AeM SERIES No. 6

Outcomes of the 2020 Survey on the Impacts of Climate Change and Variability on Aviation

Standing Committee on Services for Aviation

A subsidiary body of the WMO's Services Commission

Geneva

October 2020

Full report

WEATHER CLIMATE WATER

WORLD
METEOROLOGICAL
ORGANIZATION

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WORLD METEOROLOGICAL ORGANIZATION

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CONTENTS

PREFACE

Weather is a global phenomenon, one that is unconstrained and unconcerned by national or international borders. Aviation is a global business with, by the end of 2019, more than 150,000 flight operations performed daily worldwide – although 2020 has of course seen a massive reduction in global air traffic due to the Coronavirus (COVID-19) pandemic. Through services that are provided around-the-clock nationally, regionally or globally, aeronautical meteorological service providers of WMO Members play a vital role in helping ensure that international civil aviation operates safely, efficiently, economically and in as environmentally-responsibly way as possible, whatever the weather (and its nuances) might have to offer.

Increasingly, the aviation industry is becoming sensitized to the operational and developmental impacts of a changing climate scenario, not least through the increased frequency and intensity of extreme weather events such as tropical cyclones, heat waves and cold waves that can have immediate and longer-term impacts at airports and in airspace. More subtle but no less important changes in the Earth atmosphere are manifesting in the form of changes to, for example, the strength and location of the jetstream, the location and severity of significant convection, turbulence and icing, and the incidence of fog. Any changes to these and other key parameters of interest, however small or large, have the potential to impact aviation operations and development.

As aviation emerges from the COVID-19 crisis, potentially in a leaner yet more efficient form, as international air traffic recovers ground lost due to the pandemic and starts to grow again year-on-year, and given that climate change predictions, based on current warming trends not being constrained or reversed, point towards a future with more extremes of weather, the margins for performing safe, efficient, economic and environmentally-responsible flight operations are likely to be reduced.

With this in mind, WMO, through its Services Commission (SERCOM) Standing Committee on Services for Aviation (SC-AVI) and the former Commission for Aeronautical Meteorology (CAeM), conducted this 2020 survey to ascertain the perceived needs and concerns of a cross-section of the aviation industry to the impacts of climate change and variability on both the operations and future developments. The outcomes of the survey will help inform and potentially direct future scientific and technological developments by WMO Members, in particular their aeronautical meteorological service providers. SC-AVI, in particular, will continue to pay close attention to the impacts of climate change and variability on aviation and to fostering collaboration with aviation stakeholders in this regard.

I would like to express my appreciation to all those aviation professionals who took part in the survey. I also wish to acknowledge the kind support of the SC-AVI Expert Team on Climate Change and Variability Impacts on Aviation (ET-CCV), particularly Ms Anna Ivanova who served as the survey task lead, as well as Mr Greg Brock, Head, Services for Aviation Division of the WMO Secretariat. Without everyone’s support and valuable contribution the conducting of this survey and the production of this report would not have been possible.

Ian Lisk
President, WMO Services Commission
Chair, WMO Standing Committee on Services for Aviation
October 2020

EXECUTIVE SUMMARY

The conducting, by WMO, of this *2020 Survey on the Impacts of Climate Change and Variability on Aviation* (hereinafter referred to as the '2020 Survey' or simply 'survey') was in response to the outcomes of a WMO Aeronautical Meteorology Scientific Conference in 2017 and the Sixteenth Session of the WMO Commission for Aeronautical Meteorology (CAeM-16) in 2018, which had both addressed issues relating to the impacts of climate change and variability on aviation.

The objective of the survey was to clarify the interest and concerns of an array of aviation professionals around the world, including airline operators, pilots/flight crew and air traffic services personnel, to the climate change and variability issue[1] and to its impact on aviation operations now and into the future.

The survey, comprising 10 multiple-choice questions, was conducted online and dispatched to more than 400 aviation professionals across all WMO regions. Between 22 January and 31 March 2020, the survey yielded a total of 71 responses[2]. Airline operators and pilots/flight crew collectively represented around two-thirds of all the responses received. Europe, Asia and the Middle East collectively represented around two-thirds of the geographic regions best represented by the 71 respondents, given their affiliation and/or operations.

In the context of the estimated likelihood of occurrence and severity of impact on **airport infrastructure performance**, an expressed concern was associated with an increased likelihood of airfield flooding due to heavy rain and/or storm surge and an associated high severity of impact. These concerns were particularly noted amongst the airline operator and pilot/flight crew respondents but, in contrast, not particularly noted amongst the airport operator and air traffic service respondents. There appeared to be only limited expressed concern amongst respondents for aspects such as ground subsidence and the need to adapt the cooling or heating of facilities on airports.

In the context of the estimated likelihood of occurrence and severity of impact on **airport operations performance**, an expressed concern was associated with longer take-off and landing distances in a warming climate and a reduced runway capacity due to higher runway occupancy times. These concerns were particularly noted amongst the airport operator and air traffic service respondents, and to some extent the airline operator respondents but, in contrast, not particularly noted amongst the pilot/flight crew respondents. There appeared to be only limited expressed concern amongst respondents for aspects such as reduced aircraft movements due to ground operations at high temperatures and increased noise problems due to shallower climbs or choice of runway due to shift of wind patterns.

In the context of the estimated likelihood of occurrence and severity of impact on **air traffic management performance**, an expressed concern was associated with increased challenges in managing terminal area capacity and air traffic sector capacity due to increased risk of thunderstorms as well as increased impacts on low visibility operations due to changes in the occurrence of fog. These concerns were particularly noted amongst the airline operators and airport operator respondents. Increased challenges in managing air traffic control sector capacity due to changes of high-altitude

[1] In this context, climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. Natural climate variability arises as a result of natural internal processes within the climate system or because of variations in natural external forcing such as solar activity.

[2] Given the number of responses (71 in total), a degree of caution should be exercised when considering the findings and observations, conclusions and recommendations stemming from the 2020 survey in that they may not necessarily reflect global consensus. Notwithstanding, WMO sincerely appreciates those aviation professionals who took the time to respond to the survey within the timescale given.

air temperatures was viewed by a majority of respondents as possessing a low likelihood of occurrence and a low severity of impact. Overall opinion on the likelihood and severity of increased challenges in managing air traffic control sector capacity due to changes in wind patterns (jet streams) was fairly divided, however air traffic service and original equipment manufacturer respondents did highlight this as a particular concern for them.

In the context of the estimated likelihood of occurrence and severity of impact on **flight safety performance**, an expressed concern was associated with an increased frequency and severity of turbulence (convection-induced turbulence and clear air turbulence). This concern was particularly noted amongst, but not limited to, the airline operator and the airport operator respondents. Similarly, an increased risk of bird strike due to changes in bird migration patterns was particularly noted amongst respondents, especially the pilots/flight crew and air traffic services. There appeared to be only limited expressed concern amongst respondents regarding the presence of strong low-level temperature inversions affecting aircraft performance during take-off and landing. High-altitude icing phenomena was cited as an additional flight safety performance concern within the original equipment manufacturers group.

In the context of the estimated likelihood of occurrence and severity of impact on **airline operations performance**, an expressed concern was associated with more frequent disruption due to extreme weather events and increased fuel consumption due to longer routings. These concerns were particularly noted by most respondents. The carrying of reduced payloads due to a warmer climate was also cited as a concern by many respondents, particularly airline operators and those responsible for administration and governance. There appeared to be only limited expressed concern amongst respondents for aspects such as increased fuel consumption due to more auxiliary power unit usage during the turnaround of an aircraft and increased fuel consumption due to reduced cruising speeds.

In the context of the **degree of impact of future climate change and variability on aviation operations**, there was almost unanimous agreement amongst respondents (93% agreed) that the impact could be moderate or greater, reflecting a significant concern that exists amongst those responsible for aviation operations and development.

In the context of those **parameters whose change in climatic variability will be most important to aviation operations**, low visibility (including fog) and low cloud, turbulence, convection and temperature (surface and upper-air) were identified as the most important by respondents. Other parameters were considered of lesser importance. It is worthwhile to note, however, that when considering responses across the different user groups, varying opinions often appeared – for example, what was important to one group of users did not necessarily mean it was important to another. These differences perhaps reflect a fact that different user groups may be impacted in different ways as the climate changes, therefore their perceived importance of the changing nature of the various parameters on their operations may differ.

In the context of the **timescale of climate change and variability of most interest to aviation operations and development**, a majority (around two-thirds) of respondents indicated ‘within the next 10 years’ to be of most interest, reflecting an immediate to near-term concern that many in the aviation community appear to share. It is worthwhile to note, however, that when considering responses within some of the user groups, divided opinion sometimes appeared, perhaps illustrating that within a group of users there can be differing viewpoints and differing needs depending on the precise nature of the operation or the development.

In view of the foregoing, **WMO should**, in particular, identify scientific research papers and other literature that demonstrate how a changing climate scenario may or will:

- increase the likelihood of heavy rain and storm surge events leading to localized flooding at airports,
- increase the likelihood of extreme heat days leading to a requirement for longer runways and/or reduced runway throughput capacity at airports,
- increase the likelihood of thunderstorms as well as the occurrence of low visibility/low cloud leading to operational impacts particularly at airports,
- influence the frequency, severity and/or location of convective-induced turbulence and clear-air turbulence leading to operational impacts particularly in airspace, and
- influence flight trajectories and flight optimization including, for example, routes flown, payload capacities and fuel usage.

In addition, **WMO should** identify scientific research papers and other literature on possible changes to wind patterns (including surface wind speeds/direction/gusts and the upper-air Jetstream), possible changes to bird migration patterns (particularly as it relates to the potential incidence of bird strikes at or near airports) and the incidence of high-altitude ice-crystal icing (particularly as it relates to en route flight safety and efficiency performance).

Lastly, **WMO should** ensure that any and all such materials are communicated to aviation users and other concerned stakeholders in a manner that is relevant to the user, easy to understand (including impact-based assessments where available) and, wherever feasible, downscaled to the regional or local level.

1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVE

In November 2017, WMO convened an Aeronautical Meteorology Scientific Conference in Toulouse, France. The conference, the first of its kind in almost 50 years, was dedicated to showcasing scientific and technological advancement of meteorology in support of the evolving needs and expectations of aviation users. One of the three major thematic areas of the conference addressed the impacts of climate change and variability on aviation operations and the associated science requirements. A broad array of presentations and panel discussions illustrated how the meteorological and the aeronautical communities were, individually and collectively, responding to a changing climate scenario through advances in science and technology and enhanced service delivery. The conference formulated Recommendation 3 as follows:

> *In the context of climate change and variability on aviation and associated science requirements, the conference recommended that:*
>
> - *The potential impacts of climate change and variability on aviation operations on the ground and in the air, downscaled to the local level, must be well researched and communicated;*
> - *The mitigation of extreme weather events and the adaptation to a changing climate demands a multidisciplinary effort involving both the physical and the social sciences. Furthermore, all stakeholders in meteorology and aviation must work together, including through WMO and ICAO, to build consensus on robust, sustainable global solutions;*
> - *Responding to climate variability will require a high degree of flexibility on the aviation users' side. While the incidence of high-impact extreme weather events is expected to increase, they will be infrequent relative to the norm. The foreseen continued growth of aviation worldwide in a changing climate scenario may present new challenges as demand for airspace capacity increases;*
> - *Improved availability of and access to high-quality in-situ observations of meteorological parameters, including water vapour, is a key enabler to improving climate prediction model capabilities. The preservation of such data is essential for validating and calibrating climate predictions; and*
> - *A changing climate scenario may render some of today's aerodrome, airspace and airframe design and operation standards inadequate in the years or decades to come. Using past climatological records alone as an indicator of future climate at an airport, say, may be insufficient given the (current) rate at which the world's climate is changing (warming).*

In July 2018, following-on from the success of the conference, WMO convened the Sixteenth Session of its Commission for Aeronautical Meteorology (CAeM-16). Through Recommendation 1 (CAeM-16), the Organization recommended, inter alia, that collaboration be sustained and improved between technical commissions and programmes responsible for scientific and technological advancement consistent with the evolving needs of aviation users.

