POTENTIAL ADAPTATION to IMPACTS of CLIMATE CHANGE on AIR TRAFFIC MANAGEMENT

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Abstract - The need for all sectors of society to adapt to climate change is now gaining prominence in the scientific and political arena, for the financial and insurance institutions, and for many industries. Aviation has historically focussed on reducing its carbon dioxide emissions, placing less emphasis on adapting to the effects of climate change itself. However, with increasing certainty that climate change-related impacts will occur, and given aviation's sensitivity to climate and weather, the need to take pre-emptive action becomes more pressing.

New research commissioned by EUROCONTROL, the European Organisation for the Safety of Air Navigation, identifies three areas where climate change impacts may have adaptation issues for air traffic management (ATM): shifts in passenger demand due to changes in local temperature, loss of airport capacity through sea-level rise, and impacts to en-route operations due to increases in extreme weather events (storminess). This paper considers how each issue may affect ATM and whether current ATM planning and research can adequately meet any new challenges which may need to be faced. The paper concludes that although some impacts will not be experienced in the short-term, it would be prudent to begin to consider adaptation in current medium to long-term planning.

Keywords: adaptation planning, demand shift, storminess, long-term planning, climate change, airport capacity, SESAR

I. INTRODUCTION

There is now increasing scientific consensus that mankind is unlikely to keep global average temperature rise within the widely accept target of 2°C, despite the ongoing efforts being made to reduce global anthropogenic carbon dioxide (CO_2) emissions. It is now suggested by several respected members of the scientific community that all sectors of society should be prepared for the potential impacts arising from global average temperature increases of above 2^{o}C [1]. These impacts may be significant in the medium term, especially for industry sectors that are sensitive to changes in climate and the resulting changes to weather patterns. Aviation is one such industry.

Additionally, it is now increasingly recognised that even if steps were taken to drastically cut global greenhouse gas emissions immediately (which many consider to be unlikely), further global warming, and the associated impacts, would still occur due to climate system inertia. The challenges which may be faced include not only impacts such as increased temperatures and the unavoidable associated rise in sea-levels, but less obvious impacts such as an increase in the occurrence and severity of extreme weather events. This is an issue of particular importance to understand as a globally averaged temperature rise can disguise much more extreme local changes in climate and thus in the associated weather disturbances. Other potential consequences of climate change identified as of relevance to ATM include altered aircraft performance, decreases in water availability in certain areas and increased energy use due to hotter conditions (figure 1). Thus the possibility of multiple impacts potentially affecting the aviation industry suggests the need for planning for a range of scenarios across the sector.

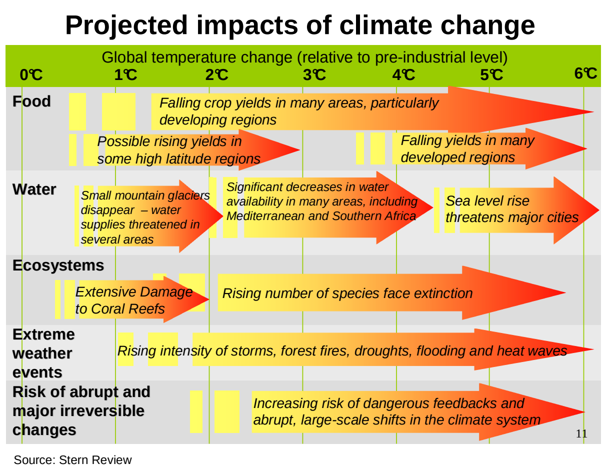

Figure 1: Projected impacts of climate change according to global temperature change (Stern, 2007)

Whilst uncertainties remain over precise timescales and impacts, any changes are likely to be wide-scale and comparatively rapid compared to documented recent experience. This means that, although carbon reduction should not be ignored or forgotten, adaptation planning now becomes a necessity rather than a back-up plan, something which national and international policy is increasingly recognising. Consequently, the aviation industry like most, if not all, industrial sectors and society as a whole, needs to have adaptation strategies in place to deal with the potential climate challenges which it is likely to face.

Short-term weather patterns are not, of course, to be confused with longer-term changes in climate. Yet, such climatic changes do cause changes in local and regional weather patterns. In 2009, weather caused 13% of primary flight delays in Europe, although of course, linking that to climate change would be tenuous in the extreme. Nevertheless, with European traffic estimated to be at 1.4 to 2.2 times 2009 levels by 2030 any potential increase in weather-related disruption is likely to be even more severe [2] (figure 2).

