Lightning in the Arctic

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Abstract

WWLLN (World Wide Lightning Location Network) data on global lightning are used to investigate the increase of total lightning strokes at Arctic latitudes. We focus on the summertime data from June, July and August, which average >200,000 strokes each year above 65^o North latitude, for each of the years from 2010 – 2020. The influence of WWLLN network detection efficiency increases is minimized by normalizing to the total global strokes for each northern summer.

The ratio of strokes occurring above 65^o increases with latitude, showing that the Arctic is becoming much more influenced by lightning. We compare the increasing fraction of strokes with the global temperature anomaly for those months, and find that the fraction of strokes above 65^o to total global strokes for these months increases linearly with the temperature anomaly and grows by a factor of 3 as the anomaly increases from 0.65 to 0.95 degrees C.

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WWLLN (World Wide Lightning Location Network) data on global lightning are used to investigate the increase of total lightning strokes at Arctic latitudes. We focus on the summertime data from June, July and August, which average >200,000 strokes each year above 65^o North latitude, for each of the years from 2010 – 2020. We minimize the possible influence of WWLLN network detection efficiency increases by normalizing our results to the total global strokes during northern summer for each year.

Our findings show that the ratio of strokes occurring above a given latitude increases with latitude, showing that the Arctic is becoming much more influenced by lightning. We compare the increasing fraction of strokes with the NOAA global temperature anomaly for those months, and find that the fraction of strokes above 65^o to total global strokes for these months increases linearly with the temperature anomaly and grows by a factor of 3 as the anomaly increases from 0.65 to 0.95 degrees C.

Introduction

In 2019 it was widely reported that multiple lightning strokes had been detected within just a few hundred miles from the North Pole (cf Washington Post, 8/13/2019 https://www.washingtonpost.com/weather/2019/08/12/lightning-struck-within-miles-north-pole-saturday-rapid-arctic-warming-continues/). Indeed, multiple reports in recent years show strong evidence that the Arctic is warming faster than expected (e.g. Carey 2012), the sea ice is melting (e.g. Dirk and Stroeve, 2016) as is the permafrost (e.g. Farquharson et al, 2019). One might assume that with global warming we would see an increase in global lightning, but this is both a controversial prediction and difficult to prove with existing global lightning data. In 2004 Williams discussed the expected and measured meteorology and climate variations on the frequency of lightning and concluded that the question was undecided about whether global lightning would increase or decrease as the planet warmed. Others have predicted an increase in lightning (Romps et al, 2014) or a decrease (Finney et al, 2018).

Another assumption one might have, given that global lightning monitoring in real time has been available since 2004 (see http://wwlln.net), is that we should be able to simply count strokes and compare stroke occurrence rate to the temperature rise. Unfortunately during the last decade, even the oldest global lightning location network has had such growth in its detection efficiency, that inter-comparison between years is not simple. Because of the improving detection efficiency one might expect strong increases in lightning stroke counts even without any climate impacts.

In this paper we look specifically at the lightning occurring at high northern latitudes over the last 11 years. Global lightning has a seasonal variation resulting in major lighting activity which is dominant in the summer hemisphere. Thus the major regions of lightning strokes switch from the northern mid-latitudes (June/July/August) to the southern mid-latitudes (in Dec/Jan/Feb) every year, while lightning activity in the tropics has a smaller annual total stroke variation. Furthermore we find few lightning strokes in the high Arctic outside of these summer months.

Additionally, the southern hemisphere at high southern latitudes has very little lightning at any time of the year. There are some summer strokes near the Palmer Peninsula, but almost no strokes poleward of 65 ^{o}S, and certainly not enough for a comprehensive statistical analysis, even though WWLLN has 5 stations in Antarctica.. As such we consider only northern hemisphere summer data.

In this study we discuss the data sets to be used, motivate the work with a global look at northern latitude lightning distributions, and then present an analysis using latitudinal and annual variations to investigate the increasing fraction of global lightning which occurs at high latitudes. These lightning data are then compared to the three-month global temperature anomaly for northern hemisphere summer to arrive at a linear relationship between the fraction of global lightning occurring above 65 degrees, with the temperature increase.

