Lightning and Thunderstorm Early Warning System for Makkah Region

نظام إنذار من البرق والرعد بمنطقة مكة

إعداد:

أ.د. محمد حامد الشويهدي
قسم الهندسة الكهربائية
جامعة الملك فيصل

د. سليمان فورتيه
كلية الهندسة والعمارة
بجامعة الدمام

ملخص البحث

يهدف البحث بعرض سريع على البرق والرعد والسحب الكثيفة التي تسبب امطارا غزيرة وكذلك عرض موجز على الخرائط الايزوكرونيكية المستنبطة للسعودية. يبين الاخطار الناجمة عن البرق وما يسببه من خسائرمثل قطع الكهرباء نظرا للجهد العالي الذي يصاحب البرق والرعد وكذلك الحريق وخاصة بمواقع الخيام ومعسكرات الحجيج والتي تنتج من الصاعقة والتي تحمل شرارة ووميض كبير وعندما يلامس الارض يحدث لهيبا واصواتا عالية ويهدف فوق كل هذا الحرص على سلامة الحجيج وضمان استمرارية الكهرباء والتي هي الان العامل الرئيسي بكل ايام الحج والنقل والتدفئة والتبريد.

بعد دراسة الخرائط المستنبطة و معرفة اتجاهات واعداد مثل هذه السحب الكثيفة والتي تسبب الامطار والبرق والرعد عندها تقدم الورقة اقتراحا مطورا وباجهزة تكنولوجية حديثة للانذار المبكر وتحدد مواقعها لتشمل اكبر حماية ومساحة وارسال انذار مبكر لاقسام الدفاع المدني لياخذ الحيطة والاستعداد لتفادي اخطار الفياضا نات والحرائق ببعض المساحات الاهلة بالحجيج.

Abstract

Usually, Lightning is accompanied with thunderstorms; such cause rain and floods, also fires specially in dry climate. lighting is very spectacular and hazard phenomena, which need to be investigated before it happens. Recent global meteorological and climatologically changes have been taken throughout the world due to many phenomena as well human actions. These metrological changes have led to the development of many thunderstorms over Saudi Arabia in general and in specific to the areas that were known with low Isokeraunic level (number of thunderstorms days per year) such as the western portion of the Kingdom.

Worldwide, lightning thunderstorms accounts for most of the power supply interruptions in power lines. In the U.S.A. alone, an estimated 30% of all electric power outages related to lightning every year, with total costs approaching one billion dollars. This includes equipment damaged, loss of lives etc… during thunderstorms. In most area of the world, an indication of lightning activity may be obtained from Isokeraunic data Maps.

Thunderstorm days (TD) maps have been developed [1] in different areas of Saudi Arabia specifically those where lightning strikes are more likely to occur has been determined. The Presidency of Metrology and Environment (PME) base the results of what established in this paper on data and records available on lightning incidence in Saudi Arabia.

There have been many recent heavy thunderstorms development come about during the Hajj season, need to be carefully evaluated and assessed for many reasons, mainly for the safety of pilgrimages, avoiding fires, and floods. The Hajj season proscribed by the lunar system, which makes it happen in different climate season, which is based on Gregorian calendar.

PME, which has been established since 1951 do make records and data, bases of different climatology and metrology parameters for weather and environment in Saudi Arabia. Only weather information can be observed on-line at many locations of the Kingdom. The PME has no on-line thunderstorms and lighting detection or warning systems, by which it can predict the development and characteristics of lightning as well as send warning to surrounding inhabitable places about the approaching of severe lighting thunderstorms.

This paper presents Isokeraunic developed maps to indicate the thunderstorm days distribution all over the Kingdom, it also presents layout early warning for thunderstorms on-line detection network system that may assist pilgrimages during the Hajj and Umrah periods for more safety, electric outages and other safety warnings.

Definitions

Flashover (General). A disruptive discharge through air around or over the surface of solid or liquid insulation, between parts of different potential or polarity, produced by the application of voltage wherein the breakdown path becomes sufficiently ionized to maintain an electrical arc.

Isokeraunic (or Isoceraunic).The number of thunderstorms measured daily (Td/yr) i.e. Kampala, Uganda 185 Td/yr; Florida 110 Td/yr.

Lightning flash. The complete lightning discharge, most often composed of leaders from a cloud followed by one or more return strokes.

Lightning outage. A power outage following a lightning flashover that results in system fault current, thereby necessitating the operation of a switching device to clear the fault.

Ground flash density (Ng). The average annual ground flash density is the number of lightning flashes per square kilometer per year.

Abbreviations

GFD	ground flash density
GIS	geographical information system
HV	high voltage
IKL	isokeraunic level
NASA	National Aeronautics and Space Administration
NLDN	National Lightning Detection Network
OTD	optical transient detector
PME	Presidency of Meteorology and Environment
SEC	Saudi Electricity Company
TD	thunderstorm day

Introduction

The direct danger posed by lightning strikes warrants a better understanding of the phenomenon. Characterizing the spatial and temporal distributions of lightning is fundamental to understanding the phenomena and mitigating its negative impacts on human life. It is well known that lightning accounts for most power supply interruptions in power lines and is one of the leading causes of disturbance in transmission and distribution systems. In the US alone, an estimated 30% of all electric power outages are related to lightning every year, with total costs of loss approaching one billion dollars.

This includes damage, equipment loss and loss of life during thunderstorms. In most areas of the world, an indication of the lightning activity may be obtained from Isokeraunic data (thunderstorm days per year). Technological developments over the last 30 years have made remote sensing of cloud to- ground lightning a possibility (The IEEE Working Group 2001, De la Rosa *et al* 2000, Whitehead *et al* 1993, Anderson *et al* 1984). This relatively new data source has improved spatial and temporal studies of thunderstorm occurrence, increasing our ability to mitigate the risks posed by lightning and, moreover, assist meteorological centres and utilities to better improve prediction, designs, operation and safety -(De la Rosa *et al* 1998).

Mapping and contouring lightning flash densities (Ng) are improved when finer grids are implemented in many studies, and allow for realistic visualizations of local scale lightning distributions, important in risk assessments. Other regional lightning studies have made use of high spatial and temporal resolution analyses (De La Rosa *et al* 1994). In Burrows *et al* (2002), Petersen and Rutledge (1998) and Boccippio *et al* (1995), cloud-to-ground and intra-cloud lightning were studied over Southern Ontario and the adjacent Great Lakes as well as other places to investigate the development and evolution of thunderstorms. The temporal analysis of the lightning activity combined with flash density analysis lends insight into the dynamics of storm events in this region and supports the utility of lightning data in local thunderstorm research; others have also explored the influence of latitude and climatology on lightning distributions (Burrows *et al* 2002, Janischewskyj *et al* 1998).

