The lightning climatology of South Africa

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In 2005, the South African Weather Service installed a state-of-the-art cloud-to-ground lightning detection network across the country. The data recorded by this network in 2006 was utilised in the development of an initial lightning climatology of South Africa. Until 2010, this climatology was based on data from a single year. This paper updates this climatology with the lightning data for the 2006–2010 period, which is the first actual lightning climatology by the South African Weather Service based on data covering 5 years. A number of different maps were created from these lightning data. These were lightning ground flash density, median peak kiloampere, percentage positive and average flash multiplicity maps. These four maps were in turn used to develop lightning intensity risk, positive lightning risk and total lightning risk maps. Analysis of the maps showed that the highest concentrations of lightning are found over the central to northern interior of the country, with areas along the northern parts of the eastern escarpment experiencing the highest flash densities and falling within the extreme risk category. Both the positive and total lightning risks are severe for almost the entire country. Only towards the west of the country does the lightning risk decrease. This lightning climatology can now be used throughout South Africa for various disciplines. It will be especially useful for setting lightning safety standards and identifying priority areas for installing lightning conductors and conducting public awareness campaigns.

Introduction

Lightning activity has probably been present on earth since before any life developed.[1] The phenomenon of lightning has received a vast amount of research over the years but some issues still require answers.[2] Scientific lightning research only started in the 18th century,[2] when some of the first studies of electricity in thunderstorms were made by Benjamin Franklin with his famous kite experiment in 1752.[1] Franklin also proposed using lightning rods for protection against lightning and theorised that most cloud-bases are negatively charged.[1] Franklin's work paved the way for lightning research around the world.[2] During the late 19th century, photography and spectrometry became new tools for lightning research.[1] It was not until the 1970s, however, that electric and magnetic field measurements began a new era of lightning research.[1] Rakov and Rachidi[3] give an overview of recent topics of lightning research and protection. These include observations on lightning discharges, the modelling of lightning discharges, the occurrence of lightning together with lightning detection networks, the electromagnetic fields of lightning, the effects of lightning and lightning protection.

In southern Africa, recent lightning research is focused on the new South African Lightning Detection Network (SALDN), the analysis of the lightning data recorded by SALDN, the effects of lightning on electrical distributions, different forms of lightning protection, the development of a database on how lightning influences humans and animals and overcoming cultural myths to do with protecting people from lightning.[4]

South Africa is a country that frequently experiences lightning.[2] The summer (October to March) rainfall region is dominated by convective storms, and a large portion of this region receives more than 60 thunderstorm days a year,[5] whilst areas over the Highveld and the eastern escarpment record on average between 10 and 15 lightning flashes/km^2/year. South Africa does not experience as much lightning activity as the equatorial parts of Africa and South America but is still considered a lightning prone country.[2] Lightning-related deaths in South Africa account for an average of between 1.5 and 8.8 per million of the population,[4] which is said to be about four times higher than the global average.[2] Insurance claims in South Africa as a result of lightning amount to more than R500 million per year.[5]

Almost all insurance-related queries received by the South African Weather Service (SAWS) are lightning related. During the 2010/2011 financial year, 2103 insurance queries for lightning verification were received by the Climate Information section at the SAWS. These queries made up 72% of all commercial enquiries received by the section. Furthermore, 36% of the income generated by the Climate Information section for this particular financial year was earned from insurance queries related to lightning (De Jager E 2011, personal communication, March 29). Eskom is also a large commercial client of the SAWS. Up to about 24% of the utility faults reported by the Eskom Transmission Division are lightning related,[6] making lightning data a necessity in attempting to ensure an uninterrupted power supply to the country. Lightning information can also be supplied to various other institutions such as universities, as well as the aviation, telecommunication and forestry industries. These functions clearly show the importance of a SALDN, without which the SAWS would be limited in both its service delivery and public good. Until 2010, the only segment the SAWS lacked with regards to lightning queries was an up-to-date lightning climatology, which could also add immense value.

Prior to 2005, the SAWS had no means of measuring lightning activity.[5] Eskom, the major power utility of South Africa, operated a network of six Lightning Position and Tracking System lightning detection sensors.[6] The purpose of this network was primarily to monitor the influence of lightning activity on power lines and to ensure the correct distribution of lines over South Africa.[2] These sensors were discarded when the more advanced SALDN became operational.[7] Before this, the Council for Scientific and Industrial Research (CSIR) also operated a lightning detection network of lightning flash counters.[5] South Africa had about 400 flash counters.[8] These sensors had a range of about 20 km for ground flashes, resulting in some flashes that occurred between the counters being missed.[1] The CSIR operated a 60 m lightning research mast in Pretoria for 15 years, which was used for direct measurement of lightning discharges and also to verify the flash counters.[7] Results of these tests showed that frequent location accuracy errors were observed in these flash counters.[2] Then, in 2005, the SAWS made a large capital investment by purchasing a state-of-the-art lightning detection network from Vaisala, making South Africa one of only three countries in the southern hemisphere to operate such a network.[5] This network provided the SAWS with its first opportunity to explore lightning in thunderstorms and also to provide lightning information to the public.

The CSIR was the first institution to produce a lightning flash density map for South Africa, based on the data measured by the network of flash counters they operated.[5] This map was created with flash counter data for an 11-year period and was considered the most accurate flash density map created with flash counter data.[1] These flash counters only operated with a range of about 20 km,[1] and were not as technologically advanced as the new SALDN. To eliminate the annual and individual storm variations in lightning, it is recommended that a lightning climatology be produced over a period of at least 11 years, which is also the approximate period of a solar cycle.[1] The South African lightning climatology has only been completed for a 5-year period, and thus has not yet been done for a full solar cycle but has been done for the period of the El Niño southern oscillation cycle, and it may change slightly as the effects from annual and individual storms are smoothed out. The CSIR flash density map, however, has been compiled for 11 years, which will have smoothed out the effect of annual variations. However, the SALDN flash density map will be more accurate than the CSIR map as a result of the more technologically advanced lightning detection network.