Data Sets

The WWLLN (World Wide Lightning Location Network) has been locating lightning globally for over a decade. WWLLN uses the radio noise emitted by lightning (in the VLF - Very Low Frequency - range) and detected at receivers all over the world to locate lightning using the time of group arrival (Dowden et al, 2002, Rodger et al 2006, Hutchins et al, 2012, Virts et al, 2013). Lightning produces a strong, narrow impulse during each return stroke which results in the emission of radio frequency (RF) energy which peaks in the range of 10 to 15 kHz (e.g. Malan, 1963, Dowden et al, 2002). This narrow impulse, which can be recognized as a noise transient on AM or FM band radio, produces a wave packet which propagates around the world in the Earth Ionosphere Wave Guide (EIWG). During propagation the wave packet spreads out in frequency by a process called dispersion, requiring a careful analysis of the wave packet to find the time of group arrival (TOGA) (Dowden et al, 2002). When the TOGA is measured with 100 ns accuracy by several receivers spaced globally around the lightning source, it is possible to locate lightning to within < 5 km and within about a microsecond. Currently WWLLN locates 600,000 to 800,000 strokes globally every day, while in the past the detection efficiency was about a 10th of what it is today. Here we use the data from 2010 – 2020 to analyze the increase in high latitude lightning and concentrate on the northern summer months of June, July and August.

Figure 1

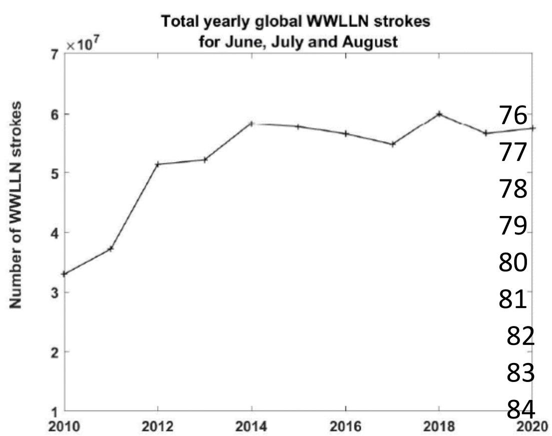


Figure 2

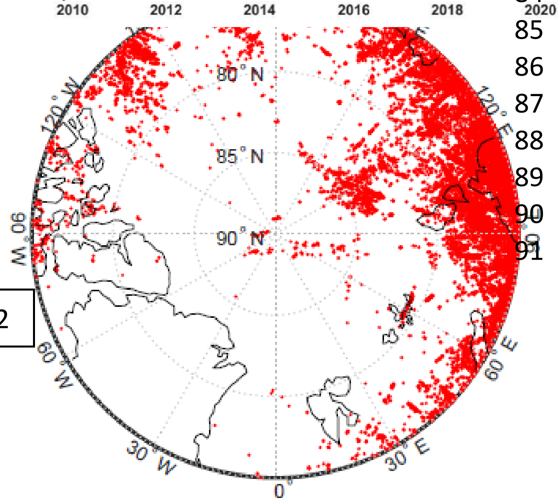


Figure 1, for reference, shows the total, global strokes detected by WWLLN during June, July and August each year. We can see an increase in total strokes located during these months, from 3.21×10^{7} strokes in the northern summer in 2010 to about twice that beginning in 2014, and more or less steady after that. There is little or no lightning in the Arctic outside of northern summer time, hence we focus here on just those three months each year.

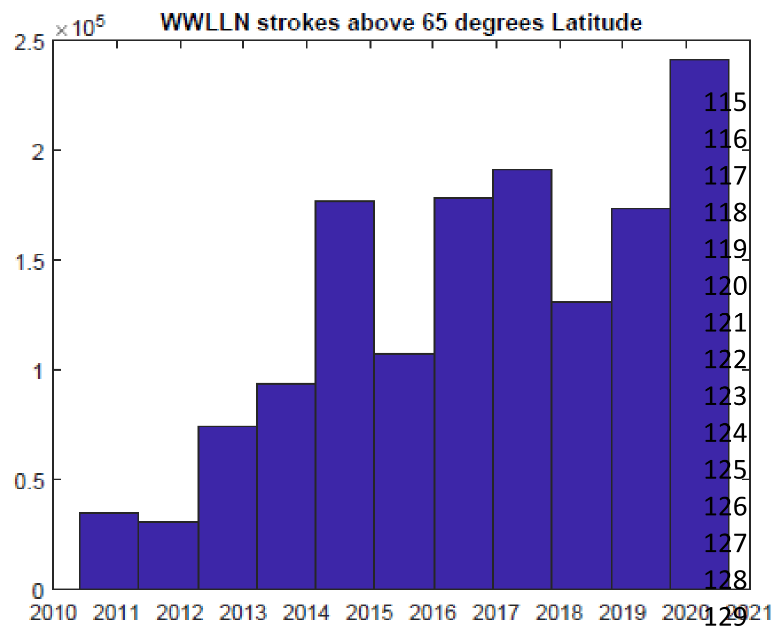
The distribution of high latitude lightning found during these 11 years is shown in Figure 2, which is a plot of just the strokes north of 75^o latitude. In Figure 2 we can see that the stroke distribution is dominated by lightning in the eastern hemisphere from about 70^o E to 170^o E, with relatively little lightning north of Canada/Alaska by comparison. This is probably due to the fact that mainland Canada is mostly south of 70^o, while mainland Russia reaches up to over 77^o, with substantial mainland Russia north of 70^o latitude.