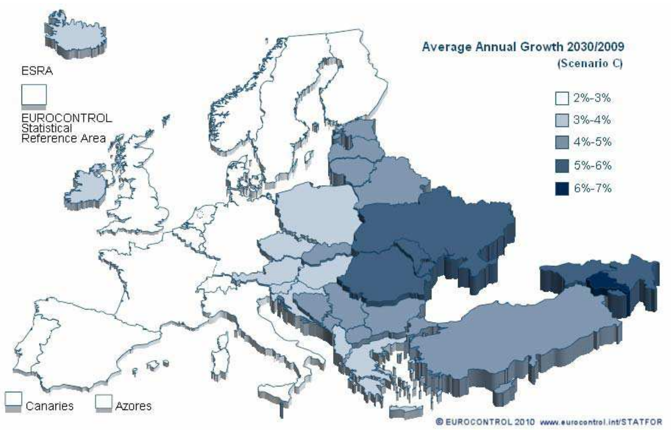

Figure 2: Average annual growth 2009-2030 by State for a scenario incorporating both regulation and growth (STATFOR Scenario C: regulated growth) (EUROCONTROL, 2010)

II. BACKGROUND

Climate change mitigation, through measures such as reducing carbon dioxide (CO_2) emissions, is now an integral part of business planning for many industrial sectors. The aviation industry has taken considerable steps to mitigate its contribution to climate change and, through the work of organisations such as ICAO and ATAG[1], has worked hard to find globally acceptable policy solutions to facilitate this, including a range of measures aimed at cutting greenhouse gas emissions [3]. On a European level, several initiatives have been established which include measures to both improve operational efficiencies and reduce environmental impacts. For example the Flight Efficiency Plan [4] and European Joint Industry CDA Action Plan [5] have both delivered significant environmental *and* operational benefits.

Of course, there are always new and more effective mitigation actions which can be implemented. However, with some climate change-induced impacts now considered inevitable, those areas of the aviation sector which have not yet done so would be prudent to begin putting adaptation strategies into place.

There are two key reasons that make aviation particularly vulnerable to any potential change in climate. Firstly, aviation is one of the most weather-dependant sectors of the transport industry and thus particularly vulnerable to the potential changes in local weather conditions which may be instigated by climate change. Secondly, considering the interconnectedness of both the European and global Air Traffic Management (ATM) networks, loss of performance in any single component has an unavoidable knock-on effect on other components. For example, when one major airport or national airspace sector has its operations disrupted, average European air traffic delay can increase across the entire region, often taking the rest of the day to recover. And, due to the ever-increasing interconnectedness which aviation facilitates, this can also have a global effect, as witnessed recently during the weather-related closure of many European airports in December 2010, when planes scheduled to fly to Europe were grounded around the world. Therefore any potential impact which may have consequences for one, or multiple, areas of the network needs to be understood in order to mitigate its impact on the system as a whole.

With this in mind, EUROCONTROL, the European Organisation for the Safety of Air Navigation[1], commissioned one of the first studies into this potential adaptation challenge. This study formed part of a broad review of future environmental challenges in the Environment Technical Report [6] of the 2008 update to EUROCONTROL's Challenges of Growth (CG08) work [7]. The Challenges of Growth work is carried out periodically by EUROCONTROL with the intention of looking at long-term traffic forecast scenarios, and the related challenges and opportunities they present, in order to offer advice to decision makers on the key challenges facing the European air transport system. The CG08 work covers a time horizon up to 2030 and thus covers the period where initial climate change impacts may begin to be experienced by the industry. As part of the CG08 work an environment study was carried out by the OMEGA Consortium, a partnership of UK Universities, and the UK Met Office and highlights several areas where climate change could impact on the European ATM System.

[1] The Air Transport Action Group (ATAG) is a consortium of aviation organisations (including ANSPs, Airports, Airspace users and industry) working together to find solutions for the sustainable growth of aviation http://www.atag.org/content/default.asp

The Environment Technical report [6] highlights a range of climate related risks including:

- Geographical and seasonal demand distribution due to changes in average temperatures, humidity and water availability;
- Changes in aircraft performance due to increased temperatures;
- Increases in noise contours[2];
- Changed de-icing and snow clearance requirements – including the loss of "white" runways in Northern regions ;
- Reduced ability to meet demand due to water shortages;
- Loss of coastal airport availability due to local sea-level rise or storm surges;
- Loss of ground access to airports through local sea-level rise and flooding;
- Changes to storm tracks and hence changes to location of possible weather disruption;
- Economic costs due to operational disruption.