The initial idea of this lightning research can be traced back to 1995 when the author was contacted by farmers, and an individual who reported the loss of human lives and also fire in palm trees in different areas of Qaseem, and Taif. In the Central Province city of Qaseem, it was reported that some livestock were struck dead by lightning. The author was also contacted by many engineers and other technical personnel who described the lightning damage to valuable distribution equipment in different industrial locations. The large amount of losses resulting, and reported, triggered a systematic investigation of the frequency, distribution and Iskeraunic level maps for lightning in Saudi Arabia. Although recently, more lightning data have become available from a variety of other sources, there is as yet an insufficiently long period of data on which to obtain reliable averages.

Also, the author assisted the Power Technology Inc. (PTI) team in their study of lightning-related problems in the southern area of Abha where a large number of distribution transformers were burned, largely due to the use of old Td/yr data taken from the world Meteorological Organization Isokeraunic map of thunder days (1956) as shown in figure 1 (IEEE Standard P1410 2001). This map shows that Saudi Arabia has approximately 5 to 12 thunder days per year, but this is not accurate at all, as compared to the latest results of mapping thunderstorm days in Saudi Arabia.

Figure 1. World Isokeraunic map (WMO 1956).

For this reason, the lightning activity continues for the present to be represented by thunderstorm frequency, which is routinely recorded at meteorological observation sites (WMO 1956). Thunderstorm occurrence at a particular location is usually expressed as the number of days in a calendar year when thunder was heard, averaged over several years.

Thunderstorms are spectacular but hazardous weather phenomena which, together with developments of high gusty winds and notable decreases of temperature, top the list of concerns in the Presidency of Meteorology and Environment (PME) and Saudi Electric Company (SEC). PME has no documented records of actual lightning losses. To date, the PME does not use real time detection and monitoring networks, and still uses human observers at its 28 locations scattered all over the country (http://www.pme.gov.sa/). The

PME is working to acquire a more advanced online prediction and alarm network for the country. This was triggered by the latest serious thunderstorm, where high winds and heavy rainfalls in Makkah (December 2004 and thereafter) caused the deaths of some pilgrims and stranded students in schools etc... At present, PME provide monthly and annual data for each year from 28 locations. Some stations have reported over longer or shorter periods ranging between 19 and 24 years (http://www.pme.gov.sa/).

Lightning is a fascinating phenomenon. For a small number of scientists around the world, it has been a prime focus of study for many years. As a result, the meteorological community is benefiting from a variety of innovations in lightning detection. All these technologies, which come from various sources, are helping to improve daily observations of lightning events and improve safety warnings for people and assets. An ideal situation would be when the world has no casualties due to lightning. But at present it is estimated that globally there are 24,000 fatalities and 240,000 injuries each year due to lightning, although these statistics are very difficult to verify (Holle, 2010). In addition, many billions of dollars in damages and avoidance costs are incurred internationally every year.

Each year new research further evolve detection technology ,and new competition helps to push the members of the lightning detection community to keep challenging each other. All companies is no exception to this research initiative; they have been developing lightning detection equipment for years, and have produced many generations of lightning detection equipment. Some company's lightning detection sensors are currently operating in more than 60 countries; they have helped to save lives and also improve operational efficiency at weather-critical operationally based facilities such as airports, power utilities, mining operations, offshore platforms, and wind energy parks, as well as many other different applications. Lightning detection technology started with various methodologies. It began by using the very low-and low Lightning detection technology started with various methodologies. Figure 2 illustrates one of such developed sensors.

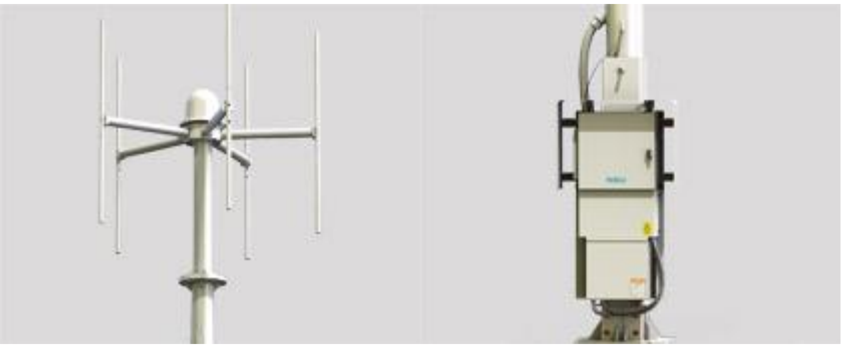


Figure 2 Some sensors for lightning detection

Geographical and meteorological peculiarities of Saudi Arabia

Saudi Arabia is the largest country of the Arabian Peninsula. It lies between 18◦ and 35◦ N and 36◦ to 48◦ E. Geographically, the location of the Kingdom categorizes it as a tropical to subtropical desert. All the major sand deserts of the world fully or partly lie in the Kingdom and 40% of its area is covered with eolian sand. The climate is influenced by its tropical desert features (hot, dry hot air masses dominate throughout the year mild winters and very hot summers, and little precipitation (generally <10–20 in.)) and by its location. The Kingdom's aridity index (2.6) indicates true desert conditions. Because of the general aridity, Saudi Arabia has no permanent rivers or lakes. The Kingdom's terrain is mostly uninhabited sandy desert with elevation extremes: the *lowest point* is the Arabian Gulf, 0 m, whilst the *highest point* is Jabal Sawda' (south),
3133 m (http://www.pme.gov.sa/).

Wind development

Located along the coastal region of the Arabian Gulf, Saudi Arabia is under the influence of tropical pressure in winter and Asian low pressure in summer. The average direction of the surface wind is closely related to the pressure distribution. Wind tends to flow from the high-pressure towards the low pressure region. This pressure difference is created in different ways. For instance, during the summer, warm surface air rises and creates a low-pressure area along the Arabian Gulf coastal region. The wind blows from the Mediterranean Sea, which is a high-pressure area. The barren land surface of the Jafura sand sea area has a much smaller specific heat, and becomes warmer, creating a low-pressure area. During the spring period, the temperature increases and the pressure distribution changes (Fryberger and Dean 1979). A low-pressure region develops over the Arabian Gulf; strong wind blows from the Rub'alkhali ('empty quarter') towards the southwest of Saudi Arabia.

This northerly strong wind, locally termed a shamal, often blows continuously for two to three days several times in a month during this period. This strong wind has great potential to blow sand. The autumn months of October and November are again a transitional period during in which the temperature begins to drop and the relative humidity begins to rise. During this period most of the Arabian Gulf coastal region remains hot. However, the Asian low-pressure area weakens and by November the hot wind is replaced by cool and dry wind. In the winter months of December, January and February, the wind behavior in most parts of the kingdom is dominated by the high pressure. When this wind passes through the Arabian Gulf the relative humidity rises and causes rainfall in and around the coastal region of the Arabian Gulf (Saudi Arabia Atlas 1989, Fryberger and Dean 1979).

