Climate Change Risks for European Aviation

Summary report
Foreword

Eamonn Brennan, Director General EUROCONTROL

This report carried out by Egis and the UK Met Office on behalf of EUROCONTROL sets out how our industry faces increasing disruption on the ground and in the air from climate change, and highlights the growing danger that climate change poses to all parts of the aviation sector.

It provides extensive quantitative data on storms, wind pattern changes, sea-level rise and temperature increases that can help our industry better understand how these will impact aviation in the years ahead, and update their climate change risk assessments and adaptation strategies in order to build in resilience to adapt and address future climate impacts.

The findings highlight the importance of the work done at network level by the EUROCONTROL Network Manager and partners to mitigate weather impacts on delays and the environment.

Taking an integrated and collaborative network approach to managing bad weather has helped reduce the impacts of major storms on the network in terms of extra costs, emissions and delays, and its importance will further increase in the years ahead as extreme weather events increase in frequency.
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Introduction

Overwhelming scientific evidence demonstrates that the Earth’s climate is changing due to rising levels of greenhouse gases in the atmosphere. The link between modern day climate change and emissions caused by human activity is widely recognised, and increasingly so at the policy level. Whilst the recent European Green Deal commitment to achieve carbon neutrality in Europe by 2050 is certainly cause for optimism, the latest analysis from the United Nations Intergovernmental Panel on Climate Change reports that the earth’s global average surface temperature is likely to reach 1.5°C above pre-industrial levels, the optimal target set out in the Paris Agreement, within the next 20 years, regardless of any actions taken to cut greenhouse gas emissions in that time. In a worst case scenario where no mitigation action is taken, global temperatures could reach over 5°C above pre-industrial levels by the end of the century.

It is therefore expected that the impacts of climate change will increase across the century. It is not just rising temperatures, but also the secondary impacts that are cause for concern. Higher temperatures are associated with increasingly unpredictable or severe weather events, whilst the melting of land ice and the warming of the oceans threatens coastlines around the world due to sea level rise. These impacts pose threats to infrastructure, transport, supply chains, communities and the resilience of the global economy. More positively, although it may seem counterintuitive, certain regions may see a more favourable climate for certain activities, although this would not balance out the damage that climate change is likely to inflict.

This study consists of five work packages which explore the risks posed by climate change to the European aviation sector. The findings of each are summarised in this report, whereas the technical detail can be found in the corresponding annexes:

- **Annex 1** – An overview of short-term weather impacts on European aviation: assesses the link between disruptive weather and delays over the past ten years and next five years as a basis for the wider study.
- **Annex 2** – Impact of changes in storm patterns and intensity on flight operations: considers the potential impact of changes in the intensity and frequency of storms on flight operations up to 2050.
- **Annex 3** – Impact of sea level rise on European airport operations: investigates the progression in flooding risk expected for European coastal airports up to 2090 due to sea level rise and storm surge.
- **Annex 4** – Impact of climate change on tourism: assesses projected changes in the attractiveness of the climate at European tourism destinations during summer and shoulder months and examines how intra-European traffic could be impacted by 2050.
- **Annex 5** – Impact of changes in wind patterns on flight operations: investigates how flights could be affected by changing wind patterns by 2050.
## Summary of the key findings

### Short-term weather outlook
- **There are clear links between high impact weather events and disruption to the European aviation network.**

### Storms & flight operations
- **On average, storms are responsible for up to 7.5% of total en-route ATFM delays at network level, and the trend is increasing.**
- **In 2019, over 1 million km were flown as a result of avoiding a major storm. This corresponds to over 6,000t of extra fuel consumed, or over 19,000t of CO₂ produced.**
- **A small number of localized storms cause substantial increases in Horizontal Flight Efficiency. Historic performance on days where storms accounted for at least 90% of all en-route ATFM delays was 35%, but in general it rarely worked to more than 4%.**
- **Horizontal Flight Efficiency could potentially rise from 35% today on days when major storms occur to 40%-42% in 2050. An increase of 0.5% corresponds to the emission of an additional 5,000t of CO₂ per year.**

