

Guide to Services for Aviation

2023 edition

WEATHER · CLIMATE · WATER



WORLD
METEOROLOGICAL
ORGANIZATION

WMO-No. 732

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EDITORIAL NOTE

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FOREWORD

Wilbur and Orville Wright, two brothers with a passion for aeronautics, made the successful flight of a human-carrying, power-driven, heavier-than-air machine on the 17 December 1903. However, to reach that point Wilbur wrote to the United States Weather Bureau asking for information on the windiest places in the United States of America. Among the possibilities offered, the brothers selected a remote sandy area on the outer banks of North Carolina named Kitty Hawk. They then wrote to the weather observer at Kitty Hawk, who confirmed on the 16 August 1900 that: "the beach here is about one mile wide, clear of trees or high hills and extends for nearly sixty miles same condition. The wind blows mostly from the north and northeast September and October". That was the first step of a long-standing relationship between meteorology and aviation.

The development of civil aviation in the first half of the twentieth century and its spectacular growth gave an enormous new impetus to the development of meteorological services and expanded the horizons of the International Meteorological Organization, the predecessor organization to WMO, which had so far flourished to a great extent in response to the need for international cooperation in maritime services. However, international civil aviation increasingly required meteorological observations, forecasts and warnings at aerodromes and en route, and a communications system to permit the exchange of the information. This rapid expansion led to the growth of observing systems and to new meteorological services being created in regions where previously there had been none.

This Guide updates and supersedes the information previously provided in the 2003 edition of the *Guide to Practices for Meteorological Offices Serving Aviation* (WMO-No. 732). It takes into account the impact of evolving requirements and the observing and forecasting techniques used for the provision of aeronautical meteorological services. Where applicable, the Guide encourages the application of WMO and International Civil Aviation Organization (ICAO) standards and recommended practices.

I wish to express my gratitude to all those who have devoted time and effort to the task of updating this Guide, including Sue O'Rourke for authoring the Guide and to Bryan Boase, Greg Brock, Kaspar Bucher-Studer, Tim Hailes, Andrea Henderson, Colin Hord, Bill Maynard, Frank O'Rourke, Ian Robertson, Karen Shorey, Michael Terkildsen, Helen Tseros and Stéphanie Wigniolle for providing input to or a review of all or part of the Guide.



(Prof. A. Celeste Saulo)
Secretary-General

1. INTRODUCTION

1.1 PURPOSE OF THE GUIDE

1.1.1 The purpose of this publication is to provide guidance for WMO Member States and Territories (Members) in the provision of aeronautical meteorological services. It consists of eleven chapters covering a range of topics from the governance of the service to the importance of good interactions with users, the framework and structure behind the service provision, and the production and delivery of observations, forecasts and other information to the users. It is to be considered as an overview of the provision of aeronautical meteorological services and is intended to be used in conjunction with a range of other WMO and ICAO publications, including [Technical Regulations](#) (WMO-No. 49) and Annex 3 to the Convention on International Civil Aviation (the “Chicago Convention”, 1944), *Meteorological Service for International Air Navigation* (hereinafter referred to as ICAO Annex 3). The Guide will be maintained by WMO through periodic review and update.

1.2 SERVICES OBJECTIVES

1.2.1 Meteorological information is important to all phases of aircraft operations, including pre-flight planning and in-flight tactical replanning, irrespective of the level of aircraft or aerodrome equipage. The objective of the provision of aeronautical meteorological services to the aviation user community is to contribute towards aviation safety, regularity and efficiency. This objective is achieved by supplying aviation users, in particular airline operators, flight crew members, air traffic service (ATS) units, search and rescue (SAR) service units, aerodrome operators and others concerned with the conduct or development of air navigation, with the meteorological services that are necessary or desirable for the performance of their respective functions.

1.2.2 The provision and future development of aeronautical meteorological services should be considered in conjunction with the WMO [Long-term Plan for Aeronautical Meteorology](#) (AeM Series No. 5) as well as the *ICAO Global Air Navigation Plan* (GANP, ICAO Doc 9750) and *Global Aviation Safety Plan* (GASP, ICAO Doc 1004), by considering the evolving needs of the aviation user community and improvements in the science and technology underpinning the production and delivery of these services.

1.2.3 The GANP and its associated aviation system block upgrade methodology provide a strategic approach for achieving a globally interoperable air navigation system for all users, during all phases of flight, that will meet agreed levels of safety, provide optimum economic operations, is environmentally sustainable and will meet national security requirements. Meteorology is recognized as a key enabler for many of the operational areas reflected in the GANP, such as taxi-out, departure, en route, arrival, taxi-in and turnaround. Air transport modernization through this decade and beyond is driven by the transition to a system-wide information management (SWIM) environment and by the need for more interoperability allowing better integration of meteorological information into air traffic management (ATM) systems and collaborative decision-making (CDM).

1.2.4 Improvements in the content, format, quantity, quality, timeliness and availability of meteorological information, in particular the location, extent, duration and severity of hazardous meteorological conditions and their impacts on airspace and aircraft performance will lead to enhanced situational awareness of meteorological conditions. This, in turn, will lead to more precise estimates of expected airspace capacity, a reduction in the number of deviations and rerouting from user-preferred flight paths, more efficient flight routes with less fuel burn and consequently reduced emissions, enhanced safety through the avoidance of hazardous meteorological conditions, and a greater knowledge of the impact of meteorology on aviation system (a system of systems) performance. Despite all this, it must be considered that regardless

of planned improvements, adverse weather will not cease to exist and will continue to have a negative impact on aviation. The more the airspace reaches its capacity limits, the proportionally greater this negative impact will be. This should increase the incentive to make the best possible use of current and future meteorological information.

1.3 **METEOROLOGY FOR AIR NAVIGATION**

1.3.1 Aeronautical meteorological services are provided to help facilitate air navigation in accordance with applicable laws, standards, recommended practices, policies and procedures. They are an essential component of air navigation services alongside others that include communication services, aerodrome services and aeronautical information services (AIS). The aeronautical meteorological services supplied to aviation users consist of observed (actual) and forecast (predicted) meteorological conditions at aerodromes, in terminal areas and in en-route airspace. Each country is responsible for determining the meteorological services it will provide to meet the stated needs of civil aviation.

2. GOVERNANCE

2.1 INTERNATIONAL ARRANGEMENTS

2.1.1 International Civil Aviation Organization

2.1.1.1 Formed in 1944, ICAO is a specialized agency of the United Nations with responsibility to manage the administration and governance of the Chicago Convention that has 19 annexes dealing with various aspects of aviation. The ICAO contracting States and industry partners reach consensus on internationally applicable standards and recommended practices (SARPs), policies and procedures in support of safe, efficient, secure, economically sustainable and environmentally responsible international civil aviation.

2.1.1.2 Chapter II, Article 12 of the Chicago Convention states that:

Each contracting State undertakes to adopt measures to insure that every aircraft flying over or maneuvering within its territory and that every aircraft carrying its nationality mark, wherever such aircraft may be, shall comply with the rules and regulations relating to the flight and maneuver of aircraft there in force. Each contracting State undertakes to keep its own regulations in these respects uniform, to the greatest possible extent, with those established from time to time under this Convention. Over the high seas, the rules in force shall be those established under this Convention. Each contracting State undertakes to insure the prosecution of all persons violating the regulations applicable.

2.1.1.3 Chapter IV, Article 28 of the Chicago Convention states that:

Each contracting State undertakes, so far as it may find practicable, to:

a. Provide, in its territory, airports, radio services, meteorological services and other air navigation facilities to support international air navigation, in accordance with the standards and practices recommended or established from time to time, pursuant to this Convention...

2.1.1.4 Chapter VI, Article 37 of the Chicago Convention states that:

Each contracting State undertakes to collaborate in securing the highest practicable degree of uniformity in regulations, standards, procedures, and organization in relation to aircraft, personnel, airways and auxiliary services in all matters in which such uniformity will facilitate and improve air navigation. To this end ICAO shall adopt and amend from time to time, as may be necessary, international standards and recommended practices and procedures dealing with:

... g. Collection and exchange of meteorological information ...

2.1.1.5 The Chicago Convention annex dealing with meteorology is Annex 3. Together with other annexes, policies and procedures, SARPs in Annex 3 are adopted and applied by States to ensure that their civil aviation operations and regulations, at a national level, conform to global norms. ICAO also coordinates and facilitates, inter alia, the provision of technical assistance and capacity development within its contracting States to support aviation objectives.

2.1.2 World Meteorological Organization

2.1.2.1 Formed in 1950, WMO is a specialized agency of the United Nations with responsibility for international cooperation and coordination on the state and behaviour of

the Earth's atmosphere, its interaction with the land and oceans, the weather and climate it produces, and the resulting distribution of water resources. The Convention of the World Meteorological Organization, contained within *Basic Documents No. 1* (WMO-No. 15), conveys how WMO is to fulfil its mandate. WMO Members and industry partners reach consensus on internationally applicable SARPs, policies and procedures in support of sustainable development, the reduction of loss of life and property caused by natural disasters and other catastrophic events related to weather, climate and water, as well as to safeguard the environment and the global climate for present and future generations.

2.1.2.2 Similar to the ICAO standards-making process described above, Technical Regulations, Manuals, policies and procedures are adopted and applied by WMO Members to ensure that their meteorological operations and regulations, at a national level, conform to global norms. WMO also coordinates and facilitates, inter alia, the provision of technical assistance and capacity development within its Members to support meteorological objectives.

2.1.2.3 As outlined in *Basic Documents No. 3* (WMO-No. 60), Chapter II.3, WMO and ICAO have had formal working arrangements since 1954. The working arrangements constitute a framework within which the two organizations, based on reciprocity, undertake cooperation in fields related to their respective mandates. WMO-No. 60, Chapter II.3 is reproduced as ICAO Doc 7475, Working Arrangements between the International Civil Aviation Organization and the World Meteorological Organization.

2.1.2.4 Essentially, in accordance with the working arrangements, ICAO is responsible for defining and encouraging the provision of the services that civil aviation requires, for recommending where, in what forms and at what times such services shall be rendered, and for highlighting that the provision of meteorological information has an important place for the safe, regular, economic and efficient operation of civil aviation. WMO meanwhile is responsible for specifying the scientific foundation and technical methods and practices recommended for use in providing the required meteorological services to civil aviation.

2.1.3 **Other arrangements**

2.1.3.1 In addition to the international arrangements of ICAO and WMO described above, regional- or subregional-level complementary multinational arrangements may exist. Within the European Union for example, the European Union Aviation Safety Agency develops common safety and environmental rules at the European level and monitors the implementation of standards through inspections. Similarly, for certain States within Africa the Agency for Aerial Navigation Safety in Africa and Madagascar (ASECNA) provides en-route air navigation services over an airspace of approximately 16 million square kilometres, as well as AIS and aeronautical meteorological services. Such regional or subregional arrangements are generally consistent with the international arrangements prescribed by ICAO and WMO and may even establish more stringent requirements depending on the regional or subregional circumstances such as complexity of airspace and density of air traffic.

2.2 **NATIONAL ARRANGEMENTS**

2.2.1 **Meteorological authority and meteorological service provider**

2.2.1.1 Each ICAO contracting State is required to designate the authority, known as the meteorological authority, which in turn is responsible for designating the meteorological service provider(s) for the provision of meteorological services for international air navigation. The responsibilities of the meteorological authority also include the provision of oversight and regulation of the meteorological service. Details of the meteorological authority and the meteorological service provider(s) are required to be included in the aeronautical information publication (AIP) of the State concerned, in accordance with ICAO Annex 15, Aeronautical Information Services.

2.2.1.2 The full scope of meteorological services to be provided by a State and how they comply with international SARPs, as well as national requirements, is to be determined by the meteorological authority on behalf of the State. If a State cannot provide the required meteorological services for their area of responsibility (AOR), a bilateral agreement can be established with a service provider in another country.

2.2.2 **Legislation and regulation**

2.2.2.1 The function of the meteorological authority described above is principally a regulatory one such that the entity regulates the provision of aeronautical meteorological services to ensure that they meet the needs of users. The State determines, based on its national circumstance, the degree to which it will conform to the internationally applicable SARPs, policies and practices. Internationally applicable SARPs comprise provisions that are necessary (standards) and desirable (recommended practices).

2.2.2.2 Meteorological services for aviation at national and local levels should where possible conform with the internationally applicable SARPs, policies and practices of ICAO and WMO. The conformity or non-conformity may be enshrined through legislation and regulations at a national or regional level. For example, legislation within the European Union means that European law, except in certain circumstances, takes precedence over national legislation. Moreover, European Commission regulations are automatically binding on European Union members and will, if relevant, supersede any inconsistencies within national regulations.

2.2.3 **Safety oversight**

2.2.3.1 Safety oversight is a function performed nationally to ensure that individuals and organizations performing an aviation activity comply with safety-related national laws and regulations. Meteorological oversight is usually performed by the meteorological authority or else by an entity with delegated responsibility to perform such oversight. Regulatory oversight of meteorological services may be achieved through both routine and targeted audit of all aeronautical meteorological service providers serving international civil aviation.

2.2.3.2 The ICAO Universal Safety Oversight Audit Programme (USOAP) uses a continuous monitoring approach (CMA). Meteorological service providers in conjunction with the meteorological authority must provide evidence to ICAO on their compliance with international standards. To assist with this, ICAO has developed an online framework for:

- Completion and updates of the State aviation activity questionnaire;
- Completion and updates of the compliance checklists through the electronic filing of differences (EFOD) system;
- Completion and updates of the USOAP CMA self-assessment;
- Completion and updates of the State corrective action plans;
- Access to all safety-related information generated by USOAP CMA activities.

2.2.3.3 When there is a difference between national regulations and practices relating to the aeronautical meteorological service and the international standards, ICAO must be notified using the compliance checklist through the EFOD system. Requests for notification of differences are sent to States immediately after the adoption of each ICAO annex amendment. Use of the EFOD system is also advised for the notification of any differences from any international recommended practices when the notification of such differences are important for the safety of air navigation. If new differences occur, or there is a resolution of an existing difference, ICAO can be notified at any time. The completion of the compliance checklists provides an overview to aviation users of the level of implementation of SARPs.

2.2.3.4 A list of significant differences between the national regulations and practices and the related ICAO SARPs and procedures must be published as part of the AIP in a form that would enable a user to differentiate readily between the national and international requirements.

2.2.3.5 Further information on safety oversight is given in the publications *Universal Safety Oversight Audit Programme Continuous Monitoring Manual* (ICAO Doc 9735) and *Safety Oversight Manual* (ICAO Doc 9734).

2.2.4 **Agreement with air traffic services**

2.2.4.1 Given the intrinsic link between meteorological conditions and aviation operations, an agreement between the meteorological service provider and the appropriate ATS provider should be established. This can be extended to the AIS provider and the regulator if warranted.

2.2.4.2 Guidance on the agreement to be established between the ATS provider and the meteorological service provider can be found in the *Manual on Coordination between Air Traffic Services, Aeronautical Information Services and Aeronautical Meteorological Services* (ICAO Doc 9377). Essentially, the agreement should cover:

- (a) Arrangements for meetings at the operational and administrative levels;
- (b) Requirements for the provision of meteorological information and instrumentation from both the ATS and meteorological service providers;
- (c) The means to exchange the meteorological information;
- (d) Responsibilities and functions of the ATS units and meteorological offices;
- (e) Designation of the meteorological office with respect to individual ATS units and SAR service centres;
- (f) Arrangements for automatic and manual air reports (AIREPs);
- (g) Exchange of information regarding volcanic activity, radioactive materials, toxic chemicals and space weather;
- (h) Familiarization with each other's facilities and familiarization flights;
- (i) Meteorological training of aeronautical personnel;
- (j) Requirements for climatological information.

2.2.4.3 Other agreements may take the form of financial agreements for cost recovery.

3. USERS AND STAKEHOLDERS

3.1 USERS

3.1.1 Types of users

3.1.1.1 As previously mentioned, the objective of aeronautical meteorological services is to support safe, efficient, secure, economically sustainable and environmentally responsible civil aviation activities. This objective is achieved by supplying aviation users, in particular airline operators, flight crew members, ATS units, aerodrome operators, SAR, aeronautical information providers, flight planners, accident investigators and others concerned with the conduct or development of international air navigation, with the meteorological service that is necessary or desirable for the performance of their respective functions.

3.1.1.2 Given the variety of aviation operations (for example, flying an aircraft, providing air traffic control (ATC), managing ground movements on taxiways, and the like) each type of aviation user tends to have their own, sometimes unique, set of meteorological needs. For example, information on severe clear air turbulence at 30 000 feet will be irrelevant to a ground handler at an aerodrome but it will be crucial for a flight crew member whose flight path may intercept the affected area.

3.1.1.3 Occasionally however, there will be commonality in the meteorological needs. For example, information on the presence of a thunderstorm passing across or proximal to an aerodrome will be of paramount importance to those responsible for managing ground operations, such as refuellers, to ATC sequencing of arriving and departing aircraft, and to flight crew members attempting to take-off or land at the aerodrome.

3.1.1.4 In addition to the aviation industry users, other meteorological service providers require quality aeronautical meteorological information to ensure a seamless approach to the provision of services across neighbouring flight information regions (FIRs) and other defined areas of responsibility.

3.1.2 Aeronautical information service

3.1.2.1 The AIS is defined in ICAO Annex 15 as a “service established within the defined area of coverage responsible for the provision of aeronautical data and aeronautical information necessary for the safety, regularity and efficiency of air navigation”. Aeronautical information management (AIM) meanwhile is defined in Annex 15 as the “dynamic, integrated management of aeronautical information through the provision and exchange of quality-assured digital aeronautical data in collaboration with all parties”.

