Network Manager
nominated by
the European Commission

EUROCONTROL

Challenges of Growth 2013

Task 8: Climate Change Risk and Resilience

Contents

List of Figures

List of Tables

Acknowledgements:

We would like to thank the stakeholders who contributed to the consultation stage of this task. The ENSEMBLES data used in this work was funded by the EU FP6 Integrated Project ENSEMBLES (Contract number 505539) whose support is gratefully acknowledged. This task of Challenges of Growth has been delivered by the Environment Unit in the Directorate Single Sky of EUROCONTROL.

Summary

The aim of the *Challenges of Growth* series of studies is to provide decision-makers with the best-achievable set of information to support long-term planning decisions for aviation in Europe, with a particular focus on the capacity of the air transport network. Studies were completed in 2001, 2004 and 2008. The 2013 update is currently being finalised.

Challenges of Growth 2008 identified the impacts of climate change as a potential operational and financial risk to European aviation. Challenges of Growth 2013 (CG13) consulted industry stakeholders to determine to what extent they consider adaptation actions are necessary to address those risks, and what actions are being implemented or planned. This report presents the results of that consultation. It also reviews climate change risks out to 2050, by which time the impacts are expected to be widely felt.

Due to inertia in the climate system some degree of climate change is now inevitable. Challenges of Growth 2008 identified the risks this might entail for European aviation and there is now broad agreement on the qualitative issues that will be faced. However, impacts will vary across Europe's climate zones and there remain uncertainties as to their extent, severity and timing. Moreover, looking beyond the current challenging economic climate, the aviation sector will need to build climate resilience whilst dealing with growth in demand. Some of the regions where the highest rates of growth are expected are also areas which may experience the most severe impacts of climate change.

- In general, Europe should prepare for higher temperatures and an increase in precipitation. An exception is Southern Europe where precipitation will decrease. Such increased summer heat and humidity in the Mediterranean Basin may impact the amount and location of demand as traditional destinations would become uncomfortably hot during the traditional summer season. This would lead to both a temporal and geographical shift in demand. Increased temperatures would also cause changes to aircraft climb performance which in turn would affect the distribution of local noise impacts. Heavy precipitation events will impact airport throughput and challenge an aerodrome's surface drainage capacity.

- Snowfall will generally decrease throughout Europe although there may be heavy snow events in new areas and an increase in more challenging wet snow conditions. Snow in locations where it is not usually experienced has the biggest effect on airport operations due to relative lack of preparedness. Moreover, the impact of snow can be directly proportional to the number of aircraft affected, therefore busier airports may experience more significant disruption. Overall, more snow clearing and de-icing equipment may be required. However, a balance needs to be struck between the financial costs and an adequate level of preparedness.

- The strongest storms are expected to become larger and more powerful. Convective weather can impact flight regularity and punctuality whilst having implications for flying pre-determined 4D trajectories. An increase in larger and more intense convective systems may affect multiple hub airports in a region.

- Changes in prevailing wind direction are also expected, leading to an increase in crosswinds. Associated changes in procedure may have an environmental impact whilst capacity will be reduced at airports with no crosswind runway.

Changes to temperature, precipitation, and storm patterns are all expected in the near-term, certainly by 2030. The impacts of sea level rise are more gradual and not expected until later in the century. However, more frequent and intense storm surges will have an earlier impact, reducing capacity and increasing delay. Risk assessments should also be carried out for ground transport connections.

A central part of the 2013 work was a stakeholder consultation to determine whether the industry now considers that measures to increase climate resilience are required, and what actions they are taking. It was carried out in two parts; an online survey and a follow-up workshop. The survey was sent to operational stakeholders, industry associations and civil aviation associations. Over three quarters of respondents acknowledged that they expect to need to take action to adapt to the potential impacts of climate change, indicating a heightened level of awareness compared to feedback in 2008. A growing number of actors within the aviation industry are already taking comprehensive steps to assess potential vulnerability to climate change and put in place appropriate adaptation plans and resilience measures. Again, this indicates a clear shift compared to the limited number of organisations active in this area four years ago. However, many organisations have yet to consider this issue.

The workshop was attended by stakeholder organisations representing airport operators, air navigation service providers, industry associations, the academic community and European policy makers. Participants concluded that there is a growing need for climate change risk assessment and planning for adaptation measures. Cost-benefit analyses will be required to determine what level of impact to be prepared to cope with. However, some of the cheapest and potentially most effective ways identified to build resilience are staff training, sharing of best practices, experiences and solutions, and the implementation of processes which facilitate collaborative responses to climate change challenges. In particular, the development of realistic and objective operational responses should be considered whilst "No-regrets" or "win-win' measures which are intended to address issues such as capacity but which also contribute to building long-term climate resilience, can be cost and resource efficient solutions. Therefore, although the impacts of climate change will vary according to geographical location and type of organisation, many solutions are either already being implemented, or at least have been identified, and may include any of the following:

- Climate change risk assessments for individual organisations and the European` network;
- Identification and implementation of specific local and network-wide resilience measures, particularly no-regrets measures;
- Identification and implementation of measures such as training which can be cost-effective when implemented at both a local and pan-European scale;
- Increased collaboration with MET Services to better exploit advanced forecasting techniques.

Overall, climate change is an issue of risk management and the Challenges of Growth stakeholder consultation demonstrates that a growing number of organisations are either taking or considering action to address climate change risk. Those risks are not necessarily urgent but they are most effectively addressed by building resilience into current infrastructure and operations planning. Many cheap and no-regrets measures such as staff training have already been identified. However, the interconnectedness of the European and global aviation system necessitates an integrated approach to building resilience. Therefore, we need to work collaboratively to implement solutions as efficiently and effectively as possible whilst tackling the challenge of increasing demand. Early action is the key to building resilience at the lowest cost. Therefore, the time to act is now.

2. Introduction

Task Aims

Challenges of Growth 2013 (CG13) is the fourth update of the EUROCONTROL Challenges of Growth report, a set of studies which aim to provide decision-makers with the best-achievable information to support long-term planning decisions for aviation in Europe. Studies were completed in 2001, 2004 and 2008. The 2013 study includes a task to address the risks to European aviation from climate change. This task follows on from ground-breaking work carried out in Challenges of Growth 2008 that looked at climate change forecasts, their impact and mitigation. CG13 as a whole will look at industry trends out to 2050, by which time the impact of climate change is expected to be widely felt.

The current task had two objectives:

- to update the 2008-2010 work on identifying the potential impacts of climate change for the aviation industry and the resulting resilience measures which may be required, and
- to gather stakeholder views as to whether the industry now considers adaptation actions are necessary, and what actions they are taking.

Stakeholder Consultation

The consultation was carried out in two stages. First, a survey was issued to air navigation service providers (ANSPs), airport operators, aircraft operators and industry associations in Eurocontrol Member States with the purpose of gathering information on current climate change adaptation awareness and initiatives. Its primary aims were:

- to determine the extent to which the European aviation sector expects the impacts of climate change to affect its business and operations;
- to clarify whether organisations within the sector think that it is necessary to consider taking measures to adapt to possible climate change impacts; and
- to gather information about any actions and initiatives which organisations currently have planned or underway on climate change adaptation.

The survey was sent to approximately 100 organisations and 35 valid responses were received. The majority of respondents were either ANSPs or Airport Operators. No responses were received from aircraft operators, which is understandable to some extent given their shorter-term planning horizons. In terms of geographical spread, responses were received from all of the main climate zones identified in Section 4.1. Overall, the results indicated that a growing number of organisations expect to need to take action to adapt to the potential impacts of climate change.

Following the survey, a one day stakeholder workshop was held at EUROCONTROL Headquarters in Brussels. Participants represented 20 organisations including airport operators, air navigation service providers, the SESAR research programme, industry associations, the academic community and European policy makers. Participants concluded that there is a growing need for climate change risk assessment and planning for adaptation measures. However, concerns were expressed about acquiring financial resources for something which may not be within immediate planning horizons. To address this issue it was proposed that no-regrets solutions, measures which are already being implemented to address other issues such as capacity but which also contribute to building climate resilience, and low-cost actions such as training should be identified.

The full results of the consultation will be discussed in the following report.

Report Structure

The report is structured as follows:

- Section 3 will provide an overview of the work on climate change risk and resilience which has been carried out so far under the EUROCONTROL Challenges of Growth programme.
- Section 4 will provide a high-level overview of the climate change impacts which might affect European aviation.
- Section 5 considers the associated operational, infrastructure and business risks.
- Section 6 discusses how the sector can build resilience to those risks and provides examples of where such actions are already being taken.

3. Background

Due to inertia in the climate system some degree of climate change is now inevitable. Challenges of Growth 2008 established the impacts of climate change as a potential risk for European aviation. Key risks identified include an increase in en-route convective weather, loss of airport capacity due to sea-level rise and changes in demand patterns due to higher temperatures at popular destinations.

According to current scientific consensus even if there were a drastic and immediate reduction in greenhouse gas emissions, some degree of climate change is now inevitable due to inertia in the climate system. This may result in impacts such as increasing temperatures, rising sea levels, possible water shortages and more frequent extreme weather events. These would affect all sectors of society and, consequently, climate change impacts and adaptation are gaining increasing importance on policy agendas (c.f. UNFCCC Adaptation Programme and the European Commission Adaptation Platform).

In recent years the aviation sector has initiated a comprehensive range of measures to mitigate its greenhouse gas emissions. However, as yet, relatively little has been done to address the potential adaptation needs of the industry. Yet, aviation is highly weather-dependant. Almost 6% of total primary delay in 2011 was due to weather (EUROCONTROL, 2011). Convective activity is the biggest cause of weather regulations in the summer period whilst snow and fog is the main weather constraint in the winter. Moreover, the operation of the European aviation network is vulnerable to a loss of performance in any single component: when one major airport or airspace sector is closed average European air traffic delays can increase across the entire region. Therefore any potential impact which may put a stress on one area of the network needs to be addressed in order to mitigate its impact on the system as a whole. Climate change could pose significant financial and operational risk for the aviation industry, although there remain uncertainties as to the extent, severity and timing of impacts.

The next section will recap the findings of the Challenges of Growth 2008 climate change adaptation work. Section 4 will bring this assessment up-to-date.

Challenges of Growth 2008-2010

As part of the Challenges of Growth 2008 (CG08) work, EUROCONTROL commissioned an Environment Technical report with the purpose of identifying environmental factors which may constrain the European aviation network over the next 20 years. The report was produced by the OMEGA Consortium, a partnership of UK Universities, and the UK Met Office.

The study highlighted for the first time the potential impact of climate change on European aviation, suggesting that infrastructure, operations, and demand for travel could all be affected. It covered a time horizon up until 2030, a period where initial climate change impacts may begin to be experienced by the industry. The findings are summarised in Table 1.

Potential Effect	Primary Climate Change Effects	Confidence/Likelihood	Possible Aviation Impacts
Temperature change	▪ Higher mean temperatures, especially in winter for N. Europe and summer for S. Europe. ▪ Higher, colder tropopause	**High:** Long observational record of temperature increases, all studies considered concur on further increases and in patterns of regional and seasonal change.	▪ Demand re-distribution (geographical) ▪ Demand peak redistribution (seasonal) ▪ Runway demand mismatch ▪ Airspace demand mismatch ▪ Cruise altitude changes ▪ Airspace design changes ▪ Flow management issues ▪ Aircraft performance changes ▪ Runway length issues ▪ Yield and range issues ▪ Increase in noise contours
Snow & frozen ground	▪ Fewer days of snow/ frost (especially Alpine, Scandinavia, N. Baltic)	**High – Medium:** All regional models considered showed same broad level response, but are driven by the same global model. Regional model projections concur with independent studies.	▪ Demand re-distribution (e.g. winter sports) ▪ Changed de-icing and snow clearance requirements (+/-)
Precipitation & water supply	▪ Increased precipitation in N. Europe: winter flooding ▪ Increased freezing rain in N. Europe ▪ Decreased precipitation in S. Europe: summer water shortages	**High – Medium:** All studies considered agree on large scale regional and seasonal patterns of precipitation change but not on exact magnitude. All studies considered indicate future increases in intensity and frequency of droughts for Southern Europe. Magnitude of change is uncertain	▪ Demand re-distribution ▪ Airport and runway demand mismatch ▪ Loss of Airport availability and hence perturbation and delay ▪ Reduced ability to meet demand due water shortages
Sea level	▪ Higher mean sea level ▪ Increased impacts of storm surges and flooding	**High – Medium:** All studies considered concur that European sea levels will continue to rise. Questions remain over exact local extent of sea level rise due to regional influences such as El Niño. Confidence in changes to extreme water levels is lower than that for sea level projections due to fewer studies and the dependence on changes in the storm track, which are uncertain.	▪ Demand re-distribution ▪ Loss of Airport availability (over 30 potentially at risk in ECAC[1]) ▪ Loss of ground access to airports ▪ Major economic costs from events and from providing protection ▪ May require public economic support for ground transport infrastructure protection ▪ Delay and perturbation ▪ Some airports may become less viable ▪ New airports or infrastructure required. ▪ Knock-on impacts for diversion airports

1 The European Civil Aviation Organisation (ECAC) is an intergovernmental organisation which facilitates the harmonisation of aviation policy across its 44 Member States

Potential Effect	Primary Climate Change Effects	Confidence/Likelihood	Possible Aviation Impacts
Jet stream	▪ Jet stream changes: movement pole-ward and upward	**Medium – Low:** 11 of the 15 models considered agree on continued pole-ward movement of storm tracks. Exact changes in storm frequency and intensity remain uncertain due to uncertainties in the detailed model physics needed to represent these changes accurately.	▪ Changes to storm tracks and hence location of possible weather disruption ▪ Wind strength and direction changes at surface ▪ Possible flow management and airspace design changes ▪ Potential increased fuel costs (and CO2 emissions)due to decrease in eastbound transatlantic wind assistance
Convective weather	▪ Increased intensity of precipitation events, lightning, hail and thunderstorms	**Medium – Low:** Severe convection results derived from changes in occurrence of related phenomena, such as intense precipitation events. Uncertainty surrounding modelling of convection, and limited studies, give low confidence in exact magnitude of change.	▪ Disruption and delay ▪ Potential safety issues if frequency and severity increases or predictability reduces ▪ Potential loss of en-route capacity
Visibility	▪ Decrease in winter days affected by fog	**Low:** Fog and haze are boundary layer features not well represented by climate models due to their coarse resolution. There are no studies outside those of the Met Office Hadley Centre so although results from a single model study are plausible they are not necessarily reliable and should not be generalised.	▪ Fewer capacity restrictions due to reduced visibility ▪ Reduced business case for lo-visibility related technologies
General	▪ The summation of the above	**Medium:** Some high impact risks have medium high confidence in their probability. Timing however is less certain.	▪ Disruption to operations from combined impacts ▪ Investment borrowing capability ▪ Business case certainty ▪ Route development issues ▪ The appropriateness of major plans as presently designed (e.g. SESAR) - planned ATM performance improvements. (These may already be aligned with this challenge)

Table 1: CG08 Environment Technical report: Summary of potential impacts of climate change on ATM
(Source: adapted from Thomas et al, 2008)

As a result of these initial findings three case studies were commissioned to explore possible outcomes in more detail and to examine gaps and weaknesses in understanding of potential climate change risk. The case studies, also carried out by the OMEGA consortium, focussed on three climate change impacts which were identified as potentially significant for the European aviation sector; climate-driven changes in demand, sea-level rise and flooding and increased extreme weather. Each case study included modelling and analysis of the climate change-related risks and potential impacts for European aviation over a 2020-2090 timescale.