Of these potential impacts, three risk areas were selected as illustrative case-studies for further more detailed research in order to make the overall risk portfolio from climate change more tangible for the ATM community, and to highlight particular areas where climate change adaptation strategies may need to be considered. The objectives of the case-study approach were to make the general findings of that report more 'tangible', to explore possible outcomes in more detail and to examine gaps and weaknesses in the understanding of this risk. This paper will discuss the findings of these case-studies in the context of the need for a climate change adaptation strategy for European, and international, ATM. The paper will consider the challenges which may be faced and how ongoing or planned work through research projects such as SESAR, the Single European Sky ATM Research Programme may need to address, or indeed may already be addressing, these new key challenges. Although the paper will mainly consider the work currently being undertaken, or planned, in Europe this is not intended to overlook work being carried out in other parts of the World, nor the need for international guidance on, and planning for, aviation climate adaptation.

The case-studies together with the CG08 Environment Technical Report will be a key input to the SESAR research programme which is funded by the European Commission, EUROCONTROL and industry and is designing Europe's air traffic management system for the coming decades. It contains a specific work-package examining future environmental risk for the European ATM system, which EUROCONTROL is leading.

[2] Higher temperatures will lead to a decrease in air density which in turn affects take-off and climb performance

III. Case-Study Overview

The three case-studies undertook modelling and analysis of the following ATM climate-change risks, and the associated potential impacts over a 2020-2090 timescale.

- Potential shifting traffic demand due to climate-related changes in tourist destination preferences and resource availability in the Mediterranean basin (e.g. potable water). The study focused on a Mediterranean country with a significant percentage of its GDP sourced from tourism and where, due to geographic location, aviation is also the key means of tourist arrivals;

- The initial Challenges of Growth 2008 Environment Technical Report (Thomas *et al.*, 2008) identified 34 European Airports that could potentially be at risk from sea level rise, storm surges and flooding by the end of the century. Case Study 2 is a qualitative assessment of potential sea-level rise and flooding at three of these coastal and low-lying airports – including ground transport access and infrastructure; and,

- 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 and how this may influence European ATM. Maastricht Upper Airspace (MUA) is one of the busiest areas of airspace in Europe and has a high proportion of climbing and descending traffic from several of the major international European airports.

It is important to note that the work was carried out in the first Quarter of 2010 and thus represents a snapshot of the thinking at that point in time. The following sections consider the results of each study in greater detail, the possible implications which climate change may have and the potential adaptation measures which may thus be required. The timescales over which the various impacts may be expected to be felt vary from the short-term (2020 onwards) for increased extreme weather to the long term (the 2090s) for dangerous sea-level rise, and all depend to some extent on the degree of warming eventually experienced.

A key outcome is that these case-studies have highlighted a real need for more detailed research with a specific emphasis on identifying the possible timescales over which impacts may be felt in order to construct the scenarios on which to base realistic adaptation planning. Another key area for further research is quantifying the potential financial implications of both the expected impacts and any proposed adaptation measures. This may involve methods such as simulations of the economic costs of unforeseen airport closure or market analyses of potential changes in passenger demand to aid business planning. Other potential economic impacts which may need to be considered include insurance liability and operational costs. In parallel to the EUROCONTROL case-studies, some States are now developing Climate Adaptation Strategies, which will cover aviation; and, the European Commission has funded two transport-focused climate adaptation-related studies which will include consideration of ATM.

It should be noted that ATM itself will not be directly influenced by all the potential adaptation areas identified by the case-studies. However, some indirect impacts will be briefly discussed in the broader context of integrated cross-sector planning.

IV. Key Adaptation Area 1: Climate change driven shifts in demand

The associated case-study identifies that local rises in temperature and changes in humidity in currently popular tourist destinations might affect tourists' thermal comfort levels (an indicator of the range of pleasantly acceptable temperatures). A direct effect of such a change in regional weather patterns is that tourists may begin to find their chosen destination uncomfortably hot during the traditional peak holiday (summer) months. The implications of this are the potential displacement of high season tourism traffic either to other destinations or to the spring and autumn shoulder months in the original region. Although within Europe the largest impact could be expected to be on intra-European traffic, there may also be extra-European displacement of traffic with tourists seeking alternative destinations outside of Europe, or demand for traffic to some European destinations from non-European regions being affected. The impacts can, of course, also be extrapolated to regions outside of Europe which are likely to experience similar changes in local temperature and humidity levels.

