

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL

**THE ROLE OF METEOROLOGICAL FACTORS CAUSING
FLIGHT DELAYS AND CANCELLATIONS AT ISTANBUL
SABIHA GOKCEN INTERNATIONAL AIRPORT
(NW OF TÜRKİYE)**

MINE TEKELİ

**A THESIS OF MASTER OF SCIENCE
DEPARTMENT OF EARTH AND MARINE SCIENCES
CLIMATE CHANGE PROGRAM**

ADVISOR: PROF. DR. HAKKI BALTACI

JULY 2025

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GEBZE TEKNİK ÜNİVERSİTESİ
LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

İSTANBUL SABİHA GÖKÇEN ULUSLARARASI
HAVALİMANI'NDA UÇUŞ GECİKMELERİNE VE
İPTALLERİNE NEDEN OLAN METEOROLOJİK
FAKTÖRLERİN ROLÜ (KUZEYBATI TÜRKİYE)

MİNE TEKELİ

YÜKSEK LİSANS TEZİ
YER ve DENİZ BİLİMLERİ ANABİLİM DALI
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ABSTRACT

Flight delays and cancellations significantly impact the travel plans of millions of passengers and result in substantial economic losses for nations. Weather conditions are a critical factor in major disruptions to air travel. Istanbul, located in northwestern Türkiye, is not only Europe's most populous city but also a major global aviation hub connecting Eastern and Western countries due to its extensive network of international flights. Despite the high volume of air traffic in Istanbul, a considerable number of delays and cancellations occur due to variations in the frequency and intensity of extreme weather events. This study investigates long-term variations in departure and arrival delays, as well as cancellations, associated with meteorological conditions at Sabiha Gökçen International Airport in Istanbul. To achieve this objective, Meteorological Aerodrome Report (METAR) and Special Weather Report (SPECI) observations from 2014 to 2023 were analyzed, along with delay and cancellation records obtained from a low-cost airline operating at the airport. The findings reveal that 68.6% of all departure delays occur within one hour of the scheduled departure time. Thunderstorms, predominantly occurring between 06:00 and 18:00 UTC during the warm season from May to November, account for 31.5% of total departure delays, making them the leading cause. This is followed by snowfall with the rate of 28.5%, which primarily affects night-time operations during the extended winter months of December, January, February, and March (DJFM), and fog events 24.6%, which frequently occur during night-time and early morning hours in winter and autumn. For arrival delays, 83.5% occur within two hours of the scheduled arrival time. Unpredictable fog formation, particularly during night-time and observed year-round, is the predominant cause, contributing to 54.9% of total arrival delays. With the rate of 16.4% snowfall during the extended winter and thunderstorm activity with 14.8% in the warm season are secondary factors. Regarding flight cancellations, the primary causes are fog events and heavy snowfall, which affect both departures and arrivals.

Keywords: METAR, SPECI, Delay, Cancellation, Sabiha Gokcen

ÖZET

Uçuş gecikmeleri ve iptalleri, milyonlarca yolcunun planlarını etkilemekte ve ülkeler açısından ekonomik kayıplara neden olmaktadır. Hava koşulları, hava yolculuğundaki büyük aksamalarda kritik bir rol oynamaktadır. Avrupa'nın en kalabalık şehri olmasının yanı sıra, İstanbul (Kuzeybatı, Türkiye), doğu ve batı ülkeleri arasında bir merkez olması ve yurtdışına doğrudan uçuşların yoğunluğu ile bilinmektedir. İstanbul'da çok sayıda uçuş gerçekleşmesine rağmen, aşırı hava olaylarının sıklığı ve şiddetindeki değişimler nedeniyle önemli sayıda gecikme ve iptal meydana gelmektedir. Bu amaçla, çalışmamızda İstanbul Sabiha Gökçen Uluslararası Havalimanı'nda hava koşullarına bağlı olarak sefer kalkış ve varış gecikmeleri ile iptallerin uzun dönemli değişimleri incelenmiştir. Bu kapsamda, 2014-2023 yılları arasında METAR (Meteorolojik Havaalanı Raporu) ve SPECI (Özel hava raporu) gözlemlerinin kullanımının yanı sıra, Sabiha Gökçen Havalimanı'nda uçuş gerçekleştiren bir düşük maliyetli havayolu şirketinden gecikme ve iptal kayıtları analiz edilmiştir. Gecikme sonuçları, tüm kalkış gecikmelerinin %68,6'sının planlanan kalkış saatinden itibaren bir saat içinde gerçekleştiğini göstermiştir. Sıcak dönemde Mayıs'tan Kasım ayına kadar yoğunlukla 06:00 UTC ve 18:00 UTC saatleri arasında meydana gelen fırtına olayları %31,5, kalkış gecikmelerinin ana nedeni olarak belirlenmiş, bunu uzun kış aylarında Aralık-Mart gece saatlerinde görülen kar yağışı %28,5 oranı ve sonbahar-kış mevsimlerinde gece ve sabahın erken saatlerinde oluşan sis olayları %24,6 oranla takip etmiştir. Varış gecikmeleri incelendiğinde ise toplam gecikmelerin %83,5'i planlanan varış saatinden itibaren iki saat içinde gerçekleşmektedir. Özellikle gece saatlerinde yıl boyunca tahmin edilemeyen sis oluşumları %54,9, varış gecikmelerinin başlıca nedeni olarak tespit edilmiş, bunu uzun kış dönemindeki kar yağışı %16,4 ve sıcak mevsimdeki fırtına aktiviteleri %14,8 oranında izlemiştir. İptaller söz konusu olduğunda, sis olayları ve yoğun kar yağışı hem kalkış hem de varış uçuşlarının iptalindeki temel nedenler olarak belirlenmiştir.

Anahtar Kelimeler: METAR, SPECI, Gecikme, İptal, Sabiha Gökçen

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LIST OF SYMBOLS AND ABBREVIATIONS

AAT	: Actual Arrival Time
ASOS	: Automated Surface Observing Systems
AWOS	: Automated Weather Observing System
FAA	: Federal Aviation Administration
ICAO	: International Civil Aviation Organization
LLWS	: Low Level Wind Shear
METAR	: Meteorological Terminal Aerodrome Report
NAS	: National Aviation System
NOAA	: National Oceanic and Atmospheric Administration
NWS	: National Weather Service
NTSB	: National Transportation Safety Board
OPSNET	: The Operations Network
TAF	: Terminal Aerodrome Forecast
TREND	: Trend Forecast
WMO	: World Meteorological Organization
IATA	: International Air Transport Association
UTC	: Coordinated Universal Time
CATILS	: Instrument Landing System Category
SPECI	: Special Air Report
SAW	: IATA code for Sabiha Gokcen International Airport
ASQP	: Airline Service Quality Performance
ATFM	: Air Traffic Flow Management
IFR	: Instrument Flight Rules
CFIT	: Controlled Flight into Terrain
LOC	: Terminal Aerodrome Forecast
AVAWOS	: Light Emitting Diode Weather Identifier
LEDWI	: Light Emitting Diode Weather Identifier
NWP	: Numerical Weather Prediction Aviation
WDM	: Weather Delay Model
WRF	: Weather Research and Forecasting
PBL	: Planetary boundary layer
NCEI	: National Centers for Environmental Information

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1. INTRODUCTION

Delay serves as a core metric for evaluating performance across all transportation systems, both ground and air. It has long been utilized to measure air traffic performance and remains part of the Airline Service Quality Performance (ASQP) database maintained by the U.S. Department of Transportation. However, a key limitation of the delay metric lies in its definition. From a passenger's perspective, delay is simply the difference between the scheduled arrival time (SAT) and the actual arrival time (AAT) [Wieland, 1997].

Different nations may exhibit varying tolerance thresholds for flight delays, yet most monitor these disruptions through multiple performance indicators. For instance, comparative 2014 data reveal that while 16.6% of European flights and 24.7% of USA flights experienced delays exceeding 15 minutes, Brazil's domestic operations showed 19.1% of flights either cancelled or delayed beyond 30 minutes. These metrics demonstrate significant regional variations in operational performance standards and passenger expectations regarding punctuality [EUROCONTROL, 2015], [US Department of Transportation, 2015].

Different countries may have varying tolerance levels for delays, but most monitor these delays using various performance indicators [EUROCONTROL, 2024].

Comparative data on flight delays in 2023 and 2024 reveal notable trends in aviation punctuality. As shown in **Table 1.1** both average departure and arrival delays show marginal improvements in 2024 compared to the previous year. Average departure delay decreased from 17.6 minutes in 2023 to 17.1 minutes in 2024, while average arrival delay decreased from 14.7 minutes to 14 minutes over the same period. These figures suggest gradual operational improvements, potentially attributable to improved air traffic management, airline efficiency or reduced external disruptions.

Table 1.1: Average Delay Minutes for 2023 and 2024 Years [EUROCONTROL, 2024].

	2024	2023
Average Departure Delay	17.1	17.6
Average Arrival Delay	14	14.7

According to **Table 1.2**, during the summer of 2024, both departure 60.1% and arrival 66.8% punctuality across the network declined compared to 2023. This drop was partly caused by increased air traffic, requiring extra sectors and Air Traffic Flow Management (ATFM) measures to manage congestion, especially along the south-eastern and south-western routes. Poor weather conditions further contributed to delays. However, over all in 2024, network performance improved, with departure punctuality rising to 66.2% and arrival punctuality reaching 71.9%, surpassing 2023 levels.

Table 1.2: Punctuality Rates, 2024, [EUROCONTROL, 2024].

	Punctuality (%)	Total Flights	Schedule Delay
Departure	66.2	10,605,161	19.20
Arrival	71.9	10,611,569	16.21

According to **Figure 1.1**, Seven Airports ranking among the world's top 20 busiest failed to achieve 60% departure punctuality in 2024. These included major European hubs such as Frankfurt, London Gatwick, Paris Charles de Gaulle, Rome Fiumicino, Zurich, along with Istanbul Sabiha Gökçen and Lisbon.

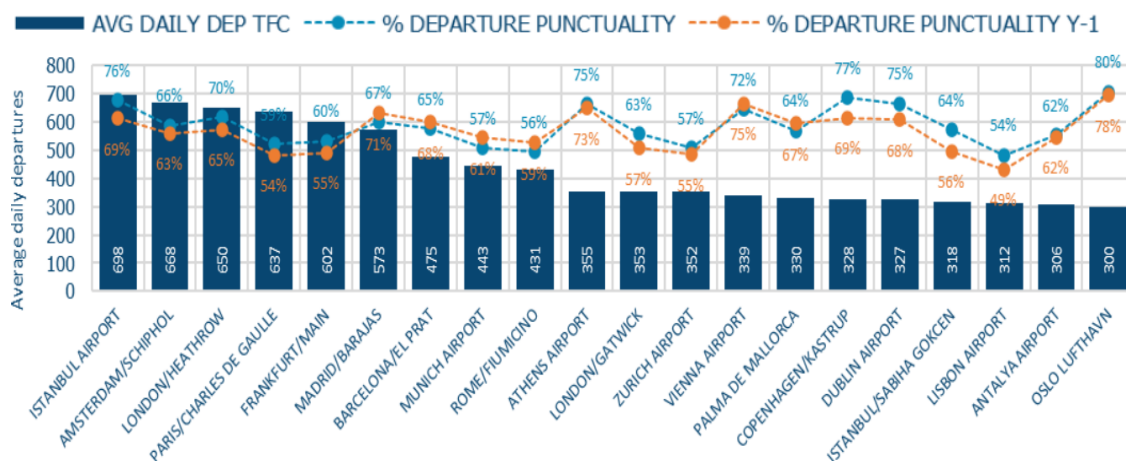


Figure 1.1: Top 20 Airports Ontime Performance [EUROCONTROL, 2024].