The lightning sensors installed by the SAWS are distributed throughout the country (Figure 1). This distribution makes it possible to detect lightning flashes with a 90% predicted detection efficiency and a 0.5-km median location accuracy over most of the country.[9] A lightning climatology based on the state-of-the-art SALDN will improve upon the previous CSIR flash density map.

Gill[5] was the first person to utilise the data recorded by this new network in the development of an initial lightning climatology for South Africa. This initial climatology was based on the 2006 data recorded by the network, which was the first complete year of data measured by the SALDN. The following lightning maps were produced: lightning ground flash density, median peak kiloampere (kA), average flash multiplicity and percentage positive. These maps in turn were used in the development of lightning risk maps: the lightning intensity risk map, which gives an indication of areas at risk from high volumes of lightning; the positive lightning risk map, highlighting areas at risk from lightning with positive polarity; and the total risk map, which shows areas at risk from both high volumes of lightning and lightning with positive polarity.

After the development of the initial lightning climatology by Gill[5], the data from 2007 to 2010 recorded by the SALDN was never utilised to update this climatology and thus it was based on the data for only 2006. This paper serves as an update to the initial lightning climatology developed by

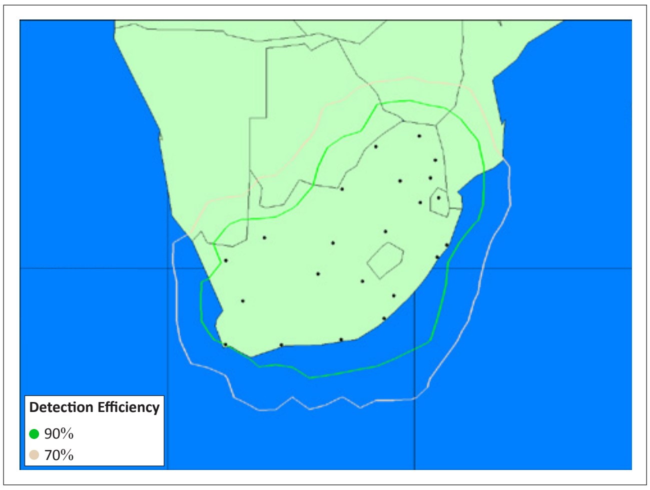


FIGURE 1: Map indicating the positions of the South African Weather Service lightning detection network sensors distributed throughout South Africa together with the detection efficiency rings at the present time.

Gill[5], with the data from 2006 to 2010. The same methodology developed by Gill[5] was utilised. The only changes were a higher resolution and slightly altered colour scale for the risk maps, to provide more detail on the maps.

Methods

Data and instrumentation

In 2005, the SAWS installed a state-of-the-art cloud-to-ground lightning detection network from Vaisala that consisted of 19 sensors across the country. During 2009, an upgrade to the network was initiated. Two new sensors were added to the network at Springbok (in the Northern Cape) and Aliwal North (in the Eastern Cape) during 2009 and a third new sensor was added at Satara in the Kruger National Park early in 2010. The addition of these sensors meant a new total of 22 sensors over South Africa, together with 1 sensor in Swaziland, to make up a network consisting of 23 sensors. The sensor at Upington (in the Northern Cape) was also relocated in 2008 to a new site near the old site as a result of new developments at the old site (Ngwato F 2011, personal communication, January 26). Future plans are to install an additional new sensor at Alkantpan (in the Northern Cape) and also to relocate the Ermelo (in Mpumalanga) sensor to Vryheid (in KwaZulu-Natal), the Nelspruit (in Mpumalanga) sensor to Lebowakgomo (in the Limpopo Province), the Thohoyandou (in the Limpopo Province) sensor to Musina (in the Limpopo Province), the De Aar (in the Northern Cape) sensor to Aberdeen (in the Eastern Cape) and the old Springbok (in the Northern Cape) sensor to Kathu (in the Northern Cape) (Ngwato F 2011, personal communication, January 26). Figure 1 shows the approximate positions of the SALDN sensors at the time that this paper was written. During the writing of this paper there were two sensors (one new and one old) running concurrently for data analysis at Springbok.

The SALDN sensors detect electromagnetic signals emitted by lightning discharges. Gill[5] described how these electromagnetic waves propagate in a number of different ways. Low frequency waves can propagate along the ground, called ground waves, and also through the atmosphere, called sky waves. Each sky wave is given a number according to how many times it has been reflected by the ionosphere. The first sky wave is reflected once by the ionosphere, the second twice, etc.[5] The SALDN sensors operate at very low frequency and low frequency ranges.[10] This range of operation is to ensure that the sensors detect only the ground waves and not the sky waves and thus cloud-to-ground lightning flashes.[5] Each lightning discharge produces a wave pulse signature that is unique. These signatures are analysed to determine the type of stroke.[5] The SALDN sensors detect electromagnetic waves by means of a combination of magnetic direction finding and time of arrival methods.[5] The magnetic direction finding method determines the angle from true north between the sensor and lightning stroke whilst the time of arrival method pinpoints the possible location of a lightning stroke based on the different arrival times between the sensors in order to use the parabolic and circular method to determine the intersection point of the stroke.[5] For a more detailed description of the time of arrival and magnetic direction finding methods, see Gill[5]. When the time of arrival or the magnetic direction finding method is used individually, three or more sensors are needed, whilst the combined technology as used by the SALDN requires at least two sensors to detect lightning.[5]

