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Research Article

Analysis of the Most Common Aviation Weather Hazard and Its Key Mechanisms over the Yangon Flight Information Region

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The aviation industry has a global economic impact of $2.7 trillion (including direct, indirect, induced, and tourism catalytic effects) and contributes 3.6 percent of global GDP. Weather is one of the most essential elements impacting how an aircraft runs and how safely it can fly. The correlation coefficient is the most significant index explaining the relationship between variables and can result in teleconnection patterns of climate indices. El Nino-Southern Oscillation (ENSO) and India Ocean Dipole (IOD) were used in this study based on the ERA5 reanalysis dataset for 30 years (1991–2020). Myanmar's Yangon International Airport has recorded more than 119874 times of observation data from 2009 to 2019. The mean percentage of occurrences of weather elements is calculated for each month and each season. Analysis of flight delay and accident data was obtained statistically from the Aviation Safety Network (ASN). According to the monthly delay index, July, August, and March are the maximum delay index months, and the correlation value between aircraft movement and delays is maximum in July and August and minimum in January and February. After examining numerous characteristics of Yangon International Airport, we identified which elements had a big impact on operations through vital interviews with operators, the accident case study section, and climatology analysis. As a result, we identified two meteorological occurrences: thunderstorm rain (TSRA) and fog (FG) are of high frequency and TSRA poses a larger risk than FG for aviation operation. The maximum frequency (%) of thunderstorm occurrences was 22% in July and the minimum was 1% in January. Annual frequency analysis revealed that TSRA days are becoming more common year after year as a result of global climate change. According to a spatial gridded analysis by ERA5 reanalysis data (1991–2020), the annual convective available potential energy (CAPE) values over local airport regions, the Bay of Bengal (BOB), the western equatorial Pacific, and the South China Sea show a positive correlation with convective rainfall. In contrast, negative convective inhibition (CIN) anomalies have been observed over the same areas as above, except for the western part of BOB along the Indian Coast. The primary innovation is that we look at the effects of thunderstorms on airport operations before determining their link with ENSO and the IOD individually and then combining them during their full phases. This raises a new question and a new possibility for viewing climatology from a new perspective.

1. Introduction

The aviation industry is critical to the economies of developed countries such as China, landlocked countries such as Laos, and small island nation states such as Madagascar. The aviation industry is a vital component of long-term economic development. It also acts as a significant driver of other economic activities like internal trade, military operations, and tourism.

According to the Air Transport Action Group, the aviation industry generated 704.4 billion dollars in direct gross benefits in 2019 and supported 65.5 million jobs worldwide (Figure 1). Aviation has a $2.7 trillion global economic impact (including direct, indirect, induced, and tourism catalytic effects) and contributes 3.6 percent of global GDP in 2019 [2].

The Republic of the Union of Myanmar (also known as Burma) is one of the world's most densely populated

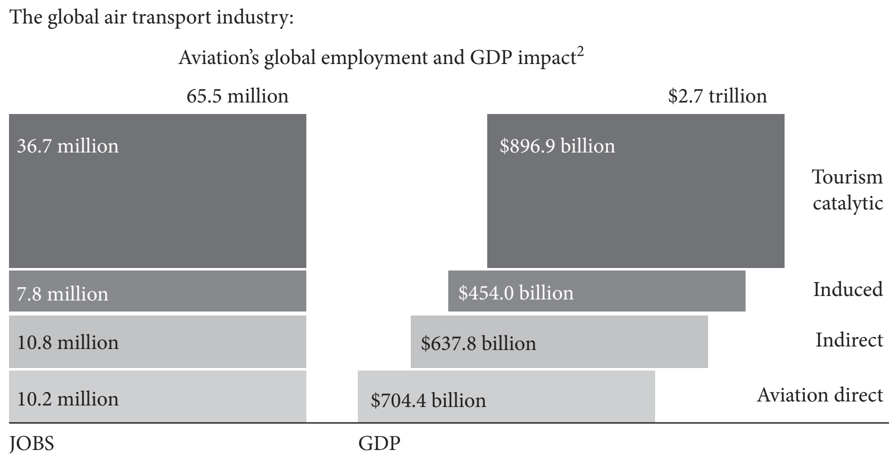


Figure 1: Aviation global employment and GDP impact (2019) [1].

countries. It is bordered on the north-east by the People's Republic of China, the east by Laos, the southeast by Thailand, and the south by India [3]. The busiest airport in Myanmar is Yangon (RGN)/Yangon International Airport (VYYY), with flights to 56 destinations in 14 countries and catering to about six million passengers [4]. Yangon International Airport is the main airport in Myanmar (formerly known as Burma). It has one runway with two touchdown zones (TDZ) and an elevation of 33.6 M (110 FT) above sea level. The airport is home to all ten Myanmar airlines as well as roughly 30 international airlines [5].

The weather is one of the most critical factors influencing how an aircraft runs and how safely it can operate. Weather is also important for the aviation industry benefits, but, unfortunately, it is an uncontrollable factor, as everyone knows. Annual analysis of flight delay causes shows that weather accounts for 6% of total aircraft operation delays (Figure 2) [6].

Aviation and meteorology have a long and illustrious history. Climatology can anticipate significant changes in local weather as well as severe weather patterns. Heavy rain, thunderstorms, hailstorms, and cyclones are all common, resulting in losses in the aviation industry as well as delayed or cancelled flights [7]. As a result, unless new solutions are found, the impact of weather on aviation is likely to increase over time. It is impossible to avoid delays in flying all of the time. Changing climatic and meteorological conditions at the same time have a significant impact on aircraft performance at the airport, which cannot be prevented in the end. These delays are sometimes necessary to demonstrate that the safety of our passengers is our first priority. As of Figure 2, the weather is the only uncontrollable factor among the five forms of aviation delays. As a result, departure delays caused by bad weather are virtually always unavoidable. It is critical to be prepared for departure delays in order for airfield operations to run properly; thus preparedness is necessary [8].

Even in bad weather on an aerodrome, air weather services do not have the authority or ability to close an airport [9]. Airport operators are the only authorities able to close an airport, and this would only be taken in extreme circumstances. The degree to which an aircraft's departure and arrival are visible (or RVR) is determined by the sophistication of ground equipment and the qualification of the flight crew [5]. At or near an airport, low cloud, fog, and rain can make visibility difficult, while thunderstorms and lightning can cause substantial delays in flight schedules. Thunderstorm rain (TSRA) and the fast rising or lowering air currents that frequently accompany it can make flying uncomfortable for passengers and difficult for pilots. Aircraft are unable to take off or land during a TSRA and are usually rerouted around storm cells or diverted from their original locations. Thunderstorms and lightning strikes near airports may cause ground operations to be halted until the storm passes. As a result, data on the spatial and temporal distribution and fluctuations of thunderstorm occurrence and convective rainfall is critical not only for understanding basic climate dynamics but also for societal uses such as airport operations and aircraft operations.

The primary research focus is Yangon International Airport (VYYY), and this work is the first to investigate the impact of aviation climatology over Yangon International Airport (Figure 3). Statistical analysis of the observation data is obtained by the meteorological station. The purpose of the studies has looked at the individual effects of thunderstorms on regions, the El Nino-Southern Oscillation (ENSO), or the Indian Ocean Dipole (IOD) on regional convective rainfall, with only a few taking into account the combined effects of all three on airport operations. Furthermore, the majority of past studies on the association between ENSO/the IOD and precipitation focused on just one or two seasons rather than the full ENSO/IOD cycle. We elaborate on this previous research in this paper by looking at the prospective effects of the ENSO and IOD phenomena, as well as their combined effects, on the annual and seasonal variance of thunderstorm or convective rainfall throughout their phases. Other aviation weather elements may have a significant impact on airport operations. However, in this study, we will just look at these two phenomena. The main difference is that we examine the effects of thunderstorms on airport operations before evaluating their relationship with ENSO and the IOD separately and then integrating them during their complete phases. It is

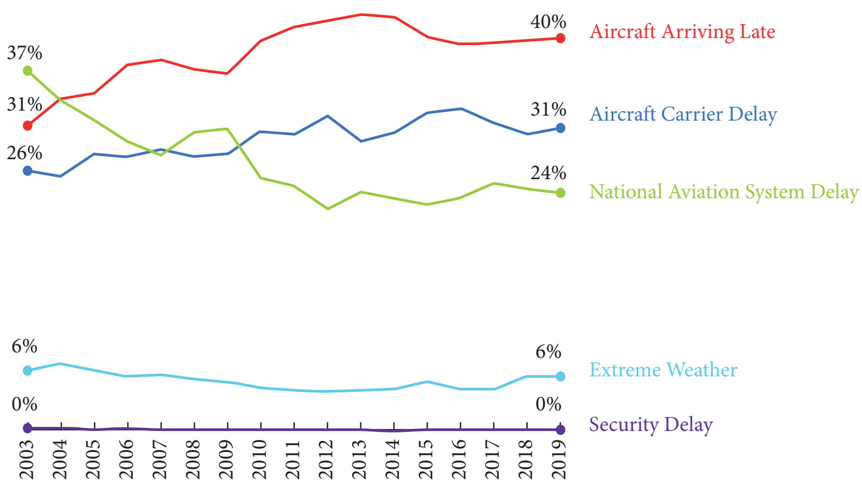


Figure 2: Delay cause by year, as a percent of total delay minutes.

