2008 20th International Lightning Detection Conference
21-23 April • Tucson, Arizona, USA
2nd International Lightning Meteorology Conference
24-25 April • Tucson, Arizona, USA

A LIGHTNING CLIMATOLOGY OF SOUTH AFRICA FOR THE FIRST TWO YEARS OF OPERATION OF THE SOUTH AFRICAN WEATHER SERVICE LIGHTNING DETECTION NETWORK : 2006-2007

Tracey Gill

South African Weather Service, Pretoria, South Africa

1. INTRODUCTION

On average, about 2000 deaths around the world occur each year as a direct result of lightning (Geerts and Linacre, 1999). This is a global annual average of approximately 0.4 deaths per million of the population. In South Africa, a recent study has confirmed that the average number of lightning-related deaths is 6.3 per million of the population (Blumenthal, 2005). This statistic for South Africa is thus more than 15 times the global average. According to Blumenthal (2005), this is probably an under-report of the number of lightning death victims since the pathology of lightning damage to the human body is still poorly understood in most areas of the country.

In the United States of America, there has been a significant reduction in the number of lightning-related deaths over the last century. This has been attributed to the fact that more of the population has become urbanized with time (Lopez and Holle, 1998). In South Africa, despite fairly rapid urbanization in the last few decades, many people still reside in the rural areas or in poorly constructed dwellings in the urban areas. These, coupled with poor education around lightning safety and the fact that South Africa is a lightning-prone country (Evert and Schulze, 2005), are the principal reasons for the high lightning-related mortality rate.

Not only are the people of South Africa at enormous risk from lightning, so too are a host of economic sectors. Besides loss of life, lightning accounts for a substantial financial loss each year. Insurance claims resulting from the loss of electronic equipment or from fires initiated by lightning strikes amount to more than R500 million per year (Evert and Schulze, 2005).

For many years attempts have been made to assess the distribution of lightning over South Africa (Malan, 1963; Anderson *et al.,* 1984; Proctor, 1993). In the early 1990s, ESKOM, South Africa's major power utility, operated a network of Lightning Position and Tracking System (LPATS) lightning detection sensors (Evert and Schulze, 2005), but the network has since become redundant. Prior to this, the Council for Scientific and Industrial Research (CSIR) operated a network of lightning flash counters across the country (Proctor, 1993). The detection efficiency and accuracy of the flash counter network was never calculated. In the absence of more accurate data, the flash counter data has been used extensively in the setting of lightning protection standards in South Africa. A validation of these standards is required from accurate lightning data in order to ensure the protection of life and property in this country.

Recent research into precipitation trends in South Africa (Kruger, 2006) indicates that in some parts of the country, notably those associated with mainly summer rainfall, the rainfall events are becoming more intense and producing larger extreme rainfall values. Most of these high rainfall events are associated with convective activity and so also with lightning. The latter specifically highlights the need for the South African Weather Service (SAWS) to issue lightning warnings, forecasts and services for the protection of life and property, in fulfillment of its legal mandate to do so. In order to satisfy this mandate, the SAWS installed a Lightning Detection Network (LDN) consisting of 19 VAISALA LS7000 sensors located across the country (Figure 1). The SAWS LDN is only one of three ground-based lightning detection networks in the Southern Hemisphere, the others being in Brazil and Australia. The installation of this network was complete by the beginning of 2006 and data from this network has provided the SAWS with sufficient information to start to develop a lightning climatology for the country. The level of accuracy of detection of cloud-to-ground lightning by the LDN has, for the first time, made it possible to study lightning strike risks accurately in South Africa.

Rainfall in South Africa is separated into two distinct seasons. The central interior, and the eastern and northern parts of the country experience summer rainfall from October to March. The southwestern and western regions experience winter rainfall from April to September, while the southern parts of the country receive their rainfall throughout the year. In South Africa the dominant summer rainfall is usually as a result of either single cell or multiple cell thunderstorm development. In winter the rainfall is frontal in nature (Taljaard, 1996).

Thunderstorms form in unstable air where there is a source of substantial heat, instability and water vapour as well as a triggering mechanism (Preston-Whyte and Tyson, 1988, Watson *et al.,*1994). The central and eastern parts of South Africa have all three of these critical elements in abundance in the summer months. Moist maritime air is fed in over the eastern parts of the country from the warm Agulhas current, which flows southwards down the east coast of South Africa. Moisture-laden air is also fed in over the country from the north as the Inter-tropical Convergence moves southwards in the summer.

A second notable feature about South Africa is its topography. Generally in the south and east, the coastal plains are rimmed to the interior by mountains. In the south, ranges of fold mountains follow a latitudinal orientation, while in the east, the escarpment rises sharply to an elevated interior plateau. Moist air from the coast is forced to rise up the mountains resulting in orographically enhanced, deep convection. South Africa's position in the southern oceans, as well as its unique topography play very dominant roles in determining its climate and therefore also the distribution of lightning in the country.

2. DATA AND METHODOLOGY

Much work has been done in the United States that has made use of the data from the National Lightning Detection Network (NLDN). Of particular interest at this early stage in data collection for South Africa are the works by Orville and Silver (1997), Orville and Huffines (1999), Orville and Huffines (2001), Zajac and Rutledge (2001) and Orville *et* al. (2002), that analyse lightning distribution characteristics for the United States and parts of Canada at different times in the life-cycle development of the NLDN. In all of these American studies, statistics relating to the lightning distribution are calculated for a grid area spanning the continental USA as well as a small part of the oceans adjacent to the country.

