www. ebscohost. com
www.gi.sanu.ac.rs, www.doiserbia.nb.rs,
J. Geogr. Inst. Cvijic. 65(3) (269–280)

*Original scientific paper*

UDC: 911.2:551.5(7/8)
DOI: 10.2298/IJGI1503269M

# TORNADO FREQUENCY IN THE USA — METEOROLOGICAL AND NON-METEOROLOGICAL FACTORS OF A DOWNWARD TREND

*Jovan Mihajlović*[1], *Vladan Ducić*, Dragan Burić***
* University of Belgrade, Faculty of Geography, Belgrade, Serbia
** Institute of Hydrometeorology and Seismology of Montenegro, Podgorica, Montenegro /University of Montenegro, Faculty of Philosophy, Nikšić, Montenegro

Received: November 15, 2015; Reviewed: November 17, 2015; Accepted: November 19, 2015

**Abstract:** Citing numerical simulations, climate alarmists believe that global warming will lead to more frequent and more intensive tornadoes. Considering temperature increase data in the contiguous USA, this study has investigated the trend of strong tornadoes in F3+ category in the 1954–2012 period. Statistically significant decrease of tornadoes per year at an average rate of 0.44 has been recorded, that is, 4.4 tornadoes per decade. Tornado increase has been recorded with F0 and F1 categories and the cause of this increase lies in meteorological and non-meteorological factors. By using upper and lower standard deviation values, the stages of tornado activity have been singled out. The 1957–1974 period may be considered as an active stage and the 1978–2009 period as an inactive stage. Upward trend of air temperature increase does not correspond with the downward trend of the number of F3+ tornado category, while the correlation coefficient between these two variables is $R = -0.14$. This fact does not correspond with the simulation results and output data of various numerical models anticipating an increase in the number and intensity of tornado events in the conditions of surface air temperature growth.

**Key words**: tornado, trends, air temperature, global warming, Fujita Scale, USA

## Introduction

The results of numerical models indicate that air temperature increase (at 2 m height level), as a consequence of an increasing level of $CO_2$ and concentration of other greenhouse gases, could have an influence on the development of extreme weather events, like tornadoes. Regarding numerical simulations, climate alarmists[2] usually suggest that global warming will lead to more frequent and more intensive tornadoes. General Circulation Models[3] (GCMs), Intergovernmental Panel on Climate Change (IPCC) numerical models, predict

[1] Correspondence to: millennijum@hotmail.com
[2] Alarmists usually overrate the dangers of the climate change.
[3] More info at: http://www.ipcc-data.org/guidelines/pages/gcm_guide.html

more frequent and violent weather extremes and storms, which corresponds with a general picture of air temperature increase in the USA.

Circulation changes in atmosphere over the continent in temperate latitudes affect the atmosphere stability and, therefore, climate extremes and convective activity in North America, which corresponds with output data of various numerical models. The simulation results of climate numerical models predict an increase in annual air temperature of 1–3°C in North America, for the 2010–2039 period (Christensen et al., 2007).

Global climate models and climate change projections in the future (Marsh et al., 2007; Trapp et al., 2007) speak in favor of the fact that the increase in greenhouse gas (GHG) concentration will probably cause an increasing number of severe storms in the USA and, thus, tornadoes. Bearing in mind that the research has just started and that there is a relatively small number of studies dealing with the topic, the results of these investigations should be accepted with reservation.

The starting hypothesis of this study is the correlation between air temperature increase in the contiguous USA and the number of strong tornadoes (F3+). The US territory has been chosen because of a continuous tornado reporting[4] and, regarding an absolute number of registered tornadoes per year, the USA ranks first in the world with an average number of 1,253 tornadoes per year (in the 1991–2010 period) (www.ncdc.noaa.gov). The 1954–2012 period has been observed for the purpose of conducting this research.

The paper shows the results related to the dynamics of tornado number in the USA. Particularly, analysis is dedicated to the study of tornado dynamics according to categories (from F0 to F5), while the data were available by decades.