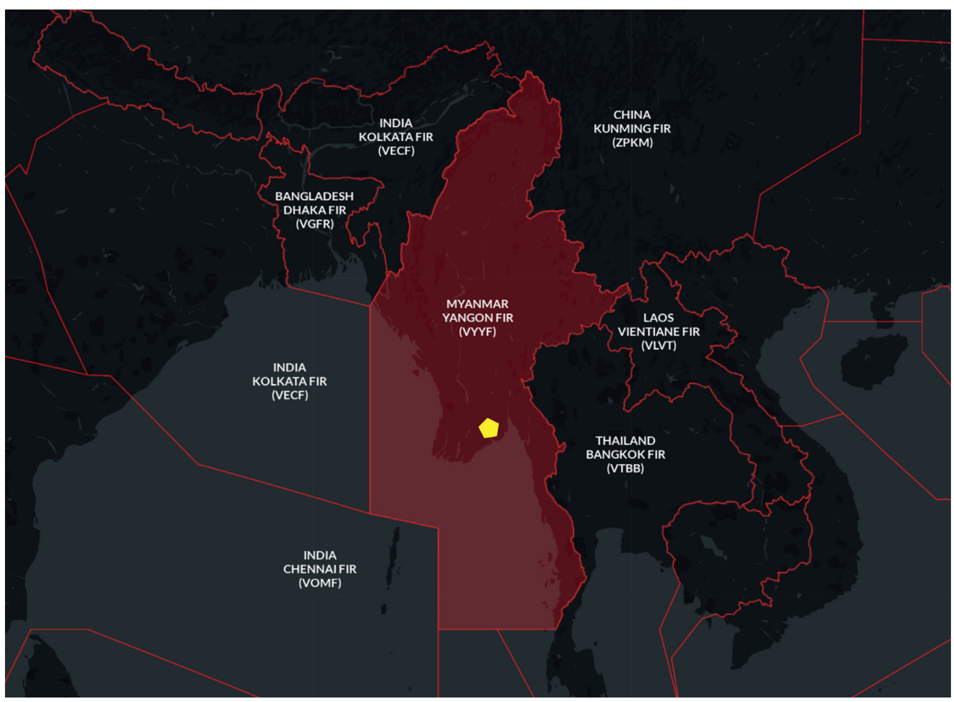


Figure 3: Study area. The red box shows the Flight Information Region (FIR) coverage area of Yangon International Airport Control (Yellow Polygon) [11].

also intended not only for airport operations but also for a diverse group of users, including international and domestic civil airlines flying to and from Myanmar airports, private pilots, airport operational and administrative services, aeronautical administration, air navigation service providers, and the Myanmar Civil Aviation Agency. Besides the potential users mentioned above, this summary can also be used by specialists from other domains for scientific research.

2. Materials and Methods

The International Civil Aviation Organization (ICAO) and the World Meteorological Organization (WMO) have issued recommendations for the processing of climatologic data, which are followed in the creation of statistical data [12]. Count 119874 times of observation data (thirty-minute (xx20, and xx50) METARs) from Yangon International Airport between 2009 and 2019.

Flight delay and accident data are obtained from the Aviation Safety Network (ASN) and the ICAO Safety API Data Service. The aerodrome's data is supported by YIA Service Company Limited and MC-Jalux Airport Services Company Limited. The depicted observation data from the meteorological stations at Yangon Airport meets all the established requirements: the data is representative, continuous, and reliable. The Meteorological Service holds a Quality Management ISO 9001 : 2015 Certificate, which was issued by the SGS international organization.

The large-scale atmospheric parameters such as sea surface temperature (SST) and two-component wind (1991 to 2020) data are taken from the ERA5 reanalysis dataset produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). Also, atmospheric stability indices like Convective Available Potential Energy (CAPE), Convective Inhibition (CIN), K-Index (K), and Total Totals Index (TT) data are taken from the same ERA5 reanalysis (0.25×0.25) resolution dataset of ECMWF for 30 years (1991–2020).

Frequency is a measure of the number of occurrences of a particular score in a given set of data [13]. The climatology is the examination for each month and each season to determine the mean proportion of occurrences of meteorological factors at the study area. The percentage is obtained by dividing the frequency of the category by the total number of participants and multiplying by 100% [14].

$$\text{Frequency Percentage} = \frac{\text{Frequencies of element}^{*}}{\text{Total of Observation Times}}. \quad (1)$$

To improve the climatology results, we performed the vital and online qualitative survey questionnaire about weather experiences for aviation people, resulting in the worst weather phenomena for flight operations at VYYY and a case study of weather-related aircraft accidents at that airport. 15 senior pilots from three airlines (Myanmar International Airline, Air Than Lwin Airline, and Air KBZ Airline) are interviewed.

There are several statistical relationships for perceiving the relationships between two variables which are expressed in both linear and nonlinear equations. The correlation coefficient, which displays the intensity and type (direct or reverse) of the association, is the most important statistic for explaining the relationship between variables. This coefficient's computed value ranges from −1 to +1. Based on the average values, we carried on and performed a correlation coefficient for deep analysis. Before performing composite and correlation analyses, all climatic parameters' data were detrended. Generally, the most common index for showing the correlation is Pearson's correlation coefficient. This index shows the degree and direction of correlation. The Pearson correlation coefficient (r) is calculated using the following equation:

$$r = \frac{n(\sum xy) - (\sum X)(\sum y)}{\sqrt{\left[n\sum x^2 - (\sum x)^2\right]\left[n\sum y^2 - (\sum y)^2\right]}}. \quad (2)$$

Teleconnection patterns can be the result of correlation analysis, as with other techniques. This method has been widely used in climate research, and each offers some advantages [15]. The global climate indices El Nino-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) were used in this study and were studied from the same ERA5 SST. The average SST anomaly in the region of 5N to 5S and 170W to 120W (NINO3.4 region) index is a largely used indicator of ENSO. Similarly, the Indian Ocean Dipole (IOD) is the difference between two SSTs in the equatorial Indian Ocean's western (50E–70 E and 10S–10 N) and eastern (90E–110 E and 10S–10 N) halves [16]. Our study also analyzed annual and seasonal correlations of gridded data for SST, convective rainfall over Yangon Region, and CAPE index based on the ERA-5 dataset to calculate TSRA occurrence indices using IBM SPSS, CDO, and open-grads. Student's t-test with a 95 percent confidence interval was used to establish the statistical significance of the composite analysis in this study. The application of this technique to South Asian countries has been presented in a previous number of works [7–9]. The Pearson correlation analysis is used in this study to show the association between the variables with a 95% confidence level.

3. Results and Discussion

3.1. Flight Delay Causes. It is critical to investigate airplane delays and their causes in order to preserve airspace efficiency and safety [21]. Delay samples, on the other hand, are not independent because they consistently display the same aggregation pattern. These delays take one of three forms: ground delay programs, ground stops, or general airport delays. A ground delay program may be instituted when the arrival demand at an airport is greater than the determined capacity of the airport [21]. These programs limit the number of aircraft that can land at an affected airport. Because demand is greater than the aircraft's arrival capacity, flight delays will result [22]. Second, when severe weather is forecast for a short period or the weather at the airport is unsuitable for landing, ground stops are issued. Ground stops mean that traffic bound for the impacted airport is prohibited from leaving for a set amount of time. Finally, there are general delays in arrival and departure. This usually means that arriving traffic is encountering airborne delays or that outgoing traffic is suffering longer than usual cab wait times or gate delays. This could be caused by a variety of factors, including nearby thunderstorms, heavy departure demand, or a runway modification. Total flight delay categories at VYYY during 2019–2021 are shown in Figure 4.