Figure 1.2 summarizes the national airline on-time arrival performance for the year 2024. According to the main findings, while 78.1% of arrival flights are shown on time, primary causes of delays included air carrier delays 6.44% and National Aviation System (NAS) issues 5.52%. Weather-related delays 0.76% and security delays 0.05% had a minimal impact. Additionally, 1.36% of flights were cancelled, and 0.25% were diverted. The data highlights that operational challenges played a more significant role in delays compared to weather disruptions.

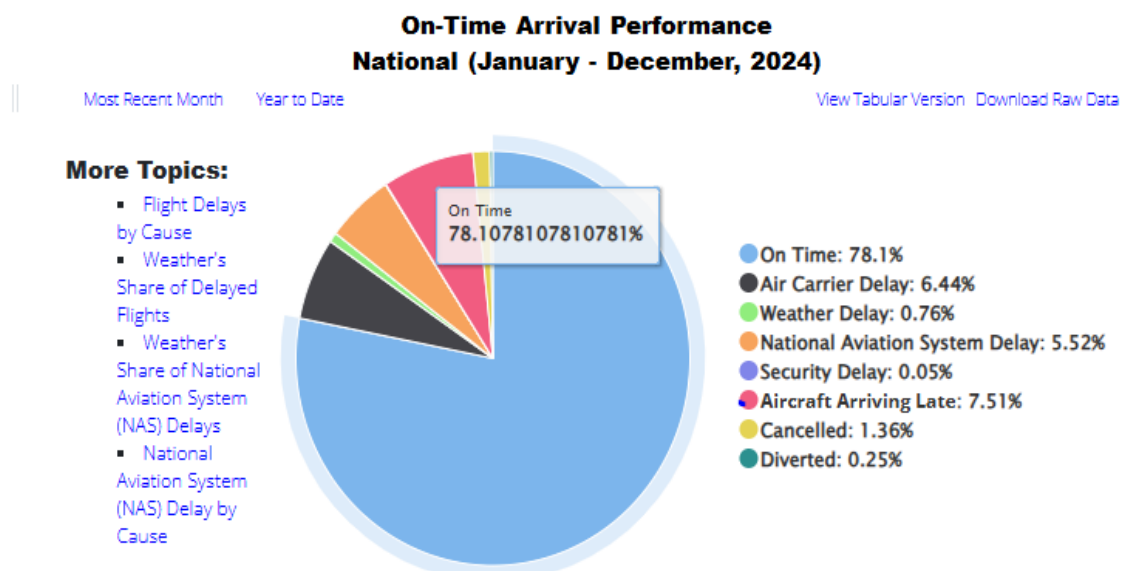


Figure 1.2: On Time Flight Statistics and Delay Causes [US Department of Transportation, 2024].

The aviation market experiences dual impacts from flight delays, influencing both consumer demand and airline operations. When selecting flights, travelers increasingly consider expected delays as part of their decision-making process. As delays grow more frequent, they effectively raise the true cost of air travel, depressing overall demand. For airlines, persistent delays create operational challenges - requiring longer scheduled block times, reducing aircraft productivity, and raising labor expenses. These added operational costs constrain airlines ultimately putting upward pressure on ticket prices [Britto et al., 2012]. Operational disruptions like diversions to alternative Airports and cancelled flights create multiple cost impacts. Extended flight durations, route deviations, and aircraft repositioning all contribute to higher fuel consumption. These events generate expenses across stakeholders: Airports face service charges, airlines incur maintenance and crew expenses, while passengers experience reduced satisfaction and potential compensation claims. Furthermore, extreme weather conditions exacerbate environmental impacts through elevated CO₂ emissions from additional fuel usage [Pejovic et al., 2009].

On-time performance remains a critical driver of passenger loyalty in aviation. As a fundamental operational metric, punctuality should take precedence over competitive differentiators and service enhancements. In China's aviation market, delays consistently rank among the top passenger grievances, prompting regulatory intervention to elevate performance standards [Vlachos and Lin, 2014].

Among the main findings of the study conducted by Sternberg et. al. [2016], the duration of flight delays due to fog, storm, rain and changes in flight schedules at hosts was highlighted. Flight delays are often linked to airlines' operational decisions, such as fleet size, flight schedules, and ticket pricing, which can lead to an increase in customer complaints. Understanding the causes of flight delays helps guide investments in aviation infrastructure, improves decision-making processes for Airports and airlines, and allows passengers to adjust their travel plans accordingly [Sternberg et al., 2016]. Despite the significance of commercial aviation in Brazil and the availability of public flight data, research on flight delays has remained largely observational, lacking in-depth analysis. This study identifies fog, storms, rainfall, and Instrument Flight Rules (IFR) operations as primary contributing factors to flight delays [Sternberg et al., 2016].

A typical commercial flight starts at the departure Airport's terminal and runway, travels through airspace, and concludes at the arrival Airport's runway and terminal. During this process, various delays can arise, including technical problems with the aircraft, ground service delays, adverse weather conditions, air traffic control restrictions, runway congestion, and capacity limitations [Reynolds-Feighan and Button, 1999]. Since aircraft are the most constrained resource, airlines design flight routes to maximize the utilization of their available fleet. This minimizes idle time between flights in an aircraft's schedule. As a result, any delay in a single flight can trigger a cascading effect, disrupting all subsequent flights in the route and impacting the schedules of other dependent resources (e.g., crew, maintenance) [Abdelghany et al., 2004]. These issues can lead to congestion in the airspace or other Airports, causing delays for other flights [Sternberg et al., 2016]. The flight cancellations were analyzed using an econometric model that accounted for delay factors, potential delay mitigations, flight characteristics, and segment attributes [Xiong and Hansen, 2013]. Initial findings revealed that cancellations are affected by factors such as aircraft size, occupancy rate, and flight distance [Sternberg et al., 2016].

Severe weather conditions can disrupt aviation operations, whether on the ground or during flight. The most critical parameters in aviation meteorology include wind and turbulence, visibility/fog, aerosol/ash concentration, cloud ceiling, rain and snow intensity/accumulation, icing, ice microphysical parameters, convection and precipitation intensity, microbursts, hail, and lightning [Gültepe et al., 2019]. Weather conditions contributing to aviation accidents include wind, visibility/cloud ceiling, high-density altitude, turbulence, icing, updrafts/downdrafts, precipitation, thunderstorms, wind shear, thermal updrafts, temperature extremes, and lightning [NTSB, 2010].

Figure 1.3a presents a bar chart statistic of weather conditions affecting near-surface aviation operations from 1994 to 2003, which are predominantly related to wind and visibility [NTSB, 2010]. In **Figure 1.3a**, conditions involving visibility, cloud ceiling height (hc), and precipitation occurred 485 times, while wind and turbulence were recorded 1,381 times, and icing/engine icing appeared 150 times. This study suggests that between 2003 and 2007, there were 8,657 aviation-related accidents, with weather being a contributing factor in 1,740 of them. **Figure 1.3b** displays these parameters in percentile terms for the 1994-2003 period, confirming that wind and visibility remain

the most critical factors. For small, non-commercial aircraft, adverse winds were the primary cause of weather-related accidents from 2000 to 2011, followed by cloud ceiling height (hc) in **Figure 1.3c**. In contrast, the trend differs for commercial jet aircraft at cruise altitudes, where over 70% of weather-related accidents from 2000 to 2011 were associated with turbulence, as shown in **Figure 1.3d** [Sharman and Lane, 2016].

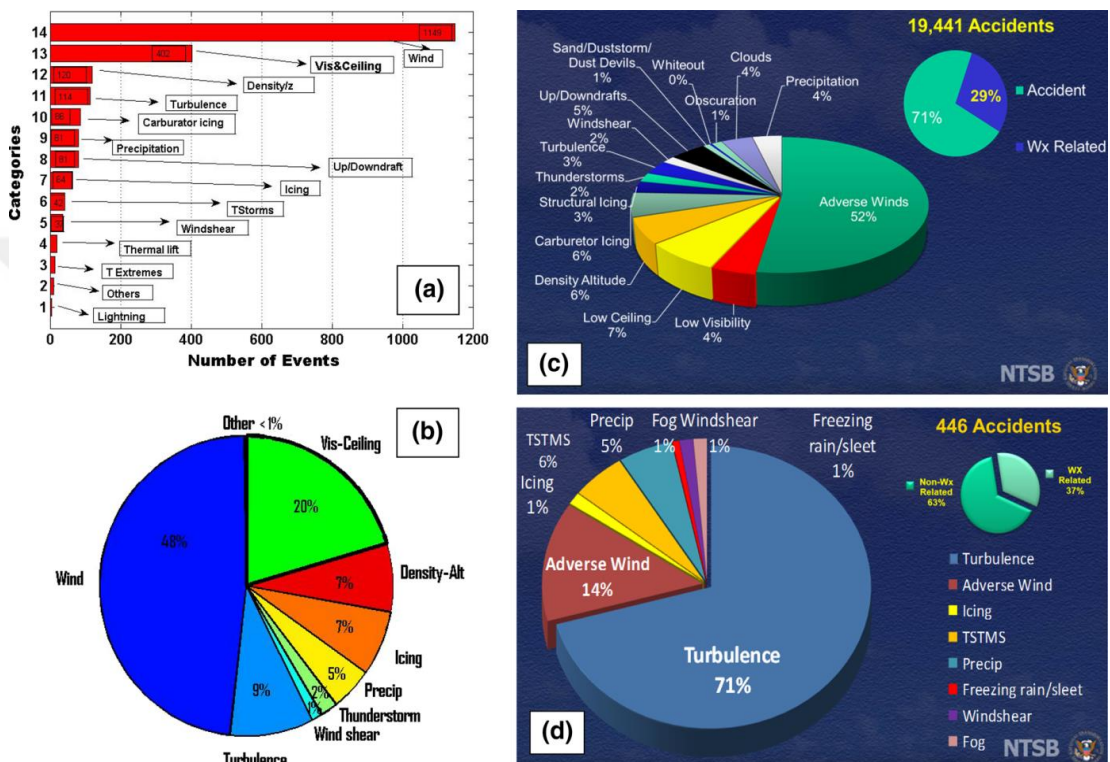


Figure 1.3: A Review of High Impact Weather for Aviation Meteorology visibility [NTSB, 2010].

An analysis of aviation accidents from 2008 to 2022 reveals that weather was a factor in 164 out of 420 total accidents 39 %, as indicated in **Table 1.3**. Among fatal accidents, the weather played a role in 3 of 11 cases 27%, while the majority 73 % were attributed to other causes. These findings highlight weather as a significant but not dominant contributor to accidents, particularly non-fatal ones. The NTSB investigates such incidents using the "Man-Machine-Environment" framework, emphasizing the need for integrated safety strategies that address weather risks alongside human and technical factors [NTSB, 2024].

Table 1.3: Weather-Related and Non-Weather-Related Accidents [NTSB, 2024].

	Weather-Related	Total	Non-Weather Related	Weather Related Percentage
Accidents	164	420	256	39 %
Fatal Accidents	3	11	8	27 %

Figure 1.4 Categorizes critical aviation safety events alongside numerical values, potentially reflecting incident frequency, risk severity, or composite safety scores. Turbulence is the most common event, suggesting a relatively lower risk profile compared to lower-impact events. Notably, the aggregated category of Runway Excursion, Powerplant Failure, Thunderstorm/ Winds, and CFIT (Controlled Flight into Terrain) holds the least event, underscoring their higher risk in aviation operations. Intermediate contributors include Bird Strike and LOC-Inflight (Loss of Control), both recognized as persistent fatal challenges in aviation safety literature.