### Sea level rise & airport operations
- **Storm surges will still represent the main driver of marine inundation along most European coasts in the 21st century.**
- **The number of airports at risk from severe/full flooding will increase by 15% by 2090 under the lower intermediate emissions scenario and by 21% by 2090 under the worst case scenario.**
- **A total of 91% of the airports identified to be at risk of flooding in the future are small airports. These airports play a key role in transportation for local communities or have an important role for the military, tourism or the General Aviation community.**
- **Unplanned loss of airport capacity due to sea level rise can pose a significant threat to the efficiency and delay performance of the entire European Air Traffic Management system.**

### Tourism
- **The increase in Tourism Climate Index in the summer months in the North-West ECAC area suggests this destination will become increasingly attractive for general tourism by 2050.**
- **The proportion of summer tourists that are flexible in travel plans should see the summer season (shoulder months) is set to increase by 2050 – there could be 50% more passengers aged 65 and older.**
- **Longer periods of optimal index values in the shoulder months, coupled with the rising level of tourist flexibility regarding travel dates, indicate potential for a widening summer traffic peak by 2050.**

### Upper winds & flight operations
- **Flight durations are likely to decrease in both directions during summer and winter on transatlantic flights, as well as between Europe and Asia, except in winter when flight durations from North Europe to the Canaries could increase.**
- **The overall impact of changing wind patterns on flight duration is expected to be small when considering the impact on a single flight.**
- **The reduction in flight times as a result of projected changes in high-altitude winds is likely to bring annual savings of more than 55,000t of aviation fuel and almost 175,000t of CO₂ on the traffic flows analysed.**
An overview of short-term weather impacts on European aviation

The impacts of weather can be disruptive and costly for the European aviation sector. A clear link between disruptive weather and delays is apparent, yet the exact sensitivity of operations to different weather events and between regions is not as well understood. Given that scientific literature suggests that certain weather events could change in frequency, intensity, or both, in the future, it was important to assess the current relationship and short-term outlook for the impact of weather on flight operations before exploring the longer term trends associated with climate change.

The initial analysis outlined in full in Annex 1 aimed to explore:

- The links between weather and Air Traffic Flow Management (ATFM) delays;
- Patterns of European-scale weather associated with those ATFM delays; and,
- Periods throughout the year when certain ATFM delays occur.

Both airport arrival and en-route ATFM delays\(^1\) were investigated to determine the number of significant weather days impacting airports and countries across the European network. These trends were investigated over the past ten years and forecast for the next five years to establish a baseline for the relationship between weather and delays.

As expected, the analysis found clear seasonal trends in the datasets. Impactful weather that causes airport arrival ATFM delay occurs more often in winter, for example windstorms, snowstorms and fog. Meanwhile, impactful weather that causes en-route ATFM delays (i.e. convective activity\(^2\)) occurs overwhelmingly in summer.

Significant weather days for both airport arrival and en-route ATFM delays were compared against the classification of weather pattern\(^3\) observed on that day. As expected, there is variability in the weather patterns that are responsible for disruption across European airports and countries. The likelihood of a pattern causing an ATFM delay was found to be related to the weather conditions expected with that weather pattern, for a given geographical location and season.

There is no evidence for significant changes in these weather patterns over the next five years. This suggests that, while weather events will continue to cause ATFM delays across the European aviation network, the large-scale weather setups for these events are not expected to change in frequency due to climate change in the short term. This does not mean that localised weather events that have the potential to generate severe disruption will not occur. Over the next five years, the role of year-to-year natural variability is considerable, and uncertainty due to this is expected to dominate any trends related to climate change. This does not mean that changes will not occur out to more distant time horizons, as explored in the rest of the study (Annexes 3 and 5).