As the delay index, compiled by Airports INFO Statistics, shows that the relationship between aircraft delays and adverse weather is primarily relative at Yangon International Airport (Figure 5). Weather delays can occur in both direct and indirect ways. If airport weather is bad, that can be a direct impact, and bad weather situations on the route of the aircraft can be an indirect impact, as a flight can be arriving late.

After categorizing the delay causes, we found that the weather-related delay index is high. The delay index represents the percentage of delayed flights (take-offs) [23]. For example, if there are 10 flights on a day and 5 are delayed, then the delay index would be 50%.

By the monthly delay index, we found July, August, and March are the maximum delay index months, and May is the minimum month within 2019–2021 (Figure 5). As the above delay index with aircraft movement by month, the correlation value is maximum in July and August and minimum in January and February (Figure 6). Aircraft movement means all airport movements for this airport. A movement can be a take-off or a landing, which are summed up.

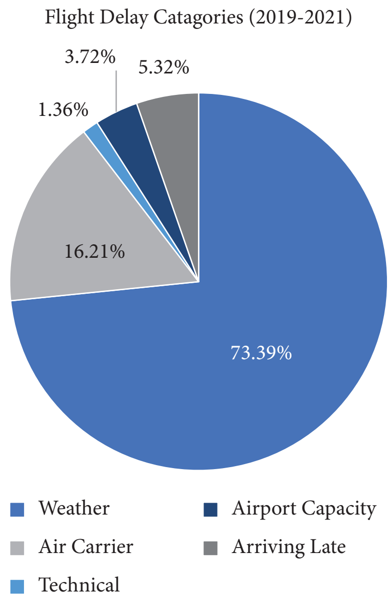


Figure 4: Flight delay categories during 2019–2021.

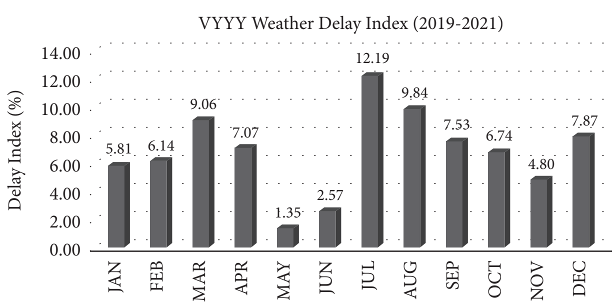


Figure 5: Weather delay index for VYYY (2019–2021).

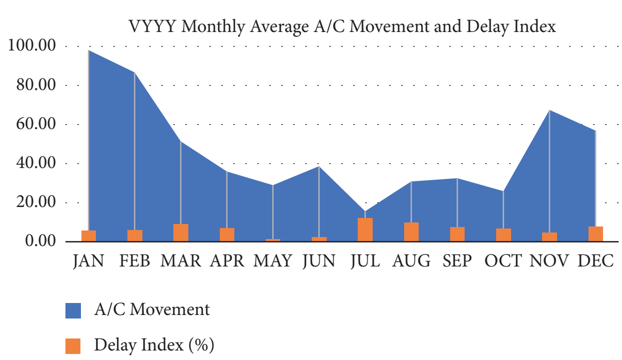


Figure 6: Correlation of monthly aircraft movement and delay index.

Weather conditions can create major delays in air travel [22], resulting in the cancellation or postponement of hundreds or thousands of flights, affecting the itineraries and budgets of millions of people. More than that, bad weather conditions may lead to flight accidents. A comprehensive study was conducted on Yangon International Airport using climatology data and the aircraft delay index to identify the particular meteorological elements that cause flight delays and cancellations by month.

Airport weather directly impacts airport operations, and other aviation hazards also occur based on these weather phenomena. Thus, as a result, we found that, among the 20219 times weather phenomena occurred, including 1237 times of thunderstorms (maximum in July) during this study period. Compared to the flight delay index, July is also the highest delay index during 2019–2021 (Figure 6).

3.2. Qualitative Survey Results and Accident Cases Study. Interviews are conducted with the 15 senior pilots from 3 airlines (Myanmar International Airline, Air Than Lwin Airline, and Air KBZ Airline). The questionnaires included the following questions:

(1) What are the worst weather-related aviation hazards?

(2) What time of day is the best for weather conditions for flying?

(3) How much visibility is important in flight and in which phase of flight?

(4) What is the worst weather phenomenon at Yangon International Airport?

For the survey result of vital or online question No. 1, 52% answered that thunderstorms are the worst weather phenomenon for flight operations, and 10% answered that fog conditions are the worst also. Other weather phenomena were mentioned by 38% of those polled, but the majority of them were thunderstorm-related (Figure 7(a)). Thus, we can assume that thunderstorms and fog are the worst weather phenomena for flight operations in Myanmar.

For question No. 2, 55% said that 09:00 am to 12:00 pm local time (01:30 UTC to 05:30 UTC) is the best time to fly (Figure 7(b)). For question No. 3, 87.5% answered that visibility is very important for aircraft approach and landing (Figure 7(c)). As the survey result of question No. 4, 30% answered that thunderstorms are the worst weather phenomenon at Yangon International Airport and 10% answered that fog conditions are the worst also. Another 20% answered that rain on airplanes' approaches is relative to poor visibility, and the other 16% answered that heavy gust wind is the worst weather phenomenon at Yangon International Airport. Other answers are low ceilings with cloudy conditions (Figure 7(d)). However, most of them are thunderstorm-related phenomena. Thus, we can assume that poor visibility, low ceiling, and thunderstorm and fog weather conditions are the worst weather phenomena for Yangon International Airport according to survey results.

3.3. Causes of Aircraft Accidents over Myanmar. It is quite rare for an accident to be explained by one single cause. Almost every catastrophe is the result of a series of circumstances, and most accident reports distinguish between the main cause and multiple contributory elements. Figure 8 shows the distribution of the main causes identified in an aircraft accident. The main root cause is weather-related accidents. Also, some loss of control accidents may be unfortunate factors that can result in aviation accidents.

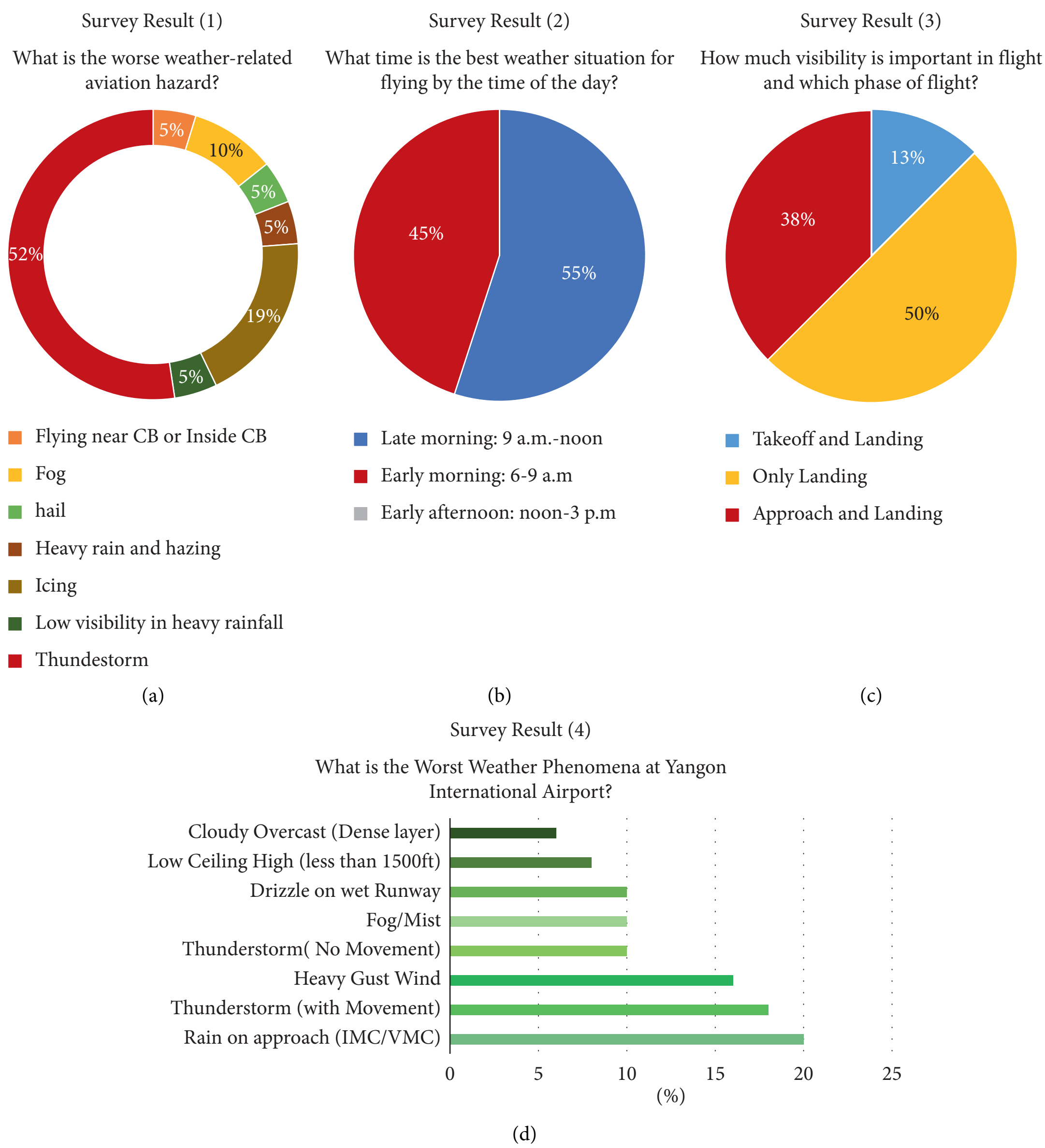


Figure 7: Questionnaires survey results.