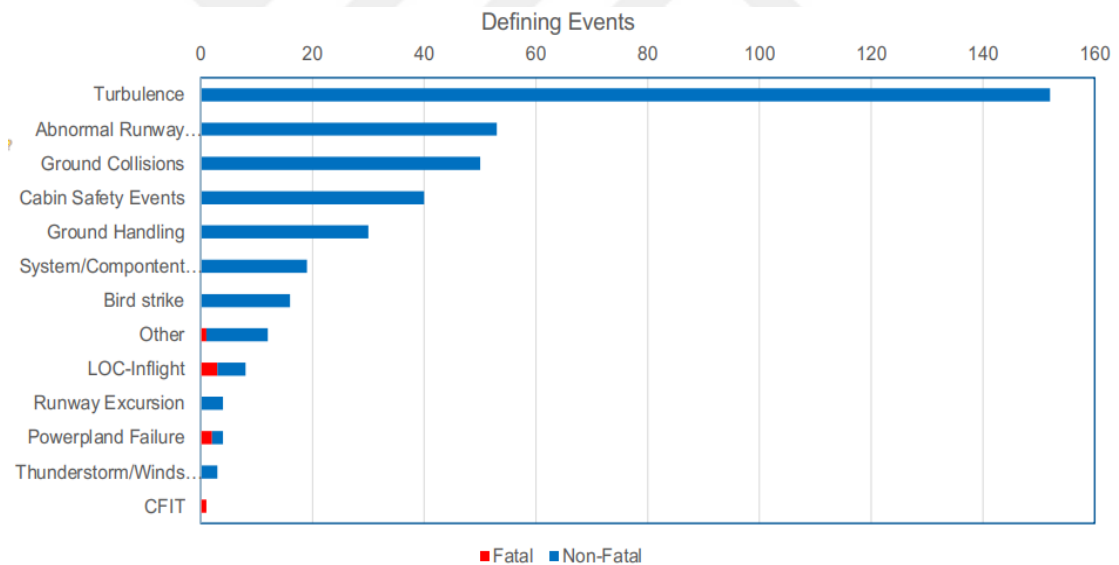


Figure 1.4: Defining Events [NTSB, 2024].

Figure 1.5 illustrates the distribution of weather-related aviation accidents among U.S. scheduled air carriers over a 15 years period from 2008 to 2022. It shows that turbulence was the dominant cause, followed by general weather conditions, thunderstorms, low ceiling/visibility, and low-level windshear. The chart also lists additional weather factors like icing and adverse winds without specifying their percentages. Out of 431 total accidents, 61% were weather-related, while 39% were

non-weather related. The data is sourced from the NTSB, highlighting turbulence as the primary weather hazard in aviation safety during this period. In **Table 1.4**, critical parameters, dynamics and weather forecasting are also defined.

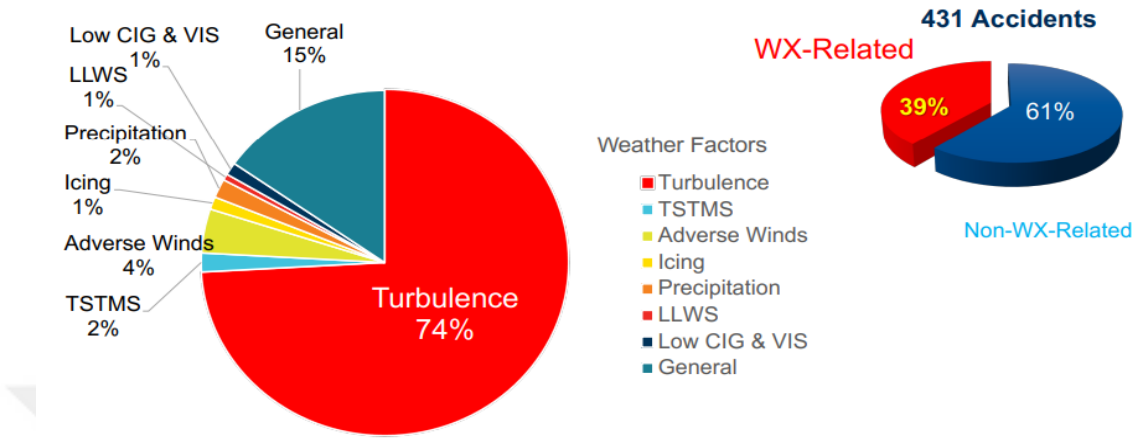


Figure 1.5: Air Carrier Weather- Related Accidents [NTSB, 2024].

Categorizes critical parameters, weather dynamics, and forecasting methods in aviation meteorology across different scales. **Table 1.4**.

Table 1.4: Critical Parameters, Dynamics, Weather Forecasting [Gultepe et al., 2019].

Critical Parameters	Weather Forecasting	Weather Dynamics
Clouds and Fog	Reporting Systems for Aviation Meteorological Applications	Turbulence and Energy Dissipation
Ice and Droplet Microphysics	NWP Time and Space Scale Issues)	Wind Gusts
Precipitation Type and Rate	Data Integration	Waves
Freezing Precipitation	Artificial Intelligence	Jet Stream Intensity
Icing, and Ground De-icing	Deterministic Versus Probabilistic Methods for Nowcasting	Low Level Wind Shear
Frost		
Visibility and Ceiling	Integrated Systems	Microburst and Tornado
Blowing Snow	Climate Change Modeling for Aviation Applications	Temperature and RH
Convective Activities and High Ice Water Content	Contrails And Climate Change Reporting Systems for Aviation Meteorological Applications	
Lightning		
Ash and Dust Physical Parameterizations		

The Aviation Automated Weather Observing System (AV-AWOS), initially proposed by **Mandel et al. [1975]**, delivers meteorological parameters critical for aviation operations. The proposed AWOS also incorporated additional variables, such as visibility and sky conditions. Later, **Wade et al. [2003]** distinguished drizzle precipitation from other particles by integrating the Light Emitting Diode Weather Identifier (LEDWI) sensor with Automated Surface Observing Systems (ASOS), since drizzle rates typically remain below 0.25 mm/h. Both AWOS and ASOS are designed for unmanned locations and employ multi-sensor algorithms **[Ramsay et al., 1999]**.

“Weather forecasts for aviation operations are provided 2 hours in advance based on trend type forecasts (TRENDS) and over 2 hours as terminal aerodrome forecasts (TAFs).” **[Jacobs and Maat, 2005]**.

Meteorological data from Airports is updated every 30 minutes through standardized reports known as METARs. For short-term predictions, trend forecasts (TRENDS) cover the next two hours, while longer-term outlooks for the current and following day are provided as terminal aerodrome forecasts (TAFs) **[Gultepe et al., 2017]**. In METAR reports, the main meteorological parameters are recorded every 30 minutes, especially for international airlines. These meteorological parameters include horizontal visibility, wind speed and direction, temperature, present weather, sea level pressure, cloud cover and height, precipitation type and intensity etc. For meteorological forecast in Airport, TAF are recorded every 3 hours. As a result, TAF is issued 12 times in a day, consisting of 8 short TAFs covering forecast periods of 1 to 10 hours and 4 long TAFs extending from 8 to 26 hours **[Jacobs and Maat, 2005]**.

In most of the landing and take-off decisions, flight plans are decided based on meteorological conditions such as wind speed and direction, visibility, and cloud base height. Both the World Meteorological Organization (WMO) and International Civil Aviation Organization (ICAO) have suggested that automated weather observing systems (AWOS) with detail surface observations of wind and visibility should be used at Airports. These systems are dedicated to data acquisition, processing, dissemination, and display in real time of meteorological parameters that affect landing and take-off operations. The surface parameters include surface wind, visibility, runway visual range, height of cloud base, air and dew-point temperatures, and atmospheric pressure, all of which affect flight conditions at the surface **[Gultepe et al., 2009]**. For practical applications, encoding software has been developed to convert

the TAF and TREND guidance into an automatically generated alphanumeric code. The TAF and TREND guidance, along with the AUTOTAF encoding software, were created and deployed in collaboration with the German firm Meteo Service Weather Research [Knuppfer, 1997]. The TAFs use meteorological observing systems and Numerical Weather Prediction (NWP) outputs [Kilpinen, 1994]. For aviation products prepared by National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS), some extreme meteorological events are also included in the observation and forecasting reports such as volcanic ash detection, lightning detection, turbulence, icing, fog etc. [Schmit et al., 2017].

Several future Level 2 products, made possible by ABI's additional spectral channels, have been developed, with their algorithms detailed in Algorithm Theoretical Basis Documents (ATBDs). These products include aircraft icing threat, cloud liquid water, cloud type, convective initiation, ice cover, low cloud and fog, total ozone, SO₂ detection (for volcanic eruptions), surface emissivity, tropopause folding turbulence prediction, vegetation index, and visibility, among others [Schmit et al., 2017]. Thunderstorm is a vital importance for nowcasting forecast because it causes numerous delays and cancellations in Airports. For this purpose, The PGLM (Pseudo geostationary Lightning Mapper) product serves as a nowcasting and early warning tool, enhancing forecasters' situational awareness by detecting rapidly intensifying thunderstorms capable of producing severe weather events, such as microbursts [Goodman and Griswold, 2013].

The Federal Aviation Administration (FAA) defines a flight that is 15 minutes or more behind schedule as a delayed flight. In 2013, weather-related delays caused almost 10 million minutes of disruption. If weather conditions become too severe to be safe for a flight, cancellations may occur instead of delays. Weather is the primary reason for air traffic delays in the National Airspace System. According to OPSNET's "delay by cause" data from June 2017 to May 2023, 74.26% of significant delays (lasting more than 15 minutes) were due to weather conditions, as illustrated in **Figure 1.6**. Meteorological conditions constitute the primary cause of air traffic delays, primarily due to capacity constraints imposed on critical aviation resources. Comprehensive analyses reveal that weather-related factors account for approximately three-quarters of total delay incident.

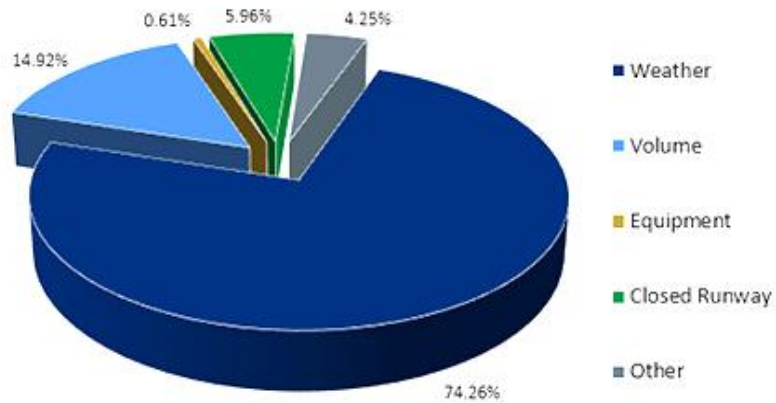


Figure 1.6: Causes of Air Traffic Delay in the National Airspace System 2017-2023 [FAA].

According to a study published by **Goodman and Griswold [2019]**, they investigated the role of meteorological conditions causing delays and cancellations at major Airport in Midwest **Figure 1.7**. **Weber et al. [1991]** developed a more aviation-focused method called the Aviation Weather Delay Model (AWDM), using historical data to predict weather-related delays at 20 major U.S. Airports. Their findings revealed that 52% of annual delays were due to reduced visibility, while thunderstorms and dense fog contributed to 25% and 23% of delays, respectively **[Ballesteros and Hitchens, 2017]**.