This identifies potential implications for both aviation planning and management, and the tourism industry in general. A key concern is planning for aviation infrastructure which, by its nature, is driven by forecast demand. The long lead times required for new infrastructure necessitate that such projects are planned significantly in advance of when they will actually come into operation. The study considers that changes in demand such as those discussed above introduce the risk that taking current demand forecasts as the driver for both the planning of aviation infrastructure development, and ATM planning in general, may not be appropriate in the longer-term as it doesn't take into account potential reductions or redistributions of demand patterns that a changing climate may induce [8]. This implies that new infrastructure projects should begin to integrate the potential of climate-change induced changes in demand in their risk assessments. The key issue is timing as the next section will explore.

The study used data on climate change forecasts for the case-study area and information relating to the thermal comfort of tourists provided by the UK Met Office for two scenarios based on IPCC B1 and IPCC A1B. This was compared to a baseline using temperature data averaged over 1954-2003. The analysis projected significant increases from around 2050 when temperature increases might be expected to exceed 4°C (Table 1).

	Scenario B1		Scenario A1B	
Time	July	August	July	August
2020	+2.33	+2.3	+2.07	+2.10
2030	+2.38	+2.57	+2.35	+1.82
2050	+4.46	+3.74	+4.67	+4.16
2080	+4.70	+3.91	+7.22	+5.49

Table 1: Projected change (from 1954 – 2003 values) in July and August (peak season) daily mean maximum temperatures for case-study area. (Dimitriou & Drew, 2010)

This was then analysed, using long term forecasting techniques, in conjunction with traffic forecast scenarios based on three of the four scenarios for growth used in the EUROCONTROL Long-Term Forecast Flight Movements 2008 – 2030 report to predict passenger and traffic scenarios for the case-study area. The 2030 traffic projections from the EUROCONTROL report were used as a baseline. This analysis concluded that in all but the most optimistic scenario a reduction in annual average growth could be expected (Table 2).

	Average annual growth (%)				Average annual change (%)	Traffic multiple
Scenarios	2031/40	2041/50	2051/65	2066/80	2031/80	2030/80
A: Global growth	+1.5	+0.5	0.0	-0.5	0.22	1.13
C: Business as Usual	+0.8	0.0	-0.5	-1.0	-0.45	0.86
D: Fragmenting world	0.0	-0.5	-1.0	-2.0	-0.99	0.65

Table 2: Summary of forecast for Greece between 2030 (base year) and 2080 (Dimitriou & Drew, 2010)

The analysis therefore broadly concludes that, at current rates of warming, the significant effects of climate change are unlikely to be felt in the case-study State, and thus in comparative regions, before 2030. Yet, the analysis also suggests that by 2050 the reduction in *summer* tourism demand could be as much as 40% with significant changes being felt around or soon after 2030, although this may be offset by an increase in demand in both the Spring and Autumn shoulder periods (Figure 3). If these changes in traffic demand do occur, it is likely that aircraft operators, whose assets are by definition mobile, would adapt quickly to the new situation. Air navigation service providers, however, with their fixed facilities of control centres and towers, may discover that their investment planning delivers capacity for the summer peaks that may no longer be necessary, particularly as present planning horizons are focused on meeting annual demand growth of 1.6-3.9% between now and 2030 [8],[2].

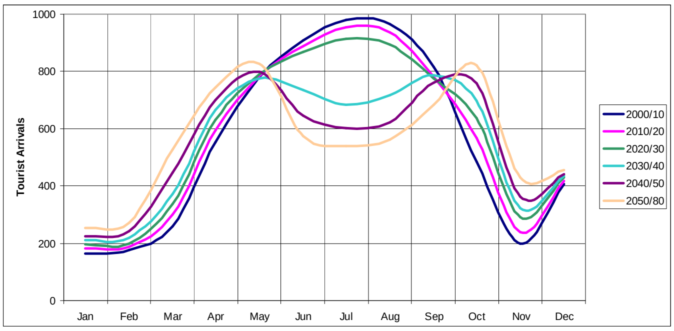

Figure 3: Projected Changes in tourism demand pattern for Greece from 2010 to 2080 (Dimitriou & Drew, 2010).

