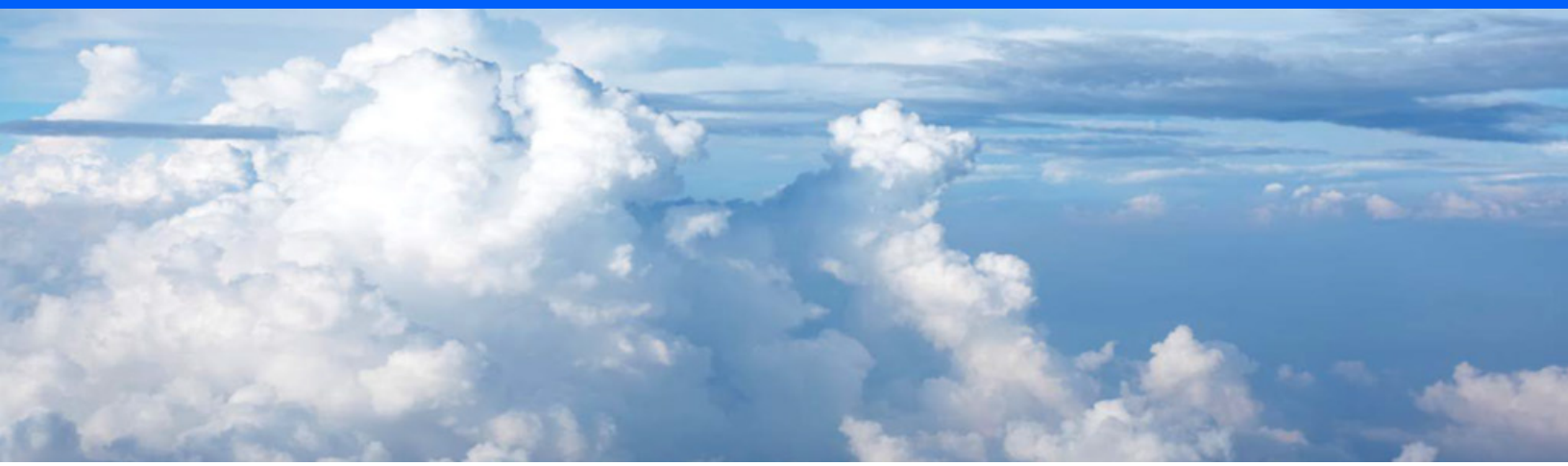
ICAO

ENVIRONMENT

Climate Adaptation Synthesis

Background information

Factsheet



2018

FACTSHEET COVER SHEET

During the CAEP/11 cycle from February 2016 until February 2019 the CAEP Working Group on Airports and Operations (WG2) was tasked with developing a Climate Adaptation Synthesis:

> *Synthesizing existing information on the range of projected climate impacts for the aviation sector to better understand risks to airport and Air Navigation Service Providers' planning, infrastructure and operations, including how they relate to safety, capacity and efficiency. [And to] identify impacts that are already being experienced and that may relate to climate change, on a local, regional and global level … Examples of related adaptation and resiliency efforts/actions which are identified, or already being implemented, will also be provided.*

The report was finalised in October 2018 and presented to the CAEP/11 Plenary in February 2019. The CAEP 11 meeting then tasked the working group to prepare the information in the report for ICAO to disseminate. The CAEP WG2 has prepared eight factsheets covering eight physical climate change impacts detailed in the 2018 Synthesis. The fact sheets cover the following physical impacts:

- sea level rise
- increased intensity of storms
- temperature change
- changing precipitation
- changing icing conditions
- changing wind
- desertification
- changes in biodiversity

The business and economic effects of these physical impacts, as well as more detailed information on climate change risk assessment and adaptation planning will be addressed in additional factsheets.

All material in the factsheets is drawn directly from the Synthesis report: *no new material has been added*. Therefore it is important to be aware of the parameters of the information included in the analysis.

Parameters of the 2018 Analysis

- For the purpose of the analysis, 'aviation sector' covers: aircraft operators, airport operators, air navigation service providers (ANSPs), and regulatory authorities. Aviation sector components included in this analysis are: infrastructure, aircraft operations (en-route and airport), airport operations (e.g. ground operations), and airport ground transportation access.
- The analysis uses the term 'impacts' to refer to physical climate change impacts (e.g., temperature change, sea level rise) and the term 'effects' to refer to the potential consequences of climate change impacts on the aviation system.
- Any regional analysis is based on ICAO regions. However, it is noted that even within regions there are differences in impacts and effects as there can be multiple climate zones within one ICAO region. Therefore, these analyses can only give a high-level indication of regional differences.
- The main part of the literature review for the 2018 Synthesis was completed in early 2017. However, as the global research community continued to produce new material on this topic the Task Group considered further updates to this analysis, as relevant. The full literature review was completed in February 2018.

Climate Change Science Background

- The Synthesis report, and thus the factsheets, draw on the scientific information presented in the Fifth Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR5) and other relevant literature.
- The IPCC AR5 covers many aspects of climate change that are not addressed in the CAEP climate adaptation synthesis report including the observed changes in climate in the past, and causes of climate change.
- This synthesis report, and thus the factsheets, examines only those projections of future climate change impacts which were identified as relevant for the global aviation sector by WG2 and the ICAO CAEP Impacts and Science Group during the CAEP/11 cycle (2016-2018).

It is important to note that most of the drafting of scientific information was completed in early 2017 Therefore, the information in the factsheets should be understood as being correct as of early 2017 and that there may be more up-to-date information available in some areas.

The drafting of the Synthesis also included a literature review of seventeen documents relevant to aviation climate adaptation issues and challenges. Some of the documents were global in context, while others were regionally or state-specific. Each document was analysed separately and the relevant information on climate impacts, effects on the aviation sector, adaptation and resilience measures and other pertinent information was extracted and synthesised so as to provide a high-level synthesis of the best available information rather than to reproduce the detailed information already available in other sources.

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ENVIRONMENT

Climate Adaptation Synthesis

Sea Level Rise

Factsheet

2018

Aviation and Sea Level Rise

Global average sea level is rising, and will progressively increase over time. Impacts will vary by location with some areas more at risk than others depending on a number of factors, including geography. Sea level rise can increase flooding, both in frequency and in area flooded, contribute to greater coastal land erosion, increase the height of sea level extremes, such as storm surges, and, in some areas, cause permanent sea water inundation.

Potential Effects

- Inundation of low-lying coastal aviation infrastructure such as aviation navigation and communication equipment, airport assets, the airfield, and ground transportation.
- Inundated ground transport may prevent airport access for sector employees, passengers and freight.
- Amplification of water issues at coastal airports including storm surge, reduced effectiveness of drainage systems, and more frequent and damaging flooding.
- Extreme sea levels can be temporarily compounded by storm surges.
- Small Island Developing States (SIDS) are particularly vulnerable to the impacts of sea level rise. Impacts from sea level rise on aviation infrastructure and operations in SIDS may have greater security and economic implications than for non-island countries due to a heavier reliance on aviation for connectivity and tourism development.