## Database and research methodology

The data about annual number of strong to violent tornadoes (F3+) in the USA for the 1954–2012 period used in this research are available on the web site of National Centers for Environmental Information (NCEI), National Oceanic and Atmospheric Administration (NOAA) (https://www.ncdc.noaa.gov). The data about the tornado number by decades for the 1970–2011 period were taken from the web page https://notalotofpeopleknowthat.wordpress.com/2012/01/05/us-tornado-trendsupdated-to-2011/, and were processed according to NOAA/ NWS

[4] Official data gathering and tornado reporting started in the 1950s (Brooks & Dotzek, 2008)

Storm Prediction Center data (http://www.spc.noaa.gov). The data about air temperature (for the 1954–2008 period) in the contiguous US were taken from the site http://www.co2science.org in the Global Historical Climatology Network (GHCN).

GHCN is an integrated database of climatological measurements from surface weather stations all over the planet. The data were gathered from more than 20 sources. There are data old less than an hour, as well as those older than 175 years (https://www.ncdc.noaa.gov). Monthly climatological data for thousands of weather stations all over the world are gridded (into 5x5$^{\circ}$ cells) and available for each station. GHCN base consists of historical data for temperature, precipitation and atmospheric pressure. Gathering data period varies from station to station. A few thousand stations deal with the gathering period back to the 1950s, while the data are being updated monthly on a few hundred stations by CLIMAT report. The data are available National Climatic Data Center (NCDC) anonymous FTP service (http://datahub.io/dataset/ghcn).

In order to estimate the number of tornadoes by years for the 1954–2012 period, statistical methods of arithmetic mean ($\overline{X}$) and standard deviation ($\delta$) were used. The data about air temperature, total number of reported tornadoes, as well as the data obtained for decades for all categories of tornadoes, have been presented by using a simple linear regression. For these data the Pearson's correlation coefficient has been calculated.

Statistical significance of these correlations has been determined by the two-tailed Student’s t test and trend significance by the equation:

$$y = R\sqrt{\frac{n-2}{1-R^2}} \qquad (1)$$

where $R$ is Pearson's correlation coefficient, $R^2$ is determination coefficient and $n$ series length.

The Fujita Scale (F-scale) method has been used in the study. F-scale is used for rating tornado strength based on the damage survey, since it is very difficult to measure directly tornado speed. Soon after the implementation of F-scale in 1971, meteorologists and other experts noticed certain limitations of the scale. A new, updated version of F-scale responds to these limitations was implemented on February the 1$^{st}$ in 2007, in the USA and is referred to as the Enhanced Fujita Scale (EF-scale). EF-scale recognizes 28 different building structures, that is, 28 damage indicators. Wind speeds on F-scale are calculated from (Fujita, 1981):

$$V_F = 6.30(F+2)^{1.5} \tag{2}$$

where $V_F$ denotes the wind speed on F-scale [m/s].

## Research results

For the purpose of research, the data related to the total number of tornadoes (in F3+ category) in the contiguous US for the 1954–2012 period have been processed.

In order to gain a better understanding of the tornado number dynamics in the USA, trend line has been graphically presented by using simple linear regression. Statistically significant drop in the total number of tornadoes (F3+) at an average rate of 0.44 tornadoes/year (4.4 tornadoes/decade) (Figure 1) has been noticed. Applying two-tailed t-test the linear trend values have been calculated and it has been noticed that the trend is negative and statistically significant on $p = 0.01$, while the largest number of tornadoes was recorded in 1974 (131 tornadoes), and the smallest number in 1987 (15).

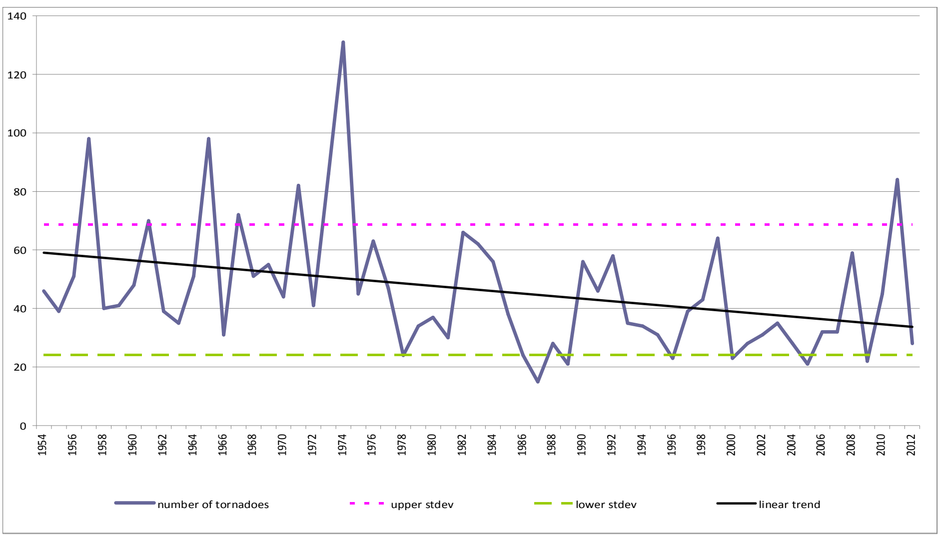


Figure 1. Number of registered tornadoes in *F*3+ category in the contiguous US for the 1954–2012 period with a linear trend

