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A statistical scheme to forecast the daily lightning threat over southern Africa using the Unified Model

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ABSTRACT

Cloud-to-ground lightning data from the Southern Africa Lightning Detection Network and numerical weather prediction model parameters from the Unified Model are used to develop a lightning threat index (LTI) for South Africa. The aim is to predict lightning for austral summer days (September to February) by means of a statistical approach. The austral summer months are divided into spring and summer seasons and analysed separately. Stepwise logistic regression techniques are used to select the most appropriate model parameters to predict lightning. These parameters are then utilized in a rare-event logistic regression analysis to produce equations for the LTI that predicts the probability of the occurrence of lightning. Results show that LTI forecasts have a high sensitivity and specificity for spring and summer. The LTI is less reliable during spring, since it over-forecasts the occurrence of lightning. However, during summer, the LTI forecast is reliable, only slightly over-forecasting lightning activity. The LTI produces sharp forecasts during spring and summer. These results show that the LTI will be useful early in the morning in areas where lightning can be expected during the day.

1. Introduction

Severe thunderstorms are a major concern to the weather community and the public due to their ability to cause death, injury and damage (Lang et al., 2004). Lightning, tornadoes, strong wind, heavy rainfall and hail are some of the phenomena associated with severe thunderstorms (Kohn et al., 2011). Lightning alone poses a severe threat, since it can cause injury or death to humans and animals (Blumenthal et al., 2012), damage to infrastructures (Lynn and Yair, 2010), and can be a hazard to various industries like aviation and forestry (Price, 2013). It is estimated from satellite observations that about 39–49 lightning flashes occur around the globe every second (Christian et al., 2003). This equates to > 1.4 billion flashes a day. Lightning is one of the leading causes of death from natural disasters. It causes approximately 24,000 deaths and 240,000 injuries annually around the globe (Blumenthal et al., 2012).

In South Africa, the annual mortality rate due to lightning is estimated to be between 1.5 (in urban areas) and 8.8 (in rural areas) people per million of the population (Blumenthal et al., 2012; Holle, 2008). These statistics are based on published data (Blumenthal et al., 2012), but it is likely to be an underestimate of the actual mortality rate, since lightning deaths are often not reported, especially in rural areas (Trengrove and Jandrell, 2011). Bhavika (2007) stated that the number of lightning deaths in South Africa is about four times higher than the global average. South Africa is a country that consists of mainly two rainfall seasons, austral summer and winter rainfall seasons. The central to northern interior of the country falls within the summer rainfall region and receives most of its rainfall from convective thunderstorms (de Coning and Poolman, 2011; Kruger, 2007; Landman et al., 2012; Tyson, 1986; Dyson et al., 2015). Most of the rainfall in the winter rainfall regions of the south-western and coastal parts of the country originates from either stratiform clouds or shallow convective clouds that form from the on-shore flow by ridging high-pressure systems and cold fronts (de Coning and Poolman, 2011). Consequently, these systems are associated with low lightning activity (Fig. 1d). On the other hand, the summer rainfall area of South Africa is extremely vulnerable to cloud-to-ground (CG) lightning, which occurs predominantly during spring (Fig. 1a) and summer (Fig. 1b). The lightning activity decreases during autumn (Fig. 1c). Since most lightning activity occurs during spring and especially summer (Fig. 1a, b), these were the seasons of interest in this study.

Due to the hazardous nature of lightning, there is a need for

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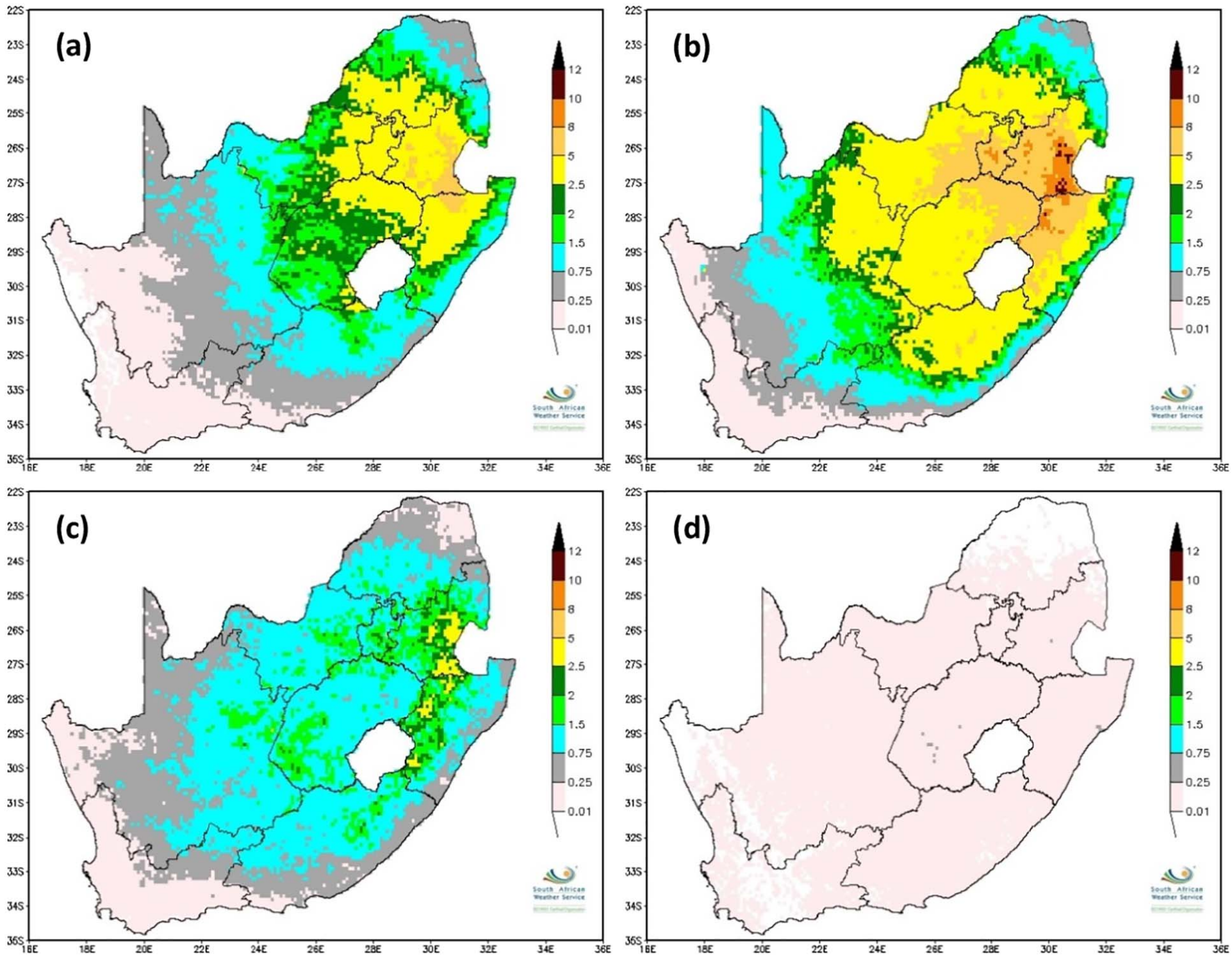