Adaptation and Resilience Measures

- In areas where impacts from sea level rise are already being experienced or are expected in the near to mid-term, it is essential to identify specific vulnerabilities and time frames, implement adaptation measures and improve operational resilience.
- Potential adaptation and resilience measures include installing sea defenses and other protective measures for vulnerable areas. This can include elevating or relocating vulnerable infrastructure, building or re-enforcing sea defenses, retaining or introducing natural barriers, allowing a safe amount of inundation, and developing new secondary airports that will not face impacts from sea level rise.
- Planning of new airports in coastal regions should take sea level rise projections into account.
- Sea level rise projections and vulnerabilities should be assessed at the local level.

Sources and Additional Information:

2018 ICAO CAEP WG2 Task O7.0 Climate Adaptation Synthesis Analysis

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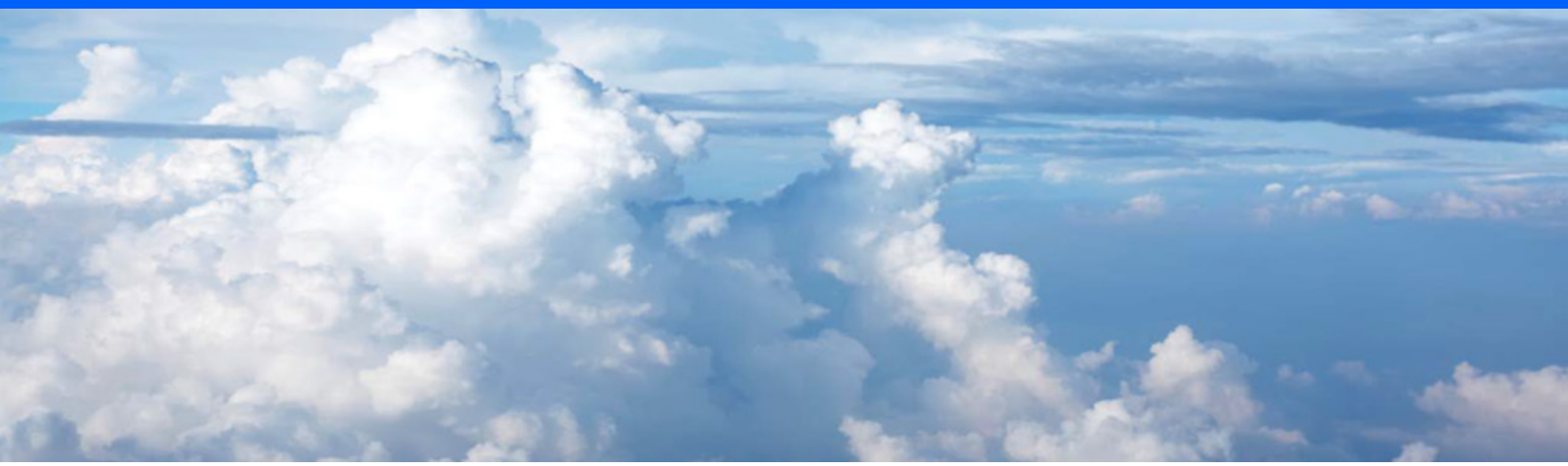
Climate Adaptation Synthesis

Increased intensity of storms

Factsheet



2018

Aviation and Storms

Storms are projected to become stronger as the climate changes but there is less certainty as to the frequency of future storms. There will also be regional differences: storms in some areas may become more powerful and more frequent, while in others they may only become more powerful. Potential effects on aviation from increased intensity of storms vary widely. Storm surges are also projected to have greater impacts due to sea level rise and an increased frequency and severity of storms.

Potential Effects

- Storms may damage or destroy infrastructure, and disrupt Air Traffic Management (ATM) operations.
- Storms and extreme winds can impact airport and air traffic operations, affect en-route and airport capacity and even lead to runway closure.
- The local effects of storms can also cause network-wide effects as loss of capacity at one airport can impact the airspace system as a whole.
- Access to ground transportation to and from airport facilities may be impacted.
- Impacts on aircraft from storms may increase maintenance requirements and costs.
- Storm surges can damage or cause inundation of infrastructure and ground transport access (see sea-level rise fact sheet).
- Operational costs may also increase across the aviation sector.
- As global temperatures increase, lightning strikes are projected to increase causing aircraft and other aviation infrastructure to require more frequent maintenance checks and repair.

Adaptation and Resilience Measures

- A move towards proactive rather than reactive responses can help reduce the impact of storms, by anticipating risks and developing contingency action plans.
- Better understanding and forecasting of weather events is needed to prepare for storms before they happen.
- Prepare for forecasted storms by securing loose items, ensuring lights and navigational aids are working, stock-piling fuel for back-up generators, and clearing debris.
- When forecasted storms are severe, some airlines may preemptively cancel flights and airports relocate equipment to ensure the safety of their operations, and to reduce business impacts.
- Vulnerable people or infrastructure will either need to be protected or moved to mitigate the effects when a storm surge is forecast.
- Additional adaptation and resilience measures to accommodate lightning strikes to aircraft and other aviation infrastructure.

Sources and Additional Information:

2018 ICAO CAEP WG2 Task O7.0 Climate Adaptation Synthesis Analysis

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Climate Adaptation Synthesis

Temperature change

Factsheet

2018

Aviation and Temperature Change

Global average annual temperatures are rising, although with regional differences to temperature change rates. More frequent occurrences and more consecutive high-heat days are projected for some regions, particularly in the summer months. However, occasional cold winter extremes will continue to occur. In some regions, increased humidity may lead to more fog in the mornings.

Potential Effects

- Decreases in air density caused by rising temperature reduces aircraft lift and the ratio of lift to weight, and can increase the required runway length to maintain normal operations or limit climb performance. This may also result in maximum take-off weight restrictions.
- High-heat days may stress existing cooling systems creating a demand for additional cooling facilities and affect employees.
- High-heat days can increase risk of fire at airport facilities.
- More extreme cold temperature days in northern climates can directly affect aviation. For example, flights can be cancelled if the temperature falls below an aircraft's certification limits. Extreme cold spells, especially for an extended period, can cause equipment underperformance, chemical reaction rates to change (melting ice and snow), increased aircraft turnaround times leading to congestion, fueling delays due to equipment freezing and issues within the terminal facilities themselves, including burst water pipes and challenges to maintain acceptable indoor temperatures.
- In northern areas, warmer temperatures may cause permafrost to thaw, destabilizing and damaging ground infrastructure, including the airfield, and contributing to erosion.
- Higher temperatures can damage the airfield surface if temperatures exceed design standards.
- Groundwater can influence permafrost thaw: the combination of higher temperatures and advective heat transfer from groundwater flow can accelerate thawing.
- Changing air temperature can alter destination travel preferences affecting demand for certain routes.
- There may be costs associated with repairing or replacing damaged or vulnerable infrastructure.

