INVESTIGATION OF THE INFLUENCE OF SEVERE WEATHER ON AIRCRAFT OPERATIONS OVER KENYA

Francis Jagero

Department of Meteorology, University of Nairobi, KENYA.

jagerof2017@gmail.com

ABSTRACT

The study investigates the influence of severe weather on aircraft operations over Kenya using analyzed investigated weather-related aviation accident and incident causes data extracted from Kenya Civil Aviation Authority database system from 2008 through 2014. The China based geostationary Fengyun (FY2E)Satellite and MSG Infrared 10.8 imagery were used to identify the dominant cloud types and the distribution of the convective cells during the dry and wet seasons. Key findings revealed that Wind, Fog, Turbulence, Precipitation, and Thunderstorms influenced the accidents and incidents over Kenyan airspace.. Other factors were as a result of Fog encounter and Low Ceiling due to Stratus and Stratocumulus clouds being reported as Overcast or Broken. It was also noted that clouds of all types do not appear in the sky at the same time and a few clouds are rarely ever seen whereas some are only seen during certain seasons.

Keywords: Severe Weather, Aircraft Operations, Clouds, Aviation

INTRODUCTION

Severe weather may impact negatively on air traffic management systems including the ability to ensure timely flight schedules. In 2007, for instance, the Department of Transportation (OAEP, 2008) documented one in four flights delayed due to bad weather.

Aviation provides for the movement of People and goods and enables economic growth (Waitz et.al., 2004), and may influence the reputation and the economy of air transportation industry and contributes to overall increase in the GDP.

Unlike the road transport, aviation is subject to weather changes which are beyond human control. In Kenya the helicopters play a big role as they are used for rescue missions and by politicians when they conduct their campaigns. The helicopters are unlike, the military aircrafts that are designed to endure adverse weather while the commercial aircrafts have to carry optimum capacity to make profit -- they are usually optimized in the best weather. Conducive operations depend on weather which is a crucial component for them to expand in terms of growth. We need to understand the impacts so that key players are aware of this to take necessary precautions to avoid losses.

Aviation hazards during the cumulus stage of thunderstorms are mainly caused by supercooled water (Okoola, 2005). Hazards during the mature stage of the thunderstorms are due to strong winds, lightning and precipitation, while those in the final stage arise from downbursts. Thunderstorms are produced by convective instability, moisture, and a source of lift. In forecasting thunderstorms, it is important to know whether they will occur; their severity; the associated severe phenomena; and the type of storm likely to be observed.

LITERATURE REVIEW

Visibility/Ceiling and Clouds

Some clouds are dangerous to aviation as they are capable of producing precipitation, thunder and lightning. Clouds are classified according to general form and the three basic forms are

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Cumuliform (heaps), Stratiform (layer form) and Cirriform (fibrous) lines. They can also be classified according to average height of base above the ground- Low, Medium, and High clouds (Mwebesa, 1978)

In a study by Verlinde *et al*., (2007), it was found that mixed-phase clouds, such as Arctic stratus and stratocumulus, altocumulus and altostratus, cover approximately 22% of the earth's surface and that the clouds are persistent, with supercooled water existing both within ice clouds and above ice layers at temperatures as low as −30 ◦C. It was also observed that the clouds contain supercooled water that can be a serious aircraft icing threat. Smith *et al.,* (2009) indicated in a separate study that supercooled water is particularly hazardous for small aircrafts, such as unmanned aerial vehicles, which they noted to have suffered several accidents due to icing during both civilian and military surveillance.

According to Sharman *et al.,* (2015) in their study on the effects of rain to aviation, the investigation concluded that torrential rain has significant effect on an airplane in landing configuration. This is due to effect of poor visibility and flooded runways that may lead to runway excursions.

According to Mahringer (2008), unexpected visibility below minimum threshold (1000m) affects the airport operations to a large extent. The study found that airport operations are adversely affected by adverse weather. It was noted that atmosphere is obscured due to the presence of high concentration of hygroscopic nuclei, small and large water droplets, fine sand, smoke, and smog. The high concentration of these particles tends to reduce the distance through which an observer/pilot can see and identify an object situated some distance away from the observer/pilot.

Gultepe *et al.,* (2009), in their study indicated that fog is another troublesome problem. They observed that fog is capable to cause airport delays, and that the major problem with fog encounter is the effect of poor visibility.