EUROCONTROL's analysis considers that this initial case-study, although limited in scope, has identified issues resulting from climate change which should now be considered by the aviation sector when undertaking long-term capacity planning. In particular, a number of key issues for consideration in future ATM adaptation planning have been identified. As with many climate change-related issues, at least in the short-term there are both winners and losers.

Although a decrease in tourist numbers at a particular location is rarely advantageous for the local tourist industry, particularly when due to changing tourist preferences, from an ATM-perspective a non-realisation of forecast demand can ease pressure to accommodate increasing throughput, which in turn could lead to a lesser investment in infrastructure capacity development being required. Of course, from a financial perspective there is the associated loss in revenues to be considered from a reduction in traffic.

If, as the study considers, some demand is displaced to the shoulder seasons of Spring and Autumn this may reduce the annual peak in demand by spreading it over a greater proportion of the year. This may allow more optimum use of parts of the ATM system and, in less-congested systems, the easier implementation of measures to increase operational efficiency and reduce environmental impact. However, it should not be forgotten that there are major social constraints on the timing of the traditional family *summer* holiday which are related to school holidays and traditionally quiet periods in some other industries. If such influences do not change in-line with changes in tourism preferences – then it is not unreasonable to conclude that a significant element of demand will be shifted geographically rather than temporally.

The geographical displacement of tourist preferences will naturally lead to changes in passenger demand and thus load factors on popular routes. This in turn will stimulate changes in scheduling and eventually routing. Although this will almost certainly lead to a reduction in demand to some destinations it also implies that there may be increases in demand to alternative destinations. This means that present forecasts may be –significantly- exceeded, with available infrastructure proving insufficient, as such climate-change driven demand increases have not been accounted for in current planning. This suggests that capacity planning should be increasingly sensitive to the risks from the potential displacement of tourism demand, otherwise ATM capacity and infrastructure planning could be inappropriate in scale, timing or location. Of course, it should not be overlooked that if tourists from Northern Europe are choosing to holiday in climatically cooler destinations closer to home, this may stimulate a modal shift from air travel to the train, boat or car [8].

The study also takes into account the potential effects of policy responses to climate change (e.g. taxes and market-based measures) which could have a more general effect on disposable income and hence on tourism demand in the case-study State, and thus in comparable States. It concludes that policy response influences on demand may be felt before 2030, and is thus another key area for consideration.

EUROCONTROL's analysis therefore concludes that although present capacity and infrastructure plans will still be required if near-term forecast capacity demands are to be met, it is nevertheless prudent to take possible climate-change induced demand changes into account in longer-term planning, particularly when the business case for ATM infrastructure proposals with a life expectancy of more that 20 years is being considered. However, it should be noted that robust and commonly agreed information on this topic is not readily available at present and that, consequently, further detailed studies are required if this risk is to be adequately understood. Additionally, although the study focused on one Mediterranean country the results are potentially applicable to the majority of this region due to the similarities in tourism patterns and current climate as well as to other areas around the globe which might be susceptible to similar impacts of climate change.

V. KEY ADAPTATION AREA 2: LOSS OF AIRPORT CAPACITY THROUGH SEA-LEVEL RISE

To date, 34 European Airports have been identified as potentially at risk from sea level rise, storm surges and flooding by the end of the century [6], (figure 4). The case-study commissioned by EUROCONTROL selected three airports to carry out a more in-depth qualitative analysis of the specific challenges that may need to be faced in adapting to climate change.

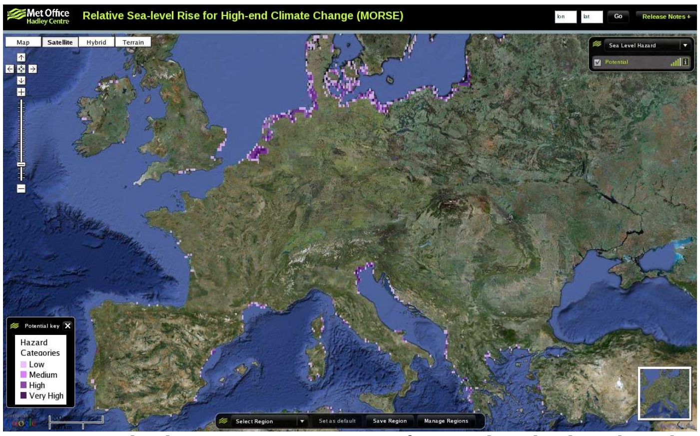

Figure 4: Sea–level rise in Europe, mapping of potential sea level rise hazard in a high-end warming world based on a worst-case scenario of +4°C warming by 2099 (MORSE, +4°C) (Source: de Gusmão, 2010)