3.1.2.2 An AIS is required to ensure that aeronautical data and information, including meteorological information, are made available in a form suitable for the operational requirements of the ATM community, including those involved in flight operations (that is, flight crews, flight planning and flight simulators), to ATS units responsible for flight information services and the service providers responsible for pre-flight information.

3.1.2.3 The AIS is responsible for the maintenance of the State AIP. Detailed specifications concerning the presentation and contents of the meteorological information services to be provided to aviation within the AIP is outlined in *Procedures for Air Navigation Services – Aeronautical Information Management (PANS-AIM, ICAO Doc 10066)*.

3.1.2.4 Formal arrangements must be established between the originators of aeronautical meteorological information (that is, the meteorological service provider) and the AIS. Guidance on these arrangements is given in ICAO Doc 9377.

3.1.3 **Air traffic services**

3.1.3.1 ATS include the services providing flight information, alerting, air traffic advice and ATC (area control service, approach control service or aerodrome control service). The objectives of the ATS are to:

- (a) Prevent collisions between aircraft;
- (b) Prevent collisions between aircraft in the manoeuvring area and obstructions within that area;
- (c) Expedite and maintain an orderly flow of air traffic;
- (d) Provide advice and information useful for the safe and efficient conduct of flights;
- (e) Notify appropriate organizations regarding aircraft in need of SAR and assist such organizations as required.

3.1.3.2 ATS also help to minimize environmental impacts, such as noise pollution and unnecessary fuel burn and emissions. Further information on ATS is given in ICAO Annex 11, *Air Traffic Services*, and also in *Procedures for Air Navigation Services – Air Traffic Management (PANS-ATM, ICAO Doc 4444)*.

3.1.3.3 Air traffic flow management is a service established with the objective of contributing to a safe, orderly and expeditious flow of air traffic by ensuring that ATC capacity is utilized to the maximum extent possible and that the traffic volume is compatible with the capacities declared by ATS.

3.1.3.4 ATS require meteorological information in order to provide their services to aviation. Meteorological personnel should have knowledge of the ATC system in general and be familiar with the impact of meteorological conditions on the task of the ATS units with which they are directly concerned. As pointed out in 2.2.4, formal arrangements should be established between the meteorological service provider and the relevant ATS. Guidance on these arrangements is given in ICAO Doc 9377.

3.1.4 **Airline operations and flight planning**

3.1.4.1 Airline operations use meteorological information in all phases of flight, including flight planning, standing, pushback, taxi, take-off, initial climb-out, en route, approach, landing and ground servicing.

3.1.4.2 Flight planning is the process that describes the intended operation of an aircraft from a point of origin (departure aerodrome) to a point of destination (arrival aerodrome). The meteorological conditions at the departure aerodrome, arrival aerodrome, alternate (diversion) aerodrome(s), terminal area and in en-route airspace are a key consideration in the flight-planning process since such conditions are integral to pre-flight aircraft loading, including fuel and cargo, and in-flight fuel use calculations. Efficient use of fuel not only yields economies for the airline operator but also helps minimize the impact of the flight on the environment through reduced fuel burn. Knowledge of the flight duration will also have an impact on staff scheduling, such as duty hours of flight crew, refuellers, caterers, and the like.

3.1.4.3 Flight planning essentially falls into the following phases: strategic pre-flight planning, pre-tactical planning, in-flight tactical replanning and post-flight analysis:

- (a) Strategic pre-flight planning may commence between one week and several months prior to the intended operation of an aircraft. Climatological and meteorological information can be used for research into an optimal flight path, for example, for planning and as part of the CDM process to evaluate the likely meteorological conditions and their variance at aerodromes and airspaces of interest, on a network basis or for individual flights.

- (b) Pre-tactical planning is usually applied during the six days prior to the day of operations. It considers the proposed demand and compares it with the available capacity for the day of the operation, then adjusts as necessary. The expected (forecast) meteorological conditions are a key consideration at the pre-tactical planning stage. As part of the CDM process, this helps to optimize efficiency, and balance demand and capacity.
- (c) In-flight replanning and tactical flow management occurs in real time on the day of operations. Accurate and timely meteorological information – both observations and forecasts – is critical in this phase to minimize any negative impact of an event and maximize both safety and efficiency. Fuel use and route replanning are important during this phase, as diversions to alternate aerodromes may be required.
- (d) Post-flight analysis takes place post-operations. It involves the analysis of the operations and investigates and reports on relevant processes and activities. It gathers information from a variety of service providers (including meteorological service providers), users and stakeholders to look at the difference between the anticipated outcome and the actual outcome to improve future operations.

3.1.5 **Aerodrome operations**

3.1.5.1 Aerodrome operations encompass a multitude of facilities and services including but not limited to ATC (ground and tower), navigational aids, runway and taxiway signage and lighting, ground handling, and maintenance. Meteorological information is integral to the safe and efficient operation of the aerodrome, particularly during adverse weather. The recovery of aerodrome operations following a period of adverse weather is often just as important as the reduction or suspension of operations prior to or during an event. For example, forecasting the improvement of visibility or of thunderstorms moving sufficiently far away from an aerodrome is critical for getting aerodrome operations back to normal and to the safety of airline personnel, ground crew and passengers.

3.1.5.2 The throughput capacity of an aerodrome, more specifically the number of aircraft able to take-off and land during each hour of operation, relies heavily on the prevailing and predicted meteorological conditions. Changes in wind speed and direction, strength of gusts, occurrence of thunderstorms in the aerodrome vicinity, reductions or improvements in visibility and the height of the cloud base, inter alia, can and often do have significant impacts on the capacity of the aerodrome. To maintain safe operations and safety margins, the capacity of the aerodrome will often be reduced during periods of low visibility, low cloud base or strong crosswinds. Similarly, during a thunderstorm refuelling and other ground operations will be suspended. Delays and “ground-handling-stops” at an aerodrome may have network consequences far beyond the aerodrome, for example resulting in a reduction in flow rate (throughput) of air traffic in the terminal area.

3.1.6 **Commercial air transport, general aviation and helicopter operations**

3.1.6.1 ICAO Annex 6, *Operation of Aircraft*, defines civil aviation aircraft operations in three categories: commercial air transport operations, general aviation operations and helicopter operations.

3.1.6.2 A commercial air transport operation is an aircraft operation that involves the transport of passengers, cargo or mail for remuneration or hire. A general aviation operation is an aircraft operation other than a commercial air transport operation or an aerial work operation. A helicopter operation (sometimes also referred to as a rotorcraft operation) is a heavier-than-air aircraft supported in flight chiefly by the reaction of the air on one or more power-driven rotors on substantially vertical axes.

3.1.6.3 General aviation therefore covers the private transport and recreational parts of aviation, and includes flight training, sports aircraft, light aircraft, ultralights, gliding, and the like. Aerial work is aircraft operations used for specialized services such as agriculture, construction, photography, surveying, observation and patrol, SAR and aerial advertisement.

3.1.6.4 Weather is often a contributing factor to general aviation accidents, particularly when a flight operating under visual flight rules moves into instrument flight rule conditions, or during thunderstorm events. As such the provision of timely and accurate meteorological information is just as important for general aviation as it is for all other aviation operations. Some accidents have been attributed to the pilots' lack of meteorological knowledge and the information that was available to them. The provision of meteorological information must be both easily accessible by the pilot and easy to understand. Information should be provided on product interpretation, what services are available and how to obtain them.

3.1.7 **Search and rescue**

3.1.7.1 SAR services for aviation aid both aircraft in distress and survivors of aircraft accidents, regardless of the nationality or status of such persons or the circumstances in which such persons are found. Further information is given in ICAO Annex 12, *Search and Rescue*.

3.1.7.2 The supply of meteorological information for SAR is often time critical and location dependent. Appreciating that aviation accidents can occur anywhere, ditching at sea or in extremely cold weather conditions is particularly time critical. Prior agreement on the information to be made available should be established along with procedures to follow during the SAR operation. A rapid and reliable two-way communication must be made available, and the meteorological office concerned should maintain close liaison with the SAR coordination centre throughout an operation and supply any information requested as quickly as possible. The best available meteorological information should be supplied to SAR coordination centres and comprise:

- (a) Meteorological conditions in the last known position of the missing aircraft and along the intended route of that aircraft;
- (b) Information on the current and forecast conditions in the search area;
- (c) Current and forecast conditions en route, covering flights by search aircraft from and to the aerodrome from which the rescue is being conducted;
- (d) Any other meteorological information requested by the SAR service or ATS unit in connection with an aircraft emergency. This may include information required by ships undertaking SAR operations.

3.1.8 **Accident investigators**

3.1.8.1 Accident investigation authorities are responsible for investigating aircraft accidents and incidents. An accident is defined when a person is fatally or seriously injured, or the aircraft sustains significant damage or structural failure, or an aircraft is missing or inaccessible. An incident is an occurrence, other than an accident, associated with the operation of an aircraft that affects, or could affect, the safety of that operation. Further information is given in ICAO Annex 13, *Aircraft Accident and Incident Investigation*.

3.1.8.2 Accident investigators are required to collect a range of factual information, including meteorological information. This will include a statement outlining the meteorological conditions appropriate to the circumstances, including both actual and forecast conditions, the meteorological information that was available to the crew, and the natural light conditions at the time of the accident (that is, sunlight, moonlight, twilight). It is important that investigators contact the aeronautical meteorological service provider immediately, so that critical meteorological information can be promptly collated.

3.1.8.3 When meteorological staff become aware that an accident or incident has occurred anywhere within their AOR, such as an FIR, the time should be noted and a full set of observations and forecasts, closest to the location of the accident or incident and over the actual flightpath of the aircraft, obtained and checked for accuracy. All documents, reports, analyses, forecasts and warnings relevant to the accident or incident should be retrieved without delay. Steps should be taken immediately to inform the manager that an accident or incident has occurred. Additional information should be obtained from the other operational meteorologists on duty at the time of the incident. It is the responsibility of the manager to make sure that all necessary actions have been taken with respect to liaison with the accident investigators and that all documents that may be required as evidence are available and subsequently archived.

3.1.9 **Meteorological service providers**

3.1.9.1 Observational data, information and derived products are freely exchanged in real time or near real time between WMO Members around the world. An extension of this is the exchange of aeronautical meteorological information between aeronautical meteorological service providers to ensure that information is provided to centres with a global and regional AOR and those in neighbouring FIRs. Procedures for cross-FIR and cross-AOR collaboration should be established to ensure the highest level of consistent information is provided to the aviation industry and to minimize discontinuities across boundaries.

3.2 **STAKEHOLDERS**

3.2.1 **Regulatory bodies**

3.2.1.1 As signatories to the Chicago Convention, States are committed to implementing ICAO SARPs. The civil aviation authority within a State, which is usually a government entity, has the role to regulate aviation safety within the State according to these SARPs. The functions of the civil aviation authority will normally include:

- Identifying safety risks;
- Setting the aviation safety standards and practices within the State that the government may pass into law;
- Developing advice, guidance and training to improve aviation safety and to mitigate safety risks;
- Providing safety oversight and monitoring compliance against the aviation safety standards;
- Filing differences to the SARPs within the ICAO annexes;
- Enforcing safety standards when required;
- Issuing approvals (for example, pilots' licences, aircraft registration, and the like).

Sometimes civil aviation authorities also have an investigatory role following an incident; however, to preserve impartiality, this is often assumed by a separate organization or government department.

3.2.1.2 The meteorological authority provides oversight and regulation of the meteorological service in accordance with ICAO Annex 3. This includes ensuring compliance with the requirements of WMO with respect to qualifications, competencies, education and training of aeronautical meteorological personnel, as well as ensuring that the service provider establishes and implements a properly organized quality management (QM) comprising

procedures, processes and resources necessary to provide for the QM of the meteorological information supplied to the aviation user. In many States, the civil aviation authority is the designated meteorological authority.

3.2.1.3 It is important that the meteorological service providers have a good relationship with both the civil aviation authority and the meteorological authority to ensure that the aviation safety risks are assessed and mitigated accordingly and that any differences between the relevant ICAO SARPs are minimized.

3.2.2 **International stakeholders**

3.2.2.1 A number of aviation stakeholders are involved internationally in the establishment of requirements governing the meteorological service for international air navigation. These stakeholders work collaboratively with ICAO and WMO in the establishment and maintenance of the international SARPs and procedures. A summary of some of the main stakeholders now follows.

3.2.2.2 The International Air Transport Association (IATA), established in 1945, is the organization that represents the airline industry. IATA represents approximately 290 airlines, both passenger and cargo, in approximately 120 countries. IATA member airlines carry in excess of 80% of the world's air traffic. IATA helps airlines to operate safely, securely, efficiently and economically under clearly defined rules. The aim of IATA is to assist airlines by simplifying processes and increasing passenger convenience while reducing costs and improving efficiency.

3.2.2.3 The International Federation of Air Line Pilots' Associations (IFALPA), established in 1948, is the global voice of pilots. IFALPA represents over 100 000 pilots in approximately 100 countries. The aim of IFALPA is the worldwide promotion of the highest level of aviation safety and to be the global advocate of the piloting profession through the provision of representation, services and support to its members and the wider industry.

3.2.2.4 The International Federation of Air Traffic Controllers' Associations (IFATCA), established in 1961, is an international collective of air traffic controller associations. IFATCA represents more than 50 000 ATC professionals in more than 130 countries. The objectives of IFATCA include the promotion of safety, regularity and efficiency in international air navigation as well as assistance and advice in the development of safe and orderly systems of ATC.

3.2.2.5 The Civil Air Navigation Services Organisation, established in 1996, is an industry association aiming to bring air navigation service providers (ANSPs), leading industry innovators and ATM specialists together to share knowledge, develop best practices and shape the future for a secure and seamless airspace.

3.2.2.6 The International Coordinating Council of Aerospace Industries Associations (ICCAIA), established in 1972, is an international organization of aerospace industry associations. The six member associations of ICCAIA are engaged in the design, development, manufacture and in-service support of aeronautical and space products and technologies. Member companies of the six ICCAIA member associations include manufacturers of aircraft, engines, ground and space systems, avionics and aircraft parts, and also international suppliers of components.

3.2.3 **Other stakeholders**

3.2.3.1 There are several other global, regional and subregional organizations involved in civil aviation of relevance to aeronautical meteorological services, including but not limited to the Airports Council International, the International Federation of Airline Dispatchers Associations, the International Business Aviation Council, the International Council of Aircraft Owner and Pilot Associations, ASECNA, the European Organisation for the Safety of Air Navigation (EUROCONTROL) and the European Union Aviation Safety Agency.

3.2.3.2 Additionally, there are many other stakeholders of relevance including universities, research institutes and organizations, flight-planning companies, pilot training academies, aircraft and aircraft component designers and manufacturers, and emergency services.

3.3 **USER AND STAKEHOLDER ENGAGEMENT**

3.3.1 **The need for engagement**

3.3.1.1 The requirements of operators need to be understood and, to the greatest extent possible, met. Regular consultation and liaison with operators are an essential part of a QM system (QMS) to ensure that the maximum benefit of meteorological information is to be gained, as both user requirements and the availability of meteorological information can change with time. Different users often have different requirements; for example, general aviation or helicopter operations need substantially different meteorological information from that required by international airline operators.

3.3.1.2 There has been a long and close relationship between meteorological service providers and the aviation community. With the advent of centralization and automation, there is less day-to-day contact with users than in the past, but there is still a need to maintain a close relationship between the provider and user. This close relationship helps to ensure that users' needs are being met, and that both the provider and user better understand the capabilities, limitations and requirements of each other. This engagement can be carried out directly between the provider and their users and stakeholders, or by a representative such as the meteorological authority.

3.3.1.3 A closer relationship can enhance the satisfaction of the aviation users, who feel that the provider cares, listens and understands how services can be and are provided to support their needs. This relationship can equally benefit the provider, through having more satisfied customers who value the service rather than seeking alternative providers, and through higher job satisfaction when the staff gain a deeper understanding of industry needs.

3.3.1.4 There may be times when the parties involved in the consultation or negotiations will disagree or are finding it difficult to reach consensus. In these situations, it is important that all parties concerned commit to forging and sustaining the level of engagement necessary for the pursuit of aviation safety, efficiency and regularity. It is important that parties listen and understand each other's point of view while asking the right questions, be professional and prepared and understand the requirements of each party. Finally, parties should be prepared to look at other options and alternatives to achieve the required results.

3.3.2 **Formal and informal engagement**

3.3.2.1 Suitable working relationships should be developed with regulatory bodies, aerodrome management, air traffic and communications services, and airline personnel. These should be integrated into day-to-day operations to gain a thorough understanding of aviation operations. This should provide a fully effective aeronautical meteorological service. When meteorological personnel are co-located with aviation personnel, such as in a shared operations centre, this will increase the opportunities for the meteorological personnel to interact directly with their customers.

3.3.2.2 Consultation can greatly assist in understanding and evaluating user requirements, analysing changes resulting from changing operating conditions and technological developments, and understanding how meteorological information is used and translated into decisions by users. Knowledge of the economic and safety implications of meteorological information, and its inherent accuracy and reliability limitations are also important.

3.3.2.3 Formal, multilateral liaison and consultation meetings should be organized with representatives of the aviation industry. These should be regular, at least annual, but more

frequently if required. They provide a forum to discuss the latest developments from both the customer and provider viewpoint, to review the quality of services, to review and update service specifications, and to cover matters such as cost recovery.