Thunderstorms

Murray (2002) in a study about the influence of thunderstorms to aviation state that the storm is formed by convection whereby instability, availability of moisture, and lifting or trigger mechanism are needed for formation. They are associated with convective clouds (cumulonimbus) and are usually accompanied by precipitation.

Maloba (2015) studied thunderstorms over eastern region of Lake Victoria basin in Kenya and in the conclusions found that thunderstorms were most observed in the afternoon from 1200Z to 1500Z when there is maximum heating. It was noted that thunderstorm activities were more intense during the wet seasons of MAM and OND due to the presence of ITCZ. The study indicated that the higher ground areas such as the Mau Hills experienced higher distribution of the storm compared to the lowland areas. It was shown that 850mb and 700mb levels are important when locating areas of convergence and the source of moisture which are conditions necessary to produce thunderstorms.

.Showalter (1953) found that unstable air is a necessary ingredient for the development of thunderstorms. It is necessary that the rising parcels to ascend above the level of free convection (LFC).

Ngaina (2015) modeled aerosol-cloud precipitation interactions for weather modification over East African region. The study found that CAPE is a useful tool that enables identification of areas where energy for convection is available. It was noted that CAPE has both meridional and zonal transitions during MAM season and that at the end of the season, extreme values of 1800 J/Kg were observed over parts of Kenya.

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Bothwell (1988) examined surface moisture in terms of mixing ratio while Scofield *et al*., (1990} studied surface and standard-level moisture in terms of equivalent potential temperature. Mahoney (1988) indicate that thunderstorms are mesoscale phenomena, and the source of lift needed to initiate them must be sought on mesoscale space and time scales. The study noted that rising parcels of air move upward through a negatively buoyant layer below the Level of Free Convection (LFC) before positively buoyant upward acceleration is achieved. Upward movement through the negatively buoyant layer is provided by mesoscale mechanical lift produced by low-level convergence.

Bothwell (1988) in the study found that in some cases, thunderstorms occur in the presence of weak synoptic-scale subsidence. They develop due to strong near-surface convergence and high convective instability that compensates for any synoptic-scale downward motion that might impede convection in cases of weak forcing or low convective instability.

Lightning

Hardwick (1999) in a study on lightning in the North Sea region found out that helicopters were at higher risks. The study concluded that the protection against the strikes is not foolproof to averting the effects of lightning strikes in the region. The study noted that fixed wing aircrafts flying at the same altitude as the helicopters were equally vulnerable to the strikes and it was further observed that during winter the lightning strikes were stronger and resulted in more damages to aircrafts.

Wilkinson *et al*., (2013) in another study on triggered lightning by helicopters in the North Sea region noted that the phenomenon affected operations during winter. An algorithm was developed based on weather conditions that were observed to be prevailing during past triggered lightning strikes. To locate the convective cells, they used temperatures and precipitation rate of the typical flight levels of helicopters. The study showed that most strikes occurred when cumulonimbus clouds are embedded in stratocumulus clouds and the dangerous regions for the helicopters to fly through are near the base of Cb clouds and underneath the anvil.

Wind shear

Abrupt and rapid changes in wind speed and direction near the surface are at times caused by thunderstorm outflow and may pose adverse effects during landing and takeoff phases of flight- the pilot may find it difficult to maintain control of the aircraft. The Federal Aviation Administration (FAA) Aviation Safety Information Analysis and Sharing (ASIAS) analysts performed a study of the National Transportation Safety Board (NTSB) from 2003 through 2007 and found that most wind shear incidents occurred during the approach and landing phases of flight (NTSB, 2010).

Aircraft Icing

Structural icing disrupts airflow over aircraft surfaces which results in reduced lift and increased drag. Lift is supposed to overcome both the force of gravity and the drag, for the aircraft to takeoff from the runway and to continue with the journey while airborne (AOPA,2008).

Vivekanandan *et al.,* (1996) on a separate study, used both visible reflectance and Infrared emittance to estimate cloud properties with the aim of examining the size and path of cloud water droplets. The study was able not only to characterize the location of the cloud systems, but also the size and depth. The study concluded that the cloud -top phase, which they were able to monitor, were important in determining possible icing conditions.