Case Study 1:

Case study 1 examined potential shifting traffic demand due to climate-related changes in tourist destination preferences and resource availability in the Mediterranean basin (e.g. potable water). It focused on a state in the Mediterranean region with a high proportion of summer tourism and concluded that there may be potential displacement of high season tourism traffic either to other destinations or to the spring and autumn shoulder months due to rising summer temperatures. This has implications for aviation planning, management and infrastructure provisions in existing and potential replacement destinations. It also identified that there may be resource issues due to the availability of freshwater for competing needs and increasing energy requirements. However, it did not expect significant changes before 2030 (Dimitriou and Drew, 2010).

Case Study 2:

Case study 2 carried out a qualitative assessment of potential sea-level rise and flooding at three coastal and low-lying airports, including an analysis of risks to ground transport access and infrastructure. It found that the main potential impacts differed by airport. For example, at Airport B runway and taxi-ways are expected to be frequently affected by inundation by 2099 and at Airport C its low elevation above sea level will increase its susceptibility to inundation by high tides. Whereas, at Airport A loss of ground access was identified as the most significant impact (de Gusmao, 2010).

In general, the case study concluded that significant flooding risk can be expected by the end-of-century but some increased flooding could already be experienced by mid-century. It also stressed the system-wide implications of this as the potential unplanned loss of one or more ECAC runways is a very significant risk for the capacity, efficiency and delay performance of the European ATM system.

Case Study 3:

Case study 3 examined the potential impact of increased extreme weather (convection) events on en-route air traffic in the Maastricht Upper Airspace, one of the most congested in Europe. It predicted an increase in individual occurrences of convective weather systems by 2020 and an extended period of potential storminess for a greater proportion of the year rather than during the 'traditional' summer months. Although the implications for this in terms of reduced annual air traffic management (ATM) performance are not yet known the study did identify a potential decrease in route efficiency when analysing operations for a specific day experiencing storminess when compared with a 'normal' weather day. However, due to the limited scope of the analysis it cannot be treated as statistically significant (McCarthy and Budd, 2010).

Case Study Conclusions

The case studies identified three very different risks which will impact the industry over differing time scales and require a range of responses. Consequently, location-specific risk assessment will be required in order to develop appropriate and effective adaptation plans. More generally, there may also be a requirement for market analyses to aid business planning. For example, the potential impacts on insurance liability, passenger demand, and operational costs should all be explored.

The work also emphasised the need for coordination both within the sector so as to address system-wide effects in conjunction with localised impacts and for strategic planning between aviation and other critical sectors.

4. Overview of Climate Change Forecasts for Europe

Impacts will vary across Europe's climate zones. Key impacts will include increased temperatures and precipitation, an increase in convective weather, changes in wind patterns and sea-level rise.

The potential risks resulting from climate change are both multi-faceted and vary greatly with region. The 39 EUROCONTROL Member States cross a wide-range of climatic zones. This means that the impacts of climate change which are experienced will differ greatly. The exact geographical divisions vary, but can be broadly taken as:

- Northern Europe
- North-Western Europe or Maritime
- Mountain regions
- Central and Eastern Europe
- Southern Europe or Mediterranean

Some studies put specific emphasis on coastal zones. Figure 1 gives an overview of expected physical impacts by region.

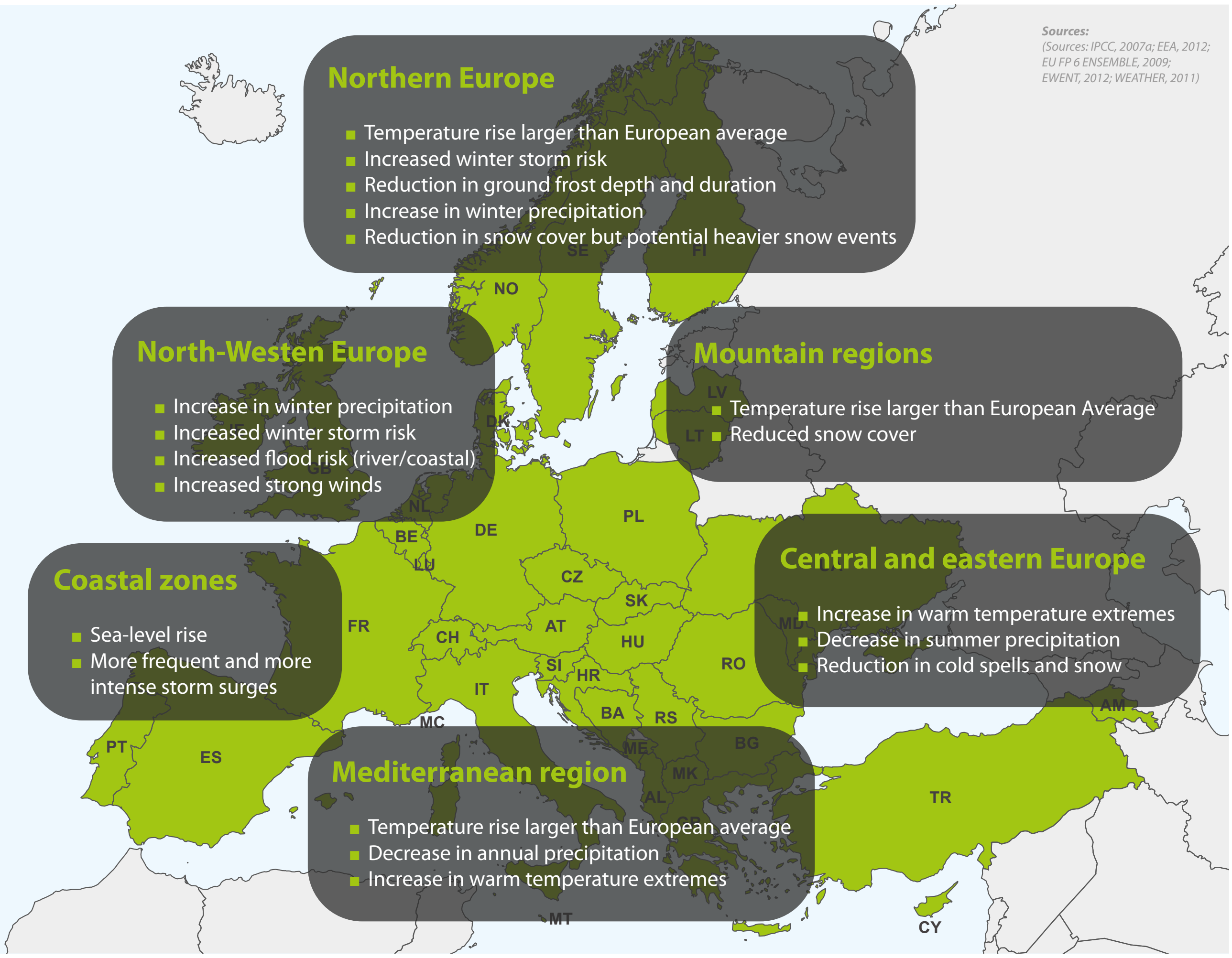


Figure 1, Potential impacts of climate change for Europe's main climate zone

The main climate change impacts which European aviation stakeholders expect to be affected by are more incidences of extreme weather such as storms, an increase in precipitation (rain and snow) and higher temperatures (Figure 2). An additional impact which was consistently identified by stakeholders is potential changes to wind direction. This is broadly in line with the impacts identified by the CG08 work (see Table 1 and Thomas et al, 2008).

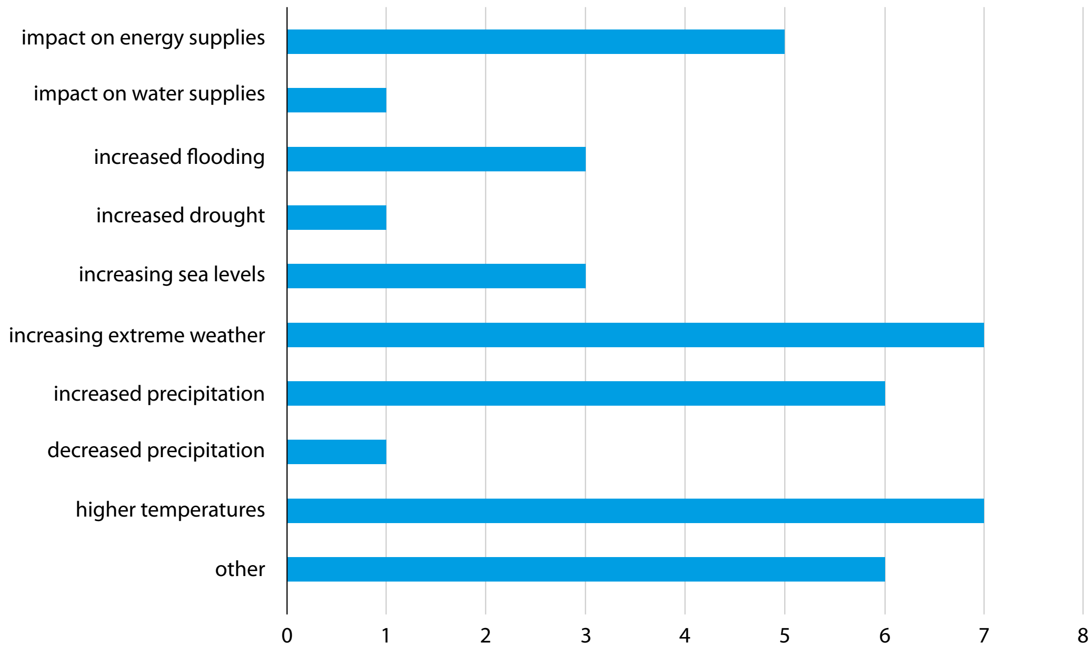


Figure 2, Main climate change impacts which European aviation stakeholders expect to be affected by

In general, although extreme weather should not automatically be labelled as the result of climate change, climate change does increase the likelihood of extreme weather events. The United Nations World Meteorological Organisation (WMO) expects both increases of weather extremes and an increase in the persistence of weather patterns, such as periods of heavy snowfall lasting for longer. Moreover, there is a need to be prepared for multiple eventualities: in 2012 Hurricane Sandy, which hit the East Coast of the USA, demonstrated how it is possible to have a tropical storm and heavy snowfall within close temporal and spatial proximity, (H. Puempel, WMO). Nearly 17,000 flights were cancelled due to Sandy[2]. According to the International Air Transport Association (IATA) 'at the peak of the storm on Monday 29 October 8-9% of global capacity was grounded which is equal to 1.6 billion available seat kilometres. A conservative estimate of lost revenues as a result of the hurricane is $0.5 billion' (IATA, 2012). An increase in such events will have a significant operational and financial impact. Finally, it should be noted that there is limited data on the impact and likelihood of rare events: reliable statistics and data tend to be mostly available for the types of event which occur more regularly and for which, consequently, there are large quantities of data (H. Puempel, WMO). This understandably limits the precision of the forecasts which can be made.

The following sections update the Challenges of Growth 2008-10 work by providing an overview of current forecasts for the main climate change impacts which might affect aviation. For further details on all potential impacts of relevance see the CG08 Environment Technical Report by Thomas et al.