Adaptation and Resilience Measures

- In areas where higher temperatures may be a challenge for aircraft take-offs, future temperature and aircraft runway length calculations may need to be reconsidered when determining the appropriate runway length.
- Incorporate projected temperature changes in the decision-making, design and renovation of airport infrastructure.
- Harden runways, taxiways and access roads in areas affected by permafrost thaw.

- Monitor permafrost depth and land subsidence, through actual instrumentation or through remote sensing, to better understand changes to permafrost underlying runways and airport infrastructure.
- Airports located in colder climates could learn how airports in warmer climates consider and adapt to warmer temperatures while maintaining operations.
- During extreme cold events proactively deploy warming stations to protect ground support crews and develop procedures to service frozen equipment and fuel hydrants as required. Consider back-up and additional measures for heating terminal areas.
- Schedule changes to allow fog to dissipate can mitigate the effects of more frequent fog events. This could mean moving early morning departures to late morning for some locations.

Sources and Additional Information:

2018 ICAO CAEP WG2 Task O7.0 Climate Adaptation Synthesis Analysis

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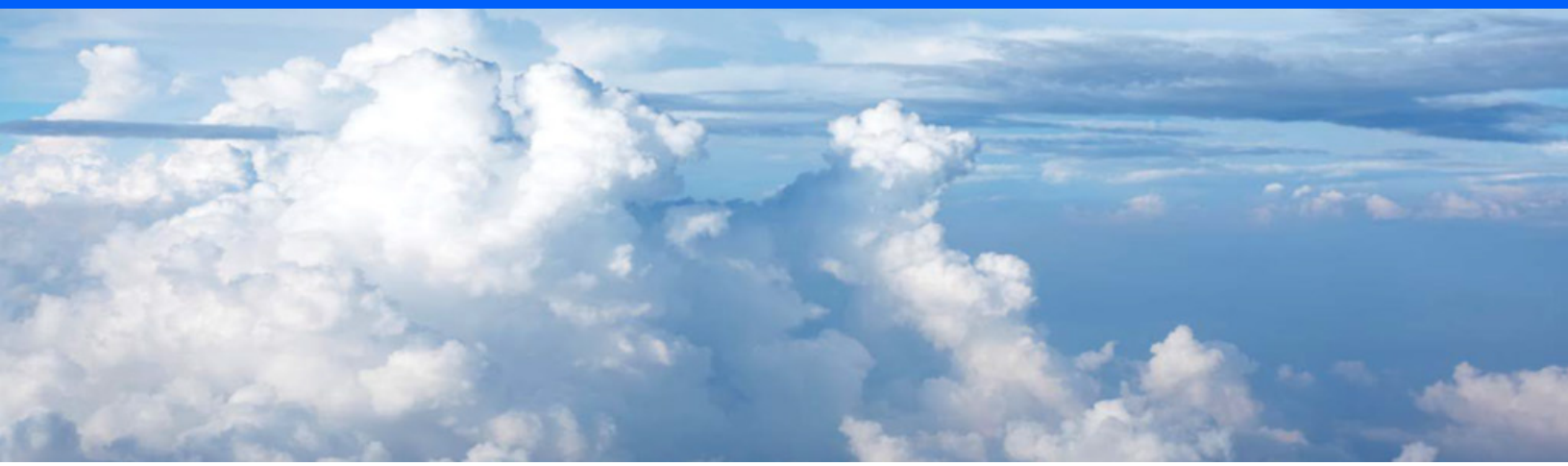
Changing precipitation

Factsheet



2018

Aviation and Precipitation

Precipitation can include rain, sleet, snow, hail and drizzle as well as a few less common occurrences such as ice pellets, diamond dust and freezing rain. Climate change is expected to change types and quantities of precipitation. Most regions of the world are already experiencing an increase in extreme precipitation events such as extreme rainfall or prolonged drought.

Potential Effects

- More frequent or more intense precipitation can cause flooding and flood damage to runways, and infrastructure. This may affect operations leading to capacity reduction, delays and cancellations and inundation of infrastructure
- Storm drainage systems may not be designed to handle the increased volumes of water. Drainage systems failure could cause pollution control systems to fail, risking groundwater contamination.
- Disruption of ground transport links can reduced access to airports.
- Hazardous take-off and landing conditions may result in the closure or reduction in capacity of airports, or reduction of capacity of Air Traffic Control (ATC) sectors.
- Reduced visibility can increase the application of low visibility procedures.
- Forecasting conditions and precipitation type (e.g., rain, snow, freezing rain) will be more challenging due to warmer temperatures at higher latitudes leading to temperatures fluctuating around the freezing point.
- Drought conditions may lead to reduced water availability with restrictions imposed on water intensive activities.
- Changes in snow conditions may lead to increased requirements for snow clearing and de-icing equipment in some locations but reduced requirements at others. Increased snowfall may cause delays and cancellations, or there may be staffing issues if staff cannot reach the airport.
- In some regions, increased snowfall may cause flooding when temperatures warm, which can damage permafrost under runways.
- The cancellation or delay of flights due to disruptive or extreme weather conditions has financial implications due to lost revenues and increased operating costs and passenger inconvenience

Adaptation and Resilience Measures

- Implementing operational measures to increase robustness and flexibility
- Using augmented low visibility procedures, for example ground based augmentation system (GBAS).
- Improving use of meteorological (MET) forecasting
- Establishing decision-making procedures such as Airport Collaborative Decision Making (A-CDM) and information sharing and training.
- Determining needs for adequate snow and ice removal equipment.

- Implementing a strategy for snow and ice removal at airports, designating a specified number of runways to keep open, measures to enable better access during weather disruptions and grooving of runways to improve traction and drainage during heavy precipitation events.
- For drought conditions, measures to reduce water consumption, protect freshwater resources and build drought resistance are needed.
- Precipitation projections should be taken into account when planning and developing new infrastructure as well as ensuring that appropriate design standards are applied to new buildings to address risks from water ingress and flooding

Sources and additional Information:

