İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

VARIABILITY OF TAKEOFF DISTANCE AND CLIMATE RATE DUE TO CLIMATE FACTORS

M.Sc.Thesis by

Şeyda YALÇINKAYA ÇAĞLIYAN

Departmant of Meteorological Engineering

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

İKLİM FAKTÖRLERİNE BAĞLI KALKIŞ MESAFESİ VE TIRMANMA ORANI DEĞİŞİKLİĞİ

YÜKSEK LİSANS TEZİ

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To my darling husband and family,

FOREWORD

In this thesis study, climate change's takeoff performance in terms of takeoff distance and climb rate for the Boeing 737-800 aircraft type was investigated. Future takeoff distance predictions are important to ensure that flights are carried out reliably and safely. Investigating the impact of climate change on aviation is important in order to prevent incidents such as accidents and property.

I acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and I thank the climate modeling groups for producing and making available their model output. For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.
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February 2024 — Şeyda YALÇINKAYA ÇAĞLIYAN
(Meteorological Engineer)

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ABRREVIATIONS

AP	: Pressure Altitude
AYT	: Antalya Airport IATA Code
BPS	: Boeing Performance Software
CESM1	: Community Earth System Model version 1
CMIP5	: Coupled Model Intercomparison Project Phase 5
CMIP6	: Coupled Model Intercomparison Project Phase 6
CR	: Climb Rate
DIY	: Diyarbakır Airport IATA Code
DLM	: Dalaman Airport IATA Code
ERA5	: ECMWF Re-Analysis
ESB	: Ankara Esenboğa Airport IATA Code
GCMs	: General Circulation Models
GZT	: Gaziantep Airport IATA Code
IATA	: International Air Transport Association
ICAO	: International Civil Aviation Organization
IST	: İstanbul Airport IATA Code
KSY	: Kars Harakani Airport IATA Code
KYA	: Konya Airport IATA Code
LTAC	: Ankara Esenboğa Airport ICAO Code
LTAI	: Antalya Airport ICAO Code
LTAJ	: Gaziantep Oğuzeli Airport ICAO Code
LTAN	: Konya Airport ICAO Code
LTBS	: Muğla Dalaman Airport ICAO Code
LTBU	: Tekirdağ Çorlu Airport ICAO Code
LTCC	: Diyarbakır Airport ICAO Code
LTCF	: Kars Harakani Airport ICAO Code
LTCG	: Trabzon Airport ICAO Code
LTFM	: İstanbul Airport ICAO Code
m	: Meter
MGM	: General Directorate of Meteorology (Meteoroloji Genel

Müdürlüğü)

MPI-ESM1-2-LR : Max Planck Institute Earth System Model
MTOW : Maximum Takeoff Weight
RCP : Representative Concentration Pathway
TD : Takeoff Distance
TEQ : Tekirdağ Çorlu Airport IATA Code
TZX : Trabzon Airport IATA Code

SYMBOLS

AP	: Pressure Altitude
CR	: Climb Rate
$\boldsymbol{CR_{sl}}$	: Climb Rate at Sea Level Under Standard Atmospheric Conditions
$\boldsymbol{f_C}$	: Climb Rate Factor
$\boldsymbol{f_t}$	: Takeoff Distance Factor
h	: Altitude Above Sea Level
P	: Air Pressure
Po	: Sea Level Pressure
T	: Air Temperature
$\boldsymbol{T_{cont}^{BC}(d)}$	: The Bias Corrected Historical Temperature Data
$\boldsymbol{T_{cont}(i)}$	: Daily Historical Simulated Data
$\boldsymbol{T_{obs}(i)}$	: Observed Temperature Data
$\boldsymbol{\mu_m}$	: Monthly Average Value
$\boldsymbol{T_{scen}^{BC}(d)}$	: The Bias Corrected Future Temperature Data
$\boldsymbol{T_{scen}(i)}$	: Daily Future Simulated Data
TD	: Takeoff Distance
$\boldsymbol{TD_{sl}}$	: Takeoff Distance at Sea Level Under Standard Atmospheric Conditions

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VARIABILITY OF TAKEOFF DISTANCE AND CLIMATE RATE DUE TO CLIMATE FACTORS

SUMMARY

Climate change, resulted from increased fossil fuel combustion after the Industrial Revolution, has triggered a persistent global warming trend. Rapidly increasing global temperatures have a significant impact on the aviation industry, and a comprehensive understanding of their impacts is required to ensure the safety and efficiency of future flight operations. As a result of rapidly increasing global temperatures, aircraft performance during takeoff is considerably endangered, affecting important measurements such as weight considerations and fuel consumption, which are especially important at airports with shorter runways or higher altitudes. The interaction between rising temperatures and lower air density amplifies the challenge of generating sufficient lift force for aircraft taking off in less dense air. These adverse conditions greatly affect prominent parameters that determine takeoff performance, including takeoff distance and climb rate. As temperatures soar and pressure altitudes alter, the future forecast for aviation operations is determined by increased takeoff distances and descended climb rates. This comprehensive study scrutinizes the impact of climate change on takeoff distance and climb rates across ten prominent Turkish airports. The findings reveal a very clear fact: there are significant air temperature increases as well as different changes in pressure altitudes between these airports. Projections emphasize inevitable heightened takeoff distances and descended climb rates, all stemming from the anticipated elevation in temperatures and pressure altitudes. Examining distinct time frames 1980-2010 (past), 2023-2053 (near future), and 2069-2099 (far future) during the summer months reveals a changing trend. Anticipated average takeoff distance increments by 1-3% from 1980-2010 to 2023-2053 and leaps by 4-7% from 2023-2053 to 2069-2099. Conversely, average climb rates are anticipated to decline by 1-2% from 1980-2010 to 2023-2053 and descent by 3-5% from 2023-2053 to 2069-2099. Furthermore, these insights underline a critical necessity: the aviation industry must proactively devise adaptive strategies and technological advancements to alleviate the projected impacts of climate change on flight operations. The significant correlations between rising temperatures, fluctuating pressure altitudes, and the intricate dynamics of flight highlight the urgent need for ongoing research and innovative solutions within the aviation sector. Determining these challenges becomes crucial not only for operational safety but also for encouraging sustainable aviation practices that overcome the challenges that emerge from climate change.

İKLİM FAKTÖRLERİNE BAĞLI KALKIŞ MESAFESİ VE TIRMANMA ORANI DEĞİŞİKLİĞİ

ÖZET

İklim değişikliği, genellikle on yıllardan yüzyıllara uzanan zaman dilimlerinde gözlemlenen ve geniş bir yelpazedeki değişiklikleri içeren bir kavramdır. Bu değişiklikler, sıcaklık farklılıkları, yağış desenlerindeki değişiklikler, deniz seviyesi yükselmesi ve fırtınalar, kuraklıklar ve sıcak hava dalgaları gibi hava olaylarının değişmesini içerir. Bu dönüşümün temel nedenlerinden biri insan faaliyetleridir. Fosil yakıtların yakılması, endüstriyel süreçler, ormansızlaşma ve çeşitli arazi kullanımı değişiklikleri, atmosferde özellikle karbondioksit, metan ve azot oksit gibi sera gazlarının konsantrasyonlarında önemli bir artışa yol açmıştır. Bu gazlar, sera etkisi oluşturarak atmosferdeki ısıyı tutup gezegenin ısınmasına neden olurlar. Bu etkiye genellikle küresel ısınma denmektedir. İklim değişikliğinin sonuçları çeşitlidir ve geniş kapsamlıdır. Ekosistemleri, biyoçeşitliliği, tarımı ve insanların geçim kaynaklarını etkilemektedir. Yükselen sıcaklıklar, aşırı hava olaylarının sıklığını ve yoğunluğunu etkileyebilir, bu da daha sık sıcak hava dalgaları, yoğun yağışları, artan sel risklerini ve çeşitli bölgelerde uzun süreli kuraklıkları beraberinde getirmektedir. Ayrıca, kutup buzullarının ve buzulların erimesi, deniz seviyesinin yükselmesine neden olarak kıyı toplulukları ve habitatlar için tehdit oluşturmaktadır. İklim değişikliğiyle mücadele küresel işbirliği ve çeşitli sektörlerde ortak çabalar gerektirir. Bu, daha temiz ve yenilenebilir enerji kaynaklarına geçiş yapmayı, endüstrilerden karbon emisyonlarını azaltmayı, sürdürülebilir tarım uygulamalarını teşvik etmeyi, orman korumasını artırmayı ve iklim değişikliğinin etkilerini azaltmayı ve bunlara uyum sağlamayı amaçlayan politikaların uygulanmasını içerir. Bilim insanları, politika yapıcılar ve dünya genelindeki toplumlar, gezegenin ekosistemlerine kalıcı zararları önlemek ve gelecek nesiller için sürdürülebilir bir gelecek sağlamak için sera gazı emisyonlarını azaltma ve küresel sıcaklık artışını sınırlama konusunda etkili adımlar atmanın aciliyetini vurgulamaktadır. Bunun sonucunda da hızla yükselen küresel sıcaklıkların etkileri pek çok sektörü etkilese de, havacılık endüstrisi üzerinde belirgin bir etkiye sahip olmuştur. Havacılık endüstrisi, iklim değişikliğinin etkilerini en yoğun şekilde hisseden sektörlerden biri haline gelmiştir. Uçuş operasyonlarının gelecekteki güvenliği ve verimliliği için, bu etkilerin derinlemesine anlaşılması ve öngörülmesi büyük önem taşımaktadır. Uçakların performansı, hava koşullarından doğrudan etkilenir ve küresel ısınma bu performansı ciddi şekilde etkilemektedir. Özellikle artan sıcaklıkların, uçakların kalkış ve iniş performansı üzerinde büyük bir etkisi bulunmaktadır. Daha yüksek sıcaklıklar, uçakların kalkış mesafesini uzatırken, tırmanış oranlarını azaltmaktadır. Bu durum özellikle kısa pistlere veya yüksek rakımlı havalimanlarına sahip bölgelerde ciddi operasyonel zorluklar yaratabilir. Kalkış ve iniş aşamalarındaki performansın yanı sıra, uçakların yakıt tüketimi ve ağırlığı da sıcaklık artışlarından etkilenmektedir. Düşük hava yoğunluğu, uçakların gerekli kaldırma kuvvetini sağlamak için daha fazla mesafe ve enerji gerektirir. Bu