As a consequence of CAeM-16, an Expert Network on the Impacts of Climate Change and Variability on Aviation (EN-CCV) emerged. EN-CCV was tasked to:

(1) analyse the climatological variation (seasonal and inter-annual characteristics) in the location and/or intensity of jet streams, aviation hazards (including icing, turbulence and convection) and extreme weather events impacting aerodrome, terminal area and/or en route operations;

(2) support, in coordination with ICAO and other relevant stakeholders, an analysis of the impact of climate change and variability on airport operations, airspace management and capacity optimization; and

(3) support, in coordination with ICAO and other relevant stakeholders, an analysis of the impact of climate change and variability on airframe design.

As a component of the EN-CCV work plan, a survey on the impacts of climate change and variability on aviation was conducted by WMO[3].

The objective of the survey was to clarify the interest and concerns of an array of aviation professionals around the world to the climate change and variability issue and to its impact on aviation operations now and into the future.

> *Note. – In this context, climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. Natural climate variability arises as a result of natural internal processes within the climate system or because of variations in natural external forcing such as solar activity.*

The survey was dispatched to more than 400 aviation professionals across all WMO regions on 22 January 2020. The survey, in the form of an online questionnaire comprising 10 multiple-choice questions, concluded on 31 March 2020.

1.2 SCOPE

The 2020 survey addressed the following areas:

(1) Affiliation of the respondent within the international civil aviation community;

(2) Geographic region (or regions) representing the respondent's current affiliation and/or operations;

(3) Estimated likelihood of occurrence and severity of impact of extreme weather and other climate-related events in:

   a. airport infrastructure performance;

   b. airport operations performance;

   c. air traffic management performance events;

   d. flight safety performance; and

   e. airline operations performance;

[3] As part of a reform of WMO constituent bodies, in 2020 the Expert Network on the Impacts of Climate Change and Variability on Aviation (EN-CCV) of the Commission for Aeronautical Meteorology (CAeM) transitioned to become an Expert Team on the Impacts of Climate Change and Variability on Aviation (ET-CCV) of the Standing Committee on Services for Aviation (SC-AVI). The SC-AVI is a subsidiary body of the WMO Services Commission (SERCOM).

(4) Evaluation, by the respondent, of the degree of impact of future climate change and variability on aviation;

(5) Parameters whose change in climatic variability will be the most important to the respondent's operations; and

(6) Timescale of climate change and variability that may affect aviation operations and development of most interest to the respondent.

2. RESPONSE RATE

Between 22 January and 31 March 2020, the survey yielded a total of 71 complete responses from the 405 aviation professionals consulted. This equates to a response rate of approximately 18%[4].

3. METHODOLOGY AND ANALYSIS OF RESPONSES

The survey was sent to aviation professionals at the national and international level on 22 January 2020, with reminder notifications sent on 13 February and 17 March 2020. The survey closed on 31 March 2020.

The survey was conducted via an online questionnaire using SurveyMonkey. It was conducted in the English language only[5].

Each of the 10 questions within the survey were multiple-choice to which the respondent was expected to indicate their professional opinion considering their operational circumstances within the national and international civil aviation community.

On average, the response time for completing the survey was 15 minutes.

The responses to the survey were collated, anonymized and analyzed by the WMO Secretariat with the assistance of EN-CCV. As such, the results cannot be attributed to an individual organization or country and individual responses have not been published.

The following section presents the findings and observations arising from the survey.

[4] This fairly low response rate may, in part, be due to the timing of the survey inadvertently coinciding with the global onset of the Coronavirus (COVID-19) pandemic. Many of the aviation professionals who were in receipt of the survey may have been forced to re-prioritize their commitments in order to urgently respond to the pandemic that was having major operational and economic impacts on the aviation industry at the time.

[5] Experts within EN-CCV assisted with the compilation of replies from non-English speaking aviation professionals and the translation of their responses into English and insertion into the SurveyMonkey portal.

IMPORTANT NOTE.

It is worthwhile to note that only 71 responses out of a possible 405 responses were received.

Consequently, a degree of caution should be exercised when considering the findings and observations, conclusions and recommendations stemming from the 2020 survey in that they may not necessarily reflect global consensus.

Notwithstanding, WMO sincerely appreciates those aviation professionals who took the time to respond to the survey within the timescale given.

4. FINDINGS AND OBSERVATIONS

QUESTION 1

Indicate the affiliation that best represents your current role within the international civil aviation community

- ***Administration and governance***
- ***Pilot/flight crew***
- ***Air traffic service including air traffic control***
- ***Airline operator including dispatch/flight operations centre***
- ***Airport operator***
- ***Ground handling operator/agent***
- ***Original equipment manufacturer including airframe or engine supplier***
- ***Other (to be specified in the response)***

FINDINGS 1

Table 1. Affiliation of the respondents to the survey (tabular)

	Count	Percentage
Airline operator including dispatch/ flight operations centre	27	38%
Pilot/Flight crew	19	27%
Air traffic service including air traffic control	7	10%
Original equipment manufacturer including airframe or engine supplier	6	8%
Administration and governance	5	7%
Airport operator	4	6%
Ground handling operator/agent	1	1%
Other*	2	3%
Total	71	100%

* Other affiliations comprised a weather technology company and an aircraft maintenance facility.

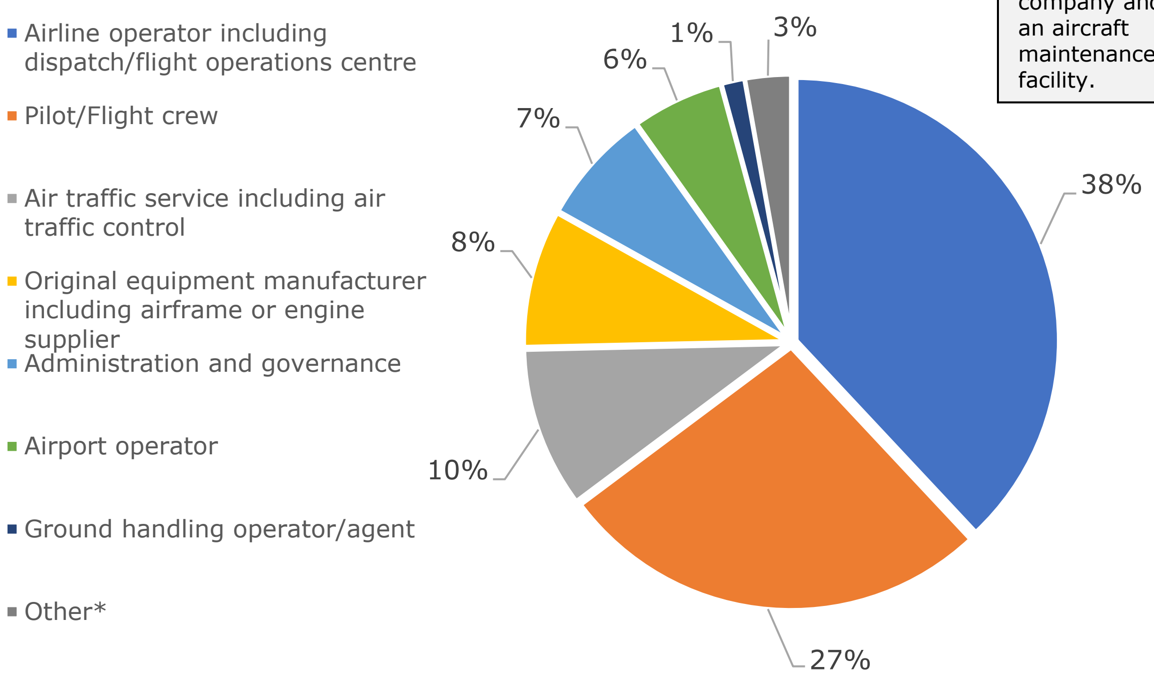

Figure 1. Affiliation of the respondents to the survey (graphical)

OBSERVATIONS 1
According to Table 1 and Figure 1, the total statistical sample of 71 responses cannot be considered as thoroughly representative. Just two groups, namely Airline operator and Pilot/Flight crew, contain enough responses to analyze (27 and 19 responses respectively). Nevertheless, in the absence of valid alternatives, all other groups of responses were taken into consideration, namely: Air traffic service (7 responses), Original equipment manufacturer (6), Administration and governance (5), Airport operator (4) and Ground handling operator/agent (1). One response from a representative of a weather technology company and one response from an aircraft maintenance facility were taking into consideration too ('Other'). As highlighted in the endnote of Chapter 3, in view of the response rate a degree of caution should be exercised when considering the findings and observations, conclusions and recommendations stemming from the 2020 survey in that they may not necessarily reflect global consensus. If WMO repeats this type of survey in the future, attention may be given to increasing the response rate from aviation professionals in those domains where the 2020 response rate was low, e.g. airport operations and ground handling. The performance of such operations may be acutely impacted by climate change and variability. In addition, consideration may be given to disseminating the survey in more than one language. The 2020 survey was conducted in the English language only.

QUESTION 2

Indicate the geographic region (or regions) that best represent your current affiliation and/or operations

FINDINGS 2

Table 2. Geographic region(s) represented by the respondents to the survey (tabular)

	Count	Percentage
Asia and the Middle East	25	35%
Europe	24	34%
The Americas	13	18%
Multi-continent*	8	11%
Oceania**	1	1%
Total	71	100%

* Note, some multi-continent operators indicated that they have operations to/from/within the African continent

** Oceania comprises Australia, New Zealand and the South-West Pacific Small Island States

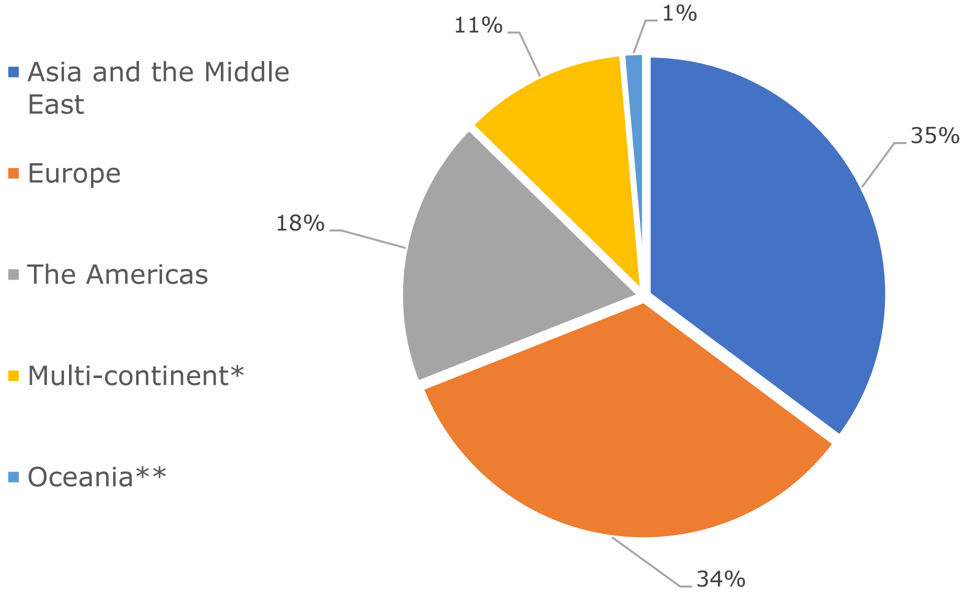

Figure 2. Geographic region(s) represented by the respondents to the survey (graphical)

OBSERVATIONS 2

According to Table 2 and Figure 2, response rates were the highest from respondents with affiliation and/or operations in Europe, Asia and the Middle East.

Eight respondents indicated that they have affiliation/operations across multiple continents, including one that had affiliation/operations on the African continent, while only one respondent indicated they had affiliation/operations in Oceania.

