



Future Aeronautical Meteorological Information Service Delivery

White Paper

Developed by the ICAO Meteorology Panel

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The Meteorology Panel white paper presents an agreed high level understanding on how meteorological service provision will most likely evolve, relevant for the stakeholders to consider in the next steps of planning, including concept and provision development, and providing further context for stakeholders involved in implementation¹.

The white paper is therefore an important set of guiding principles that the Meteorology Panel and its working structures will apply in developing revised or new provisions.

At the same time, the purpose of the white paper is also to invite informed opinions on the high-level vision posed, and where alterations may be needed.

Given this declared purpose, the white paper does not include detailed proposed provisions nor does it include detailed implementation considerations.



1 Introduction

To enable international air navigation, Annex 3 to the Convention on International Civil Aviation 1947 (the Chicago Convention), *Meteorological Service for International Air Navigation*, contains the standards and recommended practices (SARPs) for the provision of aeronautical meteorological (MET) information services by ICAO Contracting States. Together with these core aeronautical meteorological information requirements, Annex 3 contains provisions relating to the organisation of national aeronautical meteorological ‘functions’¹. Additionally, Annex 3 contains provisions requiring select Member States to provide regional and global functions.

The ICAO *Global Air Navigation Plan* (GANP) (Doc 9750) and *the Concept for the integration of Meteorological information for Air Traffic Management* (not yet formally published) together provide guidance on how international civil aviation will evolve and what the conceptual relationship is between operational improvements identified and the aeronautical MET information required to enable this. It is important to note that the guidance provided by the GANP is not specifically designed, but where appropriate, supports discussions on how aeronautical MET functions could support the GANP objectives and the evolving air transport system in general.

Accordingly, this white paper on the *‘Future Aeronautical Meteorological Information Service Delivery’* has been developed to provide the strategic view needed in addition to the GANP. It outlines the wider context of what is required by describing the most likely development scenario of how aeronautical MET information will be delivered to users in the future, based on observed trends in the business and relevant ICAO plans. It additionally considers the functions and governance required to meet GANP objectives, whilst ensuring that the change described is proportional to the user’s needs and expectations, and adds value to the current system of aeronautical MET information service delivery.

The described evolution of aeronautical meteorology in this white paper is generally written from the perspective that the complete air traffic management (ATM) system will continuously evolve to meet emerging GANP objectives. The white paper follows the same logic of describing the coming 20 years and updates should be considered every time a new version of the GANP is published.

While the white paper has a basis in discussions and endorsed outcomes from the Meteorology Divisional Meeting 2014 (MET/14) goes beyond the views of that time to meet emerging GANP objectives and evolving ideas in its terms of vision and approach on how future MET service provision delivery should progress.

The Meteorology Panel (METP) white paper presents an agreed high level understanding on how MET service provision is likely to evolve, relevant for the stakeholders to consider in the next steps of planning, including concept and provision development, and providing further context for

¹ Functions in this context refer to organisational entities that are assigned to perform certain duties to provide defined MET information relevant for an associated aerodrome or airspace. This includes Aerodrome Meteorological Office, Meteorological Watch Office, etc.



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stakeholders involved in implementation². The white paper is therefore an important set of guiding principles that the METP and its working structures will apply in developing revised or new provisions.

At the same time, the purpose is to invite informed opinions on the high-level vision posed, and identify where alterations may be needed. Given this declared purpose, the white paper does not include detailed proposed provisions nor does it include detailed implementation considerations.

² Further implementation aspects based on the white paper are addressed by the METP and its working structures for consideration by the appropriate ICAO bodies. When included in revised or new provisions, the PIRGs will have a key role in the implementation of these provisions related to the MET information service delivery.



2 Evolution of International Air Navigation

For the period 2011-2030, world economic growth³ is expected to continue at an average annual rate of 4.0% in real terms. World scheduled airline passenger traffic, measured in terms of Revenue Passenger Kilometers, is forecasted to increase at a “most likely” average annual rate of 4.6%. International and domestic traffic in 2030 are expected to be 2.6 times and 2.3 times that of 2010, respectively [*Reference: Global Air Transport Outlook to 2030 and trends to 2040 (ICAO Circular 333, 2013)*]

The period to 2030 is likely then to witness a significant growth in airline operations with an associated increase on sound aeronautical MET information to mitigate increased competition and airspace saturation logistics⁴.

The GANP approach essentially responds to this growth in airline operations and related airspace issues.

Where the overall GANP objective is to globally evolve towards full four dimensional trajectory based operations, the global ATM model in 20 years from now will probably still be a hybrid of procedural control, radar control and trajectory based operations based on local, national or regionally based performance needs.

However, in 20 years local (national) airspaces and aerodromes in most of the ICAO Regions will no longer be regarded as singular and isolated components of ATM. Each will serve as a node interlinked with all other nodes within a region or even globally. This transition to a 'whole-of-network-management' approach within many regions is essential in starting to manage air traffic within a regional, and increasingly global, partnership context to enable the greater demand for flights, to reduce delays and to improve the environmental and economical sustainability of air transport in general.

