**CLIMATE CHANGE IMPACTS ON AVIATION**

*(Submitted by the ET-ASC Co-Chairs)*

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| **Summary and Purpose of Document**  With emerging details of future states of the climate, its variability and extremes, this document seeks to establish aviation-specific impacts of this change, their likelihood, the global, regional and local aspects of these changes, and the potential for resilience and mitigation. |

**ACTION PROPOSED**

The meeting is invited to:

1. note the information contained in this paper; and
2. initiate appropriate actions for enhanced, regionalized and user-group focussed reviews of climate projections and studies with respect to the expected impact on aviation.

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1. **EXECUTIVE SUMMARY** (to be included in the final report)

1.1 The meeting was apprised of a current outlook with respect to climate change and variability and the impact on aviation stakeholders. The current outlook highlighted the following key considerations:

1. There is a significant need for further research into the regional and local effects of climate change, the role of variability and inter-annual and decadal variations, cycles and oscillations on regional and local conditions;
2. The aviation infrastructure design specifications and certification envelopes for system resilience will be strongly determined by weather elements in the meso- and micro-scale of atmospheric processes and motions;
3. There is increasingly strong evidence on the increased likelihood and intensity of extreme weather phenomena in a generally warmer climate;
4. There are indications of the emergence of highly complicated “connections” between extended periods of unseasonal or extreme weather types, oceanic ice cover and decadal oscillations;
5. The consequences of High Amplitude-Low Wave Number regimes can be very diverse for different regions. While north-eastern parts of the northern hemisphere large continental land masses may experience unchanged or even lower temperatures at times, the western parts of the northern hemisphere continents are subject to massive warming for parts of the cold season, underlining the need for very detailed regional studies;
6. There is ongoing uncertainty about the frequency, tracks and intensity of tropical cyclones in future climate scenarios. Some evidence suggests a regionally-differentiated behaviour, and a possibly noticeable role of the ENSO cycles. There is good agreement that the risk of coastal flooding will increase due the combination of sea level rise, intensity of cyclones and ensuing storm surges;
7. Extra-tropical cyclones are generally expected to become stronger with the availability of higher temperature and moisture gradients;
8. The most intense weather phenomena, such as strong convection, wind shear, hail and high-level icing, all are dependent on very small-scale weather elements with limited predictability;
9. There is confidence in a general poleward shift of the jet stream systems associated with the polar frontal zone. Whether this will result in a stronger jet stream core with higher speeds and shear is less certain; and
10. In the southern hemisphere there is some evidence that the re-building of the ozone layer there may have a weakening influence on the meridional temperature gradients in the southern hemisphere winter, with consequential light weakening of the jet stream.

1.2 In respect of the impacts of climate change and variability on aviation, the meeting considered that aviation stakeholders including but not limited to airport operators, aircraft/equipment manufacturers and aviation authorities often have very long-term planning horizons (several years to several decades or more) and that each would be influenced by a changing climate in many ways. The impacts on aviation infrastructure, accessibility, demand, etc. would therefore require localized studies specific to the users’ area(s) of operation rather than global outlooks.

1.3 The meeting noted that while some of the identified risks of a changing climate scenario on aviation operations were qualitatively evident and would need to addressed by a comprehensive risk management system, the relative importance of these risks for different regions, climate scenarios and aviation stakeholders would require a significant effort in joint research between aviation and climate scientists. It was noted that individual stakeholders (e.g. ICAO, operators, OEMs, ATM, airports), for example, have already made efforts and achieved progress in addressing their priority issues.

1.3 The meeting affirmed that it would be important for WMO, as a global meteorological standardization and coordinating body, to encourage and enable multi-disciplinary efforts in research and best practice models in climate service provision, develop the necessary standards and risk management methodologies and ensure that environmentally driven issues are cross-linked into the Global Air Navigation Plan (GANP) of ICAO for consistency and resilience of the global aviation system. Governance questions including directions for cost recovery, outlining as well State responsibility for national efforts, would require adequate guidance and suitable manuals to support a successful risk management.

1.4 The meeting appreciated the importance and direct relevance of the foregoing with an upcoming WMO Aeronautical Meteorology Scientific Conference (AeroMetSci-2017) to be held in November 2017 I Toulouse ([Doc. 7](file:///\\INTERNAL.WMO.INT\GS\DATA\SHARED\DEPT\WDS\AEM\ETs\ET-ASC\2nd%20meeting\DOCS\FINAL_DOCS\d07_upcoming-events_et-asc-isa-2.docx) refers).