If WMO repeats this type of survey in the future, attention may be given to increasing the response rate from aviation professionals in those regions where the 2020 response rate was low, i.e. Africa and Oceania. Both these regions may be acutely impacted by climate change and variability. The availability of the survey in more than one language (as alluded at Observation 1 above) may also contribute to increasing the response rate to any future survey.

QUESTION 3

Indicate the estimated likelihood of occurrence and severity of impact on <u>airport infrastructure performance</u> of the following:

- ***a. Heat damage to runway surface in more frequent extreme temperature events***
- ***b. Higher chance of airfield flooding due to heavy rain***
- ***c. Higher chance of airfield flooding due to storm surge***
- ***d. Drainage of runways, taxiways, apron areas need to be improved***
- ***e. Ground subsidence***
- ***f. Adaptation to changed cooling and heating requirement on facilities***
- ***g. Other (to be specified in the response)***

FINDINGS 3

Table 3. Estimated likelihood of occurrence and severity of impact on airport infrastructure performance – all responses (tabular)

Sample size: 71. Actual number of responses per question as indicated.	Likelihood of occurrence			Severity of impact		
	Unlikely or very unlikely	Neutral	Likely or very likely	Low or very low	Neutral	High or very high
Heat damage to runway surface in more frequent extreme temperature events	29	13	18	14	15	29
Higher chance of airfield flooding due to heavy rain	27	11	22	18	10	32
Higher chance of airfield flooding due to storm surge	24	14	23	19	10	32
Drainage of runways, taxiways, apron areas need to be improved	16	23	19	12	27	18
Ground subsidence	28	14	14	22	16	16
Adaptation to changed cooling and heating requirement on facilities	25	15	15	21	22	11
Other*	2	4	4	2	4	3

* 'Other' comprised increased incidence of urban heat island effect, tropical diseases and storm damage to infrastructure.

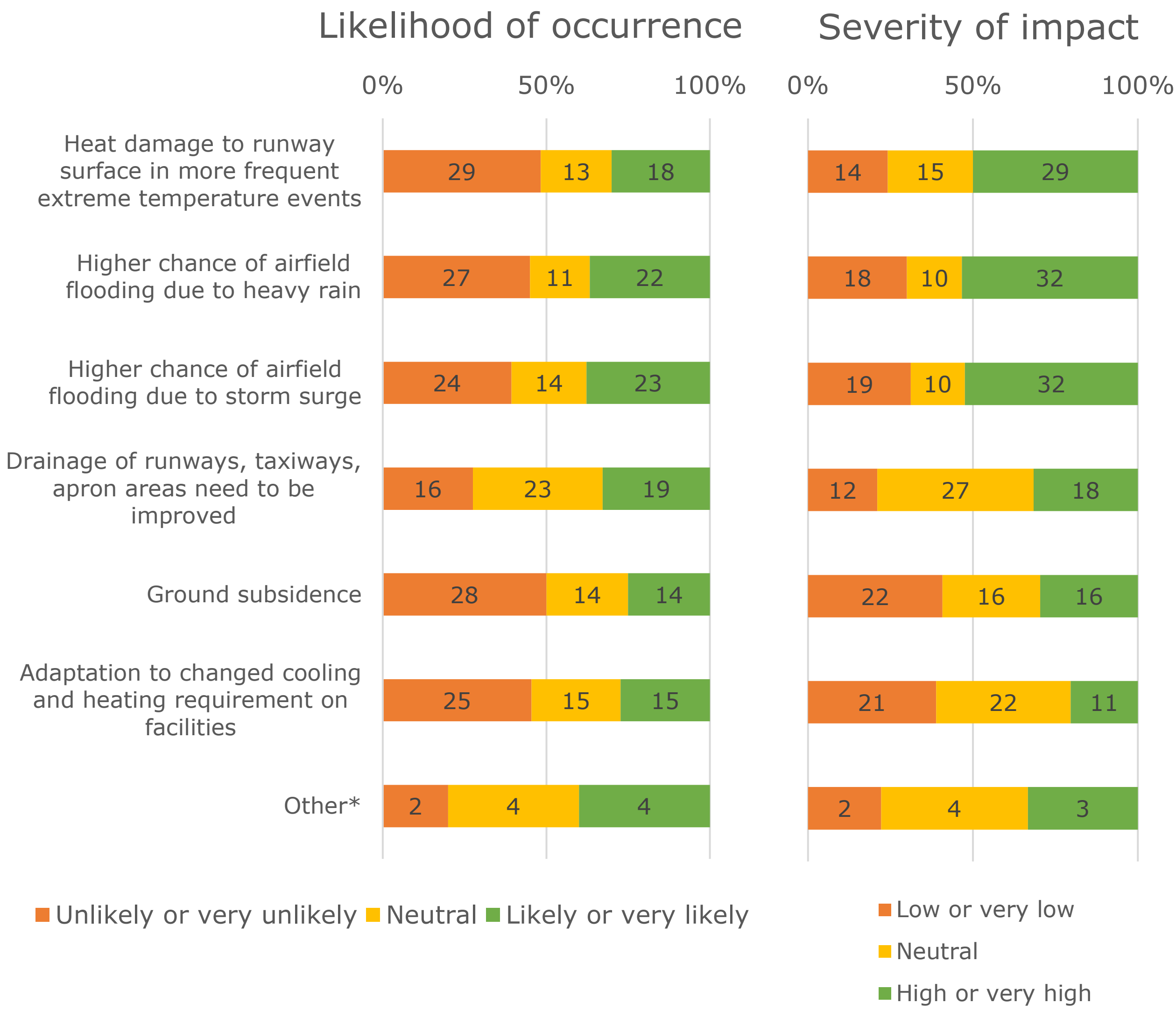

Figure 3. Estimated likelihood of occurrence and severity of impact on airport infrastructure performance – all responses (graphical)
Sample size: 71. Actual number of responses per question as indicated.

* 'Other' comprised increased incidence of urban heat island effect, tropical diseases and storm damage to infrastructure.

OBSERVATIONS 3

According to the total sample, the most likely negative influence on airport infrastructure and performance could be caused by heavy rain as well as storm surge flooding at an airfield. These factors have the greatest severity of impact, according to the replies received. Representatives of the two major respondent groups, namely airline operators and pilots/flight crew, were of the same view in this regard.

Four airport operator respondents, however, considered airfield flooding to be unlikely, with 3 out of these 4 respondents estimating the severity of impact of flooding to be low.

The only ground handling operator respondent considered all above mentioned consequences of climate change as very likely and most affecting airport infrastructure and performance (*excluding* 'Drainage of runway, taxiway, apron areas need to be improved' for which the respondent's position on the severity of impact was estimated as 'Neutral').

The views of representatives of the 'Administration and governance' group differed greatly. Some assessed all factors as unlikely or neutral while others highlighted as likely the risks of airport flooding and ground subsidence.

Two of the seven air traffic service respondents estimated future flooding at airfields as highly likely and most severe while the other 5 respondents considered all factors as not significant.

'Other' responses received comprised an increased heat island effect due to more concrete around airport reducing snow accumulation in borderline snow events, storm damage to infrastructure, and tropical diseases.

QUESTION 4
Indicate the estimated likelihood of occurrence and severity of impact on <u>airport operations performance</u> of the following: ***a. Increased noise problem due to shallower climbs or choice of runway due to shift of wind patterns*** ***b. Longer take-off and landing distances in a warming climate*** ***c. Reduced runway capacity due to higher runway occupancy times*** ***d. Reduced aircraft movements due to ground operation at high temperatures*** ***e. Other (to be specified in the response)***
FINDINGS 4

Table 4. Estimated likelihood of occurrence and severity of impact on airport operations performance – all responses (tabular)

	Likelihood of occurrence			Severity of impact		
Sample size: 71. Actual number of responses per question as indicated.	Unlikely or very unlikely	Neutral	Likely or very likely	Low or very low	Neutral	High or very high
Increased noise problem due to shallower climbs or choice of runway due to shift of wind patterns	31	10	19	30	18	10
Longer take-off and landing distances in a warming climate	15	16	32	14	23	26
Reduced runway capacity due to higher runway occupancy times	17	17	24	12	21	23
Reduced aircraft movements due to ground operation at high temperatures	24	15	16	20	22	13
Other*	2	2	1	2	2	1

* 'Other' comprised increased incidence of urban heat island effect and extreme weather events.

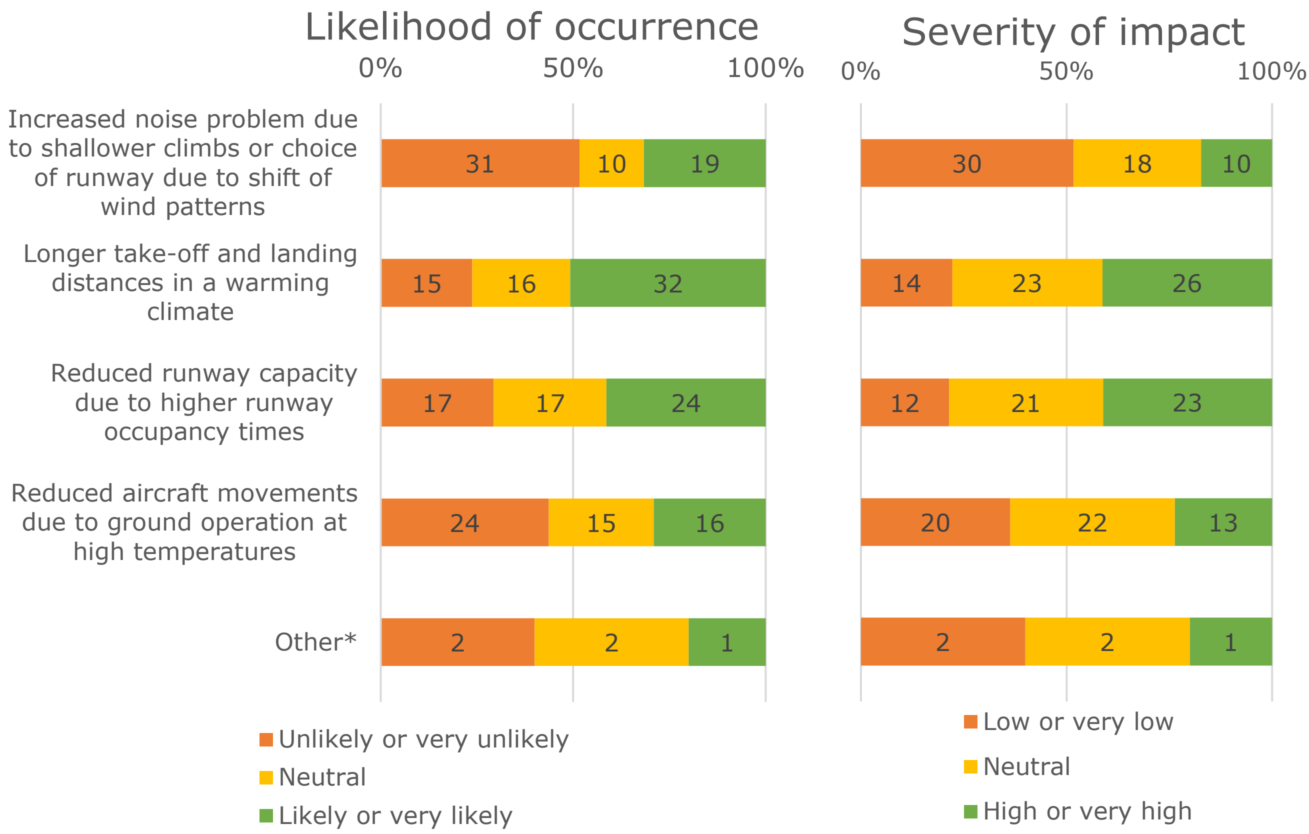

Figure 4. Estimated likelihood of occurrence and severity of impact on airport operations performance – all responses (graphical)
Sample size: 71. Actual number of responses per question as indicated.

* 'Other' comprised increased incidence of urban heat island effect and extreme weather events.