³ Gross Domestic Product (GDP) at Purchasing Power Parity (PPP).

⁴ In 2030, overall airline yields are expected to remain unchanged in real terms. However, traffic and passenger volumes will have increased markedly:

- Airlines in the Middle East, Latin America, the Caribbean, and Asia/Pacific regions are expected to experience the highest growth in passenger traffic at 7.6%, 6.1%, and 6.2 % per year, respectively. Forecasts suggest that North America will experience the slowest growth of any region, at 2.3% per year. Aircraft movements, as measured by the number of aircraft departures, are expected to grow by 3.6% per year.
- World scheduled air cargo traffic measured in terms of FTKs is forecast to increase at a “most likely” average annual rate of 5.3%. By 2030, world scheduled air cargo traffic is expected to be 2.8 times that of the 2010 figure.
- Airlines of the Middle East, Latin America and the Caribbean, and Asia/Pacific regions are expected to experience the highest growth in air cargo traffic at 7.6%, 5.7%, and 5.7% per year, respectively. Forecasts suggest that North America, Europe and Africa will experience slower growth — below 5 % per year.
- In terms of flows to, from, and within regions, the fastest growing passenger and air cargo traffic are expected to appear in South-West Asia, China, and the Middle East with an annual average growth rate of 6.9%, 6.4%, and 6.2%, respectively, for passenger traffic, and 6.1%, 6.6%, and 5.9% per cent, respectively, for air cargo traffic.
- The European region will become the largest in terms of passenger traffic with a 4.4% average annual growth rate. China will become the largest region for air cargo traffic by 2030, winning two places in the ranking compared to 2010.

[*Reference: Global Air Transport Outlook to 2030 and trends to 2040 (ICAO Circular 333, 2013)*]

A fundamental element to this increasingly ‘borderless’ operation is to start managing the risk and costs for all ATM stakeholders by employing fully supportive and collaborative processes that take due account of the impacts MET conditions have – both positive and negative. This is especially important since MET phenomena have no regard for national or flight information region (FIR) boundaries. This dynamic management of airspace, of flight demand and of flight operations, requires an increased focus on fully understanding the impacts of MET conditions and how to translate this impact into actionable, borderless, aeronautical MET information provision. This includes embracing the notion of managing quantified uncertainty, and maximising the quantified certainty of the MET conditions. The aeronautical MET information required, therefore needs to evolve and become a truly common, harmonized, and consistent set of information to support a common operating picture for all ‘networked’ (regionally or globally) operational users.

The increased complexity of ATM decision making, especially for areas around the globe that are considered complex and/or congested, and the general need to cater for more flights, or to reduce delays, promotes the use of decision support systems to manage complex information. This development has an extremely high reliance on automation and an increase in the portfolio of services provided and consumed by the various stakeholders in the system. This networked approach is enabled by the implementation of System Wide Information Management (SWIM) with the air transport system improvements increasingly designed using the principles of Service Oriented Architecture (SOA).

The SOA perspective introduces an environment where qualified parties (e.g. authorized organisations including States, private organisations and hybrids) provide information for the benefit of civil aviation information consumers. The SWIM architecture will establish interconnected registries that list the information services, the information that these services exchange and the related details, including metadata, for consuming them. Traditional consumers such as pilots, airline operations staff, air traffic controllers, flow managers, airport operations staff can make use of the information to make operational decisions. However, the advent of SWIM will allow other domains and stakeholders to make use of the information as part of the complex decision making for the issues at hand and for which, up until now, were unable to be undertaken due to the lack of time critical, easily accessible and tailored aeronautical MET information available to them.

In general, aviation stakeholders, including aeronautical MET information providers, over the coming 20 years will become more empowered to capitalize on opportunities, create new and more tailored services and increase their capabilities by becoming more agile in data mining, information construction, service delivery, systems simplification, and by lowering integration costs. This will lead to better informed and more consistent decision making.

Importantly the aeronautical MET community and, more particularly, the METP will need to exercise its newly developed abilities to clearly identify user needs as the first step in identifying what MET information, and supporting infrastructure, will meet those needs best.

3 MET Technology and Science Outlook

The role of MET as a key enabler to aviation's vision for a globally interoperable, harmonized ATM system of the future that is safer, more efficient and more environmentally responsible, will be realised through the accelerated transition of research into operations, based on aviation user needs and supported by new and improved community partnerships.

The 2017 WMO Aeronautical Meteorology Scientific Conference (AeroMetSci-2017) formulated recommendations for three key areas of science and research developments over the next 15 years in support of aviation.

3.1 Observations, forecasts, advisories and warnings

The foreseen improvements required on the observations, forecasts, advisories and warning to meet emerging user needs focus around:

- a) enhanced meteorological information with global coverage for flight planning and en-route operations;
- b) enhanced 4-dimensional information for meteorological hazards of any type, and;
- c) enhanced high-resolution 4-dimensional meteorological information for airport and terminal area operations.