2018 ICAO CAEP WG2 Task O7.0 Climate Adaptation Synthesis Analysis

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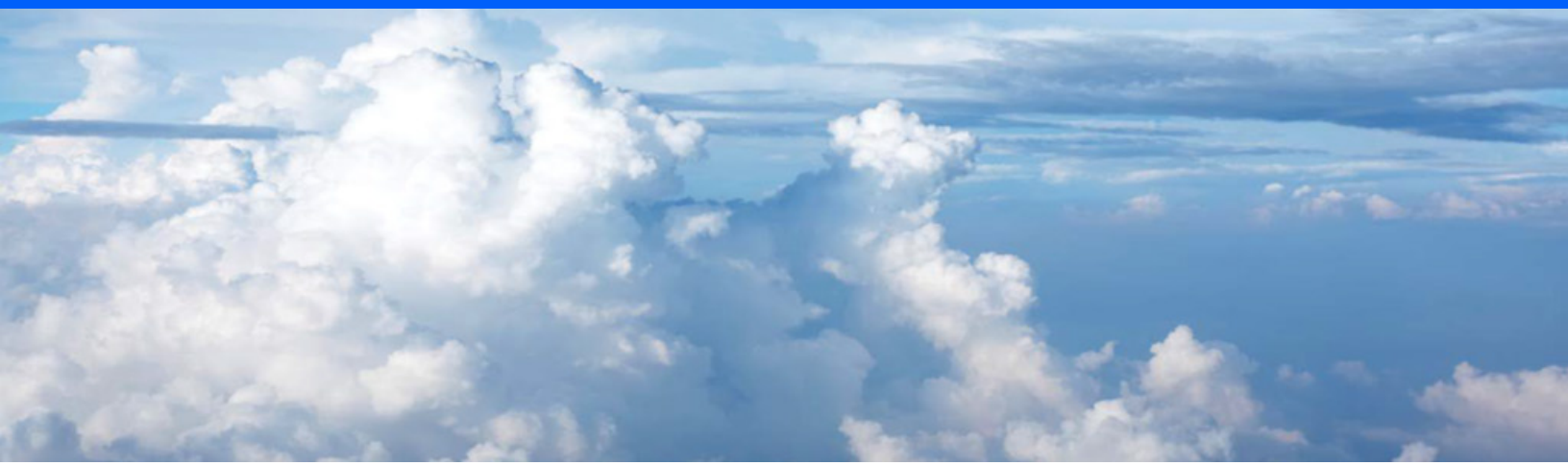
Changing icing conditions

Factsheet



2018

Aviation and Changing Icing Conditions

Icing condition may change due to changing climate and temperatures, increasing the likelihood of both ground and airborne icing. Runway conditions may be affected. Requirements for de- and anti-icing will change.

Potential Effects

Ground icing:

Aircraft icing:

- De-icing requirements will change, increasing in some areas and decreasing in others. For example, increased temperatures in some regions may lead to a reduction in de-icing.
- Increased de-icing requirements and operational risks from freezing rain.
- Increased use of de-icing fluids increases their concentration in run-off, resulting in the possible breaching of certain environmental limits. This is because it increases concentrations of chemical pollutants in the water supply as it runs off the airfield, which can cause various water issues. In many places, discharges from airports (e.g., runoff, treated wastewater) are regulated; the airport must meet water quality standards regarding these discharges. Water quality is tested on a regular basis to ensure that standards are being met.

Runway and taxiway icing:

- Runway operations may be affected, causing the delay or cancellation of flights. For example, rain and freezing rain can decrease traction on runways and taxiways and also require the use of de-icing products prior to take-off.

Airborne icing:

- In-flight icing is a safety risk. When ice forms on an airframe, it alters the airflow around the wings, causing a loss of aerodynamic lift. Ice may also block the pitot tubes. This may be a particular risk for the northernmost parts of some transatlantic flight tracks.

Adaptation and Resilience Measures

Measures identified to mitigate changing icing conditions include ensuring that future development and contingency plans include climate change. However, a better understanding of this risk is required to be able to predict and plan for future scenarios. More specific measures include:

Ground icing: Consideration should be given to both protecting underground infrastructure from freeze-thaw damage and to strategies for the use of de-icing agents. For example, some remote northern airports use portable forced air heaters to reduce ice build-up on aircraft. Operators could also

consider adopting changes to both engine and wing de-icing procedures including increased use of glycol-based de-icing and anti-icing agents.

Airborne icing: Aircraft manufacturers may also need to assess airframes for performance in changing climatic conditions. For safety reasons, regulations for twin-engine aircraft operations over oceanic airspace should be reviewed.

Sources and Additional Information:
2018 ICAO CAEP WG2 Task O7.0 Climate Adaptation Synthesis Analysis

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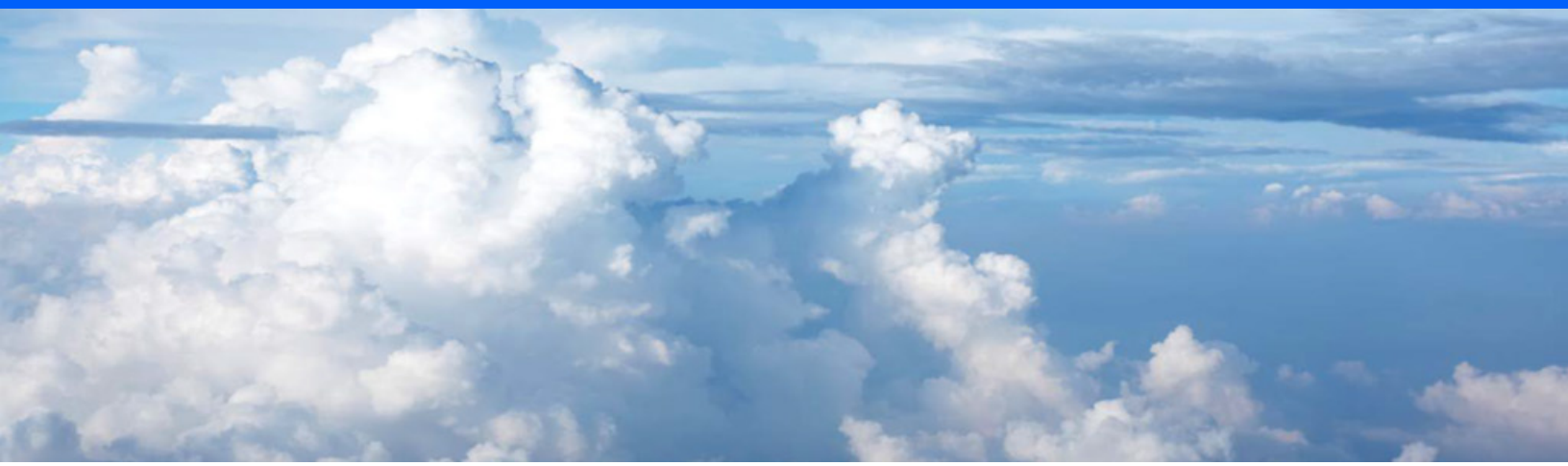
Changing wind

Factsheet



2018

Aviation and Changing Wind

In the lower troposphere, changes in wind strength and direction are projected. In the upper troposphere, changes to the jet stream are projected.