Temperature and rainfall

Along the coastal regions of the Red Sea and the Arabian Gulf, the desert temperature is moderated by the proximity of these large bodies of water. Temperatures seldom rise above 38 ◦C, but the relative humidity is usually greater than 85% and frequently 100% for extended periods. This combination produces a hot mist during the day and a warm fog at night. Prevailing winds are from the north and, when they blow, coastal areas become bearable in the summer and even pleasant in the winter. A southerly wind is accompanied invariably by an increase in temperature and humidity and by a particular kind of storm known in the Gulf area as a jauf. In late spring and early summer, a strong north-westerly wind, the shamal, blows; it is particularly severe in eastern Arabia and continues for almost three months. The shamal produces sandstorms and dust storms that can decrease visibility to a few meters (Saudi Arabia Atlas 1989).

A uniform climate prevails in Najd, the Al Qaseem Province, and the great deserts. The average summer temperature is 45 ◦C, but readings of up to 54 ◦C are common. The heat becomes intense shortly after sunrise and lasts until sunset, followed by comparatively cool nights. In the winter, the temperature seldom drops below0 ◦C, but the low humidity and the high wind-chill factor make a bitterly cold atmosphere. In the spring and autumn, temperatures average 29 ◦C.

The region of Asir is subject to Indian Ocean monsoons, usually occurring between October and March. An average of 300 mm of rainfall occurs during this period—60% of the annual total. Additionally, in Asir and in the southern Hijaz, condensation caused by the lifting of air in higher mountain slopes contributes to the total rainfall. For the rest of the country, the rainfall is low and erratic. The entire year's rainfall may consist of one or two torrential outbursts that flood the Wadis (valleys) and then rapidly disappear into the soil to be trapped above layers of impervious rock. This is sufficient, however, to sustain forage growth. Although the average rainfall is 100 mm per year, the whole region may not experience rainfall for several years. Some droughts occur, as they have done in the north of the country.

The eastern region, being host to the largest sand desert the Rub' al-khali, cities such as Jafurah and Dahna are representative of the world's arid region. There are essentially two prime factors responsible for the development of climatic aridity: the relief and distribution of the land and sea, and the nature of the general atmospheric circulation and associated ocean current. In some parts of Rub' alkhali, no rain has been experienced for the last ten years.

The rainy season extends from November to April with the heaviest rainfall occurring during January and March. During the summer, the area remains dry and hardly any rain is recorded.

Mapping and analysis

The spatial analyses were performed using ESRI ArcView 3.2 GIS software. Data were aggregated by displaying long-term lightning data in units of thunderstorms per square kilometer based on grids superimposed on the study area. Thunder day (Td/yr) maps were created to show the daily frequency of

lightning events across the study area for each year of the study. The thunder day is similar to the traditional meaning given by National Weather Service 'thunderstorm day', defined as the number of days that thunder is heard at a weather observing station. The thunderstorm day is logged by observers and is prone to human error (Janischewskyj *et al*

1998, De La Rosa, *et al* 1994). Total thunder day maps were created for the entire country for the average of all years. Lightning data for this study were collected from three sources, mainly to validate the raw data collected by PME observers rather than detection systems. The source data are from PME and NASA. The latter source is used for the validation of PME data and for the development of a map of thunderstorm climatology. Figure 3 shows the newly developed thunderstorms day per year for Saudi Arabia.

The method for getting any contour is to enter the coordinate of any city and determine the number of months in the desired period. In Saudi Arabia, the seasons are defined as follows:

1. Winter months (December, January, February).
2. Spring months (March, April, May).
3. Summer months (June, July, August).
4. Autumn months (September, October, November).

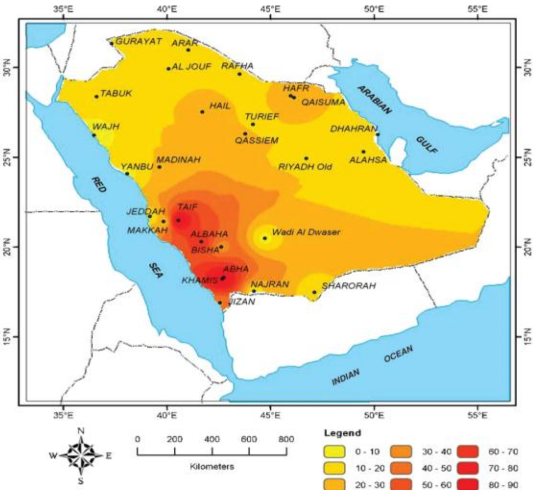


Figure 3. The annual average thunderstorm distribution in color contours in thunderstorm days per year.

The analysis was done to produce a gridded This information is developed in a formal map using GIS, showing the total number of thunderstorm days expected annually, averaged over a number of years for the spring season (March, April and May), during which the highest thunderstorm frequency occurs (figure 4). In contrast, there are fewest thunderstorm days in the winter season (December January and February), as shown in figure 5.

It is obvious that, the highest concentration of thunderstorm days (Td/yr) during the whole year is found in the southern and mountainous regions such as Taif, Abha and Al-Baha. In contrast, the concentration of Td/yr is very low on the coastline of the Red Sea e.g. at Jeddah.

Moreover, the seasonal average within this study period was established in separate maps, called IKL charts, also by using Arc View GIS. The charts do not give information on the severity of lightning, that is, the density of lightning strikes, but supply valuable data on the relative probability, frequency and distribution of lightning in different regions of Saudi Arabia.

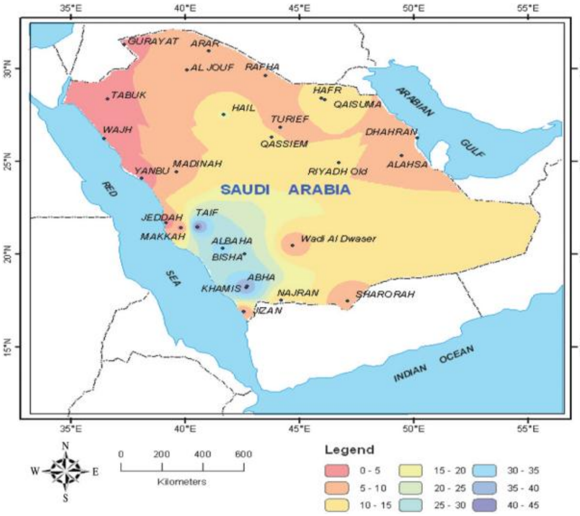


Figure 4. The annual average Td⁄yr level for the spring season (March, April and May).

