SUMMARY

This paper presents an overview for Meteorological (MET) information services in support of global Air Traffic Management (ATM) and Performance-Based Navigation (PBN).

1. INTRODUCTION

1.1 Concepts for global air traffic management (ATM) and performance-based navigation (PBN) are well documented in:

   — Performance-based navigation (PBN) concept in ICAO Performance-based Navigation (PBN) Manual (Doc 9613);

   — Global ATM concept in ICAO Global Air Traffic Management Operational Concept (Doc 9854);

   — ICAO Manual on Air Traffic Management System Requirements (Doc 9882);

1.2 A new concept document “Flight and Flow Information for a Collaborative Environment” (FF-ICE), has been introduced by the Air Traffic Management Requirements Performance Panel (ATMRPP) to improve the efficiency of traffic flow with PBN.
1.3 All of the above documents mention or reference “weather” (meteorological services - MET) in general terms, but do not specify or identify the meteorological services required for global ATM and PBN. This study note (SN) is written to raise awareness for the need to incorporate MET information into future ATM decision making, as well as to illustrate the need to restructure the MET provisions in ICAO. Tomorrow’s needs (ref. Doc 9854) for meteorological information will be more complex, digitally based and as such different from today’s weather products in ICAO Annex 3 — Meteorological Service for International Air Navigation.

2. MET SUPPORT TO GLOBAL ATM

2.1 The international air navigation system is currently undergoing a paradigm shift from the past air traffic control (ATC) environments to the more integrated collaborative and performance based ATM systems. This change aims at ensuring that ICAO’s vision of a secure, efficient and environmentally sustainable air transport system will continue to be available to all aviation stakeholders at the global, regional and national levels. The new ATM systems will make use of the enhanced capabilities provided by advances in science and technology, and will allow the effective application/sharing of information under the concept of collaborative decision making (CDM).

2.2 A gap has been recognized between the MET products stipulated in the existing ICAO Annex 3 and the evolving ATM user needs for MET information to support global ATM and PBN. For instance, ICAO Annex 3 stipulates meteorological data products such as the aerodrome forecast (in meteorological code form) (TAF), trend-type landing forecast (TREND) and aerodrome warnings, which are presented to the users in highly simplified and condensed codes in textual format. The coded aspect of this weather data was developed to address the limitation in bandwidth in legacy telecom systems back in the mid-20th Century, but has increasingly become a severe constraint for both meteorologists and aviation users as the huge increase of available and valuable weather information (as supported by the growth in knowledge and improvement in capabilities) in many cases cannot be conveyed.

2.3 In addition to safety, an objective of MET support global ATM and PBN (MET-ATM-PBN) is their quest to minimize the impact of weather on the total air transport system so as to ensure that optimum throughput is sustained in all meteorological conditions, and that an effective mitigation of the impact can be introduced based on improved planning.

2.4 Some initiatives to address this challenge include the Next Generation Air Transportation System (NextGen) in the United States and the Single European Sky ATM Research (SESAR) programme in Europe. In the past few years, an Expert Team (ET) of the Commission for Aeronautical Meteorology (CAeM) of the World Meteorological Organization (WMO) have also been studying the concept of Meteorological Services in the Terminal Area (MSTA) with a view to submit a proposal for the enabling provisions for consideration by the Conjoint ICAO MET/AIM Divisional Meeting / WMO CAeM Session in 2014.

2.5 The above objectives call for greater integration of MET information into the ATM processes, compared to today’s concept where users (e.g., controllers, traffic manager, dispatcher, and pilots) separately interpret MET information before subjectively integrating the information into traffic decisions based on their understanding of the information presented. In the future, MET information will need to be integrated more into Flight Management Systems, as well as ATM decision-support systems to support safe and more efficient flight.
2.6 MET-ATM-PBN promotes sharing common MET information and replaces the use of individual and potentially conflicting weather products with network-enabled consistent weather information that supports a common situational awareness both in the air and on the ground.

