Adapting European Aviation to a Changing Climate:

Guidance on Risk Assessment and Adaptation

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EXECUTIVE SUMMARY

The European aviation sector is increasingly vulnerable to the impacts of climate change, introducing significant risks to operations, infrastructure, safety, and economic viability. Rising temperatures, shifting precipitation patterns, and more frequent extreme weather events are already disrupting airport operations, airline schedules, and air traffic management. These impacts will intensify without proactive adaptation measures.

This guidance provides a framework for airports, airlines, and Air Navigation Service Providers (ANSPs) to strengthen climate resilience. It outlines the regulatory context, regional climate projections, and practical steps for assessing climate vulnerabilities and implementing adaptation strategies. Key actions to take include:

- **Infrastructure adaptation**: Upgrade drainage and cooling systems, reinforce runways and taxiways, and integrate nature-based solutions to manage flooding, heat stress for passengers and personnel, and soil instability.
- **Operational resilience**: Adjust flight planning and scheduling to account for extreme temperatures, wind shifts, and storm disruptions; enhance turbulence forecasting and emergency protocols.
- **Resource management**: Prepare for water scarcity and energy demand fluctuations through efficient technologies and sustainable practices.
- **Biodiversity and ecosystem integration**: Adopt measures that reduce wildlife hazards while leveraging ecosystems for climate regulation and resilience.
- **Collaborative planning**: Engage stakeholders across the aviation network and related sectors to address cascading risks and ensure continuity of critical services.

The document emphasises that adaptation is not only an increasing regulatory expectation but a strategic imperative. By investing in climate resilience now, European aviation can safeguard connectivity, maintain safety standards, and support long-term sustainability goals—including commitments to achieve net-zero emissions.

Ultimately, the goal is to empower aviation organisations to anticipate climate risks, implement robust adaptation measures, and maintain their essential role in Europe’s economy and global connectivity. By taking decisive action now, the aviation sector can enhance its resilience against future climate impacts.

How to use the Guidance?

Select a Climate Zone

First, identify the climate zone relevant to your analysis. For instance, where an airport is located.
→ *cf.* ***Section 3: Regional Climate Effects for Aviation for detailed description***

Example: Atlantic Region

Expected Climate Scenarios

Consult the overview of projected climate change scenarios and their expected effects for the selected region.
→ *cf.* ***Section 4: Understanding Climate Change Impacts on Aviation*** *for more information on these projections.*

Example:
→ Increase in heavy precipitation events
→ Increase in river flow
→ Increasing risk of river and coastal flooding
→ Increasing damage risk from winter storms

Understanding Climate Change Impacts on Aviation

Within the selected climate scenario, explore the detailed information provided to understand how climate change may affect aviation operations and stakeholders.

Example: **→ Changes in precipitation**

- **Details of impacts, impacted actors and expected consequences**
  → *flooding leading to high groundwater*
  - *Impact: water on the surface*
  - *Impacted actors: Airport/Airlines/Air Navigation*
  - *Expected consequences: soil erosion and/or bird strike risk (attractive effect on bird flocks)*
- **Potential adaptation measures**
  → *ideally no/low flow velocities, develop water retention areas; or implement Above-ground drainage/pumping into flowing water bodies*

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1. Introduction

The aviation sector stands at a critical crossroads as it confronts the escalating impacts of climate change. According to the ACI World 2020 stakeholder survey, 53% of European airports have already experienced disruptions due to adverse weather events. Rising temperatures, shifting precipitation patterns, and an increase in extreme weather occurrences underscore the urgent need for comprehensive climate adaptation strategies across the entire aviation ecosystem—not only for airports but also for airlines and Air Navigation Service Providers (ANSPs).

This imperative for sector-wide adaptation is echoed by the work of the International Civil Aviation Organisation's Committee on Aviation Environmental Protection (ICAO CAEP), which in 2022[1] emphasised the need for robust adaptation measures across civil aviation. The CAEP highlights that integrating climate adaptation into aviation planning and operations is essential to safeguard infrastructure, operations, and long-term sustainability.

These climatic changes threaten operational efficiency, passenger and staff safety, and the economic viability of air travel. Airports face infrastructure vulnerabilities such as flooding and heat stress; airlines contend with increased fuel consumption, flight delays, and altered operational windows; while ANSPs must manage more complex and variable air traffic flows under challenging weather conditions. Together, these impacts demand coordinated adaptation efforts to ensure the resilience of the sector as a whole.

1.1 The importance of Adaptation Strategies

Europe is the continent with the fastest projected temperature rise.[2] Therefore, adapting to climate change is no longer optional – it is essential. First and foremost, airports and airlines must ensure safety and operational continuity in the face of rising sea levels, extreme temperatures, and severe storms. For example, studies indicate that two-thirds of coastal airports in the European region are at heightened risk of flooding, which could lead to substantial economic losses from flight cancellations and delays. A single day of closure due to flooding can cost medium-sized airports up to €3 million and major hubs approximately €18 million in diverted flights and clean-up efforts.[3]

[1] https://www.icao.int/environmental-protection/pages/adaptation.aspx
[2] https://op.europa.eu/en/publication-detail/-/publication/26731a63-b904-11ef-91ed-01aa75ed71a1/language-en
[3] https://www.eurocontrol.int/publication/eurocontrol-study-climate-change-risks-european-aviation

The aviation industry is used to dealing with weather, although it still has the potential to cause significant disruptions. Moreover, as extreme weather events increase in frequency and intensity disruptions will increase, leading to potentially significant operational delays and increased fuel consumption. For example, in 2019 alone, major storms resulted in an estimated €2.2 billion in costs due to en-route delays, highlighting the financial implications of inadequate resilience measures[4].

For ANSPs, climate change introduces increased complexity in managing traffic safely and efficiently, with weather-related disruptions requiring adaptive traffic management and contingency planning. For airlines, climate change is expected to increase operational disruption, leading to delayed, diverted and cancelled flights and unhappy passengers. The interconnected nature of airports, airlines, and ANSPs means that climate impacts to one stakeholder reverberate throughout the wider aviation system.

Climate adaptation strategies are an important part of safeguarding sector and minimising impacts for passengers and staff. Implementing advanced weather monitoring systems and improving infrastructure resilience are critical steps in mitigating risks associated with changing climatic conditions. Additionally, adapting aircraft operations—such as adjusting flight schedules during periods of extreme heat—can help maintain safety standards while optimising performance.

Climate change poses significant challenges to air transport operations worldwide, threatening infrastructure, safety, and economic viability. As extreme weather events become increasingly frequent and severe, it is imperative for airports, airlines and ANSPs to develop robust adaptation strategies that not only mitigate risks but also enhance resilience.

This guidance document aims to provide a comprehensive framework for airports and stakeholders to assess climate-related vulnerabilities, implement effective adaptation measures, and integrate climate resilience into their long-term planning processes. Although it is aimed at European aviation stakeholders many of the processes and recommendations with be applicable for aviation sector stakeholders worldwide.

1.2 Proactive Measures for Resilience

Airports, airlines, and ANSPs collectively form the backbone of the global air transport network, enabling connectivity, commerce, and mobility worldwide. However, these critical stakeholders are all increasingly vulnerable to the escalating impacts of climate change—rising sea levels,

[4] https://www.eurocontrol.int/publication/eurocontrol-study-climate-change-risks-european-aviation

extreme temperatures, severe storms, intense and prolonged precipitation and other extreme weather events pose significant risks to infrastructure, operations, and safety.

Recognising these challenges, immediate and coordinated action is essential. By proactively addressing climate risks through comprehensive planning, investment in resilient infrastructure, and collaborative approaches, airports can safeguard their facilities and ensure the safety and comfort of passengers and staff whilst minimising disruption. Similarly, airlines must adapt operational procedures—such as flight planning, scheduling, and fuel management—to mitigate increasing weather-related disruptions and maintain efficiency. ANSPs face the challenge of managing more complex and variable air traffic flows under increasingly unpredictable weather conditions, requiring flexible and adaptive airspace management strategies.

This document outlines best practices for conducting climate risk assessments, retrofitting existing infrastructure, and mainstreaming resilience into the design of new facilities. It emphasises the importance of stakeholder engagement and knowledge-sharing among aviation organisations, local authorities, and industry experts to foster a collective response to climate challenges.

The objectives of the guidance are three-fold:

1. **Raise awareness of the multifaceted impacts of climate change across the aviation sector.**
2. **Offer actionable recommendations to reduce climatic impacts and increase resilience.**
3. **Share practical examples and case studies illustrating successful adaptation measures.**

1.3 A call to action for sustainable aviation resilience

As regulatory pressures mount and public awareness of climate issues grows, the aviation sector must prioritise climate resilience not only to comply with regulations but also to meet stakeholder expectations for sustainability. By investing in adaptation measures now, the industry can better prepare for future challenges while contributing to broader efforts to combat climate change.

The importance of climate change adaptation for aviation extends beyond immediate operational concerns; it encompasses long-term sustainability goals that are vital for the future of global air travel. Embracing these strategies will enable airports, airlines and ANSPs to navigate the complexities of a changing climate while ensuring safety, efficiency, and economic stability.

Ultimately, the goal is to empower aviation organisations to adapt effectively to a changing climate while maintaining their essential role in the global economy. By taking decisive action now, the aviation sector can enhance its resilience against future climate impacts.

2. Regulatory state of play

The regulatory framework in the European Union (EU) regarding climate adaptation obligations for companies is evolving within a broader EU strategy aimed at making the Union climate-resilient by 2050. The European Adaptation Strategy, adopted in 2021, emphasises the need for smarter, faster, and more systemic adaptation actions across all sectors, including business. While the strategy primarily targets Member States to develop and implement adaptation plans, it promotes the use of robust data and risk assessment tools accessible to all stakeholders to manage climate-related risks effectively.

Beyond climate-specific frameworks, the EU Critical Entities Resilience (CER) Directive (Directive (EU) 2022/2557) complements these objectives by requiring Member States and operators of essential services, including those in transport infrastructure, to strengthen their resilience against a broad range of disruptive risks, including those stemming from natural hazards and climate change. The Directive reinforces the integration of resilience planning at the operational level and encourages critical entities to assess climate-related vulnerabilities as part of their risk management obligations.

Legally, the 2018 Governance Regulation requires EU Member States to include adaptation objectives in their integrated National Energy and Climate Plans (NECPs), which are updated regularly. The European Climate Law, in force since 2021, further strengthens this by establishing a binding duty to adapt, mandating continuous progress in enhancing adaptive capacity. Although the Law sets overarching climate neutrality and adaptation goals, it does not yet specify detailed obligations for individual companies. However, it provides a framework for delegated acts that may define such measures in the future, considering economic competitiveness and best available techniques.

The Corporate Sustainability Reporting Directive (CSRD) significantly advances the regulatory obligations for companies in Europe regarding climate adaptation. Under the CSRD, nearly 50,000 large and listed companies are required to disclose detailed information on how climate change impacts their business and how they are adapting to these risks. Specifically, the CSRD mandates companies to report on their processes for identifying and assessing material climate-related impacts, risks, and opportunities, including physical risks from climate hazards and transition risks related to the shift to a low-carbon economy. This includes disclosing the resilience of their strategy and business models to climate change, their transition plans aligned with the Paris Agreement goals, and the financial effects of climate risks over short, medium, and long-term horizons.

The European Sustainability Reporting Standards (ESRS), particularly ESRS E1 on Climate Change, provide the detailed framework for these disclosures. Companies must report on their greenhouse gas emissions (Scope 1, 2, and 3), climate risk assessments, and adaptation measures taken to mitigate physical risks such as extreme weather events or long-term climate shifts.
The CSRD thus places a clear regulatory obligation on companies not only to disclose their environmental impact but also to demonstrate proactive climate adaptation strategies and risk management processes. This aligns with the EU's broader climate adaptation goals and ensures that companies contribute transparently to climate resilience, enabling investors and stakeholders to make informed sustainable decisions.

While direct regulatory obligations on companies for climate adaptation are currently limited and largely mediated through national plans and future delegated acts, the EU's evolving legal and policy framework increasingly integrates adaptation as a binding and systemic priority, signalling growing expectations for adaptation efforts in the near term.

3. Regional Climate Effects for Aviation

To address the climate change adaptation needs of European aviation organisations, the guidance uses the seven biogeographical regions delimited by the European Environment Agency[5] (EEA, Figure 1). This regional approach recognises that climate impacts—and thus adaptation needs—vary significantly across Europe's diverse climates and landscapes.

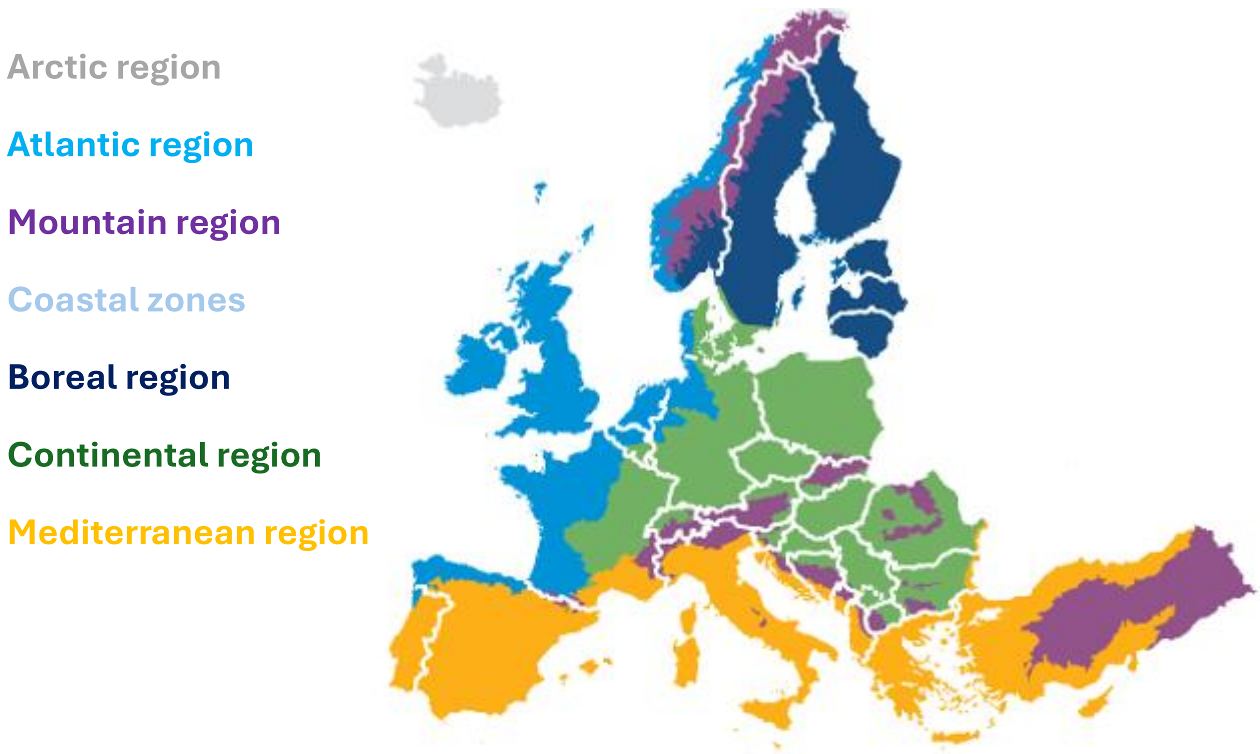

Figure 1: European Environment Agency's seven biogeographical regions

[5] https://www.eea.europa.eu/en/analysis/publications/climate-change-impacts-and-vulnerability-2016

Climate projections are based on Representative Concentration Pathways (RCPs), which model future warming scenarios depending on greenhouse gas emissions. These range from ambitious mitigation pathways limiting warming to around 1.5°C (RCP 1.9/2.6) to high-emission scenarios where temperatures could rise by 4°C or more by 2100 (RCP 8.5). The differences between these scenarios are stark: at 1.5°C warming, climate risks such as heatwaves, flooding, and infrastructure stress are serious but more manageable, whereas at 4°C, extreme weather events become far more frequent and severe, threatening aviation operations, safety, and economic viability.

The seven biogeographical regions — Arctic, Atlantic, Mountain, Coastal, Boreal, Continental and Mediterranean — face distinct climate challenges, from rising sea levels and increased flooding in coastal areas to heat stress and drought in southern Europe or permafrost thaw in the north. Tailoring adaptation strategies to these regional differences is essential for airports, airlines, and ANSPs to build resilience effectively.

By integrating climate projections and regional specificities, the guidance approach supports the aviation sector in preparing for a range of future climate conditions, ensuring operational continuity and safety amid a changing climate.

3.1 Arctic

<u>Overview of climate effects & projected climate change scenarios</u>

Key Climate Effects
• Temperature rise much greater than global average • Decrease in Arctic sea ice coverage • Decrease in Greenland ice sheet • Decrease in permafrost areas • Increasing risk of biodiversity loss

The Arctic region is experiencing rapid and profound changes driven by climate change, with warming occurring at nearly four times the global average. This phenomenon, known as Arctic amplification, results from the loss of reflective sea ice, which exposes darker ocean waters that absorb more solar heat, further accelerating warming.

In 2025, the Arctic sea ice reached its lowest winter maximum extent on record, continuing a long-term trend of shrinking ice cover that has severe implications for the region's climate system and ecosystems. The diminishing ice cover disrupts atmospheric and oceanic circulation patterns, contributing to more extreme weather globally.

Climate projections based on Representative Concentration Pathways (RCPs) illustrate the scale of these transformations. Under high-emission scenarios such as **RCP 8.5**, Arctic temperatures could rise by 7 to 12°C above late 20th-century averages by 2100, leading to nearly ice-free Arctic summers, a 422% increase in winter rainfall, and extensive ecosystem disruption. In contrast, limiting warming to around **1.5°C** (aligned with RCP 1.9/2.6) could delay or reduce these impacts, preserving more summer sea ice and moderating temperature and precipitation extremes.

For example, while occasional ice-free months may still occur at 1.5°C warming, the duration and extent of open water would be substantially less than under higher warming pathways. The difference between 1.5°C and 4°C warming is stark: at 4°C, the Arctic faces near-total summer sea ice loss, extreme temperature rises, and profound hydrological changes, whereas at 1.5°C, these changes remain significant but more manageable, allowing ecosystems and communities more time to adapt.

In summary, the Arctic is undergoing a climate crisis characterised by record low sea ice, rapid warming, and ecological disruption. This regional specificity is critical for tailoring adaptation strategies for airports, airlines, and air navigation service providers operating in or dependent on the Arctic environment.

Arctic region references: Rantanen et al., 2022; Bocquet et al., 2024; Carrivick et al. 2023; Copernicus Climate Indicators; Verdonen et al. 2023; Lemieux et al., 2025 ; Vincent et al., 2012; IPCC Sixth Assessment Report (AR6), 2022.

3.2 Atlantic

<u>Overview of climate effects & projected climate change scenarios</u>

Key Climate Effects
• Increase in heavy precipitation events • Increase in river flow • Increasing risk of river and coastal flooding • Increasing damage risk from winter storms • Increase in compound events (multiple climate hazards occurring at the same time).