1.5 *<Additional text to be developed based on the discussions>*

**2. DISCUSSION**

***Current outlook***

2.1 While the body of research on climate change is beginning to firm-up its findings on global effects, there is a significant need for further research into the regional and local effects of climate change, the role of variability and inter-annual and decadal variations, cycles and oscillations on regional and local conditions.

2.2 Atmospheric processes cover a very large range of space and time scales, whereby the detectability and predictability of weather elements typically increase with the dominant space and time scales. Similarly, aviation stakeholders require information on all time and space scales with clearly identifiable priorities for individual stakeholders. While planners and designers of aviation infrastructure, in particular airports, original equipment manufacturers (OEM) and air navigation service providers with a technological and financial planning horizons of several decades rely on climate information for such time frames, the design specifications and certification envelopes for system resilience will be strongly determined by weather elements in the meso- and micro-scale of atmospheric processes and motions.

2.3 The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), in building on the findings of earlier reports has stressed not only the changes to the annually, seasonally and zonally averaged conditions of atmospheric states, but has provided increasingly strong evidence on the increased likelihood and intensity of extreme weather phenomena in a generally warmer climate. Recent anomalies in the mid-latitudes of the northern hemisphere, which are linked to High Amplitude-Low Wave Number regimes, seem to indicate the emergence of highly complicated “connections” between extended periods of unseasonal or extreme weather types, oceanic ice cover and decadal oscillations.

2.4 While a degree of uncertainty still exists on the likelihood, severity and location of future extreme events, the industry requires early guidance on possible mitigation strategies to contain the risks – in terms of safety, regularity, and economic viability – for future aviation, advice on priorities for developing resilient systems and also a strong inter-disciplinary effort on the societal conditions under which they are going to operate. Cross-linking economic, ecological and societal effects of changing agricultural production capabilities, transport needs, and issues of globalized economies and tourism will be important factors in investment decisions and R&D priorities.

2.5 An excellent example for the question of extremes is the increased likelihood of heat waves, and overall increase of precipitation in some regions such as, for example, the northern mid-latitudes, whereas the lower mid-latitudes are generally expected to experience increased droughts.

2.6 By the same token, new studies are focussing on the changes to the planetary-scale oscillations, their typical frequency and intensity, such as the ENSO, Arctic Oscillation, monsoons and other such high-impact events.

2.7 Snowfall is another example for a multi-faceted phenomenon. Increasing surface temperatures were assumed in many early reports on climate change to eliminate snow cover for many hitherto regularly snow-covered areas, with the ensuing consequences for traffic and tourism. The prevalence of extended periods of strongly meridional flow types over much of the northern hemisphere has modified the earlier expectations. While snow-cover in many regions has become clearly less reliable, with overall higher temperatures and extended episodes of warm extremes, particularly in the earlier parts of winter, the backlash of similarly extended northerly to north-westerly flow regimes coupled with the larger ice-free surface of the Arctic Ocean. The consequences of these High Amplitude-Low Wave Number regimes can be very diverse for different regions. While north-eastern parts of the northern hemisphere large continental land masses may experience unchanged or even lower temperatures at times, the western parts of the northern hemisphere continents are subject to massive warming for parts of the cold season, underlining the need for very detailed regional studies. *(Refer to* [*INF. 1*](file:///S:\AEM\ETs\ET-ASC\2nd%20meeting\DOCS\FINAL_DOCS\inf01_climatological-characteristics_et-asc-isa-2.docx) *presenting a study for different aerodromes in the Russian Federation)*

2.8 The complexity of intense and organized convection events clearly makes simple and straightforward statements about their future frequency and nature extremely difficult. The development of severe convection not only depends on the thermal structure of the atmosphere, where a warmer surface together with a higher tropopause would be indicative of stronger and higher-reaching convection. The development of organized convection into tornadic storms and meso-cyclones, however, is strongly determined by the helicity of the wind field from ground to the upper troposphere. This would be indicative again of rather markedly regionalized effects depending, for example, on topographic and orographic channelling of flows, sea breeze and dry line location and intensity and similar effects.