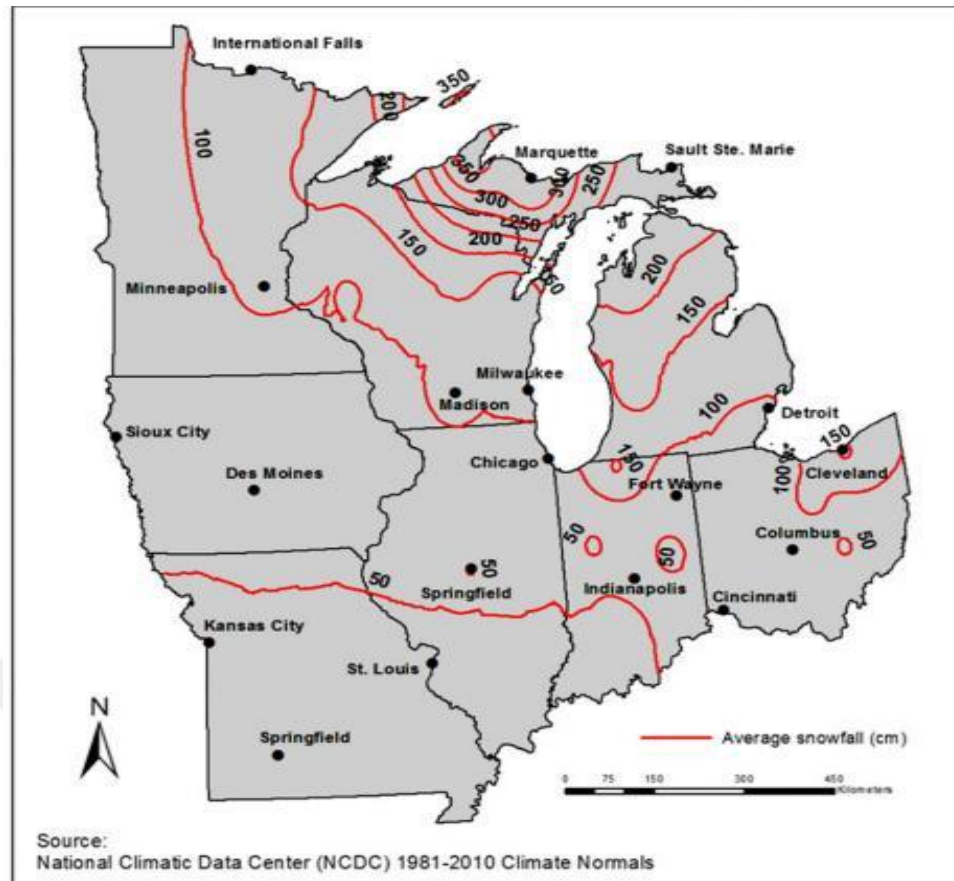


Figure 1.7: Average Snowfall [Goodman and Griswold, 2019].

To analyze flight cancellations, large-scale weather patterns were studied to identify the systems responsible for these disruptions. Despite the significance of such events, there remains a considerable lack of research on the specific meteorological factors that lead to Airport operational challenges. Although delays and cancellations are often used to measure the impact of winter storms, the exact weather conditions triggering these disruptions are poorly understood. Their research aims to identify the meteorological factors contributing to flight delays and cancellations in the Midwest during winter [Ballesteros and Hitchens, 2017].

In the Midwest, typical winter temperatures between 1981 and 2010 varied from around -38°C in northern Minnesota to approximately 8°C (35°F) in the southern regions near the Ohio River. A similar pattern exists for snowfall, with southern Missouri receiving less than 50 cm per year, while northern Michigan -particularly exposed areas- gets over 350 cm annually, as illustrated in **Figure 1.7**. The heaviest snowfall occurs along the downwind shores of The National Weather Service (NWS) operates as the primary agency responsible for issuing weather warnings and

advisories in the United States when meteorological systems meet predetermined disruption thresholds. Utilizing an integrated network of monitoring tools including satellite imagery, radar systems, and atmospheric observations, NWS meteorologists assess storm impacts across specific regions. A critical component of this network is the Automated Surface Observing System (ASOS) - a nationwide array of Airport-based weather stations that provide real-time atmospheric data essential for aviation operations [NWS, 2012]. This system plays a pivotal role in operational decision-making, enabling aviation professionals to evaluate whether to delay or cancel flights when encountering hazardous weather conditions, thereby ensuring both safety and operational efficiency within the national airspace system.

Their research could also be useful to winter weather researchers, serving as a climatic record of the region and showing how severe winter storms can affect daily community operations [Ballesteros and Hitchens, 2017]. As Goodman and Griswold's study employs historical hourly weather data alongside FAA performance metrics to analyze how different weather conditions-including precipitation types (drizzle, rain, snow), visibility restrictions (fog, mist, haze), weather descriptors (freezing conditions, thunderstorms), and intensity levels (none, mild, moderate, severe)-affect flight disruptions such as delays and cancellations [Goodman and Griswold, 2019]. The research focuses on 77 FAA-reporting Airports, with particular emphasis on ten major U.S. aviation hubs selected based on two key criteria: availability of extensive historical weather data, and high-volume flight operations. These strategically chosen Airports provide a robust dataset for analyzing weather-impact patterns in high-density air traffic environments.

As shown in **Table 1.5** Rain 39% and mist 32% are the most frequent weather disruptions, particularly at major hubs like MIA, JFK, and SFO. However, freezing conditions cause the worst delays-averaging 83 minutes for departures peaking at 96 minutes at JFK and ATL and 67 minutes for arrivals. Thunderstorms follow closely, with 74-minute departure delays 90 minutes at ORD and SFO and 68-minute arrival delays. Fog severely impacts MIA and PHX, causing 98-minute departure delays and reducing Airport efficiency to 66-72%. While mist/rain accounts for 73% of disruptions at busy Airports like JFK, their delays (~60 minutes) are less severe than rarer freezing/thunderstorm events, which cause 90+ minute delays and major efficiency drops the scores of 68-74% [Goodman and Griswold, 2019].

Table 1.5: Statistics for Weather Type Categories [Goodman and Griswold, 2019].

Weather Type (%)											
	JPK	ATL	MIA	MSP	OBD	DAL	SLC	PHX	SEA	STO	Avg
Drizzle	4	6	1	1	5	1	0	2	1	2.8	-
Rain	33	32	38	22	28	32	79	66	54	40	39
Snow	7	1	0	2	3	2	17	0	1	1	7.2
Freezing	1	1	0	2	2	1	3	0	2	1	1.3
Thunder-storm	3	7	17	4	4	8	4	16	1	1	3.9
Fog	5	3	3	17	4	4	18	0	1	11	3.9
Mist	40	40	30	35	39	20	13	32	36	-	32.2
Haze	7	10	3	8	7	12	10	4	1	9	7.1
Average Departure Delays (minutes)											
	JPK	ATL	MIA	MSP	OBD	DAL	SLC	PHX	SEA	STO	Avg
Drizzle	56	49	32	65	60	62	38	n/a	42	58	46.9
Rain	69	56	63	81	69	52	43	82	69	62	54.5
Snow	80	99	n/a	48	68	84	40	n/a	42	41	65.4
Freezing	100	152	n/a	68	91	50	68	n/a	88	41	83
Thunder-storm	101	74	74	64	88	70	85	100	47	71	75.3
Fog	98	61	96	68	181	73	80	67	58	-	71.7
Mist	62	50	94	47	64	44	46	58	45	58	56.7
Haze	59	41	50	41	47	38	41	58	43	53	47.1
Average Arrival Delays (minutes)											
	JPK	ATL	MIA	MSP	OBD	DAL	SLC	PHX	SEA	STO	Avg
Drizzle	59	56	27	49	70	36	42	n/a	49	63	49.1
Rain	62	51	24	34	72	45	48	45	47	67	54.1
Snow	61	78	74	51	77	42	46	48	55	60	57.4
Freezing	90	200	n/a	63	90	38	86	n/a	62	40	67.1
Thunder-storm	76	76	62	60	108	78	65	57	47	64	67.8
Fog	70	66	82	60	107	65	86	132	47	64	74.2
Mist	59	57	34	61	72	35	44	56	42	60	53
Haze	60	49	32	46	57	32	63	34	43	55	43.3
Airport Scores (%)											
	JPK	ATL	MIA	MSP	OBD	DAL	SLC	PHX	SEA	STO	Avg
Drizzle	92	95	99	92	92	96	91	n/a	96	93	94
Rain	80	90	89	90	88	88	87	90	87	92	91
Snow	80	74	80	82	89	73	83	84	88	98	81.9
Freezing	68	57	n/a	72	78	84	71	n/a	72	98	75.1
Thunder-storm	74	76	82	77	77	74	78	97	78	88	79.4
Fog	84	87	72	81	83	79	75	66	91	94	80.8
Mist	50	93	87	88	90	92	87	87	98	94	90.3
Haze	92	97	97	96	92	97	95	89	97	96	95.1

2. DATA AND METHODOLOGY

2.1. Study Area: Sabiha Gokcen International Airport

Istanbul, which is in two continents: Asia and Europe, is the most industrialized, agriculturally developed and populated geographical division in Türkiye with a population density of up to 2500 people per km². Because of economic capital of the country, this region continues to take migration from inside and outside of Türkiye. Factors such as proximity to Europe and Asia, development of trade, tourism and uncontrolled population growth have rapidly affected the development of the aviation sector. Basically, two International Airports serve both domestic and international flights: Istanbul- and Sabiha Gokcen- International Airports. From these Airports, Sabiha Gokcen International Airport (International Civil Aviation Organization (ICAO): LTFJ, International Air Transport Association (IATA): SAW) is in the Asian part and 32 km southeast of the city center and as known as the hub for the major commercial airlines **Figure 2.1**. When we analyzed passenger statistics of the Airport, it was shown an obvious increase in total passengers from the beginning of 2014 to the end of 2023, except Covid pandemic times **Table 2.1**. While domestic passenger transportation was quite high in the beginning, there has been a significant increase in the number of international passengers and flights, especially in recent years. Therefore, in order to increase capacity, new runways were added to the Airport along with the new terminal building and tower during 2023.

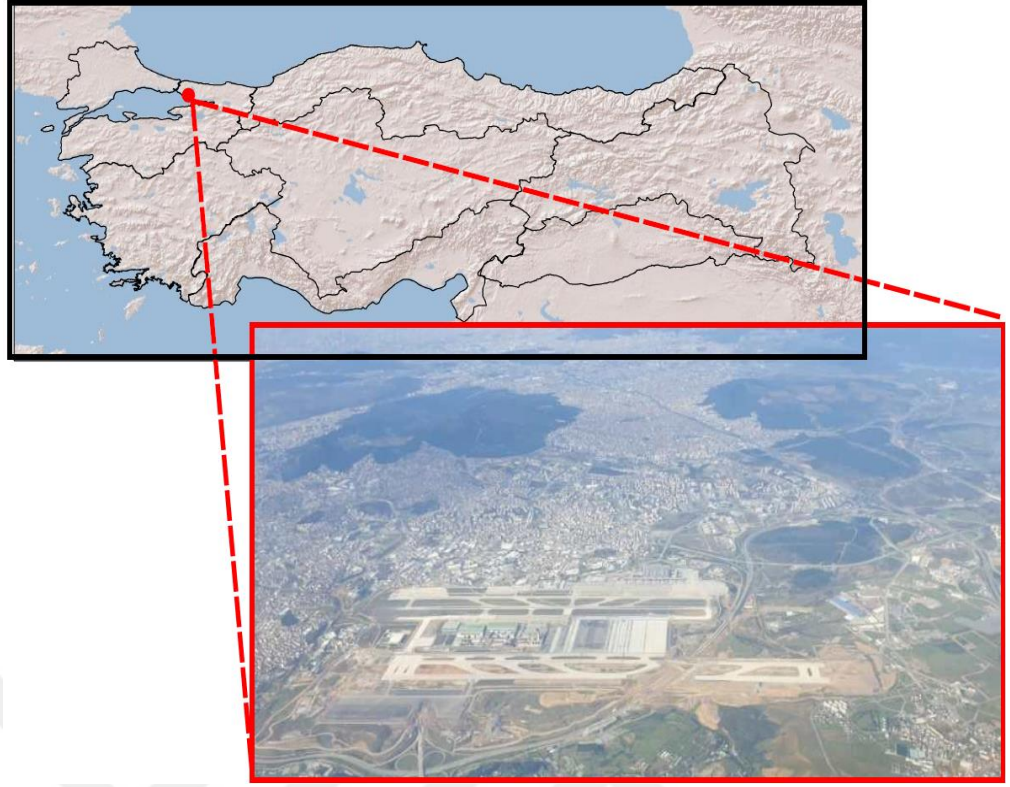


Figure 2.1: Bird's eye view of Sabiha Gökçen International Airport with its location in Türkiye

Table 2.1: Annual Total Number of Passengers and Flights at Sabiha Gökçen International Airport ([06-haziran-2024-yolcu-ve-ucus-statistikleri.pdf](#)).