The European Atlantic region is facing significant climate change impacts driven by rising temperatures, changing atmospheric patterns, and sea level rise. Recent observations show Europe experiencing some of its warmest months on record, with April 2025 being among the warmest, about 1°C above the 1991-2020 average, contributing to increased heat stress and ecosystem shifts.

A key driver of regional climate variability, the North Atlantic Oscillation (NAO), is projected to reach unprecedented magnitudes by the end of the century, potentially causing more frequent and severe flooding, storm damage, and extreme winter weather in northern and western Europe. This intensification of the NAO is linked to greenhouse gas emissions and could exacerbate extreme weather events, posing challenges for infrastructure and communities.

Climate projections under different Representative Concentration Pathways (RCPs) indicate substantial warming and changes in extreme events for the region. Under a high-emission scenario such as **RCP 8.5**, average temperatures in the European Atlantic could rise by 3.5 to 5°C by 2100, with marine heatwaves becoming more frequent and intense. This warming will exacerbate coastal flooding, infrastructure stress, and ecosystem disruption. In contrast, limiting warming to around **1.5°C** (aligned with RCP 1.9/2.6) would substantially reduce these impacts, moderating the frequency and severity of heatwaves, extreme precipitation, and sea surface temperature rise, thereby allowing ecosystems and human systems more time to adapt.

Sea level rise along the European Atlantic coast is expected to closely follow global trends, with projections ranging from 0.28 to 0.55 meters by 2100 under low emissions scenarios, and potentially higher under RCP 8.5. This rise will increase the frequency and severity of coastal flooding, with historically rare 1-in-100-year flood events projected to occur up to 10 times more frequently by 2050 in countries including Portugal, Spain, France, Belgium, and the Netherlands. Coastal erosion and changes in wave dynamics will further affect ecosystems and human settlements. While a collapse of the Atlantic Meridional Overturning Circulation (AMOC) is considered unlikely this century, a weakening AMOC is anticipated, which could lead to drier summers and more pronounced seasonal droughts in Europe, stressing water resources and agriculture.

The difference between **1.5°C and 4°C warming** is critical for the European Atlantic region. At 1.5°C, increases in heatwaves and extreme precipitation remain within a range more manageable through adaptation, whereas at 4°C, these extremes become far more severe and frequent, causing widespread impacts on ecosystems, human health, and economic activities such as aviation and maritime transport. Changes in the AMOC could amplify or moderate these impacts, influencing temperature and storminess patterns.

In summary, the European Atlantic region faces warming temperatures, increased storm intensity, rising sea levels, and altered hydroclimatic patterns, all demanding enhanced adaptation and resilience strategies to reduce impacts to aviation infrastructure, and operations.

Atlantic region references: Veronika Ettrichrätz et al., 2023; Rousi et al., 2021 ; Copernicus, 2023; European Environment Agency, 2021 ; Arnal et al., 2018 ; Vousdoukas et al., 2020; Maycock et al. 2025; European Environment Agency, 2024; Severino et al., 2024; Filahi et al., 2024; Deroubaix et al., 2021; Tomrukçu & Ashrafian, 2024 ; Snow and ice — snow, glaciers and ice sheets — European Environment Agency; IPCC AR6 WG2, Chapter 13, 2022.

3.3 Coastal

Overview of climate effects & projected climate change scenarios

Key Climate Effects
• Sea level rise • Increase in sea surface temperatures • Potential increase in frequency and intensity of storm surges

Sea level rise along European coasts is projected to closely follow or exceed global mean trends, driven by glacier and ice sheet melt combined with ocean thermal expansion. Under moderate emissions scenarios (e.g., RCP 2.6), sea levels are expected to rise by approximately 0.28 to 0.55 meters by 2100, while under high-emission pathways (RCP 8.5), this rise—and associated extreme sea levels—could be substantially greater.

Historically rare 1-in-100-year coastal flood events are projected to become up to 10 times more frequent by 2050 along many Atlantic and Mediterranean coasts, with some areas facing near-annual flooding under high warming scenarios. These trends threaten coastal infrastructure, ecosystems, tourism, trade, and livelihoods, complicating efforts to balance environmental protection with economic development. Climate projections for the European coastal region indicate that under **RCP 8.5**, average temperatures could increase by 3 to 5°C by 2100, accompanied by more frequent and intense marine heatwaves, extreme precipitation, and storm surges.

For example, ocean bottom temperatures in parts of the Atlantic basin may rise by up to 3.5°C, with air temperatures increasing by as much as 5°C during heatwaves. These changes exacerbate coastal flooding, accelerate erosion, and disrupt ecosystems. In contrast, limiting warming to **1.5°C** (aligned with RCP 1.9/2.6) would substantially reduce the frequency and severity of these extreme events, providing more time for ecosystems and human systems—including airports, coastal communities, and maritime industries—to adapt. Coastal erosion, saltwater intrusion, and altered wave dynamics further stress vulnerable coastal zones.

Governance and adaptation challenges are significant due to the long-term nature of sea level rise, uncertainties in projections, and the need for coordinated action across multiple sectors and scales. Many European countries are integrating sea level rise into national adaptation plans and marine spatial planning, increasingly adopting innovative and cost-effective nature-based solutions—such as restoring wetlands, dunes, and reefs—that enhance coastal resilience while supporting biodiversity and local communities.

Approximately two-thirds of coastal or low-lying airports face increased flooding risks during storm surges. Even a single day of closure from flash floods can result in substantial economic losses, estimated between €3 million for medium-sized airports and €18 million for major hubs[6].

In summary, the European coastal region faces escalating climate risks from rising temperatures, sea level rise, and extreme coastal events. These impacts demand urgent, integrated, and regionally tailored adaptation strategies to protect critical airport and ANSP facilities and transport links, while maintaining sustainable economic activities and safeguarding coastal communities.

Coastal regions references: Copernicus, Ocean Monitoring Indicators; European Environment Agency, 2025; European Environment Agency, 2025; Copernicus: ESOTC 2024 – European ocean report, 2025; ECMWF, 2024; Varela et al., 2023 ; IPCC AR6 WG2, Chapter 13: Europe, 2022; OSPAR Quality Status Report 2023: Ocean Acidification, 2023; Finlay et al., UK waters facing accelerated ocean acidification, 2025.

[6] https://www.eurocontrol.int/sites/default/files/2021-09/eurocontrol-study-climate-change-risk-european-aviation-summary-report-2021.pdf

3.4 Mountains

Overview of climate effects & projected climate change scenarios

Key Climate Effects
• Temperature rise much greater than the European average • Decrease in glacier extent and volume • Upward shift of plant and animal species • Increasing risk from rock falls and landslides • Changes in hydropower potential

European mountain regions are experiencing accelerated climate change, with temperatures rising faster at higher altitudes than in surrounding lowlands. This elevation-dependent warming, projected to increase by 3 to 5°C by 2100 under medium to high emission scenarios (RCP 4.5 to RCP 8.5), is driving significant environmental and operational challenges for air transport infrastructure and services in these sensitive areas. Glaciers are retreating rapidly, smaller glaciers may disappear by mid-century, and snow cover duration is decreasing, affecting water availability crucial for downstream ecosystems and communities.

These physical changes are compounded by more frequent extreme weather events such as heavy rainfall, storms, and landslides, which threaten airport infrastructure, access routes, and flight safety. For airports located in mountain regions, these climate impacts translate into increased risks of operational disruption. Extreme weather events—such as sudden heavy rainfall—can cause flash flooding, runway closures, and damage to critical infrastructure, resulting in costly delays and cancellations.

While mountain airports are less exposed to hazards such as sea level rise, they remain vulnerable to intense storms and hydrological hazards that are increasing in frequency and severity due to climate change. Airlines operating in these regions also face challenges from altered wind and turbulence patterns.

Limiting warming to **1.5°C** (RCP 1.9/2.6) would significantly reduce the frequency and intensity of these extreme weather impacts, allowing mountain airports and airlines more manageable conditions to maintain safe and efficient operations. Conversely, at **4°C warming** (RCP 8.5), the European mountain aviation sector faces severe disruptions: glacier retreat and permafrost thaw could destabilise airport foundations and access roads, while more frequent heavy precipitation and storms would increase the likelihood of closures and delays, amplifying economic costs and safety risks. Adaptation strategies must therefore include enhanced climate risk assessments, infrastructure resilience upgrades, and coordinated contingency planning among airports, airlines, and ANSPs.

In summary, climate change poses escalating operational risks for air transport in European mountain regions. Proactive, integrated adaptation measures—supported by ongoing monitoring and collaboration across the aviation sector—are essential to safeguard connectivity, safety, and economic viability amid a rapidly changing climate.

Mountains regions references: Faranda et al., 2025; IPCC Sixth Assessment Report (AR6), WG2- regional findings for Europe; Airbus satellite study, 2025; Schuster et al, 2025; Dumont et al, 2025; Chan et al., 2024; Couet et al., 2022 ; Zu et al., 2021 ; Barredo Cano et al., 2020; European Environment Agency - State of Habitat and Species, 2025; Barredo Cano et al., 2020; European Climate and Health Organisation, 2025; Caleca et al., 2023; Wechsler et al., 2023 ; Duratorre et al., 2020 ; Bombelli et al., 2019; European Commission Joint Research Centre, 2018 ; Steiger et al., 2024; Ranocchiari et al., 2025; François et al., 2023 ; Notarnicola, 2022.

3.5 Continental

Overview of climate effects & projected climate change scenarios

Key Climate Effects
• Increase in heat extremes • Decrease in summer precipitation • Increasing risk of river floods • Increasing risk of forest fires

The European continental region is experiencing accelerated climate change, with temperatures rising faster than the global average and significant shifts in weather extremes. These changes increasingly affect air transport operations, infrastructure, and safety.

Record-breaking heatwaves, such as the prolonged 13-day event in southeastern Europe in 2024, have direct implications for airports and airlines, including increased risks of heat stress on infrastructure and personnel, and altered aircraft performance. Rising temperatures reduce air density, which negatively impacts aircraft lift during takeoff, especially at airports with shorter runways or located near hills and mountains, potentially forcing airlines to reduce passenger loads or cargo to maintain safety. Studies project that by 2065, under high-emission scenarios, some European airports—including those in continental regions—may have to reduce payload per flight during hot summer months due to these constraints, leading to operational challenges and economic impacts[7].

Flooding and extreme precipitation events are also on the rise, with over 30% of Europe's river networks exceeding high flood thresholds in 2024 and severe flood events, such as Storm Boris, causing widespread disruption across Germany, Poland, Austria, and Italy. Such hydrological extremes threaten airport infrastructure, access roads, and air traffic management systems, increasing the likelihood of delays, cancellations, and costly repairs. Prolonged droughts in parts of southeastern Europe further stress water availability, impacting airport cooling systems and potentially leading to airport closures if firefighting capacity is impacted.

Climate projections under **high-emission scenarios (RCP 8.5)** indicate that continental Europe could warm by 3 to 5°C by 2100, intensifying heatwaves, droughts, and flooding frequency. This warming would exacerbate operational disruptions due to increased turbulence, altered wind patterns,

[7] https://www.mdpi.com/2226-4310/12/3/165

and more frequent extreme weather events. Conversely, limiting warming to **1.5°C (RCP 2.6)** would moderate these impacts, reducing the frequency and severity of extreme heat and precipitation events, thereby easing adaptation pressures on the air transport sector.

In summary, climate change poses escalating risks to air transport in the European Continental region. Consequently urgent, integrated adaptation and mitigation efforts are required to safeguard connectivity, economic viability, and environmental sustainability.

Continental region references: Copernicus Climate Change Service - European State of the Climate, 2024 ; Schwingshackl et al., 2024 ; Vautard et al, 2023; IPCC AR6 WG2, 2022 ; Arellano et al., 2025 ; Dittus et al., 2024; ; Steinhausen et al., 2022; El Garroussi et al., 2024; JRC PESETA IV, 2020; Elnagar et al, 2023; European Commission JRC, 2025.

3.6 Mediterranean

Overview of climate effects & projected climate change scenarios

Key Climate Effects
• Large increase in heat extremes • Decrease in precipitation and river flow • Increasing risk of droughts • Increasing risk of biodiversity loss • Increasing risk of forest fires • Increasing competition between different water users • Expansion of habitats for southern disease vectors • Decreasing potential for energy production

The European Mediterranean region is a climate hotspot experiencing warming at a rate faster than the global average, with both air and sea temperatures projected to rise substantially throughout the 21st century. Under a high-emission scenario (**RCP 8.5**), summer temperatures could increase by **4 to 6°C** by 2100, accompanied by a sharp rise in the frequency and intensity of heatwaves and marine heatwaves. For example, the Adriatic Sea may warm by up to **3.5°C** in shallow waters, with marine heatwave intensity increasing sixfold compared to historical conditions. These changes threaten marine ecosystems, fisheries, and coastal infrastructure, all of which are critical for the Mediterranean's tourism and transport sectors.

Air transport in the Mediterranean is particularly vulnerable to these climate shifts. Rising temperatures and more frequent heatwaves can reduce aircraft performance due to lower air density, forcing payload restrictions and potentially increasing flight delays or cancellations during peak summer months. Airports face increased risks of overheating equipment and infrastructure, impacting ground operations and passenger comfort. Additionally, extreme weather events such as intense rainfall and storms, projected to become more frequent especially in northern Mediterranean areas, pose flooding risks to airport facilities and disrupt air traffic management.

Sea level rise, projected to increase by **0.1m to 0.26 cm by mid-century** and more by 2100 depending on emissions, intensifies coastal flooding and erosion risks for many Mediterranean airports located near vulnerable shorelines. Water scarcity, exacerbated by declining precipitation and rising demand, threatens airport cooling systems and could potentially lead to airport closures if firefighting capacity is impacted.

The Mediterranean's strong dependence on air transport for tourism—accounting for over half of international tourist arrivals—means that climate impacts on aviation have significant economic implications. Adaptation strategies must therefore balance operational resilience with sustainability goals, including investments in more efficient aircraft technologies, improved infrastructure resilience, and integration with alternative transport modes such as high-speed rail.

Limiting global warming to **1.5°C** (aligned with **RCP 2.6**) would substantially reduce the severity of climate impacts on Mediterranean air transport. Heatwaves and extreme weather events would be less frequent and intense, easing operational constraints and infrastructure stress. Conversely, at **4°C warming** (RCP 8.5), the sector faces severe challenges: more frequent payload restrictions, infrastructure vulnerabilities, and disruptions to tourism-dependent economies.

In summary, climate change poses escalating risks to air transport, including tourism demand, in the European Mediterranean region, necessitating urgent, integrated adaptation and mitigation efforts to safeguard connectivity, economic vitality, and environmental sustainability.

Mediterranean region references: Seneviratne et al., 2021; Lionello and Scarascia, 2018; Cherif et al.,2020; Zittis et al., 2016; Hoegh-Guldberg et al., 2018; Cherif et al., 2020; Darmaraki et al., 2019a e 2019b; Soto-Navarro et al., 2020; Iona et al., 2018; Pastor et al., 2019 ; Mariotti et al., 2015; Hertig and Tramblay, 2017; Lionello and Scarascia, 2018; Mathbout et al. 2021; Kim and Raible, 2021; Darmaraki et al., 2019b; Fox-Kemper et al., 2021; Marbà and Duarte, 2010; Lozano et al., 2017; Peñuelas et al., 2017; Varela et al., 2019; Jobbins and Henley, 2015; Guyennon et al., 2017; Negev et al., 2015; Liu-Helmersson et al., 2019 Semenza et al., 2016; Springmann et al., 2016; Carleton and Hsiang (2016); Spinoni et al., 2018a; Coppola et al., 2021; Cellura et al., 2018; Salvati et al., 2017; Zinzi and Carnielo, 2017; Grillakis et al., 2016; Jacob et al., 2018; Braki and Anagnostopoulou, 2019; Koberl et al., 2016.

3.7 Boreal

Overview of climate effects & projected climate change scenarios

Key Climate Effects
• Increase in heavy precipitation events • Decrease in snow, lake and river ice cover • Increase in precipitation and river flows • Increasing damage risk from winter storms • Increase in hydropower potential • Permafrost thaw

The European boreal region—which includes northern Sweden, Finland, Norway, and northwestern Russia—is undergoing rapid warming, with temperatures projected to rise by **3 to 6°C by 2100** under high-emission scenarios (RCP 8.5). Winters are expected to warm faster than summers, leading to shorter snow seasons and more frequent precipitation, falling as rain rather than snow.

These climatic shifts will increase the frequency and intensity of extreme weather events such as storms, heatwaves, and heavy rainfall, all of which pose growing risks to aviation infrastructure and operations in this climate-sensitive region. For air transport, these changes translate into multiple operational challenges. Increased storm intensity and frequency—linked to higher convective available potential energy (CAPE)—are projected to cause more frequent flight delays and air traffic flow management (ATFM) restrictions, particularly during peak summer months when storms are most intense. EUROCONTROL's analysis indicates that storm-related en-route delays already cost the European aviation sector billions annually, with these costs expected to rise as storm activity intensifies. Airports in boreal areas may also face infrastructure vulnerabilities due to thawing permafrost, which can destabilize runways, taxiways, and support facilities, increasing maintenance costs and operational risks.

Moreover, changing wind patterns, including shifts and strengthening of the jet stream, will affect flight routes and durations. While transatlantic flights may see modest reductions in flight times due to stronger tailwinds, regional flights within and near the boreal zone could experience altered wind conditions that complicate flight planning and fuel efficiency. Increased turbulence associated with stronger convection and storm activity is also a growing safety concern.

The difference between limiting warming to **1.5°C** and experiencing **4°C** warming is critical for the boreal aviation sector. At 1.5°C warming, extreme weather events and permafrost degradation will be less severe, allowing more manageable adaptation of infrastructure and operations. At 4°C warming, the frequency and severity of storms, infrastructure damage from permafrost thaw, and operational disruptions are expected to increase substantially, posing significant challenges to maintaining safe, reliable, and efficient air transport.

In summary, to build resilience, the aviation sector in the boreal region must invest in climate-proofing infrastructure, enhance weather forecasting and early warning systems, and develop flexible operational strategies to manage increasing weather variability.

Boreal region references: Ettrichrätz et al, 2023; Bouchard et al., 2024; Pongracz et al. 2024 ; Kellou et al., 2024 ; Imrit et al., 2021; Burrell et al., 2021 ; Choulga et al. 2014 ; Nunez-Romeiro et al., 2022 ; Ruiz-Perez et al., 2020; Nunez-Romeiro et al., 2022 ; Rädler et al, 2019 ; Larsen et al., 2020; Soomro et al., 2024; Gøtske et al., 2021; Hilden et al., 2018; Joint Research Centre, European Commission, 2023.

4. Understanding climate change impacts on aviation

Climate change presents a multifaceted and interconnected challenge for European aviation, with impacts varying significantly depending on regional and local climate specificities. This section identifies the key effects and impacts of climate change for airports, ANSPs and airlines. A more detailed overview is provided in Section 7.

4.1 Addressing Interdependencies and cascading effects

The resilience of the aviation sector is deeply intertwined with the robustness of critical supporting systems, including utilities (such as electricity and water supply), telecommunications infrastructure, and surface access networks like roads, railways, and public transport. Disruptions or vulnerabilities in any of these sectors due to climate-related hazards—such as flooding, heatwaves, storms, or drought—can cascade and severely affect airport operations, passenger accessibility, cargo logistics, and overall connectivity.