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1. ATFM delay is defined as the duration between the last take-off time requested by the aircraft operator and the take-off slot allocated by the Network Manager following a regulation communicated by the Flow Management Position (FMP), in relation to an airport (Airport ATFM Delay) or sector location (En-Route ATFM Delay).
2. Convective activity here refers to the vertical movement of air that can pose a hazard to aviation and is linked with thunderstorms.
3. The weather patterns used are primarily based on the classification of daily mean sea level pressure (MSLP) fields.
**Impact of changes in storm patterns and intensity on flight operations**

The analysis of short-term weather impacts on European aviation investigated the link between weather and ATFM delays. This was used as a basis to assess the impact of changes in storm patterns and intensity, and to quantify the impacts of storms on aviation for historical and future periods (up to 2050) using a set of operational metrics. The methodology and findings are described in detail in Annex 2.

The climate analysis established a link between weather that is associated with ATFM delays and a small number of weather pattern categories. The projected changes in these weather patterns out to 2050, as indicated by climate models, enabled an assessment of how the likelihood of potentially disruptive weather will change by mid-century. Changes in the frequency of intense, disruptive storms were also directly quantified using climate model simulations.

A very strong relationship was found between:

- **Significant Weather Days** (SWDs) with the most major en-route ATFM delays; and,
- **Storm intensity**, for which the respective country average of the convective available potential energy (CAPE) is used as a proxy.

This confirms that convection is responsible for a large proportion of the major en-route ATFM delay days.

The level of disruption associated with the different categories of weather patterns was investigated in more detail. It was found that weather patterns characterised by drawing warm and humid air northward from the Mediterranean are associated with a greater probability of en-route ATFM delay due to disruptive convection likely to be concentrated in southern and central Europe. Weather patterns characterised by deep low-pressure systems across northern and western Europe are associated with a greater probability of arrival ATFM delay in these areas due to disruptive high surface wind speeds. By understanding the link between weather patterns and SWDs the projected changes in weather patterns can be used to determine the projected changes in ATFM delays.

Considering the changes in weather pattern occurrence projected by climate models out to 2050, a possible shift towards more frequent settled weather regimes across northern Europe in summer is expected. This suggests that weather patterns for impactful summer storms may become less common but does not necessarily mean that there will be less Significant Weather Days (SWDs) overall.

Using extreme daily rainfall as a proxy for convective activity (i.e. storms), extreme rainfall days are projected to increase across northern Europe, but decrease across southern Europe. The regions of northern Europe that are projected to have the greatest increases in days with extreme rainfall actually have the least potential for en-route ATFM delays in the current climate. Given the very localised impact of disruptive wind speeds it is difficult to make robust statements about the projected changes in these events in climate models, nevertheless changes by 2050 are not expected to fall outside the present-day observed variability.

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4 Significant weather days (SWDs) refer to days on which considerable ATFM delays were experienced.
5 CAPE is measured in joules per kilogram of air, and when greater than zero this indicates instability and that an increasing possibility of thunderstorms and hail exists.
6 Here, northern and southern Europe refers to the general regions. The operational impact analysis in the report explores impacts at the level of five areas: Western Europe, Mediterranean, Central/Eastern Europe, Northern Europe and Iberian Peninsula.
Storms are historically responsible for up to 7.5% of total en-route ATFM delays at network level. If a flight is affected by a storm, then the average en-route ATFM delay due to that storm can be expected to be around 17-18 minutes per delayed flight. By 2050, the proportion of flights experiencing en-route ATFM delays due to a major storm is likely to decrease, but if a flight ends up being delayed by a storm, the delay will be on average greater by 3-5 minutes than it is today.

The horizontal flight inefficiency measured at ECAC network level during days of major storm activity was historically around 20% worse than the average performance measured throughout the year. However, inefficiency on days with major storms rarely increased above 4%. Although performance on individual days when major storms occurred deteriorates significantly, the localised geographical extent of such storms means the overall impact on annual performance remains very small. The horizontal flight inefficiency measured across all days when major storms accounted for at least 50% of all en-route ATFM delays was 3.5% (2013-2019). This should be compared to overall average performance, which ranged between 2.7% and 2.9% across 2013-2019.