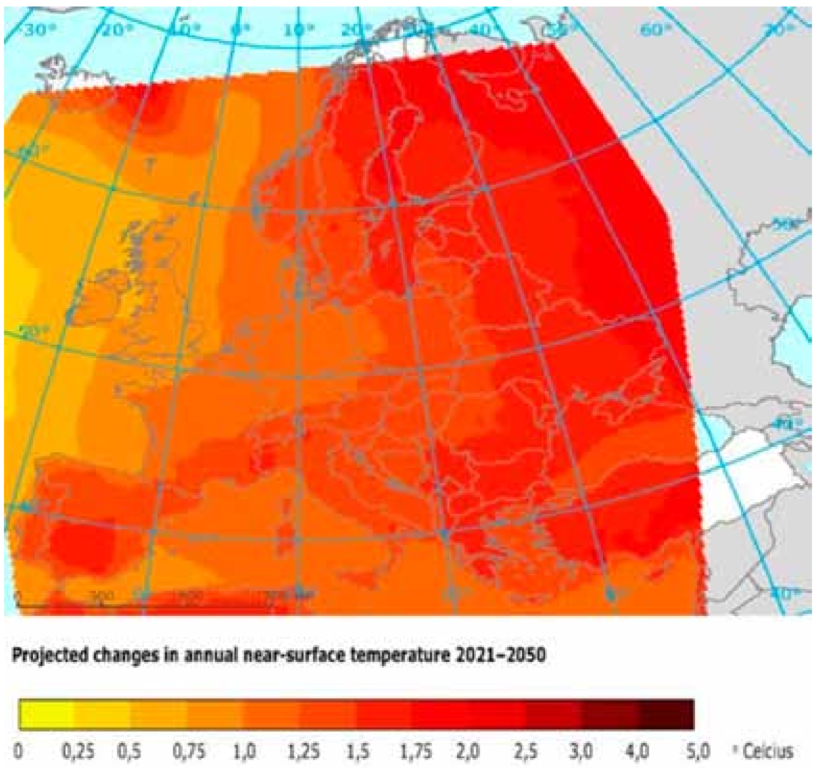
[2] Based on the five most affected airports: John F. Kennedy, Newark, LaGuardia, Washington-Dulles and Philadelphia

4.1 Temperature increase

Europe should prepare for hotter temperatures with more frequent and longer lasting extreme high temperatures.

According to a 2012 report from the European Environment Agency (EEA)[3] average annual land temperatures across Europe are already increasing faster than the global average and are expected to further increase by between 1.0° and 2.5°C by 2050[4] (van der Linden and Mitchell, 2009). However, this warming will not be even, with Eastern and Northern Europe expected to see the largest rises in winter and Southern Europe the greatest summer increases. Figure 3 gives an indication of the geographical distribution of the forecasts. However, the map portrays average annual temperatures and therefore may disguise seasonal extremes: extreme high temperatures are forecast to both become more frequent and to last longer, whilst cold extremes are predicted to lessen (IPCC, 2007)

Figure 3, Projected changes in annual near-surface air temperatures for the period 2021-2050 (*Source: FP6 ENSEMBLE)*



---

[3] In the corresponding analysis "EEA Europe is defined as the area between 35 °N to 70 °N and 25 °W to 30 °E, plus the area from 35 °N to 40 °N and 30 °E to 45 °E (including also the Asian part of Turkey)". It is thus roughly comparable with the geographical coverage of Eurocontrol member states

[4] Based on the IPCC SRES A1B emission scenario

4.2 Changes to precipitation (rain and snow)

Precipitation will increase in most of Europe, with the exception of Southern Europe which will experience a decrease. Snowfall will generally decrease but there may be heavy snow events in new areas.

In general, an increase in precipitation in Northern and Central Europe and a decrease in Southern Europe is expected (EEA, 2012). Figure 4 gives an indication of the projected increases. However, as this gives annual averages, it disguises potential seasonal extremes. Moreover, the number of consecutive dry days is likely to increase significantly in Southern Europe (especially in summer) but decrease in Northern Europe (especially in winter) (IPCC, 2012). Heavy precipitation events are likely to become more frequent in most of Europe, particularly in Scandinavia in the winter and Northern and Eastern Central Europe in the summer (EEA, 2012).

Overall, snowfall days are predicted to decrease although there may be some increase in the numbers of heavy snowfall days (above 10cm) in Northern Europe. Currently observed reductions in snow cover are predicted to continue with decreases expected in duration and extent although it should be noted that there are many uncertainties in snowfall projections (EEA, 2012).

However, due to warming of the North Atlantic and Arctic seas it is expected that there will be longer periods where weather patterns become blocked preventing warmer westerly winds from penetrating into Europe and thus leading to regionally colder, potentially snow-heavy weather events. Due to the general warming trend, winds originating from the Arctic and Siberia, which would prevail in such situations, may not be as cold as before, whilst due to larger ice-free surfaces the warmer air is able to hold more moisture. In turn, this leads to greater snowfall early in the winter. As a consequence, some intense snow events may occur over the northern continents due to a large, cold air pool, seen as pre-requisite for snowfall, even in regions where they have rarely been observed in the past. Such events may last longer leading to increased requirements for snow clearing and de-icing equipment. Consequently although the overall number of snow days is not necessarily expected to increase, the geographical distribution of snow events will widen leading to a much greater area which needs to be prepared for potential heavy winter weather (H. Puempel, WMO). Moreover, warmer temperatures at higher latitudes may lead to temperatures fluctuating around zero which makes forecasts of precipitation type (e;g. rain, snow, freezing rain) trickier and less reliable.

At higher latitude locations a reduction in ground frost depth and duration may alter aerodromes' load-bearing capacity, potentially destabilising runways and buildings (SCCV, 2007). Thawing of permafrost, the soil below the ground surface which remains permanently frozen throughout the year, may also have a similar impact at a minimal number of locations

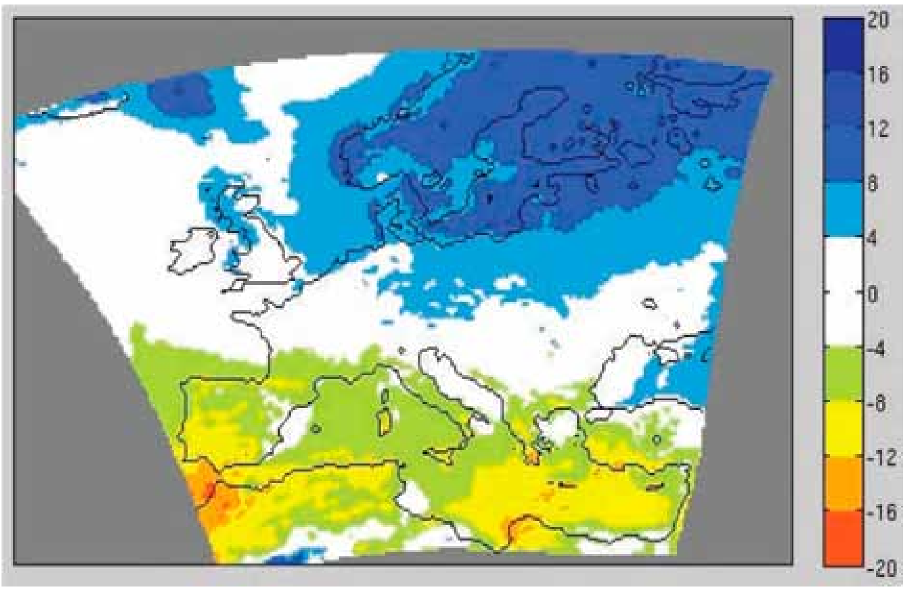


Figure 4, Projected changes in annual precipitation (%) for the time period 2021–2050 relative to the 1961–1990 mean
(Source: FP6 ENSEMBLE)

4.3 Increased convective weather

Predictions as to future frequency, location and intensity of convective weather systems are uncertain, although the strongest events are expected to become larger and more powerful

The Challenges of Growth Case study modelling work carried out in 2010 forecasts an increase in convective weather systems with the potential to disrupt ATM operations of around 3-4 days in the summer months, with the potential for significant storminess by 2020. This equates to a potential doubling in the number of days where ATM may be affected by extreme storminess when compared to the present. By 2050 it is possible that summer season occurrences of storminess may fall below present day levels due to a shift in convective activity to the shoulder months during spring and autumn. This indicates that the impact of convective weather is likely to be a risk for a greater proportion of the year rather than being confined to the 'traditional' summer months (Budd and McCarthy, 2010).

In general, forecasts as to the frequency, location and intensity of storms are uncertain, although a number of studies predict that the overall number of storms will decrease whilst the most powerful storms will be more intense (particularly in northern and western Europe). Recent studies which forecast a shift in the Atlantic storm track towards the equator suggest that this could increase winter precipitation in North-Western, Western and Central Europe (McDonald, 2011; Scaife et al, 2012). However, overall, there is no consensus as to the direction of any potential geographical shift (EEA, 2012).

Instances of convective weather in the summer period in European continental areas may cover larger areas in the form of so-called meso-scale convective systems, as well as becoming more intense. While factors such as increased public awareness and online communication may have contributed to more observations of serious convective and even tornadic storms in Europe, it would be wise to prepare for a trend to see more of these events (H. Puempel, WMO). Continental Europe is expected to be most affected. In particular, areas at the edge of mountain ranges, peri-alpine lakes with their combination of moisture and steep topography, and the so-called "storm kitchens" where mountains and the Black or Mediterranean seas meet, are expected to be affected during the late summer and autumn season. Stronger convective weather may also be experienced later in the season due to warmer ocean temperatures (H. Puempel, WMO).

4.4 Changes in wind patterns

Changes in wind speed will vary with region. Changes in prevailing wind direction can also be expected.

According to the EEA (2012, p.70) "a recent study involving 20 climate models projects enhanced extreme wind speeds over northern parts of central and western Europe, and a decrease in extreme wind speeds in southern Europe." Warming surface temperatures will cause increased instability which may lead to stronger winds in the lower troposphere. This is because warming at the surface will lead to increased vertical transport momentum which in turn causes higher surface wind speeds (H. Puempel, WMO).

A recent study suggests that greater extreme wind speeds can be expected in the north of Western and Central Europe. Conversely, wind speeds in Southern Europe may decrease (Morse et al, 2009). Climate change is also expected to lead to changes in prevailing wind directions due to shifts in the position of the jet stream and storm tracks (Thomas et al, 2008).

4.5 Sea level rise and storm surges

Impacts of sea level rise will be experienced over the longer term and will not be uniform. An increase in storm surges may be more immediate although due to assumptions in the modelling predictions are uncertain. There are also likely to be significant geographical differences in impact.

Modelling work carried out by the UK Met Office as part of the Challenges of Growth 2008-2010 work identified 34 European Airports as potentially at risk from sea level rise, storm surges and flooding by the end of the century (de Gusmão, 2010, Figure 5).

However, sea-level rise estimates are regularly revised due to the availability of new scientific data with a general trend for new assessments to indicate more severe impacts than previously expected. For Europe, mean sea-level is currently predicted to rise by between 20 cm and 2m over the course of the 21st century, although the EEA (2012, p.101) hypothesise that takinginto account inherent uncertainties "it is more likely to be less than 1 m than to be more than 1 m". It should also be noted that sea level rise is not uniform: some areas will be subject to a larger rise than others and vertical land movement can have a positive or negative impact on local or regional sea level (EEA, 2012).

Although the impacts of sea-level rise are expected to be experienced over the longer term, the impacts of an increase in storm surges may be more immediate with the EEA (2012) predicting changes in storm surge height and frequency[5]. However, there are many uncertainties in the predictions due to inherent assumptions based on modelling of potential changes in mid-latitude storms. Moreover, changes in extreme water levels are closely related to changes in local relative mean sea level. There are also likely to be significant geographical differences in the impact with various studies predicting: small increases in storm surge height for the UK (Lowe et al., 2009); a reduction in the frequency and magnitude of storm surge events in the Mediterranean (Marcos et al., 2011); increases in storm surge height in the Baltic Sea (Meier, 2006) and; an increase in number and height of storm surge events around the coast of Ireland, with the exception of the southern coast (Wang et al., 2008). However, the EEA (2012, p109) notes that "not all of the changes were found to have a high statistical significance", indicating the significant uncertainties in this area.

Figure 5 Sea–level rise in Europe, mapping of potential sea level rise hazard in a high-end warming world based on a worst-case scenario of +4°C warming by 2099 (MORSE, +4°C) (Source: de Gusmão, 2010)

5 Results from studies using IPCC SRES A1B, A2 or B2 scenarios

5. The Impact of Climate Change for European Aviation

A growing number of European aviation organisations expect climate change to impact their business. There is now broad agreement on the qualitative issues that are being faced. These are: increased summer heat and humidity in the Mediterranean Basin impacting the amount and location of demand; increased frequency and intensity of storm systems and snow events disrupting operations; and mean-sea level rise threatening coastal airports and thus network capacity. Impacts will mainly affect infrastructure, operations and operating costs.

A growing number of European aviation organisations expect climate change to impact their business. 52% of respondents to the Challenges of Growth 2013 consultation expect it to impact them between now and 2050 (N = 33, Figure 6). The majority of the other organisations do not yet have an official position. This shows a definite shift in opinion; when this issue was first discussed with the industry in 2009 most organisations did not consider it to be a concern. However, of those without an official position who answered a follow-up question asking whether their organisation is taking any measures to establish such a position, the majority answered either 'don't know' or 'no', indicating that this is still an emerging issue for many organisations.