Median stroke location accuracy is determined by means of the confidence ellipse of a two-dimensional Gaussian distribution model. The SALDN assumes a 0.5 probability level, meaning that there is a 50% probability that a stroke falls inside the confidence ellipse where the centre of the ellipse is considered to be the likely position of the stroke. Therefore, the median location accuracy, as determined by the confidence ellipse, is 0.5 km.[5] The predicted detection efficiency of the SALDN is 90%.[9] With the installation of the SALDN, Vaisala stated that the detection efficiency of the SALDN would be 90%. However, no study has quantified this value. If this value were quantified to be true, it means that at least 90% of all lightning flashes will be detected. The location accuracy of 0.5 km means that 50% of all strokes will be located within the confidence ellipse. The change from the original 19-sensor network to a 23-sensor network meant that an even larger part of the country would fall inside the 0.5 km median location accuracy and predicted 90% detection efficiency range (Ngwato F 2011, personal communication, January 26). Figure 1 displays these predicted detection efficiency rings of the SALDN over South Africa at the present moment. From Figure 1 it can be seen that most of the country falls within the 90% detection efficiency ring.

In the development of the lightning climatology, only cloud-to-ground lightning flashes were considered because the SALDN detects this type of lightning. A lightning flash is the entire lightning discharge, whilst the pulses in a flash are known as strokes.[11] One lightning flash can consist of a number of lightning strokes (typically, three or four). The number of lightning strokes that make up a lightning flash is referred to as the lightning flash multiplicity.[1] Lightning flash data recorded by the network are obtained by using the peak current of the initial stroke, by setting the peak current of the flash to be the same as the peak current of the initial stroke.[5] In this paper, the same assumption was made as that by Gill[5], namely, that the initial stroke will carry the most energy in a flash. This assumption also means that a flash will be classified as positive if the peak current of the initial stroke, and thus also the peak current of the flash, is positive. The following describes how to cluster strokes into flashes.[12] Strokes are considered to make up a flash if they occur within 1 s of the initial return stroke, fall within 10 km of the first stroke and occur within 500 ms of the previous stroke. One flash can only consist of 15 strokes, where stroke number 16 is considered to be the first stroke of a new flash. When a stroke falls within two flashes, it is placed in the flash with the nearest first stroke. If the stroke occurs within 1 s of the previous stroke, or within 500 ms of the previous stroke but also falls outside the 10 km range of the first stroke and remains within 50 km of the first stroke (where its median location accuracy confidence ellipse overlaps the confidence ellipse of the first stroke), then the stroke is considered part of the flash.

Raw data recorded by the sensors are sent to the network control centre at the SAWS headquarters in Pretoria, where a central analyser processes the data.[5] These data are stored on a database and can be retrieved by the Fault Analysis and Lightning Location System[13] software package. With this software package there is an option of selecting either lightning flash data or lightning stroke data to extract from the database, and for the purposes of this update of the lightning climatology, flash data were used.

Methodology

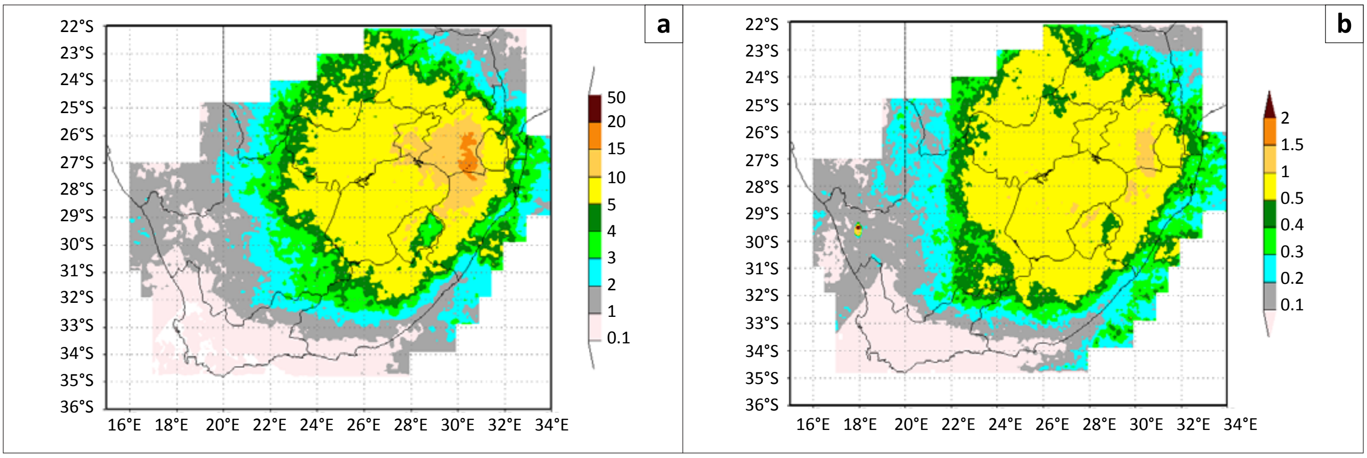
The same methodology developed by Gill[5] was used in this update of the initial climatology of South Africa. The lightning climatology created for South Africa consists of lightning ground flash density, median peak kiloampere, average flash multiplicity and percentage positive maps. These four maps were in turn used to develop three lightning risk maps, namely, the lightning intensity risk, positive risk and total risk maps. The methodology for the development of the lightning risk maps was developed by Gill[5] in her initial climatology. Gill[5] could not find many references to general purpose lightning risk maps. Only literature on risk maps created for specific purposes could be found and thus the risk maps were developed from first principles as proposed general purpose risk maps.[5] Gill[5] stated that these risk maps are simple models that are proposed as general purpose risk maps and can be easily modified depending on individual needs.