Year	Domestic Passengers	International Passengers	Total Passengers	Domestic flights	International Flights	Total Flights
2014	15,028,244	8,603,620	23,631,864	112,798	72,612	185,410
2015	18,581,984	9,703,594	28,285,578	136,732	81,894	218,626
2016	20,118,328	9,531,709	29,650,037	146,057	84,429	230,486
2017	20,977,293	10,338,817	31,316,110	139,321	80,345	219,666
2018	22,387,047	11,671,870	34,058,917	145,554	86,716	232,270
2019	21,393,028	14,072,480	35,465,508	135,385	100,086	235,471
2020	11,703,985	5,278,471	16,982,456	83,843	42,545	126,388
2021	16,137,849	8,854,067	24,991,916	111,717	69,761	181,478
2022	15,247,815	15,532,542	30,780,357	97,130	102,906	200,036
2023	17,731,692	19,366,740	37,098,432	107,580	120,298	227,878

The increase in the number of flights and carried passengers has made both flight safety and timely delivery of passengers to their destinations more important, aiming to minimize possible economic losses and dangers. Delays and/or cancellations in the take-off or landing of aircraft affect the schedule of other flights, creating negatives in

terms of air traffic as well as economic losses. Weather conditions are known as one of the most important reasons for these delays and cancellations. As indicated by Federal Aviation Administration (FAA), weather is the largest cause of air traffic delays, accounting for 69% of all air traffic delays from 2008 to 2013 [FAA 2017a, b]. Therefore, air traffic controllers and meteorologists are always in contact in terms of weather forecast and possible formation of extreme weather conditions. However, geographical, topographical, and atmospheric features can enable the sudden development of extreme meteorological events, and hence, can negatively affect the accuracy of the forecasts.

Istanbul is an area where extreme weather conditions develop suddenly and are difficult to predict. Some important factors such as the existence of the Bosphorus strait, land-sea interaction, significant changes in land cover with urbanization, surrounded by seas, and the influence of maritime and continental air masses enable the occurrence of specific meteorological events. For this reason, in order to better understand the formation mechanisms of hazardous weather conditions [Taszarek et al., 2020], researchers specifically focused on occurrence of unpredicted hailstorm [Baltaci et al., 2018], [Toker et al., 2021], fog [Ezber and Sen, 2022], thunderstorm [Yavuz, 2024], snowfall [Kindap, 2010], extreme precipitation and flash-flood events [Yucel, 2015], [Akkoyunlu et al., 2019] over Istanbul for the selected episodes. In addition to these studies, we need climatological perspective for the occurrence times and frequencies of meteorological events causing delay/cancellation for Sabiha Gokcen International Airport.

2.2. Delay and Cancellation Records and Meteorological Data

The study initially presents data on flight delays and cancellations caused by weather conditions between 2014 and 2023. Both departure and arrival flights at SAW Airport (Sabiha Gökçen Airport) were considered in the analysis of delays. For departure flights, it was recorded that a total of 520 flights experienced delays over 83 distinct days during the 10-year period. The total delay time for departure flights due to extreme weather conditions was 31,139 minutes (averaging 1 hour per delay). For arrival flights at SAW, a total of 356 delays occurred on 102 distinct days, all attributed

to meteorological factors, resulting in a cumulative delay of 25,743 minutes (averaging 72 minutes per delay).

To identify the primary meteorological factors contributing to flight delays and cancellations, METAR and SPECI reports were obtained for selected time intervals. Specifically, climatological data from hourly METAR and SPECI observations at Sabiha Gökçen International Airport (SAW) were utilized, covering the period from 2014 to 2023. These datasets were sourced from the National Centers for Environmental Information (NCEI) database (<https://www.ncei.noaa.gov/data/>), which provides comprehensive and reliable historical weather records. The integration of these observations enabled a systematic analysis of weather-related disruptions, offering insights into the temporal and climatic patterns affecting aviation operations at SAW.

2.3. Analysis Method

To analyze the relation between weather conditions and flight delay/cancellation, we have assessed by looking at the weather parameters 1 hour before the scheduled departure/arrival time of each delayed flight to determine which meteorological factors had the most influence in the decision to delay the flight, similar to the FAA's classification factors for delaying flights [FAA, 2008], which were adapted from the guidelines of National Weather Services and International Civil Aviation Organization (ICAO). In this part, we have focused on the present weather, surface wind speed and direction, snow on the runway, thunderstorm, low visibility, cloud base, and combinations of factors (any combination of two or more of the meteorological factors being reported at the same time). From the METAR and SPECI records, specific weather conditions causing delays for Sabiha Gokcen International Airport were classified in **Table 2.2**.

Table 2.2: METAR Code Explanations Causing Delays at Sabiha Gökçen Airport.

Meteorological Factors	METAR Code Detail		Main Result For Delays
Visibility	BR	Mist	Poor or no horizontal visibility and runways
	FG	Fog	
Precipitation	SN	Snow	Poor visibility during heavy precipitation, CB (cumulonimbus) cloud activity at runways, icing at runways due to precipitation
	TS	Thunderstorm	
Wind characteristics	G-KT	Wind direction and/ or speed	Involuntary change of course of plane, or it may not be able to safely take off or land depending on crosswinds and runway direction.
Freezing fog / Icing	FZ	Freezing fog is a significant concern in aviation due to its potential to impair visibility and cause dangerous ice accumulation on aircraft surfaces. It occurs when supercooled water droplets remain in a liquid state at temperatures below freezing.	
Combination of factors	Any combination of two or more of the above factors being reported at the same time. For example, strong thunderstorm activity, which resulted in severe wind speed with gust and poor visibility, conditions due to heavy precipitation.		

For cancellations, similar to the ICAO guidelines, we have classified storms that can cause cancellations from METAR/SPECI record, as shown.

3. RESULTS AND DISCUSSION

3.1. Distribution Delays for Departure and Arrival Flights

From the annual distribution, departure delay days have significantly increased from 2014 to 2023. **Figure 3.1a** Additionally, there are significant increases in departure flight delays. As can be seen from **Figure 3.1a**, the maximum number of departure delay days occurred during the years 2022, 2023 and 2017 with 15, 11, and 11 days. On arrival delays, there has been significant increase in the number of arrival delay days, with maximum number of delays occurred during 2022, 2017, and 2023 years with 21, 13, and 11 days, respectively **Figure 3.1b**. As can be seen from the results, delays caused by departures and arrivals have occurred frequently, especially in the last decade.

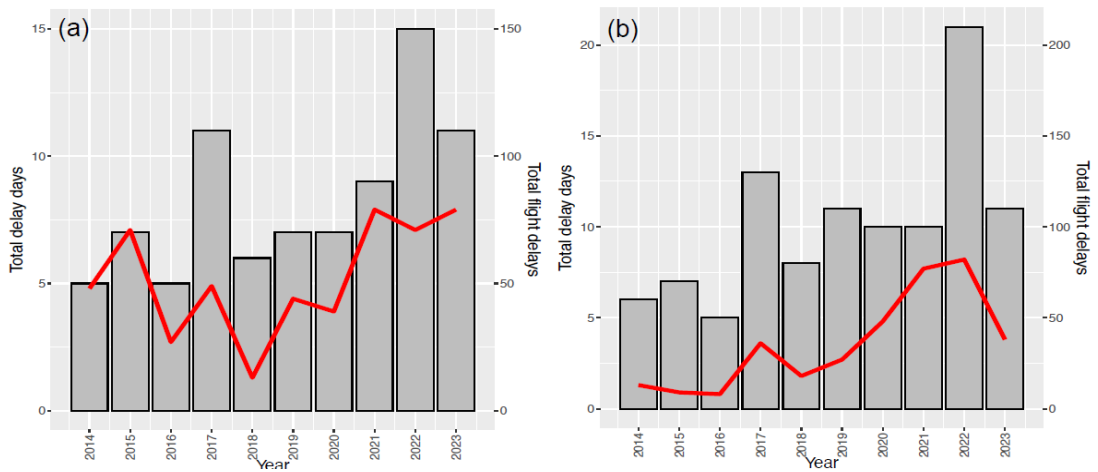


Figure 3.1: Annual total number of delay days (bar plot) and total flight delays (line plot) for a) departure and b) arrival flights at Sabiha Gökçen International Airport (Istanbul) for the period 2014-2023.

An analysis of the monthly distribution of departure delays reveals that the highest number of delayed days occurred in January 12, February 12, and March 9 days **Figure 3.2a**. Seasonally, departure delays were most frequent in winter 32, followed by summer 19, spring 17, and autumn 15. Similarly, arrival delay data indicate peak delays in January 13, October 13, and February 12 days **Figure 3.2b**, with seasonal trends showing the highest incidence in winter 31, trailed by autumn 28, spring 26,

and summer 18. These findings demonstrate that the majority of both departure and arrival delays occur during winter, while summer for departures and autumn for arrivals emerge as secondary periods of significance for delays.

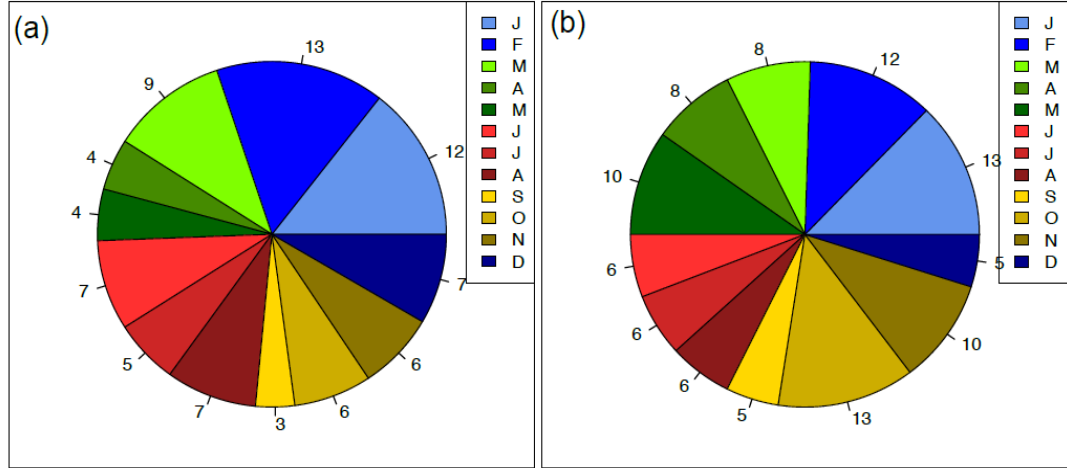


Figure 3.2: Monthly distribution of delay days for a) departure and b) arrival flights at Sabiha Gökçen International Airport (Istanbul) for the period 2014-2023.