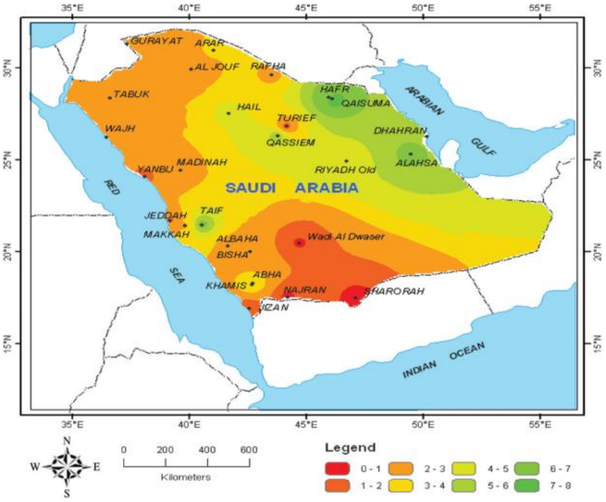


Figure 5. The annual average Td/yr level for the winter season (December, January and February).

Nature and distribution of thunderstorms and Rain

In general, convection refers to the transport of some property by fluid movement, most often with reference to heat transport. As such, it is one of the three main processes by which heat is transported: radiation, conduction and convection.

Meteorologists typically use the term convection to refer to heat transport by the *vertical* component of the flow associated with buoyancy. Transport of heat (or any other property) by the non-buoyant part of the atmospheric flow is usually called *advection* by meteorologists; advection can be either horizontal or vertical. Convection takes many forms in the atmosphere. Severe convection is the variety of hazardous events produced by deep, moist convection. Severe weather events (large hail, damaging wind gusts, tornadoes and heavy rainfall) are generally the result of the energy released by phase changes of water (Williams 1991).

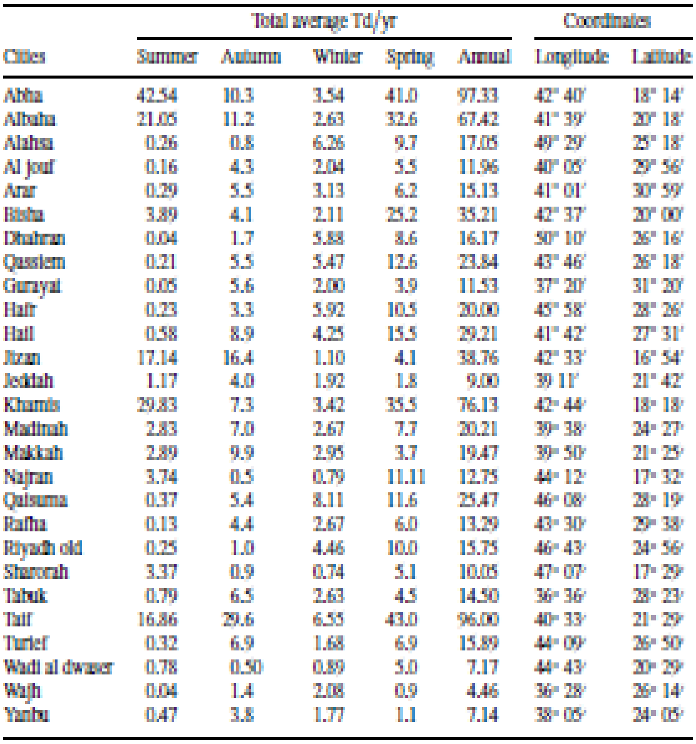
The weather of Saudi Arabia is characterized in the summer by cloudless skies and clear visibility and no thunderstorms except in the southwest region. With the exception of the province of Asir with its towns of Jizan on the western coast and Najran, Saudi Arabia has a desert climate characterized by extreme heat during the day, an abrupt drop in temperature at night and slight, erratic rainfall. Because of the influence of a subtropical high-pressure system and the many fluctuations in elevation, there is considerable variation in temperature and humidity. The two main extremes in climate are felt between the coastal lands and the interior.

The location of Saudi Arabia is in the tropical overheated region with low clouds in the summer which do not cause thunderstorms foremost of the seasons all over the country. The clouds usually accumulate on the land in the winter and spring seasons. The exception to this rule occurs in the southwest region because of the southwest wind from the cool Indian monsoon carrying the clouds. The average annual number of thunderstorm days does not exceed 30 over the majority of the land area of Saudi Arabia, except in the southwest region where on some mountains it reaches 97 thunderstorms in a year; about nine thunderstorms are more common on the coast of the Red Sea. In the winter, the average thunderstorm day count on the coast of the Arabian Gulf is approximately five while only two are observed on the coast of the Red Sea.

Thunder and lightning observations are more prevalent during the winter season in Riyadh and vicinity, Dhahran and vicinity, Abha, Taif, Al-Baha and surroundings. In general, from January to May thunderstorms are quite numerous all over southern, northern, central and eastern regions in Saudi Arabia. They occur usually in the afternoons and early evenings. The axis of maximum thunderstorm occurrences is located in a north–central–south direction from Al-Jouf to Riyadh, to Taif to Abha in south in April. In May, the number of days with thunderstorms is maximum for almost all stations, that is, 43, 41, 35, etc... as shown in table 1 under the column for spring.

Table 1 shows the annual average frequency of thunder days over Saudi Arabia for the period all the years. Clearly, thunderstorms are most frequent over the southwest portion of the country, and generally decrease westward, with lowest frequencies at the coast of the Red Sea. A secondary maximum is also apparent in the central west extending into the northeastern cities of Qaseem and Haill, as well as Hafr in the east.

Table 1. The annual average thunder days (Td/yr) and seasonal average determined for all years.