All three airports considered are busy international facilities handling between 5 and 30 million passengers per year in coastal locations. However, although all the three airports selected are from geographically separate and disparate parts of Europe, the study concludes that the challenges they may face in adapting to climate change are not dissimilar [9].

- Airport 'AA' - The primary risk from sea level rise for airport AA is the loss of ground access, with the main areas affected in the vicinity mainly lying outside of the airport. However, with gale-force winds and flooding both regular occurrences, direct disruption at the airport itself from increased weather-related events cannot be ruled out.

- Airport 'BB' - Airport BB is on an intertidal coastal location where the geomorphology causes a high water table which already exacerbates flooding. Analysis with the Met Office MORSE Tool for assessing sea level rise shows that by 2099 there is a high risk that the airport runway and taxi-ways will be frequently affected by inundation caused by sea level rise.

- Airport 'CC' - Airport CC already has a substantial sensitivity to flooding generally as a result of its unique situation regarding its surrounding topography which is susceptible to erosion. The low elevation of the runway above sea level increases its susceptibility to inundation by high tides.

It should be noted that the study uses a 4°C global mean surface temperature increase scenario and then models the projected sea level rise expected for each airport location for this amount of warming by 2099. 4°C is at the upper end of predicted climate scenarios, but is now accepted by many in the scientific community as being the most likely scenario given the lack of progress in achieving significant global cuts in emissions [10]. Inertia in the climate system means that the full effects of today's greenhouse gas emissions (or of any emission reductions induced by regulation) may not be seen for several years to come. Thus, the use of a 4°C scenario in the study can be seen as illustrating both the potential worst-case situation, but also one which, given current emissions projections, remains possible.

As with the effects of climate-induced changes in passenger demand, the effect of sea-level rise on coastal airports is not expected to be experienced in the short-term. Nevertheless, although the study indicates that significant flooding risk won't be experienced until the end of the century, some increased flooding could already be experienced by mid-century. It is important to note that in some cases the actual airport itself may not be the main infrastructure risk but that there might be ground transport infrastructure which could pose a much larger-scale engineering and economic problem for mitigation strategies [9]. Of course, as with changes in tourism demand patterns, this also implies that in such cases adaptation planning is not a matter for the aviation industry alone but is an issue which requires collaboration and action from a range of regional stakeholders including government and the business sector.

As mentioned above, the interconnectedness of the European and global ATM systems is of particular significance. The system-wide effects of perturbation in one part of the ATM system have been witnessed only too recently during the extreme snowy conditions experienced in Winter 2010. In a different example, in 2000 the closure of runways at a major European airport led to an increase in average European delay from around 1-2 minutes to 40 minutes within a few hours [11]. This highlights how the unplanned loss of one or more ECAC[3] runways is a very significant risk for the capacity, efficiency and delay performance of the entire European ATM system, with of course delay implications for flights originating from other regions that are scheduled to land at a European airport.

With over 30 European airports potentially at risk of loss of runway capacity through such impacts as sea-level rise and storm surges, 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. However, with major impacts from sea-level rise and increased flooding not expected until at least mid-century there should be sufficient time to put adaptation strategies in place.

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

VI. Key Adaptation Area 3: Increase in extreme weather events

Climate change is widely expected by the scientific community to instigate an increase in severe weather events, specifically in increased convective activity which induces storminess. It is considered probable that changes will be experienced in severity, likelihood and location of such events which have implications for delay, capacity and safety. Unlike the other two adaptation areas identified it is likely that impacts could be experienced as early as 2020.