The time of the day during which the delays occur is quite important. Therefore, we divided the day into four equal time periods as: 00-06, 06-12, 12-18, and 18-24 UTC. As shown in **Figure 3.3**, the highest number of departure delays occurs between 06:00-12:00 UTC, followed by delays during the late hours of the night. As for arrival delays, while delays are frequently observed during the late hours of the night, they are followed by delays occurring between 06:00 and 12:00 UTC.

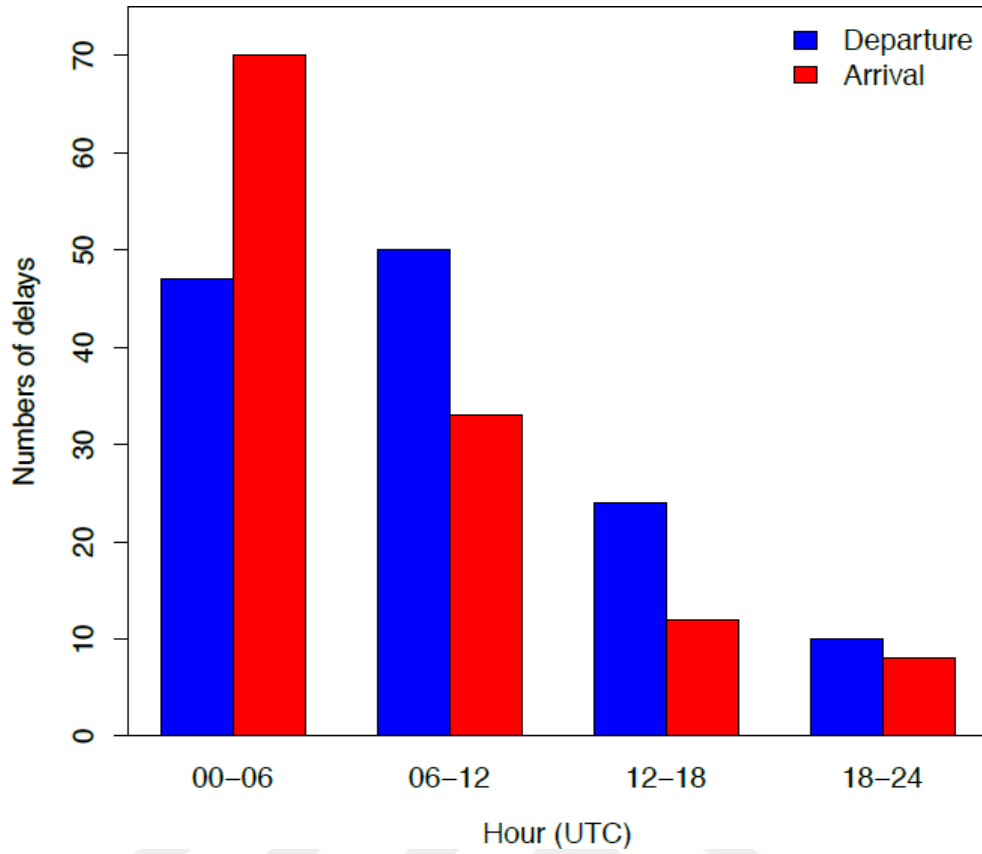


Figure 3.3: Hourly distribution of delay days for departure and arrival flights at Sabiha Gokcen International Airport for the period 2014-2023.

Delay durations are quite important, especially for connecting flights. While 43.1% of total departure delays occurred within the first half hour, 25.5% took place in the 30-60 minutes interval, meaning that 68.6% of all departure delays involve a delay of first one-hour **Figure 3.4**. It was found that 83.5% of all arrival delays occurred within the 2-hour time frame.

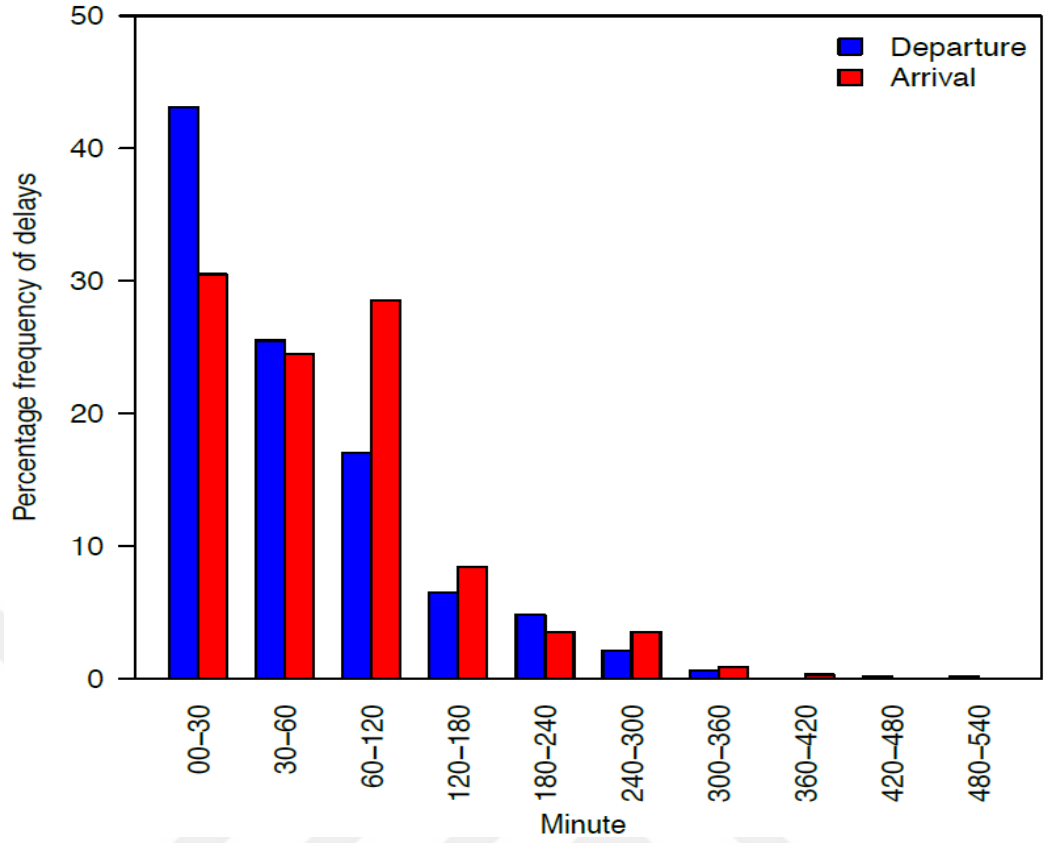


Figure 3. 4: Percentage (%) frequency distribution of flight delays in terms of times (min) for departure and arrival flights at Sabiha Gokcen International Airport for the period 2014-2023.

3.2 Meteorologically Originated Delays for Departure and Arrival Flights

When we matched the flight data with METAR/SPECI records for the 2014-2023 period, it was found that delays were primarily caused by six meteorological events at Sabiha Gokcen International Airport. These meteorological events are identified as: snow, thunderstorm, wind, icing, fog, and mist.

In departure delays originated from weather extremes; thunderstorm, snow, and fog account for 84.6% of total delays, with thunderstorm being the leading cause of departure delays with 31.5% percentage **Figure 3.5a**. Along with its location, frequent sudden development of thunderstorms around the Airport is one of the main reasons causing departure delays at Sabiha Gokcen International Airport. Difficulties in predicting thunderstorm activity hinder the safe and timely planning of flights, causing significant economic losses. As mentioned by **Kahraman et al. [2020]**, Mediterranean

coasts are projected to experience a significantly higher frequency of severe thunderstorm environments. They declared that warming of sea surface, and the local factors such as shear frequency are the main atmospheric factors for the increase across Mediterranean. **Kokal et al. [2023]** ve **Baltaci et al. [2024]** emphasized that there is obvious increasing trend in sea surface temperature of the Sea of Marmara and Black Sea, respectively. This means that further departure delays can be expected in the future due to the susceptibility to atmospheric instability conditions at Sabiha Gokcen Airport.

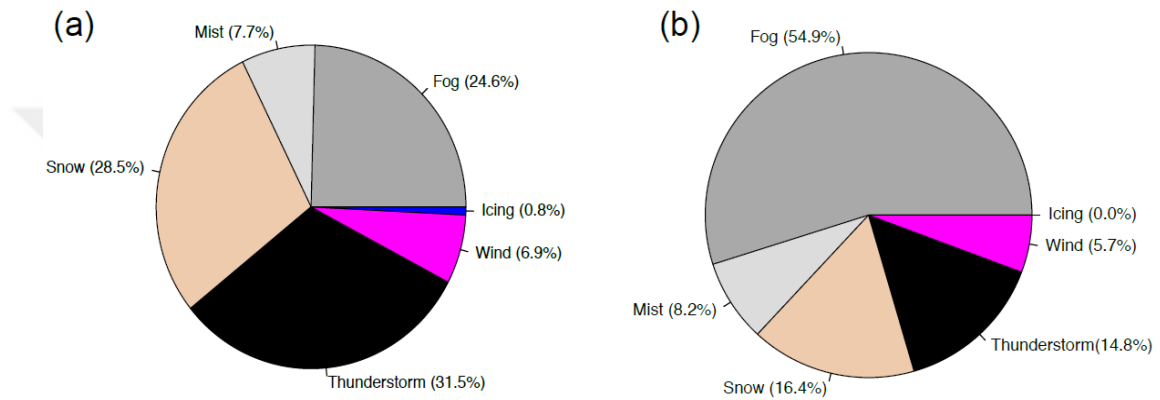


Figure 3.5: Percentage frequency of (a) departure and (b) arrival delays originated from weather extremes at Sabiha Gokcen International Airport for the 2014-2023 period.

In arrival delays; fog, snow, and thunderstorm account for 69.7% of total delays, with fog being the most significant cause of arrival delays with 54.9% percentage **Figure 3.5b**. The Airport's proximity to major moisture sources (Ömerli Dam and the Sea of Marmara), and hence, easy transferring of moisture to the Airport via northerly and southerly winds, and favorable topographical conditions are the distinctive features that cause fog formation. As a result of fog occurrence, sudden reduced visibility causes arrival delays. In METAR/SPECI records, visibility is reduced to 100 meters due to fog and remains over the Airport for a long time. Therefore, flights are being diverted to alternate Airports due to fog conditions. In terms of causing serious economic losses, researchers have been focused on the predictability of fog occurrence and dispersion times at Sabiha Gokcen International Airport. **Ezber and Sen [2022]** investigated the predictability of dense advection fog over Istanbul using Weather Research and Forecasting (WRF) model forced by the ERA-Interim reanalysis data. They found that a configuration with the YSU planetary boundary layer (PBL) scheme

with Dudhia shortwave and RRTM longwave schemes produced comparatively low RMSE for temperature depression, 0.31 °C during the fog hours at Sabiha Gokcen Airport. They declared that while model well simulates the onset time of the afternoon fog, it reproduces the onset and dissipation times of morning fog earlier than the observations.

When we examined monthly distribution of meteorologically originated departure delays, thunderstorm activity plays critical role, especially during the warm season (from May through the end of November, in **Figure 3.6a**. Snowfall is considered as the second most significant meteorological phenomenon causing departure delays, and it is frequently observed during the winter months and in March. Fog events are considered one of the departure delays in all months, except August and September, and they are among the most significant causes of departure delays after thunderstorm and snowfall episodes. Unpredicted fog events occurring throughout the year are found as the main cause of arrival delays at Sabiha Gokcen Airport **Figure 3.6b**. Snowfall occurring during the extended winter months is of secondary importance, followed by thunderstorm events that occur in the warm season from 1 May to 30 November.