For example, power outages caused by extreme weather can halt airport operations, while telecommunications failures may disrupt air traffic management and passenger communications. Similarly, damage to road and rail networks from flooding or landslides can impede surface access for passengers, staff, and freight, impacting the airport's role as a transport hub. These interdependencies highlight that airport resilience cannot be achieved in isolation; it requires integrated planning and collaboration across multiple sectors and stakeholders.

Addressing these complex challenges demands coordinated efforts among policymakers, aviation industry stakeholders, utility providers, transportation authorities, emergency services, and environmental organisations. By fostering cross-sectoral partnerships, sharing data and risk assessments, and aligning adaptation strategies, the entire transport ecosystem can enhance its capacity to withstand and recover from climate impacts. Such holistic approaches are essential to ensure the sustainability, safety, and reliability of European aviation amid an increasingly volatile and changing climate landscape.

4.2 Changes in average and extreme temperatures

i. Overview of impacts, impacted actors and implications

Climate change is causing significant increases in both average and extreme temperatures, which are having profound impacts on aviation operations, in Europe and globally. This is especially concerning as average warming across Europe is expected to exceed the global average, with the strongest winter warming in Northern and Eastern Europe, and the most intense summer warming in the Mediterranean[8]. The projected increase in both average and extreme temperatures presents a range of operational, infrastructural, and safety-related challenges for the aviation sector with European aviation organisations likely to experience adverse effects due to regional warming trends that exceed the global average. Temperature related risks include:

- **Reduced aircraft performance** due to lower air density, resulting in longer take-off distances, weight restrictions, and revised operational procedures.
- **Thermal stress on infrastructure**, affecting the structural integrity of runways, taxiways, terminals, and landside access routes.
- **Higher energy demands and operational costs** stemming from the need for increased cooling in terminal buildings and control towers.
- **Increased fire risks** related to fuel venting and wildfires in adjacent green areas.
- **Health and safety risks** to personnel and passengers due to overheating and heat stress.
- **Environmental and operational disruptions** caused by changes in local ecosystems, including the spread of disease vectors.

As global temperatures rise, the mean temperature at all airports is expected to increase, resulting in more frequent and severe heat events. This warming trend affects air density, which is critical for aircraft performance. Warmer air is less dense than cooler air, leading to a reduction in lift generated by aircraft wings. Consequently, higher temperatures necessitate longer take-off distances and can impose weight restrictions on aircraft.

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[8] *Bednar-Friedl, B., R. Biesbroek, D.N. Schmidt, P. Alexander, K.Y. Børsheim, J. Carnicer, E. Georgopoulou, M. Haasnoot, G. Le Cozannet, P. Lionello, O. Lipka, C. Möllmann, V. Muccione, T. Mustonen, D. Piepenburg, and L. Whitmarsh, 2022: Europe. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1817-1927, doi:10.1017/9781009325844.015.*

Extreme heat can exacerbate operational challenges at airports. Increased temperatures can lead to higher cooling costs for terminal buildings and air traffic control towers, impacting overall operational efficiency. Furthermore, persistent high temperatures may alter travel demand patterns, particularly at popular tourist destinations that rely on favourable weather conditions. If summer temperatures rise significantly, it could deter travellers from visiting these areas, thereby affecting airline schedules and revenue streams.

In addition to extreme heat, increasing atmospheric instability associated with higher surface and upper-air temperatures is expected to intensify cumulonimbus activity. Such convective developments can produce hazardous conditions for aviation, including turbulence, lightning, hail, and severe wind shear, leading to more frequent flight diversions, delays, and cancellations, as well as challenges for air traffic management and ground handling operations.

In terms of infrastructure, rising temperatures pose risks to runway surfaces and airport facilities. Heat damage can lead to increased maintenance costs and necessitate repairs or upgrades to ensure safety and operational integrity. Moreover, climate change is linked to more intense weather phenomena such as storms and flooding, which can disrupt airport operations through closures or delays.

Changes in average and extreme temperatures are also expected to have an impact on noise insulation strategies for nearby communities, which face challenges as weather warms. Many communities and airports currently use enhanced glazing to mitigate noise intrusion, but warmer temperatures often prompt residents to open windows more frequently, diminishing the effectiveness of such glazing and other sound insulation measures. This compromises the noise reduction these measures provide and may necessitate alternative solutions such as air conditioning or mechanical ventilation to maintain both indoor comfort and noise insulation.

As outlined in the previous chapter, due to climate change, Europe will face multiple risks in the near future associated with rising average temperatures, extreme heat events, and drought conditions, underscoring the urgent need for targeted adaptation measures and long-term resilience planning within the aviation sector.
See section 7.1 for a more detailed overview of impacts, impacted actors and expected consequences.

ii. Overview of potential adaptation actions

Organisations can implement various measures to minimise impacts, prevent damage, and prepare for emergencies. In doing so, it is crucial to carefully assess the balance between costs and benefits. Additionally, insurance coverage for climate-related risks should be regularly reviewed and adjusted as needed to ensure comprehensive protection.

Airports must implement comprehensive strategies to enhance resilience against the escalating impacts of rising temperatures and extreme heat events. Effective adaptation in the aviation sector requires a comprehensive suite of measures that not only respond to immediate vulnerabilities but also anticipate long-term shifts in climate patterns. For changes in average and extreme temperatures key measures include adjusting flight schedules or reducing payload to account for reduced aircraft take-off performance, reinforcing infrastructure to be resilient to higher temperatures, and increasing cooling capacity in terminals and ATC workstations.

The proposed adaptation strategies place a strong emphasis on several interconnected areas of intervention.

First, the enhancement of climate monitoring and data acquisition systems is critical to support evidence-based decision-making, enabling more precise forecasting of climate-related disruptions and better risk assessments.

Second, the revision and modernisation of design standards is necessary to ensure that both existing and future infrastructure can withstand more frequent and intense temperature extremes, as well as associated stresses such as frost-thaw cycles or increased cooling demands.

Third, investment in the structural resilience of airport facilities, including airside and landside assets, is essential to maintain operational continuity and safeguard passenger and staff safety.

Finally, operational procedures must be systematically reviewed and updated to reflect new environmental realities—this includes adjustments to aircraft handling, ground operations, energy management, emergency protocols, and staff welfare practices.

See section 8.1 for a more detailed overview of potential adaptation measures.
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4.3 Changes in frequency and intensity of storms

i. Overview of impacts, impacted actors and implications

The impact of climate change on storm patterns in Europe has become a significant area of research, revealing varying regional trends in storm frequency and intensity. Over recent decades, warming global temperatures and shifting atmospheric conditions have led to more frequent and intense storms in certain regions, while others have experienced changes in the nature of these events.

In Northern Europe, particularly Scandinavia, storm intensity and frequency have increased significantly. Research indicates that the warming Arctic and changes in atmospheric circulation, such as the North Atlantic Oscillation (NAO), have contributed to more frequent and severe winter storms. The intensity of these storms is driven by warmer sea surface temperatures, which provide additional energy, allowing storms to develop more rapidly and with greater force. This trend is particularly evident in countries like Norway and Sweden, where extreme weather events have become more common.

Southern Europe, including countries like Spain, Italy, and Greece, experiences a different pattern. Although the overall frequency of storms has not significantly increased, the intensity of extreme weather events has grown. Rising temperatures and increasing moisture in the atmosphere have led to more intense rainfall, which in turn causes flash floods and increases the risk of landslides. Additionally, the Mediterranean has seen a rise in "medicanes" (Mediterranean hurricanes), which are rare but powerful cyclonic storms. These storms, though less frequent, are becoming more intense, leading to severe flooding and damage.

Western Europe, particularly Ireland, the UK, France, and the Benelux countries, has also seen an uptick in storm activity. Increased frequency of winter storms is linked to shifts in jet stream patterns, resulting in more low-pressure systems crossing the region. These storms often bring heavy rainfall, flooding, and strong winds, causing widespread disruptions.

Eastern Europe has experienced an increase in storm intensity, with countries like Poland, Hungary, and Romania seeing more frequent and intense convective storms. These storms, characterised by rapid development, are associated with severe local impacts such as hail and flash floods.

Looking ahead, climate models predict that both the intensity and frequency of storms will continue to rise across Europe, with regional variations. Northern Europe will likely experience more frequent and severe winter storms, while Southern Europe may see more intense cyclonic events. These changes will present significant challenges to infrastructure, ecosystems, and communities, and will also require airports and the aviation sector as a whole to adopt adaptive strategies in order to mitigate the impact of future extreme weather events.

The increasing intensity of storms results in numerous consequences, risks, and hazards that also impact aviation infrastructure and operations, as well as staff and passengers.

The increasing frequency and intensity of storms due to climate change pose significant risks and challenges for airports and aviation operations such as:

- **Increased flight delays, cancellations, and operational disruptions** due to more frequent and intense storms significantly affecting airport schedules and reliability.
- **Operational interruptions** due to adverse weather conditions such as high winds, heavy precipitation, and reduced visibility requiring grounding of aircraft for safety, compounding delays and logistical challenges.
- **Heightened safety risks** due to wind shear and turbulence, necessitating enhanced preparedness for airline crews to navigate increasingly hazardous conditions effectively.

In addition to the direct operational impacts, intensified storms bring broader disruptions to airport activities. These include delays and cancellations, route extensions, diversions, and reductions in en-route capacity and airport throughput. Ground transportation access can also be disrupted, affecting both passengers and staff. The risk of injuries, including those caused by turbulence, increases for both passengers and airport personnel. Furthermore, infrastructure vulnerabilities, such as power outages and the risk of lightning strikes, can compromise airport operations and safety. Airports must also consider the potential for disruptions in utility supplies, further affecting their ability to maintain regular services.

See section 7.2 for a more detailed overview of impacts, impacted actors and expected consequences.

ii. Overview of potential adaptation actions

Airports can implement various measures to minimise risks, prevent damage, and prepare for emergencies. In doing so, it is crucial to carefully assess the balance between costs and benefits. Additionally, insurance coverage for climate-related risks should be regularly reviewed and adjusted as needed to ensure comprehensive protection.

For changes in frequency and intensity of storms key measures include lightning warning systems, reinforcement of infrastructure against higher windspeeds and increasing surface drainage capacity.

Given these emerging challenges, it is crucial for aviation organisations to adopt adaptive strategies to ensure safe operations and maintain their competitiveness in the future. This includes investing in infrastructure improvements, enhancing emergency response protocols, and utilising advanced weather forecasting technologies. These measures will enable better anticipation and response to severe weather events, ensuring resilience and the ability to operate safely amid increasingly volatile storm patterns. Proactively addressing these issues is vital not only for safety but also for maintaining operational efficiency and financial sustainability in the long term.

See section 8.2 for a more detailed overview of potential adaptation measures.

4.4 Changes in precipitation

i. Overview of Impacts, impacted actors and implications

Due to climate change the distribution of precipitation across Europe is altering significantly, leading to increased variability in rainfall and heightened risks of both flooding and drought.

As the global average temperature is rising due to climate change, the Clausius-Clapeyron equation predicts that the amount of water vapor increases by approximately 7% for each degree Celsius of warming. This rise in water vapor also influences the intensity of precipitation events, which consequently increases at a similar rate. Furthermore, research indicates that the intensity of the convective component of precipitation can increase by as much as 14% per degree Celsius of warming. This phenomenon is often referred to as the super-Clausius-Clapeyron relationship.

Future precipitation patterns in Europe reveal a distinct north-south contrast. Northern Europe is projected to experience a 9% increase in precipitation, while Southern Europe is expected to see a 12% decrease. The most significant increase in precipitation will occur during winter in Northern Europe, whereas Southern Europe, particularly the coastal Mediterranean region, will face the greatest reduction in summer.

In Central Europe, precipitation is anticipated to decrease in summer and increase during winter months. Additionally, the snow season in Northern Europe is likely to shorten by 1 to 3 months, with snow depth potentially decreasing by up to 100% in some locations. These changes will have substantial implications for winter tourism, ice coverage in water bodies, and the levels of freshwater reservoirs and rivers throughout the year.

When considering the impacts, risks, and implications of changes in precipitation, it is important to distinguish between droughts caused by insufficient precipitation and flooding resulting from excessive precipitation.

- **Summer droughts** heighten risks of water shortages and wildfires, potentially disrupting airport water supply systems and increasing fire hazards near critical infrastructure.
- **Intense rainfall and flash floods** during summer can damage runways, taxiways, and drainage systems, leading to operational delays and costly repairs.
- **Winter flooding and saturated soil conditions** from heavy precipitation (snow or rain) increase risks of infrastructure flooding, runway contamination and reduced braking performance.

Aviation organisations must adapt to these changes by identifying potential risks, assessing impacts, and implementing measures to mitigate these challenges, ensuring safe operations.

See section 7.3 for a more detailed overview of impacts, impacted actors and expected consequences.

ii. Overview of potential adaptation actions

To avoid material and financial damages, aviation organisations can adapt recommended preparedness actions. Airports must implement comprehensive strategies to enhance their resilience against the impacts of changing precipitation patterns and extreme weather events.

These strategies involve improving drainage systems, reinforcing infrastructure to withstand flooding, and developing contingency plans for adverse weather conditions. One key approach is the use of large-scale rainwater retention basins, infiltration systems, and multifunctional flood-prone areas. These solutions help reduce the load on drainage systems by retaining rainwater, incorporating green spaces, infiltration ponds, and retention basins. Additionally, new construction projects should prioritise increasing the capacity of drainage systems, outlets, and channels, ensuring proper sizing to handle heavier rainfall.

To address the risks posed by rising groundwater levels, airports should establish a groundwater monitoring network to gather live data. Higher groundwater levels can lead to operational challenges, particularly in runway safety, as they may compromise the effectiveness of drainage systems and potentially contaminate the ground due to hazardous substances flushed from the runways and apron. To mitigate these risks, airports should assess the feasibility of local technical measures to lower groundwater levels and develop groundwater models to inform decision-making.

Flooding from excessive precipitation can also disrupt runway operations and damage underground infrastructure, including tunnels, streets, and parking areas. To prevent such incidents, organisations must develop flood models that incorporate groundwater levels, surface structures, nearby water bodies, and drainage system capacity. Additionally, updating weather and flood warning systems, alongside establishing emergency protocols and clear action plans, ensures a swift response in crisis situations. Collaboration with relevant divisions, such as fire departments and security services, is essential to ensure effective incident management.

Lastly, airports should consider the adoption of the "Sponge City" concept, focusing on efficient rainwater management and natural water cycle integration. This includes reusing rainwater for non-potable purposes like irrigation, road cleaning, and fire service training, while also addressing water shortages for maintenance and firefighting. Implementing such adaptive measures will help airports enhance their resilience to climate-related challenges and ensure safe, efficient operations.

See section 8.3 for a more detailed overview of potential adaptation measures.

See Case Studies A, B, C and D for examples of how airports and ANSPs have implemented measures to build resilience to flooding. Case Study E provides an example of the implementation of measures to address a water shortage.

4.5 Changes in wind

i. Overview of impacts, impacted actors and implications

In Europe, climate change is altering wind patterns in ways that are increasingly impacting aviation operations. One key change is the shifting behaviour of the jet stream—a high-altitude, fast-moving air current that significantly influences flight routes. Projected changes to the jet stream are complex, with it expected to speed up at higher altitudes impacting transatlantic flight routings and duration. Conversely, at lower altitudes Arctic amplification, whereby the Arctic warms more rapidly than mid-latitudes, may lead to a slower jet stream.

In the North Atlantic region, variability in the position and strength of the jet stream directly affects the core track structure within the Shanwick Oceanic Control Area, where daily adjustments to the Organized Track System (OTS) optimise traffic flow with prevailing winds. Increased variability in the core track configuration can disrupt established traffic patterns between OTS entry and exit points, complicating network-level flow management, slot coordination, and fuel optimisation for both eastbound and westbound traffic.

For aviation, these wind changes have several critical consequences:

- **Changing jet stream patterns** increase headwinds for westbound flights, lengthening travel time, while eastbound flights may be shorter in duration due to greater tailwind benefits impacting scheduling and fuel planning.
- **Increased risk of clear-air turbulence** caused by unstable wind shear at cruising altitudes, heightening safety concerns for passengers and crew and requiring adaptive flight planning and enhanced turbulence monitoring.
- **Changing crosswind patterns at European airports**—especially during storms or frontal systems—may make take-off and landing more hazardous, occasionally rendering runways unusable and causing delays or diversions.

See section 7.4 for a more detailed overview of impacts, impacted actors and expected consequences.

ii. Overview of potential adaptation actions

These impacts underscore the need for the aviation sector in Europe to enhance its climate resilience through improved weather forecasting, more flexible routing systems, and greater integration of climate risk into operational planning and infrastructure design.

In particular, continuing to improve forecasting of turbulence is essential so as to enable aircraft to avoid it to the extent possible. This includes onboard technologies for aircraft that can assess wind and turbulence changes in real-time. Infrastructure can be reinforced to withstand more extreme wind conditions, while regular maintenance is essential.

However, many uncertainties remain, particularly regarding changes to local prevailing wind conditions. Therefore, more research is essential.

See section 8.4 for a more detailed overview of potential adaptation measures.

4.6 Sea level rise

i. Overview impacts, impacted actors and implications

Global mean sea level (GMSL) has risen about 21cm since 1900, at an accelerating rate. GMSL reached its highest value ever in 2023. GMSL will likely rise by 0.28-0.55m under a very low emissions scenario (SSP1-1.9) and 0.63-1.02m under a very high emissions scenario (SSP5-8.5) by 2100, relative to the 1995-2014 average. GMSL simulations that include the possibility of fast disintegration of the polar ice sheets project a rise of up to 5m by 2150. Most coastal regions in Europe have experienced an increase in sea level relative to land, except for the northern Baltic Sea coast.

Coastal regions will experience small increases in both absolute sea level and relative sea level in the short-term period (2020-2050), the latter being more relevant for coastal protection. Absolute sea level rise is expected to follow the global average, while sea level rise relative to land will depend on local geophysical characteristics (uplift or subsidence) which will have either an enhancing or diminishing effect.

The impacts of sea level rise in the Mediterranean basin will be more evident in the long-term period (2070-2100). Most vulnerable locations are river deltas, coastal plains, including seaside urban centres and islands.

- **Rising sea levels** increase groundwater levels and reduce drainage capacity at coastal and low-lying airports, heightening vulnerability to water-related disruptions.
- **More frequent and more severe flooding** can disrupt airport operations, causing delays, diversions, and potential damage to critical facilities.
- **Storm surges** amplify flooding impacts during extreme weather events, threatening critical infrastructure, operational continuity and surface access routes.

Island airports can be particularly vulnerable to sea level rise may face severe disruptions in the mid- to long-term, a major concern given their importance for connectivity as they.

See section 7.5 for a more detailed overview of impacts, impacted actors and expected consequences.

ii. Overview of potential adaptation actions

Measures to address sea level rise range from allowing a safe amount of mitigation to, in extreme cases, permanent inundation of infrastructure leading to the need for airport relocation and include:

- Continuous monitoring of sea level rise
- Engineering and maintenance measures to enhance the affected infrastructure, including nature-based solutions
- Operational and strategic planning with internal and external stakeholders.