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Belo-Pereira (2015) on a study on aircraft icing to predict icing potential and severity of aircrafts flying below 23,000 feet over Eastern United States, used two algorithms based on forecasts of temperature and relative humidity. It was found that the algorithms were most suitable to locate icing and no-icing conditions but were less skillful to predict whether the icing was severe or not. Better results were achieved when the algorithms combined temperature, relative humidity, and vertical velocity when cloud liquid water (CLW) was used in the prediction. The study also stated that the algorithm gave accurate prediction of a severe icing situation that had occurred over mainland Portugal in February 2014.

Turbulence

According to the 2010 annual report of the National Transportation Safety Board (NTSB, 2010), turbulence was the main cause of aviation accidents related to weather from 1997 to 2006. In South Korea, turbulence has accounted for about 24% of weather-related aviation accidents since 1957.To reduce these damaging events, the study recommends that adequate prediction of turbulence require knowledge of the generation mechanisms of turbulence that can be established through observational analysis and numerical modeling.

Gill *et al*., (2014) used data for one year from November 2010 through October 2011 to forecast turbulence globally. The turbulence forecasts were verified using 2x2 contingency tables and every forecast was categorized with the corresponding observations. These were as follows: a hit(when the event was forecast and occurred); miss (when the event was not forecast but occurred); false alarm(if the event was forecast but did not occur); and correct rejection (if the event was not forecast and did not occur). 95% confidence interval was used. The study found that the main sources of turbulence are wind shear, convection, and mountain waves. It was noted that most shear induced turbulence was due to jet streams.

DATA AND METHODOLOGY

Data

Satellite Data

Data used in this study include the Meteosat Second Generation data displayed on the Synergie at the Kenya Meteorological Department, a production of the French MeteoFrance. In it, several metrological products are availed: - Satellite imagery from the USA GOESW and East satellites, RGB Composite products for various products, MPEF products from MSG, Aerie weather Models amongst others. In the Synergize, it has been made possible that at every 15 minutes, data is downloaded, saved, and processed for viewing and analysis by the Forecasters on duty.

Data of the Weather-related phenomena that lead to aviation incidents/accidents

Data for weather-related aviation incident/accident **causes** was extracted from the Kenya Civil Aviation Authority (KCAA) database from 2008 through 2014. The data that was collected was guided by the final investigation report where it was indicated that weather had influenced aircraft accident and incident.

Methodology

For purposes of this study, two satellite imageries were used. The China based geostationary Fengyun 2E (FY2E) satellite, which is located above the equator at Longitude 105ºE, was used to classify clouds over Kenya. MSG Infrared 10.8 Imagery was also used to identify cloud temperatures. Areas with cloud temperatures below -40ºC were identified and marked, as they would be zones associated with deep convective cells, and/or raining clouds. Two sets

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of images from each satellite were picked, from January and April, 2017 to demonstrate and represent dry and wet seasons respectively.

Raw data from GIOVANNI was also used. GIOVANNI is an interactive page for accessing Earth data from NOAA. Atmospheric data can be analyzed, compared, and investigated for various spatial and temporal scales. One of the products, which has been analyzed and used in this study, is time averaged cloud fraction. With appropriate settings, monthly cloud fraction (cloud cover) was obtained for the months of January and April 2016, to demonstrate the dry and wet seasons in Kenya.

Quantum-Geographical Information System (QGIS) is a GIS tool that can read geotiff images as raster layers, hence making it possible for further superimposition, overlaying and extraction. The images from FY2E, MSG IR 10.8, and GIOVANNI, were analyzed further by QGIS so as to enhance the rendering and enable visualization. Kenyan external boundary and counties were labeled and demarcated to depict variables investigated.

RESULTS AND DISCUSSION

Characterization of the Cloud Types over Kenya

Figure 1 shows the analyzed cloud imagery from GIOVANNI, displaying the cloud fraction for various parts of the country for the month of January, 2016.

Results obtained from the various methods used are discussed in this chapter and they include: characterization of the cloud types and cloud temperatures and weather hazards to aviation.

January climatologically marks a dry spell in Kenya. The figure shows higher cloud fraction in central and western parts of Kenya that superseded other parts of the country. The high concentration of thunderstorms in western Kenya may be attributed to the interaction between large scale winds, the sea breeze circulation and the influence of the ITCZ. Over the central highlands, Nairobi and the coast, effects of orography, large scale systems, urban heat island, the ocean, can be the major factors that caused the greater fraction of cloud cover.