2.7 It is of utmost importance in the future that MET information be translated directly into ATM constraints and impacts to support the ATM decision-making process. Weather information will be expressed as calibrated factors that can be assigned to aircraft types and scenarios rather than characterized as light, moderate, or severe without regard to what aircraft type is penetrating the weather. Ultimately, the interpretation and translation of weather information should be automated and objective rather than left to the subjective experience of individual users.

2.8 ATM will also require decision support tools (DST) that can deal with the MET information which has been translated into ATM constraints and impacts and provide ATM with best choice options. DSTs will generally be multifactoral software applications used to automate the weather impact evaluation and air traffic/customer response.

2.9 Integration of MET information into ATM processes and the use of sophisticated DSTs are a prerequisite for efficient trajectory-based operations (TBO) and operations in high-density airspace. Integration will incorporate the weather information into the DSTs that formulate the most efficient air traffic routing and flight profile solutions and continually account for inherently dynamic weather phenomena. The ultimate goal of integration is to objectively translate weather information from purely meteorological data into weather impacts on air traffic operations – allowing end users to make decisions based on impacts rather than on meteorological interpretation. The underlying weather information may eventually not need to be presented at all, just as today’s flight planners may not need to look at winds aloft if the winds are integrated into a competent flight planning system.

2.10 Another key precept of MET-ATM-PBN is the characterization of weather forecast uncertainty. Proper use of uncertainty information expressed as probabilistic forecasts of events and intensities is the most appropriate form of risk management. In traditional OPMET codes, “deterministic” weather information essentially conveys that the probability of occurrence is greater than or equal to 50 per cent without conveying the level of uncertainty. A 50 per cent threshold for decisions may be appropriate if all possible outcomes are equally costly. However, if some outcomes are very much more expensive than others, then the threshold for decisions may be higher or lower than 50 per cent. For example, a user may choose an expensive course of action only if they are very certain that the forecast condition will occur. Or a user may make another decision if there is even a slight chance of adverse weather occurring to avoid expensive weather damage. The availability of probabilistic weather information enables decision-makers to make binary decisions according to their own objectively-determined thresholds for action.

3. A GLOBAL MET INFORMATION SERVICES INFRASTRUCTURE

3.1 The world area forecast system (WAFS) program has provided a framework for a global MET information service structure by the introduction of a global coverage of grid-point values of wind and temperature forecasts in Amendment 65 to Annex 3 (1983). Amendment 75 (2010) added trial forecasts of turbulence, icing and cumulonimbus (CB) clouds in grid point format to the WAFS global data set. All these elements are provided in 4 dimensions, albeit in coarse spatial, vertical and temporal resolutions and at different levels of accuracy depending on the parameter.
3.2 The WAFS data is thought to be sufficient for present flight planning needs in uncongested airspace. Nevertheless, users have stated that it is not sufficient for the needs of PBN, or operations today in congested airspace.

3.3 The development of information exchange standards that ensure global interoperability is an integral part of a global MET information infrastructure. This information system will have to be interlinked with other identified data domains that are relevant for ATM and PBN. Future DSTs will not only use meteorological information but will combine meteorological information with other relevant information from sources such as aeronautical information service / aeronautical information management (AIS/AIM) and Flight Information to support knowledge-based objective and repeatable decision making. As a first crucial step, the ICAO Aerodrome Meteorological Observation and Forecast Study Group (AMOFSG) together with WMO and the ICAO Aeronautical Information Services/Aeronautical Information Management Study Group (AIS/AIMSG) are developing a common baseline for the future information exchange based on regional developments such as the weather information exchange model (WXXM). These are clearly linked with (regional) developments for other data domains such as Aeronautical Information Exchange Model (AIXM) and the emerging flight information exchange model (FIXM).

4. GLOBAL EFFORTS ON ENHANCING PROVISION OF MET-ATM-PBN

4.1 The AMOFSG has been tasked to provide guidance on operational requirements for the provision of MET information services, based on the concept provided by the ICAO ATMRPP to improve the efficiency of air traffic flow with PBN. The task has been assigned to its ad-hoc working group (WG/6) to develop an outline for MET information services required which is categorized by airspace capacity: en-route and terminal control area (TMA, including aerodromes) for high and low density operations in a common code form. In addition, it will identify an initial set of performance metrics for MET elements that are required for PBN. Appendix A to this paper is the proposed outline while Appendix B contains the proposed MET elements for global ATM and PBN. Work in defining performance metrics for these elements has been deferred.