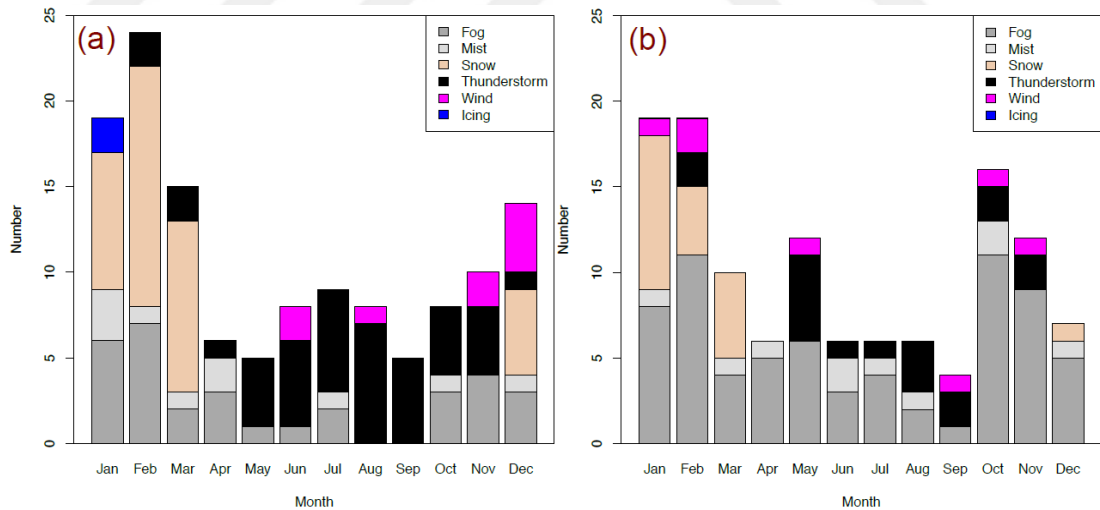


Figure 3.6: Monthly frequency of (a) departure and (b) arrival Flight delays originated from weather extremes at Sabiha Gokcen International Airport for the 2014-2023 period.

Hourly distribution of the numbers of departure delays indicated that thunderstorm events generally occur between 06:00-18:00 UTC hours, mostly afternoon times of the day **Figure 3.7**. One of the most dangerous thunderstorm activities over Istanbul occurred in the afternoon times of the 27 July 2017, with large hailstones between 3-6

cm diameter. As indicated by **Baltaci et al. [2018]**, many flights at Istanbul Atatürk International Airport were postponed or cancelled. Some planes were forced to wait in air, and some of them were diverted to nearby Airports. An airplane in the air was damaged due to the hail and lightning. Snowfall events are frequently seen during the extended winter months, usually at night and in the morning hours when the temperature is low enough, causing departure delays at Sabiha Gokcen International Airport. For snowfall episodes, the Black Sea-effect snowfall bands carried by northerly winds over the Black Sea remain in the region for a long time and result in a significant snow cover depth over Istanbul [**Baltaci et al., 2021**]. As a result, departure delays occur on consecutive flights. Fog is the third most common meteorological event causing departure delays, especially at night and early morning hours of the day during the winter and fall seasons. Except local fog formation, advection type of fog causes dense fog occurrence over a large area and remains in the region for a long time. As explained by **Baltaci et al. [2022]**, the dense fog layer coming from the Black Sea on November 6, 2021, stayed in the Istanbul and Marmara regions for a long time (3 days) and resulted in transport cancellation and delays.

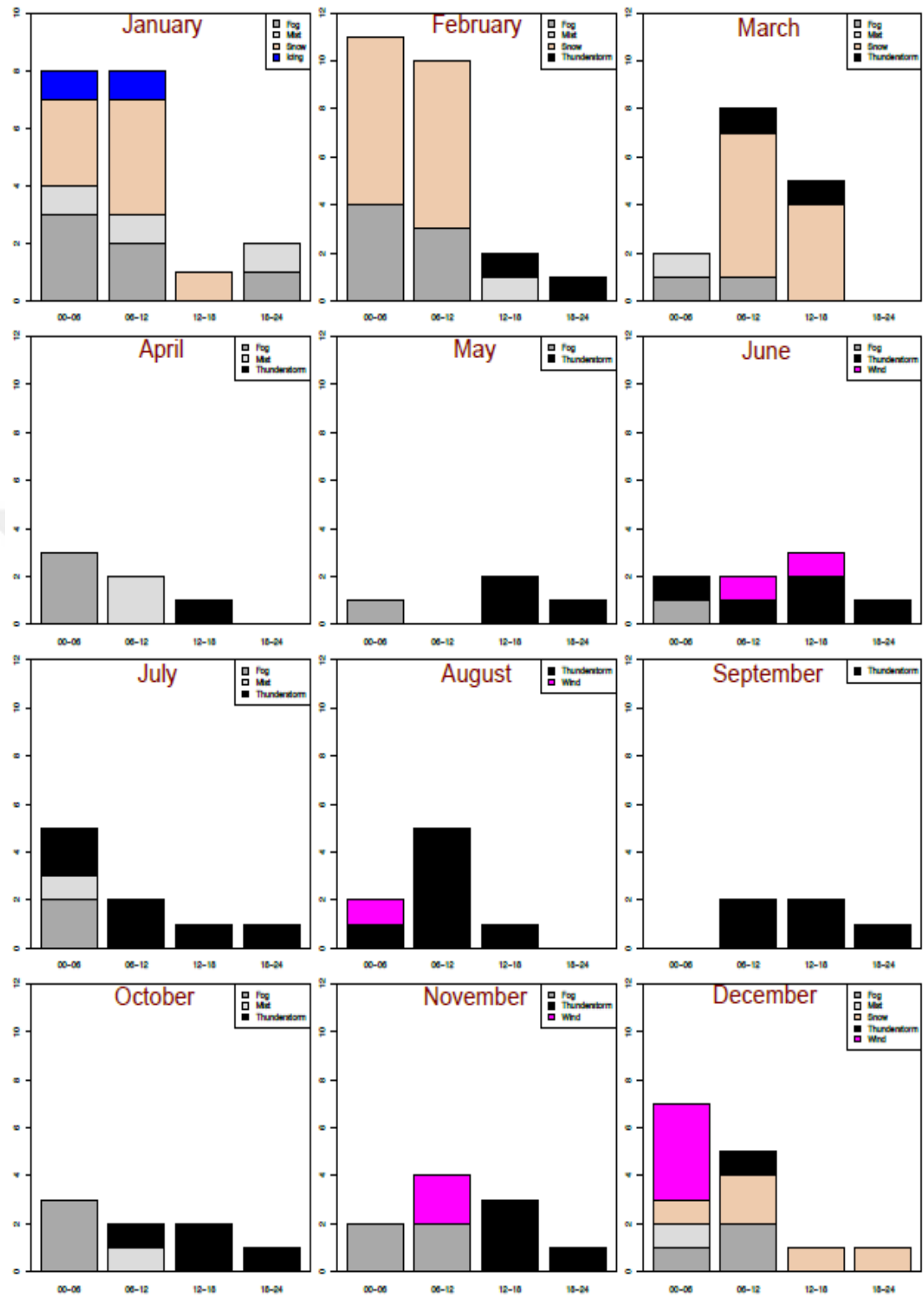


Figure 3.7: Hourly distribution of monthly flight departure delays originated by weather conditions at Sabiha Gokcen International Airport for the period 2014-2023.

As shown in **Figure 3.8**, from the hourly distribution of meteorological originated arrival delays. Dense fog settling over the Airport during the day and calm weather conditions are the main causes of arrival delays. Therefore, it is the most important reason for planes to be diverted to alternate Airports. After fog, the second most important cause of arrival delays are observed as snowfall events occurring extended winter months, especially at night and morning hours of the day. Thirdly, thunderstorm events occurring over the Airport, especially in the afternoon during the warm season, cause arrival delays.



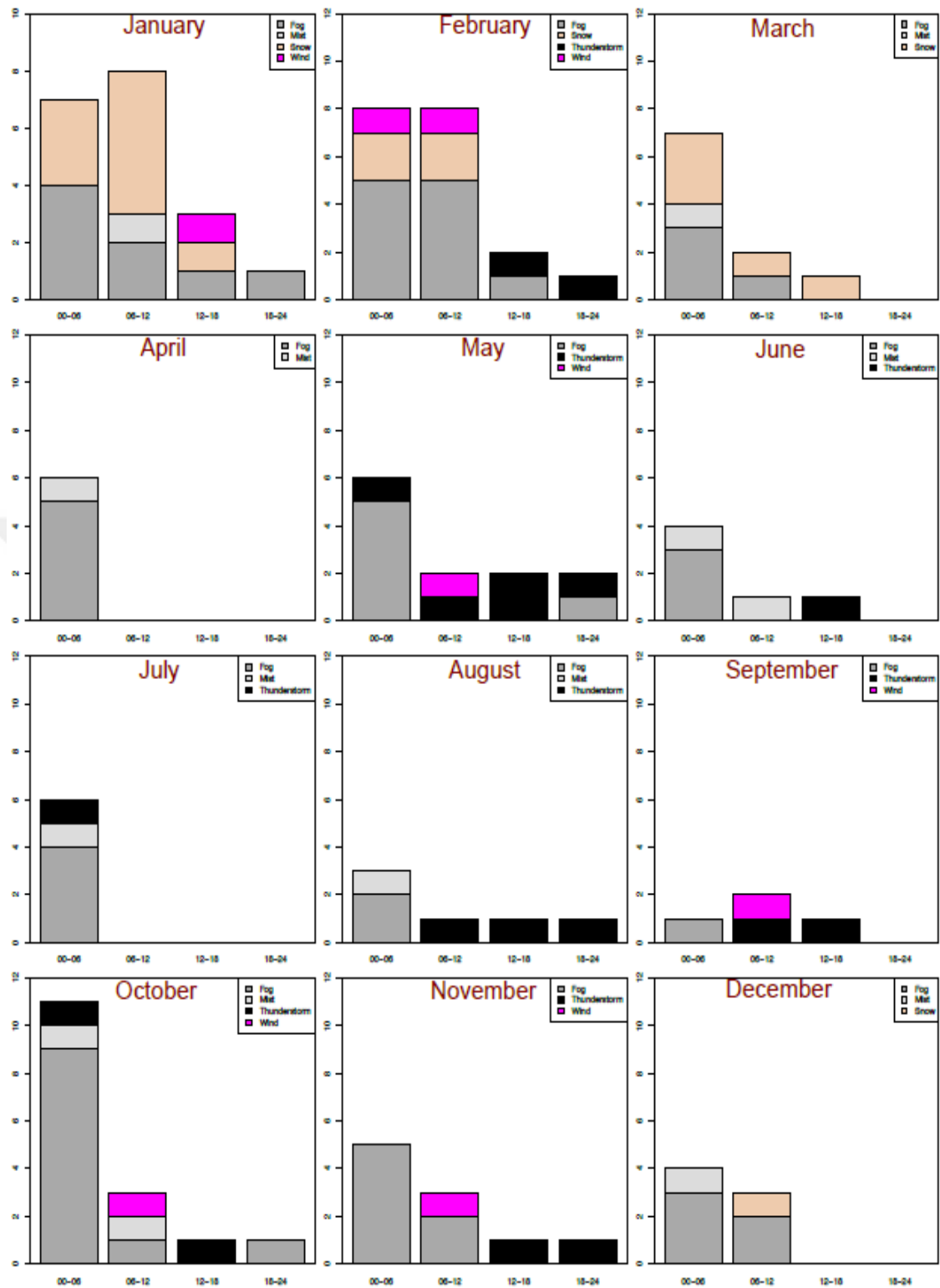


Figure 3.8: Hourly distribution of monthly flight arrival delays originated by weather conditions at Sabiha Gokcen International Airport for the period 2014-2023.