In order to investigate the dynamics of the total number of registered tornadoes per years, the mean value ($\overline{X}$) and standard deviation of the whole series ($\delta$)

have been used. Graph analysis shows 7 recorded years with the number of tornadoes above the upper standard deviation ($\delta_1 = 68.6$) up to 1974. After the year of 1974 and up to 2010 inclusive, the number of tornadoes did not exceed the value of upper standard deviation ($\delta_1$) in any year. If we look at the lower standard deviation ($\delta_2 = 24.2$), we can see that the numbers of tornadoes did not exceed the value of the lower standard deviation ($\delta_2$) in the 1978–2009 period. In the 1957–1974 period all 7 cases of the number of tornadoes per year above the upper standard deviation ($\delta_1$) were recorded in the whole series and this stage can be referred to as an *active stage*.

In the 1978–2009 period, there was a concentration of all 7 years with the number of tornadoes below the lower standard deviation ($\delta_2$) and this stage can be referred to as an *inactive stage*. If the whole series is observed in the terms of moving pentad values (Figure 2), it can be noticed that the most active pentad was from 1971–1975 with an average tornado number of 77 per year. The smallest number of tornadoes was recorded in the 1985–1989 period (25.2).

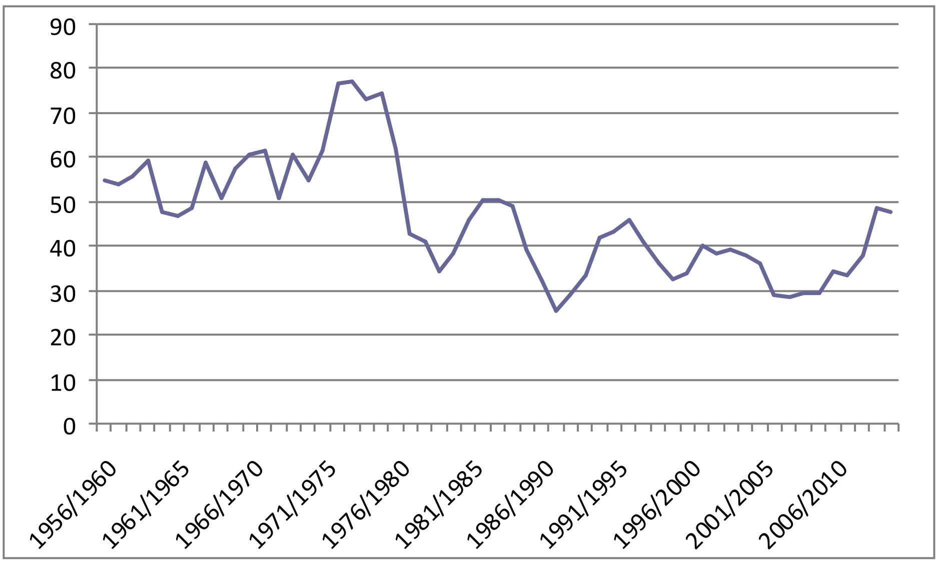


Figure 2. Moving pentad values of the number of registered tornadoes in *F*3+ category in the contiguous US for the 1954–2012 period

In case that we should observe moving decade values of the whole series (Figure 3), it can be noticed that the most active decade was from 1965 to 1974 (69.1

tornadoes per year on the average). The smallest number of tornadoes was recorded in the 2000–2009 period (31.1 tornadoes per year on the average).