Potential Effects

Changes to prevailing wind direction

- Changes to, or deviation from, the prevailing wind direction at airports could affect runway utilisation and schedules. It may also change the criteria for approach and departure procedures.
- Flights might be cancelled, delayed or redirected when crosswinds are too strong for aircraft to safely take off or land which could reduce airport and aircraft operating efficiency and capacity. It may also reduce arrival and departure punctuality of flights.
- Changes to procedures due to deviation from prevailing wind direction could have environmental impacts, such as changes to noise distribution and increased emissions.

Extreme storms and strong winds

- Extreme storms and strong winds can result in flight delays and cancellations, economic losses, and passenger inconvenience. It can also damage or destroy assets and infrastructure.

Changes to the jet stream

- Changes to the jet stream could impact en-route traffic. For example the most efficient routings and flight times for transatlantic flights (expected to be faster eastbound and slower westbound) might change. This may result in modification of en-route flight levels and Air Navigation Service Providers (ANSPs) and airlines will have to react to changing flow patterns and sector loading. This may impact fuel-critical operations on transatlantic and other long haul flights. There may be a knock-on effect for airports due to reduced arrival reliability.

Clear Air Turbulence

- There may be an increase in Clear Air Turbulence (CAT) leading to greater diversions and “bumpier” flights. This may affect the application of Reduced Vertical Separation Minima (RVSM), which could lead to a reduction in airspace capacity.
- It could also lead to increased injuries to passengers and crew and damage to aircraft.
- If forecasts for affected areas are accurate, aircraft might be able to avoid CAT entirely. Pilots may also relay information on un-forecasted CAT back to the ANSPs and other pilots as they experience impacts.
- As the climate changes, maintenance intervals may need to be reviewed and inspection methods revised more frequently to detect any signs of aircraft fatigue, or equivalent, particularly when assessing new, composite materials of modern aircraft.

- Changes in the jet stream can cause blocking of weather system propagation: this may result in extreme weather events, such as heavy snow, to airports, which have not been previously affected.

Adaptation and Resilience Measures

Changes to prevailing wind direction

Measures proposed or already being implemented are more limited for changes in wind conditions than for other climate change impacts. Implications of prevailing winds need to be assessed at the local level and operational measures identified to maintain safety and increase robustness and flexibility. Some sources stated more scientific research is needed as many uncertainties remain as to how winds may change.

Clear Air Turbulence

- Technologies for aircraft that can assess wind and turbulence changes in real time are being studied. Technologies under development may be able to identify Clear Air Turbulence (CAT) up to 10-15 kilometres ahead, which would give pilots enough time to alert passengers and crew, (e.g., to ensure that everyone had fastened their seatbelts, or to attempt a diversion around the area).
- As a result, there is a need to improve the accuracy of operational CAT forecasts so as to be able to avoid areas of CAT as much as possible. Increased use of Pilot Weather Reports (PIREPs - brief reports from pilots of observed in-flight weather conditions) could help provide other pilots with increased information on areas with likely Clear Air Turbulence and enable them to take preventative measures.
- Airframe design may need to be adjusted to adapt to changing turbulence beyond the features manufacturers have already built in to accommodate CAT, especially as “Many of the aircraft that will be flying in the second half of the present century are currently in the design phase”. For example, some newer aircraft are fitted with an accelerometer in their nose cones. If the accelerometer registers a sudden change in altitude, which is large enough to indicate potential turbulence, then the wing flaps are rapidly adjusted in an attempt to decrease the vertical movement and reduce the acceleration.

Sources and Additional Information:

2018 ICAO CAEP WG2 Task O7.0 Climate Adaptation Synthesis Analysis

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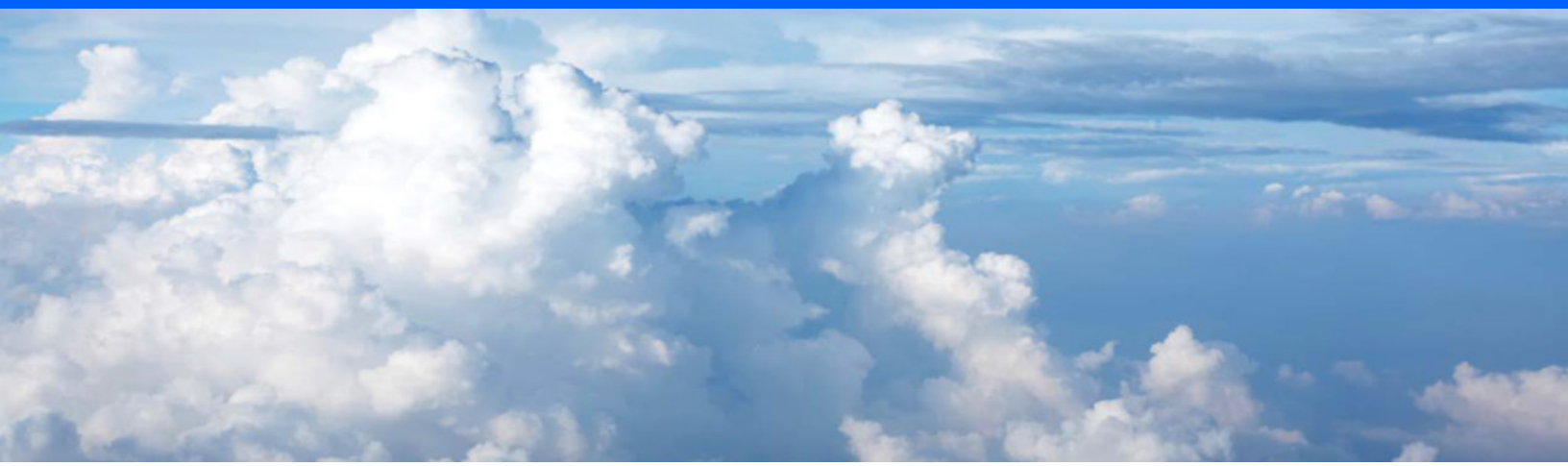
Desertification

Factsheet



2018

Aviation and Desertification

Desertification is the process in which more land becomes desert. Climate change is contributing to desertification by leading to many dry regions becoming dryer and hotter, and having more dust or sand in the air. Desertification is also responsible for increased water scarcity and increased frequency of weather events, such as high-intensity tropical cyclones and sand storms. The rate of desertification is dependent on many factors including precipitation, evaporation, runoff, vegetation, and soil moisture.

Potential Effects

- Desertification may lead to increased dust storms, which may affect aircraft engine design for fuel efficiency and engine performance and maintenance.
- Impacts from desertification and an increase in dust storms may also result in safety risks and increased maintenance costs due to degradation of ground and onboard equipment and increased maintenance requirements.
- Other potential effects for aviation:
  - Increased risk of soil erosion around apron and runway
  - Water shortages
  - Sand storms disrupting operations
  - Risk of encroachment of sand dunes
  - Effects of sand dunes on aircraft operations
  - Effects of sand damage on airframes and engines

Adaptation and Resilience Measures

Adaptation measures include designing windbreaks to reduce dust and sand. These include planting non-invasive endemic trees and vegetation that require little water and that do not attract wildlife, which would be hazardous for aviation operations, and using recycled water for irrigation.