3.3.2.4 Additional ways that meteorological personnel can interact with aviation users and stakeholders include:

- Familiarization flights, which, provided security conditions are met, enable meteorological personnel to travel on the flight deck to gain valuable insight into the weather issues faced on a day-to-day basis by the flight crew, as well as providing the opportunity to explain to the crew the challenges of observing and forecasting the weather, thereby being a mutually beneficial experience;
- ATC centre visits, which provide meteorological personnel with a deeper understanding of the weather concerns of ATC personnel and management;
- Flight operations centre visits, which allow meteorological personnel to see how meteorological information is used for flight planning and briefing;
- Participation in pilots' training and refresher courses to allow both meteorological personnel and pilots to exchange views on meteorological products and services, consider incidents involving meteorology, and discuss possible improvements to the provision of meteorological services;
- Involvement in air shows or in general aviation or sporting aviation events (for example, ballooning or gliding) to provide on-site weather interpretation, forecasting and briefing;
- Visits to meteorological offices by aviation users (for example, airlines, regulators, ATC, flight crew, briefers, planners, general aviation) to see the forecast or observing operations, which will assist with their understanding of the forecasting process and of the infrastructure required.

3.3.2.5 Performance assessment is an integral part of an organization's QMS and assists with evaluating whether the users' needs have been met. This applies equally to the consultation process where customer satisfaction should be measured. Examples of how performance may be measured include surveys, questionnaires, interviews and direct feedback. Measurable performance indicators should be set by the service provider to look at performance (improvement or otherwise) over time.

3.3.2.6 Gaining feedback from users on the services provided should include what is working well and which areas may need improvement. When a complaint is made, the problem should be dealt with without delay and formally recorded in a register, with details of any action and further investigations undertaken, and any recommendations for improvements. The complaint should be "closed off" by providing a response to the customer explaining what occurred and what is being done to resolve the issue so as to prevent a repetition. Compliments should also be formally recorded in a register. Both customer complaints and compliments should be made known to all concerned staff and routinely analysed to identify trends.

3.3.2.7 At a national level, the aviation industry may require enhanced services over and above those specified in ICAO Annex 3. These services may be provided as part of the nationally regulated service, or a service provided to a specific user or user group, on a cost recovery or commercial basis. Services that are tailored to the needs of individual customers on a commercial basis may be subject to compliance with national competition laws.

3.3.3 Collaborative decision-making

3.3.3.1 The *Manual on Collaborative Air Traffic Flow Management* (ICAO Doc 9971) provides guidance on CDM and its use in both air traffic flow management and in aerodrome operations. Managing air traffic involves many different users and stakeholders with different, sometimes

conflicting needs. The CDM process ensures that service providers (including air traffic and meteorological service providers), stakeholders and airspace users can discuss airspace and aerodrome issues through regular, ad-hoc or event-based decision-making meetings in an open and transparent manner. It recognizes both the expertise of the group and that no single stakeholder has all the information.

3.3.3.2 Application of CDM facilitates more effective communication and information exchange and helps to enhance operational safety and increase efficiency. ICAO Doc 9971 highlights that:

The impact of weather is an example of how uncertainty can require decision-making at several time-horizons. Early decisions (such as planning operations assuming an arrival delay due to forecast snow) can be made taking into consideration the uncertainty and the ability to respond closer to the time of the event. As the situation unfolds and becomes more certain, decisions respond to this more certain information, with changing decisions contributing to the dynamism.

The aeronautical meteorological service provider plays a crucial role in any operational decisions upon which weather has an impact, with the level of involvement in the CDM process usually determined by the complexity of the decision-making and the severity of the expected meteorological phenomena. Tools, procedures and systems used for CDM require the integration of meteorological information, so it is important to understand the needs of the users with respect to CDM.

4. SERVICE PROVISION

4.1 SERVICE PROVISION TO AVIATION

4.1.1 Meteorological service provider

4.1.1.1 Aeronautical meteorological service providers tend to fall into two categories: those that are part of a National Meteorological and Hydrological Service (NMHS) and those that are not (that is, non-NMHS).

4.1.1.2 Generally, but not exclusively, NMHSs are a public-sector enterprise. An aeronautical meteorological service provider that is part of an NMHS will typically have direct access to the basic meteorological infrastructure, management and operations that the NMHS has at its disposal at both the national and international levels to perform its duties.

4.1.1.3 A non-NMHS service provider may not have direct access to such infrastructure and will typically be part of an ANSP, part of a private-sector (commercial) enterprise or part of the armed forces (military). In these instances, the non-NMHS provider may need to establish a bilateral or multilateral agreement (or similar) to access the basic meteorological infrastructure and information. Conversely, the non-NMHS provider may have access to its own facilities and services that it makes available to NMHS providers, again under some form of bilateral or multilateral agreement.

4.1.1.4 The combination of NMHS and non-NMHS entities is, in part, a reflection of the history of meteorological services. Many were established to serve aviation, particularly military aviation during the First World War, and were subsequently found to be indispensable to service the rapidly expanding civil aviation industry in the post-war years. Nowadays, meteorological service providers have a range of responsibilities, often including aviation but also extending to, for example, public weather services, marine meteorological services and disaster risk reduction services.

4.1.2 National, regional and global service provision

4.1.2.1 For ICAO contracting States and WMO Members, the provision of meteorological services to aviation is facilitated through a combination of global, regional, national and local services. All are integral to the safety and efficiency of air navigation, the economic sustainability of air transport and the reduction of aviation's impact on the environment, so processes need to be in place for the exchange of meteorological information to ensure that a harmonized, consistent service is provided to aviation users worldwide. An ICAO white paper – Future Aeronautical Meteorological Information Service Delivery (2018) – highlighted a need to meet the objectives of the ICAO GANP with a move towards four-dimensional trajectory-based aviation operations.

4.1.2.2 A “whole-of-network” management approach needs to be implemented by aeronautical meteorological service providers since meteorological phenomena are not bounded by any territorial borders or FIRs. The risks and costs need to be managed in this borderless, phenomena-based approach through supportive and collaborative processes between aeronautical meteorological service providers, relevant aviation users and stakeholders. There is also an increased need to understand the impacts of meteorology on airspace and flight management with a greater emphasis on providing probability of occurrence of the phenomena, as well as the level of uncertainty of a forecast.

4.2 INTERNATIONAL SYSTEMS

4.2.1 World Area Forecast System

4.2.1.1 The World Area Forecast System (WAFS) is a worldwide system by which two World Area Forecast Centres (WAFCs), namely London and Washington, provide aeronautical meteorological en-route forecasts in a form suitable for use by other aeronautical meteorological service providers, airline operators, flight crew members, ATS units and other aviation users. These forecasts include significant weather (SIGWX) forecasts and upper-air gridded forecasts of wind, temperature, humidity, geopotential altitude of flight levels, tropopause flight level and temperature, cumulonimbus cloud, icing and turbulence. Distribution of the meteorological information is performed through the Secure Aviation Data Information Service (SADIS) from WAFS London and the WAFS Internet File Service (WIFS) from WAFS Washington. Further information on SADIS and WIFS can be found in their respective user guides.

4.2.2 International Airways Volcano Watch

4.2.2.1 The International Airways Volcano Watch (IAVW) is an international arrangement for monitoring volcanic eruptions and providing volcanic ash cloud information to aviation users. Nine Volcanic Ash Advisory Centres, namely Anchorage, Buenos Aires, Darwin, London, Montreal, Tokyo, Toulouse, Washington and Wellington, use information from State volcano observatories, a number of other observing sources, including ground-based observations, special air reports (ARS) and satellites, and forecasting capabilities based on numerical weather prediction (NWP) modelling capacities, to produce volcanic ash advisory information that includes the observed and forecast positions and height of volcanic ash clouds and other hazards relating to volcanic activity. Useful sources of information on IAVW include the *Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds* (ICAO Doc 9691) and the *Handbook on the International Airways Volcano Watch (IAVW): Operational Procedures and Contact List* (ICAO Doc 9766).

4.2.3 Tropical Cyclone Advisory System

4.2.3.1 Seven Tropical Cyclone Advisory Centres (TCACs), namely Darwin, Honolulu, La Réunion, Miami, Nadi, New Delhi and Tokyo, provide advisory information to aviation users regarding the position, forecast direction and speed of movement, central pressure and maximum surface wind of tropical cyclones. Each TCAC monitors the development of tropical cyclones in its AOR using geostationary and polar-orbiting satellite data, radar data and other meteorological information. Each TCAC is also a WMO Regional Specialized Meteorological Centre or a Tropical Cyclone Warning Centre with broader responsibilities to the community for issuance of tropical cyclone information. Guidance on tropical cyclone forecasting can be found in the [Global Guide to Tropical Cyclone Forecasting](#) (WMO-No. 1194) and the [Compendium on Tropical Meteorology for Aviation Purposes](#) (WMO-No. 930).

4.2.4 Space Weather Advisory Information Service

4.2.4.1 Four Global Space Weather Centres, namely the consortium comprising Australia, Canada, France and Japan (AFJC); the Pan-European Consortium for Aviation Space Weather User Services (PECASUS); the China–Russian Federation Consortium (CRC); and the United States; and one Regional Space Weather Centre, namely South Africa, monitor and provide advisory information on space weather phenomena that are expected to affect high-frequency radio communications, satellite communications, Global Navigation Satellite System (GNSS)-based navigation and surveillance systems, or pose a radiation risk to aircraft occupants. Further information regarding space weather services is given in the *Manual on Space Weather Information in Support of International Air Navigation* (ICAO Doc 10100).

4.2.5 **Others**

4.2.5.1 ICAO Annex 3 requires information to be supplied to aeronautical users on several other hazards, such as radioactive materials and clouds, toxic chemicals, and tsunami.

4.2.5.2 As part of the WMO World Weather Watch programme, a number of Regional Specialized Meteorological Centres are assigned to provide information, advisories and warnings regarding the specific hazards, including nuclear and chemical hazards. These centres run specialized particle transport, dispersion and deposition models during these emergencies. In addition, the International Atomic Energy Agency provides an intergovernmental forum for scientific and technical cooperation in the nuclear field. It works for the safe, secure and peaceful uses of nuclear science and technology, contributing to international peace and security.

4.2.5.3 The Intergovernmental Oceanographic Commission tsunami programme aims at reducing the loss of lives and livelihoods that could be produced worldwide by tsunamis. The programme supports Commission members in assessing tsunami risk, implementing tsunami early warning systems and educating communities at risk about preparedness measures. The tsunami early warning systems are based on observation networks of seismometers and sea-level measuring stations, which send real-time data to national and Regional Tsunami Warning Centres. Based on these observations, the Tsunami Warning Centres are able to confirm or cancel a tsunami watch or warning. When a potentially destructive tsunami is detected, national authorities then decide if a tsunami warning and an evacuation order must be issued to the public and aviation users.

4.3 **NATIONAL SERVICE PROVISION**

4.3.1 **National service delivery models**

4.3.1.1 Meteorological services for an aerodrome and its surrounds are often provided centrally by the aeronautical meteorological service provider. Larger aerodromes, or those with specific meteorological requirements, may have meteorological personnel situated at the aerodrome, either in a stand-alone office or integrated into the operations of ATC or aerodrome operations. Additional meteorological information is often provided by suitably competent air traffic controllers, the automatic terminal information service (ATIS) or aerodrome operators, for example to inform flight crew of conditions for arrival or departure.

4.3.1.2 ICAO Annex 3 requires each State to establish one or more aerodrome or other meteorological offices for the provision of aeronautical meteorological services to:

- Prepare or obtain observations and forecasts of local meteorological conditions and other relevant information for its AOR;
- Maintain a continuous “weather watch” of meteorological conditions over designated aerodromes;
- Provide briefing, consultation and flight documentation to aviation users;
- Exchange relevant meteorological information with other national and international aviation providers.

4.3.1.3 While many of the en-route services are delivered through global and regional systems, there are still critical en-route forecasts and warnings that are delivered nationally. ICAO Annex 3 requires each State to establish one or more meteorological watch offices to provide aeronautical meteorological services within their State’s FIR or within a “control area”. A meteorological watch office is required to:

- Maintain continuous watch over meteorological conditions affecting flight operations within its AOR;

- Prepare and disseminate SIGMET (information concerning en-route weather and other phenomena in the atmosphere that may affect the safety of aircraft operations) and other hazardous information not already issued as part of a SIGMET relating to its AOR, such as pre-eruption volcanic activity, a volcanic eruption, volcanic ash cloud, release of radioactive materials and their forecast trajectories, tropical cyclones, space weather, and the like;
- Prepare and disseminate AIRMET information related to its AOR as per regional air navigation agreement;
- Ensure close coordination with neighbouring meteorological watch offices.

4.3.1.4 There is a growing requirement at the national level for enhanced briefings and input into the CDM process and for enhanced forecast information for the terminal area. Whichever national service delivery model is chosen, close communication between meteorological personnel and operational stakeholders is essential.

4.3.2 **Multinational service delivery models**

4.3.1.1 Multinational service delivery models aim to deliver an improved aeronautical meteorological service through the flexible use of resources across multiple States. Some examples include the Northern Europe Aviation Meteorology Consortium and ASECNA.

4.4 **COST RECOVERY**

4.4.1 **Cost recovery for aeronautical meteorological services**

4.4.1.1 Irrespective of whether a designated aeronautical meteorological service provider is an NMHS or a non-NMHS entity, under article 15 of the Chicago Convention (ICAO Doc 7300) the State with responsibility to provide meteorological services for international air navigation is entitled to cost recovery for the meteorological facilities and services it provides to serve aviation. It is worthwhile to note that some States do elect to recover cost, while others do not. This determination is made by each State based on its national circumstances.

4.4.1.2 Article 15 of the Chicago Convention, in summary, establishes three basic principles:

- Uniform conditions shall apply to the use of aerodrome and air navigation facilities in one State by aircraft of all other States;
- Charges for facilities shall not be higher for aircraft of other States than those paid by national aircraft;
- No charge shall be imposed by a State solely for granting authorization for a flight into, out of, or over its territory.

4.4.1.3 In those instances where cost recovery is applied, the precise nature of the cost recovery model often varies from one State to the next due to variations in the responsibilities of the aeronautical meteorological service provider. Nevertheless, all cost-recovery models applied are expected to conform to the four ICAO key charging principles of non-discrimination, cost-relatedness, transparency and consultation.

4.4.2 **Cost recovery guidance**

4.4.2.1 Extensive guidance on cost recovery models for the provision of meteorological services for international air navigation, and the implementation thereof, is available from both WMO and ICAO. Notable publications include:

- [Guide to Aeronautical Meteorological Services Cost Recovery: Principles and Guidance](#) (WMO-No. 904);
- *ICAO's Policies for Airport and Air Navigation Services* (ICAO Doc 9082);
- *Manual on Air Navigation Services Economics* (ICAO Doc 9161).

4.5 **QUALITY AND SAFETY MANAGEMENT**

4.5.1 **Quality management**

4.5.1.1 Consistent with an ICAO Annex 3 Standard, an aeronautical meteorological service provider will establish and implement a properly organized quality system comprising procedures, processes and resources necessary to provide for the QM of the meteorological information to be supplied to the users. It is recommended that this quality system should be in conformity with the International Organization for Standardization (ISO) 9000 series of quality assurance (QA) standards and should be certified by an approved organization. Moreover, demonstration of compliance of the quality system is by an audit.

Note: ICAO requires contracting States to abide by Standards and also suggests recommended practices. ICAO defines the two conditions as follows:

Standard: Any specification for physical characteristics, configuration, matériel, performance, personnel or procedure, the uniform application of which is recognized as necessary for the safety or regularity of international air navigation and to which Contracting States will conform in accordance with the Convention; in the event of impossibility of compliance, notification to the Council is compulsory under Article 38.

Recommended Practice: Any specification for physical characteristics, configuration, matériel, performance, personnel or procedure, the uniform application of which is recognized as desirable in the interest of safety, regularity or efficiency of international air navigation, and to which Contracting States will endeavour to conform in accordance with the Convention.

4.5.1.2 Quality management is a process that focuses not only on the quality of the product or service, but also on the means to achieve it. It is centred on four activities: quality planning, quality control (QC), QA and quality improvement. QC aims to ensure that quality requirements have been fulfilled prior to the dissemination of a product or the delivery of a service. QA aims to instil confidence that quality requirements have been met. It involves the systematic monitoring and evaluation of the processes associated with the generation of a product or service.

4.5.1.3 The primary guide for QM within an NMHS and other relevant service providers is the [Guide to the Implementation of Quality Management Systems for National Meteorological and Hydrological Services and Other Relevant Service Providers](#) (WMO-No. 1100).

4.5.2 **Principles of quality management**

4.5.2.1 The principles of QM provide a sound foundation for achieving the goals and objectives associated with providing an aeronautical meteorological service. They are fundamental for leading, operating and developing an organization, with the objective of continually improving performance over the long term through a focused approach to all stakeholders, particularly customers. The underpinning principles of QM are:

- Customer focus;
- Leadership;
- Engagement of people;
- Process approach;
- Improvement;
- Evidence-based decision-making;
- Relationship management.

4.5.3 **Benefits of quality management**

4.5.3.1 The implementation of QM and the application of QM principles through, for example, a QMS, should have the following objective benefits:

- Compliance with legal and statutory requirements (for example, ICAO Annex 3);
- Determination of users' requirements in addition to their statutory requirements;
- Ensuring customers' expectations are satisfied;
- Meeting contractual obligations;
- Aligning activities with the corporate vision and goals;
- Taking effective corrective and preventive action when processes fail, to ensure there is no reoccurrence;
- Continually improving performance.

4.5.4 **Safety management**

4.5.4.1 All service providers are required to establish and maintain a management system. The meteorological community has adopted a QMS, whereas the broader aviation community is required to implement a safety management system (SMS), which is a systematic approach to managing safety, including the necessary organizational structures, accountabilities, responsibilities, policies and procedures. As an example, ATS providers have managerial control over functions directly affecting the safety of the flight (for example, the air traffic controller is required to separate aircraft from each other). In this instance, the management system will take the form of an SMS.