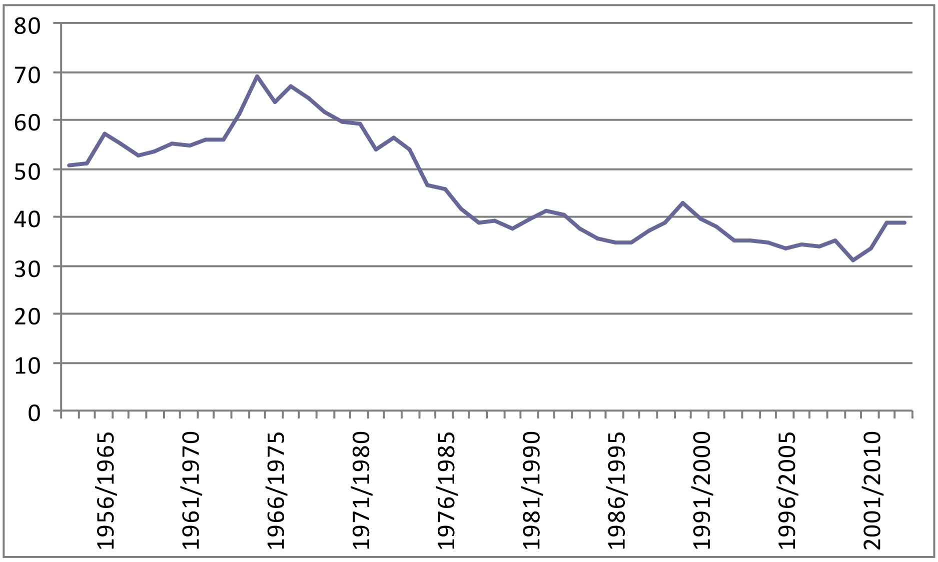


Figure 3. Moving decade values of the number of registered tornadoes in *F*3+ category in the contiguous US for the 1954–2012 period

In order to carry out a thorough research of the tornado number dynamics by categories (from F0 to F5), available data for decades from 1970 to 2011 were investigated (Table 1). Looking at decade values in F0 category, a statistically significant ( $p = 0.05$ ) increase in the total number of tornadoes at an average rate of 202.2 tornadoes per decade can be noticed. In F1 category, the trend is statistically insignificant ( $p = 0.040$ ), with an average increase rate of 7.5 tornadoes per decade; in F2 category, the trend is statistically significant $p = 0.10$ , with an average drop rate of 25.5 tornadoes per decade; in F3 category, the trend is statistically insignificant ( $p = 0.20$ ), with an average drop rate of 4.6 tornadoes per decade; in F4 category, the trend is statistically significant ( $p = 0.05$ ), with an average drop rate of 2.1 tornadoes per decade; *F*5 category was not investigated because of the small number of cases. Regarding the total number of tornadoes in all categories, from F0 to F5, a statistically significant trend ( $p = 0.05$ ) has been recorded, with an average increase rate of 176.9 tornadoes per decade. Looking at the total number of tornadoes in $F1+$ category, a statistically insignificant trend on $p = 0.30$ and an average drop rate of 25.3 tornadoes per decade have been recorded.

Table 1. Average annual number of tornadoes per decades in USA

| Category | 1970–1979 | 1980–1989 | 1990–1999 | 2000–2011 |
|---|---|---|---|---|
| *F*0 | 274 | 331 | 739 | 812 |
| *F*1 | 343 | 334 | 331 | 369 |
| *F*2 | 188 | 124 | 109 | 108 |
| *F*3 | 50 | 33 | 38 | 33 |
| *F*4 | 14 | 9 | 9 | 7 |
| *F*5 | 3 | 1 | 1 | 1 |
| Total | 872 | 832 | 1,227 | 1,330 |
| Total *F*1+ | 598 | 501 | 488 | 518 |