The modelling work was carried out by researchers from the UK Met Office using Convective Available Potential Energy (CAPE), a measure of instability in the atmosphere, as an indicator for storminess. Radiosonde data from the Maastricht area were used to define three CAPE threshold values of 800J/Kg, 900J/Kg and 1000J/kg, indicating low, medium and high risks of severe disruption. A range of climate simulations were then designed, each using slightly different parameters. The ensemble was then run, using the Met Office climate model HadRM3, for three different twenty-year time periods, centred on 2020, 2030 and 2050, to analyse the number of times these thresholds were exceeded, measured against a baseline period of 1989-2009. The results demonstrated a predicted increase in convective weather systems with the potential to inhibit ATM operations (storminess) 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 is highlighted by the 2020-2050 results which predicted an increase in storminess of around 1-3 days during each season, with the potential for significant storminess by 2050 (Tables 3-5). This indicates that the impact of storminess is likely to be a risk for a greater proportion of the year rather than being confined to the 'traditional' summer months. The implications for this in terms of reduced annual ATM performance are not yet known [12].

2020	MAM (spring)	JJA (summer)	SON (autumn)
>800J/Kg	0.3±3.7	3.33±12.4	1.9±3.3
>900J/Kg	1.2±2.7	3.2±11.9	0.8±3.2
>1000J/Kg	0.6±2.4	3.1±9.6	0.3±2.5

Table 3. Summary of the absolute change in the number of days with daily maximum CAPE values over 800J/Kg, 900J/Kg and 1000J/kg over the twenty year period centred on 2020, compared to the 20yr period defined as the present day (1989-2009) by three month period (Budd & McCarthy 2010)

2030	MAM (spring)	JJA (summer)	SON (autumn)
>800J/Kg	0.3 ±4.4	-0.8±11.2	1.9±2.5
>900J/Kg	0.8±3.2	0.2±11.1	0.8±3.3
>1000J/Kg	0.3±2.7	0.2±9.4	0.4±2.5

Table 4. Summary of the absolute change in the number of days with maximum daily CAPE values over 800J/Kg, 900J/Kg and 1000J/kg over the twenty year period centred on 2030, compared to the 20yr period defined as the present day (1989-2009) by three month period (Budd & McCarthy 2010)

2050	MAM (spring)	JJA (summer)	SON (autumn)
>800J/Kg	2.3±2.5	-0.3±9.8	2.7±4.7
>900J/Kg	2.2±2.2	-1.1±9.8	1.7±4.9
>1000J/Kg	1.7±2.1	-1.3±10.2	1.0±3.6

Table 5. Summary of the mean absolute change in the number of days with maximum daily cape values over 800J/Kg, 900J/Kg and 1000J/kg, over the twenty year period centred on 2050, compared to the 20yr period defined as the present day (1989-2009) by three month period (Budd & McCarthy 2010)

In parallel, analysis was carried out on a set of data supplied by Maastricht Upper Air Control Centre (MUAC) (figure 5) for two corresponding days in 2009, one a 'normal' day of operations and one a day which experienced disruption caused by a bad weather event (storminess). A route efficiency ratio, an indicator which measures the directness of the overall route flown, was used to analyse the data set. A route efficiency ratio of 1.000 indicates a perfectly straight line between the entry and exit points of a flight in a defined airspace sector. Analysing the data with this indicator demonstrated an overall decrease in route efficiency of up to 0.015 below the optimum of 1.000 between the 'normal day' and the bad weather day. Although other factors may have been involved, this *suggests* that the bad weather system had a negative impact on the functioning of the airspace [12].

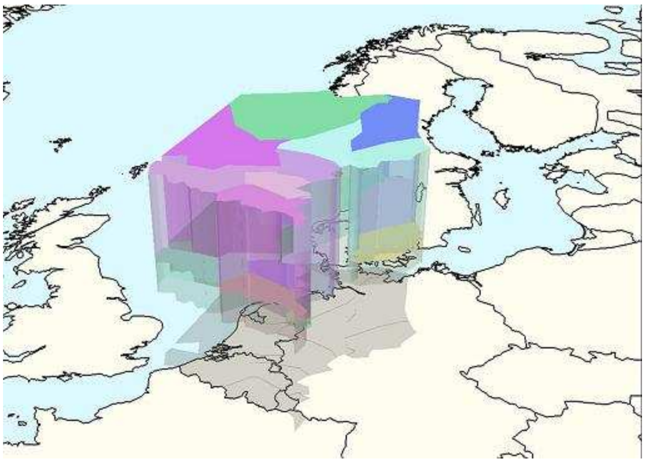

Figure 5, Chart showing the Maastricht Upper Airspace (Source: EUROCONTROL)