Specific research areas under consideration include:

1. Ice crystal icing and airframe icing;
2. Turbulence; Significant convection;
3. Detection and prediction of low-level wind shear and wake vortex;
4. Low visibility including fog;
5. Space weather;
6. Atmospheric aerosols and volcanic ash;
7. Advances in observing methods and use of observations;
8. Seamless nowcast and numerical weather prediction, and
9. probabilistic forecast and statistical methods.

For these developments to contribute to a safer and more efficient air transportation system, further research is required on:

1. Improved access to data, especially aircraft-based observations, to support validation, verification and calibration of MET research;
2. How to accelerate and communicate the transition from research to operations following validation;
3. Conveying 'uncertainty' to inform risk management, which remains a challenge that needs further research and guidance, and;
4. The understanding of how sensitive air transport decision-making is to MET (hazards).



3.2 Integration, use cases, fitness for purpose and service delivery

Closely related to the prospect of having improved observations, forecasts, advisories and warnings available is the issue of integrating this meteorological information into the globally interoperable air traffic management (ATM) system.

System-wide information management (SWIM) based MET information exchange is a prerequisite to ensure that enhanced situational awareness is obtained. Decision-making support for strategic, pre-tactical and tactical ATM decisions can be provided, and concepts such as collaborative decision-making (CDM) and trajectory-based operations (TBO) can be supported.

Specific research under consideration, related to supporting the operational stakeholders on the integration of MET information,:

- in-cockpit and on-board MET capabilities,
- terminal area and impact-based forecast,
- en-route hazards information systems,
- translation of MET information for impact and risk assessment,
- collaborative decision-making (CDM),
- air traffic flow management (ATFM) and network management,
- trajectory-based operations (TBO),
- flight planning and user-preferred routing,; and
- use of MET information for climate-optimized trajectories.

For these development to contribute even more to a safe and efficient air transportation system, further research is required on:

1. How to establish improved, closer collaboration within and across MET and ATM communities;
2. Blending of MET parameters through ensemble approaches that yield a higher quality, more usable forecast should be further pursued but with an acknowledgement of the potential masking of extremes. In addition, probabilistic methodologies with proper verification and calibration should be applied to better convey to users where and to what extent inherent forecast uncertainties exist;
3. Machine-learning to optimize MET support to ATM;
4. Emerging standardisation needs for systems that deliver harmonized MET information to pilots and other stakeholders, and;
5. Emerging training or education needs for end-users when an increasingly automated ATM operating environment will become the norm.

3.3 Impacts of climate change and variability on aviation

Besides the daily operational considerations related to weather, the improvements required to the information and how this information can be integrated; there are also considerations with respect to climate change and its impact on aviation, and potentially changing needs for operational MET information.



Specific research under consideration, to address these aspects including generic aspects of the variability of earth's atmosphere are related to:

- building awareness of expected climate change impacts such as changes in jet stream position and intensity and related phenomena, including CAT,
- changing extreme weather events and airport impacts,
- changes to the frequency and intensity of typical scenarios (storm surges, heat waves, visibility regimes, etc.),
- re-evaluation of airframe/avionics resilience standards and certification; and
- focus on the downscaling of aviation impacts to regional and local scale.

Additional research considerations to support this are:

1. 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 communicated;
2. 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;
3. Responding to climate variability will require a high degree of flexibility on the aviation users' side. While the incidences of high-impact extreme weather events are 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;
4. 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;
5. 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).



4 Today's Challenges and Opportunities

4.1 Challenges

The ATM needs set out in the GANP are one aspect in considering the evolution of aeronautical MET information service delivery. Various other perspectives, such as existing limitations with service delivery provide further justification to significantly evolve the current aeronautical MET information system.

Initiatives to overcome some of these limitations are planned but require further work and coordination to meet the final objectives. This white paper puts these developments in the wider context and identifies other challenges where a fundamental change is required. The key challenges are:

1. *Aeronautical MET information is not universally available.* For infrastructure or staff capacity reasons, some States are not in a position to meet their existing Annex 3 obligations.
2. *Aeronautical MET information not universally cost recovered by all States or not transparently cost recovered.* Where costs are recovered, there is often inadequate transparency and often these recovered costs from the user are not factored back to aeronautical meteorological provider or sometimes considered not to be appropriate to ensure a fair and equitable management and financing.
3. *Governance not always in place.* A consistent management, cohesive policies, guidance, processes and decision rights of stakeholders involved for aeronautical MET information service provision is not always in place.
4. *Aeronautical MET information may not always be provided in the most cost efficient manner.* The aeronautical MET infrastructure and service provision architecture is essentially designed around a model dating back to the 1950's which has evolved slowly. A complete re-design of the architecture appreciating the existing capabilities, the current and foreseen state-of-the-science that could provide services more cost effectively and efficiently.
5. *ATM user requirement and state of aeronautical MET capabilities or aeronautical MET science often incompatible.* For a variety of reasons, the ATM user need and the existing or foreseen aeronautical MET capabilities are not compatible. In most cases, this is related to the desire of the user community to have a precise description of the state of the atmosphere without uncertainty, instead of information with indicated objective levels of uncertainty that can directly support risk management decision making processes.⁵
6. *Aeronautical MET information generally not expressed in objective and quantitative terms, or in a machine-readable format, that would support automated decision support aids.* Controllers, operators and pilots will increasingly rely upon automated decision support tools into which quantified meteorological information must be automatically integrated.