In 2019, over 1 million kilometres were flown as a result of avoiding a major storm. This roughly corresponds to more than 6,000 tonnes of extra fuel consumed, or over 19,000 additional tonnes of CO₂ produced. This should be taken in context: the total gate-to-gate carbon dioxide (CO₂) emissions of IFR traffic in the European Civil Aviation Conference (ECAC) area was 202 million tonnes in 2019. The additional distance flown due to storms was 8.6 km per flight.

Due to the projected changes in intense convective activity (used as a proxy for storm activity) horizontal flight inefficiency could increase to 4.0%-4.2% by 2050. This was measured across all days when major storms accounted for at least 50% of delay and is based on data for all countries projected to be impacted by a major storm. This suggests a 0.5% increase in horizontal flight inefficiency compared to 2013-2019, or around an additional 5,700tCO₂ per year.

For the purpose of this study, vertical flight efficiency is measured as a distance flown level during approach or climb phases of flight. As most of the storms occur during the peak summer months (June to August), vertical flight efficiency on days when major storms took place was compared against typical summer values. Results suggest variability of impacts across the countries in the sample, with the general seasonal impact on vertical flight efficiency during the climb phase of flight being greater than its impact on vertical flight efficiency during the descent phase.

The total storm-induced costs over the ECAC area, calculated on days of major storms across the countries that incurred weather related en-route ATFM delays (and associated deterioration in horizontal flight efficiency), were estimated to be €2.2 billion in 2019. The greatest share of these costs (61.6%) relates to en-route ATFM delays caused by a major storm, followed by the cost of lost passenger time (28.8%). Less than 10% of costs can be attributed to the extra fuel and additional emissions associated with avoiding storms.

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7 In the absence of any recent long-term traffic projection, the latest STATFOR long term forecast (projected until 2040) was used as a basis for extrapolation of traffic evolution to 2050. This is described further within Annex 2.

8 As reported in the Editorial of the Spring/Summer 2020 edition of EUROCONTROL’s Skyway magazine. In fact emissions increased by 24% between 2012 and 2019 from 163 million to 202 million tonnes of CO₂.
Impact of sea level rise on European airport operations

A key impact of a warming planet is Sea Level Rise (SLR), caused by thermal expansion of sea water and the melting of ice accumulated on land. SLR generates an increasing risk of flooding along coastlines, which will be amplified by increased frequency or intensity of storm surges. It is expected that Global Mean Sea Level (GMSL) rise could reach up to 0.84 m by 2100 compared to years 1986–2005.9

In the ECAC region, there are more than 270 coastal or low-lying10 airports that classify as aerodromes and aerodromes with heliports11. Some of these airports have already recognised the risk and begun to prepare, for example by the improvement of airport drainage systems. In a world where SLR and changing storm patterns are expected across the century, however, it is likely that the level of European flooding risk will also rise. This would not only increase the risk for those airports already affected but threaten other airports not currently at risk.

The investigation into the European-level threat of rising sea level on airport capacity in the ECAC region was assessed and is detailed in full in Annex 3. To quantify the number of ECAC airports at risk from marine flooding, Geographic Information System (GIS) simulations were used to compare sea level projections against airport elevations of coastal airports based on the worst case scenario (RCP8.5) and lower intermediate scenario (RCP4.5) for greenhouse gas emissions. The projected flooding risks combine the effects of storm surges (100-year return period), expected SLR, and Glacial Isostatic Adjustment (GIA)12.

Flooding risk refers to the level of flooding of the runway track and was categorised into no flooding, partial (<50%), severe (50% to 100%) and full flooding. The year 2000 was used as a baseline from which the increase in the risk of flooding across Europe was measured. The assessed flooding conditions do not take into consideration coastal protections such as dykes and polders as these were too small to be modelled within the resolution of the Digital Elevation Model (DEM). The results of this study should thus be interpreted as a measure of the risk without natural or artificial defences.