Source: Based on the data from NOAA/ NWS Storm Prediction Center

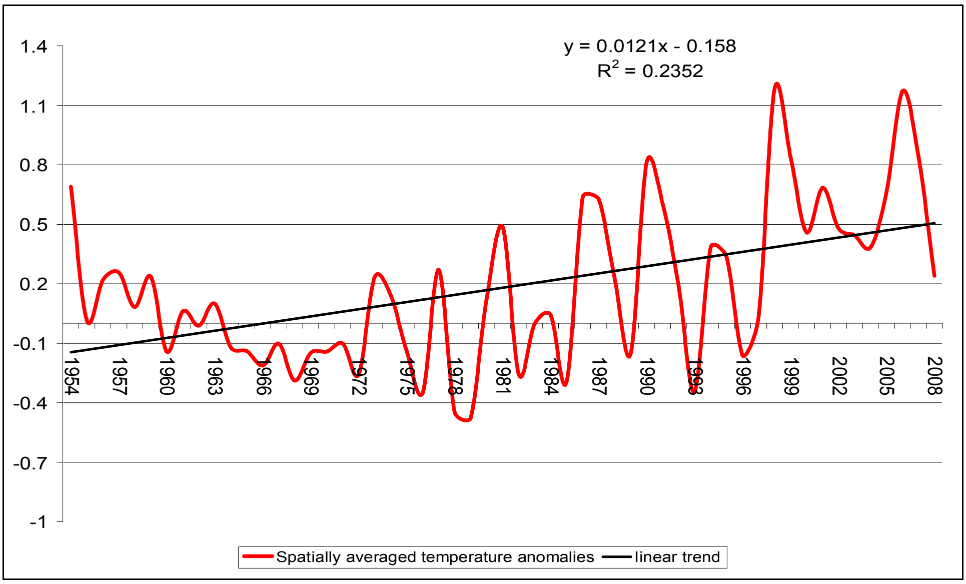


Figure 4. Spatially averaged temperature (°C) anomalies in the contiguous US for the 1954–2008 period

Looking at spatially averaged temperature anomalies in the contiguous US for the 1954–2008 period, a statistically significant trend ($p = 0.001$) and an average increase rate of 0.012°C/year, that is, 0.12°C/decade have been recorded (Figure 4).

## Discussion

Investigated dynamics of the total number of tornadoes in the contiguous US for the 1954–2012 period shows a statistically significant trend. Statistical significance on various levels is also present in the case of decade values by categories from F0 to F5, for the 1970–2011 period.

The trend of strong and violent tornadoes in F3+ category is negative and shows statistical insignificance, which also goes for F1+ category. However, the total number of F0+ tornadoes shows statistical significance and positive trend. The reason for this lies in the fact that in recent years the number of F0 and F1 tornadoes is dominant in the total number of reported tornadoes and shows a statistically significant increase, considering decade values. This leads to a false impression of an increasing trend of strong (F3+) frequency.

The total number of tornado reports has increased by factor 10 during the last 50 years (Grazulis, 1993; Brooks & Doswell III, 2001; Balling & Cerveny, 2003; McCarthy & Schaefer, 2004). Brooks and Doswell III (2001) believe that the increase in the number of tornado reports, particularly weaker tornadoes (*F*0–*F*2), is the consequence of better observations and advanced reporting procedures, as well as the population growth. Therefore, meteorological and non-meteorological factors of an increased number of reported tornadoes can be singled out as well as two periods in the last 33 years (McCharthy & Schaefer, 2004). Non-meteorological factors are connected with the first period (the early 1980s), when the NWS started warning verification and the second period (the 1990s), when NEXRAD[5] (WSR-88D) became operative. Non-meteorological factors include population growth and migrations, the coming of mobile phones, development of the NWS network of tornado spotters and local media. Many researchers deal with this matter and with the influence of meteorological and non-meteorological factors (Changnon, 1982; Schaefer & Brooks, 2000; McCarthy & Schaefer, 2004).

The number of tornado reports in the USA has increased for 14 on the average since the mid-1950s (Brooks & Dotzek, 2008). The reason for this trend is more of a socio-geographical nature and offers a better explanation than meteorological factors. Population growth and geographic dispersion of people in the tornado Alley, as well as an advanced Doppler radar technology may be attributed to the cause of the trend (Diffenbaugh et al., 2008). Cook and Schaefer

[5] NEXRAD is a shortage for the next generation of Doppler radars, also known as WSR-88D (88D means that the Doppler radar was implemented in 1988).

(2008) find a connection between a tornado outbreak[6] in winter and El Niño Southern Oscillation (ENSO).

Looking at the air temperature and the total number of tornadoes in the contiguous USA in the 1954–2008 period, the series indicate a negative correlation coefficient (R = −0,14). It can be concluded that global regional warming causes fewer tornadoes, which is a negative trend of *F*3+ category. Yet, there is a statistically significant positive trend in the total number of tornadoes in the USA. The reason for this lies in the above mentioned meteorological and non-meteorological factors.

Tornadoes develop from severe storms (most often supercells) of large scales usually defined by strong vertical wind shears and convective available potential energy CAPE (Brooks et al., 2003). Global warming would cause CAPE increase, but also a vertical wind shear decrease because of the smaller temperature gradient between the equator and poles (Trapp et al., 2007).

