $x$  = desired year,

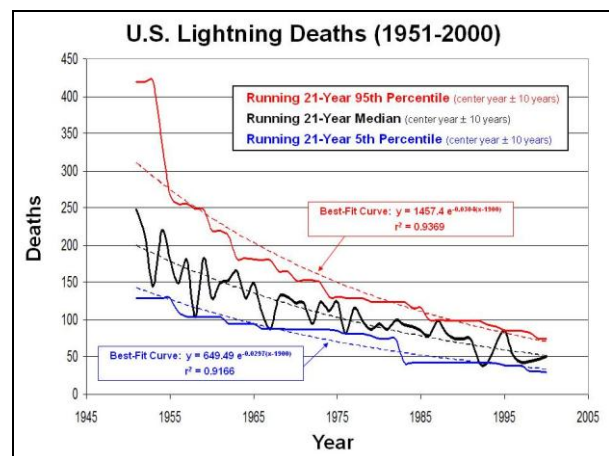
and

$$y = 1457.40e^{-0.0304(x - 1900)}$$

$$r^2 = 0.9369$$

where  $y$  = 95th percentile of lightning deaths,  
and  $x$  = desired year.

The 5th through 95th percentiles represent a 95% confidence interval for the number of expected annual lightning deaths. The confidence interval decreases in later years as the expected number of lightning deaths also decreases in later years. For the actual observed number of lightning deaths for any year, this confidence interval can be used to perform a one-tail hypothesis test at the 95% significance level. One-tail hypothesis tests are the most likely to be performed to answer if the observed lightning deaths for any particular year are statistically significantly more than expected or less than expected, as opposed to a two-tailed test to answer if the observed number of lightning deaths is different than expected, i.e. either more or less than expected.



**Figure-3.** 5th percentile (blue) and 95th percentile (red) best-fit curves for the expected number of annual lightning deaths in the U.S. for 1950-2000.

The record low of 28 lightning deaths in the U.S. occurred in 2008. The 5th percentile of expected lightning deaths for 2008 is 27.1. Since the actual number of lightning deaths was larger than the 5th percentile, the record low was not statistically significant at the 95% significance level, although it was very close.

The running  $\pm 10$  year medians, 25th percentiles, and 75th percentiles were also calculated for 1950-2000. Their best-fit negative exponential curves were also calculated.

The results of the analyses discussed above are summarized in Table-2.

**Table-2.**  
Statistical analyses of the number of lightning deaths in the U.S.

Metric	Best-Fit Curve*	Correlation Coefficient ( $r^2$ )	Period Of Record
Number of Lightning Deaths	$y = 1182.00e^{-0.0323(x-1900)}$	0.9178	1941-2010
95th Percentile	$y = 1457.40e^{-0.0304(x-1900)}$	0.9369	1950-2000
75th Percentile	$y = 986.35e^{-0.0277(x-1900)}$	0.9646	1950-2000
Median	$y = 878.88e^{-0.025(x-1900)}$	0.9580	1950-2000
25th Percentile	$y = 767.46e^{-0.0290(x-1900)}$	0.9568	1950-2000
5th Percentile	$y = 649.49e^{-0.0297(x-1900)}$	0.9166	1950-2000

y = the metric being calculated for any desired year, x = the desired year.  
For example, the number of lightning deaths expected in the U.S. for 2011 =  $1182.00e^{-0.0323(2011-1900)}$  = 32.8 deaths.

### 3. Causes of Decline in Lightning Deaths

There has been much speculation as to reasons for the decreasing number of annual lightning deaths in the U.S. Some of the proposed reasons include increased indoor plumbing and rural electrification that have made buildings safer from lightning, industrialization and urbanization that have led most people to spend less time working outdoors. This trend may be somewhat compensated by increased outdoor recreation. The increased and improved lightning safety public education may also have played a role, especially since the early 1990s and even more so starting with the national Lightning Safety Awareness Week beginning in 2001. However, it is difficult to ascribe the amount of change in lightning deaths to the various factors at various times over the years, though it is odd that all these various causes at various times yield a fairly consistent rate of decline over so many decades. Fortunately for this analysis, the cause(s) of the declining annual number of lightning deaths is not important, only the consistent decline that can be analyzed statistically.

### 4. Future Work

The next step in this study will be to study the intra-annual pattern of lightning deaths by day-of-the-year. In particular, the distribution of various percentiles and their 95% confidence intervals will

be analyzed. When combined with the expected total number of lightning deaths from this paper, these percentiles and error bars will allow hypothesis testing if any particular year is experiencing significantly less or more lightning deaths than expected. However, these data may be so noisy that identifying years with statistically slow or fast lightning death rates may be unlikely. The 50th percentile is expected to occur in early July due to the peak of lightning season at that time and the Independence Day holiday with a surge of outdoor at-risk activity.

The current analysis is for the actual number of lightning deaths. Repeating the analysis with the per capita lightning deaths may yield a more reliable estimate of the expected number of lightning deaths. This may also be more instructive for examining the behavioral changes for the declining rate of lightning deaths.

The 95% confidence intervals for the annual number of lightning deaths were estimated by curve-fitting the running  $\pm 10$  year 5th and 95th percentiles. This was done to approximate percentile regression. A dedicated statistical analysis software package would allow true percentile regression.

Statistical analysis may be able detect subtle changes in the rate of decline in lightning deaths, such as with the start of increased and improved lightning safety in the early 1990s and especially after the start of national Lightning Safety

Awareness Week in 2001. However, visual inspection of the data suggests that the data may be too noisy to detect such changes.

## 5. Summary

The lightning deaths in the U.S. from 1941-2010 were analyzed to provide the expected number of lightning deaths for any year. This was done with a best-fit negative exponential curve on the number of lightning deaths from 1941-2010. The running  $\pm 10$  year 5th and 95th percentiles were calculated for 1950-2000 and best-fit negative exponential curves calculated to provide the 95% confidence interval for the expected number of U.S. lightning deaths for any year. The median, 25th percentile, and 75th percentiles best-fit curves were also calculated.

## 6. References

- Lengyel, M. M., 2004: Lightning casualties and their proximity to surrounding cloud-to-ground lightning, *M.S. Thesis*, University of Oklahoma, Norman, 68 pp.
- Lopez, R. E., and R. L. Holle, 1998: Changes in the number of lightning deaths in the United States during the twentieth century, *Journal of Climate*, Vol. 11, No. 8, Aug 98, 2070-2077
- National Weather Service, 2011a: NOAA, National Weather Service Office of Climate, Water, and Weather Services, 1325 East West Highway, Silver Spring, MD 20910, [www.nws.noaa.gov/om/hazstats.shtml](http://www.nws.noaa.gov/om/hazstats.shtml), 2011
- National Weather Service, 2011b: NOAA, National Weather Service Lightning Safety, 1325 East West Highway, Silver Spring, MD 20910, [www.lightningsafety.noaa.gov/more.htm](http://www.lightningsafety.noaa.gov/more.htm), 2011