Earth Planets Space, **58**, 1197–1201, 2006

Inferred long term trends in lightning activity over Africa

Colin Price and Mustafa Asfur

Department of Geophysics and Planetary Sciences, Tel Aviv University, Israel

(Received December 22, 2005; Revised June 12, 2006; Accepted July 10, 2006; Online published September 29, 2006)

Global warming is becoming a reality, with growing evidence that anthropogenic activity on our planet is starting to influence our climate (IPCC, 2001). Due to the increase in significant weather-related disasters in recent years, it is important to investigate the role of global warming on such changes. In this paper we attempt to estimate the long term trends in lightning activity over tropical Africa during the past 50 years, using upper tropospheric water vapor as a proxy for regional lightning activity. We use the NCAR/NCEP reanalysis product available for the period 1948 to the present to estimate the long term trends in lightning activity. Similarity between the long term African lightning variability and observed rainfall and river discharge variability are demonstrated. Since 1950 the inferred lightning activity over Africa shows significant variability, reaching a maximum during the 1960s, followed by a decrease in activity during the following 30 years.

Key words: Lightning, climate change, Africa, ELF, Schumann resonance.

1. Introduction

Global warming is becoming a reality. It is also becoming clear that the majority of this warming in the last 50 years is due to human activity, resulting from the ever-increasing concentrations of greenhouse gases in the atmosphere (IPCC, 2001). Furthermore, recent increases in insured property losses due to intense storms (Mills, 2005) and the increased number and intensity of hurricanes over the past few decades (Emmanuel 2005; Webster *et al.*, 2005) raise the question regarding the impact of climate change on extreme weather and thunderstorms (http://www.ipcc.ch/pub/extremes.pdf). Besides lightning, thunderstorms are often associated with intense winds, hail, tornados and heavy precipitation, with potentially large impacts on society (Milly *et al.*, 2002). However, on a continental and global scale, lightning is a useful parameter to study, since lightning activity can be continuously monitored via the detection of radio waves emitted by lightning discharges, which can be detected thousands of kilometers from the parent thunderstorm.

The majority of global thunderstorms occur within the tropical regions (Christian *et al.*, 2003) while being centered over the landmasses. Unfortunately, little information is known about long term variability of thunderstorms in these regions due to the lack of long term observations. Even basic meteorological parameters such as temperature and precipitation are difficult to find in tropical regions, while the stations that do exist with long term data are few and far between. Satellite data give us only a 5-year period of lightning coverage (Christian *et al.*, 2003), while other sources of lightning data, such as the Schumann resonances, may extend for 10–15 years at a few isolated stations (Williams and Satori, 2004). Hence, we have no information on long term changes of lightning activity around the globe.

Nevertheless, various studies using present day data imply that lightning activity should be sensitive to changes in regional and global temperatures (see Williams, 2005 for review), and other climate parameters (Price, 2000; Sato and Fukunishi, 2005). Furthermore, using a global climate model Price and Rind (1994a) showed that for doubling the amount of CO_2 in the atmosphere, the amount of global lightning activity should increase by $\sim$30%.

In this paper we attempt to estimate the historical long term changes in thunderstorm activity over the African continent. This is accomplished by relating lightning activity in the present climate to climate parameters that can be obtained for the past 50 years. The data sets and the empirical model used in this study will be presented in Section 2. Our long term estimate of lightning activity over Africa is shown in Section 3. We check our results against independent data sets of rainfall and river discharge in Section 4, and summarize our results in Section 5.

2. Data and Empirical Model

A relatively simple and inexpensive method for continuously observing African lightning variability from the ground is via the Schumann Resonances (SR) (Heckman *et al.*, 1998; Price and Melnikov, 2004). Each lightning discharge emits electromagnetic radiation (radio waves) at all frequencies and in all directions. The lower the frequency of the radiation, the less the attenuation of the electromagnetic waves, and the greater the propagation distance. At extremely low frequencies (ELF: 4 Hz$<f<$40 Hz) the radiation can propagate a few times around the globe before dissipating. This is achieved by the electromagnetic waves being trapped in the Earth-ionosphere waveguide, reflecting off the ionosphere and the Earth's surface. Due to the size of the Earth (circumference$\sim$40,000 km) constructive inter-