All maps of lightning flash characteristics for South Africa were drawn at a 0.2° x 0.2° resolution since this covers a distance of roughly 20 km - the range of audible thunder. This is also the resolution used in most analyses of the NLDN and so will provide an interesting comparison base to other pieces of research of a similar nature. The mapping of the aggregated lightning flash information was done using ESRI ArcGIS software. The patterns of lightning distribution were analysed as a function of topography, latitude, longitude and the influence of mesoscale weather systems.

Lightning flash data was downloaded for the SAWS LDN for 2006 and 2007. The historical lightning data was extracted from the AP5000 historical lightning data server and so includes only cloud-to-ground lightning. The individual flash data was then mapped using the GIS software and each flash was attributed to a particular 0.2° grid box. Statistics were then calculated for all the grid boxes. Flash densities and percentage of positive lightning were calculated for all the grid boxes, irrespective of the number of flashes recorded in the specific grid box. All other statistics such as the median peak current and the average multiplicity were only calculated for the grid boxes that contained 100 or more flashes. No corrections were applied to the flash data records to compensate for the network detection efficiency.

Approximately eight months after the installation of the LDN, problems were identified with the earthing of some of the sensors, which adversely affected their performance. This was mainly as a result of the fact that the sensors were installed in the rainy summer season and the moisture content in the ground originally gave higher soil conductivity values than were experienced in the drier season. Problems with poor sensor earthing have a smaller effect on the detection efficiency than on the location accuracy of the network, mainly as a result of the redundancy built into the network by the placement of the LS7000 sensors. Thus the spatial distributions of certain distinct lightning characteristics may be only marginally affected by the reduced location accuracy of the network, especially since the analyses was be done on a fairly coarse resolution.

Outside the boundaries of South Africa, very high values of peak current and positive polarity lightning are often recorded by the LDN. These have been disregarded in all of the analyses that follow. Any lightning detected at a distance of more than 100 km from the outer ring of lightning sensors is very often a false recording since it may be the reflection of more distant lightning off the ionosphere (Zajac and Rutledge, 2001, Murphy, 2007). All analyses are thus limited to continental South Africa and the ocean regions within 100km of the coastline.

Three main lightning characteristics were mapped: the lightning ground flash density, median peak current and mean multiplicity. All maps were generated for the entire period. Maps were generated for both positive and negative polarity lightning. In fulfillment of the objective of the study, the analyses of the three main lightning characteristics were then aggregated into a very simple model of lightning risk.

3. RESULTS

3.1 Ground Flash Density

The lightning ground flash distribution for 2006 and 2007 closely follows the topography of the country (Figure 2). The highest flash densities are experienced along the windward slopes of the escarpment in the east and into the northeastern provinces. Similar topographic enhancement of lightning intensity has been observed in the USA in a number of locations as well as in Mexico (Lopez and Holle, 1986; Lopez *et al.*, 1997; Zajac and Rutledge, 2001). The highest flash densities occur in the central escarpment region and extend into the interior, following very roughly the course of the Vaal River as it forms the border between the Free State and Mpumalanga Provinces of South Africa. High flash density regions are also found on the eastern side (the windward side) of the northern Drakensberg Mountains as they extend up into Mpumalanga Province – a region known as the Lowveld. Explaining the presence of these high flash density regions of more than 10 flashes per square kilometer per year is challenging. Certainly heat and water vapour are in abundance, but the area also falls into a region of both industrial pollution and high levels of biomass burning. There is some evidence for enhanced lightning activity in areas of large-size cloud condensation nuclei production, such as those associated with fires and with large industrial processes (Westcott, 1995; Orville and Huffines, 2001). A more detailed analysis of the lightning in this area would have to take place before enhanced flash densities are conclusively attributable to increased pollution.

The altitude of the interior plateau of South Africa ranges from around 2,000 m in the east to just below 1, 000 m in the west. The flash densities exceed 5 flashes per square kilometer over most of the central and eastern plateau and decrease towards the west as the elevation decreases. Most of the moisture for the convective activity in the interior is derived from the northern tropical regions. Frequently in summer, a surface trough associated with the deep intrusion into the country of a well-defined easterly wave will result in the development of a line of convection extending from the northwest toward the southeast over the country. Such line thunderstorms are well organized and move from west to east, bringing rain and accompanying lightning to most of region (Preston-Whyte and Tyson, 1988). Heat-generated, isolated or scattered thunderstorm activity is also common over the interior plateau, especially in the late afternoon. The lightning flash densities are thus high across the entire plateau.

The very high peaks of the Maluti Mountains in Lesotho have flash densities in the order of 4 to 5 flashes per square kilometer per year. This is in contrast to the densities of 5 to 10 flashes per square kilometer per year in the surrounding areas. Similar observations were made in the United States, where increases in flash density have been observed along the sides of terrain features up to about 3,000m, but then this decreased towards the top of high features (Reap, 1986). Orville (1994) noted a similar pattern in the Appalachian Mountains where the flash densities over the mountains were lower than in the surrounding plains. This is most likely due to the fact that many of the convective storms will form below the level of these very high peaks or that the thunderstorms developing on the windward side of these mountains will already have lost most of their precipitation on the lower slopes.