2.9 There is ongoing uncertainty about the frequency, tracks and intensity of tropical cyclones in future climate scenarios. Some evidence suggests a regionally-differentiated behaviour, and a possibly noticeable role of the ENSO cycles. There is good agreement that the risk of coastal flooding will increase due the combination of sea level rise, intensity of cyclones and ensuing storm surges. Many airports have recently been built near or at the seashore or on islands (some of them purposely created for the construction of the airport), and constructive measures may be necessary to ensure continued operability both of the airport infrastructure and access ways.

2.10 Extra-tropical cyclones are generally expected to become stronger with the availability of higher temperature and moisture gradients, an effect that has become visible since the late 1980s. Surface winds may have quite diverse effects on aviation, if they are along the climatological mean direction, disturbance to operations will remain limited. In case of strong crosswinds coupled with intense precipitation, they may limit acceptance capacity of airports.

2.11 The most intense weather phenomena, such as strong convection, wind shear, hail and high-level icing, all are dependent on very small-scale weather elements with limited predictability. The situation at major hub airports with endemic capacity limitations will thus require increased efforts in accurate predictions of such conditions, an excellent network management to adapt traffic flows to rapidly changing conditions and improved communications between stakeholders, including up- and down linking of meteorological information to and from the cockpit.

2.12 There is confidence in a general poleward shift of the jet stream systems associated with the polar frontal zone. Whether this will result in a stronger jet stream core with higher speeds and shear is less certain, and in the southern hemisphere there is some evidence that the re-building of the ozone layer there may have a weakening influence on the meridional temperature gradients in the southern hemisphere winter, with consequential light weakening of the jet.

***Impact on aviation stakeholders***

2.13 Airport operators have a very long-term planning horizon, and are influenced by climate change in many ways:

* Threat to infrastructure from severe weather, flooding, storm surges, ground water table, subsidence and other hydro-geological issues;
* Threat to accessibility by similar weather elements;
* Changes to demand for typical tourist destinations;
* Societal risks (mass migration, security, epidemiological threats related to severe climate effects on people’s lives and livelihoods); and
* Changes to operational requirements (e.g. snow clearance, de-icing, occurrence of sand/dust storms.

Most of these risks have a time horizon of 5 to 50 years, and will require localized studies that are specific for their sites rather than global outlooks.

2.14 Aircraft and equipment manufacturers have a typical design cycle of some decades (e.g. B747 introduced in 1969), and need to anticipate any significant changes to the certification envelope demanded by aviation authorities in response to changed environmental conditions. Engine manufacturers and providers of sensors and other exposed arts of the aircraft require already scientific support to help them prioritize their R&D efforts, with the difficult task to continue the development of more efficient aircraft while increasing their resilience to harsher environmental conditions.

2.15 Aviation authorities require expertise on the evolution of weather related risks in a changing and more volatile climate, taking into account that aircraft will be operating globally, and thus need to be safe to operate in any conditions.

2.16 Airlines and other commercial operators will be affected by regulatory changes, changes in demand, and a potentially more volatile and possibly hostile environment. While demand may also be linked to the evolution of global, regional and national economies, all having to adapt to changing climate and weather conditions, airlines are expected to have a shorter planning horizon, as they are able to switch routes, schedules and even aircraft in line with the conditions and demand.

2.17 Air traffic managers need to adapt to more adverse conditions happening at relatively short notice, requiring a much higher degree of flexibility, based on collaborative decision making, shared data and common situational awareness. Flexible use of airspace and rapid adaptation to extreme conditions will be needed based on SWIM-based information systems.

**3. ACTION PLAN**

3.1 While some of the above-mentioned risks are qualitatively evident and need to addressed by a comprehensive risk management system, the relative importance of these risks for different regions, climate scenarios and aviation stakeholders require a significant effort in joint research between aviation and climate scientists.

3.2 Individual stakeholders (e.g. ICAO, operators, OEMs, ATM, airports) have already made efforts and achieved progress in addressing their priority issues.

3.3 It will be important for WMO, as a global meteorological standardization and coordinating body, to encourage and enable multi-disciplinary efforts in research and best practice models in climate service provision, develop the necessary standards and risk management methodologies and ensure that environmentally driven issues are cross-linked into the Global Air Navigation Plan (GANP) of ICAO for consistency and resilience of the global aviation system. Governance questions including directions for cost recovery, outlining as well State responsibility for national efforts, will require adequate guidance and suitable manuals to support a successful risk management.

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