4.5.4.2 Although QMS and SMS share commonality and are highly complementary, they differ in that SMS focuses on the safety, human and organizational aspects of an organization (that is, safety performance), while QMS focuses on the delivery of products and services of an organization to meet identified customer needs (that is, customer satisfaction).

4.5.4.3 The primary ICAO references regarding SMS are ICAO Annex 19, *Safety Management, and the Safety Management Manual (SMM)* (ICAO Doc 9859).

4.6 **RISK MANAGEMENT AND BUSINESS CONTINUITY**

4.6.1 **Risk management**

4.6.1.1 Risk is the effect of uncertainty on objectives. The ISO 31000 series of standards relates to risk management and provides principles and guidelines that organizations can use to deal with risk, including: avoiding the risk; accepting or increasing the risk; removing the risk source; changing the likelihood of occurrence; changing the consequences; sharing the risk with others; retaining the risk by informed decision.

4.6.1.2 Risk management is important for any organization as it:

- Helps focus on strategic objectives;
- Identifies any risks and measures their impact and probability;
- Identifies strategies to mitigate, transfer or eliminate risks;
- Allows planning, monitoring and control of events with unacceptable risk levels;
- Ensures that all stakeholders understand and accept the risks.

4.6.1.3 The ISO 9000 series on QM promotes risk-based thinking as a systematic approach to dealing with risk that should be implemented throughout any QMS, rather than being a separate entity. Risk-based thinking looks at both the risks and the opportunities with a focus on being proactive rather than reactive. This approach will assist with improving customer satisfaction and the implementation of continuous improvement.

4.6.2 **Business continuity**

4.6.2.1 A business continuity plan (sometimes also referred to as a risk mitigation action plan, or similar) may be established to account for situations where an unacceptable disruption to the continuity of the provision of a meteorological service occurs or is expected to occur.

4.6.2.2 The plan should look at different scenarios such as loss of communications; situations where access to offices and other facilities are reduced; and non-availability of operational meteorological personnel. It should also assign different priorities for different services, depending on the type of disruption. The plan should: identify key resources; define back-up arrangements (for example, temporary delegation of service provision responsibility to another entity) and recovery options; provide a contact list and identify who needs to be notified; decide what role individuals will have in the event of evoking contingency arrangements and emergency plans. Contingency planning should also include disruptions that may have longer time periods or be permanent, such as civil unrest, pandemics, and the like.

4.6.2.3 The ISO 22300, *Security and Resilience*, series of international standards provides further information on business continuity management systems and emergency management.

4.7 EDUCATION, TRAINING AND COMPETENCIES

4.7.1 Meteorological personnel qualifications

4.7.1.1 ICAO Annex 3 states that each contracting State shall comply “with the requirements of the World Meteorological Organization in respect of qualifications and training of meteorological personnel providing service for international air navigation”. The relevant WMO publications include:

- *Technical Regulations* (WMO-No. 49), Volume I, Part V, Qualifications and Competencies of Personnel Involved in the Provision of Meteorological (Weather and Climate) and Hydrological Services;
- *Guide to the Implementation of Education and Training Standards in Meteorology and Operational Hydrology* (WMO-No. 1083), Volume I;
- *Guidelines for Trainers in Meteorological, Hydrological and Climate Services* (WMO-No. 1114).

4.7.1.2 There are two categories of meteorological personnel, the meteorologist and the meteorological technician. Each requires the following minimum level of education and qualifications:

- Meteorologist: A person who has successfully completed the requirements of the Basic Instruction Package for Meteorologists (BIP-M) at university degree level (or equivalent) that is mandatory for all professional meteorologists;
- Meteorological technician: A person who has successfully completed the requirements of the Basic Instruction Package for Meteorological Technicians (BIP-MT).

4.7.1.3 The main components of the BIP-M are:

- (a) Physical meteorology (atmospheric composition, radiation and optical phenomena, thermodynamics and cloud physics, boundary-layer meteorology and micrometeorology, in-situ observations and instrumentation, remote sensing);
- (b) Dynamic meteorology (atmospheric dynamics, numerical modelling);
- (c) Weather systems and services (conceptual models of synoptic, mesoscale and convective-scale phenomena and real-world scenarios, extreme or hazardous weather conditions; weather observation, analysis and diagnosis; weather forecasting, service delivery);
- (d) Climate science and services (conceptual models of the Earth–atmosphere system and the general circulation, climate variability, climate change impact, adaptation and mitigation).

4.7.1.4 The main components of the BIP-MT are:

- (a) Basic geography, oceanography and hydrology;
- (b) Basic physical and dynamic meteorology;
- (c) Basic synoptic and mesoscale meteorology;
- (d) Global and local climatology;
- (e) Cloud formation;
- (f) Meteorological parameters, instruments and methods of observation;
- (g) Basic climate-data QC.

4.7.1.5 There are several pathways by which meteorological training can lead someone to becoming a professional meteorologist. Each Member will have their own requirements for satisfying the overarching outcomes defined by the BIP-M. This pathway will often be satisfied through the successful completion of a university degree in meteorology or a postgraduate programme of study in meteorology. Where this is not the case, educational institutions need to demonstrate that their programme of study provides the equivalent learning outcomes. There are also many NMHSs that operate specialist training centres to provide training for BIP-M and BIP-MT for their country or region.

4.7.1.6 An emerging pathway to obtaining the necessary qualifications is through a blended course that takes advantage of a flexible mode of study that allows for a mixture of self-directed and instructor-led learning in a time and place that better suits the learner. This model can leverage the use of on-line technologies and a range of providers to meet the desired outcomes for the BIP-M and BIP-MT, as applicable.

4.7.1.7 The BIP-MT can be obtained by either a certificate or attestation of technical or vocational meteorological training supplemented by an extensive period of practice or by a post-secondary school level meteorological training certificate or diploma following the components of the BIP-MT. Members should decide whether their national circumstances require specific qualifications of aeronautical meteorological observers, such as successfully completing the BIP-MT.

4.7.2 **On-the-job training**

4.7.2.1 Upon completion of the BIP-M or BIP-MT, meteorologists and meteorological technicians will be introduced to their respective areas via on-the-job training and supervision. This will ensure that meteorological personnel are exposed to a variety of operational conditions using a range of different procedures. Mentors and supervisors should possess the appropriate technical and professional knowledge as well as good communication skills to ensure the successful transfer of skills and knowledge to the trainees.

4.7.2.2 The length of on-the-job training will depend on factors such as the trainee's competency, the complexity of the role and the level of responsibility required. Additional on-the-job training may be required for events or situations that happen infrequently.

4.7.3 **Career progression**

4.7.3.1 Upon completion of the BIP-M programme, and after developing specific job competencies, meteorologists will normally assume operational duties. Some meteorologists may become involved in areas such as research and development or teaching.

4.7.3.2 There are three generic career levels for meteorologists:

- Entry-level meteorologists, who carry out routine duties under supervision and in collaboration with others and where some individual autonomy is expected;
- Mid-level meteorologists, who carry out a broad range of activities to be performed in a wide variety of contexts, some of which are complex and non-routine. They require the capacity to apply knowledge and skills in an integrated way and to solve problems. Autonomy and responsibility, including for the management or guidance of others, may be expected;
- Senior-level meteorologists, who can apply a significant range of fundamental principles and complex techniques across a wide and often unpredictable variety of contexts. They have the capacity to transfer skills and knowledge and work autonomously. They often have significant responsibility for the work of others or for several teams.

4.7.3.3 Career levels for meteorological technicians after completion of the BIP-MT include:

- Entry-level meteorological technicians, who carry out routine and predictable duties to be performed under supervision and in collaboration with others;
- Mid-level meteorological technicians, who may also carry out non-routine activities involving a degree of autonomy. They may have responsibility for the guidance of others but generally work under the technical supervision of senior meteorological technicians or meteorologists;
- Senior-level meteorological technicians, who are competent in a wide range of complex technical and professional work activities, to be performed in a variety of contexts and with a substantial degree of responsibility, including responsibility for the work of others.

4.7.4 **Maintaining competence**

4.7.4.1 Operational aeronautical meteorological personnel, specifically comprising aeronautical meteorological observers and aeronautical meteorological forecasters, must maintain competency in their specific areas with ongoing job-specific education and training throughout their career. Competency is defined as the knowledge, skills and behaviours required to perform specific tasks in the fulfilment of a job responsibility. Further information on competency requirements and the competency framework can be found in the [Guide to Competency](#) (WMO-No. 1205) and the [Compendium of WMO Competency Frameworks](#) (WMO-No. 1209).

4.7.4.2 Evidence used to assess an individual against job competencies can be:

- Direct – that is, direct observation, oral questioning, demonstration of specific skills (such as case studies and mock briefings), video capture;
- Indirect – that is, assessment of qualities of a final product, review of previous work undertaken, written tests of background skills and knowledge, verification statistics;
- Third party – that is, testimonials from employers, peers or customers; reports from supervisors, work diary, logbook, self-assessment, examples of reports, work documents.

4.7.5 **Continuing education**

4.7.5.1 Meteorologists and meteorological technicians should undertake continuing education and training to update their professional and technical knowledge and skills, and to acquire additional competencies where necessary. This may take the form of coaching, self-study, online learning, secondment or temporary placement, additional on-the-job training and instructor-led refresher courses.

4.7.5.2 Annual or more frequent discussions should be held with managers to develop an individual development plan and to identify areas where further training would benefit both the organization and the individual.

4.7.5.3 Areas of personal and professional development could include presentation skills, team-building, stress management, time management, communication skills, client services, media training, information technology training, coaching and mentoring, risk management, QM, project management, staff selection, staff supervision and performance management, and higher university qualifications.

4.7.5.4 Records of all qualifications, competency, including competency assessment, and continuing education should be kept as part of the organization's QMS.

4.8 PLANNING

4.8.1 The importance of planning

4.8.1.1 Planning within an organization is extremely important and is undertaken as part of the requirements for a QMS. There are several types of planning that should be undertaken, including strategic, operational, contingency and project planning. Risk management and the development of fiscal plans (budgets) form part of these.

4.8.1.2 Good planning has many benefits, such as:

- Ensuring a clear sense of direction with clear goals and objectives to provide motivation and commitment;
- Allowing for changes in a proactive way rather than being reactive using risk management;
- Providing a strong foundation to overcome highs and lows in a changing environment;
- Engaging with users and stakeholders in a meaningful way;
- Setting realistic budgets and resource requirements;
- Providing guidance to decision makers;
- Fostering teamwork and joint projects;
- Improving the use of often limited resources and adapting the organization work programme to these resources;
- Ensuring procedures, processes and contingencies are tested and understood within the organization.

4.8.2 Strategic plan

4.8.2.1 A strategic plan articulates the high-level vision, mission, core values and overarching priorities of the organization. It also outlines what actions and resources are required to achieve these goals. It will typically cover three to ten years and be reviewed annually.

4.8.2.2 When developing a strategic or long-term plan for the provision of an aeronautical meteorological service, several other plans should be considered. These will include strategic plans from the parent organization or government department, the national air navigation plan (or equivalent), the ICAO Regional Air Navigation Plan (electronic form) and GANP, and WMO long-term plans.

4.8.2.3 A typical strategic plan will include:

- Vision and strategic position;
- Core values;
- Long-term goals;
- Prioritized strategic objectives;
- How success will be measured through key performance indicators;
- Timelines for delivering the strategy.

4.8.3 **Fiscal plan (budget)**

4.8.3.1 The fiscal plan or budget is an important part of the planning process. It identifies the expected costs of operating the aeronautical meteorological service and allows for the allocation of a budget to appropriate groups, which is critical for any cost recovery that may be applied to the service (refer to WMO-No. 904). It also provides a mechanism to continually track the financial situation, considering any national or international developments that may have an impact on the service requirements or the costs for provision of service.

4.8.4 **Operational plan**

4.8.4.1 The operational plan provides detail on how the strategic plan will be implemented. It will typically include:

- Success measurement, through the key performance indicators;
- Outputs and milestones, along with detailed timelines;
- Activities to be conducted to deliver the outputs;
- Resources required;
- Risks and mitigation strategies.

4.9 **INFRASTRUCTURE**

4.9.1 **Meteorological offices serving aviation**

4.9.1.1 A meteorological office serving the needs of aviation – for example, an aeronautical meteorological station or an aerodrome meteorological office – is usually operational for 24 hours a day, every day of the year. However, if the aerodrome itself is not operational for 24 hours – for example, there may be night-time curfews or weekend closures – then the operational hours of the meteorological office may necessarily reflect the limited hours of operation of the aerodrome. For the office and its associated infrastructure to provide the most effective and reliable service to aviation, certain technical and operational requirements must be met. It is highly desirable that these be considered during the planning stage and take into account any future requirements, whether the office is to be within, for example, the NMHS, at an aerodrome or co-located with aerodrome or airspace management.

4.9.2 **Aeronautical meteorological station**

4.9.2.1 Where human observations are required at an aerodrome, the office must be located to provide an unobstructed view of the weather conditions over the aerodrome and its surrounds, be free from interference by aerodrome lighting during darkness and have easy access to the meteorological instrument installations. At large aerodromes it can be difficult to find a suitable site for the human observer. For example, if stationed at ground level, buildings may obstruct the observer's view. If positioned in a tall building, observations of visibility under certain conditions will not be representative of those at ground level. The installation of live-feed video cameras (or webcams) and automated instrumentation, such as additional visibility and cloud sensors, can help resolve this problem. Ultimately, the choice of office position may have to be a compromise. Solutions for gaining an unobstructed view of the runway complex could be the provision of access to the roof of the building, an upper-floor balcony or an observation tower, or co-location within the ATC tower.

4.9.2.2 Displays indicating the automated observed meteorological parameters at the aerodrome should be easily visible to the observer and should be placed to allow for easy

continuous viewing with minimum movement. Appropriate desk and storage space, taking into account workplace health and safety protocols, should be provided for necessary computer equipment, forms, instructions, procedures and short-term archiving.

4.9.2.3 The office should be equipped with the necessary secure communication facilities required for the dissemination of the observations and reports, both locally and beyond the aerodrome. The internal lighting should allow for subdued lighting at night to enable the observer to adjust quickly to outside conditions.

4.9.2.4 Back-up power and communications should be implemented to ensure uninterrupted provision of information to both the meteorologist(s) and aviation users.

4.9.3 **Aerodrome meteorological office**

4.9.3.1 In planning an aerodrome meteorological office that provides forecast and warning services to aviation, it is essential to strive for an environment where there is no unnecessary interference and where the duty meteorologist is protected from frequent interruptions, for example telephone calls or visits by non-meteorological personnel.

4.9.3.2 Workplace health and safety protocols should be considered when designing an office, particularly workstation ergonomics. Monitors displaying the required meteorological parameters, such as radar and satellite images, automated weather observation data and NWP model outputs should be easily accessible to the meteorologists.

4.9.3.3 Relevant documentation on office procedures, customer contact lists, WMO and ICAO Manuals and technical guidance, and the QMS documentation related to their duties should be readily to hand. There should be easy access, via appropriate in-person, video- or telecommunications to observing staff, other aerodrome meteorological offices, ATS and airline operational personnel.

4.9.3.4 Aerodrome meteorological offices are dependent on secure communication networks and message-handling systems, not only for the exchange of large amounts of data, but also to supply ATC, AIS, airline and briefing services. Adequate, stable power supply is required, including an uninterruptible power supply.

5. OBSERVATIONS

5.1 AERODROME OBSERVATIONS

5.1.1 Overview

5.1.1.1 Meteorological observations at aerodromes are made by specialist meteorological sensors, often supplemented by visual assessment of the overall conditions by humans as part of the observing system. Meteorological observations are used by meteorologists for input into the forecast and warning process, and by aviation users for management of activities at the aerodrome itself, for aircraft in the terminal area and en-route airspace, and for overall flight performance. Meteorological conditions at an aerodrome must be monitored closely and continuously leading up to and during all periods of operational activity at the aerodrome.

5.1.1.2 While ICAO SARPs must be considered when choosing a meteorological observing system, no specific system is recommended or prescribed for use by WMO. The cost of the installation and ongoing maintenance of meteorological observing systems (sometimes also referred to as weather observation systems) compared with the measurable benefits likely to be derived (cost–benefit ratio), along with any future expansion of the aerodrome, should be considered when establishing the system. The known and expected levels of aviation activity and the complexity of the aerodrome (for example, the number, configuration and aerial extent of runways and taxiways as well as terminal buildings and other infrastructure), and its climatology and terrain should also be significant factors in assessing the overall cost–benefit ratio.

5.1.1.3 Detailed information on instrumentation, systems and practices for surface observations are given in the [Guide to Instruments and Methods of Observation](#) (WMO-No. 8), Volumes I, II and III; the [Guide to the Global Observing System](#) (WMO-No. 488) and the [Manual on Automatic Meteorological Observing Systems at Aerodromes](#) (ICAO Doc 9837).

5.1.1.4 ICAO Annex 3 provides details on the reporting requirements regarding meteorological observations at the aerodrome, both for take-off and landing operations and for flight-planning purposes.

5.1.2 Surface wind

5.1.2.1 The effect of surface wind on take-off and landing performance as well as loading and unloading of cargo and passengers varies with different aircraft types. Headwinds will allow a greater weight to be lifted on take-off and a lower ground speed at touchdown, thus a shorter runway length is needed. In contrast, a tailwind results in a reduction of the maximum permissible take-off weight and a longer runway length is required for both take-off and landing. Crosswinds add additional complexity to both take-off and landing. Aircraft are subject to tailwind and crosswind limits for landing and take-off that will vary depending on the aircraft type and runway state (for example, wet, dry, ice or snow covered).