OBSERVATIONS 4

According to majority opinion (Table 4 and Figure 4), longer take-off and landing distances in a warming climate and reduced runway capacity due to higher runway occupancy times were the most significant in the context of the estimated likelihood of occurrence and severity of impact.

According to the opinion of respondents in the air traffic service category (7 responses), reduced runway capacity was the most likely and most significant for airport operations performance. Moreover, 3 out of 4 responses by airport operators agreed with this view.

The only response from a ground handling operator considered all factors as highly likely and most affecting on airport operations performance (*excluding* 'Reduced aircraft movement due to ground operations at high temperatures' for which the respondent's position on the severity of impact was estimated as 'Neutral'). This view was supported by just one out of the five administration and governance respondents, with other respondents considering that climate change and variability impact on airport operation performance to be unlikely and the severity to be low.

Pilots/flight crew mainly shared this last opinion, where just 2 respondents in this category considered longer take-off and landing distances in a warming climate as very likely and high impact.

Twelve of the twenty-seven airline operator respondents identified reduced runway capacity as the most significant and likely. 'Other' factors identified by airline operator respondents comprised increased heat island effect due to more concrete around airport that reduces fog frequency at airport.

QUESTION 5
Indicate the estimated likelihood of occurrence and severity of impact on <u>air traffic management performance</u> of the following: ***a. Increased challenge in managing terminal area capacity due to increased risk of thunderstorms*** ***b. Increased challenge in managing air traffic control sector capacity due to increased risk of thunderstorms*** ***c. Increased challenge in managing air traffic control sector capacity due to changes of wind patterns (jet streams)*** ***d. Increased challenge in managing air traffic control sector capacity due to changes of high-altitude air temperatures*** ***e. Increased impact on low visibility operations due to changes in fog occurrence*** ***f. Other (to be specified in the response)***
FINDINGS 5

Table 5. Estimated likelihood of occurrence and severity of impact on air traffic management performance – all responses (tabular)

	Likelihood of occurrence			Severity of impact		
Sample size: 71. Actual number of responses per question as indicated.	Unlikely or very unlikely	Neutral	Likely or very likely	Low or very low	Neutral	High or very high
Increased challenge in managing terminal area capacity due to increased risk of thunderstorms	12	10	40	7	10	44
Increased challenge in managing air traffic control sector capacity due to increased risk of thunderstorms	10	10	44	8	12	43
Increased challenge in managing air traffic control sector capacity due to changes of wind patterns (jet streams)	17	19	29	15	29	20
Increased challenge in managing air traffic control sector capacity due to changes of high-altitude air temperatures	33	12	14	30	17	10
Increased impact on low visibility operations due to changes in fog occurrence	11	14	37	9	13	37
Other*	2	2	1	2	2	1

* 'Other' included increased incidence of wind shear alerts.

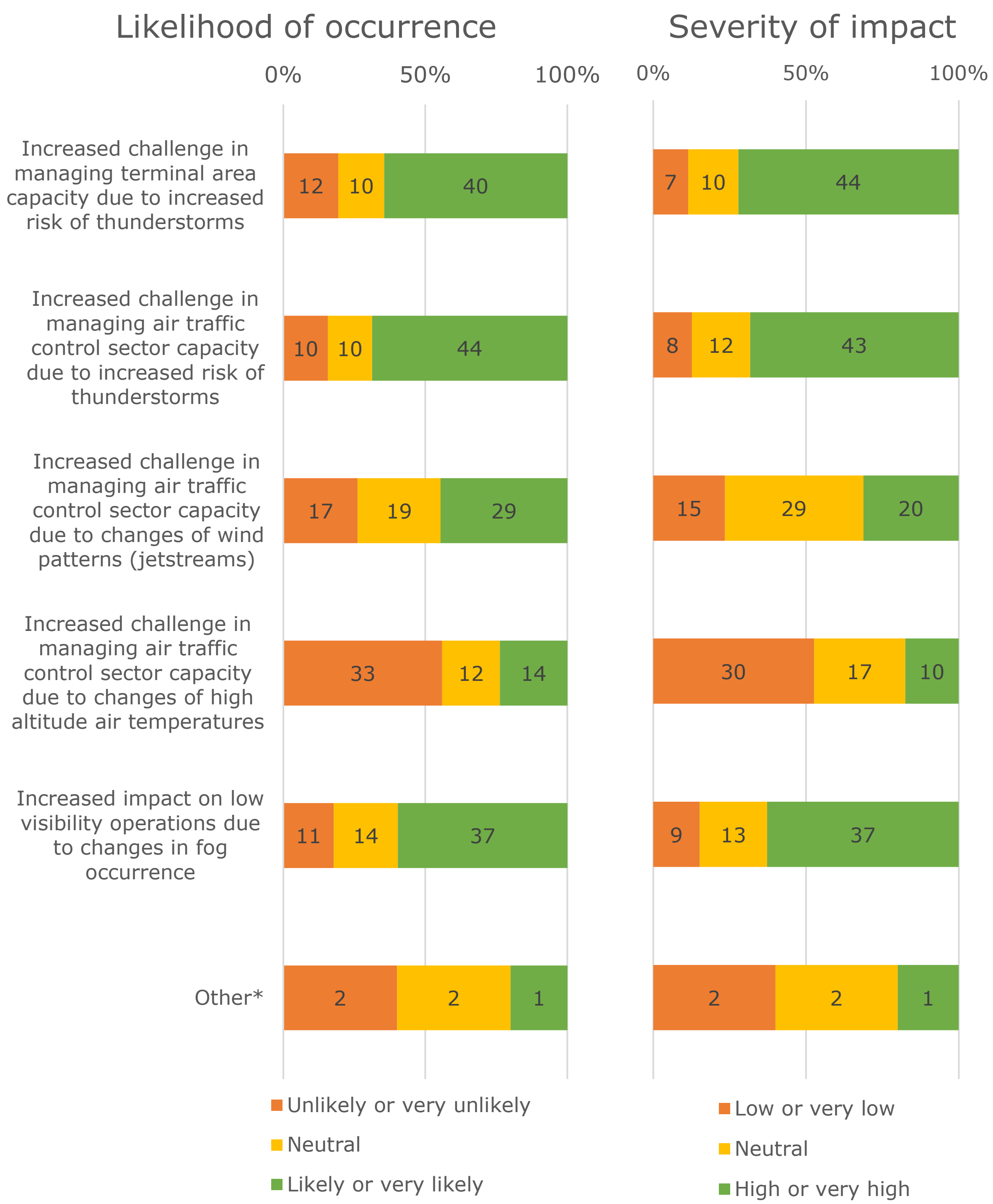

Figure 5. Estimated likelihood of occurrence and severity of impact on air traffic management performance – all responses (graphical)
Sample size: 71. Actual number of responses per question as indicated.

* 'Other' included increased incidence of wind shear alerts.

OBSERVATIONS 5
According to all responses (Table 5 and Figure 5), the most likely and affecting factors in terms of air traffic management performance are an increased risk of thunderstorm causing increased challenges in managing terminal area as well as managing air traffic control sector capacities as well as changes (increased incidence) in fog occurrences causing increased impact on low visibility operations. More than three-quarters of the airline operator respondents and practically all airport operator respondents considered these factors as the most likely to occur and the most severe impact. Air traffic service respondents gave the preference to a change of wind pattern regimes (such as jet streams) leading to increased challenges in managing air traffic control sector capacity. Original equipment manufacturer respondents were in aligned with this opinion. The ground handling operator respondent as well as two out of the five administration and governance respondents considered all factors as significant and highly likely. Besides from abovementioned factors, pilot/flight crew respondents noted an increased incidence of wind alerts that could appreciably complicate the air traffic management performance.

QUESTION 6

Indicate the estimated likelihood of occurrence and severity of impact on <u>flight safety performance</u> of the following:

- ***a. Increased risk of bird-strike due to changes in bird migration patterns***
- ***b. Presence of strong low-level temperature inversion affecting aircraft performance during take-off/landing***
- ***c. Increased severity and frequency of clear-air turbulence***
- ***d. Increased severity of turbulence associated with convection***
- ***e. Other (to be specified in the response)***

FINDINGS 6

Table 6. Estimated likelihood of occurrence and severity of impact on flight safety performance – all responses (tabular)

	Likelihood of occurrence			Severity of impact		
Sample size: 71. Actual number of responses per question as indicated.	Unlikely or very unlikely	Neutral	Likely or very likely	Low or very low	Neutral	High or very high
Increased risk of bird strike due to changes in bird migration patterns	8	23	28	7	18	31
Presence of strong low-level temperature inversion affecting aircraft performance during take-off / landing	21	23	14	15	28	12
Increased severity and frequency of clear-air turbulence	11	20	31	10	21	29
Increased severity of turbulence associated with convection	7	13	40	7	18	33
Other*	1	3	1	1	3	1

** 'Other' included increased incidence of high-altitude icing phenomena affecting safety.*

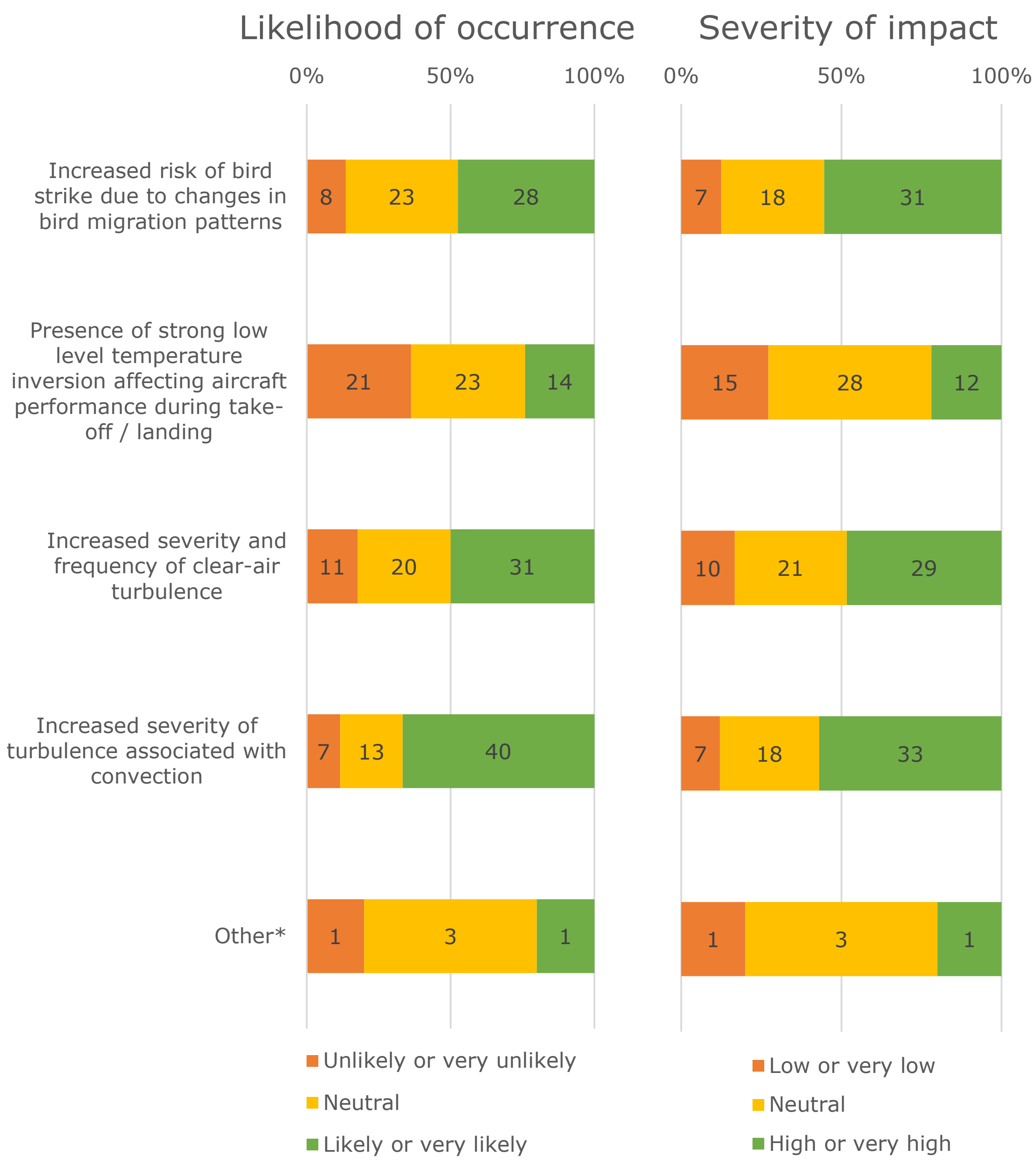

Figure 6. Estimated likelihood of occurrence and severity of impact on flight safety performance – all responses (graphical)
Sample size: 71. Actual number of responses per question as indicated.