da, daha fazla yakıt tüketimine ve dolayısıyla daha yüksek işletme maliyetlerine neden olabilir. Bu durumun irdelenmesi ve anlaşılması, havacılık endüstrisinin gelecekteki operasyonlarını planlarken önemli bir faktördür. Hava şartlarındaki değişikliklerin ve sıcaklık artışlarının doğru bir şekilde analiz edilmesi, daha etkili uçuş güvenliği politikaları ve operasyonel stratejiler geliştirilmesine yardımcı olabilir. Bu bağlamda, iklim değişikliğiyle mücadele etmek ve havacılık sektörünü sürdürülebilir hale getirmek için teknolojik inovasyonlar ve çözümler üzerine yoğun bir araştırma ve geliştirme süreci önem arz etmektedir. Sıcaklıklardaki artış ve basınç irtifalarındaki değişim, havacılık operasyonlarının gelecekteki tahminlerini belirlemede belirgin bir rol oynuyor. Önümüzdeki dönemlerde, iklim değişikliğinin etkisiyle artan sıcaklıkların ve değişen basınç irtifalarının, uçuş operasyonları üzerinde kaçınılmaz etkileri olacağı öngörülüyor. Bu değişikliklerin, özellikle kalkış aşamasında uçak performansı üzerinde doğrudan ve belirgin bir etkisi olması bekleniyor. Artan sıcaklıklar, uçakların kalkış mesafesini uzatarak, tırmanma oranlarını azaltarak ve gerekli kaldırma kuvvetini sağlamak için daha fazla enerji gerektirerek operasyonel zorluklar yaratabilir. Benzer şekilde, değişen basınç irtifaları da uçuş parametrelerini etkileyerek operasyonel stratejilerin revize edilmesini gerektirebilir. Bu nedenle, havacılık endüstrisinin gelecekteki operasyonlarını planlarken, bu değişkenlerin göz önünde bulundurulması ve adaptasyon stratejilerinin geliştirilmesi önem arz etmektedir. Bu çalışma, havacılık endüstrisinde iklim değişikliğinin uçak kalkış performansı üzerindeki etkisini araştırmayı amaçlamaktadır ve özellikle Boeing 737-800 uçağı için iklim değişikliğine atfedilen kalkış mesafesindeki değişiklikleri değerlendirmektedir. İklim değişikliğinden kaynaklanan sıcaklıklardaki artış, uçaklar için gereken artan kalkış mesafeleriyle doğrudan ilişkilidir. Bu koşullar altında, uçaklar ya kargo kapasitesini ve yakıt yüklerini azaltmak ya da yolcu kapasitesini sınırlamak zorunda kalıyor ve sonuç olarak havayolu taşımacılığı sektöründe artan harcamalara yol açıyor. Bu zorluklara karşı koymak için potansiyel çözümler, değişen sıcaklık düzenlerine ve ardından kalkış mesafelerindeki artışlara yanıt olarak havaalanı pist uzunluklarının uyarlanması gerekmektedir. İklim değişikliğinin havacılık sektörü üzerindeki etkilerinin araştırılması, yaklaşan uçuş operasyonlarının güvenliğinin korunması açısından büyük önem taşımaktadır. Bu araştırma, uçuş operasyonlarının emniyetli bir şekilde gerçekleştirmesini, iptaller ve divert gibi uçuş kesintileri sırasında oluşan hem maddi hem de manevi kayıpları azaltmayı amaçlamaktadır. Çalışmada Türkiye'nin önde gelen on havalimanında iklim değişikliğinin kalkış mesafeleri ve tırmanma oranları üzerindeki etkisini detaylı bir şekilde incelemektedir. Bu havalimanları Trabzon Havalimanı (TZX), Kars Harakani Havalimanı (KSY), Tekirdağ Çorlu Havalimanı (TEQ), İstanbul Havalimanı (IST), Ankara Esenboğa Havalimanı (ESB), Konya Havalimanı (KYA), Gaziantep Oğuzeli Havalimanı (GZT), Diyarbakır Havalimanı (DIY), Muğla Dalaman Havalimanı (DLM) ve Antalya Havalimanı (AYT)'dir. Çalışmada yaz aylarına ait (haziran, temmuz ve ağustos) günlük ortalama hava sıcaklığı verileri ve günlük ortalama deniz seviyesi basınç verileri kullanılmıştır. Kullanılan veriler, 1980-2010 periyotları için ERA5 (ECMWF Yeniden Analizi) ve CMIP6 MPI-ESM1-2-LR tarihsel veri setleri kullanılmıştır. 2023-2053 ve 2069-2099 yılları için ise CMIP6 MPI-ESM1-2-LR SSP5-8.5 simülasyon verileri kullanılmıştır. Bu analiz, sadece bireysel havalimanlarındaki değişiklikleri değil, aynı zamanda genel eğilimleri ve bu eğilimlerin sektöre olan potansiyel etkilerini de değerlendirmeyi amaçlamaktadır. Elde edilen bulgular, sadece hava sıcaklıklarında yaşanan ciddi artışları değil, aynı zamanda farklı havalimanları arasında basınç irtifalarında da değişiklikler olduğunu ortaya koymaktadır. Bu değişkenlikler, uçuş operasyonlarını doğrudan etkileyebilir ve farklı hava koşullarına sahip havalimanlarının uçuş performansları üzerinde farklı sonuçlar doğurabilir. Bu verilerin analizi, gelecekteki havacılık operasyonlarının planlanması ve yönetilmesi için önemli bir rehber niteliği taşımaktadır. Geçmiş, yakın gelecek ve uzak gelecek dönemlerdeki yaz aylarını kapsayan analizler, belirli bir trendin varlığını göstermektedir. Bu analizler, önümüzdeki yıllarda havacılık operasyonları üzerinde beklenen değişikliklere dair önemli ipuçları sunmaktadır. Yaz aylarında 1980-2010 (geçmiş), 2023-2053 (yakın gelecek) ve 2069-2099 (uzak gelecek) arasındaki farklı zaman dilimleri incelendiğinde değişen bir trend ortaya çıkmaktadır. Tahmin edilen ortalama kalkış mesafesi 1980-2010'dan 2023-2053'e %1-3 oranında ve 2023-2053'ten 2069-2099'a ise %4-7 oranında artması beklenmektedir. Tersine, ortalama tırmanma oranlarının 1980-2010'dan 2023-2053'e kadar %1-2 oranında ve 2023-2053'ten 2069-2099'a kadar ise %3-5 oranında azalması beklenmektedir. Boeing 737-800 uçak tipi için Kars Harakani Havalimanı'nda yaz aylarında ortalama kalkış mesafeleri geçmiş dönemde 2200 metre, yakın dönemde 2244 metre, uzak dönemde ise 2376 metre olması beklenmektedir. Diyarbakır Havalimanı için yaz aylarında ortalama kalkış mesafeleri; geçmiş dönemde 2596 metre, yakın gelecekte 2640 metre, uzak gelecekte ise 2794 metre olması beklenmektedir. Bu veriler, uzun vadede havacılık operasyonlarının temel parametrelerinde meydana gelebilecek değişimleri öngörme konusunda bize fikir vermektedir. Bu trendler, havacılık endüstrisinin gelecekteki planlamaları ve stratejik uygulamaları üzerinde derinlemesine düşünmeyi gerektirebilir. Bu tahminler, havacılık endüstrisinin karşılaşacağı önemli bir zorunluluğa işaret etmektedir: Bu karmaşık etkileşimlerin anlaşılması, havacılık sektörünün sürdürülebilirlik ve operasyonel etkinlik açısından daha uygun stratejiler belirlemesine yardımcı olabilir. Bu nedenle, sürekli araştırma ve yenilikçi çözümlere olan yatırım, havacılık endüstrisinin iklim değişikliğiyle mücadeledeki rolünü güçlendirebilir. Bu zorlukların belirlenmesi, havacılık endüstrisi için sadece operasyonel güvenlik açısından değil, aynı zamanda iklim değişikliğinin yarattığı zorlukları aşmak için sürdürülebilir havacılık uygulamalarının teşvik edilmesi açısından da son derece önemlidir. Bu durum, sektörün çevresel etkileri azaltma ve operasyonel verimliliği artırma yönünde yeni teknolojiler ve stratejiler geliştirme konusunda odaklanmasını gerektirmektedir. Operasyonel etkinliklerin ve teknolojilerin yeniden düşünülmesiyle, sektör karbon ayak izini azaltabilir ve çevresel etkileri minimize edebilir. Yenilikçi yaklaşımların benimsenmesi, sadece havacılık sektörü için değil, aynı zamanda çevre için de önemli bir adım olabilir. Bu süreç, havacılık endüstrisinin iklim değişikliğiyle mücadelede liderlik rolü üstlenmesini sağlayabilir.