5. MET-ATM-PBN PER AIRSPACE CAPACITY

5.1 At the eighth meeting of the AMOFSG, a briefing was provided by the WMO Expert Team on Meteorological Services in the Terminal Area (ET-MSTA). The initial concept of MSTA is to define how to make use of 4-dimensional weather data (including numerical weather prediction models, weather observations, nowcast objects/features) which could be used in conjunction with forecaster’s expertise as necessary, to enable translation of MET information into air traffic impact in high-density/congested airspace based on both current data and statistically derived dependencies.

5.2 Several national meteorological services (NMS) have developed unique products and guidance material to accommodate the growing information needs of ATM in high density terminal areas. Initially, most of these were focused on the visualization of various MET information, rather than on full integration into decision support systems. Figures 1 is an example from Hong Kong, China, showing a color coded time matrix to visualize the times when thunderstorms are expected to impact the areas of concern for existing flight corridors.
5.3 Figure 2 is a conceptual diagram of the MET information for various kinds of airspace depending on traffic density or congestion, and use of traditional navigation or PBN. The figure also begins the process of categorizing the functions and the services needed. But more work is needed to detail these functions in coordination with the stakeholders.
6. **ICAO PROVISIONS**

6.1 The global provisions structure of ICAO is categorised in four main categories in descending order of regulatory scope.

1. Annexes to the Convention;
2. Procedures (for Air Navigation Services);
3. Manuals; and
4. Other guidance material.

6.2 Annex 3 is structured for today’s weather forecasts and products in support of primarily flight planning, pre-flight briefing, and hazard avoidance during the execution of flight. This is reflected in provisions for paper-based significant weather (SIGWX) forecasts, and teletype generation-based coded TAFs, METARs and SIGMETs. Global MET-ATM-PBN will be able to use much more
information than is provided by these traditional chart and text based products and other means of exchange, which in most cases represent only a small fraction of all potentially available data. To support ATM, the MET data will be drawn from a virtual information system using data discovery, access and retrieval that will be integrated into risk-based flight path trajectory planning and execution.

6.3 Every category of provisions has its own distinct governance process. The annexes require an extensive and lengthy process of state consultation and endorsement to agree on a global baseline of services that should be provided. On the other side of the spectrum sits guidance material that can be issued by the Air Navigation Bureau without a formal approval process by the contracted States.

6.4 It should be noted that the core provisions for MET are contained in Annex 3. There is not a supporting Procedures for Air Navigation Services (PANS) document. There are only a limited number of publications that can be considered as providing ‘Other Guidance’ for MET. As a result, Annex 3 contains more detail than would otherwise be needed if there were additional supporting manuals (Figure 3).

6.5 ICAO Annex 3 and guidance materials do not differentiate between congested and other airspace in terms of MET provisions.

6.6 It is suggested that to effectively support MET-ATM-PBN, there should be a realignment of MET service provisions to address the needs of different airspace categories if required. It is proposed that this realignment will also reduce the volume of technical material in Annex 3 by transferring the more technical and rapidly changing material to a MET-ATM-PBN manual which is empowered by Annex 3.

6.7 Figure 3 illustrates the allocation of MET provisions in ICAO for routine and for congested airspace.

Figure 3: Current (left) and proposed (right) balance of MET provisions
7. ROADMAP FOR CHANGE

7.1 The process steps described in this section are linked to the currently predicted updates of ICAO Annex 3. Table 1 outlines the time schedule involved.