* *'Other' included increased incidence of high-altitude icing phenomena affecting safety.*

OBSERVATIONS 6

According to all responses (Table 6 and Figure 6), the most significant factors affecting flight safety performance relating to climate change are an increased severity of turbulence (convective and in clear-air) and the changing of bird migration patterns.

More than half (58%) of all respondents noted high severity of increased convective turbulence. Of these, two-thirds (67%) attached high likelihood of occurrence. Representatives from airline operators and airport operators especially considered convective turbulence as the most dangerous consequence of climate change and variability.

Around one-half of pilot/flight crew respondents and nearly three-quarters of air traffic service respondents marked the severity of impact of bird strike as 'high' (and more than half of these respondents considered it as most likely). Around one-half (45%) of airline operator representatives and just under two-thirds (60%) of administration and governance respondents supported this point of view.

Original equipment manufacturers were most concerned about the increased risk of turbulence and high-attitude icing phenomena. Respondents in this group considered high-attitude icing phenomena as one more possible cause of flight safety performance changing due to climate change and variability.

The ground handling operator respondent considered all causes as significant and likely *except* for the impact of bird strike (likely but neutral degree of impact).

QUESTION 7

Indicate the estimated likelihood of occurrence and severity of impact on <u>airline operations performance</u> of the following:

- ***a. Increased fuel consumption due to more APU (auxiliary power unit) usage during the turnaround***
- ***a. Increased fuel consumption due to longer routings due to thunderstorms and clear air turbulence***
- ***b. Increased fuel consumption due to reduced cruising speeds***
- ***c. Reduced payload in warmer climate***
- ***d. More frequent disruption to operation due to extreme events (intense storms, heavy snowfall, etc.)***
- ***e. Other (to be specified in the response)***

FINDINGS 7

Table 7. Estimated likelihood of occurrence and severity of impact on airline operations performance – all responses (tabular)

Sample size: 71. Actual number of responses per question as indicated.	Likelihood of occurrence			Severity of impact		
	Unlikely or very unlikely	Neutral	Likely or very likely	Low or very low	Neutral	High or very high
Increased fuel consumption due to more APU (auxiliary power unit) usage during the turnaround	18	16	26	18	23	18
Increased fuel consumption due to longer routings due to thunderstorms and clear air turbulence	9	12	43	14	17	32
Increased fuel consumption due to reduced cruising speeds	23	16	19	21	24	12
Reduced payload in warmer climate	14	12	35	13	15	32
More frequent disruption to operation due to extreme events (intense storms, heavy snowfall, etc.)	13	11	38	11	9	41
Other*	1	3	1	1	2	1

** 'Other' included increased frequency of disruption due to morning frost.*

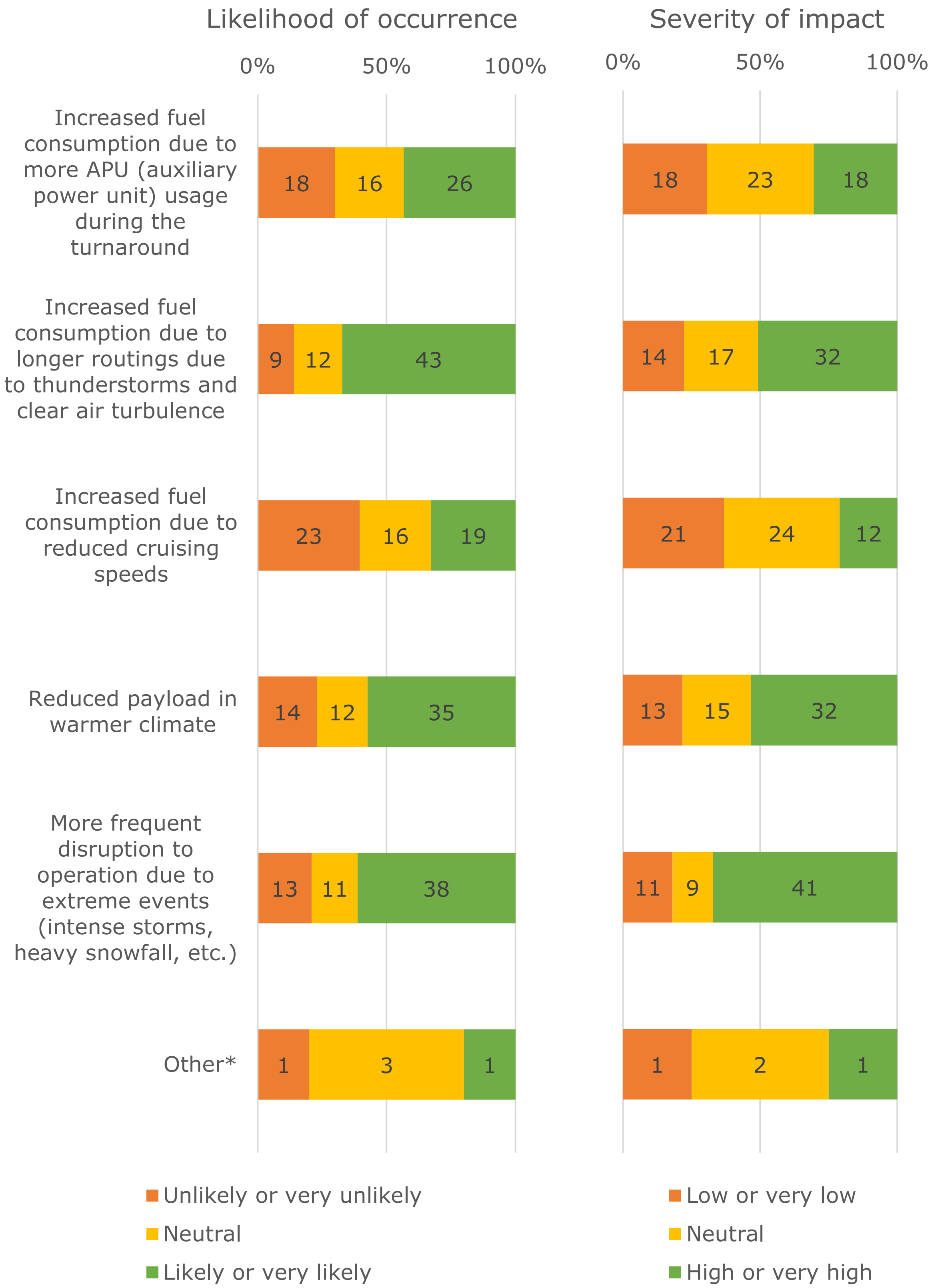

Figure 7. Estimated likelihood of occurrence and severity of impact on airline operations performance – all responses (graphical)
Sample size: 71. Actual number of responses per question as indicated.

** 'Other' included increased frequency of disruption due to morning frost.*

OBSERVATIONS 7

According to the responses (Table 7 and Figure 7), airline operations performance will be most impacted by extreme weather events that cause more frequent disruption to operations and increased fuel consumption due to longer routings to avoid, for example, thunderstorms and areas of clear-air turbulence.

More than half (60%) of respondents estimated an impact of extreme weather events as most likely and around two-thirds (68%) as most severe in terms of their impact.

More than two-thirds of respondents (70%) considered a route elongation due to thunderstorms and areas of clear-air turbulence as most likely.

Furthermore, in total, reduced payload capacity in a warmer climate with high severity of impact is considered highly likely. Unlike the airline operator respondents (up to 80%) and the administration and governance respondents (up to 80%), only around one-third (37%) of the pilot/flight crew respondents considered the likelihood of these factors as high.

One-half of the air traffic service respondents noted their attention to high likelihood of occurrence of increased fuel consumption due to increased auxiliary power unit (APU) usage during the turnaround of an aircraft.

The ground handling operator respondent and four out of the six original equipment manufacturer respondents indicated that increased frequency of extreme weather events was the main factor affecting airline operations performance.

Among other factors, airline operator respondents noted disruption to operations associated with morning frost, perhaps highlighting a concern associated with the frequency of aircraft anti-icing and de-icing operations.

QUESTION 8

What is your evaluation on the degree of impact of future climate change and variability on aviation?

- ***Little or no impact***
- ***Moderate impact***
- ***Significant impact***
-

FINDINGS 8

Table 8. Respondents evaluation on the degree of impact of future climate change and variability on aviation – all responses (tabular)

Sample size: 71	Count	Percentage
Significant impact	35	49%
Moderate impact	31	44%
Little or no impact	5	7%
Total	71	100%

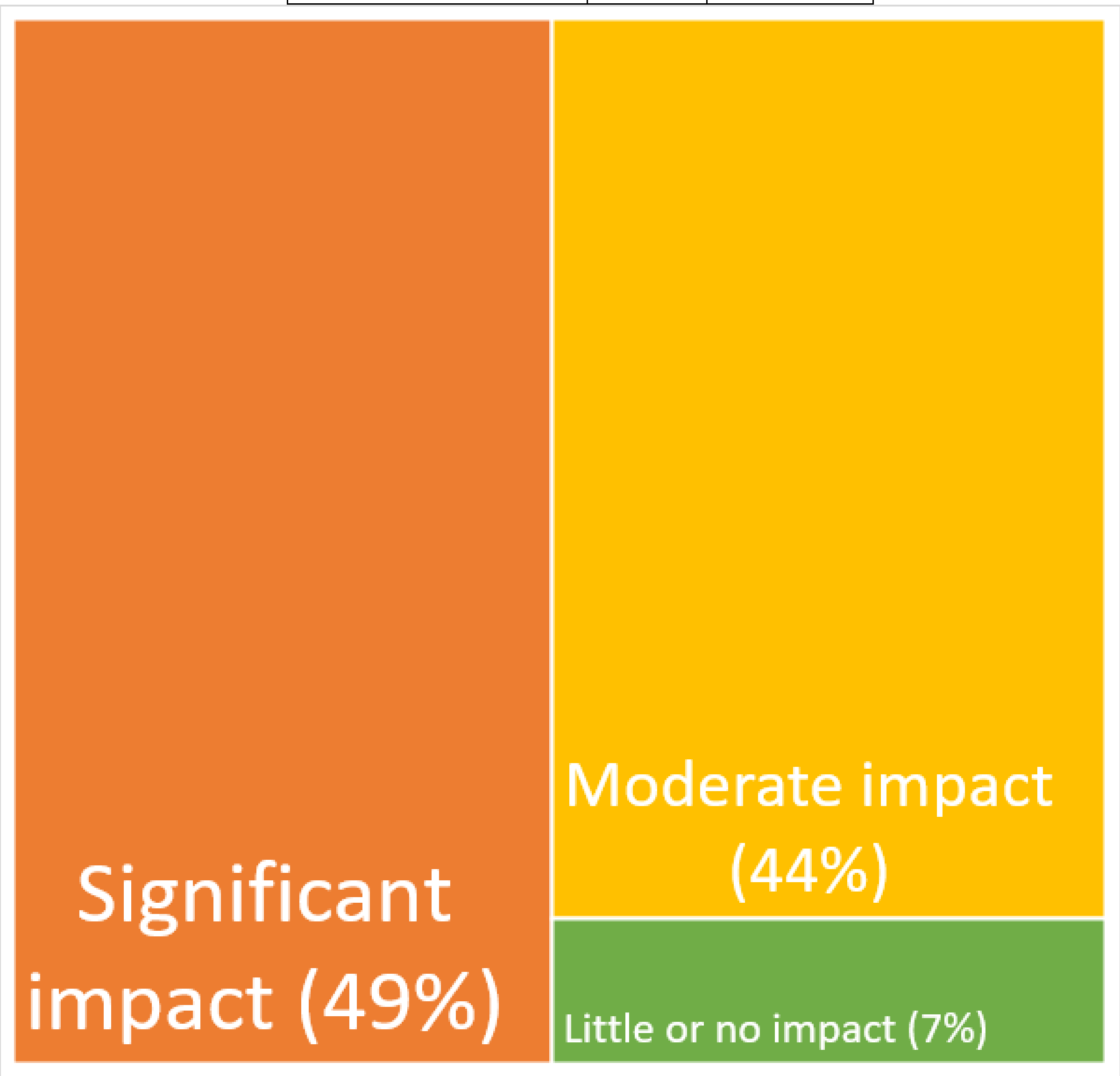

Figure 8. Respondents evaluation on the degree of impact of future climate change and variability on aviation – all responses (graphical)