See section 8.5 for a more detailed overview of potential adaptation measures. Case Studies F presents an example of implementing measures to build resilience to sea level rise.

4.7 Changes in biodiversity

i. Overview of impacts, impacted actors and implications

Climate change is putting increasing pressure on global biodiversity, profoundly altering ecosystems and species interactions. According to the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), one million plant and animal species are currently threatened with extinction. The Intergovernmental Panel on Climate Change (IPCC) added that, if global warming exceeds +2°C by the end of the century - compared to a current trajectory estimated at +2.8°C - 18% of terrestrial species will be at serious risk (IPCC Sixth Assessment Report, 2022).

While rising temperatures, changes in precipitation patterns, and the intensification of extreme weather events are contributing to an acceleration in the collapse of biodiversity, they are also disrupting species distribution, life cycles, and behaviour.

As airports provide habitats for various species of fauna and flora, airport operators can play a significant role in local biodiversity conservation. Examples of ecosystems found in airport areas include woods, quarries, permanent meadows and lawns, and wetlands. These semi-natural environments serve as refuges for species, some of which are occasionally classified as vulnerable or endangered on regional, national, or international lists. A significant change in the climate system will affect these species, their geographical distribution, the functioning of ecosystems, and the biochemical cycles in which they participate.

Climate change alters natural ecosystems, accelerating biodiversity loss and disrupting ecological dynamics. These changes can adversely affect airport operations, creating safety, operational, and financial challenges, as well as implications for regulatory compliance and reputation.

- **Shifts in ecological dynamics and accelerating biodiversity loss** can lead to unpredictable wildlife behaviour, increasing the risk of collisions with aircraft collisions causing material damage, and posing flight safety hazards.
- **Loss of biodiversity undermines soil stability and infiltration capacity**, driving up infrastructure maintenance costs, water and pollution treatment expenses, and exacerbating flooding and drought risks, impacting runway integrity and drainage systems.

- **Spread of invasive plant species** complicates vegetation control and weakens infrastructure, resulting in additional maintenance requirements.
- **Degradation of biodiversity can reduce the attractiveness of some tourist destinations**, negatively impacting ecotourism-related air traffic.

See section 7.6 for a more detailed overview of impacts, impacted actors and expected consequences.

ii. Overview of potential adaptation actions

From a regulatory perspective, an increasing number of policy frameworks - such as the Global Biodiversity Framework and the European Biodiversity Strategy - are encouraging businesses to adopt responsible biodiversity conservation practices to address climate change challenges. Biodiversity is therefore increasingly viewed as a powerful lever for adaptation and resilience. Indeed, biodiversity and ecosystems strongly influence the climate, notably contributing to the regulation of carbon dioxide and water vapor in the atmosphere, and thus to temperature and precipitation.

By rethinking environmental planning and management, airports can harness ecosystems to enhance sustainability and reduce vulnerability to climate change. Measures such as integrating Nature-Based Solutions, reducing soil sealing, and adopting more sustainable management of natural spaces could help to tackle climate change while improving the integration of airport platforms into their surroundings. Beyond regulatory requirements, adopting a proactive approach offers a strategic opportunity, not only to reduce operational risks but to enhance biodiversity resilience and promote harmonious integration with their surroundings and the future climate.

While biodiversity loss poses risks for airport safety, safety, operations, economics, regulatory compliance, and reputation it also presents an opportunity to strengthen the resilience of airport infrastructure and adapt to future climatic conditions.

From a practical perspective, wildlife monitoring and management is essential. This could include bird strike avoidance models, bird control or land management measures. Flight paths may increasingly need to be temporarily changed to avoid flocking birds. Unwanted flora can be removed, although this in turn may render mice and worms more visible which may actually attract more birds.

See section 8.6 for a more detailed overview of potential adaptation measures.

4.8 Changes in icing

i. Overview of impacts, impacted actors and implications

Climate change is altering the frequency, intensity, and geographical distribution of aircraft icing conditions in Europe. Icing occurs when supercooled liquid water droplets freeze upon contact with an aircraft's surface, typically during flight through certain types of clouds at altitudes between 1,500 and 22,000 feet.

These conditions can severely affect lift, drag, engine performance, and instrumentation, posing a significant safety risk. As Europe experiences warmer average temperatures and shifts in atmospheric moisture, icing conditions are expected to change, rather than disappear.

- **Reduced icing frequency at lower altitudes, particularly in southern and lowland regions,** may lessen the need for in-flight de-icing systems during climb and descent phases, but could shift icing risk to higher levels and different flight phases.
- **Increased icing likelihood at higher altitudes and in northern or mountainous regions** may lead to more frequent encounters at cruise altitudes, requiring enhanced weather monitoring and route planning for aircraft operating on northern or transalpine routes.
- **A higher freezing level**, as the 0°C isotherm rises, can increase the duration of exposure to icing layers during ascent and descent, demanding more precise vertical weather profiling and improved pilot awareness.
- **Longer icing seasons in transitional months (spring and autumn)** may extend the operational period during which ground de-icing fluids, equipment, and crews are required, influencing airport resource planning and operational costs.
- **Greater variability and unpredictability of icing events** can complicate forecasting and flight planning, necessitating improvements in meteorological modelling, pilot training, and adaptive flight management systems.

Overall, while some regions may experience fewer icing events, the changing vertical and seasonal distribution of icing risk introduces new operational, safety, and cost management challenges for airlines, airports, and air navigation service providers.

See section 7.7 for a more detailed overview of impacts, impacted actors and expected consequences.

ii. Overview of potential adaptation actions

Although some locations may experience a decrease in de-icing requirements, the challenge will be to still have sufficient de-icing capacity in place for when it does occur. New de-icing technologies such as infra-red technology can also be considered, thus simultaneously reducing risk of pollution from de-icing run-off.

See section 8.7 for a more detailed overview of potential adaptation measures.

4.9 Desertification

i. Overview impacts, impacted actors and implications

Desertification—the degradation of land in arid, semi-arid, and dry sub-humid areas due to climate variability and human activity—is an emerging concern in parts of southern Europe, particularly in Spain, Portugal, southern Italy, Greece, Cyprus, and southeastern France. Driven by rising temperatures, prolonged droughts, reduced soil moisture, and land-use pressures, desertification is expected to intensify under climate change, especially under high-emissions scenarios.

For aviation, desertification can have several indirect but significant impacts:

- **Dust and particulate matter from desertification** increase during dry, windy periods, reducing visibility, damaging engines, and impairing navigation and sensor systems, impacting flight safety and punctuality. Runway and taxiway surfaces may deteriorate faster due to temperature extremes and dry soil conditions that affect ground stability.
- **Loss of vegetation cover creates hotter, more arid microclimates.** This contributes to higher local temperatures intensifying the urban heat island effect and increasing heat-related disruptions at airports such as reduced aircraft performance during take-off, higher cooling demands, and worker heat stress. This places additional strain on airport infrastructure and energy systems.
- **Water scarcity driven by desertification can impact airport operations** that depend on reliable water supplies for fire suppression, cooling, sanitation, and de-icing alternatives. This may necessitate investments in water-efficient technologies, dust mitigation systems, and heat-resilient infrastructure to adapt to increasingly dry and harsh operating environments.

See section 7.8 for a more detailed overview of impacts, impacted actors and expected consequences.

ii. Overview of potential adaptation actions

Barriers or “windbreaks” can be implemented to reduce dust and sand encroachment, whilst water-management measures, such as water recycling for irrigation and methods to minimise water use via maintenance and monitoring, may be required to tackle reduced water availability. Low visibility procedures can be implemented during take-off, landing and taxiing.

See section 8.8 for a more detailed overview of potential adaptation measures.

5. An Approach to Develop a Climate Change Preparedness Strategy

Developing a climate preparedness strategy involves 1) carrying out a climate change risk assessment to identify the climate impacts which an organisation may need to address and 2) developing and implementing a climate adaptation plan. There are varying ways to carry out a climate risk assessment. This guidance presents one approach to doing so.

To understand the climate effects and impacts that an organisation may need to address recommended good practice is to carry out a climate change risk assessment. This is an analysis of potential impacts to an organisation from climate change effects. It is usually based on an analysis of local or regional scale climate change projections for an organisation's location or locations, the likelihood or probability of an impact occurring and what the consequences are if it does are then assessed.

Once the most critical impacts have been identified the next step is to develop a climate change adaptation strategy or plan to address them. Potential adaptation measures can be selected and a plan developed for their implementation, noting that this may be dependent on both available resources and an organisation's risk acceptance levels and the resources available.

The financial dimension of climate risk should also be considered as part of this process. Climate-related impacts such as infrastructure damage, operational disruption, or reduced demand can have material financial consequences for aviation organisations. These financial risks fall within the scope of corporate fiduciary duties to shareholders and, where material, should be disclosed in annual or sustainability reports. For regulated airports, financing for adaptation measures may also require regulatory approval, meaning that investment in resilience needs to be incorporated into broader capital planning and regulatory approval cycles.

Within the overall process there are a number of steps to follow (Figure 2). This section will address each step in turn.

It should be noted that within the European Union aviation organisations which meet certain criteria have to prepare climate risk assessments under the CSRD legislation. This can be done as part of an organisation's overall climate risk assessment process or, draw on an existing assessment. In particular, the risk assessment should address the climate-related risks outlined in CSRD Appendix A to ensure alignment with the DNSH (Do No Significant Harm) criteria. This approach ensures that the outcomes of the Climate Adaptation Plan are integrated into the Sustainability Report and that activities and investments related to climate change resilience can be readily incorporated into the EU taxonomy framework.

Where there are specific considerations to be taken account of for CSRD reporting they will be highlighted. However, it should be noted that this document is not CSRD guidance: specific guidance on CSRD reporting requirements should be sought from official CSRD sources.

Figure 2 Key steps in climate change risk assessment and adaptation planning

Step 1. Compliance check

Identify all relevant national legislation and reporting requirements (e.g. national reporting requirements, TCFD, CSRD). Some countries, such as the UK and France, have specific reporting obligations for aviation organisations which meet certain criteria. Alternatively, or in addition there may be other legal requirements such as compliance with the TCFD scheme or the European Union CSRD obligations (See section 2 for more details).

Check whether any national/ regional/ local-level or sector-level climate risk assessment and/or adaptation strategy exists, or is planned, and align accordingly.

Identify and review internal governance structures, risk management processes, and policies that may be relevant and require alignment

It is essential to confirm all applicable requirements before beginning the process to ensure that it is planned in line with legislation and best practice.

Step 2. Assemble the team, develop a participatory process and define the scope

Before initiating a climate change risk assessment, gain senior leadership approval. Without the active involvement of top management, adaptation studies tend to remain confined to the technical level, without being translated into policies, investments or concrete actions.

Define the organisational scope and boundaries of the climate change risk assessment and adaptation plan, and which assets and operations are included. Map and geographically locate critical assets to be covered by the assessment. To ensure that the scope covers all relevant elements engage with asset operators, operational staff, facility managers, and decision-makers as early as possible in the process. When considering the geographical scope of coverage they may be organisational specificities. A non-exhaustive set of examples is provided below example:

- **Airports**: infrastructure and operations; passengers and personnel; utilities and supply chains; surface transportation.
- **ANSPs**: operational impacts on air traffic control and management; physical infrastructure and equipment; personnel; site access.
- **Airlines**: operational impacts at the base airport, en-route and key destination airports; passengers and personnel; supply chains.

Identify the internal departments that need to be involved and designate focal points within those departments. Climate adaptation is much wider than just a sustainability issue: it is a cross-organisational issue that needs expertise from across the organisation, so it is essential that departments such as operations, safety, and finance are involved.

In addition to the involvement of various areas within the organisation, it is essential to develop the adaptation study with the involvement of external stakeholders, such as national, regional and local scientists, regional and local authorities, utilities suppliers or ground transport operators, representatives of the population (city councils, parish councils or others) and neighbouring entities with a relevant role in the adaptation response.

The participatory process may involve different types of interactions, such as interviews and workshops. The process can be introduced in more than one phase of the study, such as in the diagnosis of vulnerabilities and in the discussion and evaluation of adaptation measures.

Step 3. Select a risk assessment methodology

The climate risk assessment can be directly embedded into the organisation's existing risk assessment framework. Alternatively, a standalone climate risk assessment methodology can be employed. However, in this case it should be aligned with the organisation's own risk management process and risks identified should be subsequently integrated.

Some aviation-specific climate risk assessment methodologies include:

- ISO Standard 14090: Adaptation to Climate Change
- ICAO guidance on Aviation Organisation Climate Change Risk Assessment and Adaptation Planning
- ACRP Synthesis 147: Climate Change Adaptation Planning: Risk Assessment for Airports
- ACI Asia Pacific Tendering Guides for Climate Resilience Planning for Asia-Pacific and Middle East Airports

Step 4. Understand local climate change projections

Engage with the national or local meteorological (MET) provider, climate science organisations, or other relevant organisations/experts to acquire climate change projections at a suitable scale, identify climate scenarios and timeframes, and understand projected climate changes. It is usually recommended to select at least two climate scenarios e.g. an IPCC high scenario and a medium or low scenario, noting that there is limited variance between the IPCC RCP 4.5 and RCP 8.5 before 2050. Selecting a timeframe will be dependent on the organisation's operations and asset lifecycle, although it is usually recommended to select at least a short- and a medium-term timeframe. Check any applicable legislation for stipulations as to which timeframes or scenarios to use. For example, CSRD requires the use of two climate scenarios.

The MET and climate science organisations will be able to advise on interpreting climate change projections so as to identify potential climate effects of relevance to the organisation. It will be necessary to assess both acute risks, such as extreme weather events and flooding, and chronic risks such as sea-level rise and higher average temperatures. For an overview of potential climate effects refer to Section 4 of this guidance. For an overview of potential climate impacts refer to Section 7 Compendium of Climate Change Impacts. Other sources of information include:

- ICAO Key Vulnerabilities
- ICAO Climate Adaptation Synthesis
- EUROCONTROL FlyingGreen ClimAdapt Repository of Climate Change Impacts
- CSRD Appendix A

Transitional risks

This guidance focuses on physical climate change risks. However, note that some legislation, such as CSRD, may also require the assessment of transition risks. These are business-related risks related to societal and economic shifts toward climate mitigation and a low-carbon future. This can include policy and legal/regulatory risks, technological risks, market risks and reputational risks such as changes in demand/propensity to fly, early closure of carbon-intensive assets, or the need to implement/integrate new energy sources such as electric and hydrogen power sources.

Step 5. Assess risks and vulnerabilities

Based on the climate projections, apply the selected risk assessment methodology to identify potential impacts, and their likelihood and consequences. This involves assessing what might happen, how likely is it to happen and what are the consequences if it does. The specifics of the process will depend on the methodology chosen. When identifying potential impacts, current risk mitigations already in place such as resilience and contingency plans should be assessed. Any existing adaptive capacity, the capability that an organisation already has to respond to climate impacts should also be accounted for. Historic events which impacted the organisation can be analysed to build the evidence base and then adapt the risk scoring.

It is recommended to map the organisation's exposure and sensitivity to the expected impacts, ultimately developing an exposure catalogue that includes all potential targets, both tangible and intangible. These may encompass operational aspects (e.g., terminal management, punctuality), infrastructures (runways, taxiways, aprons, buildings, drainage, power and IT), aircraft and ground fleets, supply dependencies (energy, water, fuel), and people (workers, passengers). This comprehensive catalogue enables each risk to be assessed according to its specific “impact–exposure pair.”

Developing a risk matrix is a useful way to map risks (see Figure 3 for an example). It is used to assess risks by considering the likelihood or probability of occurrence of an event and the corresponding impact: each potential impact is assigned a risk rating according to how likely it is to happen and how severe the consequences would be if it did happen.

		Impact				
		Minimal	Minor	Moderate	Major	Catastrophic
Likelihood	Almost Certain	moderate	major	major	severe	severe
	Likely	moderate	moderate	major	major	severe
	Possible	minor	moderate	moderate	major	major
	Unlikely	minor	moderate	moderate	moderate	major
	Highly Unlikely	minor	minor	minor	moderate	moderate

Figure 3 Example risk matrix

Additionally, consider highlighting potential opportunities. For example, projections indicating fewer heavy snow days could lead to reduced operational disruptions in the future. There may also be transitional opportunities to be accounted for.

Step 6. Develop and prioritise adaptation actions

Based on the results of the risk assessment, develop a Climate Adaptation Plan, prioritising actions based on criticality and available resources. When resources are limited industry good practice generally recommends prioritising on critical safety and operational risks to increase operational resilience and maintain safety standards. The CSRD legislation requires a broader focus on critical assets which includes facilities, infrastructure, value chains and exposed locations as well as operations.

Financial implications of risks will also need to be considered when carrying out any prioritisation.

The identification and selection will need to account for the organisation's risk acceptance level and the resources available. See Section 8 the Compendium of Adaptation Measures for an overview of potential adaptation options. Other references for potential adaptation measures include:

- ICAO Menu of Adaptation Option
- ICAO Climate Adaptation Synthesis
- EUROCONTROL FlyingGreen ClimAdapt Repository of Climate Adaptation Measures

Develop a timeline and process for implementing the adaptation measures identified which prioritises addressing the most critical climate impacts. Scoring each risk according to the urgency and achievability of addressing it can facilitate prioritisation. All actions should be assigned owners and timescales. It is also highly recommended that the costs associated with each measure be identified (in greater or lesser detail, depending on the level of information available). This information is extremely relevant for informing senior management and board-level decision-making. To this end, highlighting any co-benefits of actions, such as contributing to net zero targets, would be beneficial for supporting business cases.

In addition, there may be measures whose implementation may extend beyond the airport, so it will be important to include the various stakeholders involved, both in the planning and implementation phases. A key example is catchment management to reduce flooding risk which may involve working with upstream landowners and the local environment agency. Developing a systems map can be a useful tool for stakeholder engagement so as to visualise climate impacts across infrastructure and assets.

Climate adaptation plans should also aim to ensure that the selected resilience measures are consistent with broader territorial climate planning efforts. This alignment ensures that all stakeholders in the region work together toward a shared goal of climate preparedness. In this prospective, Consider developing a communication plan for sharing the adaptation plan with relevant stakeholders and the public.

Step 7. Review and update the assessment and plan

The climate risk assessment and adaption plan should be periodically assessed, allowing for flexibility as the extent and timing of impacts evolves.

It is highly recommended that cyclical review periods be planned (triennial or quinquennial reviews are common in this type of document), which should be supplemented with immediate extraordinary reviews whenever:

- significant extreme weather events occur;
- new climate data or projections emerge;
- significant changes occur in the organisation's operations, assets or location;
- there are relevant political, economic or technological changes.

In the periods between these reviews, it is essential to monitor indicators that allow for the assessment of both the impacts of climate change (climate, environmental, socio-economic, risk and vulnerability) and the effectiveness of the adaptation measures implemented. These indicators should be defined when developing the adaptation plan.