	Total average Td/yr					Coordinates	
Cities	Summer	Autumn	Winter	Spring	Annual	Longitude	Latitude
Abha	42.54	10.3	3.54	41.0	97.33	42° 40'	18° 14'
Albaha	21.05	11.2	2.63	32.6	67.42	41° 39'	20° 18'
Alahsa	0.26	0.8	6.26	9.7	17.05	49° 29'	25° 18'
Al jouf	0.16	4.3	2.04	5.5	11.96	40° 05'	29° 56'
Arar	0.29	5.5	3.13	6.2	15.13	41° 01'	30° 59'
Bisha	3.89	4.1	2.11	25.2	35.21	42° 37'	20° 00'
Dhahran	0.04	1.7	5.88	8.6	16.17	50° 10'	26° 16'
Qassiem	0.21	5.5	5.47	12.6	23.84	43° 46'	26° 18'
Gurayat	0.05	5.6	2.00	3.9	11.53	37° 20'	31° 20'
Hafr	0.23	3.3	5.92	10.5	20.00	45° 58'	28° 26'
Hail	0.58	8.9	4.25	15.5	29.21	41° 42'	27° 31'
Jizan	17.14	16.4	1.10	4.1	38.76	42° 33'	16° 54'
Jeddah	1.17	4.0	1.92	1.8	9.00	39 11'	21° 42'
Khamis	29.83	7.3	3.42	35.5	76.13	42° 44'	18° 18'
Madinah	2.83	7.0	2.67	7.7	20.21	39° 38'	24° 27'
Makkah	2.89	9.9	2.95	3.7	19.47	39° 50'	21° 25'
Najran	3.74	0.5	0.79	11.11	12.75	44° 12'	17° 32'
Qaisuma	0.37	5.4	8.11	11.6	25.47	46° 08'	28° 19'
Rafha	0.13	4.4	2.67	6.0	13.29	43° 30'	29° 38'
Riyadh old	0.25	1.0	4.46	10.0	15.75	46° 43'	24° 56'
Sharorah	3.37	0.9	0.74	5.1	10.05	47° 07'	17° 29'
Tabuk	0.79	6.5	2.63	4.5	14.50	36° 36'	28° 23'
Taif	16.86	29.6	6.55	43.0	96.00	40° 33'	21° 29'
Turief	0.32	6.9	1.68	6.9	15.89	44° 09'	26° 50'
Wadi al dwaser	0.78	0.50	0.89	5.0	7.17	44° 43'	20° 29'
Wajh	0.04	1.4	2.08	0.9	4.46	36° 28'	26° 14'
Yanbu	0.47	3.8	1.77	1.1	7.14	38° 05'	24° 05'

The peak frequency is in the vicinity of Abha, with over 80 thunder days a year. In the remainder of the year dry, stable outflow from the subtropical high-pressure belt, which normally lies over the country, inhibits convective showers and storms. Frequencies generally decrease in the southeast parts of the tropics and the adjacent desert areas of central and east Saudi Arabia. This is because the air, though often very hot, is generally drier. The exception appears to be over central, eastern and northern Saudi Arabia where a wide area experiences over 20 thunder days a year. However, many of these would be the so-called 'dry' thunderstorms, with little or no rain, because the low-level relative humidity tends to be low and acts to evaporate any falling precipitation.

History of disasters in Saudi Arabia

A hazard can be thought of as a potential risk endangering human life or health, property or the environment. However, if this risk does lead to an incident, it is referred to as an emergency situation or, if the damage is overwhelming, a disaster. Such events are often the result of human factors, environmental hazards or natural causes. Although considerable overlap occurs between these factors, there is usually one factor that contributes significantly more than the others. This section will review hazards in Saudi Arabia classified according to the main contributory factor.

Natural disasters

Saudi Arabia has recently become known for media-attracting incidents such as terrorist attacks and major MVCs. However, less attention has been given to natural disasters, even though their incidence has been on the rise. Floods are the most frequently encountered natural disaster in Saudi Arabia. They have been the cause of 7 of the 10 most damaging natural disasters in the history of the country between 1900 and 2010 (refer to Table 2). The reason behind floods being a major threat in Saudi Arabia is multi-faceted. Rains have been relatively scarce in the area, and this has lead to the under-development of a proper drainage system in the country. Compounding this problem is the geography of some of the most populated cities in Saudi Arabia. Cities, such as Jiddah and Makkah, are on low ground and are surrounded by mountains. When rains fall on these mountains, water runs in valleys towards these cities. With poor drainage systems, this continuous flow of water could easily lead to a flash flood.

Table 2 Top 10 natural disasters in Saudi Arabia for the period 1964 to 2010, sorted by the number of people killed (source: International Disaster Database)

No. Killed	Date	Disaster
163	24/11/2009	Flood
76	11/09/2000	Epidemic
57	03/2000	Epidemic
35	9/02/2001	Epidemic
34	28/04/2005	Flood
32	24/12/1985	Flood
29	22/01/2005	Flood
20	4/04/1964	Flood
19	8/04/2002	Flood
12	11/11/2003	Flood

Hazards and Disasters in Saudi Arabia

Almost all major disasters in Saudi Arabia can be attributed to one or more of the hazards and vulnerabilities mentioned in the previous sections. Unfortunately, there is no official publicly-available database that keeps a record of disasters in the country. Most official information available comes from newspapers local to the region where the disaster occurred. The International Disaster Database (IDD) of the WHO provides the best record of disasters in Saudi Arabia (International Disaster Database, 2010). For this section, data recorded in the IDD have been compared to information published in the relevant medical literature as well as in local newspapers around the time of any given disaster to check for accuracy (2000, Aguilera et al., 2002, Almulla, 2008, Lerner et al., 2007, Thompson et al., 2004). Table 2 shows the major recent disasters in Saudi Arabia.

Management of religious mass gatherings (i.e. Ramadan and Hajj) has substantially improved compared to the situation as little as 10 years ago. Recent developments, such as Makkah metro and the flying ambulance, are projected to help and ease the trip of Hajj to the millions of pilgrims every year. On the other hand, significant improvements still need to take place before such facilities can be safely used on such a large scale. For example, helicopter bases, where patients can be received and flown, have not been established yet. This can prove difficult, especially with the already limited space available around the crowded sacred sites. Some critics have argued that the establishment of a metro that runs for only five days per year is a waste of money and resources. They have suggested that the project should be expanded to serve during other busier times, such as Ramadan, and serve potentially larger areas, such as between Makkah and Medina.

But still the threats of heavy rain and floods as well as thunderstorms and lightning that will lose electricity still exists.

The following is a description of the most significant disasters in the history of Saudi Arabia:

1964 rains: this is the earliest recorded account of a natural disaster in Saudi Arabia. Heavy rains poured continuously on parts of the country leading to a flood that killed 20 people and left about 1,000 people either injured or homeless. No further details are recorded.

Fire incident in Hajj season 1975: during Hajj season in 1975, a fire broke out in one of the pilgrim’s tents near Makkah and quickly spread to other tents. The fire was caused by an explosion of a gas cylinder, and led to the death of 200 pilgrims.

Ras al-Khafji thunderstorm: in October 1982, a severe thunderstorm hit Ras al-Khafji city on the east coast of Saudi Arabia. Hail stones were reported to be as big as tennis balls. This was followed by four hours of heavy rains. The net damage included 11 fatalities.

1985 flood: on 24 December 1985, heavy rains poured on north-western regions of Saudi Arabia, leading to what has been described as the worst flood in the area in 50 years. Estimates of damage were not recorded, except that there were at least 32 people killed from the flood.