9 GMSL rise could reach 0.43 m (Representative Concentration Pathway (RCP) 2.6) to 0.84 m (RCP8.5) by 2100 with respect to years 1986–2005.
10 Here, ‘coastal’ refers to within 10 km of the coast, whereas ‘low-lying’ refers to less than 10 m above Mean Sea Level (MSL).
11 Aerodrome classifications as per the EAD-SDO database.
12 GIA describes the adjustment process of the earth to an equilibrium state following changes in ice sheet coverage.
More than 270 coastal and low-lying airports (aerodromes and aerodromes with heliports) were assessed. In total, two thirds of airports (178 of 273) are expected to be at risk of marine flooding in the event of a storm surge during the period up to 2090. The number of ECAC airports at risk of severe or full flooding is projected to increase by just over 20% by 2090 (RCP8.5) in both cases.

The cost of diverted and cancelled flights in the case of a one-day closure due to full flooding could be in the region of €3 million (medium airports) or €18 million (large airports). The average estimated cost of diverted, cancelled and delayed flights due to partial or short-term airport closure caused by partial/severe flooding is slightly lower - around €2 million (medium airports) or €15 million (large airports). Actual costs will vary significantly based on airport operations and characteristics such as the nearest alternative airport or the extent of damage.

A total of 91% of the airports that were identified as at risk of flooding are small airports, where typically less than 10,000 movements per year are expected. These small airports may play a key role in supporting the local community, the military, the tourism sector or the General Aviation (GA) community. Whilst the costs from delayed, diverted and cancelled flights at these airports may be limited, the costs to the local or regional economies from secondary impacts are expected to be far greater.

Unplanned loss of airport capacity due to SLR can also pose a threat to the efficiency and delay performance of the entire European Air Traffic Management (ATM) system. In the event of an airport closure due to an environmental event such as a storm surge, network impacts can be observed from both tactical and strategic perspectives, as discussed further within the technical annex. Other impacts include cost implications of disrupted airport operations on airlines and impacts associated with loss of ground transport links due to flooding.

This is of the same order of magnitude as found in a JRC study published in 2019, which suggests that 196 coastal airports will be at risk of flooding in 2080 based on RCP 8.5.
Impact of Climate Change on Tourism Demand

With climate change increasingly affecting the temperature, weather patterns and environment of locations worldwide, there is a possibility that the appeal of (and thus demand for) existing tourist hotspots could change geographically or shift in time, or a combination of both. There are many aspects that inform tourist travel choices. A common consideration is climate, which can influence the choice of destination and time of year of travel, both being associated with a perceived favourability towards a certain climate and acceptable comfort level by the consumer.

This study focuses on summer tourism and the analysis is described in full in Annex 4. To estimate destination favourability, a measure of tourist comfort based on climate, the Tourism Climatic Index (TCI) was used. The TCI indicates the desirability of a destination’s climate for tourism by combining climate variables, including those representing thermal comfort, in a mathematical formula and classifying values into defined categories ranging from ‘ideal’ to ‘impossible’. Historical climate data (ERA5) and the UK Climate Projections 2018 (UKCP18) regional model were used to model European TCI levels and predict trends on the 2030- and 2050- timescales. Changes in climate have been analysed based on thirty-year averages centred on 2050.

There are significant challenges and limitations associated with modelling tourist behaviour, particularly with respect to the link between climate and tourist demand. This study instead undertook a high-level assessment to consider the proportion of tourists that would be able to alter their holiday patterns in order to take advantage of any changes in optimal destination climate favourability. A base-case traffic forecast was developed for the month of August on the 2030- and 2050- timescales using traffic data from Sabre for a sample of airports selected for their level of seasonal tourism. The potential impact of climate change on air traffic movements for August 2030 and August 2050 was explored based on a combination of projected TCI, tourism demographics and drivers of tourism.

TCI Analysis

Across the ECAC region, countries are projected to have an increasing length of time in which the climate will be ‘Good’ to ‘Ideal’ for general, low level tourist activity. For most countries, this increase will be the result of improved climate for tourism into the autumn months (September-October-November), particularly in central Europe.