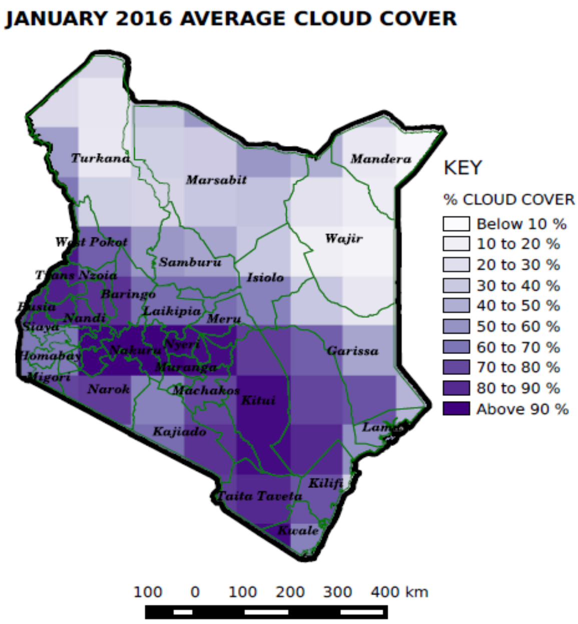

Figure 1: Cloud fraction averaged for the month of January, 2016.
Source: Giovanni from NOAA, analyzed by Q –GIS

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Figure 2 shows the cloud fraction from GIOVANNI for various parts of the country for the month of April, 2016. April was considered since it marks the peak of the MAM season in Kenya. From the figure we see that western, central highlands and most of the southern sector of the country had over 70% cloud cover. Since Giovanni tool can only give cloud cover but not characterize the clouds over an area, the importance of the two patterns is to suggest that there are always clouds over the study area both during the dry and wet seasons irrespective of the types. The western and eastern highlands, the coast, and Nairobi areas still had a greater percentage of coverage compared to the other parts of the country.

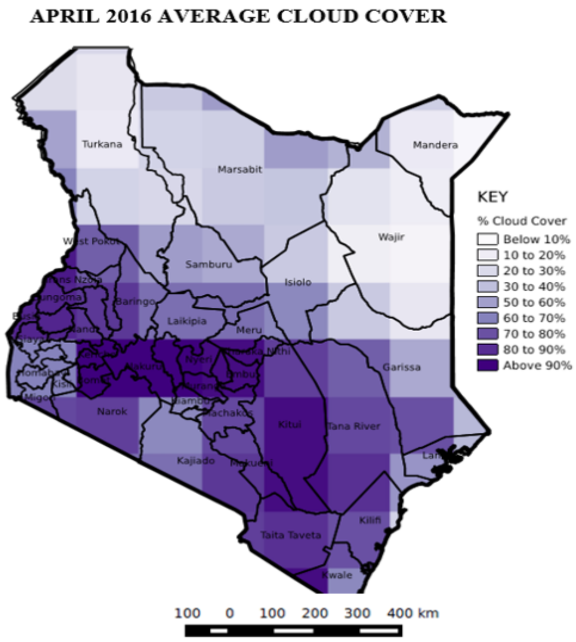

Figure 2: Cloud fraction averaged for the month of April, 2016.
Source: Giovanni from NOAA, analyzed by Q –GIS