Stampede in Hajj season 1990: as pilgrims were moving between the sacred sites on the second day of Hajj season in 1990, a massive stampede occurred in a tunnel south of Makkah. The stampede occurred after what is thought to be a failure in the ventilation system inside the tunnel. This led to the suffocation and death of 1,426 pilgrims, most of whom were from south-east Asia.

Stampede in Hajj season 1994: During one of the rituals of Hajj, a stampede occurred as pilgrims leaving the site crossed roads with those coming in. This led to a massive disorder culminating in the death of 270 pilgrims, most of whom were trampled

Yanbu flood: heavy rains poured on western Saudi Arabia in January 1997, mainly affecting Yanbu and peripheries of Jiddah. The rain lasted for 24 hours, killing 10 people and causing damage to an area of over 130,000 km2 of land.

Asir flood: Asir is a province in the Southwest of Saudi Arabia. On Monday 25 March 1997, heavy rains poured on the region, leading to floods that resulted in 16 fatalities and damaged an area of just below 100,000 km2 of land.

Fire incident in Hajj season 1997: in April 1997, a gas stove exploded in one of the pilgrim's tents, leading to a massive fire that quickly spread to other nearby tents. It claimed the lives of 343 pilgrims, and more than 1,500 were wounded. This stimulated authorities to design the currently used fire-proof tents, as well as banning gas-operated material.

Makkah 2002 flood: heavy rains started falling on Makkah area on 8 April 2002 and lasted for a whole week. This led to flooding of water in some areas, claiming the lives of 19 people; hundreds of Makkah residents were rescued by the GDCD that week.

Makkah 2003 flood: not quite recovered from previous year's rain, Makkah experienced yet another heavy shower described as the worst rains in Makkah in 25 years. Water levels were reported to have reached 6 meters. Twelve people were killed; however, estimates of physical damage are not available.

Jizan 2004 floods: less than four months apart, two floods hit the Jizan region, leading to what has been described as Jizan's worst floods in 45 years. The floods left over 400 people homeless, killed 13 people and devastated many roads and farms.

Medina 2005 flood: very heavy showers fell on Medina region in January 2005. This resulted in a flood that caused the Yatamah dam to fail, killing 29 people. Seventeen people were injured, 50 were left homeless and 43 had to be evacuated.

Riyadh 2005 flood: heavy rains poured on the Riyadh region of Saudi Arabia, as well as on other areas in neighboring countries (i.e. Oman and the United Arab Emirates). The resultant flood claimed the lives of seven people; 700 people had to be evacuated via GDCD helicopters and another 700 were left homeless.

Hostel collapse in Makkah: in Hajj season 2006, a hostel near the Holy Mosque collapsed after a fire had spread in lower floors of the building. Most pilgrims were out in the Mosque as it was time for the noon prayer. The collapse killed 76 people, most of whom were people passing by the building, and another 64 were injured.

Jiddah 2009 flood: at around 6:30 a.m. on Wednesday 25 November 2009, rain started falling heavily in Jiddah, and continued for around 12 hours. The amount of water in this relatively brief downpour (around 90 mm3) doubled the average annual rainfall in Jiddah. With a sound infrastructure and a proper drainage system lacking, this rain turned into the worst disaster that Jiddah has experienced in 27 years or so. The downpour resulted in the formation of water tides coming from the hills on the east of the city, heading west towards the Red Sea and cutting their way through the city.

Several residential houses collapsed, forcing many inhabitants to upper floors and roofs. Labs and databases at King Abdulaziz University and King Abdulaziz Hospital were destroyed, wasting valuable resources, specimens and medical records.

Major roads of the city were blocked by meters-high of water waves or by cars that have been washed out. As a result, thousands of pilgrims had to wait in buses for hours before getting to Makkah for the first day of Hajj. Furthermore, King Abdullah Bridge on the South of Jiddah had partially collapsed, adding to the chaos and fright to the situation. Power and telecommunication services were not spared either. As early as 11 a.m., floods had already resulted in a temporary power outage on the whole western region of Saudi Arabia (i.e. Makkah, Medina and Jiddah). Many people were not even able to call for help as communication with emergency services (e.g. civil defense forces, police or emergency medical services) failed due to the overwhelmed network and power outage.

Overall, 161 people lost their lives as a result of the floods, either drowning or from car crashes. This disaster had an estimated cost of around US$900 million to reconstruct Jiddah and help its victims.

Riyadh 2010 flood: on 3 May 2010, Riyadh city experienced a brief 45-minute water shower, accompanied by light hail and winds gusting up to 24 km/hour. As brief as the downpour was, however, it resulted in floods and car crashes across the city.

Local newspapers reported that at least two people were killed, and that the floods caused around 275 car crashes. Even though King Khalid International Airport was not affected, many people missed their scheduled flights due to poor road conditions. A survey committee, appointed by the Governor of Riyadh, has started assessing the extent of and the reasons behind the damage that resulted from the rain.

As far as managing natural disasters is concerned (especially floods), there has been frustratingly very little done. This might be because natural disasters are still viewed as rare and “low-impact” types of emergency. Also, trying to establish drainage systems in an already heavily-populated city, such as Jiddah, has proven difficult. Many roads will have to be closed down for extended periods; there is also little coordination between different parties providing infrastructural services, such as power cables, telephone cables and draining pipes. All of these factors have contributed to the delay in finding a solution to such a significant threat. However, Jiddah 2009 floods have shocked policy-makers and encouraged them to initiate new developmental projects and to hasten already existing ones. All of this is in the hopes of finding a practical solution to prevent similar tragedies in the future.

Proposed Detection and warning for Makkah Region

Lightning data services

The main lightning data services that can be used as part of a risk prevention approach are:

Lightning statistics

Statistics can be computed on many different lightning parameters once a large enough database of information is available. Typically the lightning density (number of flash per km² per year) and the flash current distribution are computed for a given area and time period. This information allows characterizing lightning occurrence in one region and comparing various regions or time periods. Lightning statistics are generally used as an input to the risk assessment procedure. Figures such as the lightning density or Isokeraunic level are taken in account in various models. This information is widely available and essentially stable over time.

Early threat warning

Advance warning of approaching storms can be given by local detectors such as field mills or electromagnetic sensors, or elaborated and transmitted by a Lightning Location Surveillance System (LLSS) monitoring a given area. The warning information can be send to an operator that is allowed to apply ad-hoc procedures in order to take the protective actions and modify the operations in progress.

Those procedures can cover the handling of dangerous products, isolation from the power lines, crew or personnel displacements. In some cases, the warning information can be automatically processed in order to modify a system configuration (start power generators and isolate from external utilities, …) The early threat warning information is a part of the lightning prevention domain, allowing to reduce the consequences of an existing storm.