The northeastern parts of Limpopo Province have flash densities of less than 2 flashes per square kilometer. This is also one of the few regions in the northern part of the country that receives less than 400 mm of rainfall on average per year. Most of the moisture required for the generation of thunderstorm activity over the summer rainfall region of South Africa is derived from troughs that develop in the easterly waves. These troughs feed moisture in over the country in a region west of the continental high pressure, which is dominant over the northern and northeastern parts of Limpopo Province (Preston-Whyte and Tyson, 1988). Thunderstorm activity over these parts of the province is thus inhibited by this high pressure system. Most of the rainfall over the northern parts of Limpopo Province is derived from tropical depressions that move over Mozambique from the Mozambique Channel. These systems are not very numerous and as such, the northern parts of Limpopo experience either extremely dry or occasionally extremely wet conditions.

Low flash densities are also evident in the Western and Northern Cape Provinces. The West Coast of South Africa is dominated by colder, drier and more stable air. This is largely as a result of the influence of the cold, north-flowing Benguela Current and the presence of the strong South Atlantic Anticyclone (Preston-Whyte and Tyson, 1988). There is very little lightning activity along the West Coast. Similar decreases in lightning density have been observed in Canada (Orville, *et al.*, 2002) and in the United States along the California coast (Orville and Huffines, 2001, Zajac and Rutledge, 2001). These parts of North America are also influenced by colder ocean currents.

In Kwazulu Natal, the zones of higher flash densities tend to follow the courses of the major rivers and extend out into the sea at the outflow points of these rivers. Once again, this warrants further investigation because pollution may yet again have a role to play. Many of the large industrial processing plants are located along the lower reaches of the river valleys in order to be close to a source of abundant water. The ground flash density maps of the USA for the period from 1989 to 1998, also show a distinct zone of increased flash density where the Mississippi River flows into the Gulf of Mexico (Orville and Huffines, 2001).

The distribution of flashes of negative polarity very closely resembles that of the overall flash density distribution. This is not unexpected when one considers that of the 17,267,355 flashes recorded in 2006 and 2007 over the grid area, only 9.7% of these were of a positive polarity. The percentage of positive lightning map does, however, highlight some interesting phenomena (Figure 3). The small percentage of positive lightning over much of the interior plateau indicates that most of the lightning in the high flash density regions tends to be negative in nature. As one moves off the plateau towards the western and central parts of the country, the number of flashes per square kilometer starts to decrease, but the percentage of these flashes that lower positive energy remains above 10% for the most part.

In South Africa, the regions along the escarpment and in the Interior that have the highest ground flash densities are also those regions which tend to be dominated by strong convective processes. Many of the summer thunderstorms that develop over this region are heat generated or result from some kind of other forcing (such as orography). A large percentage of these storms are either single cell storms or well-organized multi-cell storms. Preston-Whyte and Tyson (1988) indicate that scattered thunderstorms occur on about 54% of storm days over the high lying areas of the interior (called the Highveld) and that isolated thunderstorms occur on a further 39% of storm days. More than 90% of all thunderstorm activity over the Highveld is thus of the type that is dominated by negative cloud-to-ground discharges. Any positive discharges are either related to the dissipating stages of this scattered and isolated storm activity (Rakov and Uman, 2003) or to other storm types such as squall line activity.

The percentage of positive lightning increases to the west of the Highveld region. The central part of the country is very often influenced by the presence of a surface trough that is oriented from northwest to southeast over the country. Convergence occurs ahead of this trough, often resulting in well-organized line thunderstorms with trailing stratiform cloud layers (Preston-Whyte and Tyson, 1988). It would thus appear that the development of line storms, as well as the development of thunderstorms within stratiform cloud layers over the central parts of the country may be responsible for the higher percentage of positive lightning over these parts of South Africa.

More than 20% of the lightning along the West Coast, the South Western Cape and the coastal parts of the Eastern Cape is positive in nature. Since most of the rainfall in the Western Cape is frontal in nature and occurs in the winter months, the lightning in these regions is most likely associated with frontal activity and winter storms. A number of scientists have studied winter storms in Japan and have found that cold season storms, whether they be frontal in nature or not, tend to discharge a large percentage of positive strokes (Takeuti *et al.,* 1978; Brooke *et al.*, 1982).

3.2 <u>Median Peak Current</u>

The analysis of the median peak current (Figure 4a) indicates that the majority of the country is dominated by discharges of relatively low current strength. The areas of the country with the highest ground flash density experience lightning with median peak currents of less than 15 kA. There is a northwest to southeast oriented band across the country where peak current values are in the range between 10 and 20kA. The most notable regions with high peak current discharges in excess of 20kA are found off the coast of the southern parts of the Eastern Cape. These regions are close to the coast, with a good redundancy built into the network, and so are not likely to be erroneously calculated values.

Over most of the country, the median peak current for positive polarity flashes is between 15 and 20 kA (Figure 4b). There are small regions of lower median peak current values in the central, high flash density parts of the country, but these are relatively small. Most of the cells of high positive peak current occur over the provinces that experience winter rainfall and rainfall all year round. These also happen to be the regions of highest percentage of positive lightning.