1. INTRODUCTION

Since the Industrial Revolution, there has been a recorded rise of about 1°C in the average global surface temperatures, especially observed following 1980 (Lee and Romeo, 2023). As a consequence of climate changes, there's a considerable rise in the rate of temperature increase, affecting both average and maximum temperatures (Stott et al, 2004). The projected rise in average temperatures and escalating warming is anticipated to heighten the likelihood of severe heatwaves (Kumar et al, 2014; Horton et al, 2016). Reducing greenhouse gas emissions from the aviation sector poses significant challenges. As flight frequencies surge, this industry is poised to contribute increasingly higher volumes of greenhouse gas emissions (Andres and Padilla, 2018). Although there exists research on the influence of greenhouse gas emissions from the aviation sector on climate change, there remains a noticeable gap in the research concerning the aviation industry's strategies for adapting to climate change (Burbidge, 2018). Shifts in tourism and agricultural practices resulting from rising temperatures due to global warming also lead to variations in the volume of both passenger and freight transportation within the aviation sector (Koetse and Rietveld, 2009). The aviation sector, as of now, hasn't achieved significant success in proactively implementing measures to counteract climate change and adequately readying itself in response (Banister, 2019). However, there has been a recent surge in scrutinizing the present and prospective impacts of climate change on the aviation industry (Horton et al, 2016; Coffel et al, 2017). The impacts of climate on aviation encompass alterations in precipitation and temperature patterns, fluctuations in wind dynamics, rising sea levels, and the occurrence of extreme weather events (Burbidge, 2018). Periodic disturbances in flight operations often stem from various factors, with weather conditions emerging as one of the foremost causes (Koetse and Rietveld, 2009; Lan et al, 2006). As climate change progresses, the surge in extreme weather events and conditions might potentially escalate expenses and contribute to a higher incidence of accidents within the aviation sector (Koetse and Rietveld, 2009). The arrangement, direction, and quantity of runways are influenced by various elements like the dominant wind patterns, the topography surrounding the airport, the geographical coordinates of the region, temperature fluctuations across a two-decade span, and the elevation of the airport (Url-1; Sarsam and Ateia, 2011). For a particular runway and aircraft type, there exist specific thresholds in terms of Maximum Takeoff Weight (MTOW) and temperature. If these limits are surpassed, a payload restriction is enforced to facilitate the aircraft's takeoff (Coffel and Horton, 2016). High temperatures and low atmospheric pressure lead to decreased air density, subsequently reducing the necessary lift force for aircraft (Coffel and Horton, 2015). In instances where air density is low, planes need to attain increased speeds to generate a requisite lift force and consequently ascend at a slower rate (Anderson and Bowden, 2005). Airports situated at elevated altitudes experience diminished air density due to the reduced atmospheric pressure, contributing to compromised takeoff performance in aircraft, thus necessitating longer takeoff distances. Calculations for takeoff distances and climb rates are contingent upon temperature and pressure variations to ensure safe flight operations (Url-2). Multiple elements, encompassing the specific aircraft model, contribute to the assessment of runway lengths within an airport. The sizing specifications for runways often derive from the A380, recognized as the largest aircraft globally. The International Civil Aviation Organization (ICAO) has defined distinct runway categories along with their respective dimensions in length and width (Shinde et al, 2019). The consideration of takeoff distance is pivotal in ensuring the efficiency, safety, and meticulous design of airports, exerting a substantial influence on their planning and architectural framework (Young and Wells, 2011).

1.1 Aim of Thesis

This study aims to investigate the impact of climate change on aircraft takeoff performance within the aviation industry and specifically assesses the alterations in takeoff distance attributed to climate change for the Boeing 737-800 aircraft. The elevation in temperatures resulting from climate change directly correlates with expanded takeoff distances required for aircraft. Under these circumstances, airplanes are compelled to either diminish cargo capasity and fuel loads or limit passenger capacity, consequently leading to amplified expenses within the airline transportation sector. To counter these challenges, potential solutions may involve adapting airport runway lengths in response to the evolving patterns of temperature and subsequent increases in takeoff distances. Exploring the ramifications of climate change on the aviation sector holds paramount importance in safeguarding the safety of forthcoming flight operations. This research endeavors to curtail both tangible and intangible losses incurred during flight disruptions such as cancellations and diversions, among comparable scenarios.

1.2 Literature Review

Variability in the temperatures is a main factor in the flight operations. In the course of almost all the flights weight restriction is a significant factor which is altered and adapted due to local temperature. Recent studies focusing on weight restrictions due to high temperatures explained that the aircraft type determines the amount of the restrictions (Coffel et al, 2017; Zhao and Sushama, 2020). For instance Coffel et al, (2017), examined the change in the size and frequency of weight restrictions for five common commercial aircraft, Boeing 737-800, Airbus A320, Boeing 787-8, Boeing 777-300 and Airbus A380, was calculated for 19 airports in America. Future daily air temperatures were analyzed using 27 general circulation models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) model suite under both the Representative Concentration Pathway (RCP) 4.5 and 8.5 emissions scenarios. In their study, the increases in weight restrictions for Boeing 777-300 and Boeing 787-8 aircraft types were expected to be high, while the restrictions on A320 and Boeing 737-800 aircraft types were expected to be less (Coffel et al, 2017). Zhao and Sushama, (2020), who are among other researchers studying aircraft types observed point data set from previous years and ERA5 (ECMWF Re-Analysis) data set was used to control this data. For future simulation data sets, they evaluated daily maximum temperature, daily minimum temperature and wind data for 13 major airports in Canada using (RCP) 4.5 and 8.5 scenarios. As a result of these evaluations, they divided aircraft types into 3 groups in order to make weight restrictions. According to these groups, changes that may occur in aircraft takeoff performance due to weight restriction days, strong tail wind and crosswind formations were evaluated. As a result of the evaluations, they found that due to the increase in daily maximum temperatures of airports in Canada, the weight restriction depends on the latitude, longitude and altitude of the airport, and also depends on the aircraft category. They revealed that necessary precautions and decisions should be taken to prevent aircraft performance from decreasing due to climate change (Zhao and Sushama, 2020).

Differences arising due to temperature change and temperature increase not only affect weight restriction, but also takeoff performance, takeoff distance and climb rate are also greatly affected. In studies conducted for this purpose, it is stated that temperature change has a significant effect on takeoff performance (Zhou et al, 2018; Wang et al, 2023; Burbidge et al, 2023). Zhou et al (2018) on this subject examined the effect of climate change on the takeoff performance of aircraft, including takeoff distance and climb rate, for 30 international airports in the world. They divided the times into 3 groups: historical period (1976-2005), mid-century (2021-2050) and late century (2071-2100) and revealed the effect of temperature change in these periods on takeoff performance. Daily average temperature and daily average sea level pressure data measured for the historical period were used CMIP5 data were used for daily average temperature and daily average sea level pressure model data. As a result of the calculations, they found that the takeoff distance for the Boeing 737-800 aircraft type increased by 3.5-168.7 m in the summer months at 30 airports in the world (Zhou et al, 2018). Another study on takeoff distance was done by Wang et al, (2023) examined the decrease in takeoff performance of aircraft due to global warming for 8 airports in China. Using Community Earth System Model version 1 (CESM1) and Boeing Performance Software (BPS), the changes in the MTOW restrictions and takeoff distance of aircraft as the temperature increased were examined. In the study, using the RCP 8.5 scenario, it was revealed that the maximum temperature in the summer months increased in the coming years (2071-2080) and accordingly the takeoff distance increased, but the maximum takeoff weight decreased. As a result of the analysis, it was found that the number of restricted days in some airports in China reached 10, 15, 19 days and the departure distances increased in the range of 113-222 meters (Wang et al, 2023). Burbidge et al, (2023) have examined the effects of climate change on aviation and the precautions and adaptations that need to be taken as a result of these effects in 131 articles published so far. By examining many articles, they have demonstrated that the takeoff performance of aircraft will decrease as daily maximum temperatures increase and wind values intensify. Due to the increase in temperatures, takeoff distance increases and causes the MTOW to decrease. In addition, increases in temperature may cause fire risks, damage to runways and taxiways, and damage to the equipment used. To avoid these problems, adaptations have been found, such as reducing the load capacity by carrying fewer passengers or fuel, making flight plans that do not coincide with the hottest hours of the day, wider and longer runways can be built.

2. MATERIAL AND METHOD

2.1 Data and Study of Area

The research encompassed ten Turkish airports, examining Figure 2.1 for the map delineating their locations and Table 2.1, which details airport codes, names, latitude, longitude, and altitudes.

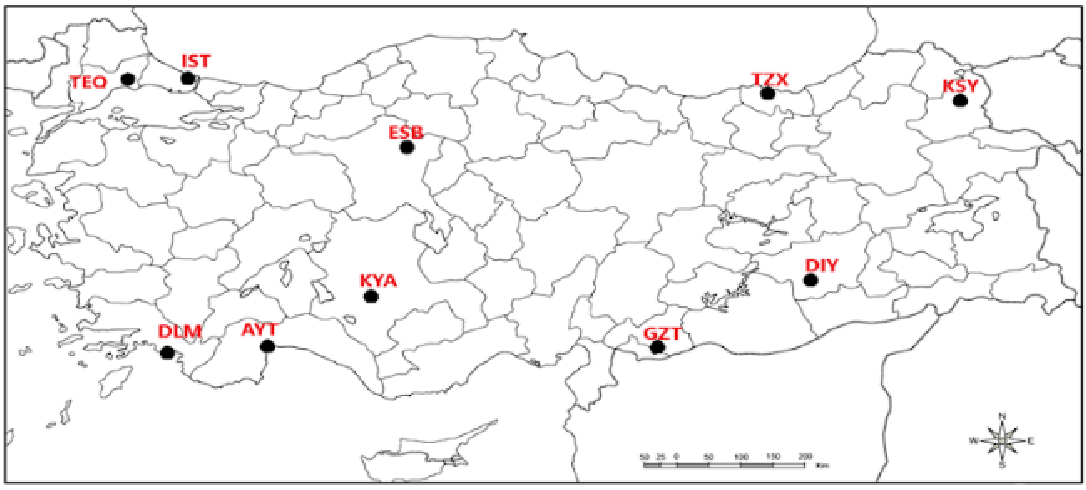

Figure 2.1 : The geographic coordinates for ten airports situated in Türkiye.