Figure 2 also shows some lightning activity extending up to very near the North Pole. In fact these WWLLN data include 32 strokes, well vetted in location and time which are within about 100 km of the North Pole which all occurred on a single day on 13 August 2019 (see Table 1 for the actual strokes). This paper does not address the meteorology associated with this northern intrusion close to the pole, but it is clear that it associated with an energetic, well organized event which lasted for hours and will be examined in a future study.

Statistical analysis of High Latitude Lightning

Looking statistically at the high latitude stroke distribution we see a growing number of WWLLN strokes above 65^o N as seen in Figure 3. This figure is not corrected for WWLLN detection efficiency, but reports actual total strokes detected during June, July and August from latitudes north of 65^o. Looking at Figure 1 as a rough guide to the gross variation in WWLLN detection efficiency, one could expect at most a factor or two increase of the strokes in 2010 as compared to dates after 2014. The latest WWLLN detection efficiency analysis is found in Holzworth et al, 2019 and shows a detection efficiency increase from 60% to 80% over the years 2010 – 2020 for all strokes over 40 kA peak current. Hence the low numbers in this plot for 2010 and 2011 could even be increased by a factor of two if one assumed that the lower stroke totals for those two years were all due to detection efficiency, and not to actual geophysical processes. In that case (artificially increasing the 2010 and 2011 values by a factor of two) the histogram would still indicate a great increase in the number of WWLLN strokes north of 65^o over this 11 year period.

Figure 3



We also note that WWLLN added only two new active stations at high northern latitudes after 2010, while the total number of WWLLN stations increased from about 35 in 2010 to about 55 in 2013, with slow increase up to 65 stations in the subsequent few years. So, there is no evidence from our growing station locations that the relative number of strokes detected in the Arctic would be favored in any way, in fact, just the opposite: one might have expected a reduced ratio in the Arctic, if anything. This is in agreeement with the more connservative analysis above.

In order to examine the question of the the impact of the growing WWLLN detection efficiency on the data, we plot in figure 4 (blue line) the fraction of total global strokes during June, July and August each year so that the increasing detection efficiency effect is minimized. In this Figure 4 the blue plot refers to the total measured strokes above 65^{o} divided by the total number of WWLLN-observed global strokes in that summer time period. Comparing the blue line to the histogram in Figure 3, one can see that the plot strongly reflects the increasing total strokes above 65^{o}, including the relative dips in 2015 and 2018. Thus Figure 4 is evidence that the fraction of global lightning occurring north of 65^{o} has increased by over a factor of 3 during this time period (from 0.002 to over 0.006). Another point to make is that the increase is evident even just looking at the 7 year period from 2014 to 2020 when the WWLLN detection efficiency did not vary by more than 10%.