<table>
<thead>
<tr>
<th>Edition</th>
<th>Applicability date</th>
<th>Publication date</th>
<th>Start consultation</th>
<th>Deadline for inputs by ANB and supporting SGs</th>
</tr>
</thead>
<tbody>
<tr>
<td>18th / amd.76</td>
<td>November 2013</td>
<td>July 2013</td>
<td>January 2012</td>
<td>October 2011</td>
</tr>
<tr>
<td>19th / amd 77</td>
<td>November 2016</td>
<td>July 2016</td>
<td>January 2015</td>
<td>October 2014</td>
</tr>
<tr>
<td>20th / amd 78</td>
<td>November 2019</td>
<td>July 2019</td>
<td>January 2018</td>
<td>October 2017</td>
</tr>
</tbody>
</table>

Table 1 Amendment cycle time schedule

7.2 The October 2011 deadline is linked to Amendment 76 to ICAO Annex 3. The changes foreseen for this amendment are of a preceding nature with respect to the changes foreseen for the 2014-2020 timeframe. Moreover, they are of an enabling character with respect to some of the early initial operating capabilities (IOC) defined by some of the regional ATM development programmes such as SESAR and NextGen potentially require support by global provisions. For 2011, the introduction of the notion of “performance based requirements” and provisions for congested airspace including a better acknowledgement of MET support to ATM. Also for 2011 is the introduction of and enabling statements for net-centric and interoperable information exchange.

7.3 The October 2014 deadline is linked to Amendment 77 to ICAO Annex 3. The changes foreseen for this amendment will build upon the introduced preceding provisions introduced by Amendment 76 with respect to performance based requirement and net-centric operations.

7.4 The dates determined for a number of IOCs related to major improvements in the ATM system to support operations in congested airspace, are in the 2016-2019 timeframe. By then, MET information will progressively be integrated into all domains of ATM operations, providing the beginnings of a single picture of airspace operations. The picture will progressively be enhanced by real time data and by forecasts of wind, temperature, turbulence, convective activity together with predictions of lightning strike probability. Such information will be ingested into ATM Flow Management systems to route aircraft on the most beneficial profiles and to ensure landing times. This “en-route” use of MET will be complemented by the incorporation of such data into departure and arrival management systems, themselves benefiting from improved MET capabilities.

7.5 It is important for all the changes that need to be incorporated in Amendment 77 that they should be scalable to the status of the ATM system under development. They should provide sufficient flexibility and should be proportional to satisfy all stakeholder needs.

7.6 Clearly the means to advanced service operations should be standardised to ensure the requirements for global interoperability. Nevertheless, the way forward would seem to be as discussed earlier, the development of procedures and guidance material referenced to the performance requirements in Annex 3.

7.7 Currently, it is foreseen that Amendment 77 to ICAO Annex 3 will be discussed by a MET/AIS Divisional meeting in 2014. It is recommended that the MET/AIS divisional meeting should agree on a new structure of the provisions as discussed in paragraphs 6.1 through 6.7 and strongly
supported by the 12th ANC and 38th General Assembly. Furthermore, general agreement should be established on the lower level information, contained in either procedures (PANS) or manuals, to be made available to support the newly introduced concepts of operations.

8. CONCLUSIONS

8.1 MET services for global ATM and PBN will become much more complex, including both deterministic and probabilistic elements, and objective by comparison to the MET products of today.

8.2 Further collaboration between MET and ATM is needed to define the operational and performance requirements, which may become dynamic and scenario-dependent, for MET information in support of ATM and PBN. This will require also clear definition of performance measures and accepted methods of validation.

8.3 User inputs have strongly demonstrated that the current content and structure of Annex 3 does not fully support MET-ATM-PBN, and that changes are required. An adjustment in the balance of ICAO MET provisions is needed. Moreover, it is suggested that the development of a PANS-MET, together with the inclusion of MET-ATM-PBN provisions into a Manual appropriately empowered by the Annex would be highly beneficial.

8.4 DRAFT ACTION 9/xx: That, an (AMOFSG) ad hoc working group will lead and work on the activity to develop the ICAO provisions for MET-ATM-PBN for inclusion in Annex 3, PANS-MET and Manuals.