The monitored indicators should also be subject to periodic critical analysis and, consequently, assessment of the need for punctual or structural decision-making (such as, for example, an extraordinary review of the adaptation plan itself). It is common to organise multidisciplinary working groups/ committees to carry out this analysis and decision-making process.

For further information on climate change risk assessment and adaptation planning please see the ICAO Guidance for Aviation Organisations: https://www.icao.int/environmental-protection/Climate-Change-Risk-Adaptation-Resilience

For tools and checklists to facilitate a climate change risk assessment and development of an adaptation plan please see the FlyingGreen ClimAdapt platform: https://flying-green.eurocontrol.int/#/clim-adapt

6. Case Studies and Good Practices

European aviation organisations are recognising the need to carry out climate change risk assessments and implement adaptation actions. This section provides cases studies of good practice from five organisations that are leading the way. Each case study sets out:

1. Organisation name and climate zone
2. Climate impact covered by the case study
3. Challenges and risks identified
4. Strategy actions and initiatives implemented
5. Lessons learned

Case Study A: Flooding impact on air navigation services in Geneva

1. Climate impact covered by the case study

In late June 2024, Geneva experienced intense thunderstorms that led to flooding in the basement of the air traffic control centre. This event disrupted cooling systems essential for maintaining safe operations. A newly installed backup cooling system, although not yet fully commissioned, was manually started by facility management personnel, preventing overheating of critical equipment and allowing for a controlled response.

2. Airport/ACC name and climate location

The incident occurred at Geneva ACC, located in the Swiss Plateau, a region with a moderately continental climate, marked by warm summers, cold winters, and frequent precipitation. Climate change is increasingly affecting this area, with projections indicating more heatwaves, tropical nights, drier summers, wetter winters, and more frequent and severe thunderstorms. These evolving conditions pose growing risks to aviation infrastructure, operational continuity, and human performance.

3. Challenges and risks associated

The flooding incident had a direct and rapid impact on operations. Water infiltration in the basement of the Geneva control centre compromised the cooling systems that support critical air traffic control infrastructure. As a result, Geneva airspace had to be temporarily closed to prevent overheating of systems, a rare and significant operational disruption directly linked to an extreme weather event.

This closure affected flight movements and capacity for several hours, with a gradual recovery over the following days. The incident demonstrated how climate-related hazards can lead to the suspension of air navigation services, underscoring the vulnerability of operational continuity to infrastructure failures.

Beyond the airspace closure, the emergency response placed significant pressure on both operational and technical teams. While operational staff continued to manage the situation under reduced capacity, technical personnel, who do not typically work around the clock, were called in outside regular working hours to manually activate backup systems and stabilise infrastructure. This led to high levels of strain and fatigue, particularly among the technical teams. Office facilities, including meeting rooms and utilities, were temporarily unavailable. The absence of a fully commissioned backup cooling system and the need to manually activate a spare unit highlighted the lack of redundancy and increased exposure to risk. Coordination during emergency procedures, such as “Clear-the-Sky,” revealed areas for improvement across control units.

4. Strategy/initiatives implemented

Emergency protocols were activated immediately, and operations were restored in stages. The backup cooling system successfully maintained temperature control in the data centre. Technical teams conducted post-event inspections and water quality analysis to assess impacts. Plans were launched to expand the backup cooling network to cover all critical rooms and ensure full technical and physical redundancy. A flood protection initiative was also developed to reinforce water evacuation systems and raise protective barriers, especially since the site is now classified as high-risk under updated regional flood maps. Future mitigation includes relocating cooling equipment to upper floors and preparing infrastructure to connect to sustainable cooling networks when available.

5. Lessons Learned

This incident confirmed what had already been anticipated within the company regarding climate-related risks. While climate change had been identified as a strategic concern, the flooding event provided tangible evidence that these risks are no longer theoretical, they are operational realities. The temporary closure of Geneva airspace due to infrastructure failure demonstrated how extreme weather can directly impact service continuity.

It reinforced the importance of building resilience into our systems and being pragmatic about the level of preparedness required. Infrastructure vulnerabilities, especially in cooling and power systems, must be addressed not only through technical upgrades but also through strategic planning and coordination.

The experience highlighted the need for rapid response mechanisms, clearly defined roles during crises, and robust collaboration across teams. It also validated the importance of preparedness tools, such as emergency checklists, system maps, and contact protocols with external partners. Temporary solutions proved effective in the short term, but the event underscored the urgency of implementing permanent upgrades.

Flood protection studies and infrastructure assessments now serve as a roadmap for long-term mitigation. Coordination during emergency procedures, particularly in airspace management, remains a key area for improvement. Overall, the incident has strengthened the company’s commitment to climate adaptation and confirmed the need to accelerate resilience-building efforts.

Case Study B: Climate Resilience, Flood Risk Management and Adaptation to Heavy Rainfall at Munich Airport

1. Airport Name and Climate Zone

Munich Airport (MUC) is located in the northeastern region of Munich, Germany, approximately 30 kilometres from the city centre. The airport is situated within a continental climate zone, characterised by cold winters, warm summers, and moderate to high precipitation levels throughout the year. In recent decades, meteorological records have shown an upward trend in the frequency of intense rainfall events, resulting in higher surface runoff volumes and increased flood risk.

2. Climate Impact Covered

Munich Airport is increasingly affected by the impacts of climate change, particularly the rising frequency and intensity of heavy rainfall events. These changes are linked to broader climatic shifts in Central Europe, where warming temperatures have altered precipitation patterns and increased the likelihood of extreme storms. Such rainfall events can cause surface flooding, overwhelm drainage systems, and pose significant operational, infrastructural, and safety challenges. The case study examines Munich Airport's proactive response to these growing threats through an integrated flood management and adaptation strategy.

3. Challenges and Risks Associated

The airport's proximity to several natural waterways, including the Isar River and multiple smaller streams, creates an inherent exposure to flooding. During periods of heavy rainfall, these watercourses can rapidly swell, increasing the risk of water entering operational areas. With climate change accelerating the hydrological cycle, Munich Airport faces a growing probability of short-duration, high-intensity rainfall events capable of causing flash floods. Such events may result in severe operational disruptions, infrastructure damage, and safety hazards.

The existing flood protection infrastructure, originally planned in the 1980s, was designed to handle flooding events with a return period of up to 100 years. However, climate projections indicate that these design thresholds may no longer be sufficient. Surface flooding can disrupt aircraft movement, damage electrical and IT systems, and impede passenger transportation. Hence, continuous monitoring and adaptive management are essential to maintain operational resilience under changing climatic conditions.

4. Strategy / Initiatives Implemented

Munich Airport has adopted a comprehensive, three-pillar approach to flood management and climate adaptation, focusing on hazard analysis, risk assessment, and preventive measures. This strategy integrates advanced hydrological modelling, infrastructure upgrades, and operational preparedness to ensure long-term resilience.

4.1 Hazard Analysis – Advanced Hydrodynamic Modelling

A critical component of Munich Airport's adaptation strategy is the development of a two-dimensional hydrodynamic runoff model capable of simulating how water behaves during extreme rainfall scenarios (up to 100 litres per square meter within one hour). The model accounts for the airport's topography, drainage network, and nearby catchment areas, providing detailed flood depth, velocity, and flow direction outputs. Combined with a sewer network model, the system enables precise calculation of overflow volumes and identification of flood-prone zones. These analyses are visualised through hazard maps (Figure-1, Figure-2) and animations, serving as essential tools for decision-making and infrastructure design.

4.2 Risk Assessment – Identifying Vulnerable Areas

Using insights from the hydrodynamic modelling, the airport performs a thorough risk assessment to pinpoint areas most vulnerable to flooding. This includes operationally critical zones such as terminals, taxiways, and transportation corridors. Risk mapping is complemented by early warning systems, operational checklists, and staff training programs. The airport also collaborates with hydrological experts and regional authorities to align its risk management framework with evolving climate scenarios.

4.3 Preventive Measures – Infrastructure and Operational Adaptation

The airport's flood protection measures combine engineering solutions with sustainable, nature-based approaches. Large-scale drainage infrastructure has been expanded and regularly maintained to manage extreme precipitation volumes. Decentralised rainwater management systems, including infiltration ponds, retention basins, and green roofs, help reduce surface runoff and relieve pressure on the central drainage network.

Additionally, new airport buildings and expansion projects are designed with flood resilience in mind, utilising permeable surfaces, green infrastructure, and water retention zones. These measures ensure that even during intense downpours, rainwater can be safely absorbed or discharged without compromising airport operations.

Complementing these physical adaptations is an advanced thunderstorm warning system. When lightning is detected within a five-kilometer radius, a 'Lightning Warning Red' is automatically issued, allowing ground operations to be suspended temporarily for personnel safety. This system reflects the airport's commitment to both infrastructure and human resilience in its climate adaptation planning.

5. Lessons Learned

Munich Airport's approach demonstrates that climate adaptation in aviation requires a combination of technical innovation, proactive planning, and cross-sectoral collaboration. The integration of hydrodynamic models has proven instrumental in visualising flood dynamics and identifying vulnerabilities with high precision. Furthermore, the use of decentralised rainwater management and green infrastructure highlights the value of combining traditional engineering with nature-based solutions.

The case also underscores the importance of continuous monitoring and flexibility. As climate conditions evolve, airports must periodically update flood protection systems, adapt maintenance protocols, and refine emergency procedures. Munich Airport's example illustrates how long-term resilience can be achieved through a balance of structural measures, predictive analytics, and organisational preparedness.

In comparison with other European airports Munich's adaptation efforts align with a broader trend of climate-resilient infrastructure planning in the aviation sector. More and more airports recognise that safeguarding critical infrastructure against climate impacts is not merely a technical necessity but a strategic imperative for operational continuity and public safety.

Overall, Munich Airport's experience can serve as a model for other major transportation hubs worldwide. Its comprehensive flood management framework demonstrates that effective climate adaptation is both achievable and essential for ensuring the sustainability and reliability of aviation infrastructure in an era of increasing climate volatility.

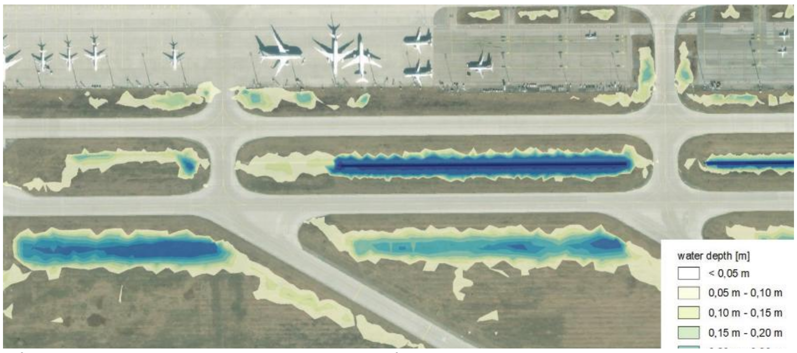


Figure 1: 2D runoff model showing flooded areas and water depths in the vicinity of aviation areas (scenario: 60 l/ m² in 1 hour)

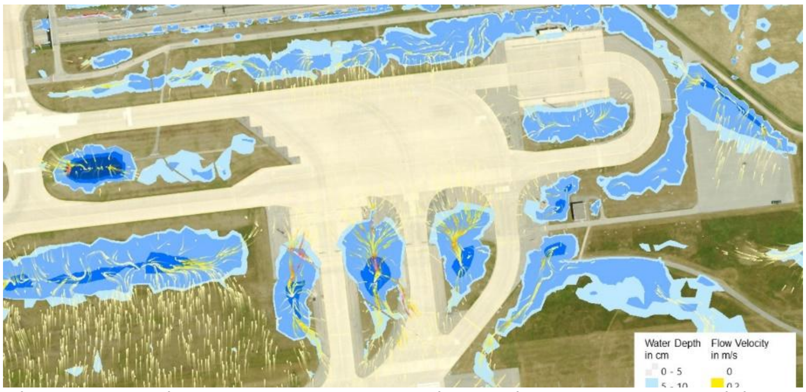


Figure 2: Revised 2D runoff model including stream velocities as well as water depths of flooded areas (scenario: 60 l/ m² in 1 hour)

Case study C: Augmenting drainage capacity at SEA Milano

1. Climate impact covered by the case study

The case study addresses the risk of exceedance of drainage infrastructure capacity associated with surface (pluvial) flooding events caused by intense rainfall. Localised flooding represents a physical risk with immediate direct effects on the airport, including damage to both infrastructure assets and aeronautical operations.

The Malpensa Resilience Project (Re-MXP) aims to address this specific physical risk intervening in five critical areas of the airport.

2. Airport name and climate location

Malpensa Airport, operated by SEA Milan Airports, is located in the southern Varese Area of Italy, within the Mediterranean region. The airport experiences a typical northern Italian continental climate characterised by high humidity. Winters are cold, with frequent fog and occasional heavy snowfall. During spring, significant rainfall often leads to thunderstorms. Summers are hot and humid, with frequent thunderstorms, while autumn is marked by substantial rainfall and persistent dense fog.

3. Challenges and risks associated

A flash flood affected a large area of MXP airport caused by an intense rainfall event on September 16, 2021. This event triggered the planning of activities for flood risk reduction, which have been incorporated into the

Malpensa Resilience project (Re-MXP). The project is now part of a broader set of mitigation actions outlined in the Climate Change Adaptation Plan (CCAP) for Malpensa Airport, released by SEA Milan Airports in 2024.

Within the CCAP future climate scenarios were identified, detailing expected climate changes in the surrounding area of Malpensa Airport. The period from 1986 to 2005 was used to represent baseline conditions, reconstructed from data monitored by regional meteorological stations in Lombardy. Climate projections were conducted for two time horizons: 2040 (short-term) and 2060 (mid-term).

These projections were based on the following IPCC (Intergovernmental Panel on Climate Change) scenarios:

- RCP4.5: Average temperature increase of +3°C by 2100.
- RCP8.5: Average temperature increase of +5°C by 2100.

The selected climate scenarios are more conservative than the Paris Agreement target (RCP1.9, which aims for a +1.5°C increase by 2100) and align with recommendations from the European Aviation Climate Change Adaptation working group.

These projections include expected changes in temperature, precipitation, and the frequency and intensity of extreme weather events, such as storms, heatwaves, and heavy rainfall. Climate projections developed for the specific territorial surroundings of Milan Malpensa indicate that climate change will result in milder winters, higher summer temperatures, and more extreme rainfall events. In the short and mid-term, the following climate evolutions are expected:

- Increased average temperatures and related extreme events, such as heatwaves, more "summer days," more "tropical nights," and fewer frost days.
- Increased daily rainfall maxima, with intense precipitation events potentially overwhelming drainage systems and causing flooding
- Increased frequency of thunderstorms, often accompanied by strong winds.

A detailed risk analysis identified the exceedance of drainage infrastructure capacity due to surface (pluvial) flooding as one of the most critical risks for Malpensa Airport by 2040. The Re-MXP project focuses on improving stormwater management through system upgrades, which will enhance the airport's resilience against flooding and operational disruptions caused by extreme rainfall.

4. Strategy/Initiatives implemented

As part of the Re-MXP project, detailed hydrological and hydraulic modelling was conducted for the site to determine the actual flood risk for

Malpensa Airport, considering both current and future rainfall events as projected by climate studies. The assessment required in-depth analyses supported by field evidence to accurately define the current state of the existing drainage system, which over the years has undergone integrations and modifications often inconsistent, without causing disruption to airport operations. This modelling enabled the identification of five critical areas where targeted activities to improve the drainage system were localised: Terminal 1, Terminal 2, the internal airport viability, the cargo area both landside and airside, Runway 35L.

Specific interventions in these areas included:

- Upgrading some sections of the pipe network and modifying existing infiltration systems.
- Constructing underground storage tanks (pervious or impervious) to manage peak flows.
- Building new infiltration wells, as the site does not have surface water bodies capable of receiving runoff water.

In the figures, excavation works and installation of new drainage pipes in the Cargo Area – land side- of Malpensa airport as part of the Re-MXP project. The inner diameter of the tubes is 1000 millimeters. Therefore, in this specific case, improving Malpensa Airport's resilience to climate change is achieved through the physical and technological adaptation of its infrastructure.

To provide a comprehensive overview of the Re-MXP project, below are some additional details regarding the Re-MXP project, including technical, economic, and organisational aspects:

- Estimated cost: approximately 9.75 million euros, excluding design and project coordination expenses. Around one-third of the total costs will be co-financed by the EU (CEF-T-2021).
- Timeline: works planned between 2022 and 2026, with an estimated duration of 62 months.

- Involvement of third parties: Italian Civil Aviation Authority, meteorological institute, scientists specialised in hydraulic modeling, hydraulic engineers, regional authorities.

5. Conclusion/Lessons learned

The implementation of the Re-MXP project at Malpensa Airport demonstrates the effectiveness of targeted climate adaptation measures in enhancing the resilience of critical infrastructure to extreme weather events. Through a combination of advanced hydrological and hydraulic modeling, strategic interventions, and collaboration with key stakeholders, the project has addressed the physical risks associated with surface (pluvial) flooding and improved the airport's capacity to manage future climate challenges.
A multidisciplinary approach and active stakeholder engagement proved essential throughout the project lifecycle, ensuring that technical solutions were robust and operational needs were met. The experience highlighted the importance of establishing long-term maintenance plans and maintaining detailed documentation to preserve the functionality, quality, and efficiency of the drainage system over time.

Looking ahead, the integration of the Re-MXP project within the broader Climate Change Adaptation Plan for Malpensa Airport offers valuable opportunities to further strengthen mitigation actions and promote sustainable airport operations. These lessons learned underscore the need for continuous improvement and proactive planning in climate resilience for aviation infrastructure.

Case study D – Heavy rainfall and flooding at Amsterdam Airport Schiphol

1. Climate impact covered by the case study

The case study focuses on the adaptation to climate change-induced hydrological risks, specifically the increased frequency and intensity of heavy rainfall leading to flooding and excess runoff water. Amsterdam Airport Schiphol, located below sea level, faces heightened vulnerabilities due to its polder location, making water management critical to prevent flooding, operational disruptions, and infrastructure damage. The case exemplifies how climate change pressures like extreme precipitation and water level management, impact low-lying infrastructures.

2. Airport name and climate location

Amsterdam Airport Schiphol is situated in the Netherlands, a densely populated delta, low-lying country with a lot of water, which is vulnerable to flooding and the consequences of climate change. The Dutch Government aims to protect the Netherlands against flooding, ensure sufficient freshwater and contribute to a climate-proof and water-robust design of our country via the national Delta Programme. Besides national programmes, there are also measures at regional level. However, also at airport-level

Schiphol needs to take its responsibility to ensure that its assets remain resilient and to reduce the risk of damage and operational interruptions.

3. Challenges and risks associated

Due to Amsterdam Airport Schiphol's unique location within a polder, land reclaimed from a lake and situated approximately 4.5 meters below sea level, managing groundwater levels is critical. Continuous pumping is required to maintain stable groundwater conditions. Climate change has increased heavy rainfall events, posing a risk of overwhelming the airport's drainage capacity, which could result in flooding or waterlogging.

Heavy rainfall causes rapid runoff accumulation, which can dangerously build up around airport infrastructure if not buffered or diverted promptly. Effective management of this runoff is essential to prevent localised flooding and maintain safe operating conditions for aircraft and ground activities.