- Countries in the south of the ECAC region will see a small decrease in destination favourability in the summer months (whilst remaining favourable) driven by changes in the climate parameters underpinning the TCI, but an improvement in both spring and autumn months.
- It is likely that central Europe, northern Spain and most of Scandinavia will become more favourable all year round for general, light tourism activity, with a

Figure 4: TCI values for peak summer tourism months (middle row) and shoulder months (March-April-May on top row, September-October-November on bottom row). Note that the ‘Ideal’ TCI category refers to the TCI range 90 – 100 (not shown on the scale bar).

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projected improvement in TCI in all seasons. The Atlantic island groups (the Azores, Madeira and Canary Islands) are also projected to increase in TCI value in all seasons, improving the existing favourability of these destinations.

- Patterns in TCI change should clearly emerge by 2030, particularly for countries projected to see an improvement in TCI during summer (June-July-August), and it is likely that these changes will develop and be observable in the next decade.

Northern and central ECAC countries will see an increased TCI (improving destination favourability) during summer months, with a number of countries improving to the same TCI levels as countries in the southern ECAC region on the 2050 timescale.

**Potential Traffic Impacts**

Based on analysis of the current and future European demographics and the flexibility within certain sections of the population to travel outside of the peak summer period, the following was found:

- Around 12% of tourists travelling by air from the top six tourist origin countries for this study’s airport sample are currently in the 65 and over age bracket. Looking ahead to 2050, however, the number could increase by 50% by 2050.

- The UK and Germany were identified as having the highest proportion of tourists in this age bracket, as well as the highest total number of passengers travelling to the airports in the sample. Changes in the time of year that elderly UK and German citizens go on holiday would most impact flows (i.e. reduce number of passengers) to the South West in August, both now and in 2050.

- Whilst the proportion of intra-ECAC traffic comprised of tourists travelling without children could not be estimated with the available data, the number is likely to be significant given that currently almost 50% of the EU population are adults without children; the proportion is set to increase by 2050.

Findings indicate a significant proportion of the passenger-base would be able to take advantage of the forecasted widening period of optimal tourism climate in Europe.

It proved difficult to assess the number of tourists that could be constrained in their choice of holiday location in peak summer months. **Whilst it is not anticipated that climate favourability will act as a key driver for changes in summer holiday location on the 2050 time horizon, tourists may choose to take advantage of increasingly favourable climates for tourists in the ECAC North West region.** The relative size of existing flows means this could have a significant impact on demand at North Western tourist-focused airports - a transfer of 10% of tourists expecting to travel to the South East in 2050 would result in a nearly 70% increase in tourists travelling to the North West based on the base case scenario for the airports sampled.

The expected rise in tourist climate favourability in France and Germany to mirror Mediterranean levels is also significant, noting these represent two of the dominant tourist origin countries. If tourist behaviour responds to these changes, projected growth in summer traffic flows to the ECAC South West and South East may be reduced. As well as shifting traffic demand away from international flights, increased domestic tourism in France and Germany would very likely lead to modal shift as those tourists take alternative means of transport.
Impact of changes in wind patterns on flight operations

The day-to-day variability of high-altitude winds has a considerable influence on the time-optimal routes of aircraft. The jet stream is a feature of high-altitude winds that has a significant influence on transatlantic flights.

The jet stream is projected to strengthen and shift poleward under climate change, impacting transatlantic flight routings and duration. Surface winds have an important impact on airport operations therefore the changes for a subset of European airports were also considered in this part of the study. The full analysis is outlined in Annex 5.

The study uses a state-of-the-art trajectory prediction (TP) algorithm that was applied to both historical observed data, and historical and future climate model data to understand past and future trends in flight duration. The historical observed flight times are classified by weather patterns, with future changes in flight duration derived through the projected changes in the weather patterns. Meanwhile, the future changes in flight times were also calculated directly using the output from climate models to provide additional detail. Finally, wind roses were plotted for a sample of European airports and linked to weather patterns to assess what the projected changes in weather patterns means for future changes in wind direction.