9. ACTION BY THE GROUP

9.1 The AMOFSG is invited to:

a) note the information contained in this paper;

b) support the proposal to develop a PANS-MET and supporting guidance material for MET-ATM-PBN;

c) support the recommendation to revise the contents and structure of Annex 3 to meet the requirements for MET-ATM-PBN accordingly; and

d) endorse the draft action stated in paragraph.
APPENDIX A

OUTLINE OF METEOROLOGICAL SERVICES (MET) IN SUPPORT TO GLOBAL AIR TRAFFIC MANAGEMENT (ATM) AND PERFORMANCE-BASED NAVIGATION (PBN)

Introduction: Deliverable (task “b” and “c”) from Terms of Reference for the ad hoc group 6 (WG/6) from AMOFSG/8:

- Develop an outline for the meteorological services required to support the ICAO concept of performance-based flight operations reflecting the needs of aircraft operators and Air Traffic Management (ATM).
- Identify an initial set of performance metrics for the meteorological elements that are required for performance-based flight operations.

The outline is presented here in Appendix A, while the meteorological elements are presented in Appendix B.

- Concept for MET support to Global ATM\(^1\) for PBN
  - Minimize the impact of adverse weather on the total Air Transport System so as to ensure that maximum throughput is sustained in all meteorological conditions.
  - Provide Common Weather Situational Awareness:
    - Definition of shared weather information
      - Weather information accessible to all decision makers,
      - 4-D weather for 4-D trajectory based operations,
      - Probabilistic weather information,
      - Deterministic weather information,
    - Integration of shared weather information
      - Weather integration for flexible airspace management.
    - Exchange of shared weather information
      - Common code form for data exchange
  - Categorized by Airspace Capacity:
    - Congested En Route Airspace
    - Congested Terminal Control Area (TMA)
    - En Route – Not congested
    - TMA – Not congested

- Global MET/ATM/PBN per Airspace Capacity

\(^1\) For this outline ATM is defined as: The aggregation of the airborne and ground-based functions required to ensure the safe and efficient movement of aircraft during all phases of operations.
Appendix A

- **Congested En Route Airspace**
  - Applies to certain areas of the globe where en-route traffic is very congested (e.g., northeast USA).
  - MET Required and Provided:
    - Common weather picture used by ATM decision makers.
    - Flight profile to be used in the participating airspace.
      - Flight profile choices that consider high resolution 4D weather (i.e., the 4D Weather Cube):
        - Observed and probabilistic (and/or deterministic) forecasts of wind, temperature, turbulence, icing, thunderstorms, space weather hazards, volcanic ash, tropical cyclones, etc.
      - Automatic updates to flight profile for changing weather (i.e., observed and probabilistic and/or deterministic forecasts of wind, temperature, turbulence, icing, thunderstorms, space weather hazards, volcanic ash, tropical cyclones, etc).
  - How MET is provided and utilized:
    - Integrated into ATM
      - Minimize weather impact. Maximum throughput is sustained in all meteorological conditions.
    - Risk-based 4D Trajectories
    - Decision Support Tools
    - Machine-readable, network-enabled, geo- and time-referenced weather information authorized for use by ATM for decision making.
    - Options for visualized output (graphic, text) for a subset of information.

- **Congested Terminal Control Area (TMA)**
  - Applies to terminals where traffic is congested (e.g., New York, USA)
  - MET Required and Provided:
    - Common weather picture used by ATM decision makers.
    - Flight profile to be used in the participating airspace.
      - Departure and arrival flight profile choices, including instrument approaches, that consider 4D weather:
        - Observed and probabilistic (and/or deterministic) forecasts of wind, temperature, turbulence, icing, thunderstorm, volcanic ash, sandstorms/duststorms, wake turbulence, etc., from the runway to the “top of climb”, and from the “top of decent” to the runway.
        - Observed and probabilistic (and/or deterministic) forecasts of aerodrome / runway(s) information: wind, wind shear, ceiling, visibility, RVR, temperature, dew point, liquid/freezing/frozen precipitation and accumulation, lightning, barometric pressure barometric pressure, volcanic ash, etc.
      - Automatic updates to flight profile for changing weather.
How MET is provided and utilized:

- Integrated into ATM.
  - Minimize weather impact. Maximum throughput is sustained in all meteorological conditions.
- Risk-based 4D Trajectories,
- Network-enabled,
- Decision Support Tools,
- Options for visualized output (graphic, text) for a subset of information.
- Derived output as needed
  - METAR, TAF, etc.