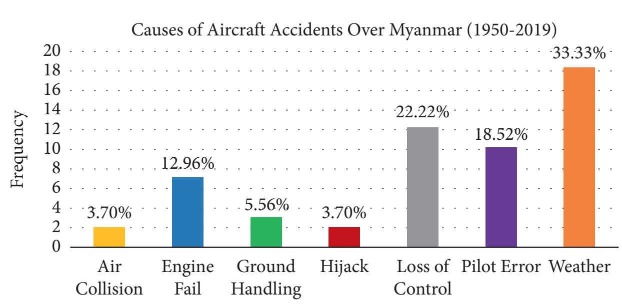


Figure 8: Causes of aircraft accidents over Myanmar (1950–2019).

Among an aircraft's greatest threats are the effects of significant flight icing or in-flight turbulence.

There are a lot of noted weather-related aircraft accidents over VYYY, such as Air Bagan 424 landing crash in 2015 [24], the Shaanxi Y-8-200F transport plane crash near Dawei in 2017 [25], and the Biman Bangladesh Airlines DHC-8-400 accident in 2019 [26]. According to accident reports, these accidents may be caused by the direct or indirect impact of a thunderstorm, and the satellite image analysis results can be seen in Figure 9.

As a result of vital or online questions, most answered that thunderstorms rain (TSRA) and fog (FG) are the worst weather phenomena for flight operations and others answered with other weather phenomena, but most are thunderstorm-related phenomena. For Yangon International Airport (VYYY), many answered that 6:00 am to 12:00 pm local time (23:30 UTC to 05:30 UTC) is the best time for flight operations and that TSRA and FG are the worst weather phenomena for operations. According to the accident case study, most aircraft accidents are found to be thunderstorm-related accidents exhibited in Figure 9 during 2009–2019. From all the above results, we may assume that

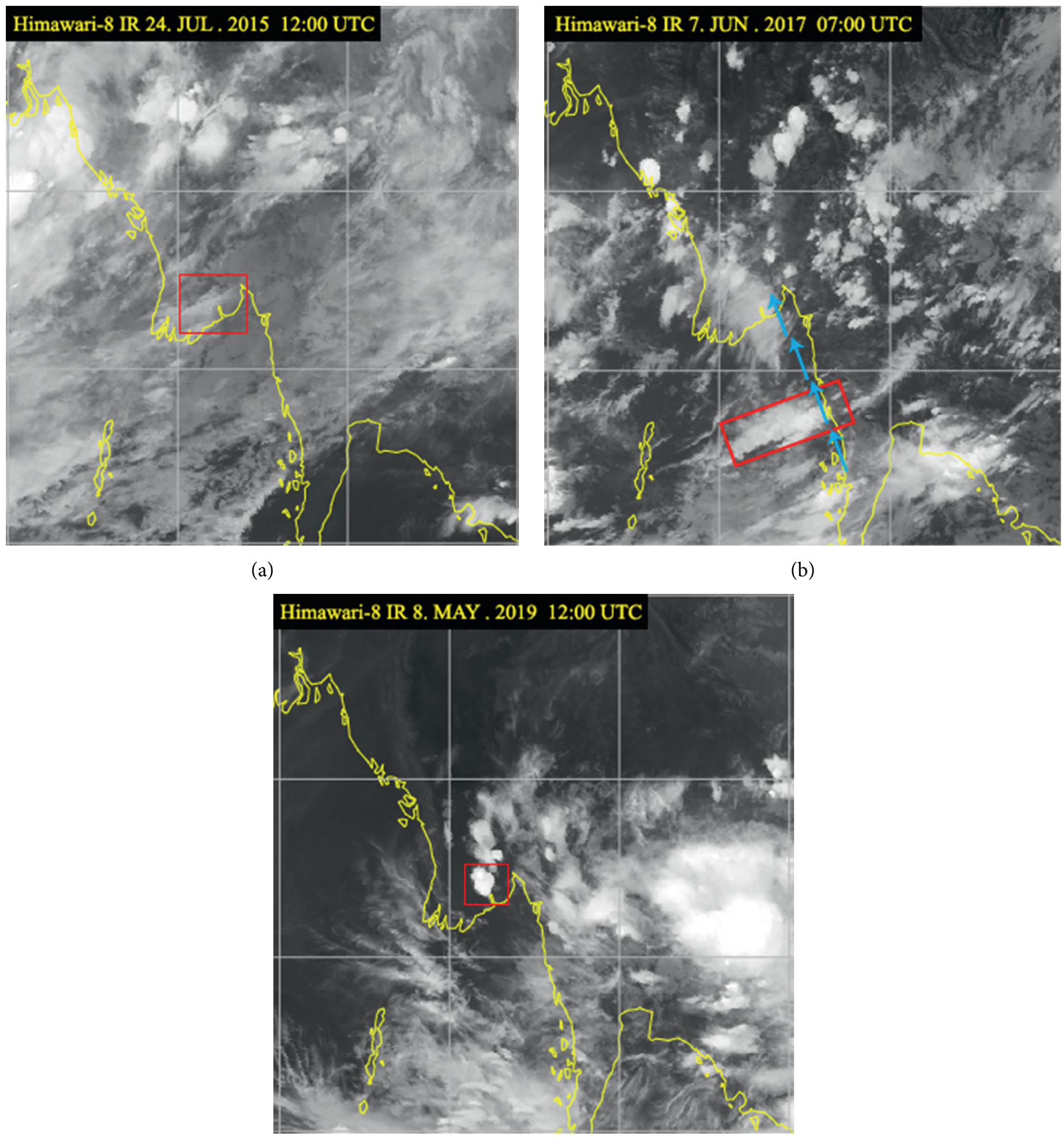


Figure 9: Actual thunderstorm cloud condition satellite image at a time of (a) Air Bagan ATR72, (b) Biman DHC-8-400, and (c) Y-8-200 F W aircraft's accidents.

the worst weather phenomena for flight operations in Myanmar are thunderstorms.

3.4. Thunderstorm Days Analysis. We count 119874 occurrences of observation from Yangon International Airport using half-hourly METAR data. This data contained 20219 instances of meteorological phenomena, including 1237 thunderstorms. The percentage of each weather phenomenon that happens, including thunderstorms, is shown in distinct hues in Figure 10. The maximum frequencies in February are mist (BR) 0.86%, haze (HZ) 8.35%, and fog (FG) 11.55%. Maximum thunderstorm rain (TSRA) of 12.13% occurred in July during 2009–2019 with Drizzle (DZ) of 9.74%, Rain (RA) of 6.49% (Figure 10).

After examining numerous characteristics for Yangon International Airport, we identified which elements had a big impact on operations, and we obtained a lot of practical information from the operators during the important interview phase. The accident case study section also demonstrates how weather, specifically TSRA and visibility, can influence aviation crashes. As a result, we identified two meteorological events (TSRA and fog) that were very likely to cause plane accidents or operational delays. Because it is associated with a range of other weather phenomena such as hail, wind shear, and lightning, TSRA provides a larger risk than fog.