Table 2.1 : Information regarding the International Air Transport Association (IATA) and International Civil Aviation Organisation (ICAO) codes, as well as the latitude, longitude, and altitude specifics of ten Turkish airports, was obtained from the General Directorate of Meteorology (MGM).

Airports	IATA Code	ICAO Code	Altitude (m)	Longitude	Latitude
Trabzon Airport	TZX	LTCG	39	39.7830	40.9950
Kars Harakani Airport	KSY	LTCF	1795	43.1116	40.5640
Tekirdağ Çorlu Airport	TEQ	LTBU	160	27.9193	41.1388
İstanbul Airport	IST	LTFM	91	28.7288	41.2647
Ankara Esenboğa Airport	ESB	LTAC	959	32.9992	40.1240
Konya Airport	KYA	LTAN	1031	32.740	37.9837
Gaziantep Oğuzeli Airport	GZT	LTAJ	700	37.4617	36.9468
Diyarbakır Airport	DIY	LTCC	674	40.2027	37.8973
Muğla Dalaman Airport	DLM	LTBS	5	28.7896	36.7229
Antalya Airport	AYT	LTAI	64	30.7990	36.9063

It focused on daily summer averages between 1980 and 2010. ERA5 data provided the basis for temperature and sea level pressure values. For future and historical simulations spanning 1980-2010, 2023-2053, and 2069-2099, high-resolution daily average temperature and sea level pressure data from the Max Planck Institute Earth System Model (MPI-ESM1-2-LR) were utilized.

2.2 Bias Correction

Technological progressions, notably in computing capabilities, have facilitated the creation of high-definition climate simulations via GCMs (Obada et al, 2016). Nonetheless, scrutinizing GCMs at a regional level can unveil notable disparities and inconsistencies (Jose and Dwarakish, 2022). The Bias Correction method is utilized as a corrective measure to rectify discrepancies present in climate models (Piani et al, 2010). Six distinct methods for Bias Correction include Delta change, Linear Scaling, Empirical Quantile Mapping, Adjusted Quantile Mapping, Gamma-Pareto Quantile Mapping, and Quantile Delta Mapping (Jose and Dwarakish, 2022). This study employed the Linear Scaling Method among the Bias Correction techniques to rectify high-resolution daily average temperature and sea level pressure simulations from the MPI-ESM1-2-LR, integrated within the Coupled Model Intercomparison Project Phase 6 (CMIP6) (Jose and Dwarakish, 2022).

$$T_{cont}^{BC}(d) = T_{cont}(i) + \mu_m\big(T_{obs}(i)\big) - \mu_m\big(T_{cont}(i)\big) \tag{2.1}$$

$$T_{scen}^{BC}(d) = T_{scen}(i) + \mu_m\big(T_{obs}(i)\big) - \mu_m\big(T_{cont}(i)\big) \tag{2.2}$$

Equation 2.1 depicts $T_{cont}^{BC}(d)$ as the bias corrected historical temperature data, while Equation 2.2 portrays $T_{scen}^{BC}(d)$ as the bias corrected future temperature data. $T_{obs}(i)$, $T_{scen}(i)$, $T_{cont}(i)$ and μ_m denote observed temperature data, daily future simulated data, daily historical simulated data, and monthly average values, respectively.

Linear Scaling method, one of the Bias Correction methods, was made using the Python module. The intent behind this Python module and its accompanying data structures is to mitigate disparities within modeled and observed climate data across diverse timeframes. Historical data serves as a reference to calibrate present and future time series variables, aligning their distributional characteristics closer to potential real-world values (Figure 2.2).

In Figure 2.3, the method of Linear Scaling for bias correction shows effective in adjusting climate variables to reduce disparities in mean values evident between forecasted and observed time-series across historical and forthcoming periods (Url-3).

For ten airports in Türkiye, the average temperature and sea level pressure data from past summers (1980-2010) were adjusted using the Linear Scaling method, a Bias Correction technique, to align with the temperature and sea level pressure projections for the near future (2023-2053) and far future (2069-2099) derived from the CMIP6 model.

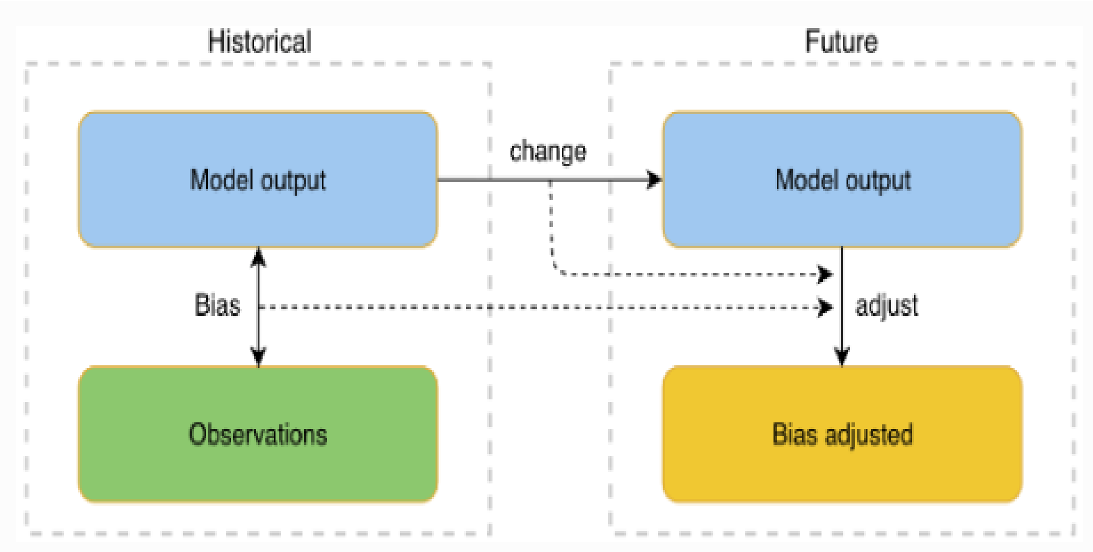

Figure 2.2 : Schematic representation of the Bias Correction method (Url-2).

```
>>> import xarray as xr
>>> from cmethods import CMethods as cm

>>> # Note: The data sets must contain the dimension "time"
>>> #       for the respective variable.
>>> obsh = xr.open_dataset("path/to/reference_data-control_period.nc")
>>> simh = xr.open_dataset("path/to/modeled_data-control_period.nc")
>>> simp = xr.open_dataset("path/to/the_dataset_to_adjust-scenario_period.nc")
>>> variable = "tas" # temperatures

>>> ls_adjusted = cm.linear_scaling(
...     obs=obs[variable],
...     simh=simh[variable],
...     simp=simp[variable],
...     kind="+"
... )
```

Figure 2.3 : Python code of linear Scaling method (Url-2).

2.3 Calculation of Pressure Altitude

The altitude reading indicated on the altimeter at 1013 hPa, configured under standard atmospheric conditions, defines pressure altitude (AP). These values hold significance in the assessment of aircraft takeoff performance (Url-3). When assessing aircraft takeoff performance, the significance of barometric altimeter values is paramount. Calculations for the airports investigated in Türkiye, pressure altitude values (AP in m) for different periods, including the past (1980-2010), near future (2023-2053) and far future (2069-2099) are shown in Table 2.2 AP formulas consisting of two steps are as follows (Zhou et al, 2018: Lente and Ösz, 2020) :

$$AP = \left(1 - \left(\frac{P}{101325}\right)^{0.1903}\right) x\ 44308 \quad (2.3)$$

$$P = p_o \left(\frac{T}{T+0.0065h}\right)^{5.257} \quad (2.4)$$

Equation 2.3 employs "P (Pa)" to represent the real air pressure in pascals, obtained using the barometric formula. Equation 2.4 utilizes "Po (Pa)," "T (K)," and "h (m)" to denote sea level pressure, air temperature, and altitude above sea level, respectively. According to these equations, a drop in air pressure corresponds to a rise in pressure altitude.

Table 2.2 : Over the span of past period (1980-2010), near future (2023-2053), and far future (2069-2099), pressure altitude (AP, m) calculations for ten Türkiye airports were evaluated.

Airports	**Past Period (1980-2010) AP (m) Values**	**Near Future (2023-2053) AP (m) Values**	**Far Future (2069-2099) AP (m) Values**
Trabzon Airport (TZX)	51.1637	52.7121	61.7668
Kars Harakani Airport (KSY)	1733.6790	1723.9190	1702.1998
Tekirdağ Çorlu Airport (TEQ)	160.7465	165.7958	180.5274
İstanbul Airport (IST)	95.7336	101.1267	116.5376
Ankara Esenboğa Airport (ESB)	935.1762	932.5688	930.5111
Konya Airport (KYA)	1006.3167	1004.9897	1003.3954
Gaziantep Oğuzeli Airport (GZT)	726.4097	729.1362	733.3810
Diyarbakır Airport (DIY)	715.7046	716.4794	719.8108
Muğla Dalaman Airport (DLM)	51.1637	61.4691	75.1488
Antalya Airport (AYT)	111.8857	120.4639	132.1255

The Pressure altitude values for each airport have been calculated using the corrected temperature and sea level pressure data derived from Equations 2.3 and 2.4 for the past, near future, and far future periods.