Figure 4

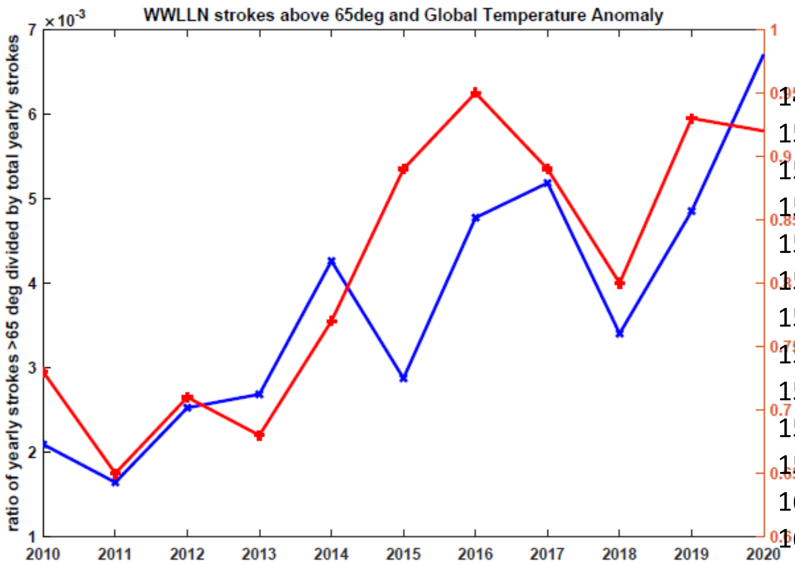
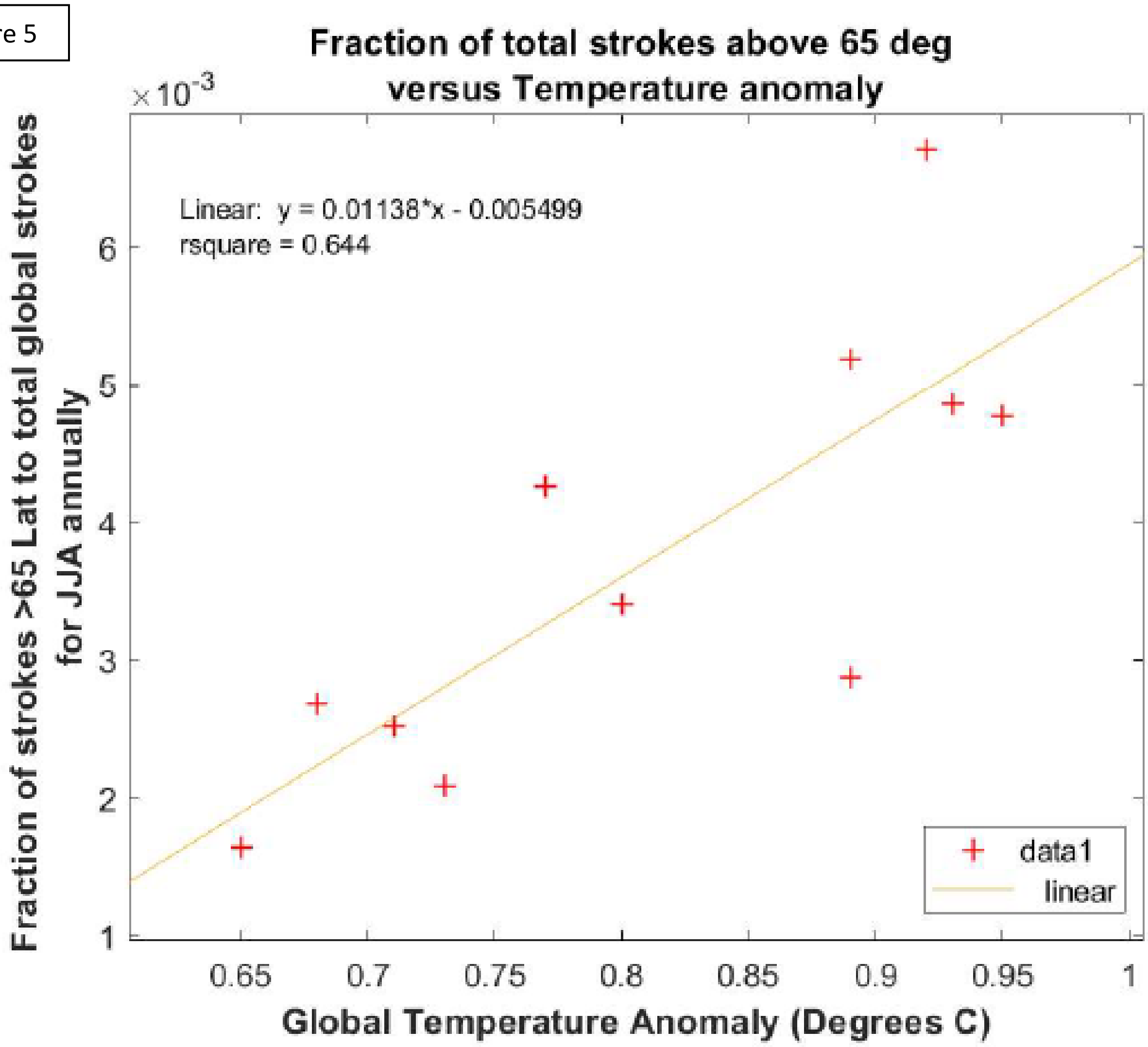


Figure 4 also includes, in red, the three month (June, July and August) global temperature anomaly in degrees Celsius reported by NOAA (see NCDE NOAA Report: https://www.ncdc.noaa.gov/cag/global/time-series/globe/land_ocean/3/8/2004-2020 and Table 2).
This figure demonstrates the strong similarity between the fraction of strokes above 65^{o}, and the three month average global summer temperature anomaly for June, July and August for the 11 year period of the WWLLN stroke data.