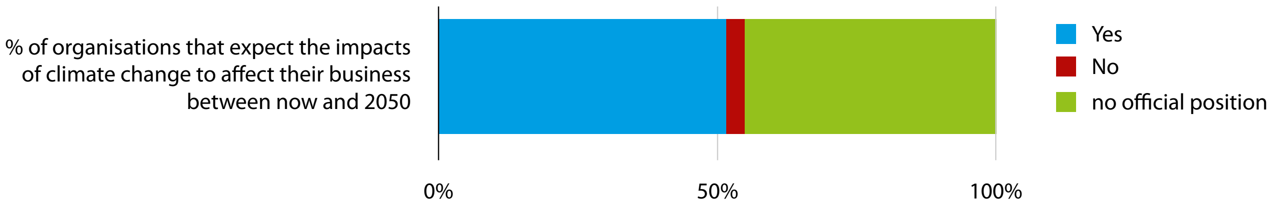


Figure 6, Percentage of respondents who expect to be impacted by climate change

The impacts identified by current research mainly affect infrastructure, operations and operating costs. This is broadly in line with the views of the consultation participants who mainly expect climate change impacts to translate into operational and financial issues (Figure 7). Notably, although climate change is often seen as bringing potential opportunities as well as challenges, none of the survey respondents considered this to be the case.

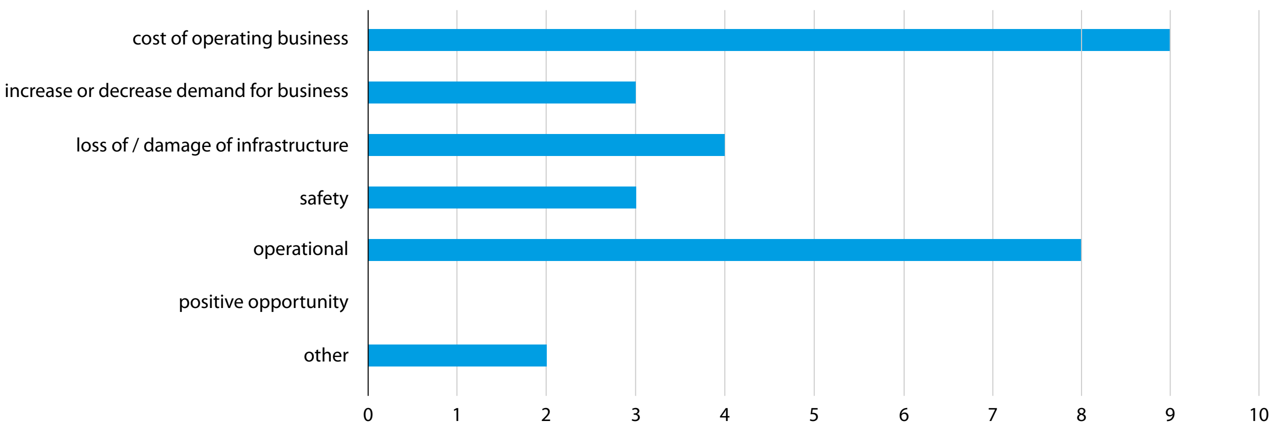


Figure 7, Main issues which respondents expect climate change to cause for their organisation

Figure 8 gives a non-exhaustive overview of expected impacts for the European aviation industry by region and may not capture all possible impacts. The following sections discuss the associated risks. For more detailed information see Thomas et al, 2008, Doll et al, 2012, Leviäkangas et al, 2011, Molarius et al, 2012.

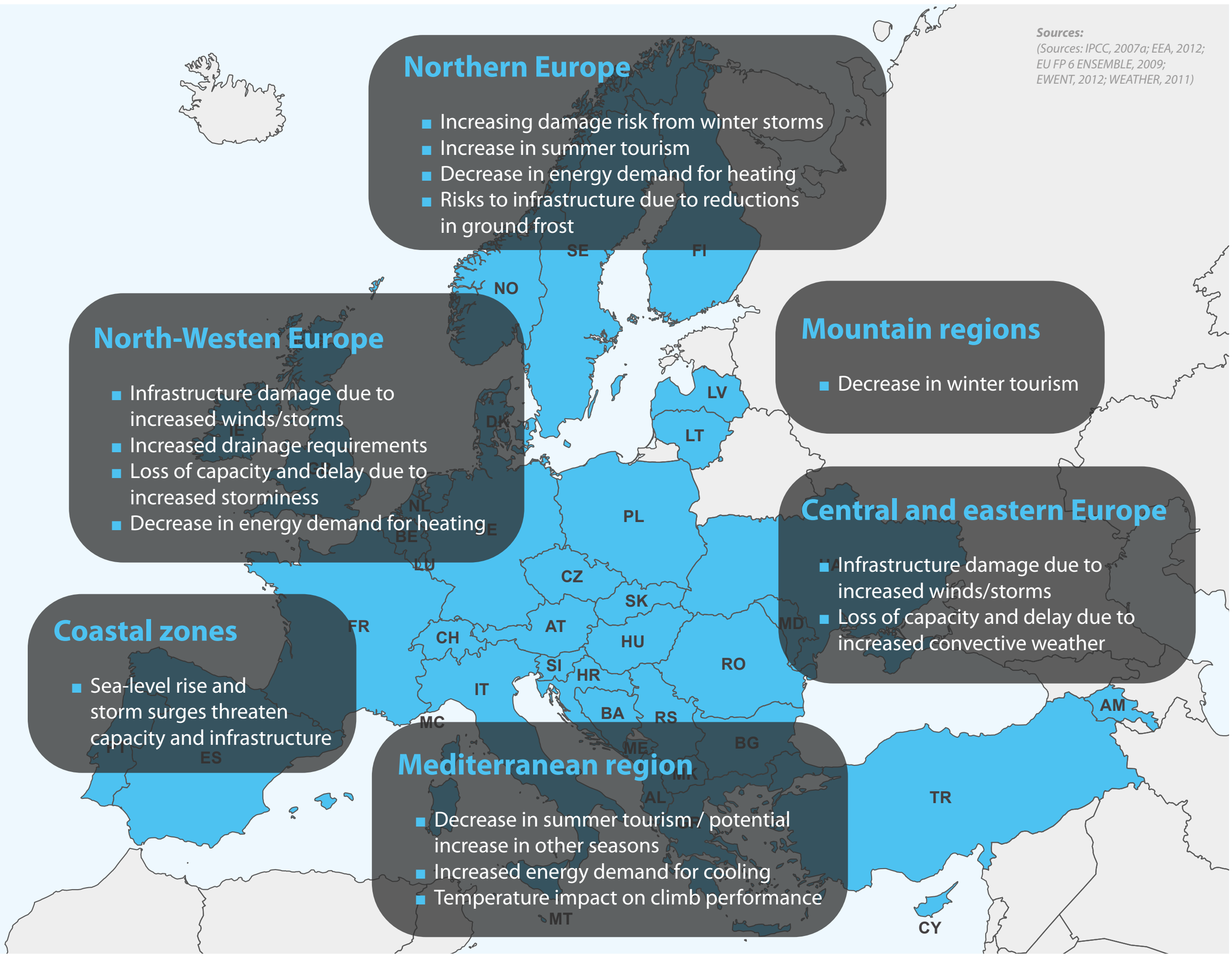


Figure 8, Potential vulnerabilities and opportunities

5.1 Temperature increase

The Mediterranean region currently attracts around 100 million visitors from Northern Europe each year. Climate change may cause tourist numbers to shift seasonally or geographically. Other potential impacts include changes to climb performance with an associated change in environmental impact.

Potential impacts: Changes in Air Traffic Demand

CG08 identified increases in average summer temperatures at particular locations as potentially affecting demand for air transport to those locations; regions where temperature increases lead to uncomfortable summer temperatures may experience a decrease in tourist demand whereas regions where summer temperatures become more pleasant may experience an increase (Thomas et al, 2008; Dimitriou and Drew, 2010). More recently this has been supported by the EEA (2012, p.209) who predict that "The regions most favourable for general tourism are projected to shift northwards as a result of climate change. The touristic attractiveness in northern and central Europe would increase in most seasons. Suitability of southern Europe for tourism would decline markedly during the key summer months but improves in other seasons." The projected overall decrease in snow cover was also predicted to have a potential negative impact on winter sports tourism.

The Mediterranean region currently attracts around 100 million visitors from Northern Europe each year, although not all of those tourists arrive by air (Amelung and Moreno, 2009). However, the CG08 Case Study on climate change and traffic demand estimated that 73% of tourist arrivals to Greece were by air (Dimitriou and Drew, 2010). Of course, some but not all Mediterranean destinations are more easily accessible from Northern Europe by ground transport. However, this still suggests that even relatively small numbers of tourists who fly to the Mediterranean during the summer months deciding to travel to alternative destinations could lead to significant changes in infrastructure and staffing requirements at both traditional and potential new destinations. More positively, if a proportion of those tourists decide to change their habits and travel to traditional holiday destinations in the spring or autumn months instead of the customary summer season, then this could ease congestion during the traditional peak season.

ATS routes are designed to cater to the largest traffic flows to and from a particular location.[6] Significant changes in traffic demand can come in various forms and have different effects on ATS route design. If services are introduced to new destinations, attempts are usually made to systemise this traffic into the existing construct of SIDs/STARs[7] and the ATS Route network. In some instances, it may be necessary to add new routes and procedures. The standard procedure in the latter instance is to design new routings (including SIDs and STARs) and to ensure their coherence within the overall route system before providing the necessary resectorisation (F. Pavlicevic, Eurocontrol). In particular the redesign of SIDS and STARS may have environmental impacts such as the redistribution of noise impacts around an airport and an increase or decrease in fuel burn and the associated CO2 emissions.

However, many factors, such as socio-economic shifts which impact airfares and propensity to fly, can affect air traffic demand. Therefore, the impact on demand of a change in local climatic conditions will seldom be isolated from other factors affecting demand characteristics (F. Pavlicevic, Eurocontrol). This suggests that the potential impact on demand of a rise in average temperatures is an issue which is still poorly understood and warrants further research.

Potential impacts: Climb Performance

CG08 identified increased temperatures as having an impact on climb performance, changing runway length requirements on takeoff and potentially affecting the aircraft payload or reducing the size of aircraft which could operate from a runway of a given length (Thomas et al, 2008).

> **"Impact on scope of sound insulation schemes"**
>
> Airport Operator, 100,000-249,000 movements per annum

6 Generally, ATS routes are streamlined and systemised so as to facilitate air traffic management and are merged as they near a particular destination to be funnelled into arrival flows. The converse happens with departure routes connecting to the ATS Route network

7 Standard Instrument Departures and Standard Arrival Routes

Although there may be some concerns where aerodromes have short runways or steep departure routes, this should not normally initiate the need for airspace redesign as take-off paths are designed with a window of approximately 3000-4000 feet in order to accommodate differing aircraft performance while obstacle clearance has to cater for worst case performance of a 3% gradient (ICAO, 2006; F. Pavlicevic, Eurocontrol). However, it may have an environmental trade-off in terms of an increase in noise impact around an airport or an increase in fuel burn and associated CO2 emissions which in turn could necessitate a need for public consultation.

Potential impacts: Infrastructure

Extreme summer temperatures will be higher than the original design specification for runways (Thomas et al, 2008). When temperatures exceed design standards then heat damage may occur to tarmac surfaces; tarmac runways or aprons may experience difficulties due to surface melting during peak heat periods. For example, in the UK the standard for tarmac roads and aprons is exceeded once temperatures in the shade are higher than 32°C, although design standards for runway surfaces are higher to be able to absorb the impact of aircraft braking (LHR, 2011).

> **"Airfield surface and sub surface structural damage to runway and aprons from extreme heat"**
>
> Airport Operator, 100,000-249,000 movements per annum

> **"Impact on heating and cooling systems"**
>
> Airport Operator, 100,000-249,000 movements per annum

In general there will be a need for increased summer cooling of airport buildings with the attendant energy costs. Some buildings which were designed for cooler climates may not be able to maintain comfortable temperatures during very hot periods leading to overheating of equipment and health issues for staff (Thomas et al, 2008).

5.2 Changes to precipitation (rain and snow)

Snow where it is not usually experienced has the biggest effect due to lack of preparedness. However, the impact is also directly proportional to the number of aircraft affected. Overall, more snow clearing and de-icing equipment may be required. However, a balance needs to be struck between the financial costs and an adequate level of preparedness. Heavy precipitation events will impact airport throughput and challenge an aerodrome's surface drainage capacity.

Potential impacts: Snow clearing and de-icing capacity

With incidences of unexpected snow, both the location and the amount of precipitation affect the severity of the impact. Snow where it is not expected has the biggest effect due to lack of preparedness. However, the impact is also directly proportional to the number of aircraft affected. In other words, the impact of weather delay is relative to air traffic demand: the busier the airport, the bigger the impact (N. Cooper, Eurocontrol).

> **"More frequent extreme weather conditions (snow, storms etc.) will present operational challenges such as frequent short-term route changes, as well as flight cancellations and compensations to users"**
>
> Airport Operator, 100,000-249,000 movements per annum

In order to keep airports functioning in snowy conditions, clearing capacity needs to be faster than the rate of accumulation of snow mass. Consequently, clearing and de-icing capacity needs to be assessed at airports which are at risk. For this, accurate meteorological information is required.

Overall, more snow clearing and de-icing equipment will be required. However, there will also be long periods when it is not used. Therefore a balance needs to be struck between the financial costs and an adequate level of preparedness. For example, an aerodrome may decide to prepare to meet 85-90% of possible extreme weather and to close for the rest. If it is assessed that the clearing capacity can not match forecast conditions then mitigation actions need to be implemented. For example, multiple runways could be cleared sequentially or there may need to be reappraisal of residual acceptance capacity in order to inform ATM as soon as possible to stagger arrivals and flow management at a European level (H. Puempel, WMO).