- **En Route Airspace – Uncongested**
  - Applies to most of the world’s en-route airspace.
  - MET Required and Provided:
    - Common weather picture used by ATM decision makers. (Optional, depending on region of the world and capabilities of the providers).
    - Flight profile choices that consider
      - Observed and deterministic forecasts of wind, temperature, turbulence, icing, thunderstorms, volcanic ash, space weather hazards, volcanic ash, tropical cyclones, sandstorms/duststorms, etc.
        - Options to use 4-D Cube for probabilistic forecasts.
    - Updates
      - Options for automatic updates to flight profile for changing weather, otherwise
      - Traditional updates
  - How MET is provided and utilized:
    - Flight planning system (machine to machine)
    - Uplink/downlink to aircraft
    - Visualized output (graphic, text) where needed.

- **Terminal Control Area (TMA) – Uncongested**
  - Applies to the majority of the world’s TMAs.
  - MET Required and Provided
    - Common weather picture used by ATM decision makers. (Optional, depending on region of the world and capabilities of the providers).
    - Observed and deterministic forecasts of wind, turbulence, icing, thunderstorms, volcanic ash, tropical cyclones, sandstorms/duststorms and radioactive cloud.
      - Options to use 4-D Cube for probabilistic forecasts.
    - Aerodrome / runway(s) observations and forecasts:
      - Wind, wind shear, ceiling, visibility, RVR, wake turbulence, liquid/freezing/frozen precipitation and accumulation, lightning, temperature, dew point, pressure, etc.
Appendix A

- Updates
  - Options for automatic updates to flight profile for changing weather, otherwise
  - Traditional updates.

- How MET is provided and utilized
  - Traditional products
    - METAR, TAF, etc.
  - Visualized output (graphic, text) where needed.
APPENDIX B

Meteorological Elements (Forecast) for Global MET in support of Global ATM for PBN

<table>
<thead>
<tr>
<th>MET</th>
<th>Route Operations</th>
<th>Terminal Control Area (TMA) Operations</th>
<th>Aerodrome</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Global High Density</td>
<td>Global Low Density</td>
<td>High Density</td>
</tr>
<tr>
<td>Wind</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Temperature</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Humidity</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Convection (thunder-storms) and associated hazards (lightning, etc)</td>
<td>P</td>
<td>D</td>
<td>P</td>
</tr>
<tr>
<td>Turbulence</td>
<td>P</td>
<td>B</td>
<td>P</td>
</tr>
<tr>
<td>Icing</td>
<td>P</td>
<td>B</td>
<td>P</td>
</tr>
<tr>
<td>Non-CB Clouds</td>
<td>-</td>
<td>-</td>
<td>P</td>
</tr>
<tr>
<td>Visibility (including RVR)</td>
<td>-</td>
<td>-</td>
<td>D</td>
</tr>
<tr>
<td>Sandstorm / Duststorms</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Precipitation (liquid, freezing and frozen)</td>
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<td>P</td>
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<tr>
<td>Atmospheric pressure</td>
<td>-</td>
<td>-</td>
<td>D</td>
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<tr>
<td>Space Weather phenomena and hazards</td>
<td>P</td>
<td>B</td>
<td>P</td>
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<td>Tropical Cyclones</td>
<td>P</td>
<td>B</td>
<td>P</td>
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<tr>
<td>Volcanic Ash</td>
<td>D</td>
<td>D</td>
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</tr>
<tr>
<td>Radioactive Cloud</td>
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<td>D</td>
<td>D</td>
</tr>
</tbody>
</table>

P = Probabilistic forecasts in the 4-D Cube for risk-based 4-D trajectories
D = Deterministic forecasts from the 4-D Cube
B = Deterministic forecasts with options for use of probabilistic forecasts from 4-D Cube

— END —