⁵ Meteorological forecast information is not absolutely certain. It is better viewed as information useful for reducing uncertainty. The concept needs work with various user communities to be further matured, creating an environment where information on aeronautical meteorological conditions with the associated uncertainty can contribute to the goals of safety and efficiency. In this regard, users' requirements that exceed scientific and technological capabilities by a significant margin may require expectation management



4.2 Opportunities

Many opportunities already exist or will emerge over the coming 20 years. From a MET perspective, this includes important changes in observations, including satellite remote sensing of Earth, in-situ airborne measurements, and automated ground/surface-based observations as indicated in chapter 3. The quality of analyses and forecasts are constrained by current, sparse (in many parts of the globe) surface based observations and this will be greatly enhanced by both satellite and airborne automated observations. Data from these platforms will have a greater spatial and temporal resolution updated more frequently and will fill the gaps over oceans and in data sparse continental areas. These improvements are important to the more globalized service provision envisioned in this paper. It is however worthwhile to note that uncertainty exists as to whether remote sensing will be able to adequately provide near-surface parameters where currently such parameters are missing.

The needs for more useful forecasts and analyses enabled by enhanced observations, improved Numerical Weather Prediction Models and data analysis techniques, faster computers and data communication, and almost unlimited possibilities with respect to data storage and data mining. Along with consistency of information across FIR boundaries, reduced cost of producing and disseminating the enhanced information, and integration of MET into decision support systems with operational information, are the main drivers for the global MET infrastructure presented in this paper. Appropriate business models and equitable cost recovery arrangements to foster implementation of these aspirations are however essential.

5 Evolution of Service Delivery

5.1 Objectives

To better exploit underpinning science and technology advances, addressing existing challenges, and to support the evolving global ATM system towards full 4-dimensional trajectory based operations, performance based planning and the supplementary needs of international airspace users, a number of significant changes to the aeronautical MET information services in support of international air navigation are identified. These changes need to be implemented within the next 20 years.

The main two themes for change are:

1. Improve the availability and quality of aeronautical MET information being provided in regions of the world where there are currently insufficient resources (mainly lack of infrastructure and staff) that have led to gaps in aeronautical MET service provision, and;
2. Provide all, existing and newly required, aeronautical MET information in a cost efficient, consistent, and globally harmonized manner that meets user needs for integration into risk management and operational decision-making systems.

5.2 Service Delivery in twenty years from now

The future aeronautical MET information service delivery model in twenty years from now is envisioned to reflect the significant changes to the roles, responsibilities, and functions of aeronautical MET service providers, globally, regionally and locally, including the creation of new functions to provide the required aeronautical MET information.

At the heart of the changes to be implemented is the notion of *phenomenon-based service provision*, sometimes referred to as the borderless service provision concept.

5.2.1 Phenomenon-based service provision (PBSP)

The Chicago Convention, from its onset, enabled international air navigation and operations while respecting States complete and exclusive sovereignty over airspace above their territory (Article 1 of the Chicago Convention). This resulted in a well-organized system of providing Air Traffic Services (ATS) and aeronautical MET Services on a State-by-State basis. However, only fifteen years after the Chicago Convention came into effect, it was recognized that State by State provision of services to support international air navigation was not always the most effective or efficient methodology. As a result, various initiatives with respect to multi-State ATS and flow management provisions commenced in the early 1960's .

Similar developments were observed in aeronautical MET information provision in support of international air navigation. Most notable was the implementation of the World Area Forecast System and its Centres (WAFCS) from the mid-1980s to the mid-2000s as the single function providing global aeronautical MET en-route forecasts for flight planning purposes. Responsive developments also included the establishment of regional advisory functions such as the Tropical Cyclone Advisory Centres (TCACs) and the Volcanic Ash Advisory Centres (VAACs).

The establishment of these global ICAO systems was an effective and efficient contribution to the improved safety and efficiency of flight. Importantly, it should be recognized that these improvements in service provision still reflected a strong 'geographically-based' approach (ICAO Region(s) or a grouping of States and/or respective FIRs) in defining the respective areas of responsibility.

The significant difference between today and the envisaged situation 20 years from now, is that all of these functions develop into a unified *global system* that is in a position to provide services directly to the end-user communities. This direct servicing is not the ICAO-norm today. At present, only the WAFS products can be used directly by end-users. Other functions such as VAAC and TCAC were set in place primarily to serve MET Watch Offices in support of their SIGMET provision responsibilities. Notably however, end-users increasingly take their guidance products directly from the VAAC and TCAC advisory products as they are regionally based, are more convenient to use and are recognized by national authorities for use by airlines; recognising that this practice is beyond the scope of the current Annex 3 provisions.