Fig. 1. The distribution of CG lightning ground flash densities (flashes per square kilometre per season) over South Africa for (a) September to November, (b) December to February, (c) March to May, and (d) June to August, during a nine-year period from 2006 to 2014.

prediction techniques to ensure the protection of people and property (McCaul et al., 2009; Lynn and Yair, 2010). Forecasting thunderstorms remains a challenge due to their small spatial and temporal scales, as well as uncertainty in the processes that govern thunderstorm development (Rajeevan et al., 2012). To predict lightning from a thunderstorm poses an even bigger challenge, since the processes that govern the electrification of a thundercloud are still poorly understood (Shafer and Fuelberg, 2008). Many techniques have been developed to forecast lightning, ranging from nowcasting (0 to 2 h ahead) and very short-range (2 to 12 h ahead) up to short-range (12 to 72 h ahead) forecasting time scales. Past studies have utilized lightning data from lightning detection networks (LDN), parameters from atmospheric soundings and numerical weather prediction (NWP) models to aid with lightning forecasts.

LDN are capable of detecting lightning strokes in real-time and the data measured by these networks could be utilized to aid in the nowcasting of thunderstorms. Many of these LDN networks however are designed to detect only CG lightning, and it has been shown that inconsistent relationships exist between CG lightning trends and thunderstorm nowcasting (Schultz et al., 2011). Total lightning sensors that can detect CG and cloud lightning have been found to be useful in the nowcasting of CG lightning strikes since lightning in the clouds mostly precedes CG lightning on the ground. MacGorman et al. (2011) showed that cloud lightning can precede the first CG lightning flash by up to an hour. This shows that total lightning sensors can be used for the nowcasting of thunderstorms or lightning but not for short-range forecasts. In South Africa the LDN detects mostly CG lightning which makes it less useful for nowcasting purposes.

Statistical techniques have been used extensively to aid in the prediction of thunderstorms and lightning (Shafer and Fuelberg, 2008). These techniques often rely on the connections between lightning occurrence and the parameters of the pre-storm environment (Rajeevan et al., 2012; McCaul et al., 2009). Many examples of such lightning prediction schemes exist (Livingston et al., 1996; Mazany et al., 2002; Benson, 2005; Lambert et al., 2005; Shafer and Fuelberg, 2006). Parameters are often derived from atmospheric soundings to predict lightning (Shafer and Fuelberg, 2008) however soundings in South Africa are typically only performed twice daily and at a limited amount of locations (de Coning et al., 2011). As a result, morning soundings are typically used to predict thunderstorms or lightning later in the day, which may result in inaccurate forecasts due to changes in atmospheric conditions later in the day or the site-specific sounding not being able to represent a large forecast domain (Shafer and Fuelberg, 2008). Due to the lack of soundings performed in South Africa, lightning cannot be forecasted using this approach.

With the advent of NWP models, many of the forecasting schemes started focusing on utilizing data from NWP models to predict thunderstorms. The latest NWP models provide accurate forecasts with a high spatial and temporal resolution (Shafer and Fuelberg, 2008), which results in the parameters related to lightning formation to be available over large domains for several hours ahead (McCaul et al., 2009). Parameters of the pre-storm environment usually derived from soundings can now be obtained from NWP models. The parameters can be obtained for the entire country and on an hourly basis for the next few days. Statistical prediction schemes that forecast the threat of lightning by relying on connections between lightning occurrence and para-