Orville and Huffines (2001) noted that median peak current values in the United States showed a very distinct discontinuity where the continental land mass met the ocean. The discontinuity in peak current was only evident in the spatial distribution of lightning flashes of negative polarity and not in those of positive polarity. They ruled out surface conductivity as the major contributor to the differences in median peak current distribution since the discontinuity was not present in the distributions of both positive and negative polarity lightning. This discontinuity was also not present between land masses and large inland water bodies (Orville *et al.,* 2002). The peak current distribution in South Africa, however, indicates a discontinuity in the positive peak current distribution along the coastline of the Eastern Cape. This discontinuity is weaker in the distribution of negative lightning, but is still evident.

Tyahla and Lopez (1994) indicated that one of the possible explanations for the appearance of higher median peak currents over the oceans is that there is a relatively low percentage of low peak current discharges and a high percentage of stronger ones over the oceans than over the land. It is evident from the distribution over South Africa and the surrounding oceans, that this may indeed be the case along the southern Cape and Eastern Cape coastlines.

3.3 <u>Average Multiplicity</u>

In international studies done on stroke multiplicity in cloud-to-ground lightning flashes, it was found that the average negative stroke multiplicity is 4.6, 6.4, 3.4 and 4.5 for Florida, New Mexico, Sweden and Sri-Lanka respectively (Rakov and Huffines, 2003). Similar results were not obtained for positive stroke multiplicity since a large majority of positive flashes consist of a single stroke (Orville and Huffines, 2001; Wantuch and

Szonda, 2005). The detection of subsequent strokes in a flash is not always an efficient process. In general, the first stroke in a flash is usually more intense than any of the subsequent strokes (Rakov *et al.,* 1994). It is often the case that the subsequent strokes are considerably weaker than the first stroke and so will not be detected by a lightning detection system (Rakov *et al.,* 1994; Rakov and Huffines, 2003). It is for this reason that calculations of multiplicity are often under-estimates of reality (Orville and Huffines, 1999) and over-estimates of the percentage of flashes consisting of single strokes (Orville *et al.,* 2002; Rakov and Huffines, 2003).

The poor earthing of the SAWS LDN sensors in 2006 will most likely have the greatest impact on the recording of stroke multiplicity than on any of the other lightning characteristics discussed thus far. The fact than many of the SAWS LDN sensors did not have earthing radials installed in 2006 may lead to an over-estimation of the percentage of single strokes as well as the under-detection of subsequent strokes in a flash for the 2006-2007 period. Since the impact of the earthing problem on some of the sensors cannot be determined, the analysis will proceed without making any compensation for poor earthing. As successive years of data are added to the data for 2006, any bias presented by the 2006 data should gradually diminish.

The stroke multiplicity across the country for 2006-2007 (Figure 5a) is highest along the central escarpment in Kwazulu Natal and in two small patches: one in the Eastern Cape and the other in Northwest Province. Multiplicity values in these regions exceed 3 strokes per flash.

Multiplicity values ranging from 2 to 3 strokes per flash are present over the entire interior plateau and extend well to the west. The eastern boundary of this multiplicity range extends far to the east over the adjacent ocean. The feature identified in the ground flash density of higher densities along the major rives in Kwazulu Natal is evident in the multiplicity as well. Multiplicities in the range of 2.5 to 3 strokes per flash are evident extending out into the ocean at the outflow of the major rivers into the Indian Ocean.

The assessment of stroke multiplicity masks very distinct differences in multiplicity distributions for different polarities. If most of the positive flashes consist of single strokes, then identifying the areas of the country where multiple stroke flashes do occur is very important from a risk perspective. Rakov *et al.* (1994) found that if a lightning channel is properly conditioned by the initial stroke, the first subsequent stroke is often a continuing current stroke. Since positive lightning discharge channels tend to lack the stepped structure of negative channels, they tend to be better conditioned at the outset. Where positive flashes consist of more than one stroke, the first subsequent stroke is very often a continuing current stroke (Malan, 1963). This has very important implications for fire risk, since it is the energy dispensed in a continuing current which very often leads to excessive heating at the strike contact point (Rakov and Uman, 2003).

The multiplicity of positive lightning lies between 1 and 1.3 over the entire country, with the exception of isolated regions of slightly higher multiplicity in Kwazulu Natal, the Free State and Northwest Province.

There is no controlling topographic influence on the distribution of the multiplicity of lightning flashes of either polarity. Nor does there appear to be longitudinal or latitudinal controls. The distribution of lightning in the northwest to southeast orientated band structure that is evident in the flash density and median peak current distributions is absent in the multiplicity distribution.

3.4 Lightning Intensity Risk Model

The Total Lightning Risk Model (TLRM) was derived to identify the parts of the country at risk from both high intensity lightning and at risk from positive polarity lightning. Different sectors of the population may require information about only high intensity lightning or mainly about lightning of positive polarity. It is for this reason that these two components of the TLRM form two distinct indexes that can be utilized separately or as part of the total model index.