Table 9. Respondents evaluation on the degree of impact of future climate change and variability on aviation – all responses grouped by region of affiliation and/or operation (tabular)

Sample size: 71. Actual number of responses for each region as indicated.	Count			Percentage within group		
	Significant impact	Moderate impact	Little or no impact	Significant impact	Moderate impact	Little or no impact
Asia and the Middle East (25)	16	9	0	64%	36%	0%
Europe (24)	9	13	2	38%	54%	8%
The Americas (13)	6	5	2	46%	38%	15%
Multi-continent* (8)	3	4	1	38%	50%	13%
Oceania** (1)	1	0	0	100%	0%	0%

** Note, some multi-continent operators indicated that they have operations to/from/within the African continent.*

*** Oceania comprises Australia, New Zealand and the South-West Pacific Small Island States.*

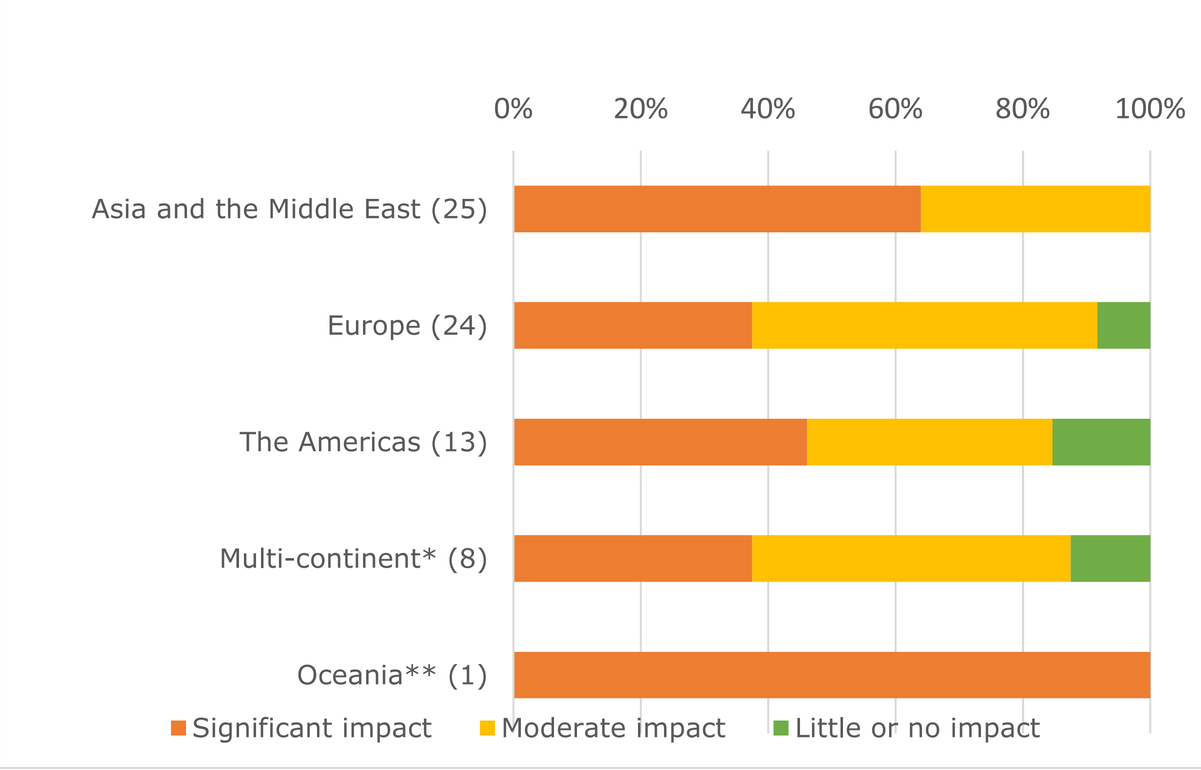

Figure 9. Respondents evaluation on the degree of impact of future climate change and variability on aviation – all responses grouped by region of affiliation and/or operation (graphical)
Sample size: 71. Actual number of responses for each region as indicated.

** Note, some multi-continent operators indicated that they have operations to/from/within the African continent.*

*** Oceania comprises Australia, New Zealand and the South-West Pacific Small Island States.*

Table 10. Respondents evaluation on the degree of impact of future climate change and variability on aviation – all responses grouped by operation (tabular)

Sample size: 71. Actual number of responses for each operation as indicated.	Count			Percentage within group		
	Significant impact	**Moderate impact**	**Little or no impact**	**Significant impact**	**Moderate impact**	**Little or no impact**
Airline operator including dispatch/flight operations centre (27)	20	6	1	74%	22%	4%
Pilot/Flight crew (19)	3	14	2	16%	74%	11%
Air traffic service including air traffic control (7)	2	4	1	29%	57%	14%
Original equipment manufacturer including airframe or engine supplier (6)	4	2	0	67%	33%	0%
Administration and governance (5)	2	3	0	40%	60%	0%
Airport operator (4)	2	2	0	50%	50%	0%
Ground handling operator/agent (1)	1	0	0	100%	0%	0%
Other* (2)	1	0	1	50%	0%	50%

** Other affiliations comprised a weather technology company and an aircraft maintenance facility*

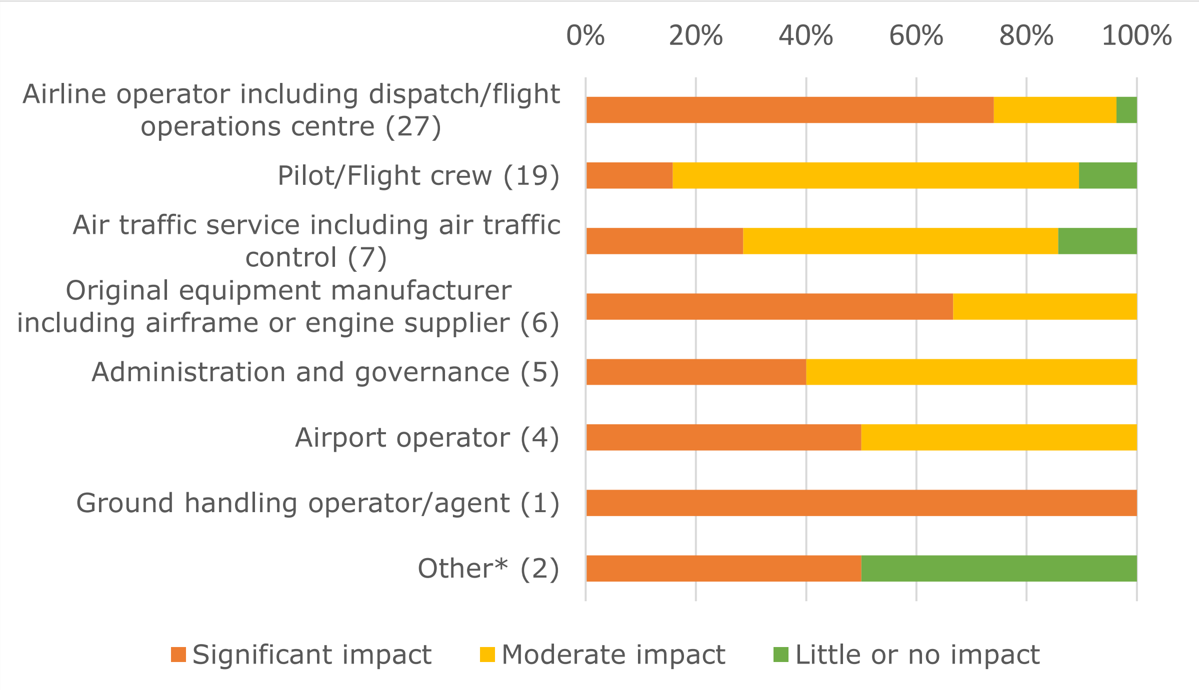

Figure 10. Respondents evaluation on the degree of impact of future climate change and variability on aviation – all responses grouped by operation (graphical)
Sample size: 71. Actual number of responses for each operation as indicated.

** Other affiliations comprised a weather technology company and an aircraft maintenance facility*

OBSERVATIONS 8
Almost one-half of all respondents (49%) estimated the impact of future climate change on aviation as 'significant', 44% as 'moderate' and just 7% as 'little or no' impacts (Table 8 and Figure 8 refer). This indicates that aviation community is sorely troubled with climate change challenge. Respondents from Asia and the Middle East expressed the impact of climate change as 'significant' more often (as did the only respondent from Oceania), whereas respondents from Europe estimated climate change impacts as 'moderate' more often. Such difference was less noticeable among respondents from Americas and respondents with operation in multi-continents (Table 9 and Figure 9 refer). The most optimistic grouping in the aviation community appears to be pilots/flight crew, with just 3 of the 19 respondents (16%) estimating the impact to the 'significant' (Table 10 and Figure 10 refer). This opinion contrasts with 74% (20 out of 27) of the airline operator respondents, 67% (4 out of 6) of the original equipment manufacturer respondents, 50% (2 out of 4) of airport operator respondents and the only ground handling operator who were of the opinion that the impact of future climate change is 'significant'. Also, the administration and governance respondents estimated the impact as 'significant' (40% or 2 out of 5) or 'moderate' (60% or 3 out of 5). Future climate change impacts on aviation was estimated as negligible (i.e. little or no impact) by approximately 1 in every 14 respondents (5 out of 71).