5.1.2.2 A gusty wind is characterized by rapid fluctuations in wind speed. At aerodromes, gustiness is specified by the extreme values of wind speed between which the wind has varied during the last 10 minutes. A variable wind is characterized by large variations in the mean directional flow. Over land, wind gusts are typically 30%–40% greater than the mean wind speed; however, wind gusts can be much higher for low mean wind speeds and in the vicinity of convection and frontal systems. At coastal aerodromes and those built on land reclaimed from the sea, mean wind speed (and gusts) tend to be higher in comparison with an equivalent synoptic situation over land. These differences arise due to differences in the frictional effect the sea and land surfaces have on low-level airflow.

5.1.2.3 For aeronautical meteorological purposes, wind direction relates to that from which the wind is blowing (in degrees true), reported using three figures rounded to the

nearest 10 degrees (for example, 180 is a southerly wind). The output of NWP models will be given in degrees true (oriented to true north). Meanwhile, ATS units will use and display wind direction information in degrees magnetic. Wind speed is generally reported in knots or metres per second. Instantaneous, 2-minute and 10-minute averaging periods, along with gusts and variability data, provided to the ATS unit should be made available for operational and flight-planning requirements.

5.1.2.5 The wind sensor, or anemometer, is often part of an integrated instrument system. Depending on the operational requirement, the complexity of the aerodrome and the terrain, several anemometers (sometimes configured as a multisensor array) may be used at the aerodrome or its surrounds.

5.1.2.6 Close to the surface, except near complex terrain, any changes of wind direction with height are generally small (a few tens of degrees typically). However, wind speed can vary considerably through the first few tens of metres above the ground due to frictional effects. For this reason, the vertical placement of a wind sensor should be 10 metres above the runway and over open terrain (defined as an area where the distance between the anemometer and any obstruction is at least 10 times the height of the obstruction). At times, it may be difficult to find suitable open terrain. In such cases, it may be necessary to locate a frangible and illuminated mast within the obstacle clearance area with the permission of the responsible aviation authority and the aerodrome owner. It should also be noted that anemometers located too close to runways and taxiways can be affected by aircraft engine exhaust and thereby give a false indication of a gust.

5.1.3 **Visibility**

5.1.3.1 Reduced visibility at the aerodrome will often hamper operations by restricting surface movement and, in the extreme, may prevent landing and take-off. Low visibility may reduce the acceptance capacity at the aerodromes due to increased separation requirements between take-off and landing aircraft as well as those taxiing to or from the runway. Reduced visibility is always a limiting factor for flights conducted under visual meteorological conditions since a pilot must maintain visual reference to the ground and to the horizon. Low visibility can be caused by fog, stratus cloud, haze and smoke, volcanic ash, blowing dust, sand and snow, hail, drizzle and rain.

5.1.3.2 Visibility is a complex psychophysical phenomenon, intimately tied to the factors involved in human sight. Its estimation is subject to variations in individual perceptible and interpretative ability, as well as to the light source characteristics and transmission factors. Thus, any human estimate of visibility is subjective. While human observations of visibility in daylight are generally of good quality, those at night are more difficult to define and control as they are strongly dependent upon the selection of lighted visibility markers (where they exist) and background luminance.

5.1.3.3 Visibility, including significant directional variations, can be determined by a human observer viewing selected objects of specified characteristics at known distances from the meteorological station. Visibility sensors, both transmissometers and forward-scatter meters, provide a snapshot of the visibility over a relatively small area, hence the installation of a multisensor array should be considered when fully automated reports are generated. When the sky is obscured, vertical visibility shall be observed and reported, where measured, in lieu of cloud amount, cloud type and height of cloud base.

5.1.3.4 Runway visual range (RVR) is defined as the range over which the pilot of an aircraft on the centre line of a runway can see the runway surface markings or the lights delineating the runway or identifying its centre line. RVR is typically measured using transmissometers or an array of forward-scatter meters. RVR assessments refer to the touchdown zone, midpoint and stop-end of the runway, depending on the category of landings. Definitions of landing categories can be found in ICAO Annex 14, Aerodromes, Volume I – *Aerodrome Design and Operations*. The exact position(s) of the site and, if necessary, additional sites for the sensors to

achieve the best possible assessments of the RVR depend on aeronautical, meteorological and climatological factors such as runway length and fog-prone areas. Further information on RVR is given in the *Manual of Runway Visual Range Observing and Reporting Practices* (ICAO Doc 9328).

5.1.4 **Present weather**

5.1.4.1 Observed present-weather phenomena of significance to aviation are reported in terms of onset, cessation, location, type and characteristics. They are qualified with respect to intensity or proximity to the aerodrome. The following present weather shall be identified, as a minimum: rain, drizzle, snow and freezing precipitation (including intensity), haze, mist, fog, freezing fog and thunderstorms (including thunderstorms in the vicinity). Other present weather phenomena include dust, sand, smoke, volcanic ash, hail, squalls and funnel cloud.

5.1.4.2 Automated systems are not currently capable of reporting all types of present weather phenomena that are of significance to aviation, so human observers often supplement automated observations for reporting the visual elements (cloud, visibility and present weather).

5.1.4.3 Information on certain weather phenomena (for example, thunderstorms) can be obtained using algorithms derived from remote-sensing techniques and instrumentation such as lightning detection equipment, radar and satellites, from observations made by ATS and competent aerodrome services personnel, or from departing and arriving aircraft.

5.1.4.4 Present weather information should be representative of conditions at the aerodrome and its immediate vicinity. Present weather sensors should be sited close to the runway strip and, where viable, in the final approach areas. Human observers at an aerodrome should be located, in so far as is practicable, so as to supply data that are representative of the area for which the observations are required.

5.1.4.5 ICAO Annex 3 lists the present weather phenomena and their characteristics as well as the terminology and abbreviations to be used. WMO-No. 8, Volume I provides information on both manual and automated measurement of present weather and the benefits and limitations of each.

5.1.5 **Cloud**

5.1.5.1 Cloud observations are made for two main purposes: for take-off and landing operations where observations are to be representative of the approach area; for use in flight-planning and in-flight information and the preparation of aeronautical meteorological products and services where observations should be representative of the aerodrome and its vicinity. Cloud observing techniques used for these two purposes are similar.

5.1.5.2 The presence of low cloud can restrict the usable airspace where visual navigation with reference to the ground may be required. This is particularly important in the case of general aviation where the flight is to be conducted under visual flight rules. For more sophisticated aircraft, low cloud is most significant in the landing phase, when the height of the cloud base can determine the category of landing. When cumulonimbus cloud is present, there is always the possibility of convective turbulence, icing, wind shear, hail and lightning.

5.1.5.3 Cloud observations consist of observations of the physical characteristics of clouds, including their vertical and horizontal extent, structure and form, their height above ground or sea surface (measured in metres or feet), and their direction of motion and speed.

5.1.5.4 Cloud amount is expressed as "FEW" (few, 1 or 2 eighths, or oktas, of cloud); "SCT" (scattered, 3 or 4 oktas); "BKN" (broken, 5 to 7 oktas) or "OVC" (overcast, 8 oktas). Cloud type is reported at the aerodrome only if towering cumulus or cumulonimbus is present. The height of the cloud base above aerodrome elevation is also reported. If there are no clouds or weather of operational significance and the visibility is 10 km or more, the abbreviation "CAVOK" is used (a contraction of "the cloud and visibility are okay"). Where CAVOK is not appropriate, the

abbreviation “NSC” (nil significant cloud) is used. When the sky is obscured, vertical visibility shall be observed and reported, where measured, in lieu of cloud amount, cloud type and height of cloud base.

5.1.5.5 The use of on-site instrumentation (ceilometers) provides measurements of cloud base height and often cloud amount. Although ceilometers can estimate cloud base to a greater degree of accuracy than a human, they are presently unable to accurately reconcile cloud types. Consequently, human observers or remote-sensing systems (including webcams) are normally needed to verify and supplement the ceilometer output as necessary. Ceilometers have only a limited field of view and so cloud heights will be accurate near the ceilometer and the cloud amount is produced by an algorithm over a period of time.

5.1.6 Temperature

5.1.6.1 Air temperature is important in relation to aircraft performance because air density depends on temperature. Higher temperatures cause a decrease in air density, which reduces lift, and thus reduces the maximum permissible take-off weight. It also impairs engine performance, where both high and very low temperatures make limitations necessary on take-off power.

5.1.6.2 The dew-point temperature is the temperature at which moist air, saturated with respect to water at a given pressure, has a saturation mixing ratio equal to the given mixing ratio, or more simply, the temperature at which moist air is saturated with water vapour. Relative humidity is the ratio (as a percentage) of the observed vapour pressure to the saturation vapour pressure with respect to water at the same temperature and pressure. Dew-point temperature can be derived from the measurement of relative humidity. Air temperature is measured using a thermometer, while dew-point and humidity are derived using a hygrometer.

5.1.6.3 Aviation is interested primarily in the temperature at engine intake levels above the runway, however it is impossible to make regular temperature observations at such locations. Therefore, observations of air temperature and relative humidity are made at a height of 1.25–2.00 metres above ground level away from areas where jet blasts are likely, and from buildings or concrete, which may radiate heat. Temperature should be observed and reported in degrees Celsius. The operationally desirable accuracy of temperature measurements is 1 °C; however, more accurate measurement of temperature is often needed to observe and forecast phenomena such as fog.

5.1.6.4 A radiation shield or louvered screen should be used to protect the thermometers from radiant heat, precipitation and other phenomena that might influence the temperature measurements. The radiation shield used may be ventilated to ensure sufficient airflow around the instruments. *Guide to Instruments and Methods of Observation* (WMO-No. 8), Volume I, provides detail on how these should be designed to ensure that the temperature is uniform with the outside air.

5.1.7 Atmospheric pressure

5.1.7.1 Pressure, expressed in hectopascals (hPa), affects the air density, where the lower the surface pressure the lower the air density and the poorer the lift and engine performance is. This factor is especially important at high-altitude aerodromes. Pressure measurements are also essential for setting aircraft altimeters. Pressure is computed in tenths of hectopascals (0.1 hPa) and for aviation purposes is referred to in the Q code as QFE and QNH, where:

- QFE is the altimeter pressure setting indicating the height above the airfield or runway threshold;
- QNH is the pressure value at which an aircraft altimeter is set so that it will indicate the official elevation of the aerodrome when the aircraft is on the ground at that location. QNH is calculated using the value for QFE and the pressure altitude relationship of the ICAO standard atmosphere.

5.1.7.2 Atmospheric pressure must be measured by a suitably exposed barometer and all possible efforts should be made to eliminate errors in the altimeter settings caused by shortcomings in the measuring system or in the processing and distribution procedures. Ground stations should be equipped with multiple well-calibrated barometers traceable to a standard reference, ensuring sufficient redundancy in the event of a failure of the primary pressure sensor. A regular schedule should be maintained for comparing the instruments against this standard instrument. When the sensor is sited indoors, it should be vented to the outside.

5.1.8 **Supplementary information**

5.1.8.1 The importance of the provision of supplementary information on significant meteorological conditions at aerodromes, particularly those in the approach and climb-out areas, cannot be highlighted enough. Supplementary information for aerodrome reports may include recent weather, turbulence, wind shear, sea-surface temperature, sea state and significant wave height. In local reports the following phenomena are reported in the supplementary section: cumulonimbus clouds, thunderstorms, hail, moderate or severe icing and/or turbulence, wind shear, severe squall line and/or mountain waves, freezing precipitation, dust storms, sandstorms, blowing snow and funnel cloud (tornado or waterspout).

5.1.9 **Automated observing systems**

5.1.9.1 Surface observations at many aerodromes are fully automated, with some stations providing manual input from qualified observing personnel (including ATS personnel where there is no on-site meteorological observer). Meteorological information from these systems is automatically collected, checked, coded, displayed and transmitted with continuous monitoring of the measurable elements. The increase in automation has relieved the human observer of many time-consuming observational duties but has increased the responsibility of monitoring the performance of the automatic system. Observational meteorological data from the aerodrome is sent to the aeronautical meteorological service provider, with an agreed subset provided to the local ATS units.

5.1.9.2 More complex automated systems can also use multiple sensors for elements such as visibility, clouds and present weather and may have algorithms that can integrate information from weather radar and lightning detection networks. However, they are limited by the spatial coverage of the sensors and the capability to resolve present weather types, and it is for these reasons that observations for visibility, cloud and present weather may be required to be validated by qualified meteorological personnel before being issued.

5.1.9.3 All instrumentation at an aerodrome must be sited at locations that do not infringe on the obstacle limitation surfaces for that aerodrome. Future requirements as well as existing limitation surfaces (for example, for planned additional runways and taxiways) should be considered when siting instruments. However, a new obstacle located in the vicinity of an existing obstacle may be allowable if it fits the regulatory authority's shielding criteria. Consideration also needs to be given to the requirements for the frangibility of equipment and their supports, particularly masts, to ensure that they will break, distort or yield under impact. More information on obstacle clearance rules is given in ICAO Annex 14, and in the *Airport Services Manual* (ICAO Doc 9137), Part 6 – *Control of Obstacles*, and on *frangibility requirements in the Aerodrome Design Manual* (ICAO Doc 9157), Part 6 – *Frangibility*.

5.2 **AIRCRAFT-BASED OBSERVATIONS**

5.2.1 **Aircraft Meteorological Data Relay**

5.2.1.1 Modern commercial aircraft are equipped with meteorological sensors and associated sophisticated data acquisition and processing systems. These provide input in real time to the aircraft flight management, control and navigation systems and other on-board

systems such as the environmental control system. Data are also recorded in the flight data recorder for off-line (post-flight) analysis and accident and incident investigations. The aircraft computers may be programmed to make meteorological observations at predetermined times or positions for automatic relay to the ground. This is usually accomplished through the Aircraft Communication Addressing and Reporting System and can provide worldwide data using either very high-frequency (VHF) or satellite radio links. These links are two-way, so it is possible to modify the reporting program in flight by uplink command. Ground processing and dissemination of data are accomplished through systems provided by the appropriate air carrier, communications service provider and meteorological message processing centres.

5.2.1.2 Meteorological observations derived from on-board aircraft sensors supplement the data gathered by other traditional, ground-based meteorological systems and help to improve the accuracy of forecasts. The WMO has established the aircraft meteorological data relay (AMDAR) program to ensure that the data collected by commercial aircraft can be widely made available to meteorological service providers, the airline industry, researchers and other users of meteorological information. Further information on AMDAR can be found in the [Aircraft Meteorological Data Relay \(AMDAR\) Reference Manual](#) (WMO-No. 958) and [WIGOS – WMO Integrated Global Observing System – The Benefits of Aircraft-based Observations and AMDAR to Meteorology and Aviation](#) (WMO Technical Report No. 2021-1).

5.2.1.3 AMDAR collects and distributes the following meteorological data:

- High-resolution vertical profiles of air temperature, wind speed and direction at aerodromes;
- Regular reports of meteorological variables from aircraft en route at cruise level and during descending and climbing phases;
- Accurate measurements of coordinates (time, latitude, longitude and pressure altitude);
- Derived turbulence, that is, derived equivalent vertical gust and/or eddy dissipation rate;
- Water vapour or humidity data (from suitably equipped aircraft).

5.2.2 Air-reports

5.2.2.1 Weather reports from aircraft are an important additional source of upper-air data. Aircraft observations and subsequent AIREPs give information on atmospheric conditions at aircraft altitudes that may be significant for aircraft in flight and are particularly valuable in areas where other observations are sparse or not available. ARS may trigger the issuance of an advisory or warning, or validate one that is already in force. AIREPs are also a vital component of the basic data used in the NWP models. AIREPs are perishable products so must be transmitted to potential users immediately upon receipt.

5.2.2.2 Aircraft observations are reported using either air-ground data link or voice communication. Details of the requirements and procedures for both routine AIREPs and ARS are given in ICAO Annex 3, the *Manual of Aeronautical Meteorological Practice* (ICAO Doc 8896) and *PANS-ATM* (ICAO Doc 4444).

5.2.2.3 Special observations are required to be made by all aircraft operating on international air routes whenever any of the following conditions are encountered or observed:

- Moderate or severe turbulence;
- Moderate or severe icing;
- Severe mountain waves;
- Obscured, embedded or widespread thunderstorms or those within squall lines;

- Heavy dust storms or sandstorms;
- Volcanic ash cloud, pre-eruption volcanic activity or volcanic eruption.

5.2.2.4 Other non-routine aircraft observations can also be made at the pilots' discretion and may include conditions such as wind shear and space weather effects, which could affect the safety or markedly affect the efficiency of other aircraft operations.

5.2.2.5 Studies show that aircraft observations play an important part in the meteorological analysis process. In regions and at levels where aircraft reports constitute a large proportion of the available data, their effect on the analysis is significant. It is also known that aircraft reports also result in a noticeable improvement in meteorological analysis and forecasting.

5.2.2.6 In that they help to manage the risk associated with volcanic ash and other hazards such as sulphur dioxide, ARS are an integral part of the IAVW. The document *Flight Safety and Volcanic Ash* (ICAO Doc 9974) provides guidance on how to manage these risks and highlights the importance of the timely issuance of AIREPs.

5.3 REMOTE-SENSING

5.3.1 Overview

5.3.1.1 Remote-sensing systems, including polar-orbiting and geostationary satellites, are used to observe weather phenomena that are of special interest to aviation operations (for example, mesoscale and synoptic-scale weather systems, lightning, and the like) and where, in many cases, more data are required than can be provided by the standard surface observations. These systems provide data for large areas in four dimensions and are extensively used for en-route meteorological information; they are important tools for ensuring safe and efficient operations to and from the aerodrome.

5.3.1.2 Detailed information on space-based and remote-sensing observing systems are given in the *Guide to Instruments and Methods of Observation* (WMO-No. 8), Volume III and Volume IV.