---

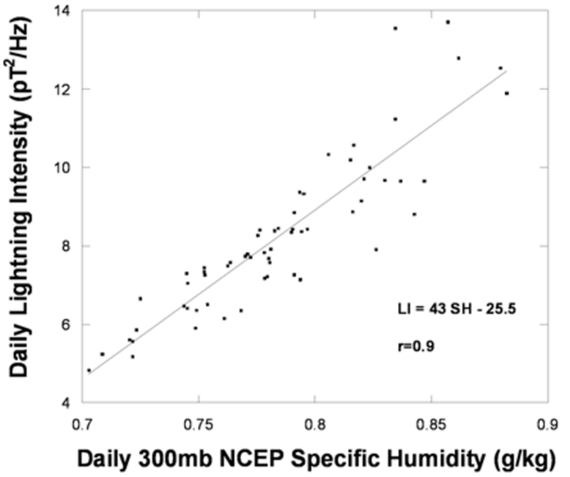

Fig. 1. Relationship between African upper tropospheric (300 mb) humidity from the NCEP reanalysis, and African lightning activity derived from Schumann resonance measurements in Israel (Price and Asfur, 2006). The empirical model used is represented by the linear fit.

ference occurs at frequencies $f \sim v[n(n+1)]^{1/2}/40,000$ ($v \sim 0.8c$, c=speed of light), such that the observed harmonics occur close to 8, 14, 20, 26... Hz, known as the Schumann Resonances (Schumann, 1952). Since there are on the order of 50 lightning flashes per second around the globe (Christian *et al.*, 2003), the variability of the SR intensity represents a continuous measure of the variability of regional and global lightning activity (Heckman *et al.*, 1998).

A SR monitoring station has been running in the Negev Desert, Israel, since 1998 (Price and Melnikov, 2004) supplying hourly information on global and regional lightning activity. We observe three components of the electromagnetic field: two horizontal magnetic field components (H_{ns}: north-south, and H_{ew}: east-west) and one vertical electrical field component (E_z). Since the east-west and north-south magnetic detectors are sensitive to radio waves arriving from different directions, we can separate spatially the three major thunderstorm regions (South America, Africa and Southeast Asia) from the global signals. Furthermore, since late afternoon in the three thunderstorm hot-spots occurs at different universal times (South America—2000 UTC, Africa—1400 UTC and Southeast Asia—0900 UTC), we can further separate the regions temporally, with three distinct maxima in thunderstorm activity observed in the diurnal cycle of the SR. Therefore, using our different detectors at different universal times, ELF radiation arriving from the African continent can be isolated (Price and Melnikov 2004; Price and Asfur, 2006). Since the magnetic field measurements are absolutely calibrated, the units in pico-Tesla (pT=10^{-12} Tesla) provide a quantitative measure of lightning intensity. These instruments can be recalibrated at regular intervals, allowing for quantitative monitoring of tropical lightning intensity, even if instruments are changed and upgraded over time. It should be noted that although absolutely calibrated, the value in pT depends on the source-observer distance as well.

Thunderstorms have a relatively short lifetime of hours, and therefore any proxy used for estimating lightning activity needs to be calculated or observed on short time scales (Price and Rind, 1992; Price and Rind, 1994b). It was recently shown (Price and Asfur, 2006) that African lightning intensity is highly correlated, on a daily time scale, with the amount of water vapor (specific humidity in g/kg) in the upper troposphere (near 300 mb$\sim$10 km) above the African continent. It was demonstrated that lightning activity over tropical Africa results in the moistening of the African upper troposphere one day after the lightning activity. The specific humidity data used in the analysis is from the NCAR/NCEP reanalysis product (Kistler *et al.*, 2001). The reanalysis product is a combination of model and historical data that provides one of the best global meteorological data sets at 6-hourly intervals, 2.5 degree horizontal resolution, 8 vertical layers, and spanning the last 50 years. The NCEP model is used to generate data when observations are not available, while the model is also forced to match the observations in regions where data are available. Hence the NCEP reanalysis supplies estimates of upper tropospheric water vapor on a daily basis, for the past 50 years.