The three seasons in Myanmar are summer or hot weather season (March–mid-May), rainy or southwest monsoon season (mid-May–October), and winter or

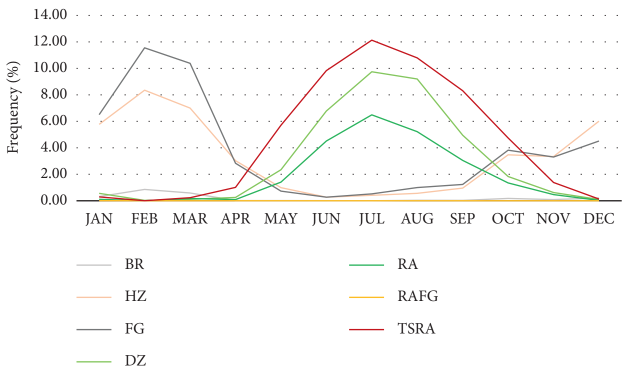


Figure 10: Climatology of monthly frequencies (%) of weather phenomena (2009–2019).

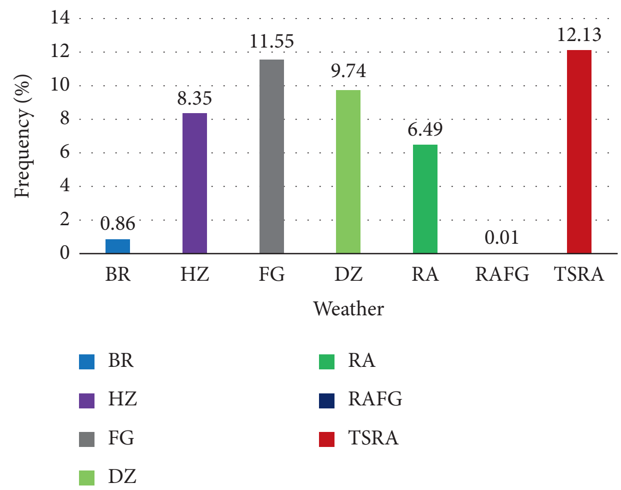


Figure 11: Maximum frequency (%) of weather occurrences by phenomenon (2009–2019).

northeast monsoon season (November–February) as by Myanmar Climate Report 2017 [27]. During the winter, fog and haze weather phenomena are more common. Thunderstorms have been reported not only during the southwest monsoon (wet) seasons but also during the second half of the summer (dry) season, which extends from April to November each year. As the result of Figure 10, maximum thunderstorm conditions have been present for at least 8 months at Yangon International Airport.

Thunderstorms (TS) and fog are the most dangerous weather phenomena at Yangon International Airport (FG) as shown in Figure 11. Thunderstorms had a greater influence on airport operations because of the numerous types of weather that followed, such as hail, strong winds, heavy rain, lightning, and extreme turbulence. All of these factors have a significant impact on aircraft and airfield operations. Thus, the following evaluations of TSRA conditions are carried out in great depth.

From 2009 to 2019, the frequencies (%) of thunderstorm occurrences were analyzed for monthly and daily occurrences are as shown in Figure 12(a). The maximum frequency is 22% in July, the minimum frequency is 1% in January, and there are no occurrences in February, March, and December. According to the seasonal distribution, July is the southwest monsoon season and thunderstorms are typical during this time of year. Tropical cyclones from the Bay of Bengal or the Western Pacific, on the other hand, are the predominant cause of thunderstorms in the winter and summer [27].

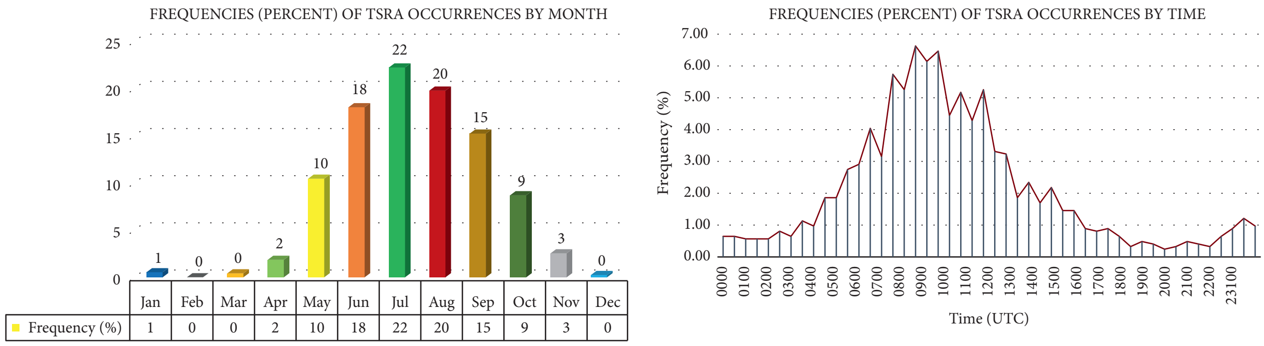
For the frequencies (%) for daily analysis of TSRA during this 2009 to 2019 period, the maximum frequency of TSRA may occur from 08:30 to 10:00 UTC during a day (Figure 12(b)). The minimum frequency may occur from 19:00 to 20:00 UTC. According to time zones, 08:30 UTC will be 15:00 afternoon in the local time. Thus, maximum TSRA occurrences may have occurred between 15:00 and 16:30 afternoon on those TSRA days at Yangon International Airport. In such TSRA days, 00:00 UTC to 04:00 UTC is the best time for daytime operations for aviation.

The yearly frequencies research revealed that TSRA days become increasingly common year after year, indicating that global climate change is to blame. In 2010, there were 255 instances, the lowest amount in the previous eleven years. The average number of incidents in 2018 was 527, and it was 920 in 2017 (Figure 13). The trend forecast showed a positively increasing thunderstorm occurrence in the future, and the regression value of this trend is strong ($R^2 > 0.7$) at more than 95% significance level.

3.5. Synoptic Mechanisms Possibly Underlying Thunderstorm Variability. Most of the world's climate change and India's monsoon system is deeply concerned with the Pacific Nino area SST [29]. To result in the teleconnection pattern, we used a correlation between the Nino Index and yearly convective rainfall. Before analysis, we performed the correlation of standardized monthly convective rainfall based on ERA5 and observed stations TSRA occurrence datasets, averaged over longitudes 96°E-97°E and latitudes 16°N-17°N during 2009–2019. The results demonstrate a strong positive connection between both variables with a 95% level of significance (Figure 14). According to the above result, the spatial analysis is carried out using ERA5 reanalysis data, as shown next.

Thunderstorms are caused by the convective downpour, which occurs when the Earth's surface warms rapidly, resulting in an unstable atmosphere. As the heated surface air rises, it cools, resulting in clouds and heavy rain [30]. In meteorology, moisture, instability, and lifting are three components required for a thunderstorm [31]. The convective available potential energy (CAPE) is a measure of thunderstorm potential [32]. CAPE is the total amount of work performed by the upward (positive) buoyancy force on a certain mass of air (called an air-parcel) if it were to climb vertically through the entire atmosphere (often abbreviated as CAPE) [33]. The index is based on measures such as "vertical temperature lapse rate, lower atmosphere moisture content, and the vertical panes of the moist layer," according to the NOAA.

The composite with annual 10 m component wind, the correlation of convective rainfall over VYYY with annual anomalies of CAPE Index, and convective inhibition of the



(a) (b)

Figure 12: (a) monthly (b) and daily frequencies of TSRA occurrences at Yangon International Airport from 2009 to 2019 [28].

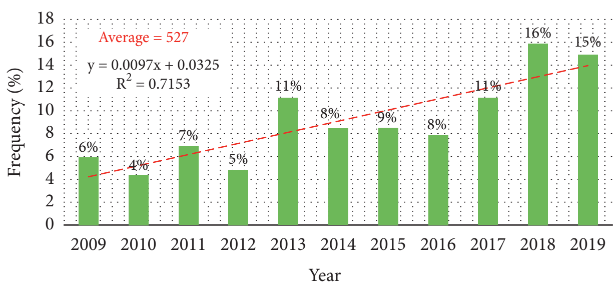


Figure 13: Annual frequencies of TSRA occurrences at VYYY (shaded bar) with their trend (red-dotted line) during 2009–2019.