However, more positively, although the geographical range of snow events is likely to increase, forecasting is also improving leading to better ability to plan in advance. This means that contingency measures can be put in place which aren't reliant on having equipment and expertise based at one particular airport but that can be transferred between different locations. Alternatively, measures could be put in place such as those being implemented at one European airport where, rather than investing in snow ploughs, the airport has bought snow plough shields which are then attached to tractors belonging to local farmers. This might also be achieved by employing equipment and employees from local construction firms. Such integrated planning will be heavily dependant on reliable data and information flows (H. Puempel, WMO).

Other potential issues include in-flight icing as some aircraft may not be certified to operate in severe icy conditions so traffic may be reduced (H. Puempel, WMO). De-icing constraints can increase delays. There are also environmental concerns associated with an increased use of de-icing fluid as environmental limits may be reached (O. Larsen, Avinor).

Potential impacts: Operational and infrastructure impacts

Heavy precipitation events may lead to increased separation distances which will impact airport throughout (LHR, 2011). Current aerodrome surface drainage capacity may be insufficient to deal with more frequent and intense precipitation events, leading to increased risk of runway and taxiway flooding.

> **"Balancing pond capacity - changes in flow rates of surface water discharges with increasing demand for balancing capacity"**
>
> Airport Operator, 100,000-249,000 movements per annum

Moreover, during periods of cold weather flooded drainage systems can freeze rendering them incapable of dealing with further runoff. An additional impact of such flooding may be the inundation of underground infrastructure such as electrical equipment. This can be exacerbated by rising groundwater levels caused by ongoing heavy precipitation (O. Larsen, Avinor).

5.3 Increased convective weather

Convective weather can impact regularity and punctuality whilst having implications for flying pre-determined 4D trajectories. An increase in larger and more intense convective systems may affect multiple hub airports in a region.

Summer convective weather can have an exponential effect on weather delay due to the high seasonal traffic levels. For example, in 2012 one European hub airport had over 300 000 minutes of weather delay in the first six months of the year, a 50% increase on the same period in 2011.

> **"Affecting regularity and punctuality"**
>
> Airport Operator, 100,000-249,000 movements per annum

The potential increase in larger and more intense convective systems has implications for flight planning and en-route capacity. If Aircraft move off-track to avoid convective systems then en-route capacity may be reduced. Moreover, calculations for extra fuel requirements are made based on the expected alternate airport should the destination airport of choice be unexpectedly unavailable. However, if larger convective systems start to affect multiple and, in particular, hub airports in a region, the choice of alternate airports may be reduced and those that are available may not have sufficient capacity for the traffic which they need to accommodate. This suggests that diversionary airport capacity may need to be taken account of in flight planning considerations: capacity-based flight planning may be required (H. Puempel, WMO). If there is uncertainty as to the destination airport then more fuel will need to be carried.

Such capacity-based planning would require reliable data inputs. The possibility of a convective system affecting a wide area can usually be detected by MET Services a couple of days beforehand. This gives an indication of the broad geographical region where there may be a problem. Around 12 hours beforehand, predictions are more precise and the area at risk can be predicted more exactly allowing for planning to begin. For example, if it is expected that a weather system may affect two neighbouring hub airports then diversionary planning can begin early (H. Puempel, WMO).

An increase in convective systems may have implications for flying pre-determined 4D trajectories as there could be a need to increase separation minima for safety reasons, which in turn has implications for flow management. This emphasises the importance of good MET Information for effective 4D trajectory management (H. Puempel, WMO). Moreover, if en-route severe weather patterns start to become predictable, leading to more en-route weather avoidance, this may change the characteristics of demand if passengers or airlines don't want to fly in certain areas. In some instances, this could change the distribution of traffic flows which may eventually lead to the redesign of some routes (F. Pavlicevic, Eurocontrol).

5.4 Changes in wind patterns

Changes in prevailing wind direction may lead to an increase in crosswinds. Associated changes in procedure may have an environmental impact. Capacity will be reduced at airports with no crosswind runway.

There are many uncertainties regarding projections for changes in wind speed and direction. However, wind directions are expected to change as the position of the jet stream and storm tracks move polewards and upwards. Consequently, runways constructed along the locally prevailing wind direction may experience more cross-winds as the prevailing direction changes. The full extent of the impact will depend not only on changes in direction, but also changes in wind strength, which are difficult to quantify (Thomas et al, 2008).

> **"Populated areas around the airport have been developed on the basis of the current airport operation and estimates of traffic growth. A change in the pre-dominant wind vector may affect the impact of the airport on the environment, which in turn may affect the ability of the airport to grow"**
>
> Airport Operator, 100,000-249,000 movements per annum

This will lead to an increase in cross winds and affect downwind approaches with implications for runway capacity and environmental impact. Turbulence and high winds might affect landing runways; crosswinds might be outside tolerance for some aircraft types or prevailing winds might change so that an airport has crosswinds but no crosswind runway. This may entail the need for a change in procedures and airspace redesign (F. Pavlicevic, Eurocontrol).

5.5 Sea level rise and Storm Surges

The impacts of sea level rise are not expected until later in the century. More frequent and intense storm surges will have an earlier impact, reducing capacity and increasing delay. Risk assessments should also be carried out for ground transport connections.

> **"Increased costs related to drainage and coastal defences"**
>
> Airport Operator, more than 400,000 movements per annum

Although the effect of sea-level rise on coastal airports is not expected to be experienced in the short-term with significant flooding risk unlikely before the end of the century, some increased flooding could already be experienced by mid-century. More frequent and more intense storm surges are also expected in several areas which will reduce capacity and increase delay. Moreover, in some cases the actual airport itself may not be the main infrastructure risk but there might be ground transport infrastructure which could pose a much larger-scale engineering and economic problem for mitigation strategies (de Gusamao, 2010).

Additionally, there are potential network wide-impacts as, with over 30 European airports potentially at risk of loss of runway capacity, the future impact on runway operations could be very significant for the European ATM system. Of particular significance is the number of secondary or diversionary airports which may also be closed if the main airport were closed.

5.6 Growth and adaptation: a double challenge

The aviation sector needs to build climate resilience whilst dealing with growth in demand. Some of the regions where the highest rates of growth are expected are also areas which may experience the most severe impacts of climate change.

As well as the climate adaptation challenges which European aviation may have to face between now and 2050, the sector has another well-established challenge to combat: accommodating the forecast increase in demand. Although the recent economic crisis has had an impact on the rate of growth, preliminary analysis carried out as part of CG13 Task 1 still expects demand to be around 1.8 times higher than 2009 levels by 2030 (Eurocontrol, 2012). This analysis will be further developed by the CG13 Long-term Forecasts. However, this growth in demand is not expected to be distributed equally with some states with emerging markets potentially experiencing 6-7% average annual growth. Moreover, as can be seen in Figure 9, some of the areas where the highest growth is predicted, such as South East and Central Europe, are also some of the areas where the greatest potential climate change impacts are predicted[8]. There are several possible consequences to this. For example, as discussed in Section 5.1, seasonal weather modifications may lead to geographical displacement of traffic meaning that forecast growth is not achieved and that higher growth is experienced in areas where it has not been forecast. Alternatively, such states may have to cope with growing demand whilst dealing with climate change impacts such as water stress or increased extreme weather. Consequently, it is important to understand how these two challenges interact, particularly because, as noted in Section 5.2, the impact of any disruption can be positively correlated to traffic numbers and relative capacity.

8 The forecast scenario shown in figure 9 does not include any large scale effects of climate change, such as changing patterns off tourism demand.

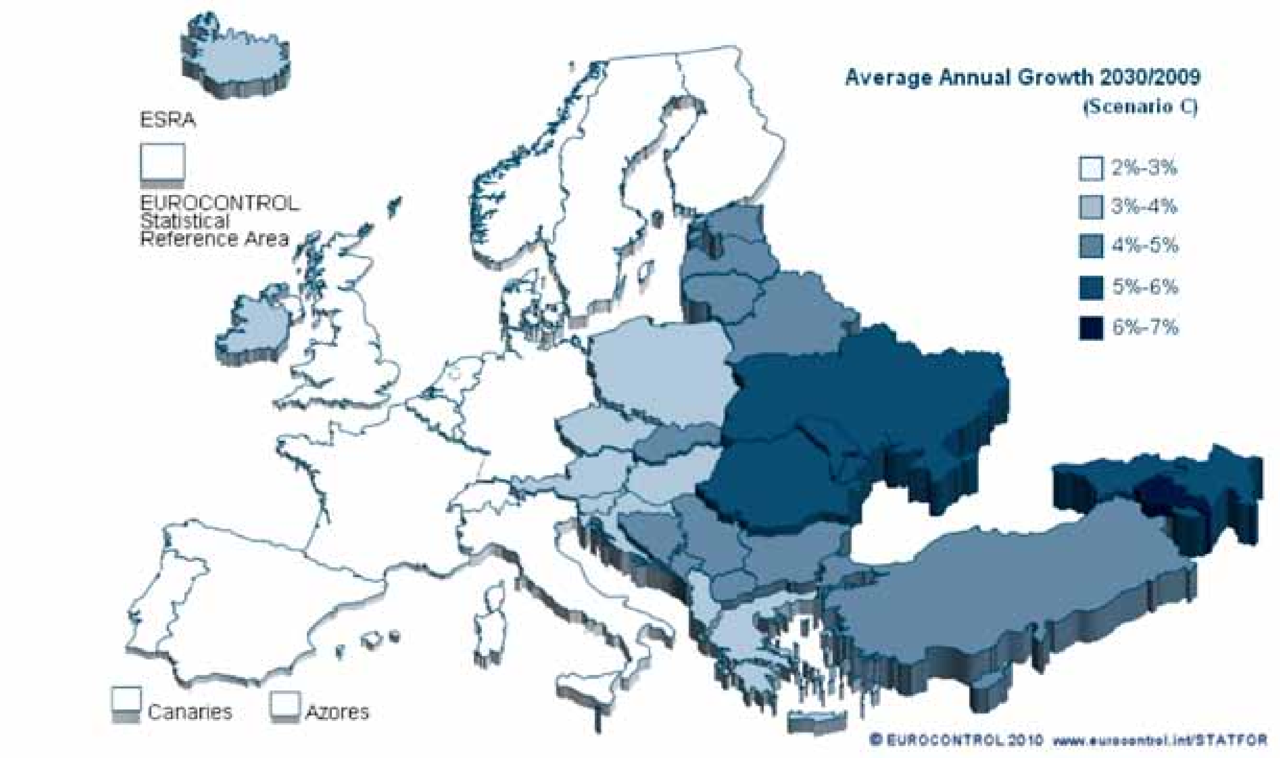


Figure 9, Average annual growth in ECAC by state according to the STATFOR 2010 Long Term Forecast

5.7 Duration and timing of impacts

Impacts will predominantly affect infrastructure, operations and operating costs and can be either intermittent or persistent. Some impacts may not be a concern until the middle of the century whilst others may be experienced sooner.

Impacts will predominantly affect infrastructure, operations and operating costs although some, such as changes in demand, may also affect business models.

Persistent impacts have a mainly constant effect once they start to occur, such as sea-level rise and temperature increases.

Intermittent impacts occur with variable frequency and intensity, such as convective weather events and heavy snowfall.

Table 2 summarises expected impacts and identifies potential resilience measures. This will be expanded on in Section 6. Figure 10, gives a high-level indication of the timeframe in which various impacts can be expected. Of course, there are inherent uncertainties in such forecasts as well as potential regional differences. However, at a high-level, it indicates that whilst some impacts, particularly intermittent events which affect operations, will be experienced in the short term, other impacts, such as sea-level rise, may not be a concern until the middle of the century.