There is obviously a strong correlation between the blue and red plots in Figure 4, which we quantify in Figure 5. At the very least, the two linear trends are consistent. In Figure 5 we see

Figure 5



that the correlation coefficient is R= 0.802 and R^2=0.644 indicating a high degree of correlation. In this figure we can clearly see the increase in the fraction of total strokes occurring at high latitudes is increasing by a factor of 3 for an increase of 0.3 ^{o}C in the global 3-month average global temperature anomaly. To put this in raw terms we could say that if one thinks there are, say, 100 lightning strokes per second globally, which would be 0.79×10^9 strokes globally during three months of summer, then we can expect 0.006×790 million strokes = 4.8 million strokes to occur in the Arctic (all in the summer) or 51,000 every day of June, July and August. We note that the total global strokes per second is not known from actual measurements from any network or spacecraft data set, but rather is projected from existing global lightning measurements. WWLLN has a detection efficiency variously identified as between 10 and 15 percent of all global strokes , so we would expect to see 480,000 to 520,000 WWLLN strokes above 65^{o} every summer. In fact we directly measured 380,000 strokes in 2020 during June, July and August (the subset of those strokes above 75^{o} were plotted above in Figure (2).

We can speculate from these numbers, and the slope of the line in figure (5) that the number of lightning strokes in the Arctic when the temperature anomaly reaches 1.5 ^{o}C will be 61% higher than it was in 2020. This increase supposes the same total number of global lightning strokes as now. But that could also increase, meaning the total lightning activity above 65^{o} would then be even larger.

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Table 1: WWLLN strokes within about 100 km of the North Pole

Year	Mo	day	Hr	Mn	sec	Lat	Lon
2019	8	13	`	56	28.12	89.05	173.73
2019	8	13	7	9	24.41	89.07	177.19
2019	8	13	7	18	48.75	89.09	177.62
2019	8	13	7	23	38.87	89.09	-179.33
2019	8	13	7	35	13.14	89.07	-175.78
2019	8	13	7	46	43.85	89.03	-10.91
2019	8	13	7	53	40.42	89.06	-171.03
2019	8	13	7	59	10.83	89.03	-20.16
2019	8	13	9	9	17.57	89.60	-104.77
2019	8	13	9	15	10.31	89.58	-105.08
2019	8	13	9	15	10.31	89.55	-104.39
2019	8	13	9	17	36.40	89.58	-107.65
2019	8	13	9	24	41.14	89.49	-100.69
2019	8	13	9	26	33.79	89.52	-103.94
2019	8	13	9	28	6.13	89.48	-103.68
2019	8	13	9	28	6.13	89.47	-101.44
2019	8	13	9	30	8.51	89.49	-102.81
2019	8	13	9	34	38.12	89.48	-103.80
2019	8	13	9	35	43.74	89.47	-99.92
2019	8	13	9	35	43.74	89.44	-100.50
2019	8	13	9	36	41.92	89.44	-98.00
2019	8	13	9	39	9.96	89.48	-102.00
2019	8	13	10	4	56.21	89.26	-96.29
2019	8	13	10	4	59.81	89.22	-82.17
2019	8	13	10	9	42.18	89.25	-84.06
2019	8	13	10	12	3.08	89.28	-98.61
2019	8	13	10	20	8.31	89.15	-91.21
2019	8	13	10	41	35.82	89.10	-96.54

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Table 2: Ratio of WWLLN strokes above 65o and 3-month summer Global Temperature anomaly

Year	Ratio	Temp Anomaly ^{o}C
2010	0.002092	0.73
2011	0.001643	0.65
2012	0.002526	0.71
2013	0.002685	0.68
2014	0.004262	0.77
2015	0.002874	0.89
2016	0.004774	0.95
2017	0.005185	0.89
2018	0.003404	0.8
2019	0.004853	0.93
2020	0.006707	0.92

249 **Temp Anomaly source:**
250 https://www.ncdc.noaa.gov/cag/global/time-series/globe/land_ocean/3/8/2004-2020