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***Session 3* – Impacts of climate change and variability on aviation operations and associated science requirements**

3.1 – Jet stream position and intensity and related phenomena

Global Response of Clear-Air Turbulence to Climate Change.

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Speaker: Paul Williams

Clear-air turbulence (CAT) is one of the largest causes of weather-related aviation incidents. Anthropogenic climate change is expected to strengthen the vertical wind shears at aircraft cruising altitudes within the atmospheric jet streams. Such a strengthening would increase the prevalence of the shear instabilities that generate CAT. Here we use climate model simulations to study the impact that climate change could have on global CAT by the period 2050-2080. We analyze eight geographic regions, two flight levels, five turbulence strength categories, and four seasons. To estimate the uncertainties in our projections, we use two different climate models and we calculate 20 different CAT diagnostics, each converted into eddy dissipation rates.

We find large relative increases in CAT, especially in the mid-latitudes in both hemispheres, with some regions experiencing several hundred per cent more turbulence. The busiest international airspace experiences the largest increases, with the volume of severe CAT approximately doubling over North America, the North Pacific, and Europe. Over the North Atlantic, severe CAT in future becomes as common as moderate CAT historically. These results highlight the increasing need to improve operational CAT forecasts and to use them effectively in flight planning, to limit discomfort and injuries among passengers and crew.

Session 3 – Impacts of climate change and variability on aviation operations and associated science requirements

3.1 – Jet stream position and intensity and related phenomena

Aircraft observations and reanalysis depictions of trends in the North Atlantic polar front jet stream wind speeds and turbulence.

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Multiple model-based studies of the North Atlantic polar front jet stream have considered the effects of doubled CO2. Two key questions are whether any effects can already be seen and whether any effects can be seen independent of computer models. A major tool in the climate change community is atmospheric reanalyses which calculate an optimum depiction of the jet stream when the reanalysis model is held fixed for 50 to 100 years. But such reanalyses do depend on the underlying assimilation model. In addition, any secular trends must be disentangled from other oscillations that affect the North Atlantic: the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO).

We have addressed these issues by using three separate sources: the NCEP/NCAR reanalyses, the underlying AMDAR/ACARS aircraft wind observation archive, and the Global Aircraft Data Set (GADS) archive. The reanalyses are somewhat correlated with AMDAR because those observations form a major component of cruise-level results. The 3 billion GADS observations (100 million over the North Atlantic during 2002-2017) taken from the flight data recorders of multiple carriers are independent of both reanalyses and AMDAR. They also provide direct measurements of the turbulence associated with the North Atlantic jet.

One result yields a small increase in the jet stream wind speeds over the period winter (DJF) 1979-2017. But that increase is not statistically significant and is possibly due to the flip in the strength of the AMO around 2000. When we eliminate the effects of the AMO by concentrating on 2002-2017, a second result shows increases in wind speed which are statistically significant at the 10% level. Their geographical distribution is consistent with the modeling results of 21st century doubled CO2 of Delcambre et al. who suggest a decrease in the Atlantic jet core and an increase in the jet exit regions. The GADS results also show wind speed increases but are only currently processed for 2002-2013. There is no clear trend in “light” turbulence. Our results are consistent with the predicted increase of the jet stream speed but too short to definitively prove the case at this time.

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Impact of Large-Scale Climate Variability to Long-Haul Flight Routes and Clear-Air Turbulence.

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Mid-latitude jet streams have seasonal and inter-annual variabilities in strength and position, which are correlated with large-scale climate variabilities like the North-Atlantic Oscillation (NAO) and El-Nino Southern Oscillation (ENSO). Near the jet stream, Clear-Air Turbulence (CAT) frequently occurs, mainly due to the shear instability. For safe and efficient strategic flight planning, it is beneficial to study the impact of large-scale climate variability on flight planning and CAT.

Wind-Optimal Route (WOR) is calculated using the global reanalysis data with 0.5 × 0.5 degree of horizontal grid spacing, which considers wind variations in the flight trajectory modeling to minimize total flight time between two city points anywhere in the world. Then, overall flight times and potential CAT encounters from turbulence along the simulated routes are calculated using the longer-term reanalysis data. We conducted two experiments. The EXP1 is for a city pair between John F. Kennedy International Airport (JFK) in New York and Heathrow Airport (LHR) in London during the wintertime of extremely positive (2004-05) and negative (2009-10) NAO periods to see the impact of NAO pattern to flight route and CAT. Another (EXP2) is for a city pair between Hawaii and western coast of US during extremely positive (1997-98) and negative (1998-99) ENSO periods.

In EXP1, the Eastbound (EB) WORs from JFK to LHR are shifted northward to take advantage of the strong tail winds (to reduce total flight time/fuel used), while Westbound (WB) WORs from LHR to JFK disperse to avoid the strong head winds near the jet stream during the positive NAO phase (2004-05) period. On the other hand, in negative NAO phase (2009-10), the EB WORs shift southward to take an advantage of southerly shifted jet stream, while the WB WORs are close to Great Circle routes (shortest distance) due to an absence of strong head winds. Turbulence encounters along the WORs are higher in EB than WB, because EB generally flies close to the strong jet stream to benefit from the tail winds.

In EXP2, EB WORs from Hawaii to the West coast are shorter and faster in positive ENSO period than those in negative ENSO period, because + ENSO modulates the mid-latitude Pacific jet to be elongated to further East. Turbulence potentials are higher in + ENSO than – ENSO period. This suggests a good relationship between the large-scale climate weather patterns and optimal (i.e., minimum fuel used and minimum chance of turbulence encounters) long-haul flight routes, which can be useful for long-term strategic planning for aviation.