A very simple methodology was utilised in drafting the three risk indexes. All lightning information derived from the ground-flash density, the median peak current and the multiplicity was reduced to indexes ranging from 0 to 1 by dividing all values for the relevant parameter by the maximum value of that parameter. These index values were then aggregated into simple linear models and the result was once again reduced to an index in the range from 0 to 1. In order to determine the index of lightning intensity, the following parameters were used: overall ground-flash density, overall median peak current and overall flash multiplicity. The index of positive lightning intensity utilizes the flash density of positive polarity lightning, the percentage of positive lightning and the median peak current and the average multiplicity of positive polarity lightning. The TLRM is derived from the sum of the lightning intensity index and the positive lightning index (Figure 6).

Almost the entire country is at severe risk from lightning. The far northern parts of Limpopo Province and the majority of the Western Cape and western parts of the Northern Cape have a moderate to low lightning risk. The areas at extreme risk from lightning are the windward sides of the Drakensberg Mountains in Kwazulu Natal, extending northwards into Mpumalanga and eastwards onto the plateau. Most of the major industrial and power generation activities in South Africa are found in the regions of most severe lightning risk.

A secondary zone of extreme lightning risk is found along the border between the Northwest Province and the Free State. Much of the mining activities in South Africa are found in the Northwest Province. A smaller region of extreme lightning risk is found in the Eastern Cape in an area known for outbreaks of severe weather and tornadic activity.

4. CONCLUSIONS

In South Africa the areas of highest flash density in the summer months are also the areas of the country with lower percentage of positive lightning, lower median peak current of both polarities, but highest negative polarity multiplicity. Most of the winter lightning occurred in the Western and Northern Cape and along the coast of the Eastern Cape and was attributed to the passage of mid-latitude cyclones.

The analyses performed on lightning ground flash density, median peak current and flash multiplicity indicate that neither longitude nor latitude played a very important role in the distribution of lightning over the country. In the United States, longitude plays quite a strong role in the lightning distribution (Orville and Huffines, 2001). One of the primary determinants of ground flash density in South Africa is topography. The major mountain ranges act to enhance convection on their windward slopes. This is true for the regions dominated by summer lightning and those affected by winter storms. The warm ocean to the east of South Africa plays a crucial role in supplying the moisture to feed the convective storms in Kwazulu Natal, up the escarpment and into the Interior.

A feature of the analysis of ground flash density and peak current is the northwest to southeast orientation of bands of distribution across the country. In the summer months, the surface trough dominates weather in the summer rainfall region and has a northwest to southeast orientation. In the winter months, the mid-latitude cyclones that progress inland also have a similar orientation.

Most of the lightning along the Escarpment and into the Interior is associated with deep convection and tends to be more negative in polarity, while the lightning over the central and western parts of the country consisted of a greater number of positive polarity discharges. The latter is associated with the stratiform regions of meso-scale systems developing as line thunderstorms along the surface trough.

Knowledge of how much lightning is recorded, the strength of the peak current and the number of strokes in each flash is important in determining lightning risk. The areas at highest risk from both intense lightning and mainly positive lightning are found along the escarpment and into the Mpumalanga as well as in the southeastern parts of the Northwest Province and northern parts of the Free State. A small area of high lightning risk is found in the Eastern Cape in a region characterized by severe weather.

5. REFERENCES

Anderson, R. B., van Niekerk, H. R., Kroninger, H. and Meal, D. V., 1984, Development of Field Evaluation of a Lightning Earth-Flash Counter, *IEE Proceedings*, **131**, 118-124.

Blumenthal, R., 2005, Lightning Fatalities on the South African Highveld: A Retrospective Descriptive Study for the period 1997 to 2000, *The American Journal of Forensic Medicine and Pathology*, **26**, 66 – 69.

Brook, M., Nakano, M. and Krehbiel, P., 1982, The Electrical Structure of the Hokuriku Winter Thunderstorms, *J. Geophys. Res.*, **87**, 1207-1215.

Evert, R. and Schulze, G., 2005, Impact of a New Lightning Detection and Location System in South Africa, *Inaugural IEEE PES 2005 Conference and Exposition in Africa, Durban, South Africa, 11-15 July 2005*.

Geerts, B. and Linacre, E., 1999, *Fatalities due to Weather Hazards*, www-das.uwyo.edu /~geerts/cwx/chap03/nat_hazards.html.

Kruger, A. C., 2006, Observed Trends in Daily Precipitation Indices in South Africa: 1910 – 2004, *Int. J. Climatol.,* **26**, 2275-2285.

Lopez, R. E. and Holle, R. L., 1986, Diurnal and Spatial Variability of Lightning Activity in Northeastern Colorado and Central Florida During the Summer, *Mon. Wea.* Rev., **114**, 1288-1312.

Lopez, R. E. and Holle, R. L., 1998, Changes in the Number of Lightning Deaths in the United States during the Twentieth Century, *J. Climate*, **11**, 2070-2077.

Lopez, R. E., Holle, R. L. and Watson A. I., 1997, Spatial and Temporal Distributions of Lightning over Arizona from a Power Utility Perspective, *J. Appl. Meteor.*, **36**, 823-831.

Malan, D. J., 1963, *Physics of Lightning*, English University Press, London, pp. 170

Murphy, M., VAISALA, Tucson, 5 June 2007 – Personal Communication

Orville, R. E., 1994, Cloud-to-Ground Lightning Flash Characteristics in the Contiguous United States: 1989-91, *J. Geophys. Res.*, **99**, 10833-10841.