Real time visualization

The real time data provided by an Laser lightning sensors system (LLSS) can be analyzed by an operator time in order to track the evolution of storms and adjust the operations of a plant or network. The information provided by the LLSS is more complex than the simple warning message described earlier, it is necessary to have some meteorological background in order to interpret a given situation and decide the relevant actions. A qualified operator is required.

This kind of organization, again part of a lightning prevention organization, is used when a large area is to be monitored and when important resources are at stake. Typically, such an organization is available in power line or telecom networks.

The Lightning Alarm Service

in lightning-prone regions of the world, airlines, airport authorities ، and owners of small airports need to ensure the safety of their ground crew employees while maximizing their operational efficiency. Thunderstorms produce dangerous cloud-to-ground (CG (lightning that can kill or injure a person through one direct or indirect strike, with baggage and cargo handlers, refueling personnel, and catering service personnel most at risk. When lightning threatens ، high-risk activities like baggage handling and refueling have to be suspended until the threat has passed. Being able to accurately detect thunderstorms and issue timely lightning warnings helps to improve airport safety and increase the time that airports can be fully operational.

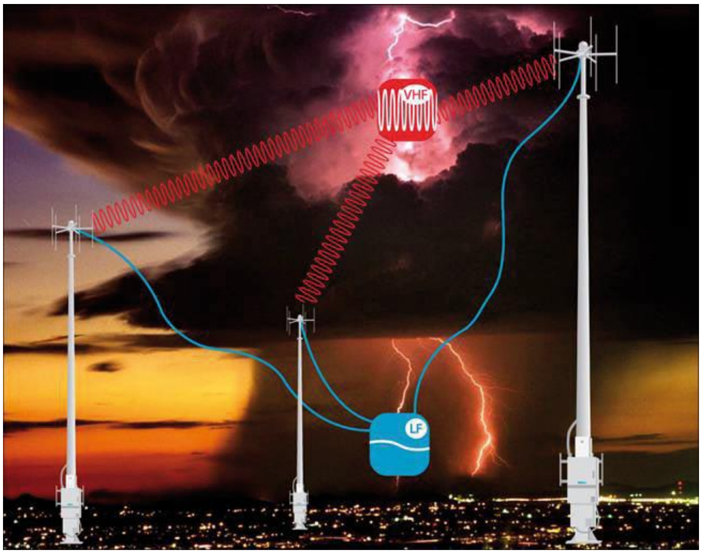
According to lightning safety expert Ron Holle, approximately 24,000 lightning casualties occur worldwide each year. Although accurate airport-related statistics are virtually non-existent, there have been at least 92 reported injuries and one death between 1991 and 2011. To address these safety concerns, Specialty companies created a range of airport and large areas lightning warning systems (LWS), which combine lightning data with decision support software that alerts staff when dangerous CG lightning is imminent.

The sensors detect lightning up to٩,٠٠٠ km from their location due to their sensitivity and breakthroughs in sensor software algorithms developed by Stanford University. Each sensor provides both direction and time-of-arrival information. Scientific studies have shown that lightning networks using a combination Reduced monitoring area. This reduced monitoring area provides improved operational efficiency through lower false alarm rates.

Figure 6 illustrates such monitoring system. These significant advances in lightning detection will help Makkah region and vicinities to provide more accurate warnings and improve their situational awareness. Most important of all, improved ground crew safety and Hajj and Umrah operational efficiency is now possible worldwide.

Operator of the French Lightning Detection Network has designed an Alarm service, a typical early threat warning service, that allows to monitor it's customer's area and send a warning message when lightning approaches it.

The area can be as simple as a circle or be defined with a more complex shape in order for example to take into account the power lines feeding the site or the known displacement of the storms in the customer's region. The warning messages are sent by automated process, by phone, fax or email. Customer specific agendas and scenario are defined and the messages convey dedicated operational instructions. This warning message is the only information users will receive as part of the service; no flash information or real time display is available to them.



VHF signals are best for detecting IC lightning and VLF/LF signals are best for detecting CG lightning . Combinations of these two technologies have proved to yield greater than 90% detection of total
lightning with channel mapping

Figure 7 illustrates locations of such monitoring system around Makkah area, such locations were selected to monitor the most frequent thunderstorms blows.

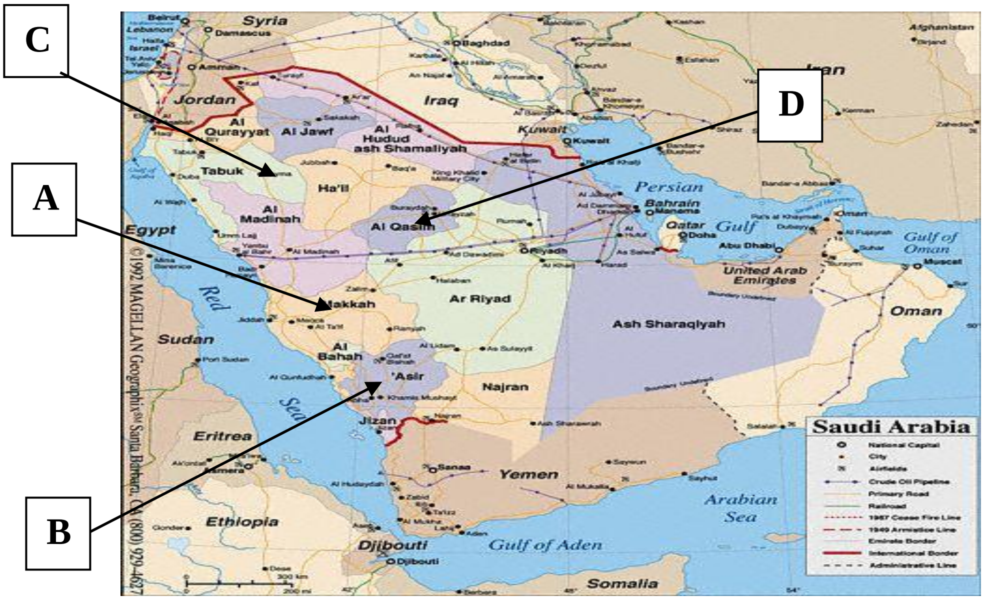


Figure 7 Proposed Lightning detector locations For Makkah Region

Total Lightning Sensor LLSS combines VHF interferometry with LF magnetic direction finding and time-of-arrival technologies for the highest level of total lightning mapping detection capabilities with calibrated lightning parameters. Total lightning mapping provides the information to improve warnings and situational awareness. This can yield improved operational efficiency with less downtime and fewer false alarms all without jeopardizing safety.