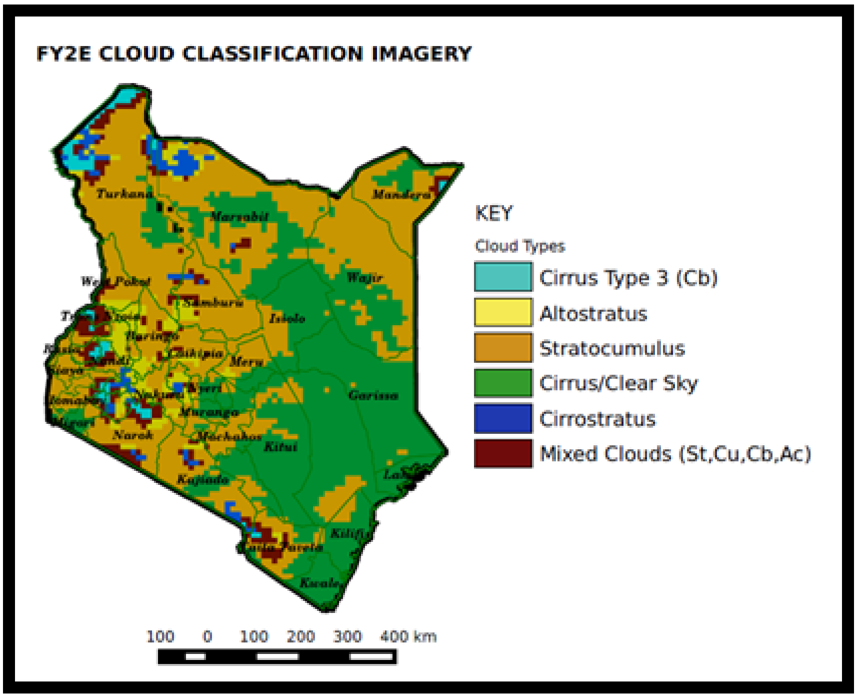

Figure 3: Cloud classification for the month of January, 2017.
Source: FY-2E Satellite, analyzed by Q –GIS

Figure 3 shows the cloud classification for the month of January, 2017 as observed by FY-2E Satellite, and analyzed by Q –GIS. From the figure, we see that Stratocumulus and Cirrus clouds covered most of the sky. Other clouds were majorly along the western corridor-As, St, Cu, Cb and Ac, agreeing with the January distribution from Giovanni averages. But it was established that cumulonimbus clouds are not extensive in spatial coverage at this time of the year because there is no interaction between synoptic (air masses, fronts, pressure systems etc) and local scale (topography, bodies of water) winds.

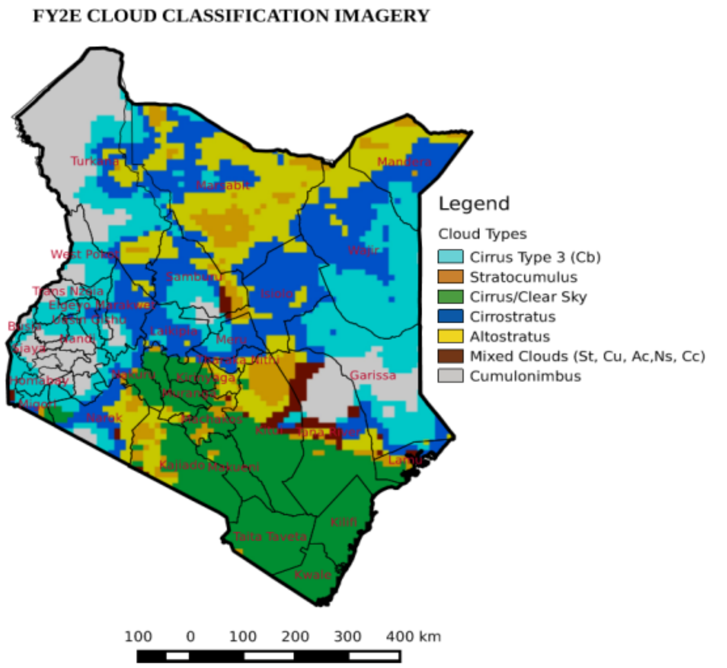

Figure 4: Cloud classification for the month of April, 2017.
Source: FY-2E Satellite, analyzed by Q –GIS