All lightning data were calculated and displayed on a 0.1° x 0.1° grid over the country. Gill[5] developed the initial lightning climatology based on a 0.2° x 0.2° grid. It was decided, however, to rather make use of a higher resolution to add more detail on the maps. Each of the lightning ground flash density, median peak kiloampere and average flash multiplicity maps were created for all lightning flashes, irrespective of the polarity of the flash, by taking the absolute value of all the ampere values. Maps for lightning flashes with positive polarity were also created. These maps are shown but are not discussed in this paper; they were used only in the development of the positive lightning risk map. The maps shown for median peak kiloampere, average flash multiplicity and the percentage of positive lightning will also not be discussed in the results of this paper.

With the 1994 upgrade of the National Lightning Detection Network in the United States of America, it was established that positive cloud-to-ground lightning strokes detected by the network with small peak currents are frequently cloud discharges.[5] As a result, lightning detection networks using similar technologies to the National Lightning Detection Network were advised to discard positive lightning strokes with peak currents less than 10 kA.[12] The SALDN adopted the same approach by discarding all positive lightning strokes with peak currents below this threshold value. Gill[5] also discarded lightning data with peak currents below 10 kA and for this update the same approach was used. More recently, the threshold value of 10 kA has been changed to 15 kA.[14] During the 2006–2010 period, the 10 kA threshold was still being used at the SAWS. More recently, Grant[15] developed a method to solve the dilemma of the misclassification problem, which can now be incorporated into the processed lightning data.

Lightning ground flash density map

The lightning ground flash density was calculated for each 0.1° x 0.1° grid box over the country. This map is displayed in Figure 2a. The number of lightning flashes that were recorded by the SALDN for the 5-year period 2006–2010 was counted for each individual grid box over the country. This summation was divided by the area of the grid box to give the number of lightning flashes per square kilometre. But, because data for 5 years were considered, this number was divided by five to give the average annual number of flashes per square kilometre. All grid boxes over the country were considered, irrespective of the number of flashes. The results are plotted on a map (Figure 2a), with a scale ranging from 0.1 to 50 flashes per square kilometre.



Source: South African Weather Service

FIGURE 2: Map showing the average annual lightning ground flash densities per square kilometre for (a) all lightning flashes, irrespective of polarity, and (b) lightning with positive polarity, over South Africa for the 5-year period from 2006 to 2010.

Median peak kiloampere map

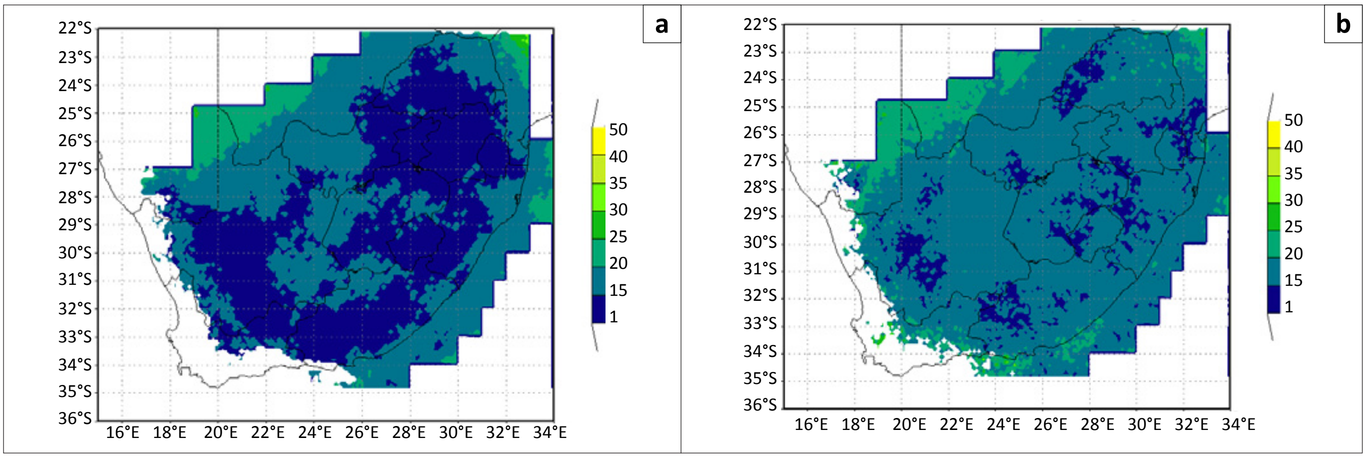
For the median peak kiloampere, the ampere value of each lightning flash was considered. The median is essentially the middle value of a data set,[16] so that there is an equal probability of the peak current occurring above this value as that below this value. In order to calculate the median peak kiloampere, ampere values for each 0.1° x 0.1° grid box over the country were sorted in ascending order, from where the ampere value in the middle position of the data set could be calculated. For the median peak kiloampere calculation to be based on a reasonably sized data set, only grid boxes with more than 100 flashes were considered in the calculation of the median peak kiloampere.[5] Figure 3a shows the median peak kiloampere map for the 2006–2010 period, with a scale ranging from less than 1 kA to more than 50 kA.

Average flash multiplicity map

Lightning flash multiplicity describes how many lightning strokes there are in one flash.[17] The average flash multiplicity is calculated simply by adding all the multiplicity values for each grid box and dividing this amount by the total number of flashes found in each grid box. This number must also be divided by five to get the annual average flash multiplicity. To ensure that the average flash multiplicity calculations were based on a suitably sized data set, only grid boxes with more than 100 flashes were considered.[5] This map is displayed in Figure 4a. The scale of this map ranges from less than 1 stroke up to more than 3 strokes in a flash.