From an aeronautical MET service provider capability perspective, it is observed that for decades, only a limited number of providers had the required technical and information capabilities at their disposal to meet the majority of global air transport development needs for global or regional aeronautical MET functions. From 2010 onwards, additional providers gained the ability to provide regional or global aeronautical MET information with the required quality of service, which was in the past only possible locally. It should be understood that the term “provider” in this context is notional and does not exclude the concept of a “consortium of providers” designated to perform the appropriate function; as such, the notion is more reflecting the authoritativeness rather than physically being one provider. This change will have significant ramifications on how the aeronautical MET information services delivery framework will evolve over the next 20 years, which is discussed in the following paragraphs.

One of the biggest conceptual evolutionary steps in service provision introduced as follow-up to the MET/14 Recommendation 2/9 (endorsed by ICAO Air Navigation Commission (ANC) and approved by Council late 2014), was the call for a move towards phenomena-based service provision of aeronautical MET information when and wherever possible⁶

This concept of phenomenon-based service provision hinges on four considerations:

1. the four dimensions of the MET phenomena;

⁶ Recommendation 2/9 — Implementation of a regional advisory system for select en-route hazardous meteorological conditions.

That an appropriate ICAO expert group, in close coordination with WMO, be tasked to:

- a) expeditiously develop provisions supporting the implementation of a phenomenon-based regional advisory system for select en-route hazardous meteorological conditions consistent with the evolving Global Air Navigation Plan (GANP) (Doc 9750), in considering users' long-standing requirements, especially in those States where notable SIGMET-related deficiencies persist using, as appropriate, the strategic, governance and cost recovery assessments provided in Appendices D and E;
- b) integrate the information produced by the referred system into the future system-wide information management environment underpinning the future globally interoperable air traffic management system; and
- c) develop appropriate guidance material to support the selection criteria of regional hazardous weather advisory centres taking account of cost-effectiveness, the processes for the preparation and dissemination of the advisory information, mutual cooperation, sustainability of the existing meteorological infrastructure and use of local expertise.



2. the required quality of services (QoS) for the associated information that needs to be provided around these phenomena;
3. the required aeronautical MET capabilities including the state of the science to provide this information; and
4. satisfactory arrangements are in place for governance and cost recovery.

Developments around all four aspects will result in the introduction, from 2020 onwards, of the first elements of the phenomenon based service provision concept that will need to reach its completion by 2030.

As indicated, significant progress is expected soon on the phenomenon-based service provision concept for a number of hazardous MET phenomena, with regionally produced advisories becoming available as a transitional phase to global provision.

However, it will take until at least 2020 before provisions and guidance can be amended to remove selected phenomena from the criteria to issue a SIGMET for each FIR, and entrusting this wider responsibility to regionalized ICAO systems. In parallel, new provisions will need to be introduced to support the *borderless service provision* approach that enables all stakeholders to use information issued by a regional or global function, as authoritative for all associated decision making.

Note.— Select hazardous meteorological conditions in this context includes, as a minimum, thunderstorms, icing, turbulence and mountain waves, but excludes volcanic ash and tropical cyclones.

5.2.2 Core MET service provision versus Aviation MET provision

The principal concept to evolve towards a phenomena-based system, and thus a more harmonized and standardized approach for the provision of aeronautical MET information services required by international air navigation, is a far-reaching proposal. As such, raising a number of issues regarding the future role and funding of the currently designated aeronautical MET service providers, including those that are a National MET Service.

Implementing a borderless, phenomena-based approach will require additional thought as to how aeronautical MET information service provision should be considered. This relates more to how States could structure and finance their core MET facilities and services⁷ in support of aeronautical meteorology for international air navigation than to the science and capabilities required to provide such services in a more centralized manner.

From 2020, it is expected that ICAO and the World Meteorological Organization (WMO) will have developed guiding principles acknowledging that an equitable cost associated with the core MET facilities and services of a State could be recovered from civil aviation even if a State is not providing

⁷ 'Core MET facilities and services' are described in the Manual on Air Navigation Services Economics (Doc 9161); where it is indicated that usually meteorological services engage in general meteorological activities, i.e. core activities, in fulfilment of a primary system requirement for meteorological information which is jointly used by all service recipients. Examples of core activities include general analysis and forecasting, automated data processing, weather radar and satellite data processing, surface and upper-air observations, telecommunications to collect and exchange basic data, training, research and development (Doc 9161 (5th edition, 2013) §5.70 and 5.115, and Appendix 2).



MET services to international air navigation directly. This should for example ensure that the provision of real-time non-aviation-specific observational data to support global or regional aeronautical MET information provision could be cost recovered when the attribution of this cost is legitimate and equitable.

This will initially require the development by WMO of detailed requirements for each State, in terms of MET observing information, as well as the core facilities required, to deliver observations to the regional and global (hazardous) weather centres.

It should be noted that many of the least developed States require substantial investments to satisfy these requirements and consequently may not be able to provide all the data needed. As a consequence, a capacity-building programme or another approach to obtaining the data will still be required to improve the availability and quality of core MET information provided to support the MET information provision to aviation directly or indirectly.

5.2.3 Non-Annex 3 User Requirements

Currently, a clear differentiation exists between MET information and service provision that is provided on the basis of Annex 3 requirements and MET information services that are provided to users based on arrangements that sit outside the ICAO context.