According to research results given by Changnon (2003), economic losses in the USA are the consequence of social changes, and not global warming. It is very difficult to make the difference between the influences caused by extreme weather and social changes. The same author suggests that the trends of extreme weather events in the USA during the last 50 years of 20th century are various. There is an upward trend of floods caused by heavy rains and a downward trend of tornadoes and other severe storm events. It is believed that the intensification of ENSO is the main factor which affects these trends. The loss values, which are the consequence of weather extremes (10.3 billion USD per year on the average), for the 1950–1997 period do not indicate an upward trend and are not, therefore, indicators of the changes caused by global warming.

Khandekar (2003), commenting on a WMO statement related to extreme weather events, states his opinion about the relationship between the global warming and extreme weather. This was presented in the IPCC report (2001), pointing out an extensive critical discussion in the media and scientific literature. The same author, citing Robert Balling's article from the University of Arizona (Balling & Cerveny, 2003), suggests that there is not a significant trend of overall storm activity (tornado) in the USA.

Contrary to the prognosis obtained by numerical models and by many researchers saying that the climate changes will affect many regions in the USA

[6] Tornado outbreak is defined as a group of six or more tornadoes developed from the same severe weather system (Grazulis, 1993).

in a different way (annual air temperature increase, precipitation growth, extreme weather events, tornadoes, etc.) it is not possible to find a relationship between the global warming and an increased frequency of severe storms in the USA based on empiric results. There is also no correlation between the tornado frequency and strength in the USA. According to Balling and Cerveny (2003), there is evidence of an increase in extreme precipitation events during the historical instrumental period, but not in other weather categories. The same authors say that there are downward trends for other weather categories during the last 50 years, as well as there is not a recorded upward trend of tornado events in the same period.

## Conclusion

The IPCC (2013) numerical models (GCMs) predict that the climate extremes in the contiguous USA will be more frequent and stronger, which will lead to an increased number of supercell storms and, therefore, to an increased tornado activity, which corresponds with the general concept of global warming.

Regarding the general concept of global warming in the contiguous US, this paper has made an investigation into the strong tornadoes in F3+ category. It has been concluded that there is a statistically significant drop at an average rate of 0.44 tornadoes per year, that is, 4.4 tornadoes per decade. F0 and F1 categories record an average rate increase and the cause for such increase lies in non-meteorological and meteorological factors. It has also been emphasized that this fact can lead to a false impression of a statistically significant positive tornado trend in all categories. In order to obtain a better estimate, the trend has been calculated without F0 category, which recorded a statistically insignificant drop at an average rate of 25.3 tornadoes per decade.

Using the upper and lower standard deviation values ($\delta_1$ and $\delta_2$) of the whole series, we tried to single out the stages in tornado activities. The 1957–1974 period may be referred to as an *active stage*, and the 1978–2009 period as an *inactive period*. If the whole series is observed in the terms of moving pentad values, it can be noticed that the most active pentad was from 1971–1975 with an average tornado number of 77 per year. In case that we should observe moving decade values of the whole series, it can be noticed that the most active decade was from 1965 to 1974 (69.1 tornadoes per year on the average).

The analysis showed that there had been a statistically significant trend and an increase of air temperature at the average rate of 0.12$^{\circ}$C/decade in the contiguous USA for the 1954–2008 period. It should be emphasized that the upward trend of air temperature increase does not correspond with the downward trend of tornado number in the *F*3+ category, while the correlation coefficient between these variables is R = −0.14. This fact certainly does not correspond with the simulation results and output data of different numerical models, which predict and increase in extreme weather events during the global warming period of Earth.

This paper offers a few possibilities for further investigation — the relationship between mesoscale synoptic conditions and variability and climate change in future. Investigations should be certainly directed towards the development of an advanced technology for the detection of tornado events.

**References**

Balling Jr., R.C., & Cerveny, R.S. (2003). Compilation and discussion of trends in severe storms in the United States: Popular perception vs. climate reality. *Natural Hazards, 29*(2), 103–112.

Brooks, H. E., & Doswell III, C. A. (2001). Normalized damage from major tornadoes in the United States: 1890–1999. *Weather and Forecasting, 16*(1), 168–176.