5.3.2 Satellite

5.3.2.1 For monitoring the displacement and development of frontal systems, upper-level winds, cloud clusters, large areas of fog, volcanic ash cloud and widespread sand or dust storms, satellite data has become indispensable. There are two main types of meteorological satellite:

- Polar-orbiting satellites that orbit the Earth approximately every 100 minutes. They are overhead at the same point on the Earth's surface only twice a day but provide cover of equatorial and polar regions with similar resolution. The height of the orbit is typically around 800 km.
- Geostationary satellites that are positioned over a fixed point directly above the Earth's equator and supply frequent images (some as frequent as 5-minute intervals or less) but have the drawback of giving a distorted view over high temperate and polar regions. The height of the orbit is approximately 36 000 km.

5.3.2.2 Meteorological satellites primarily provide images of cloud distribution in the visible light (0.4–1.1 μm) and infrared light (10.5–12.5 μm) ranges. Images in the visible channel provide information about the distribution and type of water droplet clouds, mainly at lower levels, during daylight hours. Data on the infrared channel may be interpreted as temperatures throughout the day and night. The brightest images are given by the coldest, ice-crystal clouds. A combination of the two types of imagery can help to provide a three-dimensional concept of the cloud distribution. Data on the infrared channel regarding cloud-top temperatures may

be compared with known, standard or computer model atmospheric temperatures, so that cloud-top heights may be deduced. Other channels available from geostationary satellites often include water vapour concentration in the atmosphere. The sub-satellite point resolution for geostationary satellites is of the order of 1–2 km for visible images and 4 km for infrared and water vapour, while for polar orbiting satellites it may be less than 1 km.

5.3.2.3 Central processing of satellite data can provide further information on vertical temperature profiles, humidity, sea-surface temperatures and upper winds (derived from cloud movement). Further information can be found in the *Guide to Instruments and Methods of Observation* (WMO-No. 8), Volume IV.

5.3.3 Weather radar

5.3.3.1 An important tool for the detection of meteorological phenomena of interest to aviation are weather radars (refer to *Guide to Instruments and Methods of Observation* (WMO-No. 8), Volume III), which can provide near-continuous information in real time. Weather radars are particularly valuable in areas where thunderstorms occur frequently but are also useful in the detection of other meteorological phenomena.

5.3.3.2 The optimum radar wavelength used depends on the type of precipitation, its intensity, the average drop size to be detected and the range to be covered. S-band radar (~10 cm wavelength) allows a minimum of attenuation in heavy precipitation. This is useful in tropical regions, where the tops of cumulonimbus clouds are high enough to be detected even at several hundred kilometres, despite radar beam divergence and the Earth's curvature. Where the range to be covered is smaller or where the intention is to also detect other types of precipitation, such as drizzle, an X-band radar (~3 cm wavelength) may be preferable. However, a C-band radar (~5 cm wavelength) has proved to be a good compromise.

5.3.3.3 The most common form of weather radar display is the plan position indicator, showing a horizontal 360° cross section of radar echoes in the constant plane. As the radar will usually be set up to conduct a series of scans at different elevation angles, the production of a constant-altitude plan position indicator display, combining information from different elevation angles for approximately the same height above the ground, can be obtained.

5.3.3.4 Doppler radars can provide estimates of the speed of the precipitation in the direction towards or away from the radars, based on the phase shift of the return signal. Suitable processing and display of Doppler velocities can help to detect wind shear, shear lines and other severe phenomena such as downbursts and funnel clouds (tornadoes or waterspouts).

5.3.3.5 Dual polarization radars apply both horizontal and vertical polarization. This allows them to provide information on the size, shape, distribution and type of the targets. Additional benefits include:

- Improved precipitation estimates;
- Identification of sea and ground clutter, birds, large insect colonies, anomalous propagation and debris;
- Detection of heavy rain, snow, hail and sleet information in three-dimensions;
- Detection of aircraft icing conditions;
- Identification of the melting layer;
- Updraft detection;
- Better correction for attenuation in heavy precipitation.

5.3.4 **Lightning detection systems**

5.3.4.1 In areas where there are a significant number of thunderstorms or in mountainous terrain where the effectiveness of weather radars is much reduced, consideration should be given to the use of a ground-based lightning detection system (refer to *Guide to Instruments and Methods of Observation* (WMO-No. 8), Volume III). These systems have been demonstrated to detect thunderstorm activity before detection by weather radar. The presence of lightning is a definite indication of a thunderstorm and the rate of lightning from a thunderstorm is a good indication of its severity.

5.3.4.2 Lightning detection systems rely on the fact that a lightning stroke produces a strong radio wave that travels in all directions from the location of the stroke. A detection system measures the time taken for the signal to arrive and/or the direction from which it comes. Systems analyse the characteristics of each radio impulse to identify cloud-to-cloud and cloud-to-ground lightning strokes and estimate the current amplitude of the stroke. The installation of a network with multiple sensors will provide greater accuracy on the location of the stroke through the use of triangulation techniques.

5.3.4.3 Lightning is recognized as a considerable occupational health and safety risk for aerodrome ground staff. Special ground procedures for activities such as refuelling and the use of air bridges, including temporary suspension of these operations, will often be activated when a lightning risk is present, so the early detection of lightning can provide early warning of this hazard. Thunderstorms are also a hazard to aircraft during all phases of flight and the use of national or global lightning detection networks can assist in the provision of timely en-route warnings.

5.3.5 **Atmospheric profiles**

5.3.5.1 Accurate measurements of the vertical structure of the boundary layer and troposphere are extremely important for all types of weather forecasting. Upper-air measurements are extensively used in the initialization of the analyses of NWP models. For instance, the vertical structure of temperature and water vapour determines the stability of the atmosphere and, subsequently, the amount and type of cloud.

5.3.5.2 There are several profiling techniques and systems that can be used to obtain meteorological information in the boundary layer, troposphere and beyond. These are detailed in the *Guide to Instruments and Methods of Observation* (WMO-No. 8), Volume III and include remote-sensing techniques such as microwave radiometers, acoustic sounders (sound detection and ranging), wind profiler radars, radio acoustic sounding systems, laser radars (light detection and ranging (LIDAR)) and GNSS, as well as in-situ instruments such as radiosondes and aircraft-based observations.

5.3.5.3 Radiosonde observations are measurements of upper-air meteorological variables, such as pressure, temperature, humidity and wind. Radiosonde sensing equipment is normally attached to a hydrogen- or helium-filled meteorological balloon but can also be attached to a slow-moving uncrewed aircraft or can be dropped from an aircraft or rocket (dropsonde). A radio transmitter attached to the sensing equipment will send this information back to the ground-based observing station. Radiosondes drift with the prevailing winds to heights in excess of the cruise altitude of commercial aircraft, and while they are able to provide high-resolution information for the extent of the flight, they are usually only deployed on a daily basis from select ground stations.

5.4 HAZARDOUS PHENOMENA

5.4.1 Wind shear detection systems

5.4.1.1 Low-level wind shear (see definition, 6.1.2.2), particularly when associated with microbursts and downbursts from cumulonimbus clouds, can be a serious hazard to aviation operations. Many fatal accidents have been attributed to this phenomenon due to the sudden, usually unexpected onset of strong and gusty winds of varying direction near to the ground (approximately lowest few thousand feet) and the reduced separation between the aircraft and the terrain. Information on low-level wind shear and its detection systems is given in the Manual on Low-level Wind Shear and Turbulence (ICAO Doc 9817).

5.4.1.2 If warranted by the climatology of the aerodrome, consideration should be given to installation of a wind shear detection system to provide users with automated wind shear alerts. Systems used to detect wind shear, either used individually or as part of an integrated system, include:

- Low-level wind shear alert systems;
- Doppler radars;
- Sound detection and ranging;
- LIDAR.

Given that this information is useful to pilots at a time of high workload on the flight deck during the approach or take-off phases, the means of transmission to the pilot must be given consideration.

5.4.2 Volcanic ash detection

5.4.2.1 The detection of volcanic ash can be achieved via ground-based, airborne or satellite observations. Visual observations of volcanic ash cloud from the ground are often provided from a volcano observatory where the observer has good knowledge of the phenomenon. During an eruption, observations of the ash column and ash cloud are made. Once the volcanic ash cloud spreads, more reliance is placed upon satellite and in-situ airborne methods. Radars with an optimal wavelength between 3 mm and 3 cm (K band) can also be used to detect volcanic ash and to estimate the height of the ash column. Doppler and dual-polarization radars can provide information on particle size, shape and velocity.

5.4.2.2 Satellites with advanced very high-resolution radiometers are used to observe and monitor volcanic activity as the emission characteristics are different (largely silicates) compared to water or ice clouds. Other satellite sensors, such as multi-spectral vertical-sounding radiometers can assist in detecting volcanic ash by providing information on the likely altitude of the ash cloud and the temperature and humidity of the surrounding atmosphere. Detection of sulphur dioxide can also assist in identifying and tracking volcanic ash clouds.

5.4.2.3 LIDAR can be used to detect volcanic ash concentration and assist in distinguishing between ash clouds and aerosols. The use of LIDAR in the observation network is useful in validating other observations, such as those obtained from satellites. Sun photometers, which measure direct solar radiation, are another useful instrument that can assist with observing the presence of volcanic ash and associated aerosols.

5.4.2.4 Pilots are often the first to observe and report volcanic activity and should report any instances via an ARS. Flight crew should be trained to observe and report volcanic activity and have procedures on how to deal with volcanic ash encounters (refer to ICAO Doc 9766). Indicators of volcanic activity include: smoky or acrid odour that can smell like electrical smoke,

burnt dust or sulphur; haze developing within the aircraft; engine surging; torching from the tailpipe and flameouts; decreasing or erratic aircraft speed; cabin pressure changes; static discharges from the aircraft exterior.

5.4.2.5 Any occurrence of pre-eruption volcanic activity, volcanic eruptions and volcanic ash cloud should be reported without delay. Information in the report should contain the location where the report is being made, the volcano name and location and a concise description of the event, including the level of intensity of volcanic activity, occurrence of an eruption and its date and time, and the existence of a volcanic ash cloud in the area together with direction of ash cloud movement and height.

5.4.3 **Space weather observations**

5.4.3.1 To provide the space weather services required by ICAO Annex 3, observations are needed to monitor space weather conditions all the way from the Sun to the Earth in a timely manner and with high accuracy. This is not always possible due to the spatial extent of the domain, the wide variety of physical processes governing the space weather, and limited observing capabilities. Space weather services currently rely on both operational and research observing assets, both ground based and space borne.

5.4.3.2 The Sun is the primary origin of space weather events, and thus, solar observations are an essential data source for most operational space weather services. Observations of the Sun generally comprise multi-spectral images and magnetograms of the solar disk, images of the corona and heliosphere, as well as the disk-integrated flux observed at specific wavelengths, integrated over broad wavelength bands or over the full solar spectrum. In-situ observations are also made of the solar wind nearer to Earth. Solar observations are primarily made by satellites, either Earth orbiting or located at the L1 Lagrange point; however, the ground-based solar observation network remains an important contingency for satellite outages or unavailability.

5.4.3.3 Energetic particles in the Sun–Earth environment are highly variable both spatially and temporally, and can significantly impact the lifetime and performance of satellites. Observations of energetic particles are available from both operational and scientific research satellites, while ground-based observations are used to monitor high-energy particles arising from eruptive solar storms.

5.4.3.4 The ionosphere is the electrically ionized part of the upper atmosphere at 50 to 1 000 km altitude. The properties of the ionosphere are controlled by fluctuations in solar radiation, the interaction of the solar wind with the Earth's magnetic field and by dynamic processes in the thermosphere and the lower atmosphere. The ionosphere can therefore vary appreciably from day to day, hour to hour, and with latitude. Variations in density of the ionosphere can impact the performance of high-frequency (HF) radio communications technologies, GNSS positioning and timing, as well as satellite communications. The key observational variable is electron density, which is typically monitored remotely using ionospheric sounding techniques from ground-based instrumentation such as HF radio sounders (ionosondes), ground-based GPS units and to some degree by low-Earth-orbit satellites using GPS radio occultation techniques.

5.4.3.5 The geomagnetic field at the surface of the Earth is a combination of the Earth's internal magnetic field and perturbations caused by different external sources such as space weather. Perturbations to the geomagnetic field are monitored by networks of ground-based magnetometers, supporting services to mitigate space weather effects on critical ground-based infrastructures such as power networks and pipelines, and for monitoring errors in applications relevant to oil, gas and mineral exploration.

5.4.4 **Tsunami detection**

5.4.4.1 Tsunamis are measured or observed by a variety of means. Tide gauges measure the height of the sea surface. Satellite altimeters measure the height of the ocean surface using

electromagnetic pulses. Deep-ocean assessment and reporting of tsunami (DART) stations, originally developed by the National Oceanic and Atmospheric Administration, consist of an anchored sea floor bottom pressure recorder that transmits temperature and pressure data to a surface buoy via acoustic telemetry. Two-way satellite communication between the DART system and the Tsunami Warning Centres ensures that the data is received without delay and enables the centres to change the data frequency and troubleshoot the system in real time.

5.5 MAINTENANCE AND CALIBRATION

5.5.1 Maintenance

5.5.1.1 The cost of ongoing maintenance of meteorological observing systems can greatly exceed their initial cost of purchase. It is important, therefore, that these systems have the greatest possible reliability and maintainability. Corrective maintenance is required for component failures in both hardware and software. To minimize corrective maintenance and to increase the performance, well-organized preventive maintenance, including services and instrument calibration, is required. Adaptive maintenance is required to take into account the rapid changes in technology and the availability of spare parts after a few years of operation.

5.5.1.2 Maintenance in the field should be conducted by qualified and competent technical personnel. Simple preventive maintenance and cleaning can be done by a local observer or other suitably trained personnel (when available). The regular transmission of self-checking diagnostic information is desirable to ensure rapid response to failures.

5.5.1.3 Regional maintenance centres have specialist technical personnel to replace or repair modules and instruments. They are equipped with appropriate test equipment and sufficient spare parts, modules and instruments to support the maintenance of the stations in their area. Technicians should routinely visit observation sites to check the observing systems and their environment for operational problems, vandalism, site conditions and other changes.

5.5.1.4 National maintenance centres require more highly skilled technical personnel capable of detecting and eliminating complex problems in instruments, modules and data-transmission. Any recurring defects should be referred to designers or suppliers. They should be able to execute all tasks associated with adaptive maintenance.

5.5.1.5 Some small or developing countries could consider establishing joint maintenance arrangements with neighbouring countries to keep maintenance costs reasonably low.

5.5.2 Service levels

5.5.2.1 A service-level agreement for maintenance should define the maximum delay to diagnose a problem and a maximum delay to fix it. They should consider the users' needs, the maintenance organization, distances between the maintenance centres and the observing stations, difficulties with transport arrangements and the cost of spare parts and stock. Different service levels may be defined for different stations.

5.5.2.2 Effective liaison procedures between the monitoring service and the appropriate maintenance and calibration service to facilitate rapid response to reports of fault or failure from the monitoring system need to be established.

5.5.3 Calibration and site inspection

5.5.3.1 Instruments, particularly with electrical outputs, drift in time and will require regular inspection and calibration. The calibration interval is determined by the drift specifications given by the manufacturer and the required uncertainty. Appropriate calibration facilities and instrumentation should be available prior to the procurement and installation of observing

systems to enable verification of the specifications given by the manufacturer, testing of the overall performance and inspection if transportation has affected the measuring characteristics of the equipment. A commissioning process, including performance assessment, will often be required prior to the equipment becoming fully operational.

5.5.3.2 Field inspections should also be used to control the state of the observing site, including the site environment, state of the vegetation and state of all infrastructure and power supplies; and to clean the instruments.

5.5.4 **Quality control**

5.5.4.1 It is essential to perform QC of meteorological observations because inaccurate or missing reports may impair aircraft safety, particularly in the critical take-off or landing phases of flight where most accidents are likely to occur. QC ensures quality and consistency of data output and is achieved through a carefully designed set of procedures focused on good siting, maintenance practices, repair, calibration and data-quality checks. It is an integral component of an overall QM framework.

5.5.4.2 The meteorological service provider should ensure all meteorological personnel are appropriately qualified and competent. Procedures should be developed in accordance with WMO and ICAO specifications to ensure the high quality of the observational data issued to the users. Further information on QM with respect to observing networks is given in the *Guide to Instruments and Methods of Observation* (WMO-No. 8), Volume V.

5.5.4.3 Observational data QC is achieved through screening faulty reports and, when possible, correcting the errors. This function should be performed at different times and at different points, including:

- At the observation site;
- Prior to their dissemination both nationally and globally at the telecommunications centre;
- Prior to archiving at the meteorological centre.

5.5.4.4 Observed or measured parameters consist of a true value and a systematic or random variation, that is, the error. The objective of QC is to minimize this variation by detecting the error and correcting it. The most frequent errors are those that are:

- Inherent in the technical equipment used (instruments, telecommunications, indicators);
- Due to subjective inputs by the observer (reading errors, transcription errors, observational errors);
- Caused by defective observational procedures;
- Due to unrepresentative siting of instruments.

5.5.4.5 The possibility of errors increases with the number of intermediate steps between the measurement and the transmission to, and receipt of, the data by the user. Those intermediate steps should therefore be as few as possible.

5.5.4.6 In undertaking manual observations, errors may be produced by transferring measured data from instruments to the telecommunications terminal or by computing or extracting from tables or graphical representation values not immediately available in final form.

5.5.4.7 In automated systems, suspicious or misleading errors may be detected by built-in self-checks. Observing systems may have multiple sensors measuring the same parameters that provide intra-system checks. Values can be compared with the previous values and with those at nearby observations sites. The real-time transmission of these results and any anomalies, and the

visual display of these status indicators form a tool for continuous monitoring of the network and during field or remote maintenance. Identification and elimination of errors should ensure that there is no significant delay introduced in the distribution of the data.