These two independent parameters (lightning intensity [LI] using SR, and upper tropospheric specific humidity [SH] using NCEP) were described and compared in detail in the Price and Asfur (2006) paper. The linear relationship between these data is shown in Fig. 1, showing a correlation coefficient of $r = 0.9$. This correlation implies each parameter can explain more than 80% of the variability of the other. This simple empirical linear model (LI=43 SH−25.5) will be used in the rest of this paper to first estimate the daily, and then annual lightning activity over tropical Africa during the last 50 years. The units of the lightning intensity are pT^2/Hz while the specific humidity [SH] units are g/kg.

3. Long Term Trends

It should be noted that the daily and monthly sensitivity of lightning to upper tropospheric water vapor (used in Fig. 1) may be very different to the sensitivity on long time scales of years to decades. However, the semiannual cycle (two maxima around the equinoxes) in the NCEP 300 mb level specific humidity agrees well with previously observed semiannual cycles in lightning activity from Africa (Fullekrug and Fraser-Smith, 1997). Keeping this caveat in mind, we use the above relationship to first calculate the daily, and then mean annual inferred lightning activity over the African continent, using the NCEP reanalysis data. The empirical model was generated using only lightning and specific humidity data at 1200 UT, since this is the time of available NCEP data closest to the maximum lightning activity over Africa. Hence the inferred lightning activity was calculated over Africa for every day of the year (at 1200 UT) from 1950 to 2000. The annual mean values are shown in Fig. 2. The bold curve represents the 5-year running average. There are a number of interesting features in this long term lightning plot. The first point of interest is that according to this estimation, lightning activity over Africa during the past 50 years was at its highest around 1960, with two periods of minimum activity in the mid 1970s and 1990s. According to this reconstruction of the thunderstorm activity over Africa, there does not appear to be any signifi-

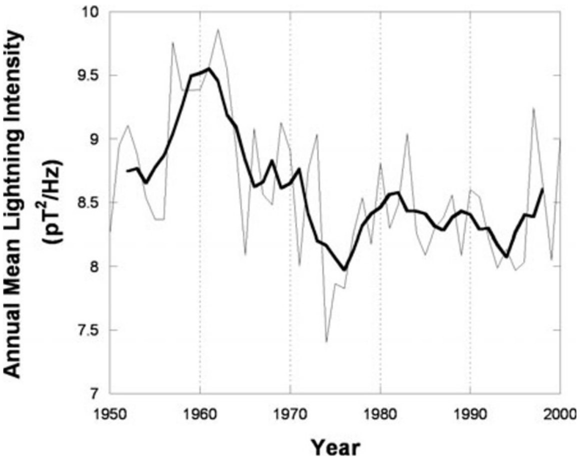

Fig. 2. Inferred annual (thin line) and 5-year running average (bold line) lightning activity over continental Africa from 1950–2000, based on the linear model in Fig. 1.

cant long term increase in the lightning activity over Africa. If anything, during the last 50 years the lightning activity over Africa may have decreased. This may appear contrary to previous studies and popular beliefs related to climate change, and this point will be addressed below.

The interannual variability of lightning activity over Africa (thin line) appears to be quite large with some years showing large increases (18% increase from 1956–57) and large decreases (20% decrease from 1973–74) in lightning activity. This is likely due to large scale climate oscillations such as the El Nino, the African monsoon, sea surface temperatures and global circulation patterns (Nicholson, 2000). However, many of these effects may be hidden by integrating all lightning activity over the continent when using the SR method for tracking regional lightning activity. Eastern African climate behaves differently to the western part of the continent, and the southern part of Africa (Nicholson, 2000).

4. Reality Check

How realistic is the estimate of long term lightning activity over Africa? Since rainfall over tropical Africa is primarily convective rainfall, the rainfall trends over tropical Africa may supply a reasonable comparison for these lightning estimates. In Fig. 3 we present a comparison between the long term inferred lightning activity (top—as shown by bold curve in Fig. 2), and the long term rainfall anomalies over the Sahel region of Africa (middle panel) (IPCC, 2001; http://www.grida.no/climate/ipcc/regional/305.htm; http://www.cru.uea.ac.uk/tiempo/floor2/data/sahel.htm). In this region of Africa the long term mean rainfall (1960–1990) is around 500 mm per year. Although the Sahel region is a subset of tropical Africa, the long term variability is assumed to be similar. The lightning and rainfall plots show many similarities, while also displaying some differences. Both lightning and rainfall had a maximum around 1960 with a long term decrease since then. Since 1970 both lightning and rainfall have been below the long term average for the past 50 years, with hints of a recovery in the early 1990s. The linear correlation between these two data sets is $r = 0.68$.