It is expected that for the next 20 years, this separation between information that is required to ensure safe, efficient and timely international air navigation, and information that is seen by an individual stakeholder or group of stakeholders to bring them specific benefits, will not change.

Debate is however expected to continue as to what extent augmented or new information services used by a stakeholder or group of stakeholders, for their specific benefit, becomes relevant for a larger community and de facto becomes a requirement for safe, efficient and timely international air navigation. Thus evolving into a service that may need to be covered by Annex 3 provisions. This will become more relevant progressing towards performance-based requirements; recognising that some needs are local, regional or for a specific sub-set of stakeholders.

Accepting that for the foreseeable future, MET information services will exist based on Annex 3 provisions and based on other arrangements, the overall context how aviation MET providers will generate revenue will continuously evolve.

5.2.4 MET Provider Revenue and Selection Principles

Independent of the type of information service, either in the scope of Annex 3 or outside, the way providers of this information should recover their (full⁸) costs is subject to many different approaches. The traditional approach is based on applying transparent cost recovery principles based on the *Manual on Air Navigation Services Economics*. (Doc 9161) by the provider or State that designated the provider to provide Annex 3 based services.

⁸ Cost allocation of MET is subject to a State's decision either to be financed partially or completely by its public budget. In the latter case, MET could be available for free. See *Manual on Air Navigation Services Economics* §5.72 (Doc 9161).

For the coming two decades, a significant factor for consideration is the increased application of market principles⁹ to aeronautical MET service provision. Today, consumers and providers exchange aeronautical MET information that is usually considered outside the scope of ICAO Annex 3 prescribed services on this basis. For example, airlines obtain services from MET service providers that apply market principles, sometimes residing within a National Meteorological Service that is also the designated provider for Annex 3 related services, in support of their demanding operations.

Increasingly, States will need to progressively move toward market principles between the State and a provider to recover costs. This will provide opportunities for other than traditional providers to provide for MET information services, even within an Annex 3 context, with the objective of delivering the best and most (cost-) efficient service for the stakeholders.

Also, in the context of adopting new technologies and means of delivering information to the stakeholder, the likelihood that providers of these services and underpinning capabilities will need to deliver these services in a market context is very high. An example of this relates to the data link provision of MET information to the flight deck. States will most likely rely on market principles based services that are developing rapidly across the globe rather than develop a State-based data link service.

Any evolution of aeronautical MET service provision for the decades to come therefore needs to consider the various models¹⁰ of operational governance of the newly foreseen functions, including the management of the global initiatives and the funding of those initiatives that could be applied including an aeronautical MET information marketplace.

5.3 Aeronautical Meteorology Information Delivery Framework

It is expected that within the coming 20 years, a seamless global ICAO aeronautical MET information service delivery framework will be developed focusing around 3 main elements, together creating a system that provides seamless and borderless aeronautical MET information services for international air navigation:

- Global Aeronautical MET Information Centres (GMC) and supporting Specialized Forecast Centres (SFC);
- Aerodrome Forecast Centres (AFC); and
- Aerodrome MET Stations (AMS).

5.3.1 Global Aeronautical MET Information Centres (GMC)

5.3.1.1 General

The framework to deliver seamless global aeronautical MET information is made up of a network of Global Aeronautical MET Information Centres (GMC), each specialising in forecasting specific

⁹ The notion Market Principles in the white paper is used to indicate some basic principles, such as preventing unfair advantage from one provider over the other and applying low barriers for newcomers. This should not be confused with delivering a service for a profit (commercial).

¹⁰ These consideration could include models around Public Private Partnerships (PPP), cooperative arrangement between two or more public and private sectors that share risks and develop innovative, long-term relationships between these sectors to deliver a service.



phenomena (all of which have formalized and tested backup arrangements in place). By 2024, these GMCs work closely together to provide a fully harmonized set of services to an agreed QoS standard that enable users to use information from different centres seamlessly. From a user perspective, there is no differentiation as to what State or GMC is providing the product.

Differing from the historical segmented approach, except for WAFS, the network of GMC is a unified system providing services with global coverage.

Depending on the evolving requirements, the end-state of the network of GMC could be a single global duty centre at any one time, with both hot and cold back-up centres that may or may not be co-located.

The GMC aeronautical MET information services are authoritative and can therefore be used directly by users for decision-making. This enables a common global reference, maintaining a level of consistency between operators and other aviation actors with respect to the information they use and base their decision on.

5.3.1.2 Information Service Scope

The GMC provides all of the aeronautical MET Information that the existing WAFS system currently provides but in higher resolution. The GMC will also provide all of the information previously provided by the VAACs and the TCACs. It should be noted that the function of the TCAC is closely related with the established WMO Tropical Cyclone Warning Centres and the evolution of TCAC in this context should be coordinated with WMO.

The provided information services by GMC will be finely tuned to the demands of full four dimensional trajectory based operations and other international aviation factors.