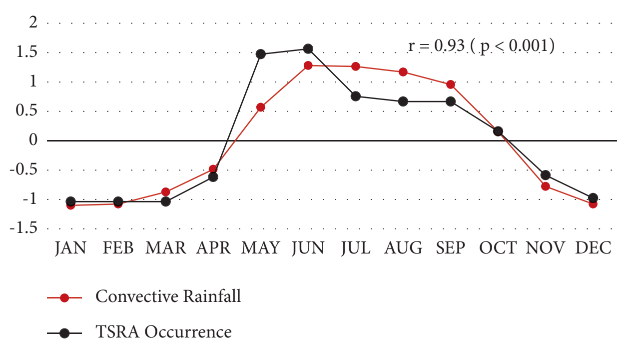


Figure 14: The correlation of standardized monthly convective rainfall based on ERA5 and observed station TSRA occurrence datasets, averaged over longitudes 96°E-97°E and latitudes 16°N-17°N for the period of 2009–2019.

region are exhibited in Figure 15. Convective available potential energy (CAPE) and convective inhibition (CIN) both respond to changes in the heat and humidity profiles of the atmosphere in the absence of moist convection [34]. These changes are explained in terms of a direct effect, which involves changes in the profile in the absence of parcel changes, and an indirect effect, which involves changes in air-parcel evolution in a developing convective boundary layer. A simple estimate of the direct influence on CAPE, which is independent of the assumptions related to choosing parcel ascent, is shown to give accurate results. As a result of Figure 15(a), the annual CAPE over local airport regions, the Bay of Bengal (BOB), the western equatorial Pacific, and the South China Sea shows a strong positive correlation with convective rainfall over the study area. In contrast, negative CIN anomalies have been observed over the same areas as above, except for the western part of BOB along the Indian Coast (Figure 15(b)). It is shown that these areas had a strong chance to experience convective activity. Furthermore, the annual component wind, which blows from the southwest sea to the northeast, may result in increased moisture transport to the BOB's northeast continental area and encourage convective rainfall over the airport regions (Figure 15). These results are agreed with previous studies on the South Asian summer monsoon [35].

Several recent studies have highlighted the ocean's role in climate and weather predictability, as well as the regional patterns of the effects of global teleconnections like IOD and ENSO. The ENSO indicator of atmospheric variability has been thoroughly investigated, and it is thought to serve as an "atmospheric bridge" connecting interannual SST fluctuations in the tropical Pacific with oceanic variations at higher latitudes [36]. The following correlation results show that interannual convective rainfall over the study area does not have any significant correlation with SST at NINO 3-4 (5N–5S and 170W–120 W) in the Pacific Ocean, but a significant negative correlation is found clearly over Indian Ocean (Figure 16(a)). However, seasonal relationship analysis shows different results, with a positive correlation over the Nino 3-4 region. Especially in the summer southwest monsoon season (JJAS) (Figure 16(b)), there was a positive (warming) strong correlation of convective rainfall with SST over the Nino 3-4 area in the equatorial Pacific regions. But there was only a weak positive correlation during the winter months (DJF) (Figure 16(c)).

There is maximum TSRA occurrence also found during the summer months (Figure 12(a)) and convective rainfall also exceeds that in the other months as in Figure 14. It means that Nino 3-4 SST anomalies can strongly impact on thunderstorm occurrence and convective rainfall over the study region during the summer months (JJAS). A weak positive IOD phase can also be found during summer (Figure 16(b)). In contrast, the negative IOD phase can be found in the winter months (DJF) (Figure 16(c)). But only Indian Ocean (IO) SST shows a strong negative correlation with convective rainfall for the annual mode (Figure 16(a)).

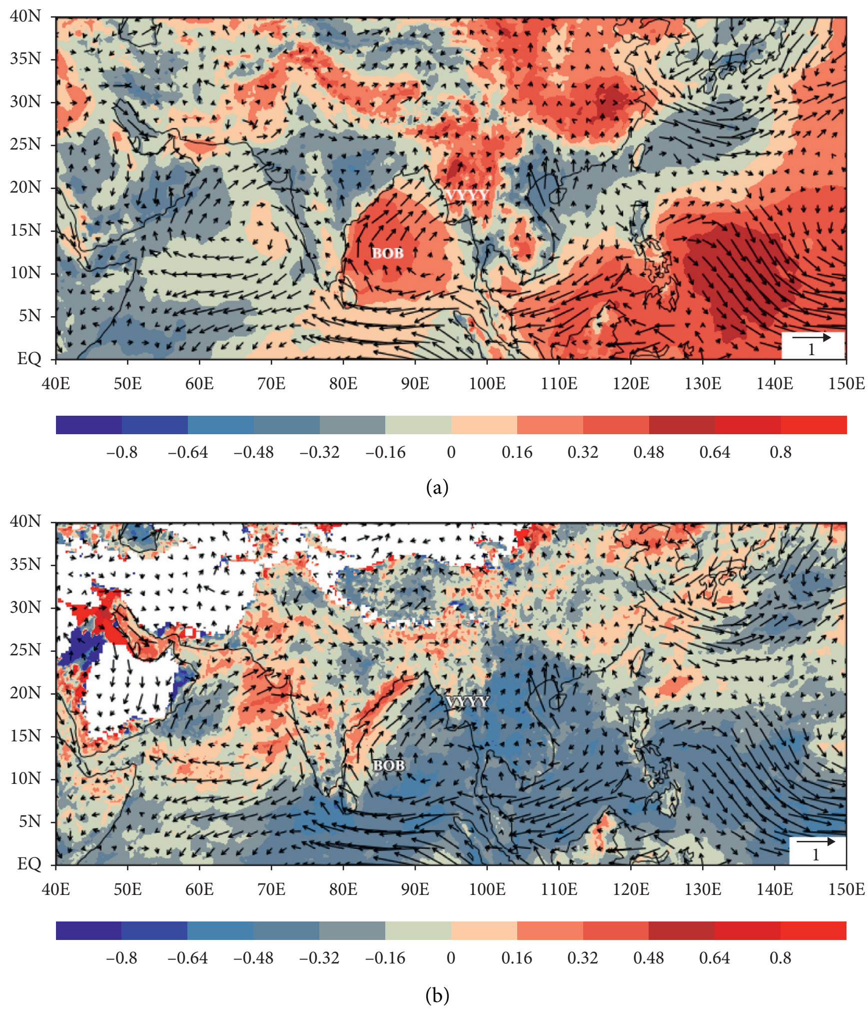


Figure 15: The composite of correlation between annual convective rainfall over VYYY and (a) annual anomalies of CAPE Index (J kg^{-1}) of the region and (b) annual anomalies of convective inhibition (J kg^{-1}) of the region (ms^{-1}), with annual 10 m component wind (ms^{-1}).

The main conclusion is that increased convective rainfall may occur during the summer El Nino phase of ENSO (JJAS). Interannual negative Indian Ocean SST anomalies may also result in increased convective rainfall over the study area as the result of Figure 16(a).

The influence of the ENSO signals on precipitation can persist from year to year [37]. Furthermore, the lagged relationship between convective rainfall over the study region, NINO 3-4, IOD, and IO during 1991–2020 was calculated for significant results (Table 1). The robust relationship of convective rainfall is observed with only summer NINO3-4 and winter IOD. Moreover, the concurrent response of NINO3-4 to summer (JJAS) convective rainfall for the study period is 0.50 ($P < 0.01$) (Table 1). A negative correlation value of −0.44 (p–0.02) with IOD is found for the winter months (DJF). But neither NINO 3-4 nor IOD found significant value for annual analysis. Only IO SST has a negative correlation of −0.65 (p 0.01) with convective rainfall over the study region during 1991–2020.

In order to select the anomalous convective rainfall exceed or less years, standardized anomalies at or above ± 1 have been used. (Figure 17). The black line represents the reference line and the black-dotted line separates the exceeding and less years during 1991–2020. The result shows each positive (exceeding: 1994, 1999, 2006, and 2008) and negative (less: 2001, 2010, 2015, 2019, and 2020) anomaly year.

Previous correlations (Figure 16) show only that summer convective rainfall over the study area has a strong positive correlation with SST at NINO 3-4 (5N–5S and 170W–120 W) and a weak positive correlation with the IOD (see Figure 16). To understand the reason for negative and positive anomalies of convective rainfall over the study area, Figure 18 depicts a composite of the correlation between convective rainfall anomalies and SST during exceeding and less years of convective rainfall. The lagged correlation between detrended seasonal convective rainfall and SST for 30 years (1991–2020) is presented in Figure 18 to observe the dependency of summer (JJAS) convective rainfall on large-scale global force.