Orville, R. E. and Silver, A. C., 1997, Lightning ground flash density in the contiguous US: 1992-1995, *Mon. Wea. Rev.*, **125**, 631-638.

Orville, R.E. and Huffines, G. R., 1999, Lightning Ground Flash Measurements over the Contiguous United States: 1995–97**,** *Mon. Wea. Rev.*, **127**, 2693–2703.

Orville, R.E. and Huffines, G. R., 2001, Cloud-to-Ground Lightning in the United States: NLDN Results in the First Decade, 1989-1998, *Mon. Wea. Rev.*, **129**, 1179-1193.

Orville, R. A., Huffines, G. R., Burrows, W. R., Holle, R.L. and Cummins, K. L., 2002, The North American Lightning Detection Network (NALDN) – First Results: 1998 – 2000, *Mon. Wea. Rev.*, **130**, 2098-2109.

Preston-Whyte, R. A. and Tyson, P. D., 1988, *The Atmosphere and Weather of Southern Africa,* Oxford University Press, Cape Town, pp. 366

Proctor, D. E., 1993, *Lightning and its Relation to Precipitation*, Report to the WRC by Ematek, CSIR, WRC Report No 279/1/93.

Rakov, V. A., Uman, M. A. and Thottappillil, R., 1994, Review of Lightning Properties from Electric Field and TV Observations, *J. Geophys. Res.*, **99**, 10745-10750.

Rakov, V. A., and Huffines, G. R., 2003, Return Stroke Multiplicity of Negative Cloud-to-Ground Lightning Flashes, *J. App. Meteor.,* **42**, 1455-1462.

Rakov, V. A. and Uman, M. A., 2003, *Lightning: Physics and Effects*, Cambridge University Press, pp 687.

Reap, R. M., 1986, Evaluation of Cloud to Ground Lightning Data from the Western United States for the 1983 – 1984 Summer Seasons, *J. Climate Appl. Meteor.*, **25**, 785-799.

Takeuti, T., Brook, M., Raymond, D. J. and Krehbiel, P., 1978, The Anomalous Winter Thunderstorms of the Hokuriku Coast, *J. Geophys. Res.*, **83**, 2385-2394.

Taljaard, J. J., 1996, *Technical Paper No. 32: Atmospheric Circulation Systems, Synoptic Climatology and Weather Phenomena of South Africa: Part 6 Rainfall in South Africa*, Weather Bureau – Department of Environmental Affairs and Tourism, pp. 98.

Tyahla, L. J. and Lopez, R. E., 1994, Effect of Surface Conductivity on the Peak Magnetic Field Radiated by first Return Strokes in Cloud-to-Ground Lightning, *J. Geophys. Res.*, **99**, 10517-10525.

Watson, A. I, Lopez, R. E. and Holle, A. L, 1994, Diurnal Cloud-to-Ground Lightning Patterns in Arizona during the Southwest Monsoon, *Mon. Wea. Rev.*, **122**, 1726-1739.

Wantuch, F. and Szonda, S., 2005, General Characterisation of the Lightnings of the Carpathian Basin, *Quarterly Journal of the Hungarian Meteorological* Service, **109**, 111-122.

Westcott, N. E., 1995, Summertime Cloud-to-Ground Lightning Activity Around Major Midwestern Urban Areas, *J. Appl. Meteorol.,* **34**, 1633-1642.

Zajac, B. A. and Rutledge, S. A., 2001, Cloud-to-Ground Lightning in the Contiguous United States from 1995 to 1999, *Mon. Wea. Rev.*, **129**, 999-1019.

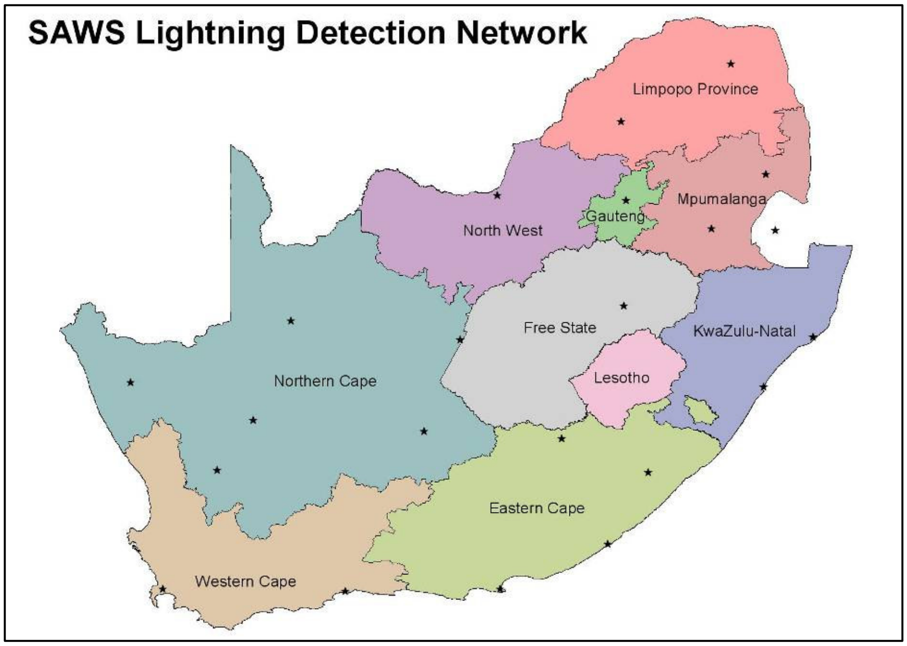

Figure 1: The SAWS LDN sensor sites (SAWS)