Of course, an analysis of just one day, cannot be interpreted as statistically significant. However, it does highlight a *potential* association between an increase in severe weather and a decrease in route efficiency. Such an effect has associated impacts for several ATM key performance areas including: safety, capacity, efficiency, flexibility, predictability and environment. However, it should be noted that SESAR is already addressing requirements for improving ATM performance in each of these areas. SESAR will also develop much more integrated information and communications in its System Wide Information Management (SWIM)-related work-packages, which will cover MET data and forecasting. These kinds of operational improvements are inherently aligned with the challenges that may arise from increased storminess and climate change-related operational impacts generally. So some mitigation of these effects is already being addressed. It should also be noted that as the study is deliberately focused on actual operations (e.g. track distance) effects in the upper airspace, it does not cover the *additional* risks from increased storminess in terminal airspace (TMAs) and at airports, for example risk of delay arising from capacity reduction (e.g. temporary airport closures). This is also an area which needs to be considered for further research as it is already a current issue of significance: 28% of flow-management delays at airports in June 2010 were due to weather [13]. On a global scale, several other regions are already susceptible to regular occurrences of extreme weather. Although the EUROCONTROL study focused on a particular area and thus cannot be directly extrapolated to areas with differing climatic conditions, the implication is that changes in extreme weather patterns, and the associated impacts for ATM may be experienced in other regions.

VII. CONCLUSIONS

Climate Change adaptation planning is not an issue for ATM, or even the aviation industry, alone but is a collective challenge which, given the linkages between the air transport industry and other parts of the economy, such as tourism, needs to be addressed by all stakeholders in a region. This indicates a need for greater integration of strategic planning between aviation and other critical sectors. Moreover, as ATM is a transnational industry, adaptation action in one region or nation can be negated by a lack of adaptation action elsewhere. Given the interconnectedness of the ATM system, as evidenced by the knock-on effect of the closure of the runways at one European airport (see above), or the disruption caused by extreme winter weather conditions in December 2010, it is essential to consider system-wide effects in conjunction with localised impacts. This necessitates tackling the problem at local, regional, national *and* international levels. Indeed, given the global nature of the issue being faced, an integrated international approach would seem logical.

Three key potential climate change adaptation areas are identified that are relevant to ATM. These are changes in the timing and location of traffic peaks and flows due to climate-induced changes in demand patterns; flooding risk to airports leading to runway closures that may have the potential for a system wide effect; an increase in convective activity (storminess) which could lead to en-route operational impacts such as increased track miles and delay or reduced capacity. Risks requiring further research have been identified in each area. Additionally, although the case-studies on which this paper is based considered three potential adaptation areas in isolation, it is also important to consider combined scenarios where these or other combinations of climate change-driven impacts coincide. The timescales over which the impacts will begin to be experienced vary from 2020 to 2090, suggesting that it would be reasonable to begin considering adaptation responses in current medium to long-term planning, as well as to carry out further research within current projects, such as SESAR, into the likely magnitude and timing of such events. This will enable informed adaptation planning across the sector. It is, of course, essential that aviation continues the substantial progress it has made towards mitigating its environmental impact in general and reducing its release of greenhouse gas emissions in particular. However, with the impacts of climate change now a clearly-identified, if not fully understood, risk for the sector, adaptating to that emerging reality should now become an essential part of medium to longer term planning.

VIII. NEXT STEPS:

Since the original CG08 report was completed several other aviation organisations have included this issue in their work programmes. These include ICAO, ACI-World and CANSO. There are also now two EU-funded research projects 'EWENT' and 'WEATHER' looking into this area as well as a number of ECAC States who have now initiated studies with a view to planning local mitigation strategies which will cover aviation. The EUROCONTROL Agency will continue this work through SESAR Work Package 16, which it is leading, specifically through WP 16.3.7 which focuses on Future

Regulatory Scenarios and Impacts. The work package will address the risk and potential implications of climate change adaptation for the European ATM system, as well as the future regulatory responses which may entail as a result. As work package leader, EUROCONTROL will therefore continue to be actively engaged in this area.

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Rachel BURBIDGE joined EUROCONTROL in 2005. Currently a member of the Environment Unit she works on several projects including the provision of support to the European Commission on the introduction of aviation to the EU Emissions Trading Scheme (EU ETS), aviation climate change adaptation research and the SESAR Single European Sky Research Programme, specifically the Work Packages covering environmental risk and regulation.