2.4 Koch Chart

The derived pressure altitude values, adjusted through Bias Correction considering temperature and sea level pressure, are utilized to evaluate their impact on takeoff performance. To analyze this influence on takeoff performance, the assessment involves the application of the Koch Chart diagram (Figure 2.4). The Koch Chart diagram allows for the calculation of the rise in takeoff distance factor percentage and the decline in climb rate factor percentage. It offers insights into various parameters influencing the takeoff performance of multiple aircraft types (Url-3).

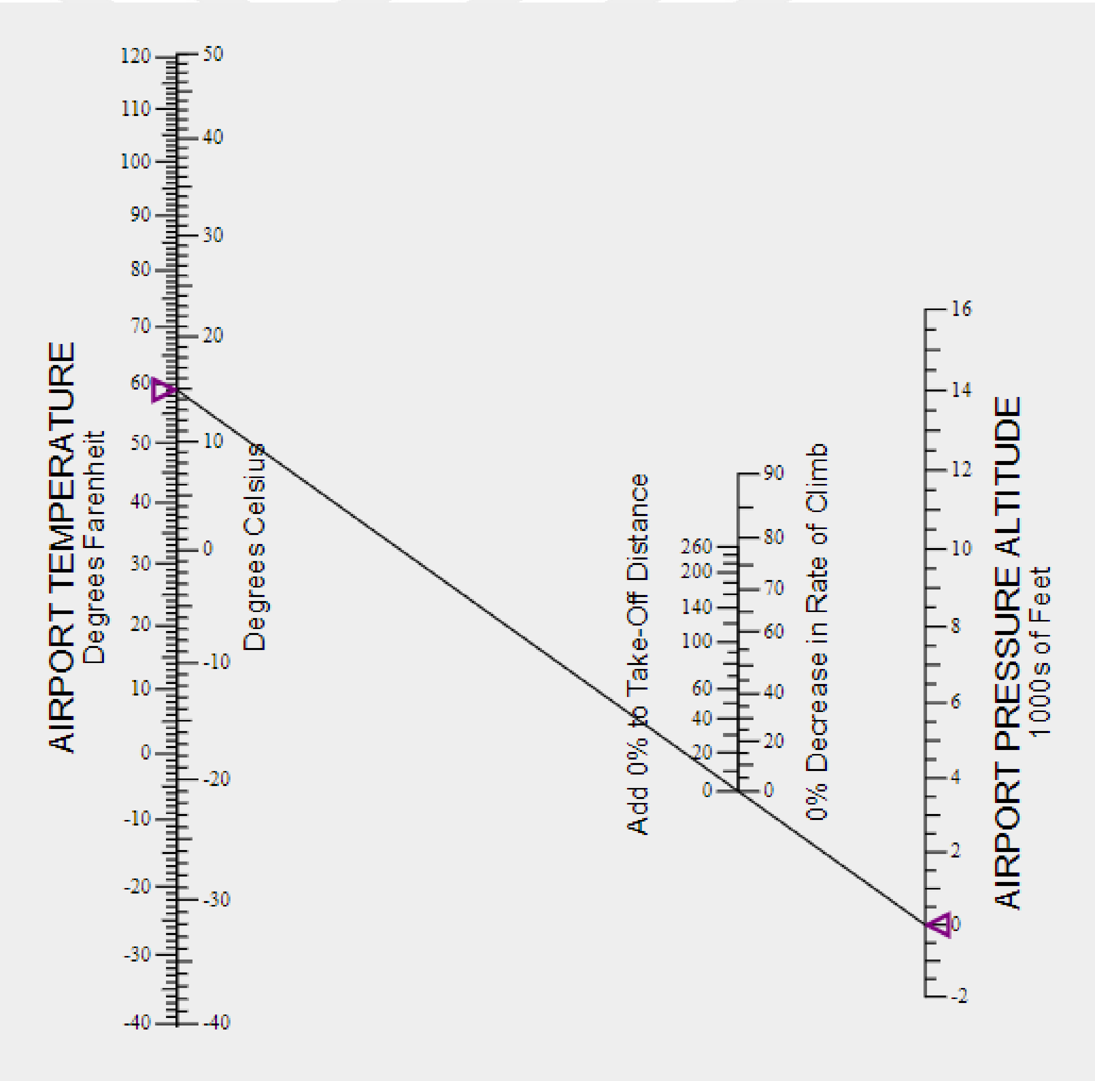

Figure 2.4 : Koch Chart (Url-4).

For the ten airports in Türkiye, the average summer temperatures (°C) and pressure altitude (feet) values for the past, near future, and far future have been plotted on the Koch Chart. Calculations have been performed to determine the percentage increments in takeoff distance factor and decrements in climb rate factor across each timeframe.

2.5 Calculation of Takeoff Distance and Climb Rate

Every aircraft necessitates a particular takeoff distance, denoted as takeoff distance (TD), which depends on the aircraft's velocity and acceleration characteristics (Hurt, 1965). Equation 2.5 presents a method to estimate the TD by multiplying the takeoff distance factor ($\boldsymbol{f_t}$), derived from the takeoff distance at sea level under standard atmospheric conditions ($\boldsymbol{TD_{sl}}$). This fixed value for each airport allows for the observation of takeoff distance fluctuations. Therefore, alterations in the takeoff distance correspond directly to variations in the takeoff distance factor extracted from the Koch Chart (Zhou et al, 2018).

$$\boldsymbol{TD = TD_{sl} x f_t} \qquad (2.5)$$

Aircraft are engineered to optimize their takeoff performance concerning factors such as takeoff distance, climb rate, and the MTOW (James et al, 2005). The climb rate defines the duration an aircraft requires to ascend to a predetermined altitude at a specified speed (Anderson and Bowden, 2005). With the impact of climate change, the elevation in takeoff distance leads to a reduction in the climb rate (Gratton et al 2022: Zhou et al, 2018). Similar to the approach outlined for estimating takeoff distance, Equation 2.6 offers a means to compute the climb rate (CR) by multiplying the climb rate factor ($\boldsymbol{f_C}$), determined from the climb rate at sea level under standard atmospheric conditions ($\boldsymbol{CR_{sl}}$). Each airport sets a standardized climb rate at sea level under standard atmospheric conditions to monitor climb rate fluctuations, establishing a direct correlation between changes in the climb rate and alterations in the climb rate factor derived from the Koch Chart (Zhou et al, 2018).

$$CR = CR_{sl} x f_C \qquad (2.6)$$

Using Equations 2.5 and 2.6, takeoff distances and climb rates are calculated in percent for each airport for the past, near future and far future periods (Table 2.3).

Table 2.3 : Takeoff distance and climb rate data (%) for the past period (1980-2010), near future (2023-2053) and far future (2069-2099).

Airports	**TD (1980-2010)**	**TD (2023-2053)**	**TD (2069-2099)**	**CR (1980-2010)**	**CR (2023-2053)**	**CR (2069-2099)**
Trabzon Airport (TZX)	7	9	14	5	7	11
Kars Harakani Airport (KSY)	0	2	8	0	2	6
Tekirdağ Çorlu Airport (TEQ)	11	12	17	8	9	13
İstanbul Airport (IST)	11	13	17	8	10	13
Ankara Esenboğa Airport (ESB)	9	11	17	6	8	13
Konya Airport (KYA)	9	12	18	7	9	14
Gaziantep Oğuzeli Airport (GZT)	17	19	24	13	14	18
Diyarbakır Airport (DIY)	18	20	27	14	16	20
Muğla Dalaman Airport (DLM)	13	15	19	10	11	14
Antalya Airport (AYT)	17	20	25	13	15	19

3. ANALYSIS

3.1 Temperature

Figure 3.1 illustrates a trend of declining temperatures correlating with rising latitudes. During the 1980-2010 period, the average summer temperature across ten airports stood at 23.57°C. Figures 3.2 and 3.3 depict a consistent rise in temperatures across the selected ten airports during the period from 1980 to 2099. In the 2023-2053 timeframe, Tekirdağ Çorlu Airport and İstanbul Airport exhibited the lowest temperature changes compared to the 1980-2010 period, recording a change of 1.49°C each, while Konya Airport registered the highest change at 2.36°C (Figure 3.2). In the transition from the near future to the far future, Muğla Dalaman Airport experienced the smallest temperature shift at 2.74°C, whereas Kars Harakani Airport marked the highest shift at 4.62°C (Figure 3.3). Notably, the daily temperature change from the near future to the far future surpassed the change observed from the past to the near future. Future temperature changes appear to intensify, suggesting a potential need for increased aircraft takeoff distances to ensure safe flight operations.

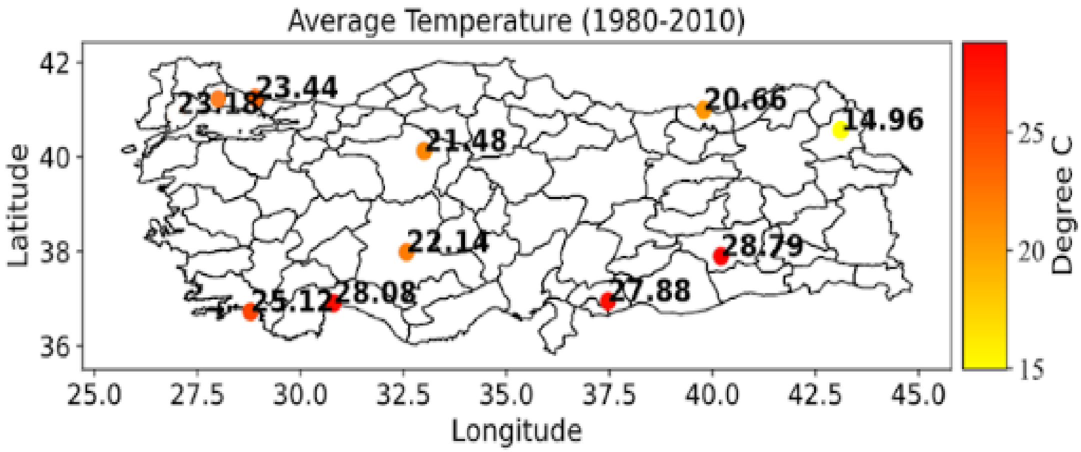

Figure 3.1 : The average daily temperature (°C) for June, July, and August during the historical period from 1980 to 2010.