QUESTION 9

Select at least 3 parameters whose change in climatic variability will be most important to your operations:

- ***Temperature (surface and upper-air)***
- ***Location and intensity of jet stream (upper-air wind patterns)***
- ***Frequency and intensity of convection***
- ***Frequency and intensity of turbulence***
- ***Tropopause height***
- ***Sea level change***
- ***Surface and in-flight icing frequency***
- ***Low visibility (including fog) and low cloud***
- ***Other (to be specified in the response)***

FINDINGS 9

Table 11. Parameters whose change in climatic variability will be most important to respondents' operations – all respondents (tabular)

Sample size: 71	Count	Percentage
Low visibility (including fog) and low cloud	49	69%
Frequency and intensity of turbulence	42	59%
Temperature (surface and upper-air)	41	58%
Frequency and intensity of convection	41	58%
Location and intensity of jet streams (upper-air wind patterns)	26	37%
Frequency of surface and in-flight icing	19	27%
Tropopause height	10	14%
Sea level change	7	10%
Other*	4	6%

** 'Other' comprised incidence of sandstorms/dust storms, frequency and intensity of snowfall, and frequency and intensity of tropical cyclones.*

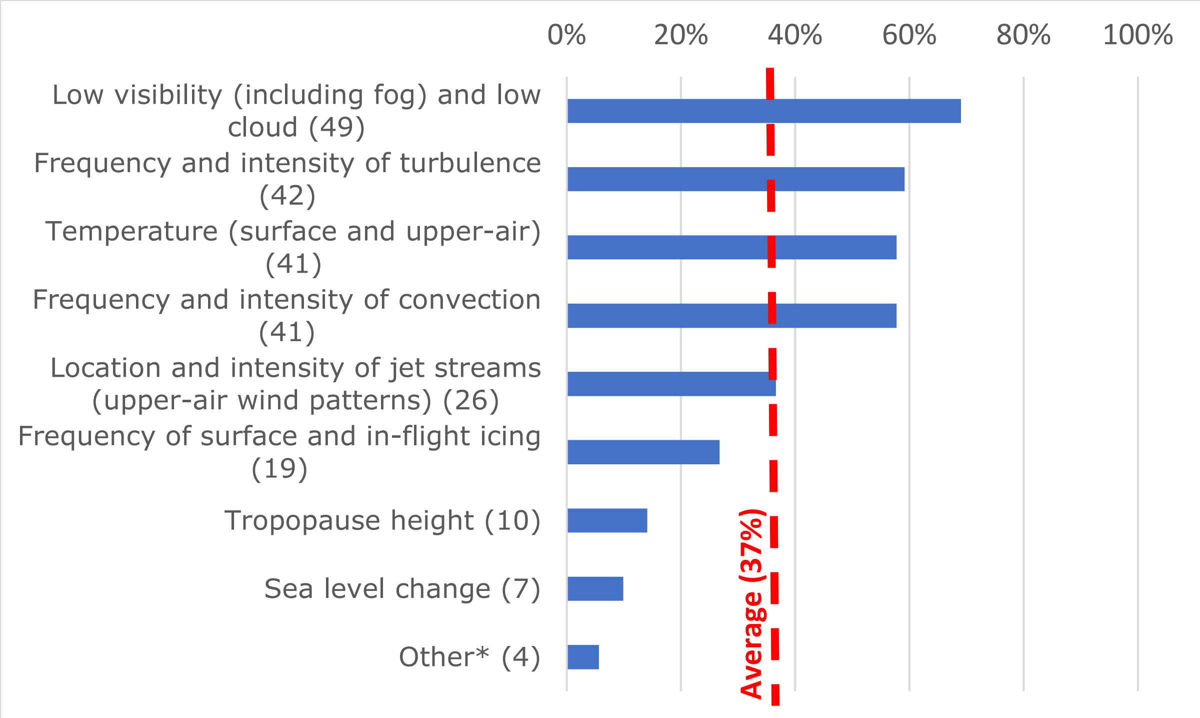

Figure 11. Parameters whose change in climatic variability will be most important to respondents' operations – all respondents (graphical)
Sample size: 71. Actual number of responses for each parameter as indicated.

** 'Other' comprised incidence of sandstorms/dust storms, frequency and intensity of snowfall, and frequency and intensity of tropical cyclones.*

Table 12. Parameters whose change in climatic variability will be most important to respondents' operations – airline operator respondents

Sample size: 27 (ranked by order of importance)	Count	Percentage
Frequency and intensity of convection	22	81%
Low visibility (including fog) and low cloud	20	74%
Temperature (at surface and upper-air)	13	48%
Frequency and intensity of turbulence	12	44%
Location and intensity of jet streams (upper-air wind patterns)	10	37%
Frequency of surface and in-flight icing	8	30%
Other (thunderstorms, tropical cyclones and snowstorms)	3	11%
Tropopause height	2	7%
Sea level change	0	0%

Table 13. Parameters whose change in climatic variability will be most important to respondents' operations – pilot/flight crew respondents

Sample size: 19 (ranked by order of importance)	Count	Percentage
Low visibility (including fog) and low cloud	13	68%
Frequency and intensity of turbulence	12	63%
Temperature (surface and upper-air)	11	58%
Frequency and intensity of convection	7	37%
Tropopause height	7	37%
Location and intensity of jet streams (upper-air wind patterns)	6	32%
Frequency of surface and in-flight icing	5	26%
Sea level change	2	11%
Other	0	0%

OBSERVATIONS 9

By all accounts (Table 11 and Figure 11), the most important parameter related to climate change impact on aviation is low visibility (including fog) and low cloud, with more than two-thirds (69%) of respondents expressing this opinion.

More than half of all respondents also highlight the significance of frequency and intensity of turbulence (59%), frequency and intensity of convection (58%) and temperature (58%).

When arranging the importance of the various parameters to the different groups in the aviation community, slightly different opinions emerge. These differences perhaps reflect a fact that different user groups may be impacted in different ways as the climate changes, and therefore their perceived importance of the changing nature of the various parameters on their operations may differ.

Analysis for the largest respondent groups, namely airline operators (27 respondents) and pilot/flight crew (19 respondents), show (Tables 12 and 13 respectively) that changes to the frequency and intensity of turbulence was the second most important parameter amongst the pilots/flight crew respondents (63%) while it was the fourth most important amongst the airline operator respondents (44%). Meanwhile, the airline operator respondents considered changes to the frequency and intensity of convection as the most important parameter (81%) while the pilot/flight crew respondents considered these changes of lower importance (joint fourth most important, 37%).

The importance of changes to the tropopause height was highlighted by 37% of the pilot/flight crew respondents (Table 13 refers), which is higher than the total sample size finding (14%, Table 11 refers) and much higher than the airline operator finding (7%, Table 12 refers).

An original equipment manufacturer respondent expressed the importance to their operations of "*increased level of mineral dust (storms) in the atmosphere*". In addition, an airline operator respondent considered "*reduced snowfall for borderline snow events, but potential for heavier snow in rare, strong winter storms*" as an important factor for their operations.

If WMO repeats this type of survey in the future, consideration may be given to including other meteorological parameters of relevance to aviation operations such as the frequency and intensity of precipitation (e.g. heavy rainfall or heavy snowfall).

QUESTION 10

What timescale(s) of climate change and variability that may affect aviation operations and development is (are) of most interest to you?

- ***Less than 2 years***
- ***Between 2 and 5 years***
- ***Between 5 and 10 years***
- ***Between 10 and 20 years***
- ***Between 20 and 50 years***
- ***50 years or more***
- ***Other (to be specified in the response)***

FINDINGS 10

Table 14. Timescale(s) of climate change and variability that may affect aviation operations and development that is (are) of most interest to respondents – all respondents (tabular)

	Count	Percentage
Less than 2 years	10	11%
Between 2 and 5 years	19	21%
Between 5 and 10 years	32	36%
Between 10 and 20 years	15	17%
Between 20 and 50 years	10	11%
50 years and more	4	4%
Total	90*	100%

** Note, the total sample size here exceeds 71 (i.e. the number of respondents to the survey) because some respondents selected multiple entries, for example 'Between 2 and 5 years' and 'Between 5 and 10 years'.*

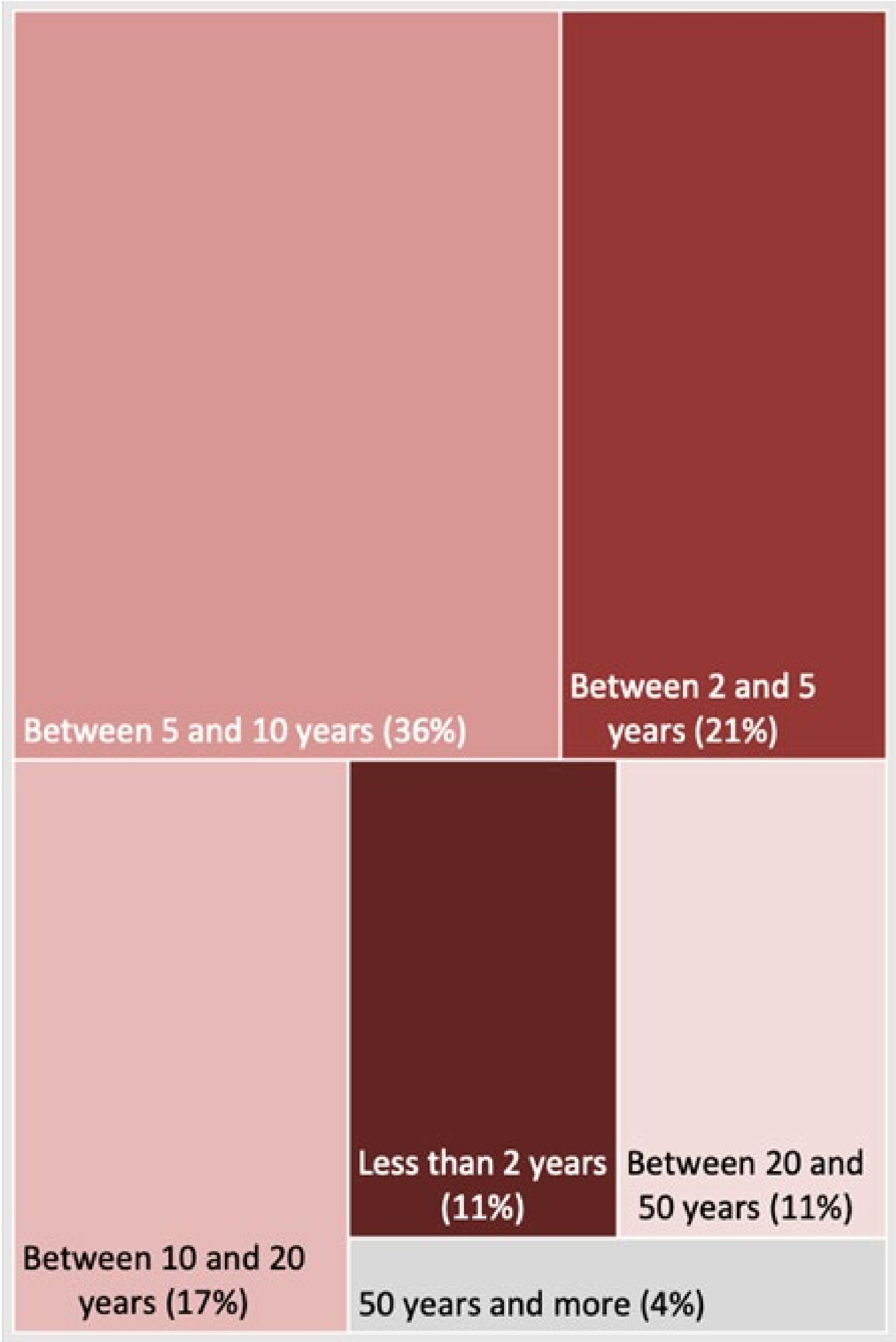

Figure 12. Timescale(s) of climate change and variability that may affect aviation operations and development that is (are) of most interest to respondents – all respondents (graphical)

Table 15. Timescale(s) of climate change and variability that may affect aviation operations and development that is (are) of most interest to respondents – all responses grouped by operation (tabular)

Sample size: 71. Actual number of responses for each operation as indicated.	**Less than 2 years**	**Between 2 and 5 years**	**Between 5 and 10 years**	**Between 10 and 20 years**	**Between 20 and 50 years**	**50 years and more**
Airline operators including dispatch/ flight operation centre (27*)	7	10	11	5	3	1
Pilot/flight crew (19)	1	1	10	5	0	2
Air traffic service including air traffic control (7)	1	2	4	0	0	0
Original equipment manufacturer including airframe or engine supplier (6*)	0	1	4	2	4	1
Administration and governance (5*)	0	2	3	2	1	0
Airport operator (4)	1	1	0	1	1	0
Ground handling operator/agent (1)	0	1	0	0	0	0
Other** (2)	0	1	0	0	1	0

** Note that some respondents selected multiple entries, for example 'Between 2 and 5 years' and 'Between 5 and 10 years'.*