However, there is limited information available on this impact specific to the aviation sector. Therefore, more aviation-specific research is needed to understand the projected impacts of desertification, and its effects on aviation.

Sources and Additional Information:

2018 ICAO CAEP WG2 Task O7.0 Climate Adaptation Synthesis Analysis

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Climate Adaptation Synthesis

Changes in biodiversity

Factsheet

2018

Aviation and Changes to Biodiversity

The main risks to aviation from changes to biodiversity are wildlife migration and propagation of invasive species. Composition of ecosystems may change, leading to changes in both local biodiversity and wildlife migration patterns. Climate change impacts are expected to lead to species loss, habitat loss especially for waterbirds and large bird species, and loss of breeding grounds.

Potential Effects

- Biodiversity changes may include shifts in the diversity of bird species that are present at an airport. For example, some areas may see an increase of heavy-weight migratory bird populations such as grey goose or white stork. Migratory birds are a challenge at airports in many regions due to their potential effects on aircraft operations, particularly the larger birds such as geese, eagles, and pelicans.
- Biodiversity changes may also change or increase other wildlife hazards at or in the vicinity of an airport, for instance an increase in flocking birds that commonly use aerodromes (for example, gulls, starlings, crows, pigeons). Changes in bird populations or migratory behaviour, or a combination of both, can increase the risk of bird-strikes. However, in the longer term, the changes described above such as less wintering and migrating are expected to lower the risks identified from larger bird species.
- There may be damage to landscaping and an increase in maintenance costs due to changes in local wildlife or an increase in invasive species. However, effects are likely to be localized depending on the ecosystem and climate change impacts in a particular area. For example, in North Africa and the Middle East, changes in rain events have increased the potential for locust swarms. Changing interactions between flora and fauna may also be possible as both are expected to migrate due to climate change. This migration may lead to introductions of alien species to new areas. For example, changes in vegetation around the airport operating area could lead to an increase or change in bird populations, which could lead to an increase in bird strikes.

Adaptation and Resilience Measures

- Airport officials can monitor wildlife populations to detect any change in timing such as timing of presence, numbers and species types. Additionally, understanding how climate change will affect birds and wildlife is essential to assess the risks to aviation and to develop adaption and resiliency measures to reduce effects.
- Any measures should be developed in co-operation with environmental protection experts and organisations, and should also take into account environmental protection.
- Expanded use of bird strike avoidance models is a potential measure.
- Up-to-date data information will allow for the preparation and use of the most effective methods in wildlife hazard reduction, whilst taking account of nature protection and relevant environmental regulations.

- In some cases, vegetation management to address unwanted flora may be a solution.
    - Mowing or trimming can be a short-term fix. However, these strategies do not completely remove unwanted vegetation and may allow them to regrow. This may also attract birds as worms and mice become more visible in trimmed flora.
    - Herbicidal treatments may provide a longer-term solution, but could lead to groundwater contamination.
    - Permanent removal though extraction or landscaping changes may be used so that the plants do not grow back.

Sources and Additional Information:

2018 ICAO CAEP WG2 Task O7.0 Climate Adaptation Synthesis Analysis

Effects of Climate Change on Aviation Business and Economics

Effects of climate change on aviation business and economics include both physical risks such as flight delays or airport closures and related costs, and contractual, regulatory or legal compliance risks. There may also be risks due to the scarcity of critical resources. Aviation business operations and financing may be affected by all of the potential climate change impacts identified in the Climate Impacts Factsheets. In the shorter-term, effects to business and economics are more likely to be associated with disruptive events, such as extreme weather events like storms or extreme heat, which can lead to delays, cancellations and infrastructure damage. In the longer-term, gradual but persistent impacts, such as temperature change or sea level rise, may lead to business and economic effects such as changes in tourist demand and damage or loss of infrastructure.

Potential Effects

- Increased weather volatility as a result of climate change can have effects on all aspects of operational performance such as scheduling, flight planning, connectivity of flights, safety planning and trajectory optimisation. Climate change can also cause direct impacts to critical aviation infrastructure, causing secondary effects on business and economic capabilities. This section provides specific examples of these effects by climate change impact category.

Sea level rise:

- Potential need to reinforce or relocate airport infrastructure due to sea level rise.
- Potential effects for local tourism industries if airport use becomes constrained or parts of territories become inundated. This can be a particular challenge for Small Island Developing States that are more exposed to sea level rise.

Increased intensity of storms:

- Costs from operational impacts such as delayed or cancelled flights, and costs due to infrastructure damage.
- Reduced access to ground transportation.
- Potential effect on jet engine performance and maintenance requirements due to storm damage.
- Closure of airports due to extreme events.
- Airports may be used during a weather event to provide shelter and support to disaster relief, which can have business and economic effects.

Temperature change:

- High-heat days can increase cooling costs in terminals and other infrastructure such as Air Traffic Control (ATC) towers, whilst employees may also be impacted by higher temperatures.
- Rising temperatures may necessitate a reduction in payload (passengers or cargo) which could have an economic cost. There may also be a fuel penalty.
- Persistently higher temperatures, particularly at popular tourist destinations, may alter demand for air travel to certain locations, which may increase or decrease revenue streams.
- Demand changes impact fleet and schedule planning by airlines, as well as infrastructure and workforce planning by airports, and Air Navigation Services Providers (ANSPs).
- Travel demand to popular winter tourism destinations may be affected if less precipitation or higher temperatures deteriorate snow conditions or shorten the winter-sports season

- Thawing of permafrost may lead to costs to reinforce or rebuild runways, whilst heat damage to airfield surfaces may also incur repair or replacement costs.
- Colder temperatures in northern climates could lead to flight cancellations if aircraft are not certified for extremely low temperatures. There may also be an increase in heating costs for terminals and other infrastructure.

Precipitation Change:

- Increased precipitation can cause flooding and flood damage to both runways and infrastructure. This flooding can impact operations by reducing capacity and increasing delays and cancellations, all of which have financial implications due to lost revenues, increased operating costs and passenger inconvenience.
- Ground transport links may be disrupted due to precipitation impacts preventing crew and passengers from reaching the airport. Unexpected heavy snowfalls are assumed to have similar financial implications.
- Some geographic areas are projected to experience more drought, which can have business and economic effects if water becomes scarce for aviation operations or it influences changes in tourism demand at a destination.