Session 3 – Impacts of climate change and variability on aviation operations and associated science requirements

3.2 – Extreme weather events at airports, changes to established scenarios

Climate change aspects of fog/smog occurrences at different low visibility ranges in Delhi Airport: Temporal change using general visibility 1964-2017 and Spatial changes within airport during 1989-2017 using multi-RVR data and linking them trends of Met parameters (RH, Temp, Wind).

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Speaker: Rajendra Kumar Jenamani

Climate change aspects of fog/smog occurrences at different low visibility ranges in Delhi Airport: Temporal change using general visibility 1964-2017 and Spatial changes within airport during 1989-2017 using multi-RVR data and linking them trends of Met parameters (RH, Temp, Wind).

Delhi IGI Airport operational since 1950s have undergone vast changes over the period both in aviation infrastructure and so also shift in its winter smog/fog occurrences as it was believed in 1950s there were some days when vis above 5000m were available for flight landing even in peak winter of Dec-Jan in contrast to even late 1990s for same period when visibility never cross 2000m due to increase of urbanizations and traffic surrounds to it. With new RWY built and operational by Aug 2008 located at far southwest corner and at rural side and on land area, where it was all open and more water body and greenery, fog being very much sensitive to local features, a high different in duration intensity of fog, we start noted when total CAT-IIIB fog duration are compared from their corresponding six number of RVR at respective RWY ends. It finds new RWY 29-11 side are very higher in total duration in a season compared to main old RWY 28-10 located at city side at more northeast of it having more urbanized one in terms of big highway lies very closed to its RWY 28 TDZ end and hence with time all aviators start naming the latter RWY as life line of IGIA, as it facilitates last flight to land in low visibility and such, this TDZ sometime closed after 4-6 hours of that TWY29 TDZ and RWY 11 TDZ during dense fog events even upto CAT-IIIB dense fog which is very unique spatial pattern fog variability and creates a complex scenario for ATM/Airport management. In the present study, Climate change aspects of fog/smog occurrences at different low visibility ranges in Delhi Airport using very longer period data at hour to 30-minute intervals of daily data for months of peak winters of Dec-Jan have been attempted. We have studied Temporal change using general visibility 1964-2017 and Spatial changes within airport during 1989-2017 using multi-RVR data. Frequencies and duration of fog/smog at Delhi at <1500, <800m, <400 and <200m since 1960s till 2015s in 5-years means when performed, it finds both geeral and dense fog duration have increased by 30-40 and 15 times respectively which has been quite alarming for aviation operation. Within the airport, there are stronger climate change signature at meso- scale upto 3-6km scale too, fog being very sensitive to local features variation as RVR studies using meso-network of RVR data finds dense fog occurrences at new RWY 29-11 which was 1.5 time to old city side RWY 28-10 , in start of its operation in 2008-09, has increased to 4-5 times in recent seasons of 2015-17. We have linked such variation with fog formation parameters e.g winds, temp, RH, pollutants acting as CCN for same period which also interestingly concluding significant increasing of moisture, fall of max temp by 2-3degc and weakening of airport surface winds and high increase of favorable pollutants.

Session 3 – Impacts of climate change and variability on aviation operations and associated science requirements

3.2 – Extreme weather events at airports, changes to established scenarios

On variation of several climatological characteristics at aerodromes in the Russian Federation in 2001-2015.

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Speaker: Anna Ivanova

Variation for several aeronautical climatologically characteristics were studied on the basis of hourly (half-hourly) meteorological terminal observations at 51 aerodromes of the Russian Federation in 2001-2015. For every aerodrome extreme temperature, wind and gusts, QNH were analyzed. Using data of three consecutive 5-year periods the variation of number of days with temperature values below -30 Celsius (very cold) degrees and above 30 Celsius degrees (hot), wind speed more than 10 ms-1, gusts more than 15 ms-1 were considered. Occurrence frequency of significant weather effecting on takeoff and landing (fog, blizzard, freezing precipitation, thunderstorm) is explored. Results for aerodromes with positive or negative trends of occurrence frequency of weather phenomena in 2001-2015 are exhibited.

Such trends occur at ~25-40% aerodromes, more often – located in European part of Russia. Between 2001-2015 a decrease of hot days at some aerodromes as well as an increase of very cold days at others were detected. The change of wind conditions at Russian aerodromes is characterized by heterogeneity. As for significant weather for landing, take-off , and terminal services operations (apart from thunderstorms), one can observe negative trends in its occurrence frequency, especially in the European part of Russia.

Many aerodromes are characterized by multiple climatic variations. So, at the Moscow aerodrome Domodedovo occurrence frequency of thunderstorm increased, the same occurrence frequencies of fogs, blizzard and freezing precipitation decreased.

Session 3 ***– Impacts of climate change and variability on aviation operations and associated science requirements***

3.4 – Re-evaluation of airframe/avionics resilience standards and certification

The Aircraft Flight Envelope.

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Speaker: Rainer von Wrede

How does climate change influence aircraft design and operation?

Aircraft are designed to operate within a given range of static temperatures and altitudes (pressures), called the aircraft flight envelope. Aircraft manufacturers strive to extend this range to the maximum to give airlines the highest operational flexibility. Although flight envelopes are of similar shape, they are specific for every aircraft type and are determined by airworthiness certification. An aircraft is not allowed to operate in atmospheric conditions which are outside the certified flight envelope. Increasing or decreasing temperatures can then e.g. prevent airlines to reach certain airports occasionally, or even permanently. The dynamic behaviour of the atmosphere is potentially also altered by climate change, and may further impact aircraft design and/or the operations.
Aircraft manufacturers therefore need to know the impact of climate change on the flight envelope and the dynamic properties of the atmosphere to adapt the design accordingly. This presentation aims at describing the limiting design aspects of a typical aircraft flight envelope.