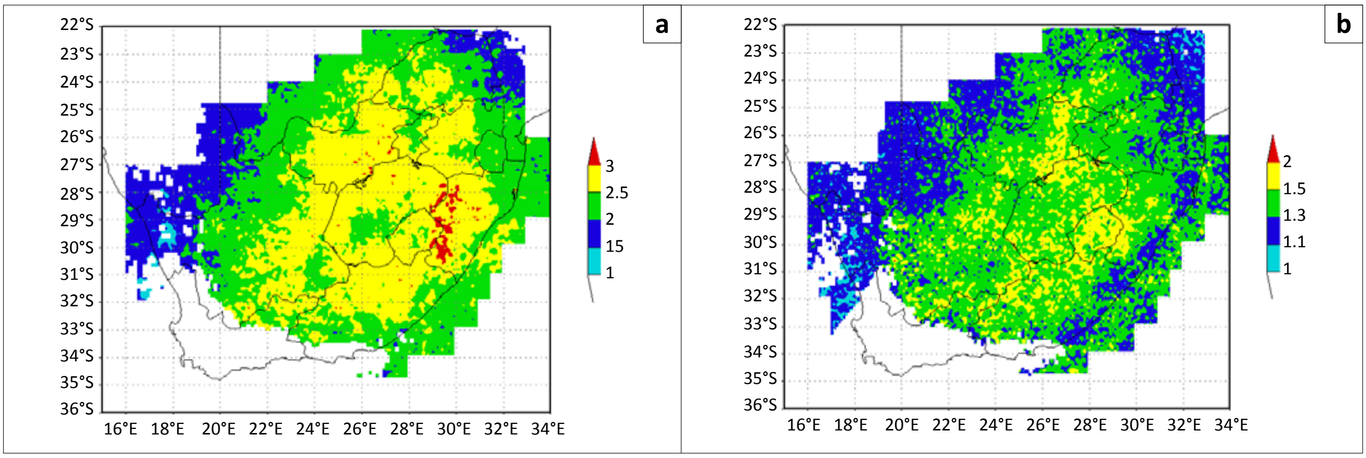
Percentage positive map

The percentage positive map shows the percentage of all lightning flashes that had positive polarity. The data for this map were calculated by counting the total number of flashes for each grid box, irrespective of polarity, as well as the number of flashes with positive polarity. The number of flashes with positive polarity were divided by the total number of flashes and multiplied by 100 to give the percentage of lightning flashes with positive polarity. It should be noted that all lightning flashes with positive polarity below 10 kA were discarded in the development of the climatology as discussed earlier in the methodology. The percentage positive map is shown in Figure 5. The scale of this map is in percentage, ranging from less than 4% up to more than 20%.



Source: South African Weather Service

FIGURE 3: Map depicting the lightning median peak kiloampere for (a) all lightning flashes, irrespective of polarity, and (b) lightning flashes with positive polarity, over South Africa for the 5-year period from 2006 to 2010.



Source: South African Weather Service

FIGURE 4: Map indicating the average flash multiplicities for (a) all lightning flashes, irrespective of polarity, and (b) lightning flashes with positive polarity, over South Africa for the 5-year period from 2006 to 2010.

Lightning intensity risk map

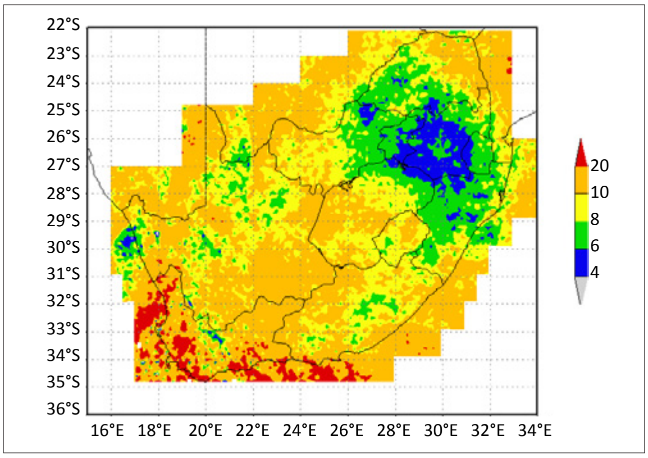
Gill[5] proposed a map called the lightning intensity risk map as one of the general risk indices in the development of the initial climatology. The purpose of the lightning intensity risk map is to give an indication of areas at risk from high volumes of lightning.[5] Three maps were utilised in the development of the lightning intensity risk map: the lightning ground flash density map, the median peak kiloampere map and the average flash multiplicity map. The lightning ground flash density map was selected for inclusion in this risk map because it identifies areas where lightning frequently occurs. This map gives the number of lightning flashes per square kilometre, which makes it ideal for analysing the risk associated with high volumes of lightning received by a specific area. Because higher currents found in a lightning flash may increase the risk associated with the flash, the median peak kiloampere map is also included in the calculations of the lightning intensity risk map. Finally, the average lightning flash multiplicity map is included in this risk map because a flash consisting of a number of strokes may transfer large amounts of energy to the ground.[5] The final lightning intensity risk map is thus used to analyse the risk based on high volumes of lightning with large median peak currents and flashes consisting of a number of strokes.

As this lightning intensity risk map is concerned with high volumes of lightning received, all lightning flashes, irrespective of polarity, were considered. Each of these input maps was reduced to an index varying between 0 and 1 by dividing the value from each grid box by the maximum number of the entire data set. The three maps, reduced to an index, were given equal importance in the development of the lightning intensity risk map and were simply added together. All the corresponding grid box values on each of the three input maps were added together. The sum of these three indices was in turn also reduced to an index varying between 0 and 1. The final map is displayed in Figure 6 and is divided into five equal main intervals, ranging from low risk to high risk. In addition to these five main categories used by Gill[5], each main interval is also divided into two subintervals. These subintervals are included in the new maps to provide more detail. Instead of the five colours used by Gill[5], the new maps now have ten colours, which indicate areas topping the scale in each main category more clearly. These risk categories are actually divided into numerical intervals between 0 and 1, where the main categories are divided into intervals of 0.2 and the subintervals into intervals of 0.1. This division means that the extreme risk category, for example, ranges from 0.8 to 1.0, whilst the brown subinterval ranges from 0.8 to 0.9 and the black subinterval from 0.9 to 1.0.