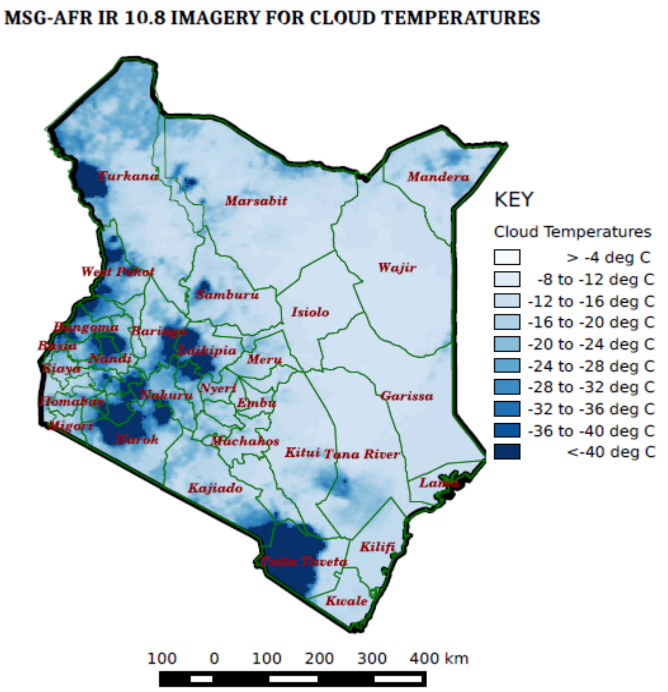

Figure 5: Cloud temperature for the month of January, 2017.
Source: MSG, analyzed by Q -GIS

Figure 4 shows the cloud classification for the month of April, 2017 as observed by FY-2E Satellite, and analyzed by Q –GIS. The figure shows that the sky was covered by almost all types of clouds. The western part of the country was covered by Altostratus, Cumulonimbus in extensive spatial coverage, and dense Cirrus from Cumulonimbus clouds. This is due to convergence of synoptic scale and local scale winds. This involves circulation due to high ground, synoptic, and the water bodies.

Figure 5 shows the cloud temperatures as read by the Meteosat Second generation satellite, and analyzed by Q-GIS software. The figure shows that lowest temperatures were observed over the western Kenya. Cloud temperatures, less than -40ºC, are associated with deep convective clouds. It therefore implies that even on drier months, western and rift valley regions would still witness development of convective cells.

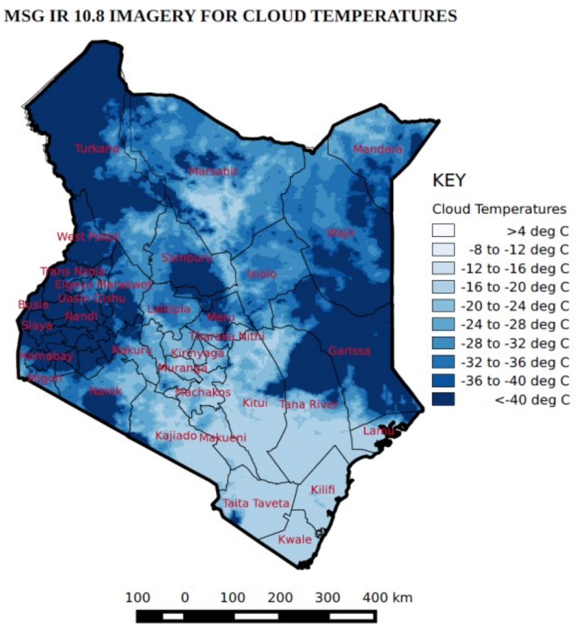

Figure 6: Cloud temperature for the month of April, 2017.
Source: MSG, analyzed by Q –GIS

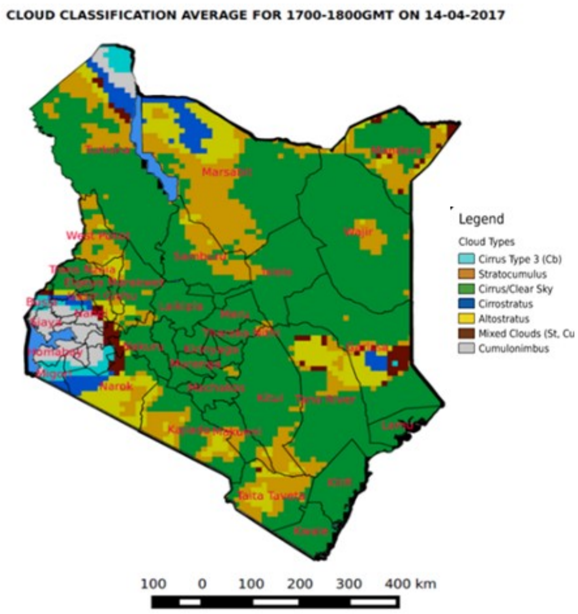

Figure7: Cloud classification averaged between 1700 and 1800 UTC on 14-04-2017.
Source. FY2E Satellite

Figure 6 shows the cloud temperatures as read by the Meteosat Second generation satellite, and analyzed by Q-GIS software. The figure shows that lowest temperatures were recorded over the western Kenya. Many places in the said region had clouds at temperatures less than -40ºC, which are clouds associated with deep convection. There was an increase in spatial coverage of the darker regions, signifying deeper convective cells during the wet season.