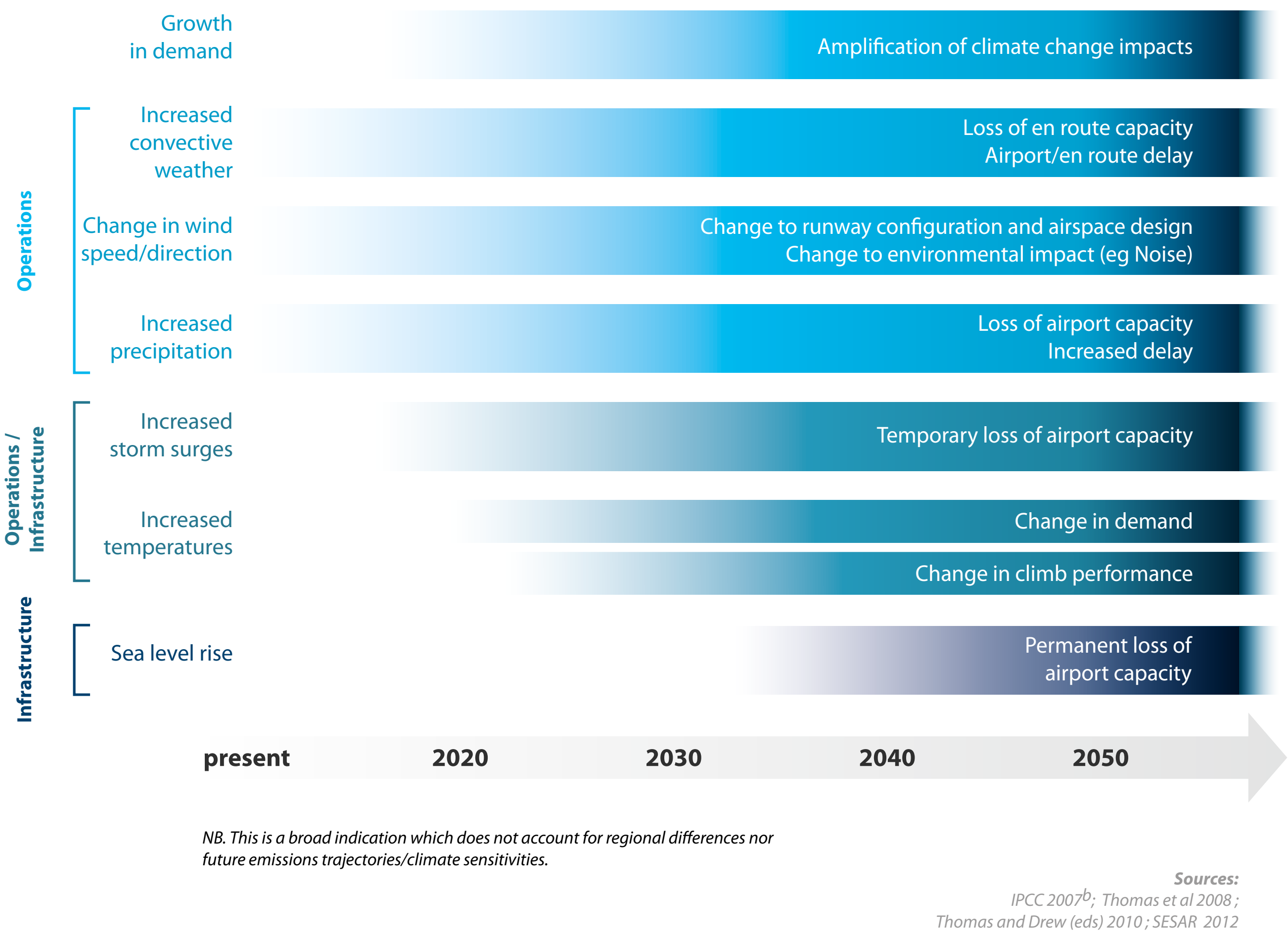


Figure 10, Timeline of expected impacts

	Effects				
	Temperature increase	**Changes to precipitation (rain and snow)**	**Increase in intensity and frequency of convective**	**Changes in Wind patterns**	**Sea level rise**
Areas likely to be affected	All Europe but severity of impact will vary according to geographical location	All Europe but direction of change and severity of impact will vary	Western and Central Europe, in particular peri-alpine areas	Northern parts of Western and Central Europe	Coastal Europe, particularly Northern European coastlines and the Southern Mediterranean
Potential impact for aviation	Changes in demand Changes in climb performance Changes in noise impact Heat damage to tarmac surfaces	Operational impacts: loss of capacity and efficiency. Increased delay Increased de-icing requirements. Increased pressure on drainage systems. Structural issues due to changes in ground frost depth and duration	Operational impacts: loss of capacity and efficiency. Increased delay.	Increased crosswinds and loss of runway capacity	Loss of network capacity, increased delays, network disruption. Temporary or permanent airport closure
Type of impact	Persistent	Intermittent	Intermittent	Intermittent	Persistent
Approximate timescales	>20 years before impacts become serious	< 20 years but potentially much sooner	< 20 years but potentially much sooner	< 20 years but potentially much sooner	>40 years before impacts become serious
Potential resilience measures required	▪ Research to understand potential demand shifts ▪ Review of infrastructure and personnel requirements (+/-) ▪ Airspace redesign ▪ Community engagement	▪ Operational improvements to increase robustness and flexibility ▪ Improved use of MET forecasting ▪ Information sharing (SWIM) ▪ Training ▪ A-CDM	▪ Operational improvements to increase robustness and flexibility ▪ Onboard technology for weather detection ▪ Improved use of MET forecasting ▪ Information sharing (SWIM) ▪ Training ▪ A-CDM	▪ Local risk assessments ▪ Operational improvements to increase robustness and flexibility	▪ Operational improvements to increase robustness and flexibility ▪ sea defences ▪ development of secondary airports

Table 2, overview of key climate change impacts and resilience measures identified

This range of timescales was reflected in the CG13 consultation with 37% of respondents considering that climate change is already impacting their business and a further 37% expecting to experience impacts by about 2020 (N = 16, Figure 12). The number of stakeholders already experiencing impacts was higher than expected suggesting that a particular part of the sector may be more vulnerable. However, cross-analysis by type of organisation showed no clear patterns. It may be that there was a certain amount of self-selection, with respondents who are already experiencing impacts such as more extreme weather being more likely to respond to this question.

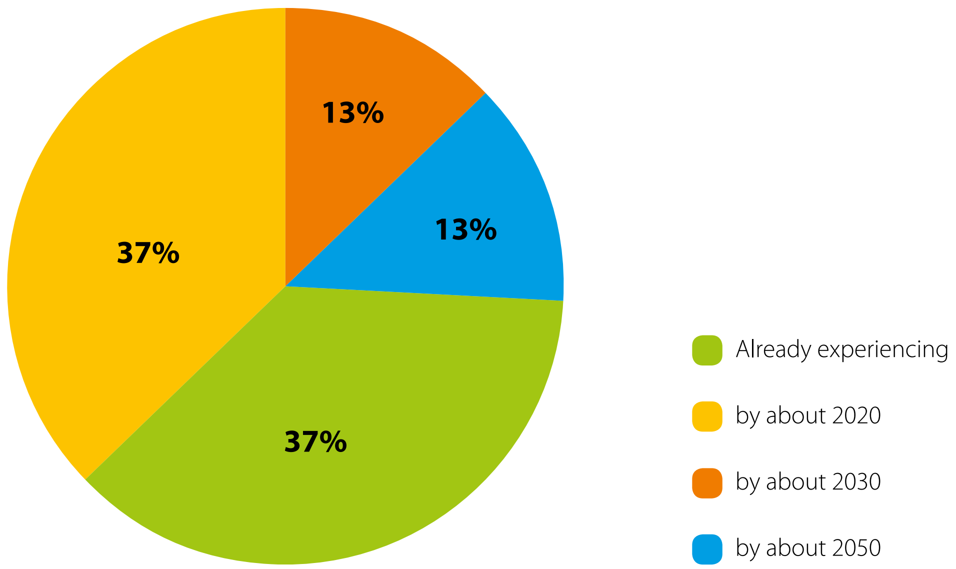


Figure 11, Timescales in which stakeholders expect to experience the impacts of climate change

6. Building Climate Resilience

The growing need to plan and implement adaptation measures is now widely accepted, although fewer organisations have started to take action. Despite costs being uncertain, collaboration, training and "no-regrets" measures can be cost-effective solutions. Early and effective adaptation action can be cost-beneficial over time.

The CG13 consultation indicates that the need for climate change risk assessment and planning for adaptation measures is growing and increasingly accepted. 86% of survey respondents expect adaptation to the impacts of climate change to be necessary, suggesting that even those organisations which don't yet have an official position consider that action may be required (N = 29, Figure 12a). However, just 48% of respondents have begun adapting to climate change suggesting that although the risk is increasingly recognised, this is still an emerging issue (N = 25, Figure 12b). Several respondents said that they don't have enough information to begin planning for adaptation, indicating a need to provide guidance on how to build resilience.

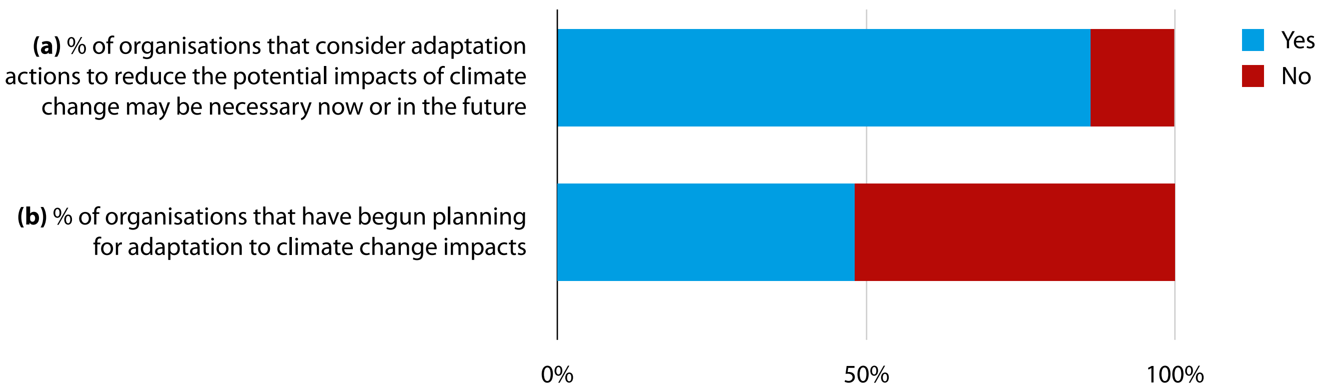


Figure 12, Percentage of respondents who (a) consider adaptation to climate change will be necessary (b) have begun adaptation planning.

6.1 Identifying Actions to Build Resilience

Greater unpredictability increases the need for collaboration. MET information and proactive responses can improve operational resilience. Cost-benefit analyses will be required to identify appropriate levels of infrastructure protection. Further sector and location specific risk assessment is required to quantify potential impacts.

In general, climate change will cause the aviation industry to have to cope with varying degrees of weather unpredictability (H. Puempel, WMO). Moreover, the overall network can be vulnerable to delays and disruption caused by severe weather in one location, particularly when a single major hub is affected. This suggests that aviation stakeholders need to work together more closely to develop and implement resilience measures (N. Cooper, Eurocontrol).

Improved MET support is now available to ATM to enable better advance planning. Probabilistic forecasting can identify potential weather issues several days in advance and models can now run at a much higher resolution than previously. When dealing with extreme weather, it is important to find a balance between dealing with the issue effectively and overreacting. Trials have demonstrated that effective proactive planning responses to severe weather can produce significant performance gains in adverse conditions compared to unstructured reactive responses which could reduce capacity and compromise safety margins. This means that decision-making needs to be built on confidence in good meteorological information and an understanding of what those conditions mean in practice (N. Cooper, Eurocontrol). Consequently, there is a need for that confidence to be built on evidence and new ways of managing expectation. Moreover, although information flows are vital, people still need to be trained in how to use the information (H. Puempel, WMO). Training in how to respond to the actual extreme weather itself is also required.

Sea-level rise is slower and more predictable in the medium term, making it easier to perform a safety and economic risk analysis for low-lying, coastal airports and leaving sufficient time to put adaptation strategies in place. Factors such as the frequency of storm surges are challenging, but major efforts are underway to improve their predictability (H. Puempel, WMO). Resilience measures may include building or improving sea defences and introducing standards for new infrastructure. For example, the Norwegian Airport operator and ANSP, Avinor, has recently introduced guidance stipulating that runways should not be built lower than 7 metres above sea level. Furthermore, all exposed runways at coastal airports have undergone an extensive programme to increase wave and storm surge protection (O. Larsen, Avinor). However, flood defences can be expensive and especially so where these are required for wide-spread infrastructure such as airports and ground-transport access networks. Therefore cost-benefit analyses will be required to determine to what extent existing infrastructure should be protected and to what extent other measures, such as relocation, should be considered. There may be cases where in the long-term it is more cost-effective to allow some degree of damage to infrastructure rather then instigate expensive infrastructure projects, as long as safety is not compromised (O. Larsen, Avinor). Moreover, in cases where there may be impacts for ground access infrastructure, or essential utilities such as energy supply or telecommunications, adaptation planning may not be a matter for the aviation industry alone but rather an issue which requires collaboration and action from a range of regional stakeholders including governments and the business sector.

However, although many concrete actions have already been identified, the specific risks in some areas are still to be quantified suggesting that further aviation sector-specific analyses and risk assessments are required to quantify those potential impacts. Several studies have now been completed which analyse the potential impacts of climate change for tourist preferences (c.f. EEA, 2012). However, as yet, only limited work has been done to translate those changes of preferences into potential changes of demand for aviation (c.f. Dimitriou and Drew, 2010). Therefore the potential impacts of climate change on traffic demand and its interaction with other economic and social factors could be better understood. It would be prudent to instigate further work to examine any possible trends. The results of such studies could then be used to inform medium and long-term operational and business planning.

Other factors such as the implications that climate change may have for en-route capacity would also benefit from greater understanding, whilst the more general consequences of a changing climate, such as potential changes in wind vector, need to be translated into specific local impacts. Therefore, whilst implementing concrete measures to build resilience to those impacts which have already been identified should not be delayed, it would be judicious to carry out further specific analyses at both local and network level.

Although, there is uncertainty as to the costs involved in building climate resilience and organisations may not be willing to pay now to avoid something which may happen in the medium to long term, early and effective adaptation can be cost beneficial over time. Moreover, some of the cheapest but most effective measures to improve overall resilience may not involve large and expensive infrastructure upgrades. Both staff training to increase awareness and prepare for effective and efficient reactions to extreme weather incidences and improved collaboration and sharing of best practices, experiences and solutions have been identified as effective low-cost measures. Additionally, there are many so-called "no-regrets" or "win-win" measures: measures which are already being implemented to address other issues such as capacity but which also contribute to building climate resilience (Doll et al, 2011). In particular, some SESAR operational improvements, such as those addressing capacity, information sharing and constraint management, may fall into this category (Jeandel et al, 2012). Moreover, many of the solutions being introduced to build greater short-term weather resilience and facilitate operations in adverse conditions also help to build long-term climate resilience.