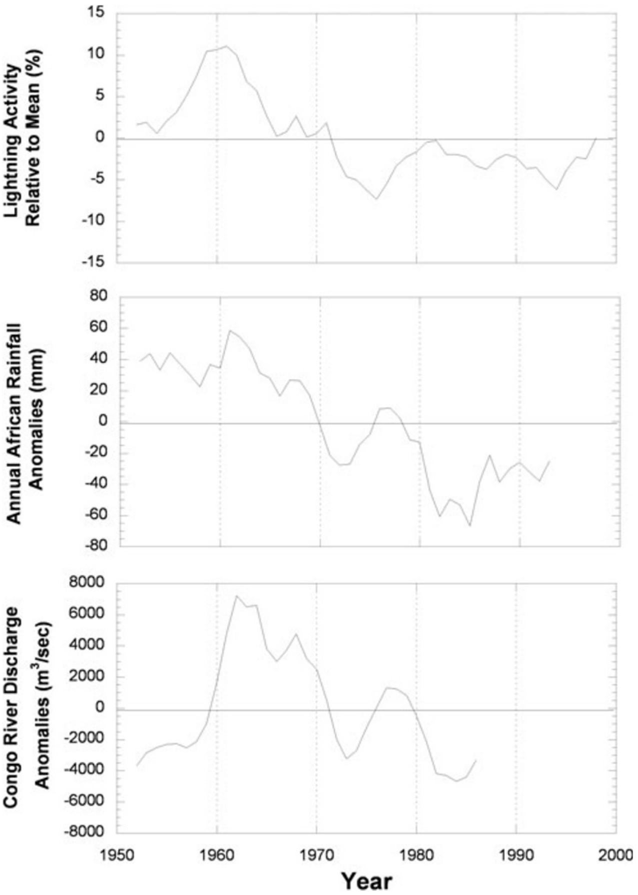

Fig. 3. Comparison between the long term changes in inferred lightning activity over Africa (top—same as Fig. 2), and the long term rainfall trends over Africa (middle), and the long term Congo River discharge (bottom).

An additional, and perhaps better, indicator of tropical thunderstorm activity is the annual river discharge of the Congo River, which represents the largest river in tropical Africa, and integrates the rainfall over the entire watershed (Amarasekera *et al.*, 1997). Unfortunately, the river discharge data are only available until the mid 1980s (http://www-eosdis.ornl.gov/). Furthermore, not all lightning activity over Africa occurs over the Congo basin. Nevertheless, the Congo River with a mean discharge of 40,000 m^3/sec (Fig. 3, bottom) also shows maximum flow in the early 1960s, with a long term decrease until the end of the data record in the 1980s. All data sets show a dry period in the mid 1970s. The linear correlation between the lightning activity and the river discharge is $r = 0.45$.

It therefore does appear that the long term patterns in lightning activity over Africa, derived using the NCEP specific humidity data at 300 mb, are in general agreement with the long term rainfall and river discharge over tropical Africa.

The question arises regarding global warming and the long term temperatures over Africa during this period. Figure 4 shows both the spatial long term temperature trend over Africa (Fig. 4(a)), together with the integrated time series of temperature anomalies for Africa (Fig. 4(b)) (IPCC, 2001). Although the entire globe has warmed significantly