5.5.4.8 Further downstream, QC may be exercised after the information has been disseminated. For instance, meteorological reports are often plotted or displayed on synoptic charts for use in the preparation of forecasts, making it possible for meteorologists to check the observations. A meteorologist who detects an inconsistent observation should take steps immediately to have the observation investigated and any errors rectified.

6. FORECASTS AND WARNINGS

6.1 AVIATION HAZARDS

6.1.1 Types of hazardous weather

6.1.1.1 There are many hazards to aviation. In accordance with ICAO Annex 3, meteorological service providers are responsible for providing related information to aviation users on the following hazardous phenomena:

- Air density;
- Wind shear;
- Turbulence;
- Icing;
- Thunderstorms;
- Precipitation (all types);
- Low cloud;
- Poor visibility;
- Frontal systems;
- Squalls;
- Sandstorms;
- Dust storms;
- Volcanic ash;
- Release of radioactive material and toxic chemical clouds;
- Tropical cyclone;
- Tsunami;
- Space weather.

6.1.1.2 Further information on aviation hazards, their impacts on aviation and the forecasting techniques that can be used to provide information to the aviation industry is given in [Aviation Hazards](#) (WMO AeM Series No. 3).

6.1.2 Impacts of hazardous weather

6.1.2.1 Changes to air temperature and pressure will change the air density, which will affect both the aerodynamic and engine performance of an aircraft. When the air density is low, aircraft will require a longer runway for both take-off and landing and will not be able to climb as quickly.

6.1.2.2 Wind shear is defined as a wind velocity change over a vertical or horizontal distance. Wind shear may be felt as turbulence or as sudden tail or head wind changes. Vertical wind shear is the change of horizontal wind velocity with height, whereas horizontal wind shear is the change in wind velocity at the same (horizontal) level. Wind shear may also be present during updrafts or downdrafts (including microbursts) associated with convection, where there is a change in wind velocity across adjacent columns of air. Wind shear severely affects the control of the aircraft during take-off and landing and has been the sole or contributing cause of many fatal aircraft accidents.

6.1.2.3 Turbulence is the irregular motion of the air resulting from eddies and vertical currents, which may result in a range of impacts from “bumpy” flight to the aircraft being temporarily out of control. Passengers and aircrew will be required to be seated with seat belts fastened. Even in these instances they can be injured during episodes of severe turbulence. Turbulence can also cause structural damage to the aircraft. Turbulence will affect different aircraft to varying degrees, depending on the aircraft size and type. The following turbulence categories should be considered when providing aeronautical forecasts and warnings: convective turbulence; mechanical turbulence; orographically induced turbulence (including mountain waves and rotors); clear-air turbulence; low-level jets; wake turbulence and wake vortices. ICAO (refer to PANS-ATM (ICAO Doc 4444)) defines moderate and severe turbulence as follows:

Moderate – Conditions in which moderate changes in aircraft attitude and/or altitude may occur but the aircraft remains in positive control at all times. Usually, small variations in airspeed. Changes in accelerometer readings of 0.5 g to 1.0 g at the aircraft’s centre of gravity. Difficulty in walking. Occupants feel strain against seat belts. Loose objects move about.

Severe – Conditions in which abrupt changes in aircraft attitude and/or altitude occur; aircraft may be out of control for short periods. Usually, large variations in airspeed. Changes in accelerometer readings greater than 1.0 g at the aircraft’s centre of gravity. Occupants are forced violently against seat belts. Loose objects are tossed about.

6.1.2.4 Icing can occur in subfreezing temperatures when aircraft fly through cloud or when parked at the aerodrome. Icing occurs if precipitation aggregates on the aircraft (airframe icing) or within parts of the aircraft such as the carburettor or engine. Icing can change the aerodynamics of the aircraft and increase its weight, thus changing the stalling speed. Icing can also cause engine failure, jam controls, reduce visibility, damage the aircraft, and interfere with communications systems. Aircraft icing can occur with rime ice, clear ice, supercooled large drops (or drizzle drops), mixed ice, freezing rain, hoar frost, snow, and sleet. ICAO (refer to PANS-ATM (ICAO Doc 4444)) defines moderate and severe icing as follows:

Moderate – Conditions in which change of heading and/or altitude may be considered desirable.

Severe – Conditions in which immediate change of heading and/or altitude is considered essential.

6.1.2.5 Many of the hazards associated with thunderstorms can be present up to several tens of kilometres from the thunderstorm itself, so it is critical that the information is conveyed in a timely manner to users in a format that is easily understood. Thunderstorms (and hence the presence of cumulonimbus clouds) are hazardous to aviation due to the associated conditions that can occur with the thunderstorm, including:

- Severe turbulence, wind shear and/or icing;
- Downbursts, microbursts, squalls, gust fronts;
- Lightning;

- High liquid water content;
- Tornadoes;
- Heavy rain, hail;
- Poor visibility, low cloud;
- Rapid changes to air pressure.

6.1.2.6 Heavy precipitation and snow can lead to poor visibility and hazardous runway conditions. If the runway is wet or covered with frost, ice or snow, it may cause poor braking and affect the take-off weight of the aircraft.

6.1.2.7 Low cloud and poor visibility, including low stratus, fog and mist are particularly hazardous when a flight is operating under visual flight rule conditions and at aerodromes that require the runway to be visual to the pilot during taxi, take-off or landing. There is an increased chance of collision, both in the air and at the aerodrome, during these conditions.

6.1.2.8 A frontal system is formed when an air mass moves from one area and meets another air mass with different properties. The frontal zone, or front, is the zone between these two air masses. A sharp discontinuity in temperature, humidity and wind can occur that poses a risk to aviation, particularly with respect to wind shear and other associated phenomena, such as thunderstorms, that can develop along the front. Squalls, which are characterized by a sudden violent gust of wind or by the presence of thunderstorms, also pose a hazard to aviation in similar ways to those of frontal systems but are often harder to predict as they are shorter lived and more localized, unless organized in a line.

6.1.2.9 Sandstorms and dust storms occur when dry sand or dust is lifted and transported by strong, turbulent winds. They reduce visibility for the pilot, can damage engines and aircraft surfaces, reduce power if ingested into the engine, and may cause serious incidents or accidents as a result. They may also interfere with aircraft communications and instrumentation.

6.1.2.10 Volcanic ash is a hazard to aviation because the pulverized rock, predominantly silica, and corrosive gases, such as hydrochloric acid and sulphur dioxide, can cause effects that include: engine failure; abrasion of engine or other aircraft parts; contamination of electrical, communications and hydraulic systems; offensive cabin odour. Volcanic ash and the associated gases can remain in the atmosphere for many days and cover extensive areas. Further information on volcanic ash, toxic chemicals and radioactive cloud can be found in ICAO Docs 9691, 9766 and 9974.

6.1.2.11 Tropical cyclones are a significant hazard for aviation. The weather associated with tropical cyclones includes strong winds, severe wind shear and turbulence, heavy rainfall, low cloud and reduced visibility. Aircraft in flight should avoid tropical cyclones and, if they are at an aerodrome, should be secured or evacuated to an alternate aerodrome away from the path of the tropical cyclone. The aerodrome, its infrastructure and services, are also at risk during a tropical cyclone event. In coastal areas, storm surge poses an additional hazard. For further information on tropical cyclones and other tropical meteorology refer to the *Compendium on Tropical Meteorology for Aviation Purposes* (WMO-No. 930).

6.1.2.12 A tsunami is a series of long-wavelength ocean waves that can be caused by a variety of disturbances in the ocean, including earthquakes, volcanic eruptions and landslides. Coastal aerodromes are at particular risk in the event of a tsunami, so it is important that the aviation users are provided with tsunami warnings in a timely manner, whether it be through an aerodrome warning or as part of any national tsunami warning service.

6.1.2.13 Space weather events pose a risk to both aviation systems and to passengers and aircrew. ICAO Doc 10100 states that:

[S]pace weather events occur when the Sun causes disruptions to aviation communications, navigation and surveillance systems, and elevates radiation dose levels at flight altitudes. Space weather events may occur on short time scales, with the effects occurring from almost instantaneously to over a few days.

and provides further information on space weather and its effects on aviation.

6.2 FORECASTS AND WARNINGS

6.2.1 Aviation forecasts and warnings

6.2.1.1 Advice on the expected meteorological conditions within the terminal area and en route is contained in a range of forecasts of varying periods, and in certain types of warnings. The primary forecast elements are wind, visibility, weather, cloud, temperature and pressure, in addition to the aviation hazards mentioned above.

6.2.1.2 Forecasts with long validity periods (such as terminal aerodrome forecasts (TAF)), generally 24 to 30 hours in length, are provided at aerodromes and distributed to other aerodromes, airline companies, meteorological offices, and air traffic and flight service offices, where they are used in flight planning and for briefing aircrew. Forecasts in the terminal area with short validity periods, typically two hours, are required for landing and take-off (such as trend forecasts) at many aerodromes. These forecasts may also be passed to aircraft in flight (either verbally or by automatic broadcast) and used in traffic flow planning. Warnings are issued for aerodromes to help ensure the safety of personnel and aircraft on the ground and the availability of aerodrome facilities and supporting services.

6.2.1.3 Each forecast and warning should be considered to represent only the most likely development of conditions. While details of fluctuations and changes in conditions are extremely important, they should focus on those that are operationally significant and be kept as short as possible to not detract from their usefulness. The inclusion of change groups should conform to the SARPs in ICAO Annex 3. Forecasts and warnings should be kept under continuous review and amended promptly when necessary. The use of automated alerting systems, which assist the meteorologist with monitoring the need for amendments, is highly desirable as they allow staff to concentrate on multiple forecasting duties.

6.2.1.4 The flight planning process is based on the use of meteorological parameters that are forecast with a significant probability. Probabilities must be used with discretion and not to cover all eventualities because this reduces the value of the message to the aviation user. The fact that actual weather conditions may be different from those that are forecast is already incorporated in the planning procedures. Aviation users therefore need concise and unambiguous information of operational significance.

6.2.2 Forecasting processes

6.2.2.1 Forecasting for aviation requires access to adequate information that should include basic observational data, analyses, meteorological satellite information, weather radar data and other observations networks, as well as NWP data.

6.2.2.2 To produce short-period forecasts for the terminal area, such as trend forecasts and aerodrome warnings, frequent observations for an area close to the aerodrome are required. For longer-period forecasts, such as TAFs, basic data are required from an area large enough to monitor relevant synoptic developments. The meteorologist should consider present conditions

(persistence is sometimes a useful guide at very short ranges), the expected movement and development of weather systems revealed by the information, and the expected local variations in weather that may occur diurnally or in response to changing weather conditions.

6.2.2.3 At the start of each duty period, the incoming meteorologist should be briefed on the synoptic situation by the outgoing or supervising meteorologist. The meteorologist should ensure familiarity with the synoptic situation and the surface and upper-air analyses and prognoses that will form the background to the forecasting work to be undertaken. This will be in both alphanumeric and graphical form from a range of different national and international sources. Where there is conflicting information, discussion on the most likely outcomes should be undertaken.

6.2.2.4 It is vital to be knowledgeable on the influence of topography and local effects, such as sea breezes and valley winds, and the diurnal variation of elements such as wind strength and cloud base. Aerodrome climatology and other local information should provide guidance on diurnal variations, persistence of fog, and typical cloud bases and visibilities in fog or precipitation for different synoptic conditions. As well as providing information on likely values of weather elements, climatology can assist in avoiding the forecasting of impossible or very unlikely values. In many places the diurnal variation of some elements of the forecast has a dominant influence and departures from the normal variation should be studied closely.

6.2.2.5 Satellite images should be studied for indications of the likely types of cloud and weather phenomena that may affect an aerodrome and conditions en route. The images usually give a good indication of the stability of the air mass. In some cases, a wind change may advect low cloud or fog over an aerodrome. This is particularly so in coastal regions where a change may occur from offshore to onshore flow.

6.2.2.6 Weather radar information is helpful for short-term forecasting. While simple extrapolation of the precipitation patterns is a useful forecast tool at this range, techniques are also available to predict the movement and changes in intensities of echoes. The movement and development of precipitation patterns are made clearer if there is a looping facility whereby the latest radar images are looped sequentially. Extrapolation, however, may not be adequate in all climate zones and weather conditions. Analysis of the radar information in three dimensions, to look at both the vertical and horizontal characteristics of the echoes, along with Doppler capability to determine the wind fields, can assist in determining the existence of severe weather. This includes the detection of wind shear, downbursts and super-cell thunderstorms.

6.2.2.7 Meteorological forecasts and warnings for aeronautical purposes are detailed in ICAO Annex 3 and the relevant ICAO Regional Air Navigation Plan. Additional national services are agreed between the meteorological authority and the operators and service providers concerned.

6.2.2.8 It is recognized that meteorological elements will vary in space and time, and that there are limitations to both observing and forecasting techniques. As such, the meteorological information provided to aviation is the best approximation or most probable value at the time the information was issued. In preparing the information the meteorological personnel should also take into account the accuracy standards provided in Annex 3.

6.2.2.9 Timely amendments are important, especially when the forecast conditions are expected either to deteriorate from those originally predicted or to be better. In the first case there are safety implications such that the pilot may fly into a dangerous situation if not advised of the changed circumstances. In the second case there are inconvenience and economic penalties – a flight may be needlessly delayed if weather conditions have improved or are expected to improve and this information has not been conveyed to the pilot.

6.2.3 **General aviation and helicopter operations**

6.2.3.1 General aviation and helicopter operations normally take place in the lowest levels of the atmosphere with shorter flight duration. They are therefore concerned with almost all

types of weather and cloud. Consequently, the forecasts must contain the necessary detail for the pilots to be able to decide whether flights can be conducted safely, and what alternatives are available if pilots encounter adverse weather conditions. It is the responsibility of the contracting State (unless alternatively arrangements have been made regionally) to provide this service. Although general aviation and helicopter operations are mainly low level, they nevertheless still operate in airspace used by international civil aviation. It is therefore recommended that the services set out in Annex 3 be used to set minimum local standards and requirements. Additional services should also be included in areas of extreme and variable flying conditions, such as over mountainous areas. It is advisable to develop these services and products in consultation with the representatives of general aviation and the relevant aviation authorities.

6.2.3.2 The meteorologist preparing the forecasts must have an intimate knowledge of the local area, including the terrain and its effects on significant weather, and continuously monitor any changes in weather conditions. Frequently, there are critical locations in an area over which many aircraft fly, for example a mountain gap. In these circumstances it is helpful for pilots to have a forecast for these locations contained within the forecast.

6.2.3.3 Helicopter pilots are interested in the same forecast elements as general aviation pilots, with increased emphasis on conditions very close to the ground such as low-level winds, low cloud, visibility and icing. Low-level turbulence seriously affects helicopter operations, particularly in mountainous terrain. Furthermore, helicopters are very sensitive to hail and icing conditions. A combination of low pressure and high temperature adversely affects the engine performance of helicopters. At elevated locations on hot days, this effect may be great and will seriously reduce the load that can be carried due to the reduced lift generated by the helicopter.

6.3 VERIFICATION AND VALIDATION

6.3.1 The importance of verification

6.3.1.1 The verification of meteorological forecasts and warnings allows for the identification of any strengths and weaknesses, as well as an assessment of their value to aviation users. Verification determines the quality of forecasts by understanding their accuracy and how this changes over a period of time. It examines differing forecast systems and enables comparisons, which in turn allows for the identification of ways to continuously improving the forecasting methods and processes.

6.3.1.2 Allan Murphy (Murphy, 1993) in his essay on what makes a good forecast, identifies the following three distinct types of “goodness” in relation to forecast verification:

- Consistency: “the correspondence between forecasters’ judgement and their forecasts”;
- Quality: “the correspondence between forecasts and the matching observations”;
- Value: “the incremental economic and/or other benefits realized by decision makers through the use of forecasts”.

6.3.1.3 Murphy describes the various aspects of forecast quality, which include: bias, accuracy, skill, reliability, resolution, sharpness, discrimination and uncertainty. The author also emphasizes the importance of forecast value as it relates to helping users make more informed decisions. For example, a forecast of little value may be one of clear conditions at an aerodrome in the tropical dry season, whereas a forecast of higher value would be the accurate forecast of unseasonal thunderstorms over that same aerodrome in the dry season.

6.3.1.4 Forecast verification is heavily reliant on observations, so the QC and error correction of these observations are important. The larger the samples of forecast and observation pairs, the more reliable the verification statistics. For verification of rare events, the sample size is

often extremely small and the false alarm rate may be larger than usual due to over forecasting, particularly if the cost of a missed event is large. So care should be taken in explaining the verification statistics to users in these situations.

6.3.1.5 Verification should be used to help in developing new methods, practices and services, rather than for comparison or criticism, since each aerodrome or geographical area has its own challenges when it comes to forecasting.

6.3.1.6 Verification statistics are useful for aviation users, so verification results should be presented in a way that is easily understood. This can be tailored to the different aviation user requirements, particularly for estimating the economic value of forecasts. The use of graphical information, such as time series and other chart-types, can help explain the change of skill over time.

6.3.2 **Verification of aviation forecasts**

6.3.2.1 Every effort should be made to achieve the operationally desirable accuracy standards set for forecasts in ICAO Annex 3. Regular evaluation of the quality of aviation forecasts is necessary on three different timescales:

Monitoring is used on the shortest timescale whereby the meteorologist will routinely check the forecasts against observed conditions as part of a continuous weather watch. Any significant differences can be immediately assessed and an amended forecast issued if necessary.

On the timescale of a few days to a few months, accumulated evaluations of forecasts can reveal problems of bias (such as pessimism in forecasting visibilities) or inaccuracy for a particular aerodrome. Feeding back this information to meteorologists will improve their awareness of the quality of their forecasts, allowing them to make improvements and reduce bias.