Flooding threatens critical infrastructure such as runways, taxiways, and operational platforms, leading to safety hazards like hydroplaning and reduced braking performance. Moreover, physical damage to surfaces and subsurface structures can occur, and operational disruptions such as delays, cancellations, or closures may reduce airport capacity and reliability.

Excess water impacts aircraft movements and ground operations, potentially causing delays and increased maintenance needs. Effective water management is therefore vital not only to protect infrastructure but also to ensure operational continuity and minimise disruptions at this major international airport.

4. Strategy/Initiatives implemented

The expansion of the Uniform Platform at Amsterdam Airport Schiphol in 2021 introduced a pioneering multifunctional infrastructure that combines a remote aircraft holding area with an advanced smart water buffering and drainage system beneath it. This innovative design effectively addresses the challenges posed by increased heavy rainfall by temporarily storing excess runoff water while maintaining essential airport operations.

Complementing this, Schiphol relies on an extensive, integrated drainage network spanning over 450 kilometres of pipes and channels. This vast system efficiently manages water flow across the site, preventing accumulation and reducing flood risk. The airport's hydraulic engineering features, such as the convex runway design, facilitate water runoff toward designated drainage points, where controlled drainage holes and pumping stations discharge water into regional canals that are part of the national polder water management system.

In addition, Schiphol collaborates closely with national and regional authorities, like the Delta Programme and local water boards, to coordinate water level regulation and handle excess runoff holistically. The airport also employs advanced hydraulic models and climate scenario analyses to guide the resilient design of infrastructure and refine operational protocols. These include innovative solutions such as green roofs, water-permeable surfaces, and gated drainage systems at critical locations, which together enhance the airport's capacity to adapt to climate-related water challenges.

5. Conclusion/Lessons learned

Climate resilience at Amsterdam Airport Schiphol demands a multi-scale approach combining national flood protection, regional water regulation, and airport-level infrastructure innovation. This integrated strategy ensures effective management of complex water challenges driven by climate change.

Innovative multifunctional infrastructure, such as the smart water buffer integrated into operational surfaces, enhances resilience without reducing airport capacity. Robust and well-maintained drainage systems, including an extensive network of pipes and channels, are essential for managing heavy rainfall and maintaining safe airport operations.

Continuous monitoring and adaptation through hydraulic modelling and smart technologies provide Schiphol with a proactive management framework that can respond flexibly to evolving climate threats. Close collaboration with water authorities and alignment with national programs are critical to maintaining stable water levels beyond airport boundaries.

Schiphol's approach offers a replicable blueprint for other low-lying or flood-prone airports to climate-proof their infrastructure against increasing precipitation risks. This holistic, collaborative, and innovative strategy stands as a model for sustainable, resilient airport operations in the face of climate change.

Case study E – Water crisis in Algarve (Faro Airport)

1. Climate impact covered by the case study

Algarve faced a severe water crisis between 2023 and 2024, characterised by extreme hydrological drought. Since May 2022, reservoir storage levels in the region were consistently below 50% capacity, with significant basins like Mira and Ribeiras do Algarve remaining below the 5th percentile of historical data. This prolonged drought resulted in the Portuguese Government declaring a State of Alert and implementing extensive contingency measures that lasted until December 2024.

These measures demanded consumption reductions of 25% in agriculture and 15% in urban sectors, including tourism, with mandates such as reduced water pressure in public supply, suspension of irrigation of green spaces and ornamental uses, and promotion of water reuse for non-potable urban functions.

2. Airport climate location

The Algarve region in Portugal features a Mediterranean climate characterised by dry summers and mild & moderately wet winters. This climate regime has increasingly faced hydrological drought and water scarcity challenges exacerbated by climate change, affecting both ecosystems and critical infrastructure, including the airport's operations.

3. Challenges and risks associated

The Algarve's extreme drought and lowered reservoir levels severely constrained water availability across multiple sectors, including urban use, agriculture, and tourism, directly affecting airport operations. The risk metrics included potential operational limitations at the airport caused by enforced governmental water consumption restrictions. These limitations posed challenges for maintaining routine airport functions and adhering to sustainability commitments amid scarce water resources.

Example of measures implemented/ required by the Government:

- Water pressure reduction in the public water supply network to the minimum essential levels that do not affect service quality.
- Suspension of water use from the public network or drinking water extracted from other natural sources for watering green spaces and gardens (public and private), except for those necessary to ensure the survival of trees of a unique or monumental nature. Watering should be carried out using reused water.
- Suspension of water use from the public network or drinking water extracted from other natural sources to ornamental fountains, artificial lakes and other elements of aesthetic use of water.
- Prohibition on washing pavements, public spaces, walls and roofs with water from the public water supply or water extracted from other natural sources.
- Use of water from alternative sources, such as water for reuse, whenever available, for non-potable urban uses, such as washing streets, pavements, vehicles and equipment belonging to public entities and urban waste containers, with the frequency of washing being reduced.
- Application of the recommendation for water supply services tariff, aiming to increase efficiency in contingency situations

4. Strategy/Initiatives implemented

Faro Airport took proactive measures to comply with government restrictions and conserve water. To ensure compliance with the limitations imposed by the government in the dry season, Faro Airport has implemented measures, such as:

- Prohibition of washing aircraft, vehicles and equipment with water; only dry cleaning is allowed.
- Washing rent-a-car vehicles is only allowed in facilities equipped with a closed water circuit.
- Due to the prohibition of green spaces disappeared, and vegetation adapted to the region's climate was planted instead.

- Development of a project (and definition of the terms of reference) to reuse treated wastewater from the municipal wastewater treatment plant located near the airport.

Despite the easing of some government restrictions following significant winter rainfall in 2024/25, the airport maintained these water-saving measures to sustain responsible water use and prepare for potential future scarcity.

5. Conclusion/Lessons learned

This case highlights the critical importance of early, proactive water management adaptation at airports vulnerable to drought and water scarcity. Effective implementation of stringent water use policies aligned with governmental contingency plans ensures both operational continuity and environmental responsibility.

Furthermore, maintaining adaptability in water management approaches, suitable to evolving hydrological conditions, is essential for the sustainable stewardship of limited water resources in the context of climate change impacts on the Algarve region and similar environments.

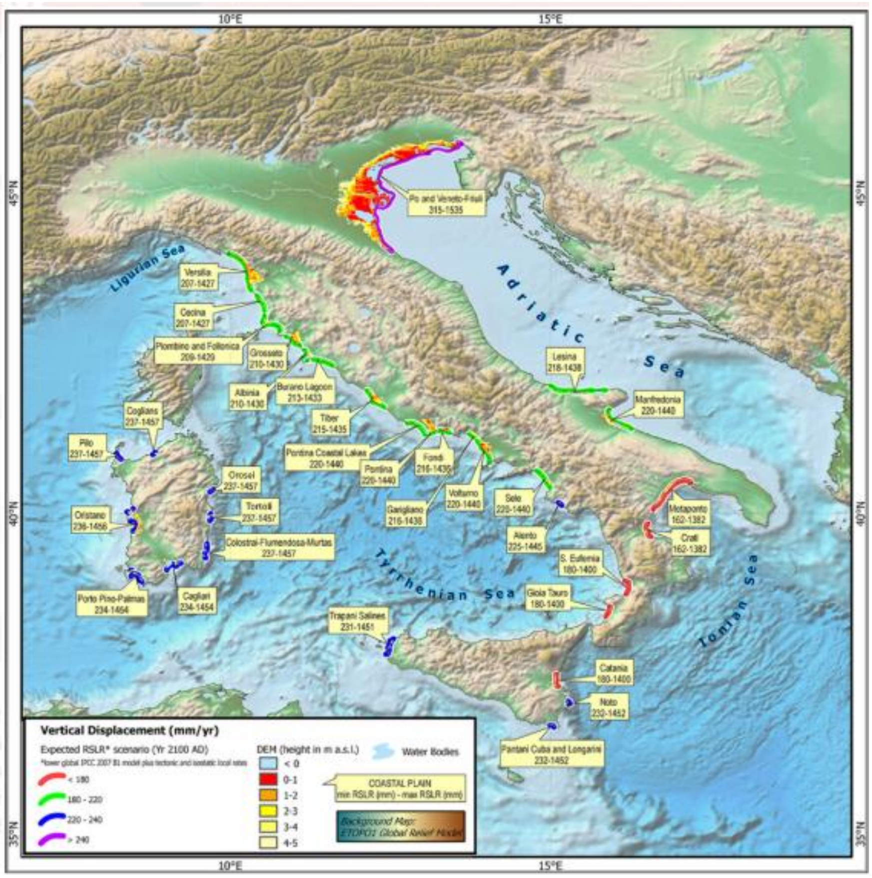
Case study F: Sea level rise at Rome Fiumicino

1. Climate impact covered by the case study

Fiumicino airport is a low-lying airport built on reclaimed land below sea level, which faces water challenges daily. Climate change projects a sea level rise of up to +1 meter by 2100 in the Mediterranean, significantly increasing flood risk in the Fiumicino coastal plain. This exacerbates pluvial flooding challenges from storm surges and heavy rainfall, threatening airport infrastructure and operational continuity.

2. Airport climate location

Fiumicino Airport (Leonardo da Vinci International Airport) is located in Rome, Italy, along the Roman littoral coastal strip. The Mediterranean climate is characterised by mild, wet winters and hot, dry summers. The airport's positioning on reclaimed, flat, low-lying land makes it inherently vulnerable to sea level rise and flooding.



Legend: Map of the 33 Italian areas at risk of being flooded by 2100, published in the study coordinated by ENEA.

3. Challenges and risks associated

The airport grounds are located in the coastal strip of the Roman littoral, in a flat area created by past land reclamation operations, and therefore lie in areas at or, in some cases, even below sea level. The drainage system therefore cannot drain by gravity into the recipients, but needs to do so via three pumping systems: Focene, Traiano, and Pista3

Making Fiumicino airport less vulnerable to (pluvial) flood risk means additional investment every year. Aeroporti di Roma constantly invests in improving the airport drainage network by enhancing the collector system, but above all by increasing its lamination capacity, through the construction of new underground and surface containment basins.

In addition, the strategic infrastructures—runways, taxiways, piers, terminals, etc.—were built at higher elevations than those of the adjacent reclaimed areas.

To fully define the operation of the pumping systems, so that the software can instantly identify the correct operating point in the characteristic curve of each pump, the levels in the recipients were determined (the Tiber River for the Traiano and Pista 3 pumping stations, and the Focene Pond for the Focene pumping station), assuming the sea level is +1 m above the hydrographic zero: this condition is imposed, with a precautionary approach, both to account for a simultaneous sea level rise due to the weather event, and in anticipation of the sea level rise by 2100 estimated by climate models developed by ENEA. The study on variations in the Mediterranean level, published in the scientific journal Quaternary International by the publisher Elsevier, demonstrates how the IPCC's forecasts for 2100 represent a clear acceleration in sea level rise, caused mainly by climate change, which will result in sea level increases in the Fiumicino coastal plain of up to a maximum of 1 m compared to the current hydrographic zero.

These projections are also confirmed in the study "Modelling present and future climate in the Mediterranean Sea: a focus on sea-level change," published in Climate Dynamics by a team of researchers from ENEA's Climate Modelling and Impacts laboratory (G.Sannino, A. Carillo, R.Iacono, E.Napolitano, M.Palma, G.Pisacane, and M.Struglia- ENEA - Climate and Impacts Modelling Laboratory, , Rome, Italy).

4. Strategy/Initiatives implemented

Aeroporti di Roma undertakes continuous investment in upgrading Fiumicino Airport's drainage infrastructure, focusing on expanding collector system capacity and constructing both underground and surface retention basins to increase water lamination capacity. Their strategy employs advanced hydraulic modelling, using InfoWorks software to simulate system behaviour under various conditions. This begins with precisely defining the reference levels at drainage outlets, which represent downstream boundary conditions influencing the entire system's operation. These levels are carefully tabulated to inform the optimal functioning of pumping stations.

For each pumping facility, initial "attack conditions" are set by conservatively assigning the maximum observed attack elevation across pumps as the starting water level. This approach is grounded in empirical data from hydrometric monitoring systems, ensuring simulations represent real system states. Furthermore, the model assumes that any manholes, pipes, or channels with bottom elevations below the starting water level begin simulation partially filled, avoiding unrealistic empty system assumptions and thus improving reliability.

ADR's Climate change risk assessment methodology includes:

- Advanced climate modelling: through the analysis of climate trends performed using historical data and future projections (using local meteorological databases and datasets with high spatial/temporal resolution), climate modelling of relevant hazards is carried out, combining different time horizons (2030, 2040, and 2050) and climate scenarios developed by the IPCC (Intergovernmental Panel on Climate Change, the United Nations body for the assessment of climate change science).
- In-depth analysis of potential impacts: examines how climate change could specifically affect assets and operations, including a detailed assessment of transition risks related to the evolution of the regulatory and market context.
- Resilience assessment: through an integrated analysis, the capacity of infrastructure and operational procedures to manage and adapt to climate impacts is evaluated, ensuring that the organisation remains resilient in the face of changes.
- Development of a strategic adaptation plan: based on the analyses, an adaptation plan is defined that includes short, medium, and long-term measures to increase climate resilience, simultaneously identifying opportunities emerging from the transition to sustainable mobility.

The critical assets analysed regarding sea level rise hazards at Fiumicino Airport include apron airfield ground lights, de-icing systems, electrical infrastructure, foul drainage and treatment facilities, Jet A1 fuel storage, navigation aids and meteorological systems, rainwater drainage networks, runway, apron and taxiway surfaces, sanitary and rainwater systems, terminal data and electrical systems, terminal HVAC systems, and water supply resources.

This rigorous, data-driven approach exemplifies best practices in climate adaptation for major coastal airports, combining infrastructure upgrades, sophisticated modelling, and strategic planning to secure operational continuity amidst growing environmental risks.

The adaptive capacity, or the qualitative ranking of the airport's ability to mitigate climate impacts, was studied across four key time horizons: the current "as is" state, short-term impacts projected for 2030, medium-term for 2040, and long-term for 2050. This multi-temporal analysis allows for understanding how resilience may evolve over time, accounting for changes in climate hazards and mitigation efforts.

Then, single asset risk assessment has been classified for each scenario, across various time horizons, and considers both mitigated and unmitigated conditions to thoroughly evaluate potential impacts and guide risk management decisions.

Single asset risk assessment

Airport 1					*SSP 2-4.5*			
Asset 1					**SEA LEVEL RISE**			
	Current state		**2030**		**2040**		**2050**	
Hazard	High		High		High		High	
Sensitivity	Low							
Recommended mitigation measures	• Measure 1 • Measure 2		• Measure 3 • Measure 4					
	unmitigated	mitigated	unmitigated	mitigated	unmitigated	mitigated	unmitigated	mitigated
Adaptive capacity	Low	Medium	Low	High	Low	High	L[illegible]	High
Risk class	Medium	Medium	Medium	Low	Medium	Low	[illegible]ium	Low

Illustrative

EXAMPLE

The assessment of physical risks for the FCO and CIA airports was carried out with a specific focus on 13 critical assets/infrastructures ("project components") in relation to potential exposure to 16 climate hazards. The evaluation activities conducted for all scenarios and time horizons resulted in over 7,000 risk classifications for each relevant combination of hazard-asset-scenario-timeframe.

5. Conclusion/Lessons learned

Fiumicino’s case highlights the necessity of long-term investment in adaptive hydraulic infrastructure for coastal airports. Combining elevated construction, enhanced drainage, and advanced hydrological modelling builds resilience against climate-driven sea level rise and extreme rainfall. Collaboration with national water management and climate science institutions ensures that adaptation strategies remain robust and responsive. The airport exemplifies best practice in integrating climate projections into infrastructure planning to safeguard critical aviation assets.

7. Compendium of climate impacts

This section provides an overview of potential impacts for airports, ANSPs, airlines and people (passengers and personnel) for each of the 8 climate effects covered in Section 4. Please note that this list is non-exhaustive and other impacts may be possible. Impacts may vary greatly according to an organisation's location and characteristics. Therefore, it is highly recommended that an organisation carries out a climate risk assessment to identify the specific impacts it may need to address.

Airports

Airlines

Air Navigation Service Providers (ANSPs)

People (Passengers & Staff)

7.1 Changes in average and extreme temperatures: impacts, impacted actors and implications

The expected changes in average and extreme temperatures results in numerous consequences, risks, and hazards that also impact airports, operational operations, materials, as well as staff and passengers.

Impacts		Impacted actors	Potential consequences
Changes in aircraft performance	Decreased aircraft's climb performance		Weight restrictions to ensure take off performance Higher maintenance demand Safety and resilience implications Financial implications
	Reduction in aircraft take Off Mass)		Disruption of operational activities Financial implications Reassessment of runway lengths
	Changes in noise impact		Re-assessment of noise impacts Impacts on the surrounding community Legal consequences Potential curfews MTOM limitations
Infrastructure damage	Infrastructure damages affecting the structural integrity of airside structures (runway, taxiway, terminal)		Repair costs Injuries (employees/passengers) Damage to reputation Disruption of operational activities
	Infrastructure damages affecting the structural integrity of landside structures (buildings, access route)		Repair costs Passenger or staff injuries Damage to reputation Accessibility issues to the airport
	Frost/thaw damage to surfaces caused by highly variable winter temperatures		Repair costs Personal injuries (employees/passengers) Material damage Damage to reputation Accessibility issues to the airport

Impacts		Impacted actors	Potential consequences
Fire risk	Increased wildfire in green areas		Safety hazards Personal injuries (employees/passengers) Material damage Repair costs Disruption of operational activities
	Increased incidence of fuel venting from aircraft in warm weather		Safety hazards Personal injuries (employees/passengers) Material damage Repair costs Disruption of operational activities Damage to reputation
	Flashpoint of aviation fuel exceeded on hot days		Safety hazards Personal injuries (employees/passengers) Material damage Repair costs Disruption of operational activities Damage to reputation
Over heating	Overheating of operationally critical buildings		Material damage Repair costs Disruption of operational activities Damage to reputation
	Heat stress risk to staff, particularly those in highly physical roles		Personal injuries (employees/) Disruption of operational activities Legal consequences Damage to reputation
	Thermal discomfort of staff and passengers in terminal buildings and aircraft		Personal injuries (employees/passengers) Legal consequences Damage to reputation Staff absenteeism
	Increased energy demand		Financial costs Damage to reputation
	Lack of capacity in HVAC systems / potential failure of cooling systems		Financial costs Personal injuries (employees/passengers) Disruption of operational activities Legal consequences Damage to reputation

Impacts		Impacted actors	Potential consequences
Local ecosystem changes	Increase in disease vectors from climate change providing a new hospitable environment for imported species.		Personal injuries (employees/passengers)
			Disruption of operational activities
			Environmental damage
			Damage to reputation

7.2 Changes in frequency and intensity of storms: impacts, impacted actors and implications

Impacts		Impacted actors	Potential consequences
Disruption to operations	Flight delays		Disruption of network flow
			Financial implications
			Capacity constraints
			Staff workload and fatigue
			Travel disruption and stress for passengers
			Technology and infrastructure stress
			Reputational risks
	Cancellations		Financial implications (revenue loss, compensation liabilities)
			Operational disarray
			Terminal congestion
			Imbalanced air traffic & scheduling inefficiencies
			Passenger and staff stress & workforce fatigue
	Route extensions/Diversions		Increased gate congestions
			Operational delays
			Resources management strain
			Higher fuel & maintenance costs
			Environmental impact
			Flight delays & crew scheduling issues
			Increased traffic complexity and inter-regional coordination challenge
			Longer travel times & missed connections
			Reputational impact (reduced passenger satisfaction)
			Overcapacity
			Ground handling strain
			Increased operating costs and financial loss
			Airspace congestion
			Rerouting workload
			Reduced airport arrival and departure rates
			Financial implications

Impacts		Impacted actors	Potential consequences
			Missed slots
			Traffic rerouting pressure
			Delays & Missed connections
			Increased stress and fatigue
Disruption to ground transport access	Infrastructure damages affecting the structural integrity of landside structures (buildings, access route)		Repair costs
			System-wide disruption of access to and from the airport
			Operational breakdowns across multiple functions (crew, passengers, logistics)
			Disruption of operational activities
			Missed flights and shifts due to late-arriving passengers and crew
			Reduced availability of essential personnel (security, baggage, maintenance)
			Drop-off/pick-up delays
			Potential increase in no-shows or last-minute cancellations
			Congestion at nearby intersections and access points
			Increased travel times, costs, and stress
			Reputational impact
			Strain on facilities (hotels, waiting areas) due to stranded passengers
	Disrupted rail, metro, and bus services		Potential increase in no-shows or last-minute cancellations
			Missed flights and shifts
			Reduced availability of essential personnel (security, baggage, maintenance)
			Congestion at nearby intersections and access points
	Inaccessibility of airport car parks due to flooding or snow		Maintenance costs
			Increased need for emergency coordination and passenger assistance
			Reduced capacity for both short- and long-term parking.
			Staff must manage overflow, vehicle recovery, and stranded passengers.