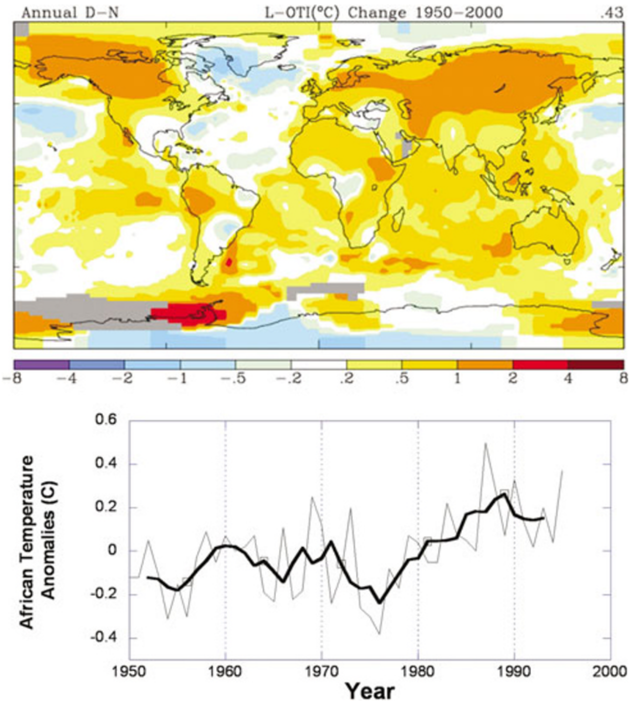

Fig. 4. a) The global annual mean temperature trends (°C) from 1950–2000 (http://www.giss.nasa.gov), and b) The long term annual (thin line) and 5-year running mean temperature anomalies only over Africa (IPCC, 2001).

since the 1950s (+0.5°C), only certain parts of Africa show a warming trend. In fact, the central tropical region around the Congo River basin shows no warming trend over the past half century, with some regions showing a cooling. This appears to agree with the lightning, rainfall and river discharge data that show no long term increase over the past 50 years for Africa. The African temperature trends for the annual, and 5-year mean values (Fig. 4(b)) show that the small warming that does appear over Africa in Fig. 4(a) is dominated by the warming since the 1980s. However, from 1950–1980 there was no warming trend over Africa.

Although the trend in the hydrological cycle appears to be opposite to the temperature trend, there are some similarities between the timing of the minima/maxima in the temperature trends and the minima/maxima in the hydrological cycle during this period. There is a local maximum in the temperature data around 1960, while the coldest period for Africa during the last 50 years occurred in the mid 1970s, when we observe the lowest rainfall, river discharge, and perhaps lightning activity. However, for a better comparison between data sets, temperature trends from the regions of thunderstorm activity need to be isolated from the integrated continental values.

5. Conclusions and Discussion

In this study we have attempted to estimate the long term lightning activity over tropical Africa during the period 1950–2000. Due to the lack of regional and global lightning activity before the 1990s, a proxy has to be used to estimate the long term lightning activity. For this we have developed a simple empirical model that relates present day regional lightning activity over Africa, to the regional concentrations of upper tropospheric water vapor above Africa (Price and Asfur, 1996). The lightning data used to develop the model was from ground-based observations of the Schumann resonance obtained in Israel (Price and Melnikov, 2004), while the water vapor data over Africa was obtained from the NCEP reanalysis product (Kistler *et al.*, 2001). Both data sets have their limitations, while the NCEP water vapor values over Africa are primarily model driven, due to the lack of observations in this region.

The linear fit to the data (Fig. 1) was used as our proxy model to estimate the regional lightning activity over Africa during the past 50 years (1950–2000). Although we need to be careful using relationships on short time scales (Fig. 1) for extrapolating to decadal time scales (Fig. 2), the inferred long term variations in lightning activity imply a period of maximum activity around 1960, with a general decrease in thunderstorm activity in the following 30 years. To check the validity of this estimation, we compared our long term lightning estimates with long term rainfall observations over Africa as well as long term river discharge of the Congo River. Similar long term trends are found in the rainfall and river discharge records, showing maximum values at the beginning of the 1960s, with decreasing values in the following decades. Since rainfall is not only due to thunderstorms, while the Congo River represents only one part of Africa, exact agreement should not be expected.

The long term trends in lightning activity do not contradict previous studies that show increasing lightning activity due to increasing temperatures. Since 1950 the temperatures over Africa have not increased much, with all of the warming occurring since 1990 (IPCC, 2001). In fact, the region of the Congo River basin shows a slight cooling over the past 50 years.

Since this study was only for Africa, we encourage similar studies for the other two lightning hot-spots (South America and Southeast Asia) of lightning activity. We also support the various efforts being made at present to continuously monitor global lightning activity via satellite and ground-based methods. Whether future global warming will result in enhanced global lightning activity is an important and interesting question (Williams, 2005) which will only be answered with long term observations of global lightning activity.

In summary, this study concludes that during the period 1950–2000 thunderstorm activity over Africa shows no clear long term increase, while the beginning of the 1960s appear to have had the greatest lightning activity over Africa during the last 50 years.