Summary and concluding remarks

New maps is to provide and establish lightning and thunderstorm records, and to map observations from the PME of Saudi Arabia for the purpose of research, and for PME and SEC operational applications. Data from 28 observation sites were collected and analyzed and these observations have been validated. The distribution of deep moisture, and in particular, latent heating in deep convection, is critical for accurate forecasts of cyclogenesis.

measured by an online detection network such as NLDN and convective rainfall obtained from PME records and sensors for a variety of storm systems. The relationships between lightning, thunderstorms and rainfall may vary significantly, depending on air-mass characteristics and cloud microphysics (Dai 2000). Our findings and results indicate that the new annual and seasonal thunderstorm data are of interest to both the PME and SEC. Using the established Td/yr database, Civil forces, public, engineers etc… line engineers can develop safety measures and have time to protect selves etc…, which are an essential consideration in the safety and avoiding disataters..

- The highest concentration of thunderstorm days during the whole year is found in the southern and mountainous regions of Taif and Abha, while the lowest is along the coast of the Red Sea as in Jeddah.

Such have a main contribution to the Thunderstorms that blow on Makkah and vicinity.

- The average annual thunderstorm day counts do not exceed 30 thunderstorm days over most land areas of

Saudi Arabia except in the southwest region where values reach, on some mountains, up to 97 thunderstorm days per year. In contrast, very low values, around 9 thunderstorm days, are observed on the Red Sea coast.

- The areas of maximum measured flash density were Abha, Taif, Khamis and Al-Baha based on PME lightning records which are validated observations. In Abha, the maximum flash density exceeds 12 flashes per square kilometer per year. Such it has an influence on number of thunderstorms going to Taif and vicinity.
- The annual mean percentages of thunderstorm days per year, as well as the seasons for the all stations of lightning records were represented in table 1.
- It is recommended that the PME acquires and operates a flexible and reliable lightning detection and location system in order to take warning and protective measures against lightning damage. Automatic detection stations are recommended to be installed at most of the PME locations, more specifically in Taif, Tabouk and Central, Qassim to EW for sharing his knowledge of semiannual effects and more, as illustrated in Figures 6 and 7. Such systems will save human being lives and stocks as well as assets.

References

Anderson R B, Eriksson A J, Kroninger H, Meal D V and Smith M A 1984 Lightning and thunderstorm parameters *IEEE Int. Conf. Lightning and Power Systems (London)*

Boccippio D J, Cummins K L, Christian H J and Goodman S J 2001 Combined satellite- and surface-based estimation of the intracloud–cloud-to-ground lightening ratio over the continental United States *Mon. Weather Rev.* 129 108–22

Boccippio D J, Williams E, Heckman S J, Lyons W A, Baker I and Boldi R 1995 Sprites, ELF transients and positive ground strokes *Science* 269 1088–91

Burrows W R, King P, Lewis P J, Kochtubajda B, Snyder B and Turcotte V 2002 Lightning occurrence patterns over Canada and the adjacent United States from lightning detection network observations *Atmosphere-Ocean* 40 59–81

Christian H J, Blakeslee R J, Boccippio D, Boeck W L, Buechler D E, Driscoll K T, Goodman S J, Hall J, Mach D A and Stewart M F 2003 Global frequency and distribution of lightning as observed from space by the optical transient detector *J. Geophys. Res.* 108 4005–19

Dai A 2000 Global precipitation and thunderstorm frequencies: part II. Diurnal variations *J. Clim.* 14 1112–28

De La Rosa F, Chisholm W, Galv´an A, Heidler F and Rakov V 1994 Lightning characteristics relevant for electrical engineering: assessment of sensing, recording and mapping requirements in the light of present technological advancements *CIGRE Task Force* 33.01.02 Brochure 94

Doswell C A III 2001 Severe convective storms—an overview *Severe Convective Storms (AMS Meteorological Monograph* vol 28 no 50*)* ed C A Doswell III (Boston, MA: American Meteorological Society)

Fryberger S G and Dean G 1979 Dune forms and wind regime *A Study of Global Sand Seas, US Geological Survey Professional Paper* 1052 pp 137–69

Goodman S J, Christian H J, Boccippio D, Koshak W J and Cecil D 2002 The NASA thunderstorm observations and research (Thor) mission: lightning mapping from space to improve the short-term forecasting of severe storms *Proc. NWA Annual Meeting (Fort Worth, TX, 21–25 Oct. 2002)*

IEEE Working Group 2001 *Guide for Improving Lightning Performance of Electric Power Overhead Distribution Lines* Approved as IEEE Standard P1410

Janischewskyj W, Beattie J and Chisholm W A 1998 Lightning ground flash density measurements in Canada: 1990–1996 *Final Report for Canadian Electrical Association Contract* 179T382A

Manohar G K, Kandalganonkar S S and Tinmaker M I R 1999 Thunderstorm activity over India and the Indian southwest monsoon *J. Geophys. Res.* 104 4169–88

Pessi A and Businger S 2004 On the relationship between lightning and convective rainfall over the central Pacific Ocean *ILDC 2004 18th International Lightning Detection Conference (Helsinki, 7–9 June 2004)* www.vaisala.com/ILDC2004 REF. NO. 21

Petersen W A and Rutledge S A 1998 On the relationship between cloud-to-ground lightning and convective rainfall *J. Geophys.Res.* 103 14025–40

Center for Disease Control. (2000) From the Centers for Disease Control. Update: outbreak of Rift Valley fever--Saudi Arabia, August-November 2000. *JAMA*, 284, 2989-90.

Adasah, J. & Hamed, M. (2010) Installation of train carriages on metro tracks. *Al-Riyadh Newspaper.*

Aguilera, J. F., Perrocheau, A., Meffre, C., Hahne, S. & Group, W. W. (2002) Outbreak of serogroup W135 meningococcal disease after the Hajj pilgrimage, Europe, 2000. *Emerg Infect Dis,* 8, 761-7.

Al-suwian, A. (2001) Potential petrochemical hazards in Saudi Arabia. *General Directorate of Civil Defense: Division of Planning and Training.*

Al-tukhi, M. (1990) Road traffic accidents: statistics and data comparing the Gulf countries and the Ruyadh area. *Saudi Med J,* 11, 1-3.

Almulla, A. (2008) Major Hajj catastrophies over the past decades. *Alwaqt Newspaper.*

Central Department of Statistics and Information (2010) Key Indicators of the 2010 Census.

Ministry of Economy and Planning (2010-2014) Ninth Development Plan.

Ministry of Interior (2001) Concepts and structural organization of Civil Defense. In General Directorate of Civil Defense (Ed.).

Ministry of Interior (2008) Traffic statistics: statistical publication of 2008. In Ministry of Interior General Traffic Department (Ed.).