5.3.1.3 Transitional considerations

The currently existing ICAO system distinguishes various specialized capabilities, in this white paper referred to as Specialized Forecast Centres (SFC), that provide clearly scoped MET information services. These are:

1. *Specialized Volcanic Ash Advisory Centres – VAACs.* The International Airways Volcano Watch (IAVW) system, comprises nine VAACs, has been successful over its 30-year life. As a result, multi-disciplinary knowledge about the characteristics of volcanic ash and gas transport is now well developed. These capacities and capabilities are now integral parts of overall meteorological understanding.
2. *Tropical Cyclone Advisory Centres –TCACs.* The meteorology around tropical cyclone development, movement and decay has been intrinsic to the field of meteorology for many decades and capabilities and capacity to work in the area is now relatively common.
3. *Space Weather Centres – SWCs (from November 2018).* These centres will be formalized before 2020 and comprise capabilities and capacities outside that of the traditional aeronautical MET field of expertise and technology. These centres are likely to remain operating as Specialized Centres allocated as defined in ICAO documents for the foreseeable future.



In addition to the existing SFC, the temporarily creation of so-called Specialized Regional Forecast Centres (SRFCs) supporting the GMC is envisaged for those phenomena or activities where the global consensus is that this cannot yet be covered by a global capability. These centres could therefore be implemented as a transitional phase toward the full global coverage of the GMC and providing regional aeronautical MET Information on significant phenomena.

It is expected that in 20 years from now all SRFCs, VAACs, TCACs will transit into the network of GMC. The SWCs however, due to their specific nature (relatively decoupled from aeronautical MET) will be the only remaining type of SRFC.

5.3.2 Governance of Global Initiatives

With the establishment of the GMC a new phase of global-service-provision-governance will be introduced. Therefore, a different approach should be introduced to the traditional selection and governance of regional or global functions compared to that covering the 1990s era of establishing WAFCs, VAACs, and TCACs.

The traditional governance regime was based on the understanding that only a select number of States were in a position to provide regional or global functions based on the aeronautical MET capabilities required and available. Given this context, these States were requested by ICAO to provide these services and were governed by a group of experts reporting to the Air Navigation Bureau and from 2015 onwards by experts in the METP reporting to the Air Navigation Commission. In the future it is expected that States providing a GMC will have to demonstrate compliance with exacting QoS requirements not only for forecast accuracy but to resilience and commitments to ongoing service development as set out in the Global Air Navigation Plan.

Alongside the work undertaken by ICAO and the METP to continue the development and optimisation of global aeronautical MET information provision, the formal operational governance of the newly foreseen functions, including the management of the global initiatives and the funding of those initiatives, needs to be considered. The principles for such a Global Aeronautical Meteorology Operations governance framework should be established in Annex 3 and detailed in the Working Arrangements between ICAO and WMO (Doc. 7475).

This governance framework should consider the selection, removal, and management of the selected provider(s) of GMC and the remaining SFCs, including the financing. Preliminary arrangements should be in place from 2022 onwards to support the end state of GMC and SFC.

5.3.3 Aerodrome Forecast Centres (AFC)

5.3.3.1 General

The responsibilities of the traditional Aerodrome MET Offices (AMO), as known in 2018, have increased through the introduction of the GANP to include a greater area than the defined aerodrome (16km radius from centre point).

This work is now undertaken by the AFCs that have evolved from the old AMOs. They have an extended responsibility to provide forecast information for the terminal movement areas (TMA).



These TMA differ in size between respective aerodromes, the nature of operations using the aerodrome, and reflect the extended requirements of full 4-dimensional trajectory based operations.

5.3.3.2 Information Service Scope

The responsibility for providing TMA and extended TMA aeronautical MET information and warnings remains a core responsibility of States alongside their real-time observing obligations. It is accomplished through the work of the AFCs.

From 2020, ICAO will increasingly encourage States to centralize their aeronautical MET functions to produce the required TMA aeronautical MET information in order to achieve greater efficiencies. In 2030, it will be usual to find States with a single centralised AFC, while some larger States maintain several AFC sites for logistical reasons. The AFCs will often be located away from the aerodromes they are responsible for.

Where there are overlapping or proximate TMA locations, States should ensure that the TMA aeronautical MET information they provide is harmonized with neighbouring TMAs regardless of whether that TMA lies within a neighbouring State.

Importantly, States should ensure that the TMA aeronautical MET Information produced by AFCs is harmonized with the GMC (and SRFC) provided aeronautical MET Information – hence a completely aligned spatial and temporal MET picture of the atmosphere is achieved.

The AFC information will be provided in IWXXM compliant formats and used directly by users to build a real-time dynamic 3D MET picture of the forecast TMA picture, to contrast with the real-time picture assembled from AMS information (see below).

5.3.3.3 Governance

Responsibility and governance of AFCs operations along with the supporting real-time observational network, both at aerodromes and at supporting locations, remains the responsibility of the State as defined in Annex 3. However, in 2030 it will be common for smaller States to have a joint approach to both AFC and AMO obligations, within a single shared management and funding system.

5.3.4 Aeronautical MET Stations

5.3.4.1 General

The traditional Aerodrome MET Station (AMS) concept continues in 2030 but has been modernized in application.