Positive lightning risk map

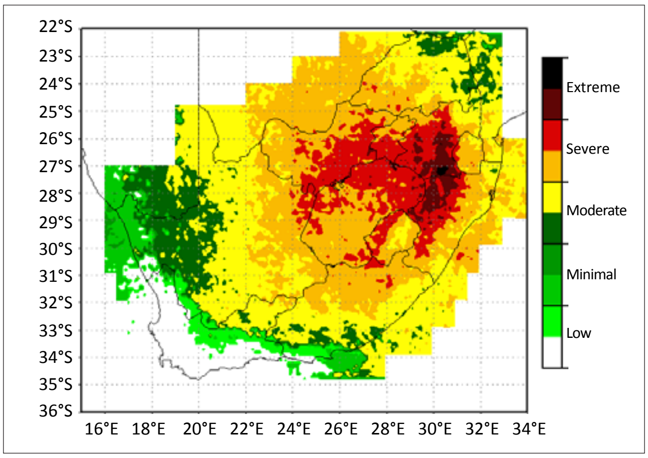
A second risk map proposed by Gill[5] was the positive lightning risk map. This risk map identifies areas where lightning with positive polarity poses the highest risk. Lightning with positive polarity typically discharges a greater charge to the ground than its negative polarity counterpart,[18] and the channels transferring the higher current typically remain conductive longer as a result of the continuing current components of the lightning, which cause an increase in the joule heating at the attachment point of the lightning.[5] Positive lightning is usually responsible for more severe damage and also for fires initiated by lightning.[1] Furthermore, Rakov and Uman[1] state that the peak current, as well as the integral of the current over time, are two properties of lightning that can lead to destruction. Because lightning with positive polarity contains both these properties, it can be considered dangerous. However, this form of lightning occurs less frequently – making up approximately 10% or less of all lightning flashes.[19]

To address the risk associated with lightning with positive polarity, Gill[5] proposed the development of a positive lightning risk map. As input to this risk map, the positive lightning ground flash density map (Figure 2b), the median peak kiloampere of positive polarity lightning map (Figure 3b), the positive flash multiplicity (Figure 4b) and the percentage positive map (Figure 5) were used. Only lightning flashes with positive polarity were considered in the development of these maps and thus all flashes with an



Source: South African Weather Service

FIGURE 5: Map showing the percentage of all lightning flashes that had positive polarity for the 5-year period between 2006 and 2010.



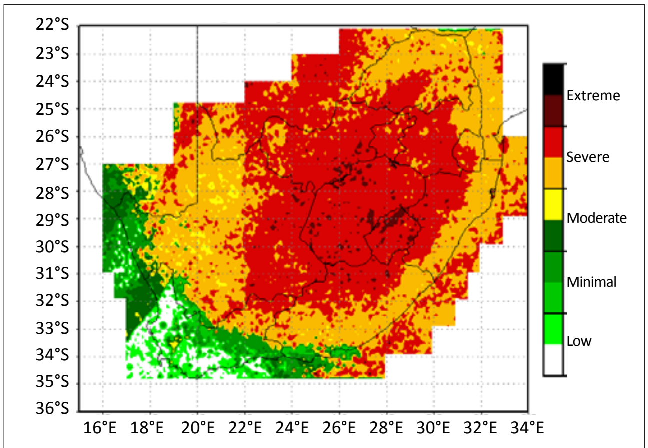
Source: South African Weather Service

FIGURE 6: Lightning intensity risk map showing areas at risk from high volumes of lightning for the 5-year period between 2006 and 2010.

ampere value of less than 10 kA were discarded. The positive lightning ground flash density map enables this risk map to take into account areas of the country which receive the most lightning with positive polarity. This map will give the number of lightning flashes with positive polarity per square kilometre as input to the positive risk map. The median peak kiloampere of positive polarity lightning map identifies the areas of the country where flashes with positive polarity have large currents. Lightning with positive polarity does typically have higher currents than lightning with negative polarity[18] but the median peak kiloampere of positive polarity lightning map will be concerned with the areas receiving the largest currents with positive polarity.

Lightning flashes with positive polarity usually consist of a single stroke, although they may consist of more strokes.[1] Rakov and Uman[1] state that positive flashes with more than one stroke are fairly rare and that some of these flashes with more than one stroke detected by lightning detection networks may be misclassified cloud discharges. In this climatology, as with the initial climatology developed by Gill[5], the positive flash multiplicity map was used without taking the above into account. The positive flash multiplicity map thus identifies areas where lightning flashes with positive polarity typically contain more than one stroke and where the possibility of the flash transferring a greater charge to the ground is accounted for.[5] As a final input to the positive lightning risk map, the percentage positive map was included. This map can be used to determine what percentage of the total number of lightning flashes an area receives will be positive. By including this map in the calculation of the positive risk map, areas which might receive low volumes of lightning with positive polarity but predominantly experience lightning with positive polarity can also be taken into account in the analysis of the risk associated with positive lightning.

Only lightning flashes with positive polarity were considered in the creation of this risk map. For the percentage positive map used as input in the risk map calculations, all lightning flashes irrespective of polarity were used to calculate the percentage of flashes with positive polarity. Each of the four input maps was given equal importance in the calculations. Each of these input maps was reduced to an index varying between 0 and 1 by dividing the value from each grid box by the maximum number of the entire data set. The four maps were simply added together. All the corresponding grid box values on each of the four input maps were added together. The sum of these four indices was in turn also reduced to an index varying between 0 and 1. The final map, shown in Figure 7, is divided into five equal main intervals ranging from low risk to high risk. Each main interval is in turn divided into two subintervals. These additional subintervals are added to the work done by Gill[5], to show greater detail on the maps. The numerical ranges for each main interval, as well as the subintervals, are exactly the same as those discussed above for the lightning intensity risk map.