The effect of weather pattern on flight duration, using historical data, is strongest in winter and weakest in summer. The simulations predict that, by 2050, summer weather patterns will have changed more than those of winter. Indeed, little change is expected in winter weather patterns. Overall, this makes identifying potential changes to flight duration from weather pattern analysis alone rather difficult. On the other hand, it has been possible to estimate changes in flight durations from a direct application of the TP algorithm to climate model data. This indicates that:

- Both eastbound and westbound transatlantic flights are projected to become shorter in duration by 2050 (by approximately 1-2 minutes), in both summer and winter.
- Flight durations are also projected to decrease for flights from Europe to Asia in both summer and winter (by approximately 2-5 minutes), and from Asia to Europe in summer (by approximately 2-4 minutes). There is unlikely to be a change in duration for flights from Asia to Europe in winter.
- Flight durations from the Canaries to North Europe (northbound) are projected to decrease (irrespective of season) by approximately 1-3 minutes.
- There is an indication that flight durations from North Europe to the Canaries (southbound) could decrease in summer (by about 1 minute) and increase in winter (by about 1 minute).

These changes can be understood by considering the most significant changes in high-altitude winds. It is found that the zonal mean (averaged over a latitude circle) zonal wind is projected to strengthen in the mid-latitudes in winter, while weakening in the high latitudes. This is interpreted as a ‘narrowing’ of the strongest high-altitude winds (in other words, these winds become stronger where they are already strongest but weaken further to the north). Therefore, eastbound flights can benefit from stronger winds where they are already strongest, while westbound flights can avoid stronger head winds due to this ‘narrowing’. This has a particularly strong impact on transatlantic flights, but this effect is expected to extend (albeit weaken) across Europe and Asia, thereby influencing flights between Europe and Asia (particularly North Asia).
Although the average impact of changing wind patterns on a single flight may look negligible, the combined impact - which takes into account all flights operating on the traffic flows considered in this study - is much more substantial. The overall reduction in flight times, as a result of projected changes in high-altitude winds, is likely to bring savings of more than 55,000t of aviation fuel per year, which corresponds to roughly 175,000t of CO$_2$ saved each year, with the greatest reduction expected on routes to and from Asia. These figures assume current fleet mix, aircraft performance and pre-pandemic traffic levels. Traffic, fuel burn and emissions are forecast to increase substantially from 2019 to 2050. The fuel and emissions that can be saved by taking advantage of changes to the jet stream on the traffic flows analysed should also increase – as presented in the table below:

<table>
<thead>
<tr>
<th>Fuel and CO$_2$ saved (1,000 tonnes)</th>
<th>2050 traffic at 2019 traffic levels (0% change)</th>
<th>Expected 2050 traffic levels (+47%)</th>
<th>Expected 2050 traffic levels (+65%)</th>
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<td></td>
<td>Fuel burn</td>
<td>CO$_2$</td>
<td>Fuel burn</td>
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<tr>
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</tr>
</tbody>
</table>

*Table 1: Fuel and CO$_2$ saved per year as a result of changing wind patterns.*

Based on the analysis of the surface wind direction at a sample of five European airports (Amsterdam, Barcelona, Budapest, Dublin and Istanbul), the results show that there will be fewer days with a southerly wind direction by 2050 and more days with a northerly wind direction, noticeably so across western and northern Europe. The results across eastern Europe, where the wind direction is less strongly delineated by weather patterns, are less clear.

There is a clear relationship between weather patterns and the likelihood of seeing fast / slow flights between continent pairs. This is most pronounced for flights between Europe and North America and between Europe and Asia in the winter months, when the jet stream tends to be strongest.
Acknowledgements

This study was undertaken on behalf of EUROCONTROL by Egis and the UK Met Office.

Find out more about them by visiting their websites:
Egis: https://www.egis-aviation.com/
Met Office: https://www.metoffice.gov.uk/services/research-consulting/weather-climate-consultancy