Changes in wind:

- Changes in, or deviation from, the prevailing wind direction at airports can affect runway utilisation and schedules, reduce airport and aircraft operating efficiency, capacity, and may impact safety. It may also change the criteria for approach and departure procedures and reduce flight arrival and departure punctuality, all of which will incur costs.
- Extreme storms and strong winds can cause flight delays and cancellations, with associated economic losses and passenger inconvenience. They can also damage or destroy transport assets.
- Changes to the jet stream could impact both flight times and fuel costs for transatlantic flights.
- There may also be an increase in Clear Air Turbulence leading to increased injuries to passengers and crew and damage to aircraft.

Changing Icing Conditions:

- Freezing rain can cause delays or cancellation of flights, with financial implications. There may also be increased de-icing requirements and associated costs, with additional risks of financial penalties if run-off quantity or quality exceeds environmental limits.

Desertification:

- An increase in dust storms could increase the presence of silicates in jet engines, which, when melted, can adversely affect the performance and increase maintenance requirements of jet engines. This can have financial implications.
- Sand may damage airframes and engines whilst sand storms may disrupt operations.

Changes in biodiversity:

- There may be an increase in both costs for wildlife management and costs from wildlife damage to aircraft (e.g. from bird strikes).
- There may also be damage to landscaping and an increase in maintenance costs due to changes in local wildlife or an increase in invasive species.

Interconnections:

- If one airport is directly impacted by climate change, other parts of the network may be affected indirectly, which can cause ripple effects across multiple business and economic sectors.

- In particular, if there is disruption at a hub airport this will have a knock-on effect for the flights which depart from that airport, the destination airports, and passenger connections, all of which can have a financial cost.
- Impacts may also affect the wider transport network.

Financial challenges as a barrier:

- There are financial costs associated with adaptation and the costs of implementing adaptation strategies could be prohibitive.

Adaptation and Resilience Measures [1]

- Limiting business and economic effects involves good planning and well-informed business decisions, which may benefit from activities such as climate risk assessments.
- For infrastructure decisions such as retro-fitting, redesign or relocation, a decision-making process such as a cost benefit analysis may be required, along with taking into account factors such as cost versus level of resilience and criticality (See the Risk Assessment and Adaptation Measures Factsheet).
- Operational measures to increase robustness and flexibility, and measures such as information sharing and training to improve operational resilience may have an initial financial cost, but by improving resilience they may ultimately reduce overall financial costs.
- Airports to consider planning measures to have adequate energy, food and water supplies to care for stranded passengers during extreme weather events which may close the airport for a significant time, and to coordinate with airlines in the event of needing to evacuate passengers before or after an extreme weather event.

Financial challenges as a barrier:

- To mitigate the financial challenge of adaptation, top management buy-in will be necessary.
- It may not be possible to adapt all infrastructure and systems such that no projected impacts of climate change are ever realized.
- While the scientific community is in broad agreement that the global climate is changing, there is still some uncertainty surrounding when climate change impacts are projected for specific regions and what those impacts may be.
- Resilience will likely be a combination of adapting infrastructure and developing processes and plans to respond to impacts quickly and efficiently as they happen.
- It will be necessary to make decisions based on costs and benefits in order to ensure critical elements are protected.

Sources and Additional Information:

2018 ICAO CAEP WG2 Task O7.0 Climate Adaptation Synthesis Analysis

[1] Specific adaptation and resilience measures for each impact are covered in the associated factsheet and in the full Synthesis document.

Risk Assessment Methodologies and Adaptation Planning

Risk Assessment Methodologies

Before developing a climate change adaptation strategy or plan, it is first necessary to carry out a climate change risk assessment to determine what assets are vulnerable to climate change. This is an analysis of impacts and probabilities, to determine "what can happen?", "how likely is an impact?" and "what are the consequences?"

To carry out a risk assessment, it is important to identify the scope. Risk assessments can be at any level - including the State level, organizational level, or asset level, depending on what is needed. Coordination and communication with the appropriate entities is important

To carry out a climate change risk assessment, an organisation can either choose to use its existing risk assessment methodology, use a climate change risk assessment methodology or tool developed by another organisation, or develop its own climate change risk assessment. There are several climate adaptation risk assessment methodologies available, but at a high level they follow the same three generic steps:

1) **Find out how the climate will change.**

- Define potential climate change variables and projections, and set baseline conditions (e.g., current stressors) before modelling or acquiring robust data on projected climate impacts.
- Decide which climate variables to assess. For example, sea level rise, changing precipitation, changing average or extreme temperatures.

2) **Risk Identification**

- Analyse how the climate changes identified can affect the organisation by assessing the potential effects, and how likely they are to occur.
- Identify and prioritise risks: evaluate the likelihood of occurrence, likelihood of consequences, severity of consequences and then establish a risk priority based on likelihood and severity. Additionally, the likelihood of a risk recurring during the lifetime of a particular asset should be considered.
    - *Note:* Identification and prioritization of risks should be done for short-, medium- and long-term timescales.
- Develop metrics to evaluate the magnitude of consequences. These may include capital and operating costs, as well as effects on society, health, economics, and the environment.
- Take into account risk control measures an organisation already has in place along with any uncertainties such as level of confidence with the projections, limited data or factors such as the lifetime of the infrastructure.
- It may be beneficial to include key stakeholders in the risk assessment and planning process

3) **Review and repeat the assessment periodically**

- Monitor risks regularly: review and revise the assessment as new information becomes available. This will enable the monitoring of progress of actual events versus predictions, and allow a periodic re-evaluation of climate change risks.

Adaptation Planning

After completing a climate change risk assessment and identifying risks that need to be addressed, the next stage is usually to develop a climate change strategy or plan, or combination thereof. This may include incorporating climate risk considerations into planning and organisational decision-making so as to better define the problem from a corporate or enterprise perspective.

Specific measures for adaptation planning may include considering climate projections when carrying out maintenance or development for other reasons. Adaptation planning can include specific strategies to build resilience against projected climate change impacts (e.g., including sea level rise as a factor in design for new infrastructure), training and building awareness on the impacts of climate change, and identifying financing strategies that may be required for resilience.

Sources and Additional Information:

2018 ICAO CAEP WG2 Task O7.0 Climate Adaptation Synthesis Analysis

2018 Adaptation Synthesis Survey Results

A survey was designed and sent via State Letter and CAEP Memo as part of the 2018 ICAO CAEP Adaptation Synthesis. 88 responses were received, with at least one response from every ICAO Region. Respondents were comprised of fifty-nine (59) States, eighteen (18) airports, six (6) airlines, four (4) Air Navigation Service Providers, and one (1) global organisation.

The survey had questions for each of the nine impact categories analysed in the synthesis and also asked respondents questions on adaptation planning, and the preparedness of the global aviation sector for the effects of climate change (see Figure 2 for a list of the nine impact categories).

Key Findings

Figure 1 below presents one of the key findings of the survey results. 65 of 88 of respondents (74 percent) said that they are already experiencing some impacts from climate change. None of the respondents indicated that they do not expect to be impacted by climate change.