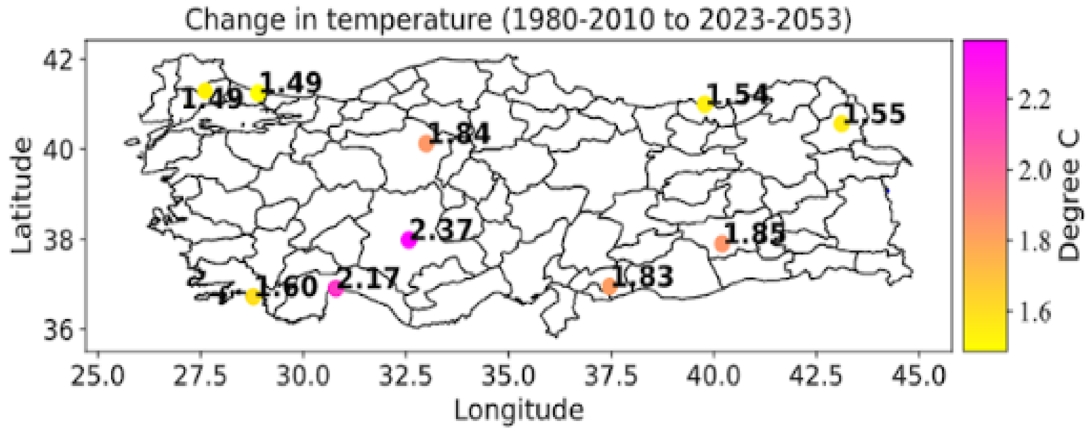

Figure 3.2 : The fluctuation in daily mean temperatures (°C) for June, July, and August between the near future (2023-2053) and the historical period (1980-2010).

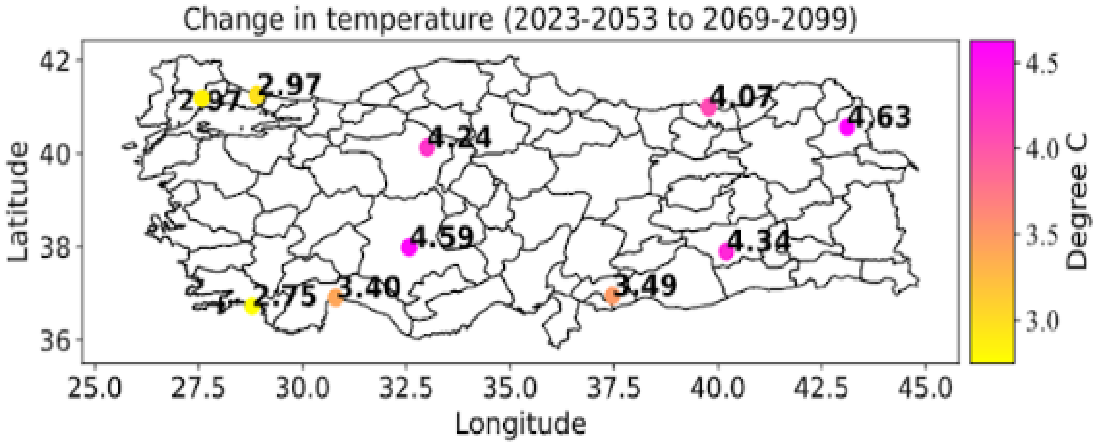

Figure 3.3 : The fluctuation in daily mean temperatures (°C) for June, July, and August between the far future (2069-2099) and the near future (2023-2053).

3.2 Pressure Altitude

Upon examining the barometric altimeter, it's evident that unlike temperature, this parameter doesn't exhibit a distinct increase (Figure 3.4). Across the transition from the past to the near future, minimal increments in pressure altitude values were observed for seven airports, whereas three airports (Konya, Ankara Esenboğa, and Kars Harakani Airports) displayed a decrease in these values (Figure 3.5). Similarly, while minimal increases in pressure altitude values were observed in seven airports in the transition from the near future to the far future, a decrease was observed in these values in three airports (Figure 3.6). This relationship is comprehended through the AP equation (Equation 2.3), where the pressure altitude value is contingent on temperature and sea level pressure. Over time, temperature displays a consistent upward trend as depicted in Figures 3.1, 3.2, and 3.3. In contrast, the sea level pressure parameter showcases a varied pattern, increasing in certain regions while declining in others. Consequently, among the 10 airports in analysis, variations in pressure altitude values reveal an upward trend in certain airfields and a decline in others. Moreover, there exists a negative correlation between the pressure altitude alteration and airport elevation, as detailed in Table 2.1. This correlation implies that at airports situated at higher altitudes, the pressure altitude experiences a more pronounced decrease.

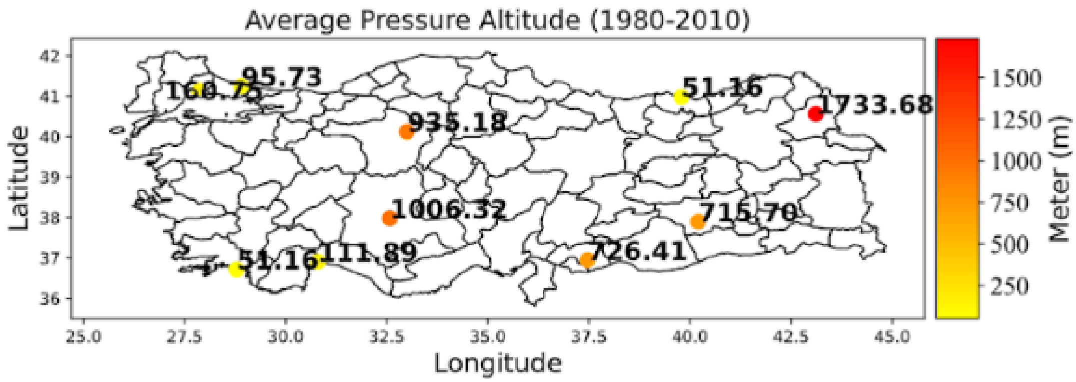

Figure 3.4 : The average daily pressure altitude (m) for June, July, and August during the past period from 1980 to 2010.

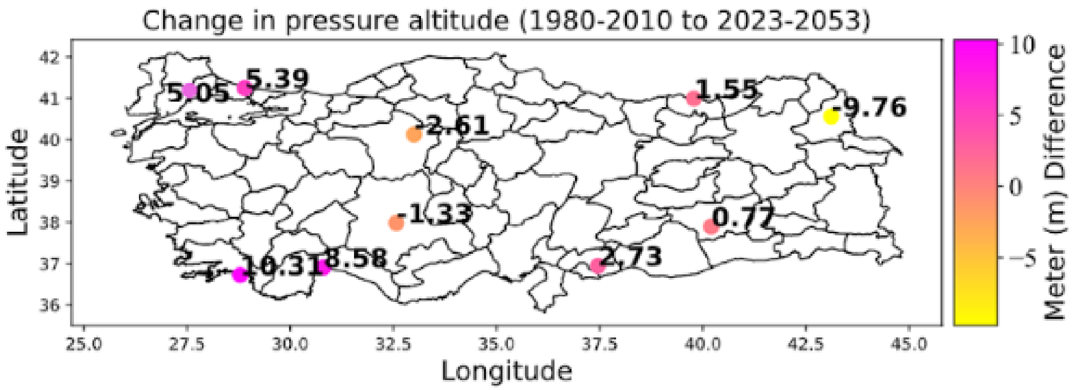

Figure 3.5 : The fluctuation in daily mean preesure altitude (m) June, July, and August between the near future (2023-2053) and the historical period (1980-2010).

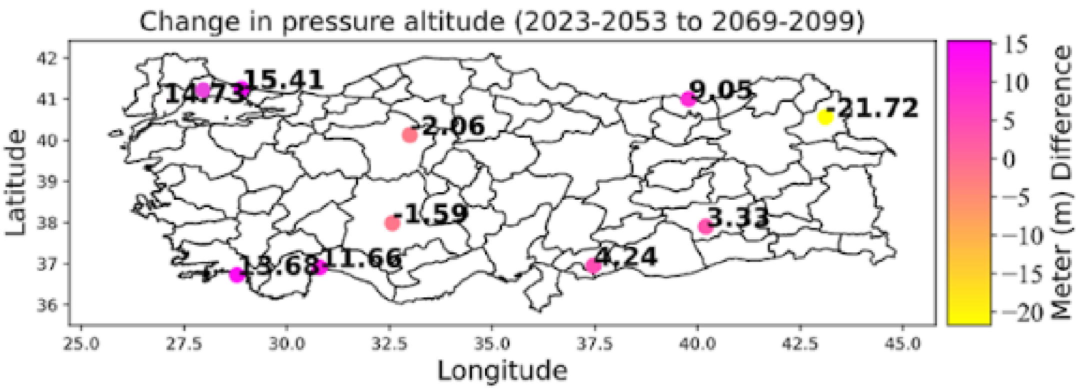

Figure 3.6 : The fluctuation in daily mean pressure altitude (m) for June, July, and August between the far future (2069-2099) and the near future (2023-2053).