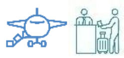
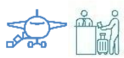
Impacts		Impacted actors	Potential consequences
			Congestion at nearby intersections and access points
			Missed or delayed flights
			Physical Safety Risks
			Employee Access Problems
			Financial implications
			Reputational implications
	Hazardous driving conditions especially for vulnerable road users (cyclists, pedestrians, motorcyclists) and high sided vehicles		Operational implications
			Disruption and delays for personnel travelling to work
Injuries to passengers and staff, including those caused by turbulence	Increased Medical Demands		Disruption of operational activities
			Damage to reputation
			Personal injuries (employees/passengers)
			Disrupted Cabin Service
			Increased insurance and liability costs
	Flight Path Alterations		Loss of vertical separation
			Longer travel times and increased fuel consumption
			Increased Congestion
			Operational Strain on ground services
			Affected crew scheduling
			Increased Air Traffic Control Workload
			Passengers stress and anxiety
			Potential passenger compensation
			Damage to reputation
			Staff fatigue
			Financial costs
			Damage to reputation
Disruption to supply of utilities (e.g. power outages)	Shutdown of terminal or CNS systems		Increased reliance on emergency power
			Cascading failures: Loss of one utility (e.g. electricity) may disrupt others (e.g. water pumps, IT systems).

Impacts		Impacted actors	Potential consequences
			Delays and cancellations
			Reduced ATC capacity
			Overcrowding and confusion in terminals without functional security systems, baggage systems or lighting
			Internal airport logistics disrupted
			Increased cybersecurity risks
			Revenue loss
			Damage to reputation
Hail	Flooding		Material damage to buildings and aircraft fleet
			Employee and passenger injuries
			Blocked drainage systems
			Disruption of operational activities
			Repair costs
			Depreciation
Wind gusts	Increased occurrence of foreign object Debris (FOD)		Passenger and staff injuries
			Disruption of operational activities (e.g. Difficulties in landing and take-off)
			Employee injuries
	Land erosion and material damage		Disruption of operational activities
			Repair costs
	Go-arounds and diversions		Same as for diversions in previous table.
Heavy rain	Flooding of runways/apron and public areas		Disruption of operational activities
			Material damage (servers/cars/electrical equipment/furnishings in basements/ground floors)
			Passenger and staff injuries
			Disruption of ground transport access to airport
			Overloading of structural capacity of large halls/hangars)
	Reduced visibility		Reduced Runway Capacity
			Delays in Ground Movements
			Temporary Closures
			Flight Delays and Diversions
			Reduced Airspace Efficiency

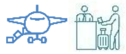
Impacts		Impacted actors	Potential consequences
			Sector Congestion Delays and Missed Connections
Freezing rain	Slippery conditions & reduced visibility		Disruption of operational activities (Runway Closures or Capacity Reduction; Ground Movement Delays) Increased use of de-icing Increased Fuel Use Reduced Airspace Capacity Higher Risk of Incursions Workforce Safety Risks
Lightning strikes (personnel, aircraft and airport infrastructure)	Damage on aircraft, airport, or air traffic infrastructure (antennas, NAVAIDS…)		Material damage and repair costs Runway/Taxiway Closures Reduce ATC capacity Flight Delays and Cancellations Fire hazard Employee injuries Safety hazards (, inability to process passengers; congestion on the apron)

7.3 Changes in precipitation: impacts, impacted actors and implications

7.3.1 Too little precipitation (Drought[9])

Impacts		Impacted actors	Potential consequences
Dusty Air	Material damage (especially to engines)		Repair costs
			Depreciation
	Deteriorated air quality		Health consequences for passengers/employees
	Limited visibility		Impairment of operational activities
Fire hazard from dried vegetation	Direct material damage from fire		Financial costs
			Impairment of operational activities
			Safety hazards
	Impairment/suspension of operations due to smoke/fire		Financial implications
	Indirect material damage from smoke/particles (e.g., engines)		Material implications
			Financial implications
	Personal injuries		Personal injuries (Burns/smoke inhalation)
Increased fine dust pollution	Deteriorated air quality		Damage to reputation
	Health consequences for employees/passengers		Employee absenteeism
Water shortage	Limited firefighting water supply		Weakened emergency response
	Lack of water for landscape maintenance (e.g., irrigation)		Fire hazard due to dry vegetation
	Soil erosion due to wind		Additional dust
	Lack of process/cooling/operational water		Impairment/failure of systems

[9] Drought meaning a prolonged dry period in the natural climate cycle that can occur anywhere in the world. It is a slow-onset disaster characterized by the lack of precipitation, resulting in a water shortage. It's not necessarily linked to high temperatures (WHO).

Impacts		Impacted actors	Potential consequences
	Material damage to e.g., channels (insufficient flow/drying out)		Financial costs
Low humidity	Health burden for employees, especially on runways/airfields		Reduced efficiency, potential employee absenteeism

7.3.2 Too much precipitation (Flooding[10])

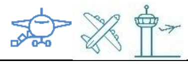
When it comes to floods three types can be distinguished:

- Flash floods due to rapid and excessive rainfall
- River floods due to consistent rain or snow melt which forces a river to exceed capacity
- Coastal floods due to storm surges

The following table does not differentiate between these three types.

Impacts		Impacted actors	Potential consequences
High Groundwater	Floating of tanks, foundations		Material damage
	Flooded basements/underground infrastructure (infiltration through walls)		Material damage (cars, electronic devices, equipment, materials, etc.)
			Personal injuries to employees (slip/trip hazards, electrical accidents, worst case drowning)
			Personal injuries to passengers (slip/trip hazards; electrical accidents)
	Water on the surface		Soil erosion
			Bird strike risk (attractive effect on bird flocks)
			Leaching of water-polluting substances from the topsoil
	High water level in water bodies		Reduced absorption capacity of water
			Backflow of water from flowing water bodies
			Backwater/capacity limit of channels/conductive water bodies
	Frost protection/ minimum distances		Impairment of operational activities
			Material damage, e.g., to underpasses/foundations (especially in frost)
	Reduced effectiveness of trenches/infiltration basins		Backwater/flooding
	Water on the surface		Accessibility of green areas restricted
Low Absorption Capacity of Topsoil	Surface runoff, no infiltration		Soil erosion
			Strain on flowing water bodies/channels; possible capacity limits?

[10] Floods occur when water overflows and submerges normally dry land, typically due to heavy rainfall, rapid snowmelt, or storm surges from tropical cyclones or tsunamis in coastal regions.

Impacts		Impacted actors	Potential consequences
	Low/no effectiveness of infiltration basins/areas		Backwater/flooding
	Flooding of traffic infrastructure, underpasses, underground infrastructure (tunnels, shafts, etc.) due to runoff		Material damage
			Personal injuries (employees & passengers)
			Impairment of operational activities
	Accessibility of green areas restricted		Maintenance/monitoring not possible
High Humidity	Restricted visibility due to clouds, fog		Impairment of operational activities
Stratiform Precipitation (Continuous Rain)	Flooding: Flooding of Underground Infrastructure: Tunnels, Shafts, Underpasses, Subways, Basements		Material Damage (Electrical Systems, Buildings/Structures, ...)
			Disruption of Operations/Supply (Power Outage, Suspension of Subway Operations, ...)
			Personal Injuries (Electrical Accidents, Slip/Trip Hazards, ...)
	Flooding: Surface Flooding: Traffic Infrastructure, Green Spaces, Taxiways/Apron		Disruption of Operational Activities (Aquaplaning)
			Material Damage to Buildings, Infrastructure, Fleet, ...
			Damage to Land Due to Erosion, When Driving on Saturated Soils (Green Space)
			Road Closures, Path Closures
	High Groundwater Levels		See Above
	Low Soil Absorption Capacity		See Above
Convective Precipitation (Heavy Rain)	Flooding of Taxiways/Apron		Disruption of Operational Activities
	Flooding in Public Areas: Traffic Infrastructure		Material Damage
			Personal Injuries (Consequential Damage)
			Disruption of Operational Activities on Roads/Rail
	Limited Visibility		Disruption of Operational Activities

Impacts		Impacted actors	Potential consequences
	High Rainfall Amount		Overloading Load Capacity of Large Halls/Hangars
			Soil Erosion
	Capacity Limit of Drainage System		Material Damage

7.4 Changes in wind: impacts, impacted actors and implications

Impacts		Impacted actors	Potential consequences
Disruption to operations	Delays		Financial implications e.g fuel/maintenance/staff costs
			Capacity constraints
			Staff workload and fatigue
			Travel disruption, missed connections, and stress for passengers
			Technology and infrastructure stress
			Reputational risks
	Cancellations		Financial implications (revenue loss, compensation liabilities)
			Operational disarray
			Terminal congestion
			Emergency services load
			Imbalanced air traffic & scheduling inefficiencies
			Passenger and staff stress & workforce fatigue
	Route extensions		Increased gate congestions
			Operational delays
			Resources management strain
			Higher fuel & maintenance costs
			Environmental impact
			Flight delays
			Increased traffic complexity and inter-regional coordination challenge
			Longer travel times & missed connections
			Reputational impact (reduced passenger satisfaction)
			Overcapacity
			Ground handling strain
			Increased operating costs and financial loss
			Airspace congestion
			Increased coordination complexity
	Temporary loss of capacity		Impacts on operational planning and staffing

Impacts		Impacted actors	Potential consequences
			Disruption to air traffic operations, including diversions, delays and cancelations, increasing complexity and workload.
			Loss of capacity at one airport can have knock-on impacts across the wider network
			En-route capacity limitations
			Strong jets causing shifts in patterns and traffic presentation
			Potentially an impact on airspace capacity where wind patterns and/or clear air turbulence effectively render volumes of airspace less available to traffic
			Increased Operating Costs
			Damage to Brand and Reputation
			Stranded passengers
			Increased Emissions
Injuries to passengers and staff, including those caused by turbulence	Increased medical demands		Increased insurance and liability costs
			Disruption of operational activities
			Damage to reputation
			Disrupted cabin service
			Employee absenteeism
	Flight path alteration		Loss of vertical separation
			Longer travel times and increased fuel consumption
			Increased Congestion
			Affected crew scheduling
			Operational Strain on ground services
			Increased Air Traffic Control Workload
			Passengers stress and anxiety
			Potential passenger compensation
			Damage to reputation
			Staff fatigue
			Financial implications
Damage to infrastructure and equipment	Impact on infrastructure buildings, network materials		Repair costs
			Operational implications

Impacts		Impacted actors	Potential consequences
			Potential reduction in airspace capacity or airspace closure (e.g. when radar, navaids, comms equipment is damaged) but can be mitigated by resilient backup systems
	Increased risk to health and safety of passengers and personnel		Liability implications
			Reputational implications
Disruption to ground transport access	Hazardous driving conditions especially for vulnerable road users (cyclists, pedestrians, motorcyclists) and high sided vehicles		Operational implications
	Road blockages and closures causing disruption and delays		Disruption and delays for personnel travelling to work
Disruption to supply of utilities (e.g. power outages)	Shutdown of terminal or CNS systems		Increased reliance on emergency power
			Safety concerns
			Cascading failures: Loss of one utility (e.g. electricity) may disrupt others (e.g. water pumps, IT systems).
			Delays and cancellations
			Reduced ATC capacity
			Overcrowding and confusion in terminals without functional PA systems or lighting
			Internal airport logistics disrupted
			Increased cybersecurity risks
			Revenue loss
			Damage to reputation
Increase in en-route turbulence	Increased Medical Incidents		Disruption of operational activities
			Damage to reputation
			Personal injuries (employees/passengers)
			Disrupted Cabin Service
			Increased insurance and liability costs
	Flight Path Alterations		Loss of vertical separation
			Longer travel times and increased fuel consumption
			Increased Congestion

Impacts		Impacted actors	Potential consequences
			Operational Strain on ground services
			Affected crew scheduling
			Increased Air Traffic Control Workload
			Passengers stress and anxiety
			Potential passenger compensation
			Damage to reputation
			Staff fatigue
			Financial costs
			Damage to reputation
Changes to optimal flight routes: impacts for ATC workload and staffing	Flight Path Alterations		Impacts on operational planning and staffing

7.5 Sea level rise: impacts, impacted actors and implications

Impacts		Impacted actors	Potential consequences
Inundation of airfield and/or airport infrastructure	Loss of capacity (temporary or permanent)		More frequent flooding of equipment.
			Damage to ATM infrastructure potentially resulting in loss of capacity or closure of airspace
			Financial implications
			Reputational risks
	Disruption of operations: delays cancellations, diversions		Financial implications (revenue loss, compensation liabilities)
			Operational disarray
			Terminal congestion
			Emergency services load
			Imbalanced air traffic & scheduling inefficiencies
			Passenger and staff stress & workforce fatigue
Temporary/permanent inundation of ground transport access			Staff arriving late on duty (or not arriving), causing potential capacity issues.
			Difficulty for passengers to access airport
			Safety risks

7.6 Changes in Biodiversity: impacts, impacted actors and implications

Impacts		Impacted actors	Potential consequences
Collisions (birds, mammals, etc.)	Flight safety risks, aircraft damage, potential delays.		Safety decrease. Increased operational workload Increased costs for wildlife management measures (control programs, habitat modifications). Financial implications Reputational risks
	Disruption of operations: delays cancellations, diversions		Financial implications (revenue loss, compensation liabilities) Operational disarray Terminal congestion Emergency services load Imbalanced air traffic & scheduling inefficiencies Passenger and staff stress & workforce fatigue
Soil destabilisation and infrastructure management			Rising infrastructure maintenance costs due to soil erosion and loss of ground stability.
Introduction and spread of invasive species	Concern over ecosystem degradation and local biodiversity loss.		Risks to infrastructure and ecosystems
Reduced attractiveness of air transport (loss of ecotourism and depletion of natural resources)	Impact on passenger traffic, particularly in destinations reliant on biodiversity-based tourism.		Impact on passenger traffic, particularly in destinations reliant on biodiversity-based tourism.
	Risks to the supply of natural resources and potential decline in transported goods at an international level.		Operational uncertainty Financial risk exposure

Impacts		Impacted actors	Potential consequences
Fragmentation of ecological corridors	Increased risk of wildlife strikes		Regulatory and reputational challenges
			Operational safety risks
Regulatory constraints (biodiversity laws, habitat protection, mitigation measures)			Potential opposition to development projects due to environmental concerns.
			Risk of sanctions, legal disputes, and infrastructure project delays due to non-compliance.
			More stringent regulations on buildings and infrastructure.
Reputational constraints			Greater scrutiny from investors and financial stakeholders regarding biodiversity commitments.

7.7 Changes in Icing: impacts, impacted actors and implications

Impacts		Impacted actors	Expected consequences
Decrease in de-icing requirements in regions experiencing warmer winters			Shift in maintenance planning
			Reduced operational delays
			Lower costs
Increase in icing events (including unexpected extreme events)			Damage to equipment
			Increased heating of premises.
			Flight diversions and emergency landings
			Increased maintenance and inspection demands
			Risk of staff injuries on the way to work or on premises
	Increase in de-icing		Departure delays
			Increased costs

7.8 Desertification: impacts, impacted actors and implications

Impacts		Impacted actors	Potential consequences
Increases dust storms or sand storms Water availability decrease & fall in groundwater table	Visibility reduction		Increased risk of soil erosion around apron and runway. It may affect take-offs, landings and taxiing operations. In more serious cases, it may lead to restricted operations and to temporary airport closure.
			Disruption of operations
	Damage to aircraft: _The entry of abrasive particles into engines can cause premature wear or mechanical failure. _The accumulation of dust on external surfaces can impair the pilot's visibility (e.g. on the windscreen) or affect the aircraft aerodynamics (e.g. on the wings). _Contaminated sensors and navigation instruments can compromise accurate readings.		Encroachment of sand dunes on apron: Risk of aircraft accidents (on the ground or in flight)
	Infrastructure problems: _Runway lighting systems obstructed by particles _Runways, taxiways and stands can accumulate sand, making the surface slippery and increasing the risk of skidding. _Ground support equipment (GSE) can suffer accelerated wear and tear.		Sand damage on airframes and engines: Risk of accidents
			Higher maintenance and investments costs

Impacts		Impacted actors	Potential consequences
	Health risks		Staff and passengers may suffer from respiratory problems due to inhalation of fine particles.
			Risk of absenteeism

8. Compendium of climate adaptation measures

This section provides an overview of potential climate adaptation measures to address the climate impacts identified in Section 7. Please note that this list is non-exhaustive and other adaptation measures may be available. Moreover, as the impacts which need to be addressed may vary greatly according to an organisation's location and characteristics it is highly recommended that identification and implementation of climate adaptation measures is based on an organisation-specific climate risk assessment.