Of course, specific locations and organisations will have to identify the appropriate balance between cost and effectiveness for their particular circumstances. Measures such as training are comparatively cheap and transferable providing improved reactions to intermittent issues such as extreme weather whereas infrastructure improvements, although expensive, may be required to address long-term persistent issues such as sea-level rise. Operational improvements which are implemented for other purposes can be seen as a way to build climate resilience for minimal or negative cost. Additionally, increased intermodal cooperation would also be beneficial in order to ensure passengers can still arrive at the airport or complete their journeys in adverse conditions (Doll et al, 2011). There is also increasing regulatory and financial sector interest. The UK Government requires climate adaptation plans from its seven largest airports and the European Commission is addressing climate resilience through its forthcoming EU Adaptation Strategy. The Strategy will promote information sharing, best practice and closure of knowledge gaps whilst mainstreaming climate action, both adaptation and mitigation, into policy and legislation. It is supported by an online adaptation platform and an adaptation guidance document produced by the European Environment Agency (EEA, 2013)[9]. Climate adaptation is also gaining momentum in the financial sector: the European Investment Bank now has a requirement for new projects to consider climate resilience when applying for funding whilst the World Bank doubled lending for climate change adaptation projects in the past year (World Bank, 2012).

9 http://climate-adapt.eea.europa.eu/

6.2 Current Adaptation Status of the European Network

A growing number of actors within the aviation industry are already taking comprehensive steps to assess potential vulnerability to climate change and put in place appropriate adaptation plans. However, the majority of actors have yet to consider this issue.

Although an increasing number of organisations now consider that climate change will have a negative impact on their organisation, a smaller number have already begun planning or implementing resilience measures (Section 6, Figure 12). This suggests that the sector still has more to do to build sufficient resilience to the potential impacts of climate change. This is reflected in the results to the CG13 stakeholder consultation with half of respondents of the opinion that the European aviation sector already has some adaptation measures in place but more needs to be done (Figure 13). However, for European ATM only a third of survey respondents consider that some adaptation measures are already in place with another third suggesting that although adaptation may have been considered no actions have yet been initiated. In both cases, a quarter of respondents are of the opinion that adaptation has not yet been considered.

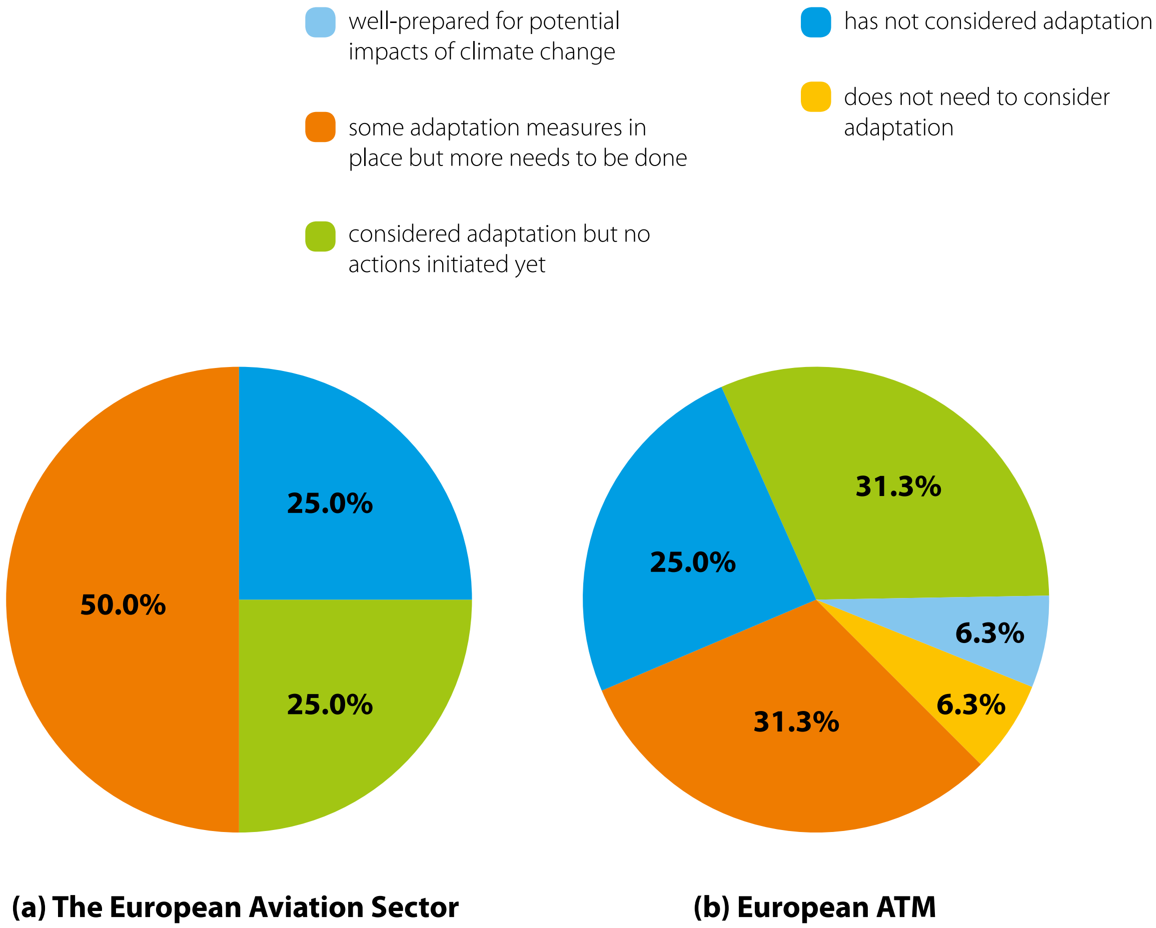


Figure 13, Stakeholder perception of level of preparedness for the potential impacts of climate change for (a) the European Aviation Sector as a whole (b) European ATM

Given the interconnectedness of the aviation network the introduction of resilience measures at both local and system-level will be required. The CG13 consultation indicated that, to date, relatively few organisations have developed climate change adaptation plans, although those that have been put in place tend to be comprehensive (c.f. LHR, 2011; MAN, 2011). Of those organisations that have begun taking action, the most common initiatives are alterations to infrastructure and contingency planning to improve the resilience of operations (Figure 14).

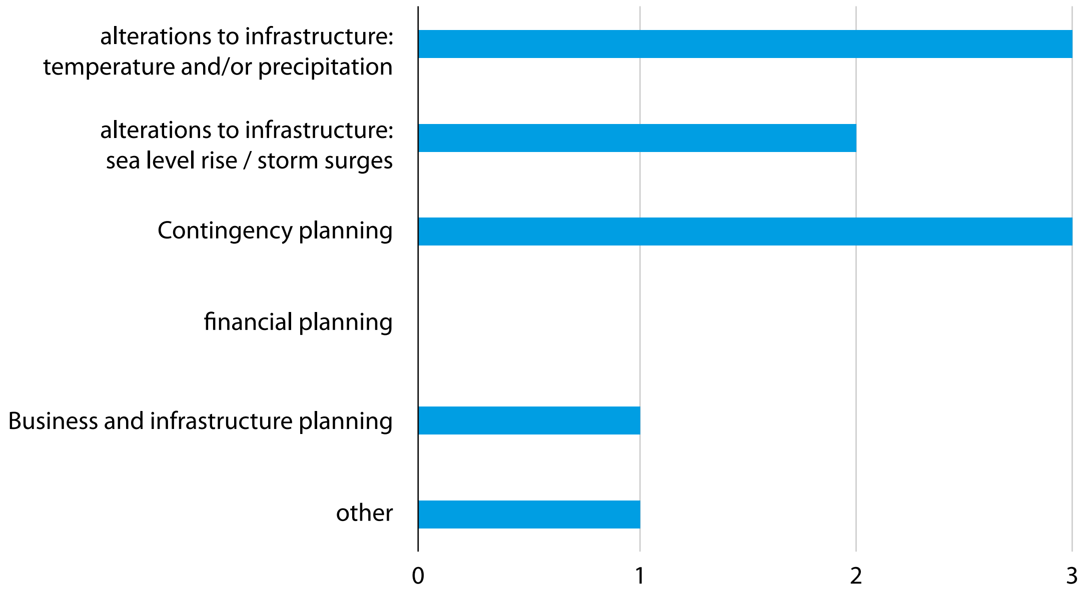


Figure 14, Measures which aviation sector organisations are taking to develop climate resilience

At network level some initiatives are already in place in order to improve predictability, and thus build resilience. The EUROCONTROL Network Manager has analysed meteorological data for a five year period in order to develop an overview of where and when challenging meteorological conditions were experienced and how much delay was caused as a result. This allows the building of a picture of both where to expect extreme weather and the extent of the impact which it might cause which. In turn, this enables planning for appropriate resilience measures (N. Cooper, Eurocontrol). The Network Manager has now implemented an ATC/ATFCM severe weather procedure which entails reporting, planning, coordination, communication and monitoring responsibilities. Strategies are also being put in place to proactively manage demand when a severe weather event is considered highly probable.

The European Aviation Crisis Coordination Cell (EACCC), established to enable the coordination of an effective response to crisis situations which have an adverse impact on the aviation network, can be convened in response to exceptionally heavy meteorological conditions. In order for this to happen, the level of disruption would have to be at a sufficiently high level for the overall network to be impacted, for example if severe weather was affecting several European hub airports.

The SESAR programme is developing MET infrastructure and services to integrate improved MET capabilities to European network operations. This increases resilience by promoting better information sharing, which in turn allows for more proactive and flexible responses to disruptive weather events. Other SESAR network improvements, for example those which aim to improve airport and en route capacity also provide benefits as they increase the overall resilience of the network to perturbation.

At local level, although many organisations have yet to consider climate resilience measures, others have initiated comprehensive adaptation programmes. The Norwegian ANSP and airport operator Avinor has been implementing resilience measures since 2001 and is carrying out comprehensive risk assessments for all 46 of its airports (O. Larsen, Avinor). Following a government regulation identifying them as critical infrastructure, the largest UK airports have developed comprehensive risk assessments and adaptation plans (c.f. LHR, 2011; MAN, 2011). The UK ANSP, NATS, has also carried out an assessment of the potential climate change risks to its business and operations (NATS, 2011).

Of course, these examples are not intended as an exhaustive list of adaptation measures planned or in progress, nor will they be appropriate in every case. However, they serve as an indication of the type of actions required.

6.3 Planning for Future Network Resilience

Impact assessment and resilience planning are required at both network and local level. Whilst this entails some further research and risk assessment, it is also time to begin implementation. Although current forecasts suggest that many actions may not be urgent it is cost-effective to identify measures which address other issues whilst building resilience. The development of a climate resilience KPI may facilitate proactive and event-appropriate operational responses.

"Avoid creating islands of resilience in an ocean of vulnerabilities"

Airport Operator, more than 400,000 movements per annum

When planning resilience measures for this risk, it is essential to keep in mind the interconnectedness of the European and global aviation networks: it is pointless for one part of the global integrated transport system to become fully protected against this risk, if another vital part does not. This suggests that an integrated network-wide impact assessment and resilience planning may be required. This can be roughly translated into four key areas of work: research, risk assessment, collaboration and implementation. Table 3 sets out proposed actions which stakeholders identified for each category.

Area of Work	Stakeholder Proposals
Research	■ Continue R&D efforts: identify and quantify possible impacts and appropriate adaptation measures ■ Research specific risks such as changing predominant wind vector and changing demand ■ Understand environmental effects in terms of populated areas affected by noise
Risk Assessment	■ General European risk assessment: assess possible impacts over a timeframe of 30 to 40 years; identify a list of realistic priorities; follow with action plans and funding ■ Risk assessments of site-specific climate change impacts, including utilities and surface access, followed by action plans
Collaboration	■ Targeted dissemination of scientific research to stakeholders ■ Communication and collaboration between stakeholders – best practice and shared solutions
Implementation: infrastructure	■ Develop knowledge/ and expertise ■ Identify where resilience can be built as part of ongoing infrastructure improvements ■ Allocate adequate funding and resources to mitigate risks.
Implementation: operations	■ Develop knowledge/ and expertise ■ Provide training on mitigating possible risks for relevant personnel ■ Identify no-regrets measures which address other issues such as capacity ■ Identify where resilience can be built as part of ongoing operational improvements ■ Make better use of MET support ■ Develop a KPI to measure ATM climate resilience

Table 3 Stakeholder proposals for improving European aviation's response to climate change risk

The European Environment Agency (EEA, 2013) suggests that adaptation actions should be evidence-based, effective, efficient and equitable. In order to take evidence-based and effective action it is necessary to more precisely identify risks and timescales at both network and local level. Following this, appropriate resilience measures can be identified, the resilience potential of other operational and infrastructure improvements can be exploited and a timetable for implementation can be put in place.

Although current forecasts, arguably, suggest that many actions may not be urgent, it is cost-effective to identify measures which build resilience whilst implementing ongoing operational and infrastructure improvements. Improved communication and collaboration will help to avoid duplication, improve effectiveness and efficiency, and ensure that the most vulnerable parts of the network are protected.

Measuring Resilience

In order to facilitate the mainstreaming of climate adaptation for ATM some stakeholders proposed the development of a key performance indicator (KPI) to quantify levels of resilience. This would serve two purposes. Firstly, it would quantify the base level of network resilience and the corresponding impact of a disruptive event in order to facilitate the development of mitigation actions. Secondly, it would also facilitate more proactive reactions to disruptive weather by identifying an event-specific performance goal which is aligned with ATM capacity management and flight safety requirements. Some general work on developing the concept of resilience for ATM has been begun by the EU FP7 project Resilience2050 and synergies should be developed in order to apply this specifically to climate change risks. [11]

6.4 Recommendations for European Aviation

As a result of the recommendations made by stakeholders during the CG13 consultation (Table 3), the following high-level actions are proposed to promote climate resilience for the European aviation sector. They should be considered both by individual organisations and as part of a potential EU-level climate risk mitigation plan:

- Assessment of gaps and vulnerabilities for the sector at local and pan-European level;
- Identification and implementation of specific local and network-wide resilience measures, particularly no-regrets measures;
- Identification and implementation of measures such as training which can be cost-effective when implemented at a local and pan-European scale;
- Continuation of the work begun by the EUROCONTROL Network Manager to implement collaborative responses to disruptive weather incidences;
- Assessment of planned SESAR operational improvements to identify their potential to implement no-regrets climate resilience;
- Development of an appropriate KPI which facilitates the mainstreaming of climate change resilience, whilst being commensurate with ATM capacity management and flight safety;
- Increased collaboration with MET Services to better exploit advanced forecasting techniques;
- Analysis of the potential impacts of climate change on air traffic demand and its interaction with other economic and social factors to inform medium and long-term operational and business planning.