3.3 Takeoff Distance

Upon reviewing Figure 3.7, the data reveals a spectrum of average takeoff distance factor increments during the past period, spanning from 0% to 18%. Kars Harakani Airport displayed a consistent takeoff distance factor, remaining unaltered at 0%, while Diyarbakır Airport experienced the most significant increase at 18%. The mean rise in the takeoff distance factor during the past period amounts to 11.2%. Analyzing the alterations in airport takeoff distances over time indicates an escalation from the past to the near future and further from the near future to the far future. The correlation between the rise in average temperature values and the increase in average takeoff distance factors is apparent. Moreover, the elevation in the average takeoff distance factor from the near future to the far future surpasses the increment witnessed from the past to the near future. The variations in the average takeoff distance factor show the lowest increase from the past to the near future at 1% for Tekirdağ Çorlu Airport, peaking at 3% for Konya and Antalya Airports in Figure 3.8. Meanwhile, the progression from the near future to the far future sees a minimum 4% elevation in the average takeoff distance factor for Muğla Dalaman and İstanbul Airports and a maximum rise of 7% for Diyarbakır Airport in Figure 3.9. Changes in the takeoff distance factor directly inform alterations in the takeoff distance, given their proportional relationship according to Equation 2.5.

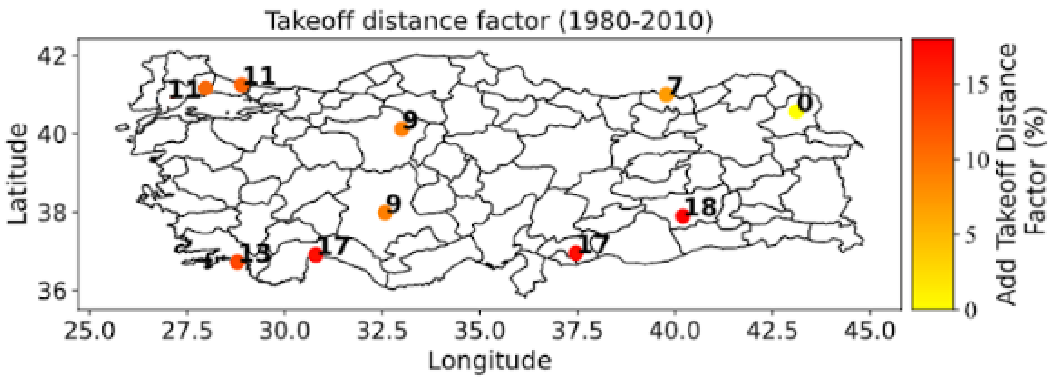

Figure 3.7 : The average daily takeoff distance factor (%) for June, July, and August during the past period from 1980 to 2010.

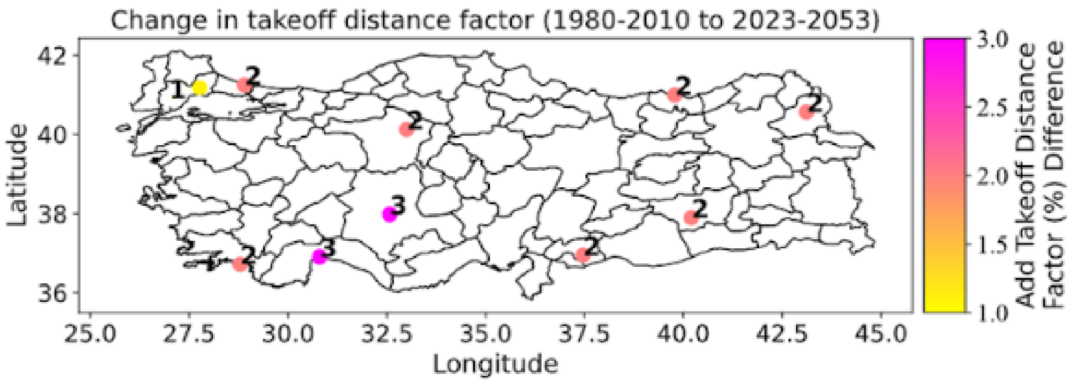

Figure 3.8 : The fluctuation in daily mean takeoff distance factor (%) for June, July, and August between the near future (2023-2053) and the past period (1980-2010).

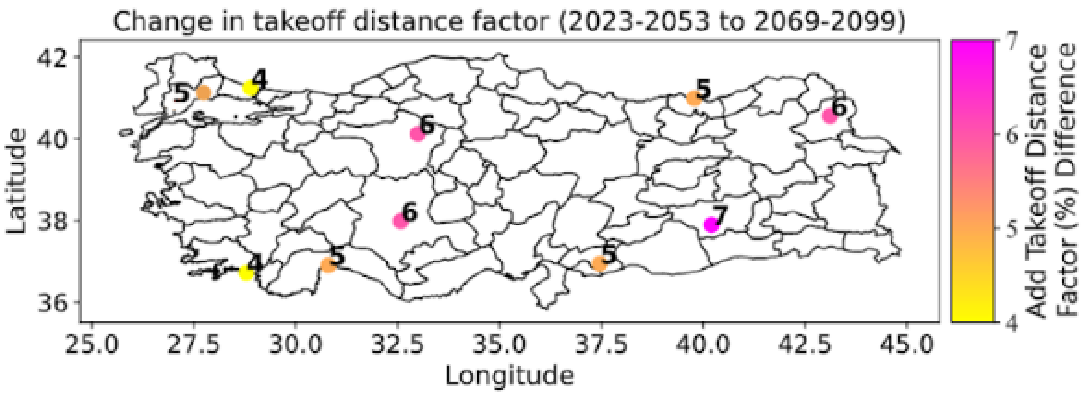

Figure 3.9 : The fluctuation in daily mean takeoff distance factor (%) for June, July, and August between the far future (2069-2099) and the near future (2023-2053).

3.4 Assessing How Temperature Alterations Impact Takeoff Distance Factor

With rising temperatures, there's a notable increase in takeoff distances. Notably, the takeoff distance factor demonstrates a positive correlation with temperature trends across periods, as depicted in Figures 3.10a and 3.10b. The acceleration of temperature and takeoff distance growth from the near future to the far future surpasses the pace observed from the past to the near future.

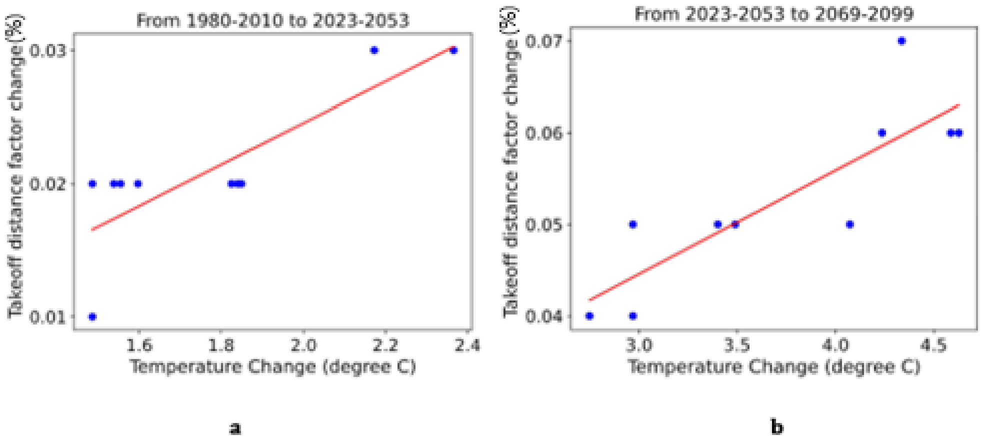

Figure 3.10 : The correlation between takeoff distance factor change and temperature change.

3.5 Climb Rate

The escalation in average climb rate decrease rates has become prominent over time (Figure 3.11). During the transition from the past period to the near future, the lowest average climb rate decrease, at 1%, is registered at Gaziantep Oğuzeli, Muğla Dalaman, and Tekirdağ Çorlu Airports, while the highest stands at 2% for Ankara, Antalya, Diyarbakır, Kars Harakani, Konya, Trabzon, and İstanbul Airports (Figure 3.12). During the transition from the near future to the far future, İstanbul and Muğla Dalaman Airports experience the lowest average climb rate decrease, measuring 3%, while Ankara and Konya Airports show the highest decrease at 5% (Figure 3.13).

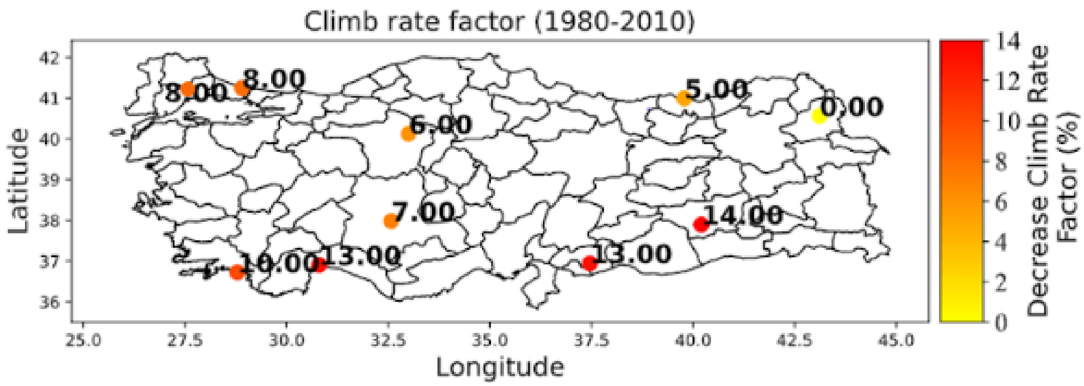

Figure 3.11 : The average daily climb rate factor (%) for June, July, and August during the past period from 1980 to 2010.