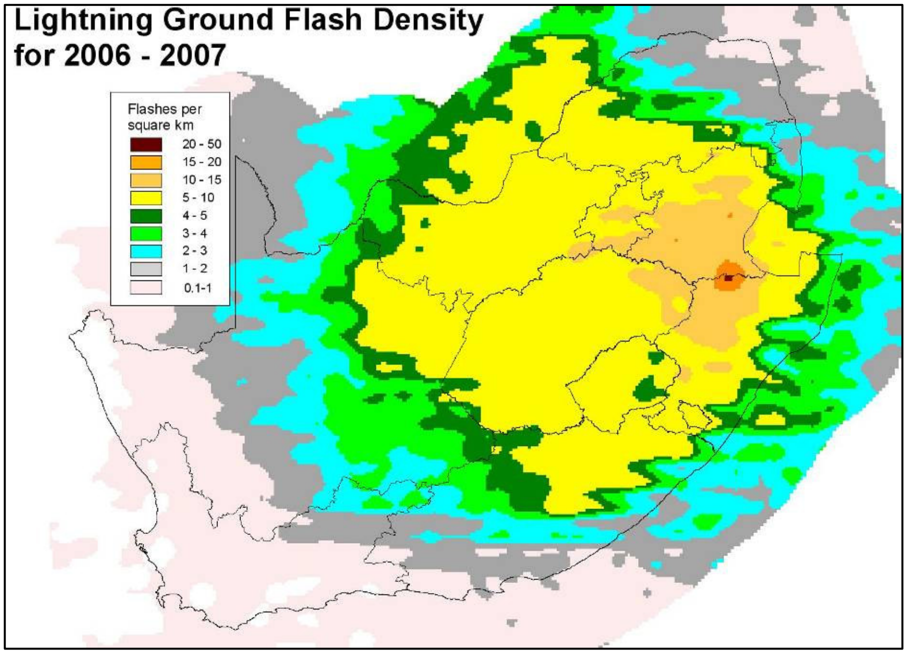

Figure 2: Cloud-to-ground lightning flash density for South Africa for 2006-2007.

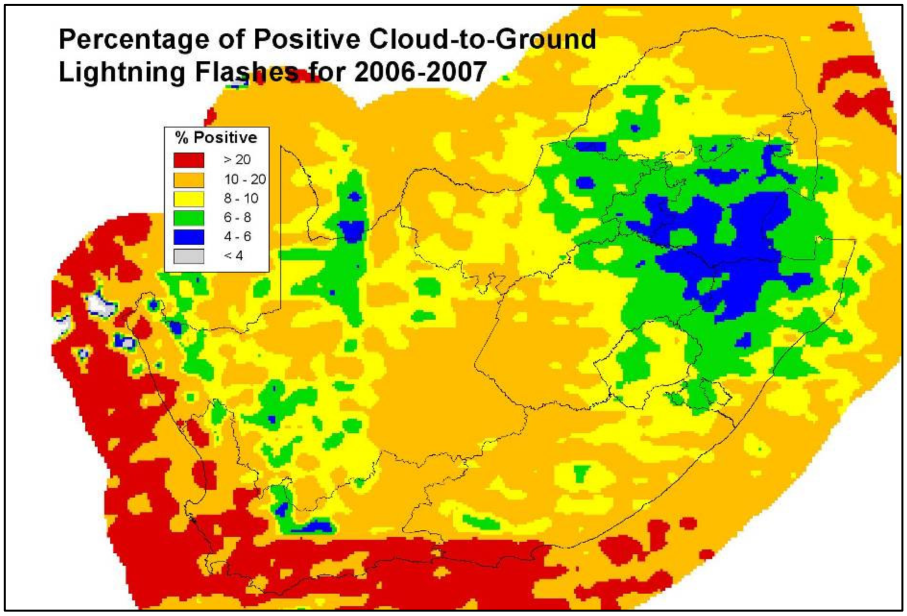

Figure 3: Percentage of positive polarity lightning over South Africa for 2006-2007.