Source: South African Weather Service

FIGURE 7: Map indicating areas at risk from lightning with positive polarity for the 5-year period between 2006 and 2010.

Total lightning risk map

Because high volumes of lightning are just as important as lower volumes of lightning with positive polarity when analysing lightning risk,[5] it is important to create a risk map that takes into account both of these different types of risk. Gill[5] proposed combining the lightning intensity risk and positive lightning risk maps. The lightning intensity risk map addresses the risk associated with high volumes of lightning whilst the positive lightning risk map shows the areas at risk from positive lightning. This combination is called the total lightning risk map and serves the purpose of being a general purpose map that takes all the risks associated with lightning into account.

As input to the total lightning risk map, both the lightning intensity risk map and positive lightning risk map were considered. The results of these two maps were already reduced to an index between 0 and 1 as discussed earlier. Thus the two maps needed only to be added together by giving each map equal importance in the calculation. The value in each 0.1° x 0.1° grid box on the lightning intensity risk map was added to the value in the corresponding grid box on the positive lightning risk map. The sum was reduced to an index varying between 0 and 1 by dividing each grid box over the country by the maximum value of the entire data set. This result was then called the total lightning risk. The final map, shown in Figure 8, is divided into five equal main intervals ranging from low risk to high risk. An addition to the total risk map produced by Gill[5] is that each main interval is further divided into two subintervals to provide a map displaying more detail than the original map developed by Gill[5]. Instead of the five colours used by Gill[5], the new map has ten colours, which indicate areas topping the scale in each main category more clearly. The risk categories are divided into numerical intervals between 0 and 1, where the main categories are divided into intervals of 0.2 and the subintervals into intervals of 0.1.

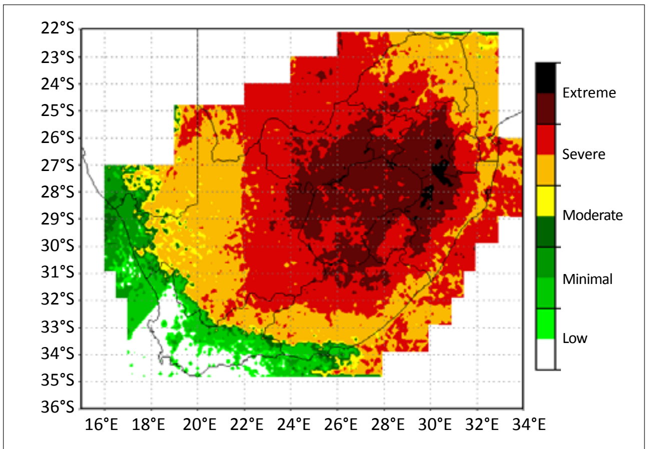
Results

Lightning ground flash density

Lightning ground flash density is the climatology map most widely used by weather services around the world, in regard to lightning, because it gives a direct indication of the amount of lightning an area receives during a certain period.[1] Figure 2a shows the 5-year average annual lightning flash density over South Africa for lightning flashes of both positive and negative ampere values for the 2006–2010 period. These lightning flash densities are expressed as the average number of flashes per square kilometre per year.

A significant feature of the lightning ground flash density is that it follows the topography of the country fairly accurately. The areas with flash densities above 3/km^2 closely correspond to areas higher than 1000 m above sea level, whilst flash densities of 10/km^2 or more correspond to elevations of 1500 m above sea level or higher. The area over Lesotho where the flash densities decrease from the surrounding flash densities to 3/km^2 – 5/km^2, is at an elevation of 2000 m to 3000 m, or at heights above 3000 m. This relationship is most probably caused by the fact that a large number of storms develop below the level of these high mountain peaks or that the thunderstorms which developed on the windward side of the mountains already rained out on the lower parts of the mountain slopes.[5] Another possibility might be that the SALDN cannot accurately measure lightning at these heights. Bhavika[2] stated that convection and thunderstorms are related to topography and can thus affect lightning activity (see Bhavika[2] for a detailed description of the influence of topography on lightning activity in South Africa).

Analysis of the ground flash density map shows that the highest flash densities of more than 15/km^2 are found along the windward slope of the Northern Drakensberg Mountains, extending from the northernmost parts of KwaZulu-Natal into the Mpumalanga Lowveld. Flash densities of between 10/km^2 and 15/km^2 are seen from the western to north-western parts of Kwazulu-Natal extending into the Mpumalanga Lowveld, the southern parts of Gauteng as well as the northern and north-eastern Free State. Small areas over the western parts of the North West Province and Lesotho also have flash densities of between 10/km^2 and 15/km^2. Most of the central interior of the country receives between 5 and 10 flashes/km^2, from where it decreases towards the west of the country. Flash densities also decrease towards the northern to north-eastern parts of the country, as well as towards the coast.



Source: South African Weather Service

FIGURE 8: Total lightning risk map indicating the areas at risk from both high volumes of lightning as well as lightning with positive polarity, based on the 5-year period between 2006 and 2010.

By comparing Figure 2a with the flash density map produced by the CSIR in the 1990s, it can be seen that the highest flash densities were found along the windward slopes of the northern parts of the eastern escarpment, extending from the northern parts of KwaZulu-Natal into the Mpumalanga Lowveld. However, these flash densities underestimated the flash densities found in Figure 2a for that area. In the map from the CSIR, an area with the same order of flash densities as over the northern parts of the eastern escarpment is also found over the Maluti Mountains of Lesotho. From Figure 2a, however, this area has lower flash densities than indicated by the CSIR map. Areas over Gauteng receive fewer flashes on the CSIR map compared to Figure 2a. The rest of the country is fairly comparable in magnitude on both maps.