Winter months from December to February accounted for 68% of cancellations, with January being the most disrupted month. The findings highlight the operational

challenges posed by SAW's meteorological conditions and propose mitigation strategies to enhance flight reliability. Additionally, in this study, quantify the frequency and primary causes of weather-related cancellations and identify seasonal trends and high-risk periods were studied.

3.3 Arrival Cancellations owing to Weather Conditions

Figure 3.9 Study analyses domestic flight cancellations to Sabiha Gokcen International Airport (SAW) due to adverse weather conditions at the arrival airport SAW between 2014 and 2023. The dataset includes 1,248 cancelled arrival flights, revealing that low visibility with the rate of 52%, snow/ice accumulation 28%, and strong winds 12% were the leading causes. Classification of cancellations were categorized based on meteorological causes: Low visibility (fog, mist), Snow/ice, Strong winds, and other (thunderstorms, rain, operational restrictions).

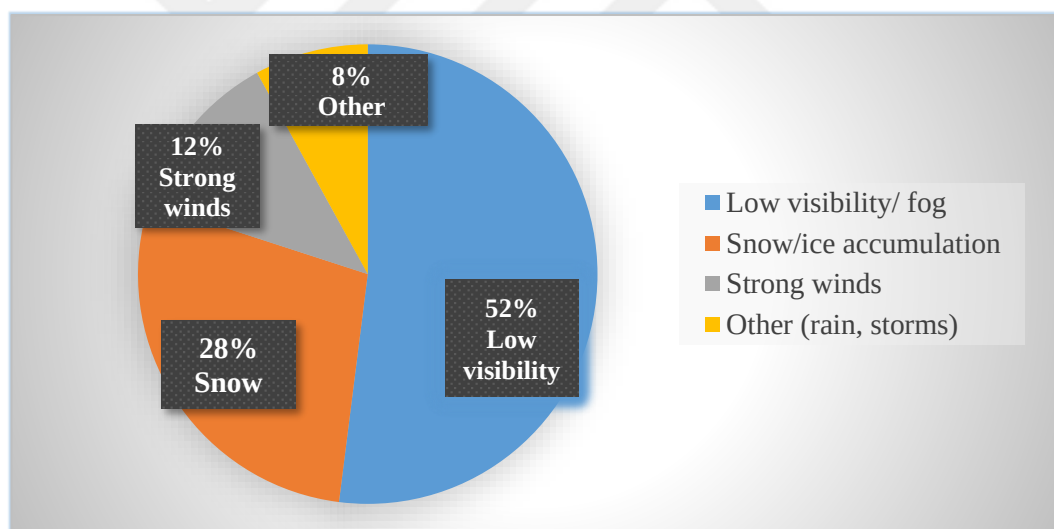


Figure 3.9: The Most Frequent Weather-Related Disruptions at SAW.

The conducted analysis reveals significant seasonal variations in flight cancellation rates at the airport. Winter months emerge as the period with the highest operational disruptions. The highest cancellation rate was recorded in January at 22%, primarily due to snow and low visibility conditions. February ranked second at 19%, with snow and strong winds being the dominant factors. December came in third at 15%, where fog and icing were the main causes of cancellations. In March, the cancellation rate dropped to 12%, influenced mainly by wind and fog. November saw a further decline

to 9%, attributed to a combination of rain and fog. The remaining months accounted for 23% of total cancellations, with thunderstorms and strong winds identified as the most prevalent issues. This table highlights the critical impact of adverse weather conditions particularly winter-related phenomena (snow, fog, icing) and convective weather (thunderstorms) on aviation operations **Table 3.2**.

Table 3.1: Cancellation Rates as Regards to Months.

Month	Cancellation Rate	Dominant Cause
January	22%	Snow, Low visibility
February	19%	Snow, Strong winds
December	15%	Fog, Icing
March	12%	Wind, Fog
November	9%	Rain, Fog
Other Months	23%	Thunderstorm, Wind

In winter season, December experiences fog-dominated disruptions of 60%, while February sees equal threats from snow and wind. Spring brings moderate risks 15% cancellations, primarily from March winds and April rains, whereas summer proves most stable with only 8% cancellations, mostly from thunderstorms. Autumn shows a gradual increase in fog-related issues 9%, particularly November morning fog events. This seasonal breakdown demonstrates how winter's combination of snow, ice and fog creates the most challenging operational environment, followed by transitional seasons with their unique weather threats, while summer remains relatively calm except for occasional thunderstorms, as shown in **Table 3.3**.

Table 3.2: Winter Season Peak Distribution Periods.

Month	Cancel Rate	Most frequent hours	Dominant Weather Condition
December	15 %	06:00-11:00 UTC	Fog 60% snow 30%
January	22 %	05:00- 10:00 UTC	Snow 45% fog 40%
February	19 %	07:00-12:00 UTC	Snow 50% wind 25%

3.4. Seasonal and Temporal Distribution Analysis on Cancellations

The spring months represent a transitional period with moderate operational risks, accounting for 15% of total weather-related cancellations at Sabiha Gökçen Airport. Meteorological analysis reveals distinct patterns during this season: March is predominantly affected by strong northeasterly winds (mean speed 18-22 knots and residual morning fog events, while April and May experience increasing precipitation frequency (monthly average 12-15 rainy days that impacts visibility and braking conditions. The wind patterns show particular significance during March-April, with 32% of spring cancellations attributed to crosswind exceedances beyond aircraft operational limits ≥ 25 knots. These conditions frequently coincide with the morning operational peak from 07:00 to 09:00 UTC, creating compounded challenges for flight scheduling and ground handling operations.

Figure 3.10 shows that Seasonal Distribution Analysis reveals distinct weather patterns affecting flight operations at Sabiha Gökçen Airport. Winter emerges as the most critical season, accounting for 68% of all cancellations, with January being particularly severe 22% cancellation rate.

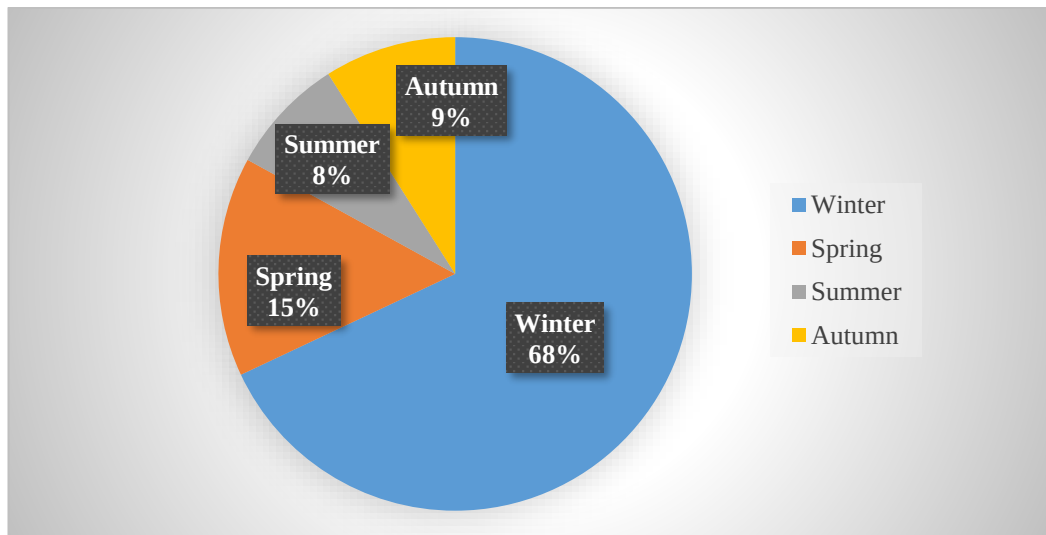


Figure 3.10: Seasonal Cancellations Distribution

Summer emerges as the most operationally stable period, with only 8% of annual weather-related cancellations. However, the season presents unique meteorological

challenges: convective afternoon thunderstorms July-August account for 68% of summer disruptions, typically occurring between 14:00-18:00 UTC when surface heating peaks. These events are characterized by rapid development, bringing intense precipitation (up to 40 mm/hr), wind shear, and occasional hail. Thermal turbulence becomes another significant factor, with temperature differentials exceeding 15°C between surface and 3000ft altitude creating moderate-to-severe turbulence reports on 22% of summer flights. The relatively low cancellation rate reflects both predictable storm patterns and effective use of weather radar systems for tactical avoidance.

The autumn months demonstrate a gradual increase in fog-related disruptions, representing 9% of annual cancellations. Statistical analysis reveals a marked progression: September shows minimal weather impact 1.2% cancellation rate, October transitions with early morning radiation fog 3.1%, while November becomes critical with 4.7% of cancellations concentrated in morning hours 07:00-10:00 UTC. These fog events are particularly problematic, with visibility frequently dropping below 300 meters for durations exceeding 4 hours on 18% of November mornings. The season also sees the return of prefrontal precipitation systems, bringing low ceilings <500ft and reduced visibility in 28% of cases. This seasonal transition period requires particular attention to crew scheduling and alternate airport planning, as weather conditions can change rapidly within the same operational day.

The data demonstrates clear seasonal progression in operational challenges, from spring's wind-dominated disruptions through summer's convective weather to autumn's visibility restrictions. This pattern underscores the need for seasonally adapted operational strategies at Sabiha Gokcen Airport.

4. SUMMARY AND CONCLUSIONS

In this paper, as a first step, we have investigated temporal departure and arrival delay distribution at Sabiha Gokcen International Airport. For this purpose, delay records of flights are used for the 2014-2023 period. Later, the role of meteorological events on delays was investigated. With this aim, METAR/SPECI records of Sabiha Gokcen meteorology office were compared to departure and arrival delay times. As a result, the temporal and percentage effects of meteorological conditions on delays were analyzed. The main results are as follows:

Our findings reveal distinct temporal patterns in weather-related disruptions: departure delays predominantly occur within the first hour 68.6% of cases, with thunderstorms 31.5% during warm-season afternoons May-November, 06:00-18:00 UTC, snowfall 28.5% during winter nights (DJFM), and fog 24.6% in winter/fall mornings emerging as primary causes. Arrival delays show greater temporal spread, with 83.5% occurring within two hours, where unpredicted fog events 54.9% - particularly at night - constitute the most significant challenge, followed by winter snowfall 16.4% and warm-season thunderstorms 14.8%. These results underscore the compounding effects of Istanbul's unique geographic position and seasonal weather variability on aviation operations. The study highlights the urgent need for improved nowcasting systems for fog prediction, enhanced cold-weather preparedness, and thunderstorm mitigation strategies to maintain Istanbul's critical role in global air transport networks while minimizing economic and operational impacts. Future research should focus on developing predictive models tailored to these specific weather phenomena and their operational impacts.

Additionally, this study demonstrates that adverse weather conditions, particularly low visibility, fog, 52% and snow 28%, are the primary causes of domestic flight cancellations at Sabiha Gökçen International Airport (SAW), with the highest-risk period occurring during January mornings 05:00-10:00 UTC and peak disruption between 07:00-10:00 37% of cancellations. SAW's coastal location increases fog frequency, yet the absence of CAT III ILS severely limits low-visibility operations, while the single-runway configuration 06/24 exacerbates crosswind vulnerabilities. Winter months December-February account for 56% of annual weather-related

cancellations, driven by fog and snow, though summer thunderstorms 23% also pose significant afternoon risks. These findings highlight predictable yet insufficiently mitigated vulnerabilities, suggesting that targeted infrastructure upgrades CAT III ILS, runway optimization, enhanced low-visibility procedures, and proactive seasonal resource allocation could reduce cancellations by 40-45%. Future research should evaluate cost-benefit analyses for these interventions to improve operational resilience at SAW.



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PUBLICATIONS AND PRESENTATIONS FROM THE THESIS

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