Figure 7 shows the FY2E satellite cloud genera, averaged between 1700Z and 1800Z.The figure places most convective cloud types, majorly over the western region of the country, and is in agreement with other results. This demonstrates that it is possible to accurately forecast the presence of cumulonimbus clouds using satellite imagery.

Weather Hazards to Aviation

Figure 8 shows breakdown of weather hazards over Kenyan airspace. The figure shows causes of weather-related accidents and incidents over Kenya. The factors that influenced the accidents and incidents were crosswind 11 %, turbulence 11 %, and visibility/ceiling 78 %.

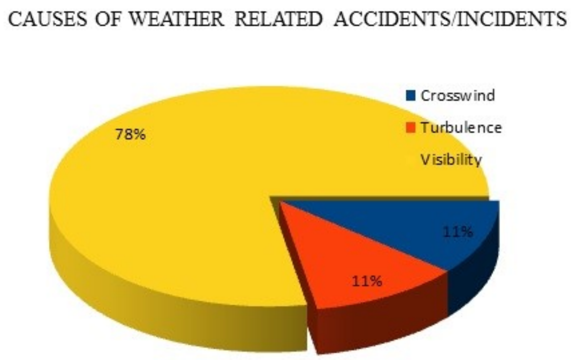

Figure 8: Breakdown of Weather-related Accident and Incident Citations over Kenyan airspace 2008-2014. Source: KCAA Aviation Accident and Incident Database.

It was observed that the aircraft experienced vibrations on landing at Eldoret Airport RWY 26 due to heavy landing resulting from crosswind and heavy rain showers that were produced by cumulonimbus clouds. Another incident occurred on the same runway during takeoff due to turbulence encounter near the surface and caused damage to aircraft but no fatal incident. Majority of accident and incident cases were due to visibility/ceiling and clouds. At Wilson Airport RWY 07 runway excursion occurred due to low cloud base. Thick fog encounter at JKIA RWY 06 caused another runway excursion-the aircrafts went off the runway after landing.

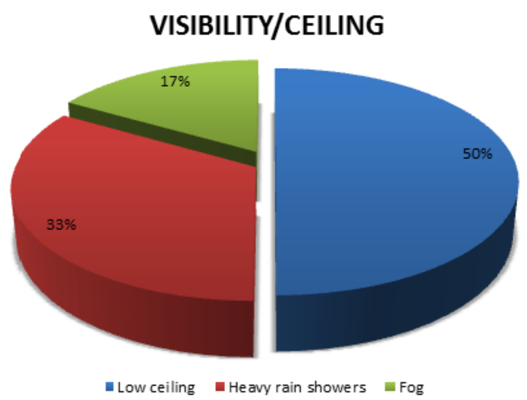

Figure 9: Visibility/Ceiling Citations over Kenyan airspace 2008-2014; Source: KCAA Aviation Accident and Incident Database

Figure 9 shows that low ceiling, heavy rain showers, and fog caused accidents/incidents over Kenyan airspace. The majority of accidents/incidents occurred due to low ceiling, followed by heavy rain showers, and fog encounter.

CONCLUSIONS

Thunderstorms occur in the afternoon at around 1200Z to 1500Z (3pm- 6pm) over the equatorial regions when there is maximum insolation. It was also observed that the Cb clouds develop under certain conditions that require convective instability, low level moisture, and trigger mechanism' Characterization of clouds in the study is important and pilots should seasonally refer to the maps to determine areas where dangerous clouds are located. The information can be used by airlines to plan the routes.

RECOMMENDATIONS

To Aviation Sector

The information about cumulonimbus clouds is important to the aviation sector. The areas of problem over Kenyan airspace should be avoided especially when adverse weather is reported. Cumulonimbus clouds are characterized by thunder, lightning, heavy rain showers, turbulence, wind shear, and crosswind that are hazardous to aviation.

To Kenya Meteorological Department

The hotspots, which have been identified in the study, should be continuously monitored and the service provider should continue to give information – updating of the forecasts. The real time information would enable the pilots, airlines, and management to adequately plan the flight schedules and information provided to the customers in appropriate timeline. The benefits to proper planning are reduced incidents, increased profitability, and enhanced safety.

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