Brooks, H. E., Lee, J. W., & Craven, J. P. (2003). The spatial distribution of severe thunderstorm and tornado environments from global reanalysis data, *Atmospheric Research. 67–68,* 73–94.

Brooks, H. E., & Dotzek, N. (2008). The spatial distribution of severe convective storms and an analysis of their secular changes. In H. F. Diaz and R. Murnane (Eds.), *Climate Extremes and Society* (pp. 35-54). New York: Cambridge Univ. Press.

Changnon, S. A. (1982). Trends in Tornado Frequencies. Preprints, *12th Conference on Severe Local Storms* (pp. 42–44) .San Antonio, TX: American Meteorological Society.

Changnon, S.A. (2003). Shifting economic impacts from weather extremes in the United States: A result of societal changes, not global warming. *Natural Hazards, 29*(2), 273–290.

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W.T., Laprise, R., Magaña Rueda, V., Mearns, L., Menendez, C.G., Räisänen, J., Rinke, A., Sarr, A., & Whetton, P. (2007). Regional climate projections. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor & H. L Miller (Eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 847–940). Cambridge and New York: Cambridge University Press.

CO2 Science (2015). Retrieved on 13th of July 2015, from http://www.co2science.org/data/temperatures/temps_plot.php

Cook, A. R., & Schaefer, J. T. (2008). The relation of El Niño — Southern Oscillation (ENSO) to winter tornado outbreaks. *Monthly Weather Review, 136*(8), 3121–3137.

Diffenbaugh, N. S., Trapp, R. J., & Brooks, H. (2008). Does Global Warming Influence Tornado Activity? *EOS, 89*(53), 553–554.

Fujita, T.T. (1981). Tornadoes and downbursts in the context of generalized planetary scales. *Journal of the Atmoperic. Sciences*, *38*(8), 1511–1534.

Grazulis, T. P. (1993). *Significant tornadoes: 1680–1991*. St. Johnsbury, Vt.: Environ. Films.

IPCC (2001). *Climate change 2001. The scientific basis. Contribution of working Group I to the third assessment report of the intergovernmental Panel on Climate Change.* Cambridge, United Kingdom, New York, NY, USA, Cambridge University Press: J.T. Houghton,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell & C.A. Johnson (Eds.)

IPCC (2013). Retrieved on 19th of May 2015, from http://www.ipcc-data.org/guidelines/pages/gcm_guide.html

Khandekar, L. (2003). Comment on WMO statement on extreme weather events. *EOS, 84*(41), 428.

Marsh, P. T., Brooks, H. E., & Karoly D. J. (2007). Assessment of the severe weather environment in North America simulated by a global climate model. *Atmospheric Science Letters, 8*(4), 100–106.

McCharty, D.W., & Schaefer, J. (2004). Tornado Trends Over the Past Thirty years. *14th Conference on Applied Climatology*. Seattle, WA. Retrieved from http://www.spc.noaa.gov/publications/mccarthy/tor30yrs.pdf

NOAA National Centers for Environmental Information, State of the Climate: Tornadoes for Annual 2013 (2014). Retrieved on 19th of May 2015, from http://www.ncdc.noaa.gov/sotc/tornadoes/201313

NOAA National Centers for Environmental Information (n.d.). Retrieved on 12th of July 2015, from https://www.ncdc.noaa.gov/climate-information/extreme-events/us-tornado-climatology/trends

NOAA/NWS Storm Prediction Center (2015). Retrieved on 13th of July 2015, from http://www.spc.noaa.gov

NOT A LOT PEOPLE KNOW THAT (2012). Retrieved on 13th of July 2015, from https://notalotofpeopleknowthat.wordpress.com/2012/01/05/us-tornado-trendsupdated-to-2011/

Schaefer, J. T. & Brooks, H. E. (2000). Convective Storms and Their Impact. Preprints, *2nd Symposium on Environmental Applications* (pp. 152–159). Long Beach, CA: American Meteorological Society.

the Datahub (2013). Retrieved on 11th of July 2015, from http://datahub.io/dataset/ghcn

Trapp, R. J., Diffenbaugh, N. S., Brooks, H. E., Baldwin, M. E., Robinson, E. D., & Pal. J. S. (2007). Changes in severe thunderstorm environment frequency during the 21$^{st}$ century caused by anthropogenically enhanced global radiative forcing. *Proceedinds of the National Academy of. Sciences of the United States of the America, 104*(50), 19719–19723.