8.1 Changes in average and extreme temperatures: potential adaptation measures

Impacts		**Adaptation actions**
Changes in aircraft performance	Decreased aircraft's climb performance	Evaluate changes for reduced aircraft take-off performance
		Extend runway length
		Move obstacles at the end of the runway (to adjust for reduced take-off performance due to reduced thrust and lift)
		Adjust flight schedules to account for higher temperatures (e.g. heavier departures at cooler times of the day)
		Reduce payload of aircraft
	Reduction in aircraft's MTOM (Maximum Take Off Mass)	Evaluate changes to safety criteria and procedures to account for reduced aircraft take-off performance
		Extend runway length
		Adjust flight schedules to account for higher temperatures (e.g. heavier departures at cooler times of the day)
		Reduce payload of aircraft
	Changes in noise impact	Fleet mix optimisation
		Aircraft operational procedure modification (e.g. routes adaptation to reduce noise impacts towards the communities)
		Extend runway length
Infrastructure damage	Infrastructure damages affecting the structural integrity of airside structures (runway, taxiway, terminal)	Focus on Airport Pavement Management System (APMS) software for surveying and management of routine and extraordinary maintenance operations
		Improve and update design criteria to align with current standards and environmental requirements (e.g. Pavement design for higher temperatures)

Impacts		Adaptation actions
		Cooling runways with recycled water
		Improve and update design criteria to align with current standards and environmental requirements (e.g. Pavement design for higher temperatures)
		Minimise asphalt surface on the airside and increase nature-based solutions
	Frost/thaw damage to surfaces caused by highly variable winter temperatures	Focus on Airport Pavement Management System (APMS) for surveying and management of routine and extraordinary maintenance operations.
		Improve and update design criteria to align with current standards and environmental requirements (e.g. Pavement design for higher temperatures).
Fire risk	Increased wildfire in green areas	Improve monitoring activities, data acquisition, and systematic recording related to the phenomenon coupled with specific weather data.
		Improve green maintenance
	Increased incidence of fuel venting from aircraft in warm weather	Verify and improve specific operating procedure (apron spill management)
		Verify and improve specific operating procedure (GSR)
		Verify and improve spill reporting and clean-up procedures
		Improve monitoring activities, data acquisition, and systematic recording related to the phenomenon coupled with specific weather data
		Collaborate with airlines and refuellers to establish systematic recording and transmission of spill events to the airport operator
	Flashpoint of aviation fuel exceeded on hot days	Verify and improve specific operating procedure (apron spill management)
		Verify and improve specific operating procedure (GSR)
		Verify and improve spill reporting and clean-up procedures
		Improve monitoring activities, data acquisition, and systematic recording related to the phenomenon coupled with specific weather data
		Collaborate with airlines and refuellers to establish systematic recording and transmission of spill events to the airport operators
Over heating	Overheating of operationally critical buildings	Monitor of indoor temperature data of air-conditioned buildings
		Routine maintenance of air conditioning systems
		Increase cooling capability in buildings
		Improve the thermal insulation of existing buildings

Impacts		Adaptation actions
		Verify that the current use of areas and spaces aligns with the intended climate control for the zone
		Ensure that future airport development Masterplans consider climate change risks, with particular focus on overheating impacts on infrastructure.
		Update design standards for future buildings and cooling systems that account for more extreme climatic conditions
		White or pale external wall colour to reduce temperature (increase reflection of solar radiation)
	Heat stress risk to staff, particularly those in highly physical roles	Routine maintenance of air conditioning systems
		Increase cooling capability in buildings
		Implement programme to promote safety in the heat for ground staff – potentially extending to aircraft operator and ground handling staff
		Review and Update of Operational Procedures
		More vegetation or irrigated green spaces
	Thermal discomfort of staff and passengers in terminal buildings and aircraft	Implement systematic monitoring of the phenomenon
		Routine maintenance of air conditioning systems
		Increase cooling capability in buildings
		Increase provision of aircraft cooling capabilities such as Preconditioned Air (PCA) or APU use
	Increased energy demand	Monitor the Energy Power absorbed by individual buildings/areas
		Improve the thermal insulation of existing buildings
		Prioritise low/zero carbon emission refrigeration systems for new installations
	Lack of capacity in HVAC systems / potential failure of cooling systems	Increase the capacity of cooling systems
		Update design standards for future buildings and cooling systems that account for more extreme climatic conditions
		Prioritise low/zero carbon emission refrigeration systems for new installations
Local ecosystem changes	Increase in disease vectors from climate change providing a new hospitable environment for imported species.	Implement or update wildlife monitoring plans to account for changes in wildlife impacts

8.2 Changes in frequency and intensity of storms: potential adaptation measures

Impacts		Adaptation actions
Hail	Blocking of drainage systems	Regular cleaning of leaves/branches/debris, multiple drainage points
		Update with large drainage systems
		Implement multiple drainage points
	Material damage to buildings, fleet, aircraft	Covered parking spaces/underground garages
	Employee injuries	Develop warning systems and protocols
		Ensure evacuation plans/shelters
	Passenger injuries	Warnings in the terminal
		Inform staff of behavioural/ safety instructions
Lightning	Lightning strikes	Ensure regular installation of lightning rods
		Preferably covered parking spaces/underground garages
		Warning system, evacuation plans, shelters
		Utilise/activate ACDM (Airport Collaborative Decision Making)
Wind Gusts	Storm damage	Regular tree maintenance; warnings/recommendations/regulations
		Recommendations, notices, warnings in the terminal/online
		Preferably covered parking spaces/underground garages; regular maintenance/control of buildings; secure objects against wind
	Disruption of operational activities	Mandatory seatbelt use, warnings (airlines)
		Pilot training
	Increased occurrence of Foreign Object Debris (FOD)	Secure objects/materials on the apron, employee awareness, increased vigilance
	Soil erosion	Soil stabilisation measures; greening/planting; irrigation
Heavy Rain	Flooding of runways/aprons	Large-scale drainage systems; retention/flood areas
	Flooding of public areas: traffic infrastructure/ buildings/ structure	Large-scale drainage systems
		Speed regulation on roads
		Retention/flood areas
		Warnings/warning systems
		Emergency pumps

Impacts		Adaptation actions
		Green spaces/permeable surfaces
	Reduced visibility	Technical assistance systems/land systems
		Ground radar
		Restrictions on driving permissions on apron/runways
	Large volume of rainfall	Large-scale drainage
		Simulation of runoff
		Calculation of peak load (weight) during extreme events
		Low flow velocities
		Soil stabilisation measures
		Greening/planting
Freezing Rain	Slippery conditions	Warnings in the terminal and warning systems on the apron – Greater frequency of runway inspections
		Behavioural/safety instructions
		Regularly maintained vehicles
		Restrictions on driving permissions on runways/aprons
		Winter service capacities on standby
	Ice layer on aircraft	De-icing capacities on standby
		Time buffers in processing
	Ice layer on fleet	Covered parking spaces/underground garages
		De-icing capacities for GHG fleet
		Consider using alternative vehicles
Snow	Blockage of apron/runways	Sufficient, readily available winter service capacities
		Emergency plans (traffic or operations limited to a single lane rather than the normal multiple lanes))
	Disruptions to public traffic infrastructure (blockage of rail/road)	Cooperation with public winter service, disaster protection/local fire department
		Sufficient, readily available winter service capacities
		Warnings/instructions for arrival
	Slippery conditions	Sufficient, readily available winter service capacities
		Warnings
	Weight	Cooperation with public winter service, disaster protection/local fire department
		Sufficient, readily available winter service capacities
		Warnings
		Evacuation plans
	Reduced visibility	Technical assistance systems/land systems
		Ground radar

8.3 Changes in precipitation: potential adaptation measures

Preparedness actions for too little water:

Impacts		Adaptation actions
Dusty Air	Material damage, especially to engines	Irrigate green areas
	Deteriorated air quality	Rooms with filtered air, offering respiratory masks, open access to drinking water
	Limited visibility	Technical assistance systems/ground systems; ground radar; restriction of driving licenses to apron/runways.
Fire hazard from dried vegetation	Direct material damage from fire	Improve monitoring activities, data acquisition, and systematic recording related to the phenomenon coupled with specific weather data.
		Improve green maintenance
	Impairment/suspension of operations due to smoke/fire	Efficient disaster protection, emergency plans, regular real-life drills, well-equipped fire department
	Personal injuries	Respiratory masks, warnings, action/safety instructions
Increased fine dust pollution	Deteriorated air quality	Irrigate green areas
	Health consequences for employees/passengers	Rooms with filtered air, offering respiratory masks, open access to drinking water
Water shortage	Limited firefighting water supply	Apply the sponge city principle: Water Retention and Storage, Water Reuse and Recycling, Green Infrastructure, Stormwater Management Sustainable Urban Design, Water Efficiency, Natural Ecosystem Support
	Lack of water for landscape maintenance (e.g., irrigation)	
	Soil erosion due to wind	
	Lack of process/cooling/operational water	
	Material damage to e.g., channels (insufficient flow/drying out)	
Low humidity	Health burden for employees, especially on runways/airfields	Rooms with filtered cool air, open access to drinking water

Preparedness actions for too much water:

Impacts		Adaptation actions
High Groundwater	Floating of tanks, foundations	Load-bearing; anchorages/safeguards
		Artificial lowering of groundwater (where to put the water?)
	Flooded basements/underground infrastructure (infiltration through walls)	Improve drainage systems
		Enhanced forecasting technologies will also be crucial for timely decision-making during adverse weather conditions
		Object protection, e.g., elevated construction of heating units/aggregates; structural precautions inside (flood barriers, drainage (backflow secured!), emergency pumps (check usage! possible risk of collapse!)) and outside (white tub foundations); are escape and rescue routes affected?
		Warning system, safety instructions, training, implemented structural object protection
		Warnings, behaviour & safety instructions, implemented structural object protection, if necessary: maintain evacuation plans: are escape routes clear?
	Water on the surface	Ideally no/low flow velocities; retention areas
		Above-ground drainage/pumping into flowing water bodies
		Careful handling of hazardous substances
	High water level in water bodies	Retention areas & basins, intermediate storage (multiple use of e.g., parking lots); decentralised infiltration; wastewater treatment plant (are capacities available?)
		Backflow valves/safeguarding measures in pipes, channels & smaller water bodies; storage capacities; flood protection through dikes; ensure adequate slope to the water body
		Generously dimension storage capacities, drainage into wastewater treatment plant (capacities?), warning systems/simulations; flooding/retention areas (multiple use); flood protection through backflow valves (sewer)/dikes/drains (surface channels)
	Frost protection/ minimum distances	Artificially lower groundwater; elevated runways, additional structural precautionary measures

Impacts		Adaptation actions
	Reduced effectiveness of trenches/infiltration basins	Retention areas & basins, intermediate storage (multiple use of e.g., parking lots); de-sealing, green areas for surface infiltration
	Water on the surface	Graveling of paths, paving/increasing paths/roads
Low Absorption Capacity of Topsoil	Surface runoff, no infiltration	Soil safeguarding measures, especially in sloped areas; greening/planting
		Artificial infiltration (pumping), trench or shaft infiltration; retention areas, water retention
	Low/no effectiveness of infiltration basins/areas	Retention areas & basins, intermediate storage (multiple use of e.g., parking lots); de-sealing, green areas for surface infiltration
	Flooding of traffic infrastructure, underpasses, underground infrastructure (tunnels, shafts, etc.) due to runoff	Retention areas & basins, intermediate storage (multiple use of e.g., parking lots); de-sealing, green areas for surface infiltration
		Warnings, safety instructions, evacuation plans, are escape routes affected?
	Accessibility of green areas restricted	Graveling of paths, paving of paths/roads
High Humidity	Restricted visibility due to clouds, fog	Technical assistance systems/land systems; ground radar; restriction of driving permissions on the apron/runways
Stratiform Precipitation (Continuous Rain)	Flooding: Flooding of Underground Infrastructure: Tunnels, Shafts, Underpasses, Subways, Basements	Emergency Pumps, Precautions: Sealing of Ventilation Shafts, Object Protection, e.g., Elevated Construction of Heaters/Aggregates, ...; Structural Precautions Inside (Flood Barriers) and Outside (Drains, Protective Plates for Ventilation Shafts, Slope to the Street, Gravel Packing); Affected Escape & Rescue Routes?
		Warnings, Signage, Blocking of Basements/Subway Stations; Emergency Pumps
	Flooding: Surface Flooding: Traffic Infrastructure, Green Spaces, Taxiways/Apron	Emergency Pumps, Retention Areas/Detention Basins, De-sealing, Green Spaces for Surface Infiltration, Multiple Use of e.g., Parking Lots, Sponge City Principle
		Soil Stabilisation Measures, Flow Speeds as Low as Possible, Plantings/Greening
		Emergency Pumps, Flood Barriers, Sufficient Drains, Protective Plates for Ventilation Shafts, Slope to the Street/Elevated Construction of Traffic Routes; Gravel Packing, Affected Emergency Routes? Emergency Plans/Detours; Precautions through Simulations
	High Groundwater Levels	*See above*
	Low Soil Absorption Capacity	*See above*

Impacts		Adaptation actions
Convective Precipitation (Heavy Rain)	Flooding of Taxiways/Apron	Large Drainage Systems; Retention/Flood Areas
	Flooding in Public Areas: Traffic Infrastructure	Large Drainage Systems; Speed Regulation on Roads; Retention/Flood Areas, Warnings/Warning Systems, Emergency Pumps; Green Spaces/De-sealing
	Limited Visibility	Technical Assistance Systems/Landing Systems; Ground Radar; Restrictions on Driving Permissions on Apron/Taxiways
	High Rainfall Amount	Large Drainage Systems; Flow Simulation; Calculation of Peak Load (Weight) during Extreme Events
		Low Flow Speeds, Soil Stabilisation Measures, Greening/Plantings
	Capacity Limit of Drainage System	Large Drainage Systems; Retention/Flood Areas; Decentralised Drainage from e.g., Buildings; Warning Systems, Emergency Pumps; Green Spaces/De-sealing

8.4 Changes in wind: potential adaptation measures

Impacts		Adaptation actions
Changes in Prevailing Wind Direction	Change in local wind patterns (related to landings/take-offs)	Include in the Extreme Events Monitoring Plan the compilation of information on wind patterns in order to analyse their relationship with airport operations, with a view to identify any changes in these patterns
		Carry out periodic reviews of operational protocols whenever necessary.
Increase in wind forces		Windproof aerial infrastructure
		Update operational procedures
		Enhanced coordination with airports and airlines
		Incorporate potential wind-related delays and route adjustments when planning operations to enhance reliability
Increased Turbulence and Wind Shear		Implement advanced turbulence detection and forecasting tools for better pilot and flight planner decisions
		Enhance pilot training focused on turbulence and wind shear recognition and management

8.5 Sea level rise: potential adaptation measures

Impacts		Adaptation actions
Flooding	Risks to runways, taxiways, buildings and equipment	Wetlands recovery. When the airport is located near marshlands, it is necessary to check whether the airport drainage conditions are affected by the state of these types of structures (usually outside airport boundaries). It may be necessary to work in partnership with the regional/local authorities responsible for these areas to draw up a Cleaning and Recovery Plan for them.
		Increase preparedness from operations staff by including sea level rise in emergency planning with all concerned stakeholders.
		Monitor and record flooding incidents at the airport related to torrential rainfall and tidal conditions (high or low tide), as well as their impact on normal airport operations. Try to understand whether, over time (long-term), there is any effect related to the rise in average sea level. The responses implemented to address these situations should also be recorded, as well as their effectiveness and any improvement opportunities that may have been identified.
		Improve Airport Drainage System Conditions: Over time, and with the collection of flood monitoring data, it may become necessary to conduct a study of the entire airport drainage systems, via engineering modifications and maintenance, network. This factor is particularly relevant in order to manage the increased runoff and higher base sea older airports, where the drainage system was designed for much lower rainfall levels. Particular attention must be paid to the drainage design of new airport infrastructure. For example, in Portugal, the legislation defining the criteria for the drainage networks design, considering factors such as the population served, design flows and terrain characteristics, dates back to 1995, when extreme weather events were not yet considered in the legal package.

Impacts		Adaptation actions
		Implement permeable pavement materials and advanced stormwater management solutions to improve infiltration and reduce localised flooding. In punctual and specific situations, it may only be necessary to use pumping systems to remove water from flooded areas.
		Monitor and conduct simulations of sea level rise based on projections (ideally integrated with extreme precipitation effects) in order to understand the expected short, medium and long-term impacts and, consequently, establish an adaptive response plan over time (with various levels of measures to be applied, from simple pumping systems to the resizing of the drainage network).
Disruption of ground access and transport	Hinder access to airports for passengers, staff, and freight.	Develop early warning and emergency response systems with local authorities and public transportation authorities
		Consider construction of sea walls, levees, and coastal defences
		Monitor infrastructure vulnerability

8.6 Changes in biodiversity: potential adaptation measures

Impacts		Adaptation actions
Collisions (birds, mammals, etc.)		Need for enhanced monitoring and improved coordination to reduce collision risks.
Soil destabilisation and infrastructure management		Need to adapt water and infrastructure management strategies to address heightened risks of flooding and droughts.
Introduction and spread of invasive species	Risks to infrastructure and ecosystems	Require costly control and management measures.
		Strengthen biosecurity protocols to prevent ecological disruptions
Fragmentation of ecological corridors		Need for adaptive planning to maintain connectivity between natural habitats.
		Increase monitoring of airport impacts on ecological networks.
Regulatory constraints (biodiversity laws, habitat protection, mitigation measures)		Need for mitigation measures (reducing light pollution, noise management) to comply with regulations. Increased scrutiny of airport impacts on biodiversity.

8.7 Changes in icing: potential adaptation measures

Impacts		Adaptation actions
Disruption to ground operations	Affecting resource allocation and operational scheduling	Optimise de-icing fluid stock management
		Anticipate optimisation of personnel deployment in response to variable icing demands
Unpredictable icing conditions	Increased complexity in air traffic management and safety risks	Implement advanced icing detection and prediction systems to allow timely operational decisions for all stakeholders
		Integrate icing risk data into route selection, altitude adjustments, and airspace management to minimise exposure to icing hazards
		Intensify training programs on handling diverse and extreme icing scenarios to improve safety and operational response
		Foster close collaboration between airports, ANSPs, airlines, meteorological services, and regulators to develop integrated icing management strategies
		Plan for adjustment of scheduling to include buffer time for potential icing-induced delays
		Implement staff welfare programs and flexible scheduling to manage higher workloads during icing seasons

8.8 Desertification: potential adaptation measures

Impacts		Adaptation actions
Increases dust storms or sand storms	Increase in the Forest Fires Frequency	Barriers or “windbreaks”, i.e. planting of non-invasive, endemic species of trees and vegetation.
		Increase of inspections and cleanings: 1. Identify critical areas surrounding the airport perimeter and the protection zone around it (never less than 50 m from the boundary). 2. Identify potential partners, taking into account the responsibilities for the critical areas identified.
		Establish partnerships for critical areas inspection and cleaning.
		Develop low visibility procedures.
	Health risks to ground personnel from dust exposure	Strengthen runway and apron maintenance regimes to manage dust deposition and surface wear
		Deploy protective measures and health monitoring programs for exposed ground personnel
		Implement dust filtration and air quality control measures in passenger terminals and work areas to safeguard health
Water availability decrease & fall in groundwater table	Increase in periods with reduced water availability	Develop water capture and recycling for irrigation Implement methods to minimise water use, i.e. using low-flow fixtures, detecting and repairing leaks, using drought-tolerant landscaping.
		Promote the use of reused water. For example, reuse of treated wastewater from existing Wastewater Treatment Plants existing at the airport or in its vicinity.

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