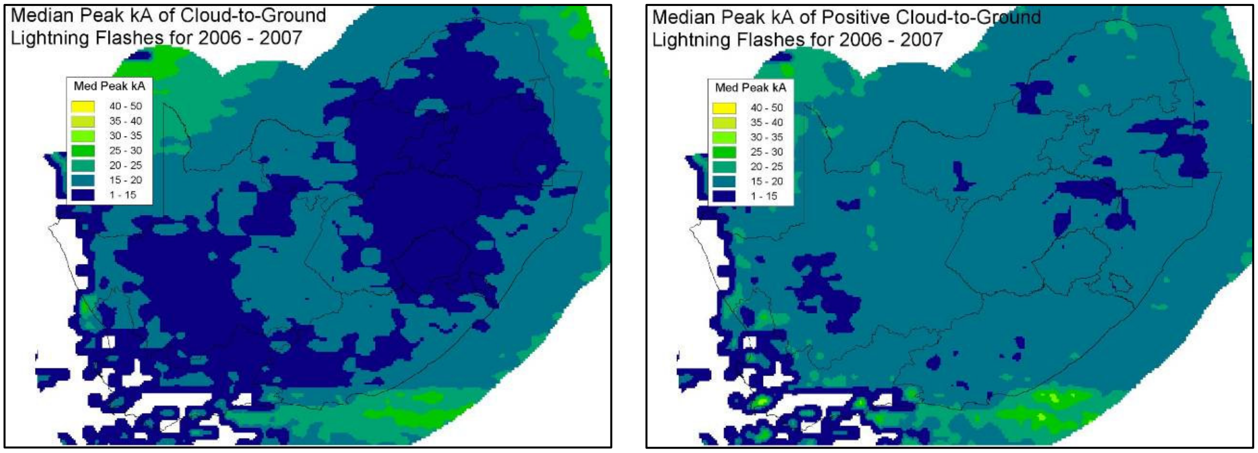

Figure 4: Median peak current of all lightning over South Africa in 2006-2007 (a) and of positive polarity lightning over South Africa in 2006-2007 (b).

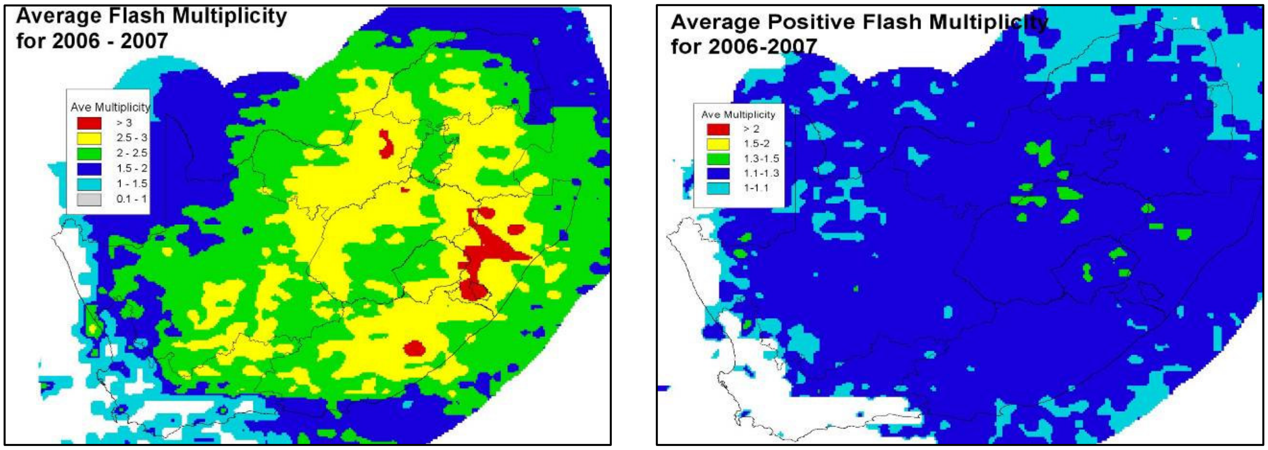

Figure 5: Average multiplicity of all lightning over South Africa in 2006-2007 (a) and of positive polarity lightning over South Africa in 2006-2007 (b).

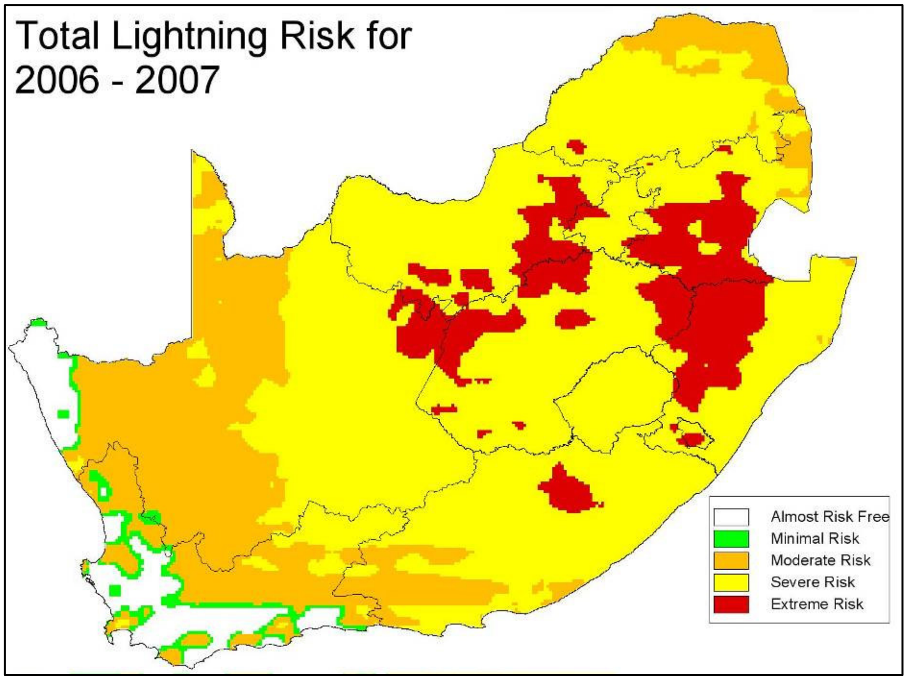

Figure 6: Total lightning risk for South Africa for 2006-2007