6.5 Recommendations for the Challenges of Growth Long-Term Forecast (LTF)

Due to its limited scope, this study has considered the potential impacts of climate change within the context of a 'business as usual' scenario. However, it is likely that if climate change impacts do develop as expected there will be wider societal and economic changes which will impact the aviation industry. Robust information as to likely outcomes is currently limited but should be considered in future iterations of the LTF as it becomes available. However, on the basis of a 'business as usual' scenario the following impacts should be taken account of in the CG13 LTF:

- **2035**: the largest impact is likely to be increased network congestion due to more frequent and intense periods of disruptive weather. Although, such instances are intermittent rather than persistent, their likely increasing frequency and severity will lead to an increased cumulative impact out to 2035. This is likely to have the biggest impact on Scenario A 'Global Growth' as a higher traffic volume can reduce resilience if appropriate measures are not in place. In Scenarios where the network is further from operating at full capacity, the impacts will be less, although greater fragmentation will reduce resilience.
- **2050**: impacts such as sea-level rise and climate-driven changes in demand will be both more strongly felt and experienced in combination with intermittent disruptive weather. This will combine to reduce overall capacity and limit opportunities for travel possibly resulting in a greater likelihood of Scenario D 'Fragmenting World' unless appropriate resilience measures have been put in place in preceding years.

[11] http://resilience2050.innaxis.org/

7. Conclusions

The science concerning the potential physical impacts of climate change for the various regions of Europe is now reasonably mature, although forecasts as to the precise extent, timescales and pace of change are, by their nature, regularly revised. Although comparatively less work has been done to assess the specific risks of climate change for the aviation industry there is now broad agreement on the qualitative issues which will be faced. Key impacts identified include increased disruptive weather events, rising temperatures and sea-level rise. However, the range of potential impacts is diverse and varies with geographical location. This suggests that resilience measures will need to be identified and implemented at both pan-European and local scale.

Overall, climate change is an issue of risk management and the Challenges of Growth stakeholder consultation demonstrates that a growing number of organisations are either taking or considering action to address climate change risk; 86% of survey respondents expect adaptation actions to be necessary. This indicates a clear shift in position compared to the limited number of organisations active in this area four years ago. However, even though many stakeholders expect climate change to be an issue in the short-to-medium term, a relatively small number have begun planning or implementing resilience measures. Several stakeholders have expressed concerns that they do not have enough information on impacts, risks or climate risk assessment processes to be able to begin planning. This suggests that, overall, more data, information and guidance are required and that this is an issue which needs to be addressed collaboratively as an industry.

To complement physical infrastructure and operational resilience measures, some of the cheapest and potentially most effective ways identified to build resilience are staff training, sharing of best practices, experiences and solutions, and the implementation of processes which facilitate collaborative responses to climate change challenges. In particular, the development of realistic and objective operational responses should be considered. A challenge going forward is to determine an appropriate KPI which facilitates the mainstreaming of climate change resilience, whilst being commensurate with ATM capacity management and flight safety.

Many of the solutions being introduced to build greater weather resilience and facilitate operations in adverse conditions also help to build long-term climate resilience. Other "no-regrets" measures which also address issues such as capacity can be cost-effective solutions. Therefore, although the potential impacts of climate change are numerous and will vary according to climate zone many solutions are either already being implemented, or at least have been identified. Nevertheless, there is a financial implication to this preparedness and cost-benefit analyses will be required to determine what level of impact to be able to cope with.

Moreover, due to the interconnectedness of the European and global aviation systems, an integrated approach to building resilience is essential to ensure that vulnerabilities in one part of the network don't exacerbate impacts for other parts. The challenge will be to implement cost-effective solutions and maintain network resilience whilst dealing with the additional constraint of growing demand. Such a synergistic approach should also be extended to other parts of the transport network to reduce overall vulnerability to the maximum extent possible. Notably, the financial sector is seeing adaptation to the impacts of climate change as increasingly important: the World Bank has doubled lending for climate change adaptation projects in the past year, whilst the European Investment Bank now has a stipulation that all new projects must address climate resilience.

Although the potential impacts of climate change are multi-faceted, with any one location likely to have to deal with multiple challenges at the same time as accommodating increasing growth in demand, to a large extent the solutions are already identified. The risks are not necessarily urgent but are best addressed by building resilience into current infrastructure and operations planning and by identifying cheap and no-regrets measures. The challenge now is to work collaboratively to implement those solutions as efficiently and effectively as possible. Early action is the key to building resilience at the lowest cost. Therefore, the time to act is now.

8. References

Primary Sources

Nicola Cooper,
Head of Network Operations Management, EUROCONTROL

Olav Mosvold Larsen,
Senior Executive Adviser, AVINOR

Franca Pavlicevic,
Head of Navigation and CNS Research Unit, EUROCONTROL

Dr Herbert Puempel,
Chief, Aeronautical Meteorology Division, World Meteorological Organisation (WMO)

Secondary Sources

Amelung, B. and Moreno, A. (2009) Impacts of climate change in tourism in Europe. PESETA-Tourism study (JRC Scientific and Technical Reports). European Commission — Joint Research Centre, Institute for Prospective Technological Studies [online] http://ftp.jrc.es/ EURdoc/ JRC55392.pdf (accessed 07/01/2013)

de Gusmão, D. (2010) Case-Study 2: European Airports and Sea Level Rise, in Thomas, C. and Drew, A. J. (eds) (2010) Challenges of Growth Environmental Update Study: Climate Adaptation Case Studies, EUROCONTROL, Brussels

Dimitriou, D. and Drew, A. J. (2010) Case-Study 1: Changes to Tourist Activity in Greece, in Thomas, C. and Drew, A. J. (eds) (2010) Challenges of Growth Environmental Update Study: Climate Adaptation Case Studies, EUROCONTROL, Brussels

Doll, C., S. Klug, J. Köhler, I. Partzsch, R. Enei, V. Pelikan, N. Sedlacek, H. Maurer, L. Rudzikaite, A. Papanikolaou, V. Mitsakis (2011) Adaptation Strategies in the Transport Sector: Deliverable 4 of the research project WEATHER (Weather Extremes: Impacts on Transport Systems and Hazards for European Regions) funded under the 7th framework program of the European Commission. Project coordinator: Fraunhofer ISI, Karlsruhe

EUROCONTROL (2010) Long-Term Forecast Flight Movements 2009 – 2030, STATFOR, EUROCONTROL, Brussels

EUROCONTROL (2011) CODA Digest: Delays to Air Transport in Europe 2011, CODA, EUROCONTROL, Brussels

EUROCONTROL (2012) Challenges of Growth 2013, Task 1: on the use of the 20-year forecast published in 2010, STATFOR, EUROCONTROL, Brussels

European Climate Adaptation Platform (EC) [online] http:// climate-adapt.eea.europa.eu/ (accessed 07/01/2013)

European Environment Agency (EEA) (2012) Climate Change Impacts and Vulnerability in Europe 2012, European Environment Agency, Copenhagen

European Environment Agency (EEA) (2013) Climate Change Adaptation in Europe, European Environment Agency, Copenhagen (forthcoming)

IATA (2012) Hurricane Sandy added to Industry Challenges in October, IATA Press Release no. 48, 29 November 2012) [online] http://www.iata.org/pressroom/pr/pages/2012-11-29-01.aspx (accessed 25/01/2013)

ICAO (2006) Doc 8168: Construction of Visual and Instrument Flight Procedures, UN International Civil Aviation Organisation, Montreal

IPCC (2007a) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller, eds.). Cambridge University Press, Cambridge. [online] http:// www.ipcc.ch/publications_ and_data/ar4/wg1/en/contents.html (accessed 07/01/2013)

IPCC (2007b) Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson, eds.). Cambridge University Press, Cambridge. [online] http://www.ipcc.ch/ publications_and_data/ar4/wg2/en/ contents.html (accessed 07/01/2013)

IPCC (2012) Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Special Report of the Intergovernmental Panel on Climate Change. (C. B. Field, V. Barros, T. F. Stocker and D. Qin, eds.). Cambridge University Press, Cambridge. [online] http://ipcc-wg2.gov/SREX/report/ (accessed 07/01/2013)

Jeandel, A., Burbidge, R., Goldmann, D., Melrose, A., Schreiber, B. (2012) Base-line Environmental Risk Review – D03 of SESAR Project 160307, SESAR, Brussels

Leviäkangas, P., Tuominen, A., Molarius, R. and Kojo, H. (2011) Extreme Weather Impacts on Transport Systems. EWENT Deliverable D1 (VTT Working Papers No. 168). VTT

Heathrow Airport (LHR) (2011) Climate Change Adaptation Reporting Power Report, Heathrow Airport Limited, London

Lowe, J. A., Howard, T., Jenkins, G., Ridley, J., Dye, S. and Bradley, S. (2009) UK Climate Projections science report: Marine and coastal projections. Met Office Hadley Centre, Exeter, United Kingdom. [online] http://ukclimateprojections.defra.gov.uk/22639 (accessed 07/01/2013)

Manchester Airports Group (MAG) (2011) Climate Change Adaptation report for Manchester Airport and East Midlands Airport, Manchester Airports Group, Manchester

Marcos, M., Jordà, G., Gomis, D. and Pérez, B. (2011) Changes in storm surges in southern Europe from a regional model under climate change scenarios. Global and Planetary Change 77(3–4), 116–128 (accessed 07/01/2013)

McDonald, R. E. (2011) Understanding the impact of climate change on Northern Hemisphere extra tropical cyclones. Climate Dynamics 37, 1399–1425

McCarthy, R. and Budd, L. (2010) Case-Study 3: Potential Changes in Severe Convection in Maastricht Upper Area Airspace, in Thomas, C. and Drew, A. J. (eds) (2010) Challenges of Growth Environmental Update Study: Climate Adaptation Case Studies, EUROCONTROL, Brussels

Meier, H. E. M. (2006) Baltic Sea climate in the late twenty-first century: a dynamical downscaling approach using two global models and two emission scenarios. Climate Dynamics 27(1), 39–68.

Molarius, R., Leviäkangas, P., Hietajärvi, A.-M., Nokkala, M., Rönty, J., Könönen, V., Zulkarnain,, K. O., Mäensivu, S., Kreuz,, M., Mühlhausen,, T., Ludvigsen, J., Saarikivi, P., Vajda,, A., Tuomenvirta, H., Athanasatos, S. et al. (2012) Weather hazards and vulnerabilities for the European transport system – a risk panorama (EWENT D 5.1). VTT Technical Research Centre of Finland.

Morse, A., Prentice, C. and Carter, T. (2009) Assessment of Climate Change Impacts in van der Linden, P. and Mitchell, J. F. B. (2009) ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, Exeter [online] http:// ensembles-eu.metoffice.com/docs/ Ensembles_final_ report_Nov09.pdf (accessed 07/01/2013)

NATS (2011) Climate Change Adaptation Report, National Air traffic Services, UK

Scaife, A. A., Spangehl, T., Fereday,D. R., Cubasch, U., Langematz, U., Akiyoshi, H., Slimane Bekki4, Peter Braesicke5, Neal Butchart1, Martyn P. Chipperfield6, Andrew Gettelman7, Steven C. Hardiman1, Martine Michou8, Eugene Rozanov9 and Theodore G. Shepherd (2012) Climate change projections and stratosphere–troposphere interaction. Climate Dynamics 1(9)

Swedish Commission on Climate and Vulnerability (SCCV) (2007) Sweden Facing Climate Change: Threats and Opportunities, Section 4.1.4: Aviation, Swedish Commission on Climate and Vulnerability, Swedish Government Official Reports, Stockholm

Thomas, C., McCarthy, R., Lewis, K., Boucher, O., Hayward, J., Owen, B., and Liggins, F (2009) Challenges to Growth Environmental Update Study, EUROCONTROL, Brussels

Wang, S., McGrath, R., Hanafin, J., Lynch, P., Semmler, T. and Nolan, P. (2008) The impact of climate change on storm surges over Irish waters. Ocean Modelling, 25(1-2), 83–94.

UNFCCC (2012) Adaptation Programme, United Nations Framework Convention on Climate Change [online] http://unfccc.int/adaptation/items/4159.php (accessed 07/01/2013)

van der Linden, P. and Mitchell, J. F. B. (2009) ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, Exeter [online] http:// ensembles-eu.metoffice.com/docs/Ensembles_final_ report_Nov09.pdf (accessed 07/01/2013)

World Bank (2012) 'Turn Down the Heat: Why a 4°C Warmer World Must Be Avoided', World Bank, Washington [online] http:// climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pdf (accessed 07/01/2013)

EUROCONTROL

For further information please contact:

STATFOR, the EUROCONTROL Statistics and Forecast Service

rachel.burbidge@eurocontrol.int
statfor.info@eurocontrol.int
http://www.eurocontrol.int/statfor

STATFOR, the EUROCONTROL Statistics and Forecast Service is ISO 9001:2008 certified.