Acknowledgments. Part of this research was funded by a grant from the Israel Science Foundation (ISF) # 183/00.

References

Amarasekera, K. N., R. F. Lee, E. R. Williams, and E. A. B. Eltahir, ENSO and the natural variability in the flow of tropical rivers, *J. Hydrology*, **200**, 24–39, 1997.

Christian, H. J., R. J. Blakeslee, D. J. Boccippio, W. L. Boeck, D. E. Buechler, K. T. Driscoll, S. J. Goodman *et al.*, Global frequency and distribution of lightning as observed from space by the Optical Transient Detector, *J. Geophys. Res.*, **108**, 4005, doi:10.1029/2002JD002347, 2003.

Emanuel, K. Increasing destructiveness of tropical cyclones over the past 30 years, *Nature*, **436**, 686–688, 2005.

Fullekrug, M. and A. Fraser-Smith, Global lightning and climate variability inferred from ELF magnetic field variations, *Geophys. Res. Lett.*, **24**(19), 2411–2414, 1997.

Heckman, S. J., E. R. Williams, and R. Boldi, Total global lightning inferred from Schumann Resonance measurements, *J. Geophys. Res.*, **103**, 31775–31779, 1998.

IPCC Climate Change 2001—IPCC Third Assessment Report, World Meteorological Organisation and UNEP http://www.ipcc.ch/, 2001.

Kistler, R. E., W. Collins, S. Saha, G. White, J. Woollen, M. Chelliah, W. Ebisuzaki, M. Kanamitsu, V. Kousk *et al.*, The NCEP-NCAR 50-Year Reanalysis: Monthly Means CD-ROM and Documentation, *Bull. Amer. Meteor. Soc.*, **82**, 247–268, 2001.

Mills, E., Insurance in a climate of change, *Science*, **309**, 1040–1044, 2005.

Milly, P. C. D., R. T. Wetherald, K. A. Dunne, and T. L. Delworth, Increasing risk of great floods in a changing climate, *Nature*, **415**, 514–517, 2002.

Nicholson, S., The nature of rainfall variability over Africa during the last two centuries, *Global and Planeary Change*, **26**, 137–158, 2000.

Price, C., Evidence for a link between global lightning activity and upper tropospheric water vapor, *Nature*, **406**, 290–293, 2000.

Price, C. and M. Asfur, Can Lightning Observations be used as an Indicator of Upper Tropospheric Water Vapor Variability?, *Bull. Amer. Meteor. Soc.*, **87**, 291–298, 2006.

Price, C. and A. Melnikov, Diurnal, seasonal and inter-annual variations in the Schumann resonance parameters, *J. Atmos. Solar-Terr. Phys.*, **66**, 1179–1185, 2004.

Price, C. and D. Rind, A simple lightning parameterization for calculating global lightning distributions, *J. Geophys. Res.*, **97**, 9919–9933, 1992.

Price, C. and D. Rind, Possible implications of global climate change on global lightning distributions and frequencies, *J. Geophys. Res.*, **99**, 10823–10831, 1994a.

Price, C. and D. Rind, Modeling global lightning distributions in a General Circulation Model, *Mon. Wea. Rev.*, **122**, 1930–1939, 1994b.

Sato, M. and H. Fukunishi, New evidence for a link between lightning activity and tropical upper cloud coverage, *Geophys. Res. Lett.*, **32**, L12807, doi:10.1029/2005GL022865, 2005.

Schumann, W. O., Uber die strahlungslosen eigenschwingungen einer leitenden kugel, die von einer luftschicht und einer ionospharenhulle umgeben ist, *Z. Naturforsch.*, **7a**, 149, 1952.

Webster P. J., G. J. Holland, J. A. Curry, and H. R. Chang, Changes in tropical cyclone number, duration, and intensity in a warming environment, *Science*, **309**, 1844–1846, 2005.

Williams, E. R., Lightning and Climate: A Review, *Atmos. Res.*, **76**, 272–287, 2005.

Williams, E. R. and G. Satori, Lightning, thermodynamics and hydrological comparison of the two tropical continental chimneys, *J. Atmos. Sol.-Terr. Phys.*, **66**, 1213–1231, 2004.

C. Price (e-mail: cprice@flash.tau.ac.il) and M. Asfur (e-mail: masfur@soc.haifa.ac.il)