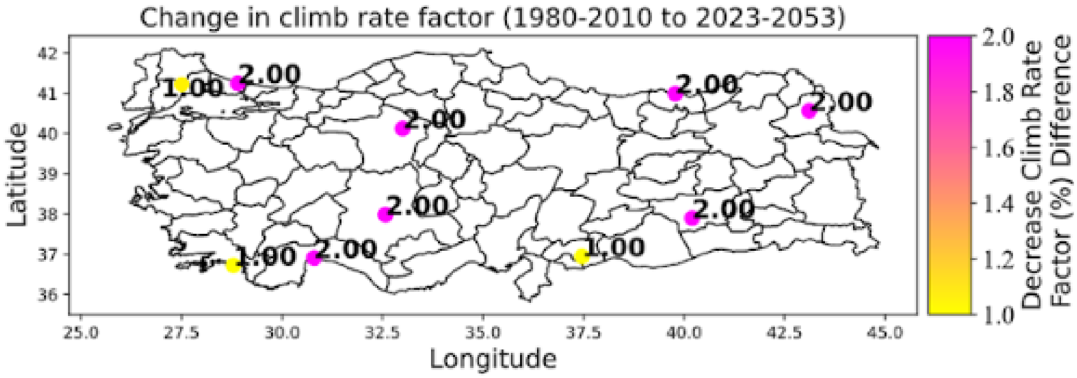

Figure 3.12 : The fluctuation in daily mean climb rate factor (%) for June, July, and August between the near future (2023-2053) and the past period (1980-2010).

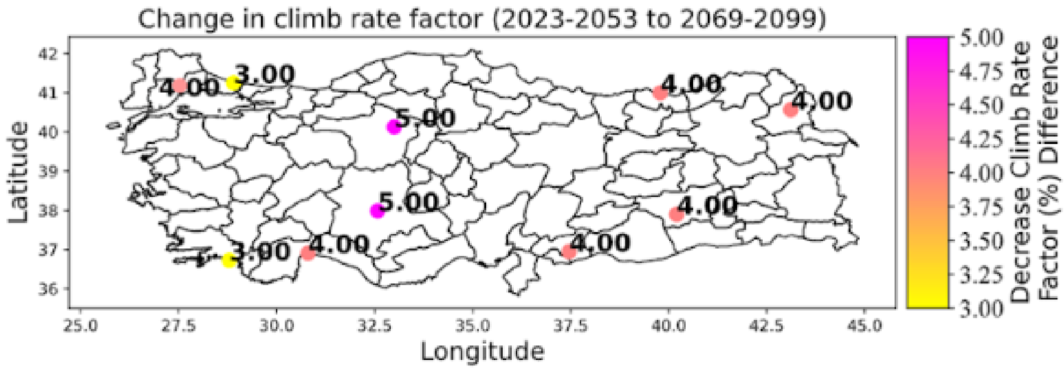

Figure 3.13 : The fluctuation in daily mean climb rate factor (%) for June, July, and August between the far future (2096-2099) and the near future (2023-2053).

3.6 Assessing How Temperature Alterations Impact Climb Rate Factor

Increasing temperature leads to a decrease in climb rate. This relationship is evidenced by the negative correlation between the climb rate factor and temperature, observed from the past period to the near future and from the near future to the far future (Figures 3.14a, 3.14b). The extent of climb rate reduction due to temperature rise is higher when comparing the near future to the far future against the reduction observed from the past to the near future.

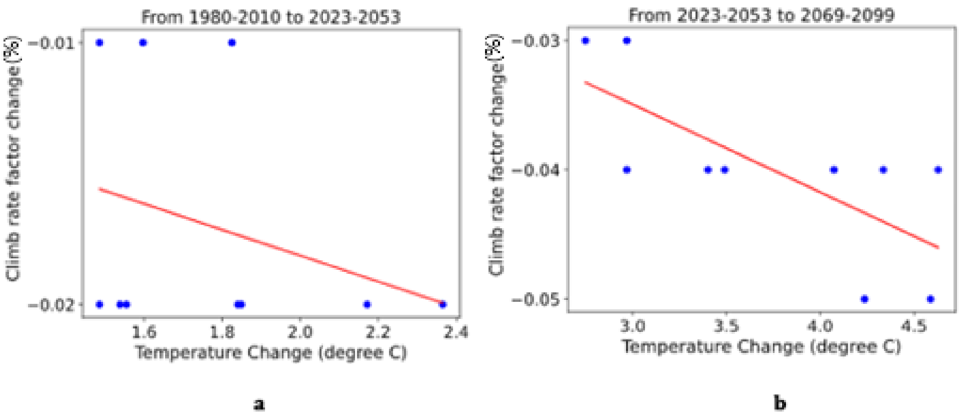

Figure 3.14 : The correlation between climb rate factor change and temperature change.

3.7 Variations in Takeoff Distances Across Various Timeframes for Boeing 737-800 Aircraft Type

The Boeing 737-800 aircraft type has a MTOW of 79,016 kg (Christie, 2014), with the takeoff distance in meters calculated using performance charts at this maximum weight (Url-5). Table 3.1 exhibits the computed takeoff distances in meters for ten airports in Türkiye across historical, near-future, and distant-future timeframes.

Table 3.1 : The derived takeoff distance measurements for ten Turkish airports across past periods, near and far future periods.

Airports	Past Period (1980-2010) Takeoff Distance Values (m)	Near Future (2023-2053) Takeoff Distance Values (m)	Far Future (2069-2099) Takeoff Distance Values (m)
Trabzon Airport (TZX)	2354	2398	2508
Kars Harakani Airport (KSY)	2200	2244	2376
Tekirdağ Çorlu Airport (TEQ)	2442	2464	2574
İstanbul Airport (IST)	2442	2486	2574
Ankara Esenboğa Airport (ESB)	2398	2442	2574
Konya Airport (KYA)	2398	2464	2596
Gaziantep Oğuzeli Airport (GZT)	2574	2618	2728
Diyarbakır Airport (DIY)	2596	2640	2794
Muğla Dalaman Airport (DLM)	2486	2530	2618
Antalya Airport (AYT)	2574	2640	2750

4. CONCLUSION AND RECOMMENDATION

The research covers ten airports in Türkiye. The focus is on daily temperature averages for the summer months (June, July and August) between 1980 and 2010. ERA5 daily average temperature and sea level pressure data were used for the past period. High-resolution daily mean temperature and sea level pressure data from the Max Planck Institute Earth System Model (MPI-ESM1-2-LR) were used for future and historical simulations covering 1980-2010, 2023-2053 and 2069-2099. The impact of climate change on aviation was examined with the data used. Takeoff performance, which affects aviation, has been investigated in terms of climb rate and takeoff distance.

This research aims to investigate how climate change affects aircraft takeoff performance in the aviation industry, particularly focusing on the changes in takeoff distance linked to climate variations for the Boeing 737-800 aircraft. The rise in temperatures due to climate shifts directly corresponds to increased takeoff distances required by airplanes. In such scenarios, aircraft may need to reduce cargo capacity or fuel loads or limit passenger capacity, resulting in heightened expenses within the aviation sector. Addressing these challenges might involve potential solutions such as adjusting airport runway lengths to accommodate the shifting temperature patterns and subsequent changes in takeoff requirements.

Takeoff distances are computed individually for each airport, considering historical, near-term, and far-term periods. The calculated outcomes reveal varied takeoff performances among different airports for a singular aircraft model due to the discrepancies in latitudes, longitudes, and altitudes across these airport locations.

Kars Harakani Airport presents the shortest takeoff distance, while Diyarbakır Airport exhibits the longest. Concerning the Boeing 737-800 aircraft, the mean takeoff distances during summer at Kars Harakani Airport are: 2200 m in the past period, 2244 m in the near future, and 2376 m in the far future. At Diyarbakır Airport, the average takeoff distances during summer are: 2596 m in the past, 2640 m in the near future, and 2794 m in the far future. The average summer takeoff distances for other airports are provided in Table 4.

The average takeoff distance for the Boeing 737-800 aircraft type is anticipated to undergo more significant alterations in the upcoming summer compared to the preceding summer months. The temperature variance between the past and near future at Tekirdağ Çorlu Airport stands relatively lower compared to other airports, while Konya and Antalya Airports experience a more pronounced temperature shift. As a result, Tekirdağ Çorlu Airport records the least average takeoff distance alteration from the past to near future, at 22 m, whereas Konya and Antalya Airports exhibit a 66 m change. Regarding the temperature shift from near future to distant future, İstanbul and Muğla Dalaman Airports indicate relatively minor changes, contrasting with Kars Airport experiencing a substantial temperature shift compared to other airports. However, the reduction in pressure altitude values at Kars Airport triggers the most considerable increase in takeoff distance, notably at Diyarbakır Airport. The minimal variation in average takeoff distance from near future to distant future is 88 m at İstanbul and Muğla Dalaman Airport, while the maximum alteration reaches 154 m at Diyarbakır Airport.

The investigation focused on the takeoff capabilities of the Boeing 737-800 aircraft type using daily average air temperatures. However, similar analyses can be conducted for various aircraft models. Additionally, alongside daily average air temperature data, utilizing daily maximum air temperature and wind data could enhance the scope of the analysis.

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PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

- **Çağlıyan, Y. Ş., and Demirhan, D.** 2023: The Effect of Global Temperature Change on the Take-off Performance of Boeing 737-800 Max. *11th International Mardin Artuklu Scientific Researches Conference*, December 13-15, 2023 Mardin, Turkey.
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