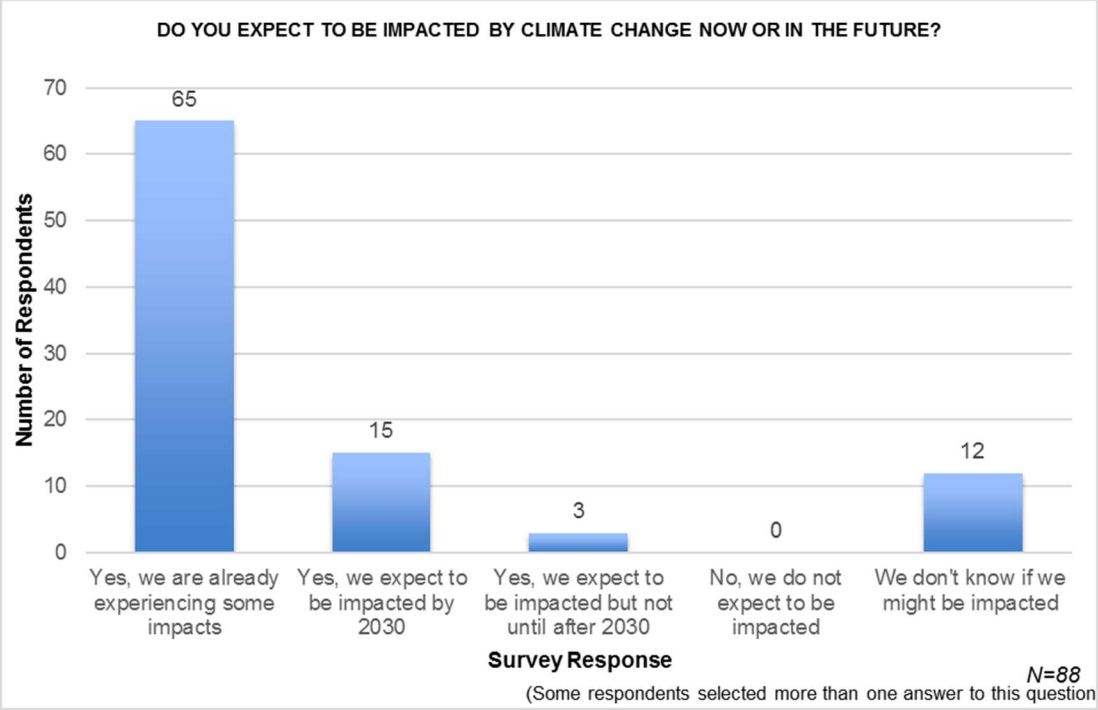

Figure 1: Timescales in which respondents expect to be impacted by climate change

The Survey asked respondents if they are affected today or expect to be affected in the future by nine impact categories. Results are presented in Figure 2. In eight of these categories 50 percent or greater of the respondents said they are affected today or expect to be affected in the future.

Respondents expected the biggest challenges to be from Higher Average and Extreme Temperature, Changing Precipitation, and Increased Intensity of Storms:

- **Higher Average and Extreme Temperatures:** 80 of 88 respondents stated they are affected today or expect to be affected in the future by Higher Average and Extreme Temperatures (91

percent).

- **Changing Precipitation:** 78 of 88 respondents stated they are affected today or expect to be affected in the future by Changing Precipitation (89 percent).
- **Increased Intensity of Storms:** 76 of 88 respondents stated they are affected today or expect to be affected in the future by Increased Intensity of Storms (86 percent).

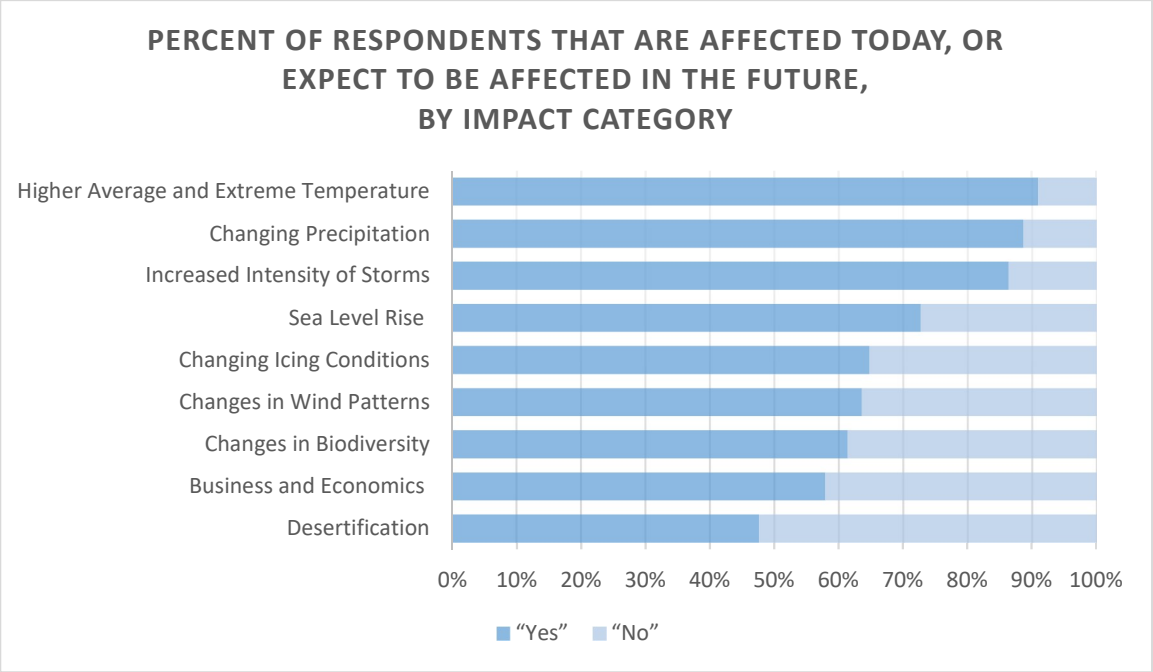

Figure 2: Percent of respondents that are affected by impact category **N=88**

Risk Assessment: 58 out of 88 of respondents (63 percent) indicated that they have already carried out a risk assessment or intend to do so in the future. Respondents also stated that adaptation risk assessment and planning both at the global and the airport level are some of the more effective things the global aviation sector can do or is doing to prepare for the impacts of climate change.

Implementing Adaptation and Resilience Measure: 26 out of 87 respondents (30 percent) stated that they are already implementing adaptation and resilience measures while 13 out of 87 respondents indicated they plan to do so in the next five years (15 percent) and 9 out of 87 indicated they plan to do so in the next 10 years (10 percent)[1]. Despite the implementation – or planned implementation – of adaptation and resilience measures, 74 out of 88 respondents (85 percent) believe that the global aviation sector still has work to do in order to prepare for the impacts of climate change.

[1] Note: One response to this question referred to climate change mitigation measures and was not included in the total.