5.3.4.2 Scope

Almost exclusively real-time aeronautical MET observational information from aerodromes and their TMA surroundings are provided by automatic systems. These systems now have integrated abilities to sense MET parameters at a distance (cloud height and location, slant range visibility on the extended centre line, background turbidity, vertical wind profiles, etc.). The information will be provided in IWXXM compliant formats and is used directly by users to build a real-time dynamic 3D MET picture of the TMA to contrast with the forecast picture.



5.3.4.3 Governance

Refer 5.3.3.3 above.

5.4 System Wide Information management - SWIM

The definition, scope, purpose and operation of SWIM is provided in the Manual on System Wide Information Management (SWIM) Concept (ICAO Doc 10039). SWIM will be well established over the next 20 years, providing vastly improved aeronautical MET information distribution and accessibility. It will address the challenge of creating an “interoperability environment” allowing the SWIM IT systems to cope with the full complexity of operational ATM information exchanges including that of aeronautical MET Information.

The advent of SWIM has and will continue to be seen in an increased number of providers and consumers of aeronautical MET information. These stakeholders can easily access a wide range of global information, including all aeronautical observational information from around the globe. The information will be in standardised digital formats, which will lead to it being easily ingested into aviation systems. With the implementation of SOA, the consequential agile and fast-paced software development environment will further highlight the value aeronautical MET information has, enabled by SWIM. It will further support initiatives of major global airlines with a need to have aeronautical MET information tailored to their own operation through their own aeronautical MET department or partner.

Access to SWIM, for providers and consumers, will be subject of ICAO governance principles. This governance ensures that the quality of the information and the service will be known and the use of the information is within a well-defined set of authorized users.

SWIM based information exchange will replace all of the traditional regional and global ICAO MET information exchange systems, such as OPMET data base systems, SADIS (WIFS). The structures around the traditional OPMET Databanks will however be transformed into the aeronautical MET-specific regional contribution to SWIM governance.



6 ICAO-WMO Cooperation

ICAO and the World Meteorological Organization have long-standing working arrangements¹¹ designed to record the understanding reached between the two organizations to delineate their respective sphere of activities in the field of aeronautical meteorology, to provide machinery for their collaboration when necessary and to give guidance for the conduct of meetings of representative bodies and the Secretariats of the two organisations.

An evolving MET information service delivery context could lead to a revised understanding of the various roles and responsibilities in the aeronautical MET domain between WMO and ICAO, to meet the end-user expectation of receiving authorized fit-for-purpose aeronautical MET information.

The separation of concern between ICAO and WMO¹² reflected in updated working arrangements should lead, for instance, to a similar approach adopted between ICAO and standardisation organisations. Consequently, specifications external to ICAO (in this case developed and maintained by WMO) are simply referenced in the ICAO provisions. The standardisation organisation itself however refrains from replicating the requirements for such a specification in their formal documentation that then becomes subject of their approval process. This approach completely removes the need to duplicate provisions in formal documentation by the two organizations, as is currently the norm.

¹¹ The working arrangements are not falling within the category of formal interagency agreements referred to in Article XVII of the Agreement between the United Nations and ICAO, or Article XIV of the Agreement between the United Nations and WMO.

¹² In the context of the white paper, an ICAO originated document, the roles and responsibilities of WMO and its Members should be understood in the context of four key capabilities WMO as an organisation and through its Members provides:

- 1) Centre of Expertise; providing the required expertise and capabilities to enable aeronautical MET service provider to deliver their services, primarily focusing on Least Developed Countries (LDCs);
- 2) Standardisation Organisation; acting as a standardisation organisation for all issues related to meteorology including aeronautical meteorology;
- 3) Core Infrastructure Provider; managing and enabling the WMO Members to operate and evolve their core, and a collective, MET infrastructure in support of aeronautical meteorology, and;
- 4) Aeronautical MET Function Provider; managing and enabling these WMO Members that operate an ICAO Aeronautical Meteorology Function.



7 Constraints

As indicated early in the document, the described future aeronautical MET information service delivery is only possible when two significant constraints are addressed. These constraints are:

- Aeronautical MET Capabilities not available;
The evolution towards GMC and SFC, and supporting AFC and AMS, requires aeronautical MET capabilities that are assumed to become gradually available. This firstly requires the availability of funding to implement these capabilities or to develop capabilities. In the likelihood of shortfalls in required capabilities, the transition from the intermediate SFCs to GMC could be delayed.
- Political and institutional barriers;
The evolution towards GMC and SFC, and supporting AFC and AMS, require States to accept that roles and responsibilities that were traditionally with the individual State, could be delegated in a controlled manner to other States or organisations. It also includes the basic principle that information produced outside the State concerned, for instance by the GMC, is as authoritative and essentially fit-for-purpose as information that was traditionally produced within the State territory.



8 Summary

The METP white paper presents a high-level understanding on how meteorological service provision is most likely to evolve over the next two decades. It provides indications and directions that support further work in moving towards a more detailed implementation planning, including concept development.

These indications and directions are an important set of guiding principles for the METP to consider when sketching its work programme, based on the objectives laid down by the ANC, for developing revised or new provisions related to MET service provision.