*** 'Other' affiliations comprised a weather technology company and an aircraft maintenance facility.*

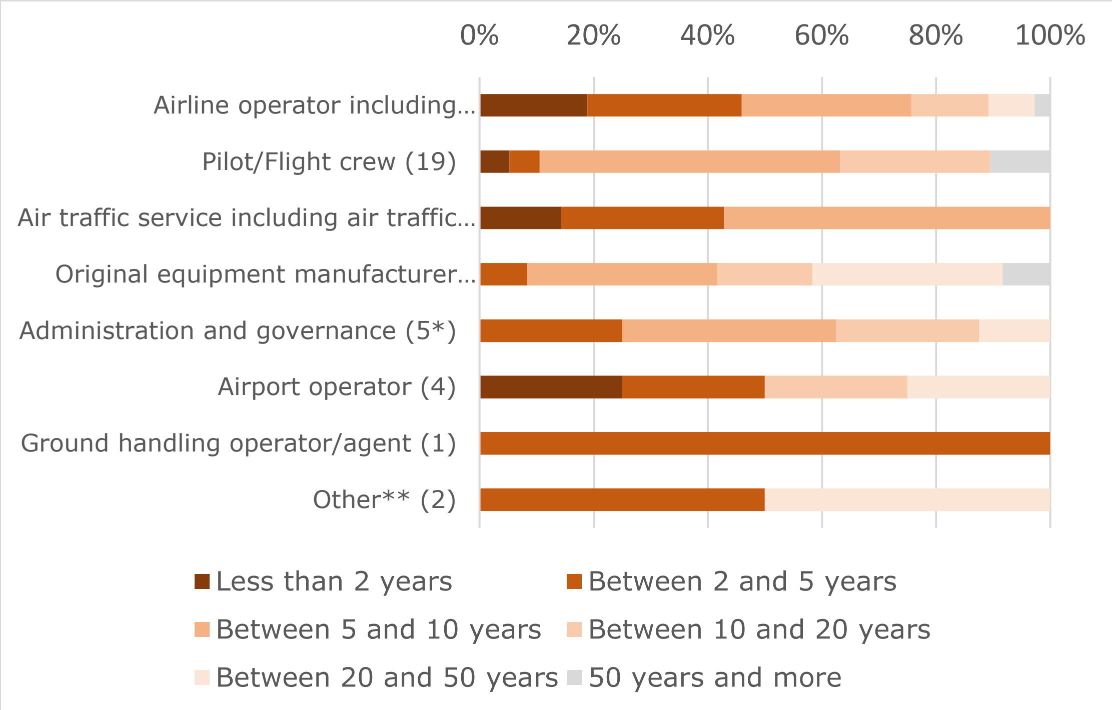

Figure 13. Timescale(s) of climate change and variability that may affect aviation operations and development that is (are) of most interest to respondents – all responses grouped by operation (graphical)

** Note that some respondents selected multiple entries, for example 'Between 2 and 5 years' and 'Between 5 and 10 years'.*

*** 'Other' affiliations comprised a weather technology company and an aircraft maintenance facility.*

OBSERVATIONS 10

According to the total sample analysis (Table 14 and Figure 12), around two-thirds of respondents perceive that climate change and variability may affect their operations and development within 10 years. Just under one-third of respondents perceive the timescale will be 10 to 50 years and the remainder (4%) perceive the timescale will be 50 years or more.

When the responses are arranged according to the different groups of respondents (Table 15 and Figure 13), the timescale '5 to 10 years' was the most prevalent for the airline operators and pilots/flight crew and, with a degree of caution due to the sample size, other groups including air traffic services.

Additionally, more than half of the airline operator respondents highlighted the next 2 to 10 years as the timescale of most interest to their operations and development.

The only ground handling operator respondent considered the next 2 to 5 years to be the most important period.

It is worthwhile to note that opinions differed even within a group. For example, the four airport operator respondents were equally divided, with each respondent giving a different response. Similarly, the six original equipment manufacturers respondents, a group which is used to working on projects that can span many years, marked all timescales (except for less than 2 years), perhaps further illustrating that each group itself can have differing viewpoints and needs.

5. CONCLUSIONS AND RECOMMENDATIONS

AIRPORT INFRASTRUCTURE PERFORMANCE	
CONCLUSION	**RECOMMENDATION**
An expressed concern with airport infrastructure performance and a changing climate is associated with an increased likelihood of airfield flooding due to heavy rain and/or storm surge and an associated high severity of impact. These concerns were particularly noted amongst the airline operator and pilot/flight crew respondents but, in contrast, not particularly noted amongst the airport operator and air traffic service respondents. There appeared to be only limited expressed concern amongst respondents for aspects such as ground subsidence and the need to adapt the cooling or heating of facilities on airports.	WMO should identify scientific research papers and other literature that demonstrate how a changing climate scenario may or will increase the likelihood of heavy rain and storm surge events leading to localized flooding at airports. WMO should ensure that such materials are communicated to concerned aviation stakeholders in a manner that is relevant to the user, easy to understand (including impact-based assessments where available) and, wherever feasible, downscaled to the regional or local level.

AIRPORT OPERATIONS PERFORMANCE	
CONCLUSION	**RECOMMENDATION**
An expressed concern with airport operations performance and a changing climate is associated with longer take-off and landing distances in a warming climate and a reduced runway capacity due to higher runway occupancy times. These concerns were particularly noted amongst the airport operator and air traffic service respondents, and to some extent the airline operator respondents but, in contrast, not particularly noted amongst the pilot/flight crew respondents. There appeared to be only limited expressed concern amongst respondents for aspects such as reduced aircraft movements due to ground operations at high temperatures and increased noise problems due to shallower climbs or choice of runway due to shift of wind patterns.	WMO should identify scientific research papers and other literature that demonstrate how a changing climate scenario, notably the frequency of extreme heat days, may or will increase the likelihood of a requirement for longer runways (due to changes in air density) and/or reduced runway throughput capacity (due to higher runway occupancy times) at airports. WMO should ensure that such materials are communicated to concerned aviation stakeholders in a manner that is relevant to the user, easy to understand (including impact-based assessments where available) and, wherever feasible, downscaled to the regional or local level.

AIR TRAFFIC MANAGEMENT PERFORMANCE	
CONCLUSION	**RECOMMENDATION**
An expressed concern with air traffic management performance and a changing climate is associated with increased challenges in managing	WMO should identify scientific research papers and other literature that demonstrate how a changing climate scenario may or will increase the

terminal area capacity and air traffic sector capacity due to increased risk of thunderstorms as well as increased impacts on low visibility operations due to changes in the occurrence of fog. These concerns were particularly noted amongst the airline operators and airport operator respondents.

Increased challenges in managing air traffic control sector capacity due to changes of high-altitude air temperatures was viewed by a majority of respondents as possessing a low likelihood of occurrence and a low severity of impact.

Overall opinion on the likelihood and severity of increased challenges in managing air traffic control sector capacity due to changes in wind patterns (jet streams) was fairly divided, however air traffic service and original equipment manufacturer respondents did highlight this as a particular concern for them.

likelihood of thunderstorms as well as the occurrence of low visibility/low cloud. Papers or literature on possible changes to wind patterns, including surface wind speeds/direction/gusts and the upper-air the jet steam, should also be identified.

WMO should ensure that such materials are communicated to concerned aviation stakeholders in a manner that is relevant to the user, easy to understand (including impact-based assessments where available) and, wherever feasible, downscaled to the regional or local level.

FLIGHT SAFETY PERFORMANCE

CONCLUSION

An expressed concern with flight safety performance and a changing climate is associated with an increased frequency and severity of turbulence (convection-induced turbulence and clear air turbulence). This concern was particularly noted amongst, but not limited to, the airline operator and the airport operator respondents.

Similarly, an increased risk of bird strike due to changes in bird migration patterns was particularly noted amongst respondents, especially the pilots/flight crew and air traffic services.

There appeared to be only limited expressed concern amongst respondents regarding the presence of strong low-level temperature inversions affecting aircraft performance during take-off and landing.

High-altitude icing phenomena was cited as an additional flight safety performance concern within the original equipment manufacturers group.

RECOMMENDATION

WMO should identify scientific research papers and other literature that demonstrate how a changing climate scenario may or will influence the frequency, severity and/or location of convective-induced turbulence and clear-air turbulence. Papers or literature on possible changes to bird migration patterns (particularly as it relates to the potential incidence of bird strikes at or near airports) as well as high-altitude ice-crystal icing (particularly as it relates to en route flight safety and efficiency) should also be identified.

WMO should ensure that such materials are communicated to concerned aviation stakeholders in a manner that is relevant to the user, easy to understand (including impact-based assessments where available) and, wherever feasible, downscaled to the regional or local level.

AIRLINE OPERATIONS PERFORMANCE

CONCLUSION	RECOMMENDATION
An expressed concern with airline operations performance and a changing climate is associated with more frequent disruption due to extreme weather events and increased fuel consumption due to longer routings. These concerns were particularly noted by most respondents. The carrying of reduced payloads due to a warmer climate was also cited as a concern by many respondents, particularly airline operators and those responsible for administration and governance. There appeared to be only limited expressed concern amongst respondents for aspects such as increased fuel consumption due to more auxiliary power unit usage during the turnaround of an aircraft and increased fuel consumption due to reduced cruising speeds.	WMO should identify scientific research papers and other literature that demonstrate how a changing climate scenario may or will influence flight trajectories and flight optimization, including for example routes flown, payload capacity and fuel usage. WMO should ensure that such materials are communicated to concerned aviation stakeholders in a manner that is relevant to the user, easy to understand (including impact-based assessments where available) and, wherever feasible, downscaled to the regional or local level.

DEGREE OF IMPACT OF FUTURE CLIMATE CHANGE AND VARIABILITY ON AVIATION OPERATIONS

CONCLUSION	RECOMMENDATION
The vast majority (93%) of respondents evaluated the degree of impact of future climate change and variability on aviation to be moderate or greater, reflecting a significant concern that exists amongst those responsible for the operation and the development of aviation.	WMO should ensure that it continually and consistently communicates with aviation stakeholders on the scientific evidence pertaining to a changing climate scenario and the current or foreseen future impacts on aviation operations and development. Such communication should be undertaken in a manner that is relevant to the user, easy to understand (including impact-based assessments where available) and, wherever feasible, downscaled to the regional or local level.

PARAMETERS WHOSE CHANGE IN CLIMATIC VARIABILITY WILL BE MOST IMPORTANT TO AVIATION OPERATIONS

CONCLUSION	RECOMMENDATION
According to all responses, the top four parameters whose change in climatic variability will be most important to aviation operations were (in descending order): low visibility (including fog) and low cloud, turbulence, convection and temperature (surface and upper-air). Changes to other parameters such as jet streams, surface and in-flight icing,	In the context of services for aviation, WMO should focus scientific research activities on how the following parameters may or will change due to a changing climate scenario: low visibility/low cloud, turbulence, convection and temperature. WMO should ensure that concerned aviation stakeholders are kept informed of

tropopause height and sea level were reported as being of less (in some cases much less) importance.

When considering responses across the different user groups, varying opinions often appeared – for example, what was important to one group of users did not necessarily mean it was important to another. These differences perhaps reflect a fact that different user groups may be impacted in different ways as the climate changes, therefore their perceived importance of the changing nature of the various parameters on their operations may differ.

these activities (and their outcomes) to help them make informed decisions in respect of their operations and development.

TIMESCALE OF CLIMATE CHANGE AND VARIABILITY OF MOST INTEREST TO AVIATION OPERATIONS AND DEVELOPMENT	
CONCLUSION	**RECOMMENDATION**
A majority (around two-thirds) of respondents considered that climate change and variability may impact their aviation operations and development within the next 10 years, reflecting an immediate to near-term concern that many in the aviation community appear to share. When considering responses within some of the user groups, divided opinion sometimes appeared, perhaps illustrating that within a group of users there can be different viewpoints and different needs depending on the precise nature of the operation or the development.	WMO should ensure that sufficient resources are available to cooperate, collaborate and communicate with aviation stakeholders on the current and foreseen future impacts of climate change and variability on aviation. Special emphasis should be placed on those aspects that, as the climate warms and associated weather patterns change and/or become more extreme, present increased risk to aviation safety and air navigation capacity and efficiency performance on the ground and in the air. WMO should take the opportunity in the immediate and near-term to assist aviation stakeholders in furthering their understanding of how to adapt to a changing climate scenario and to mitigate the impacts of extreme weather events on operations and developments within aviation.

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