The lagged years analysis was performed based on Figure 17 to show a more dominant annual and seasonal correlation. The converse pattern was observed during exceeding and less years (Figures 18(a)–18(d)) of annual and

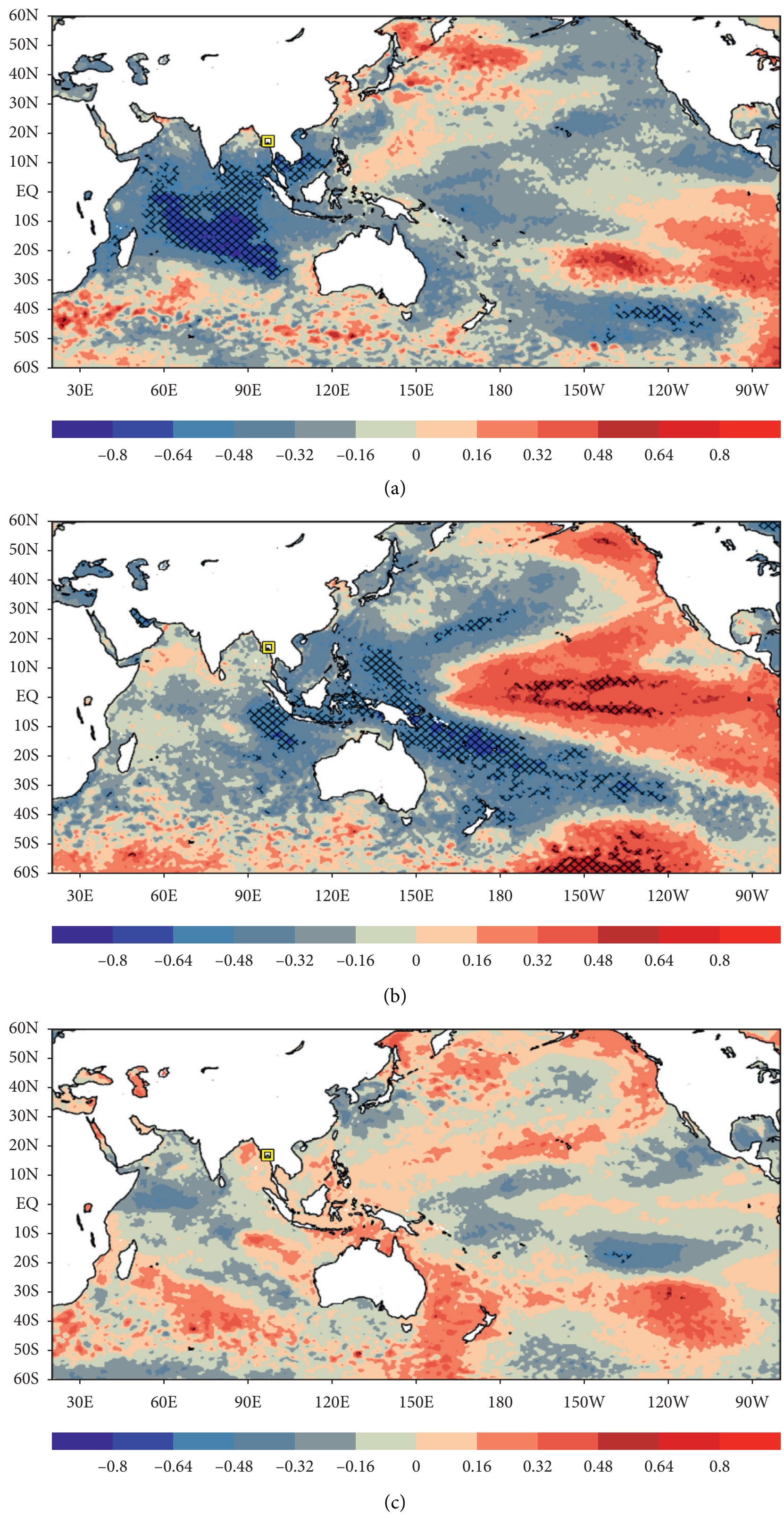


Figure 16: Correlation of SST with convective rainfall over the VYYY (shaded) and correlation significant area (hatched) for (a) annual, (b) summer (JJAS), and (c) winter (DJF) at 95% confidence level.

TABLE 1: Lagged correlation of JJAS rainfall with NINO, IOD, and IO during 1991–2020.

	NINO 3-4	IOD	IO
Annual	−0.18 ($p = 0.35$)	0.05 ($p = 0.81$)	−0.65 ($p < 0.01$)
JJAS	0.50 ($p < 0.01$)	0.14 ($p = 0.45$)	−0.17 ($p = 0.37$)
DJF	−0.02 ($p = 0.93$)	−0.44 ($p = 0.02$)	−0.14 ($p = 0.47$)

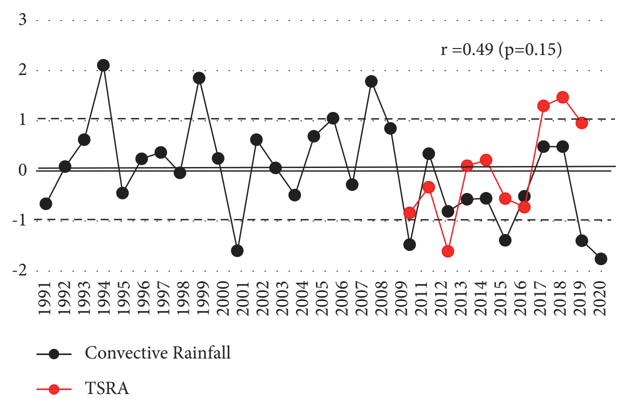


FIGURE 17: Interannual variability of standardized anomalies of TSRA occurrences (observation data) and convective rainfall (ERA5 reanalysis data) over the VYYY; the black line is the reference line and the black-dotted line bounds the value of ±1 above or below years, assuming that there are exceeding or less years of convective rainfall over study area during 1991–2020.

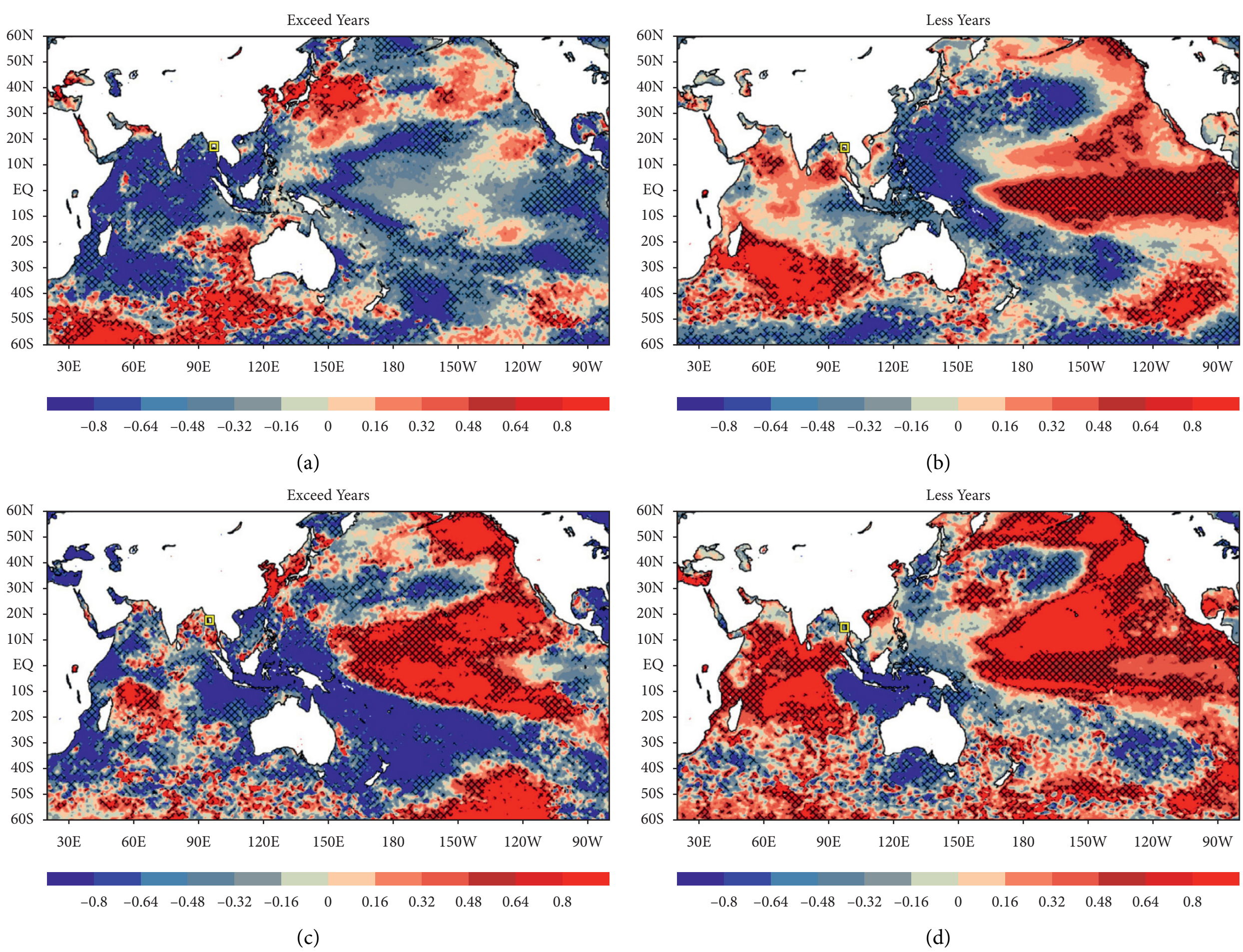


FIGURE 18: Correlation of SST with convective rainfall over the VYYY (shaded) and significant area (hatch) of (a) annual of exceeding years, (b) annual of less years, (c) summer (JJAS) of exceeding years, and (d) summer (JJAS) of less years based on Figure 17 during 1991–2020 at a 95% confidence level.