Lightning risk

Lightning intensity risk

The purpose of the lightning intensity risk map is to give an indication of the areas of South Africa at risk from high volumes of lightning. This risk map is important because it identifies regions where lightning frequently occurs, with high currents and where there is typically a large number of strokes in a flash. Figure 6 displays the lightning intensity risk map for the 2006–2010 period.

The lightning intensity risk map is divided into five main risk categories ranging from low risk to extreme risk. The lightning intensity risk map is closely related to the lightning flash density map. Areas along the windward slopes of the Northern Drakensberg Mountains are labelled as an extreme risk area, which is consistent with the highest lightning flash densities seen in Figure 2a. The central interior of the country falls within the severe risk category. The lightning risk decreases towards the west, with the Western Cape mostly risk free or at low risk. The lightning intensity risk also decreases towards the southern and eastern coastal regions, as well as towards the northern parts of the Limpopo Province.

This risk map may be useful to various industries concerned with areas at risk from high volumes of lightning. This risk map can, for example, be used to identify priority areas where lightning conductors should be installed in informal settlements that are frequently bombarded by lightning strokes and can also be used to select high risk areas where lightning safety tips should be provided to the public with great urgency. Numerous disciplines will be able to benefit from this risk map.

Positive lightning risk

The positive lightning risk map takes into account areas of the country prone to lightning with positive polarity.[5] This map is important because lightning with positive polarity may be considered a more destructive form of lightning,[1] as discussed earlier. Figure 7 shows the positive lightning risk map for the 2006–2010 period.

Most of the country falls within the severe risk category for positive lightning. The central to northern interior of the country falls in the top level of the severe risk category and corresponds to lightning flash densities exceeding 4/km^2. The remaining part of the country at severe risk from positive lightning falls within the lower level of the severe risk category. Towards the west of the country the risk decreases. The majority of the Western Cape experiences low risk, with only the north-western parts at severe risk from lightning with positive polarity. An area along the south coast of the Eastern Cape falls within the low and minimal risk category and areas along the west coast experience low to moderate risk. Some parts of the Northern Cape, Eastern Cape, Limpopo Province and KwaZulu-Natal are moderately at risk from lightning with positive polarity. Small isolated areas in the North West Province, Free State, Northern Cape, Eastern Cape, KwaZulu-Natal and Lesotho are at extreme risk from lightning with positive polarity.

The positive lightning risk map identifies areas of the country at risk from lightning with positive polarity. Because lightning with positive polarity typically discharges more energy to the ground[18] and the channels transferring the larger current to the ground typically remain conductive for longer periods as a result of the continuing current components, this type of lightning typically results in more severe damage.[1] This type of lightning is also frequently responsible for the initiation of fires because of the increase in joule heating at the point of contact of the continuing current component.[1] As a result, this risk map can be particularly useful in determining areas of the country where lightning-induced fires may occur. This risk map can also be used by electrical companies to determine the areas of the country where their systems need to be able to withstand large currents, such as where the channels in the lightning discharge remain open for a long period of time. This map can therefore also be used by various institutions that are concerned with this type of lightning.

Total lightning risk

This map combines the lightning intensity risk and positive lightning risk maps discussed previously and can be considered to be a general purpose map to assess lightning risk.[5] Figure 8 shows the total lightning risk map for the 2006–2010 period.

A large area over the central to northern interior of the country falls within the extreme risk category. The highest risk inside the extreme risk category is found along the windward slopes of the Northern Drakensberg Mountains, whilst the remaining areas experience a lower risk. The rest of the country falls predominantly in the severe risk category. From Figure 8 it is clear that the lightning risk decreases towards the west of the country. Areas along the western parts of the Northern Cape, the Western Cape and the southernmost parts of the Eastern Cape experience low to moderate lightning risk. The Western Cape is the region in South Africa with the lowest risk, with most of the province falling inside this category.

The purpose of the total lightning risk map is to take into account the risk from high volumes of lightning, as well as lightning with positive polarity,[5] which is considered to be a more destructive form of lightning.[17] In other words, it combines the two previously discussed risk maps into a single risk map that can be used by various organisations to get an overall picture of lightning risk.

Conclusions

Prior to 2006, the SAWS was unable to measure lightning activity over South Africa. This limited the SAWS in both its service delivery and public good. This inability changed with the installation of the state-of-the-art SALDN by the end of 2005, which enabled the SAWS to explore lightning activity for the first time. Gill[5] was the first person to utilise this new technology in regard to developing an initial lightning climatology of South Africa with the data from 2006. Until 2010, this initial lightning climatology had never been updated, and this paper serves to update the climatology with the data for the 2006–2010 period. These data provide South Africa with the first lightning climatology, based on data for more than a year, measured by the new state-of-the-art SALDN. Almost exactly the same methodology developed by Gill[5] was utilised, with the only differences being that a higher resolution was used and the scale of the lightning risk maps was increased.

Analysis of the maps shows that the highest concentrations of lightning are found over the central to northern interior of the country, with areas along the northern escarpment extending from the northern parts of KwaZulu-Natal into the Mpumalanga Lowveld topping the scale of lightning densities. The risk maps also confirm that these areas fall into the extreme risk category. Almost the entire country is at severe risk from both lightning with positive polarity as well lightning in general. Only towards the west of the country does the concentration of lightning, as well as the lightning risk, decrease.

This lightning climatology can now be used throughout South Africa for various disciplines. It will be especially useful for setting lightning safety standards. Priority areas can be identified to install lightning conductors in high risk areas like rural areas, as well as to focus attention on these areas for lightning safety tips to the public. Insurance companies can utilise these maps to identify high risk areas, Eskom can determine areas where lightning is most likely to interrupt power supply, areas at risk from lightning-induced fires can be identified and various other institutions may benefit from using these maps. The risk maps are also easily modifiable and can be changed to meet individual needs based on specific requirements.

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Competing interests

I declare that I have no financial or personal relationships which may have inappropriately influenced me in writing this article.

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