summer (JJAS). It is discovered that IO SST anomalies are the main driver of convective rainfall over the study area during summer (JJAS). Because SST anomalies over NINO 3-4 region have positive correlation in both exceeding and less years of summer (JJAS) (Figure 18(c) and 18(d)). The spatial result agrees with the previous temporal result in Table 1. But IO has only dominant different negative (positive) during exceed (less) years in annual analysis (Figures 18(a) and 18(b)). As a result of Figure 18(b), the positive anomalies, the warm phase of ENSO and IO SST may result in less convective rainfall over the study area. In contrast, the reverse pattern can be found during the years covered by Figure 18(a).

Generally, yearly frequency analysis showed how TSRA days occur more frequently year by year due to global climate change. During the eleven years (2009–2019), the minimum occurrences were 255 times in 2010. The average number of occurrences is 527, with 920 occurrences in 2018. Thunderstorms have occurred at their peak during half of the summer and the entire southwest season, and they have occurred at their peak at Yangon International Airport for at least 8 months. The maximum frequency of occurrence is 22% in July, the minimum occurrence is 1% in January, and there are no occurrences in February, March, and December. The annual CAPE values over local airport regions, the Bay of Bengal (BOB), the western equatorial Pacific, and the South China Sea show a strong positive correlation with convective rainfall over the study area. In contrast, negative CIN anomalies have been observed over the same areas as above, except for the western part of BOB along the Indian Coast. This indicates that these places had a good possibility of experiencing convective activity. Furthermore, the annual component wind, which blows from the southwest sea to the northeast, may result in increased moisture transport to the BOB's northeast continental area and encourage convective rainfall over the airport regions. Interannual convective rainfall has no significant correlation with SST at NINO 3-4 (5N–5S and 170W–120 W) in the Pacific Ocean, but there is a clear negative correlation over the Indian Ocean. However, the results of a seasonal connection analysis demonstrate a favorable correlation over the Nino 3-4 region, especially in the summer southwest monsoon season (JJAS). The major conclusion shows that, during the summer El Nino phase of ENSO, more convective rainfall may occur (JJAS). Increased convective rainfall over the research area may possibly be a result of negative IO SST anomalies. Positive anomalies, the warm phase of ENSO, and the IO SST, on the other hand, may result in less convective rainfall over the research area [34–19].

4. Conclusions

"Before-Flight-Briefing without weather discussion will lead to your flight as a blindfold beyond your vision."

Hlaing Myint (Flight Captain, Air Thanlwin, Myanmar).

On a day-to-day basis, the airliner is routed to take advantage of weather or atmospheric elements (e.g., jet stream tailwind to improve fuel efficiency). In addition, every pilot and aircrew need to know what weather situation has occurred on their route of flight. Before each flight, pilots should obtain all the pertinent information relevant to the flight's nature. A weather briefing obtained by the pilot from an approved weather source, via the Internet and/or from weather forecasting professional, is included in this.

In this study, we can learn the climatology of Yangon International Airport, which is a vital resource for the country's economic gateway. Weather forecasters or specialists can get a lot of important and useful information for weather forecasters or specialists, such as analyzing what weather situation is the most important or best time for flight operations. Fog and haze weather phenomena are most common in the winter. Thunderstorms, on the other hand, have been most common during the first half of summer and the entire southwest monsoon season, which lasts at least eight months. After examining numerous characteristics of Yangon International Airport, we identified which elements had a big impact on operations, and we obtained a lot of practical information from the operators during the important interview phase. Weather, notably TSRA and visibility, can influence aviation mishaps, as seen in the accident case study section. As a result, we identified two meteorological occurrences (TSRA and fog) that were extremely likely to result in plane crashes or operational delays. TSRA poses a greater risk than fog because it is linked to a variety of other weather phenomena such as hail, wind shear, and lightning. Yearly frequency of occurrence research revealed that, as a result of global climate change, TSRA days occur more frequently year after year. The lowest number of occurrences was 255 times in 2010 throughout the eleven years (2009–2019). With 920 occurrences in 2018, the average number of occurrences is 527. Thunderstorms peaked in the second half of the summer and throughout the entire southwest season, and they peaked at Yangon International Airport for at least eight months. In July, the largest frequency of occurrence is 22%.

The annual CAPE across local airport districts, the Bay of Bengal (BOB), the western equatorial Pacific, and the South China Sea is strongly correlated with convective rainfall over the study area. In contrast, negative CIN anomalies have been found over the same locations as above, except for the western part of BOB near the Indian Coast. This indicates that the study area had a good possibility of experiencing convective activity significantly. Furthermore, the annual component wind, which travels from the southwest to the northeast, could improve moisture delivery to the BOB's northeast continental area and encourage convective activity. In the Pacific Ocean, there is no significant link between interannual convective rainfall and SST at NINO 3-4 (5N–5S and 170W–120 W), whereas there is a distinct negative correlation over the Indian Ocean. But seasonal analysis reveals a positive link in the NINO 3-4 zone, especially during the summer monsoon season in the southwest (JJAS). The key finding suggests that more convective rainfall may occur in the El Nino phase of ENSO during the summer (JJAS) at study area. Negative IO SST anomalies may also result in increased convective rainfall over the study area. In contrast, the positive anomalies, the warm phase of ENSO and IO SST, may result in less convective rainfall over the study area. This may lead to direct or indirect influence over aircraft operation and accident prevention due to convective clouds or thunderstorms, which are high-risk aviation hazards as everyone knows. The main innovation is that we investigate the effects of thunderstorms on airport operations before determining their relationship with ENSO and the IOD separately and combined during their complete phases. The present finding has another implication for forecasters. Thus, to obtain a realistic prediction of Yangon International Airport, we also need to study other variables and need to simulate the model. According to a well-known physicist in another context, the current discovery raises a new question and a new possibility for viewing climatology from a new perspective and making significant progress in the predictability study.

Data Availability

Meteorological statistical data (METAR) based on the recommendations of the International Civil Aviation Organization (ICAO) and the World Meteorological Organization (WMO) are obtained from the Department of Meteorology and Hydrology (DMH, Myanmar) and the University of Wyoming (http://weather.uwyo.edu/surface/meteorogram/seasia.shtml), and these can be obtained freely. Flight delay and accident data are obtained from Aviation Safety Network (ASN) (aviation-safety.net) and ICAO Safety API Data Service (ICAO.int). These also can be downloaded freely. Historical Himawari-8 satellite images developed by Japan Meteorological Agency can be obtained from JAXA Himawari Monitor (P-Tree System) freely. Aerodrome's data are supported by YIA Service Company Limited and MC-Jalux Airport Services Company Limited and hence cannot be freely distributed. Requests for access to these data should be made at https://yangonairport.aero/index.php/en/. The SST NINO 3.4 indexes (area-averaged SSTA over 150W–90W, 5S–5N) data are taken from the website of the National Centre for Atmospheric Research (US), Climate Data Store, and they can be obtained freely from NINO SST Indices (NINO 1 + 2, 3, 3.4, 4; ONI and TNI) | NCAR-Climate Data Guide (ucar.edu). CAPE Index value, K-Index, and Bay of Bengal SST data are taken from ERA5 reanalysis data from ECMWF (https://cds.climate.Copernicus.EU/cdsapp#!/home?tab=overview). The above datasets are now freely available from 1950 to the present by registration at ECMWF. Open Grads (OpenGrADS-Home), climate data operator (https://code.mpimet.mpg.de/), and IBM SPSS are mainly used for this study. Among these the first two are open-source applications for everyone.

Conflicts of Interest

The authors declare that there are no conflicts of interest with the publication of this article.

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