Evaluation of the forecasts conducted in a systematic and consistent manner over a period of many years can be used to assess trends in forecasting skill and reveal areas where improvements to processes, to the availability of observational data or to forecasting systems are needed.

6.3.2.2 Verification of aviation forecasts in four dimensions, such as area forecasts or SIGMETs, may pose problems due to the spatial and temporal nature of the forecast and may often lack suitable observations within the particular area with which to verify against. Methods to overcome these problems include interpolation of conditions at a particular location between two or more observed locations, as well as extrapolation of observed conditions from a particular location to extend over a wider range, assuming that these interpolated or extrapolated conditions can be compared with available observations. A variety of additional data sources can be used for verification, such as radar, satellite, upper-air profiles, AMDAR and AIREP information.

7. CLIMATOLOGICAL INFORMATION

7.1 CLIMATE AND AVIATION

7.1.1 Climatological information users

7.1.1.1 Climatological information for the aerodrome and other aeronautical installations, as well as en-route climatic information, provides support for the design, planning and operations of aircraft, airspace and aerodromes. It is also used to provide information for safety and risk analysis and during incident and accident investigations.

7.1.1.2 Users of climatological information and historical meteorological data include:

- Aerodromes and other aviation-related installations;
- Aerodrome operations;
- ATM;
- Flight safety;
- Airline operations;
- Aircraft manufacturers;
- Meteorological service providers.

7.1.1.3 Some examples of how this information is used include:

- Planning the construction of runways and other infrastructure at aerodromes;
- Planning for flight operations, particularly for pre-operational route planning;
- Operational planning purposes and calculations of take-off conditions;
- Planning the design and construction of aircraft;
- Accident and incident investigations;
- Research programmes;
- Background information in the preparation of meteorological forecasts and warnings;
- Verification of meteorological forecasts and warnings;
- QC of observational data.

7.2 CLIMATOLOGICAL INFORMATION

7.2.1 Aerodrome climatological summaries and tables

7.2.1.1 ICAO Annex 3 outlines the requirements for both aerodrome climatological summaries, which provide a summary of specified meteorological elements at an aerodrome based on statistical data, and aerodrome climatological tables, which provide statistical data on the observed occurrence of one or more meteorological elements at an aerodrome.

7.2.1.2 Aerodrome climatological summaries should cover:

- (a) Frequencies of the occurrence of RVR and visibility;
- (b) Frequencies of visibility below specified values at specified times;
- (c) Frequencies of the height of the base of the lowest cloud layer of BKN or OVC extent below specified values at specified times;
- (d) Frequencies of occurrence of concurrent wind speed and direction within specified ranges;
- (e) Frequencies of surface air temperature in specified ranges of 5 °C at specified times;
- (f) Mean values, along with their variations, for a range of meteorological elements that can be used for operational planning (for example, take-off performance calculations).

7.2.1.3 Aerodrome climatological tables should cover:

- (a) Mean values and variations, including maximum and minimum values, of meteorological elements (for example, air temperature);
- (b) The frequency of occurrence of present weather phenomena affecting flight operations at the aerodrome (for example, sandstorms);
- (c) The frequency of occurrence of specified values of one, or of a combination of two or more, elements (for example, a combination of low visibility and low cloud).

7.2.2 Climatological information for planning and research

7.2.2.1 Changing weather and climatic conditions should be considered when developing or updating an airport large-scale scheme or project (the “master plan”) in order to support modernization of existing aerodromes or the creation of new ones. ICAO Annex 14 highlights the importance of meteorological information in planning the siting and orientation of runways. For example, wind statistics should be provided for the calculation of the “usability” factor to determine the maximum mean crosswind components for planning the orientation of the runways. This evaluation should be based on a period of not less than five years with observations made at least eight times per day and spaced at equal intervals of time. In many cases, a wind rose provides an excellent summary of wind speed and direction over a period of time. In addition, a study should be made of the frequency and type of wind gusts and the occurrence of poor visibility and low cloud.

7.2.2.2 It is worthwhile noting that 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, for example, the future climate at an aerodrome may be insufficient given the current rate at which the world’s climate is changing. In that context, it is important that the review and update of the climatological statistics be undertaken at an adequate frequency and include climate-change prediction.

7.2.2.3 For operational planning purposes and calculations of take-off conditions, the following parameters are required: mean daily maximum and minimum temperatures; mean pressure; if available, mean absolute humidity at approximately the times of maximum and minimum temperatures for each month of the year.

7.2.2.4 The aerodrome reference temperature, defined in Annex 14, should be published for each aerodrome. The aerodrome reference temperature is the monthly mean of the daily maximum temperatures for the hottest month of the year, where the hottest month is defined as the month with the highest monthly mean temperature. This temperature should be averaged over a period of several years.

7.2.2.5 Climatological information is extensively used in research programmes, particularly for research that is aimed at improving the detection and prediction of meteorological hazards. Meteorologists also use climatological statistics in their day-to-day forecasting role to look at weather extremes and departures from normal diurnal or seasonal patterns.

7.3 CLIMATE CHANGE IMPACTS ON AVIATION

7.3.1 Climate change impacts

7.3.1.1 Climate change and variability, such as extremes in temperature, intensification of thunderstorm activity, more intense tropical cyclones, sea-level rise, or more intense wind speed and precipitation, may impact aviation by damaging infrastructure, loss of demand, loss of capacity, network disruptions, changes to air traffic routes, increases in accidents or incidents due to hazardous weather, financial losses and changes in aircraft performance.

7.3.1.2 The results published as [Outcomes of the 2020 Survey on the Impacts of Climate Change and Variability on Aviation](#) (WMO AeM Series No. 6) highlight the potential impact of climate change and variability on the following elements:

- Aerodrome infrastructure, for example airfield flooding, damage to runway and taxiway surfaces, ground subsidence, building damage;
- Aerodrome operations, for example longer take-off and landing distances with increased temperature extremes, reduced runway capacity;
- ATM, for example challenges in managing terminal area and air traffic due to increased temperatures, thunderstorms and low visibility;
- Flight safety, for example an increase in hazardous weather such as thunderstorms and turbulence;
- Airline operations, including increased fuel consumption due to longer routings due to increased upper air speeds and avoidance of meteorological hazards.

7.3.2 Building resilience to climate change

7.3.2.1 The Airports Council International Policy Brief (September 2018), *Airports' Resilience and Adaptation to a Changing Climate*, recommended that, with respect to aerodrome design and management, aerodromes should consider:

- taking into consideration the potential impact of climate change as they develop their Master Plans;
- conducting risk or criticality assessments for their operational procedures and existing infrastructure from more adverse weather events and climate change;
- developing and incorporating actions at an early stage, in accordance with both their risk/criticality assessments and with their overall business continuity plans and emergency planning; and
- planning and developing effective communication channels with airport staff, and aviation stakeholders, including airlines, air navigation service providers, off-airport service providers, academia, communities and municipal authorities responsible for weather monitoring, climate analysis, and disaster management.

7.3.2.2 It is important that the aeronautical meteorological service provider, the climatological information provider and the aviation users and stakeholders collaborate to develop a risk assessment for climate change to ensure that resilience, adaptation and/or mitigation is built into any long-term plans for aerodromes and air routes.

8. DATA REPRESENTATION

8.1 DATA REPRESENTATION

8.1.1 Coded meteorological messages

8.1.1.1 Coded meteorological messages can be used for the exchange of meteorological information, comprising observational data and processed data (for example, forecasts, warnings and alerts). The codes are composed of a set of “code forms” and “binary codes” made up of “symbolic letters” (or groups of letters) representing meteorological or other geophysical elements. Further specifications are then given in “code tables”. Rules concerning codes can be found in the [Manual on Codes](#) (WMO-No. 306) (Annex II to the *Technical Regulations* (WMO-No. 49)):

- Volume I.1, Part A, Alphanumeric Codes;
- Volume I.2, Part B, Binary Codes; Part C, Common Features to Binary and Alphanumeric Codes;
- Volume I.3, Part D, Representations Derived from Data Models

8.1.1.2 Additional information regarding the requirements for coded messages and visualization of aeronautical meteorological information is given in ICAO Annex 3 and the Manual on the ICAO Meteorological Information Exchange Model (ICAO Doc 10003).

8.1.2 Visualization of meteorological information

8.1.2.1 Visualization or graphical representation of meteorological information has the advantage of being human readable and generally more easily understood by users, thereby enhancing situational awareness and decision-making. Annex 3 outlines a number of aviation-related graphical representations, in chart forms prescribed by WMO, that are extensively used to support safe and efficient aircraft operations. These include:

- Upper-wind and upper-air temperature charts;
- SIGWX charts;
- Tropical cyclone advisory graphic;
- Volcanic ash advisory graphic;
- SIGMET graphic for tropical cyclones, volcanic ash and other phenomena.

8.1.2.2 Other information available to the aviation industry in graphical form includes:

- Icing, turbulence and cumulonimbus charts;
- Mean sea-level surface pressure analysis and prognosis;
- Meteorological satellite imagery;
- Weather radar imagery;
- Space weather imagery;
- Lightning detection charts;

- Time series graphs or meteograms.

8.1.2.3 Graphical representation of information can be derived automatically from:

- Gridded data, typically general regularly distributed information in binary form (GRIB) or network common data form (NetCDF);
- Binary universal form for the representation of meteorological data (BUFR);
- ICAO meteorological information exchange model (IWXXM).

Note that NetCDF was designed to facilitate access to array-oriented data and is commonly used in climatology, meteorology and oceanography applications. It may be applied to aeronautical meteorological data in the future.

8.1.2.4 Depiction of meteorological information can also be manually drawn (usually by on-screen computer software) by meteorological personnel.

8.1.2.5 Meteorological data may be displayed over maps of the Earth with either polar stereographic or Mercator map projections. On a polar stereographic map, the projection is typically centred on either the North or South Pole. While this type of projection allows the user to get a good idea of the meteorological information in the polar regions, large distortions exist towards the equator. To better view meteorological information around the equator and mid-latitudes, a Mercator projection is preferred. The issues arising might become less limiting with the use of IWXXM and the ability to obtain the exact information that the user requires.

8.1.2.6 Graphical requirements for meteorological information, including the use of specific symbols, is given in Annex 3 and *Manual on Codes* (WMO-No. 306), Volume I.1, Attachment IV.

8.2 ALPHANUMERIC AND BINARY CODE FORMS

8.2.1 Alphanumeric codes

8.2.1.1 Aeronautical meteorological information has been provided in alphanumeric code form since the 1940s, the information originally being transmitted via morse code or teleprinter (see Figure 1). Due to telecommunications limitations, alphanumeric code often has a character limit for each message, which means that additional meteorological information that is relevant to flight or ground operations may be difficult to express in this restricted, relatively inflexible code form. An advantage of alphanumeric code is that it has small file sizes, so is both easy to transmit and is human readable. However, the user of the information (meteorologist, flight crew, air traffic controller or flight dispatcher) still needs to learn how to read and interpret the code. Graphical equivalents and data exchange models are now being widely introduced for meteorological information, helping to overcome some of the shortcomings often associated with alphanumeric codes.

8.2.1.2 *Manual on Codes* (WMO-No. 306), Volume I.1 provides information on coding for the following aviation-specific products:

- Aerodrome routine meteorological report (METAR);
- Aerodrome special meteorological report (SPECI);
- Aircraft report (AMDAR);
- Area forecast (ARFOR);
- Landing forecast (TREND);

- Route forecast (ROFOR);
- Terminal aerodrome forecast (TAF).

8.2.1.3 ICAO Annex 3 provides coding templates for:

- Aerodrome routine meteorological report (METAR);
- Aerodrome special meteorological report (SPECI);
- Aerodrome warning (AD WRNG);
- AIRMET;
- Area forecast (for low-level flights) (GAMET);
- Landing forecast (TREND);
- Local routine meteorological report (MET REPORT);
- Local special meteorological report (SPECIAL);
- SIGMET;
- Space weather advisory (SWXA);
- Special air-report(s) (ARS);
- Terminal aerodrome forecast (TAF);

Aerodrome forecast examples

1940s

TAMET 00181 UDO 61310 9703/ 88820 43505 55004 92024

(Aerodrome forecast for UDO valid from 0000 to 1800 UTC based on the 2100 UTC synoptic chart. Cloud cover of 6 oktas (6/8) with a surface wind of 130 degrees at 10 knots. Horizontal visibility of 10 km with clouds generally forming or developing. 8/8 of cumulus or fractoculumus cloud with a cloud base of 2 000 feet. Heavy rime ice in cloud occurring at 5 000 feet, with thickness of icing layer being 5 000 feet. Severe occasional turbulence from, lower than, 100 feet with a depth of 5 000 feet. Mean sea-level pressure of 1 024 millibars (hectopascals).)

2020s

TAF YUDO 152330Z 1600/1618 13010KT 9000 BKN020
 BECMG 1606/1608 SCT015CB BKN020
 TEMPO 1608/1612 17015G30KT 1000 TSRA SCT010CB BKN020
 FM161230 15010KT 9999 BKN020

(Aerodrome forecast for YUDO issued at 2330 UTC on the 15th valid from 0000 to 1800 UTC on the 16th day. Surface wind 130 degrees true at 10 knots, visibility 9 km with cloud cover 5/8 to 7/8 at 2 000 feet above ground level. Between 0600 and 0800 UTC on the 16th, becoming 2/8 to 4/8 cumulonimbus cloud cover at 1 500 feet above ground level and 5/8 to 7/8 cloud cover at 2000 feet above ground level. Temporarily, between 0800 and 1200 UTC on the 16th, surface wind 170 degrees true at 15 knots gusting to 30 knots, visibility 1000 metres in thunderstorm with moderate rain, 3/8 to 4/8 cumulonimbus cloud cover at 1000 feet above ground level and 5/8 to 7/8 cloud cover at 2 000 feet above ground level. From 1230 UTC on the 16th, surface wind 150 degrees at 10 knots, visibility 10 km or more and 5/8 to 7/8 cloud cover at 2 000 feet above ground level.)

Figure 1. Aerodrome forecast examples

- Tropical cyclone advisory (TCA);
- Volcanic activity report (VAR);
- Volcanic ash advisory (VAA);
- Wind shear warning (WS WRNG).

8.2.2 Binary codes

8.2.2.1 *Manual on Codes* (WMO-No. 306), Volume I.2 provides details on the structure and use of binary codes used for meteorological information, including GRIB and BUFR.

8.2.2.2 GRIB is a meteorological data format commonly used for distributing gridded data such as NWP model output. GRIB files are a collection of self-contained two-dimensional records in which individual records stand alone with no references to other records. Each GRIB record has two components, the header and the binary data. GRIB2 (the second edition GRIB), which also supports compression, was approved in 2003 and should be used instead of GRIB1.

8.2.2.3 As defined in Annex 3, the WAFS provides global forecasts of wind, temperature, relative humidity, geopotential height, cumulonimbus clouds, turbulence and icing forecasts on a regular grid. These forecasts are made available in GRIB2 format.

8.2.2.4 BUFR is a binary code used for the exchange and storage of meteorological data. It can represent data elements, along with their specific spatial and temporal context and any other associated metadata. Each data element is determined by referring to a set of tables that are separate from the message itself. BUFR is primarily used for in-situ observations, such as synoptic or temperature information, and satellite observations, but can also represent forecast data such as WAFS SIGWX forecasts where linear features and polygons are represented.

8.3 INFORMATION EXCHANGE MODELS

8.3.1 Exchange models

8.3.1.1 Several information exchange models have been created to collect, verify, disseminate and transform aeronautical information, including meteorological information. They take advantage of established information engineering standards such as unified modelling language models, geography markup language and extensible markup language schema. They are aimed at supporting both current and future aeronautical information requirements. The exchange models promote interoperability through a common exchange standard in support of SWIM and machine-to-machine data exchange. The three primary exchange models used currently in aviation are:

- Flight information exchange model (FIXM);
- Aeronautical information exchange model (AIXM);
- IWXXM.
- Over time, additional exchange models may be developed.

8.3.2 Flight information exchange model

8.3.2.1 FIXM is a global exchange standard capturing flight and flow information through all phases of flight. FIXM, like the other exchange models, is designed to be modular, allowing for the use of just the required parts of the message; to be extensible, ensuring that additional

relevant information can easily be provided; and to be flexible. FIXM allows flight plans to be able to provide substantially more information on data such as flight routes and trajectories. FIXM is aimed at improving the interactions between users and stakeholders managing air traffic, including ATC, airspace users, aviation authorities, security and defence organizations.

8.3.3 **Aeronautical information exchange model**

8.3.3.1 AIXM enables the provision of AIS data in a digital format, including information on aerodromes, heliports, airspace structures, organizations and units, navigation points and navigation aids (“navaids”), procedures, flight routes and flying restrictions. AIXM captures the information that is provided in NOTAMs (see acronyms and glossary table) and AIPs.

8.3.4 **ICAO meteorological information exchange model**

8.3.4.1 IWXXM is used to encode and exchange meteorological information. It is designed for efficient machine-to-machine interaction and easy integration into decision support tools and is not intended to be human readable. It enables the development of cost-effective meteorological information displays where software developers no longer need to have in-depth knowledge of meteorological codes and structures. The easy and reliable extraction of specific meteorological elements allows the user to pick the specific elements that they are interested in, rather than having to interpret the entire message. It can also contain greater spatial and temporal resolution or a variety of averaging periods, resulting in more focus on the particular requirements of individual users. For example, if the user is solely interested in the wind component at an aerodrome, they don't need to retrieve the whole METAR message and decode it as there is now the ability to easily retrieve just the wind element. A further example is the ability to select a weather element, such as snow, and be able to obtain information more easily on all aerodromes where snow is falling, rather than having to scan every METAR message.

8.3.4.2 IWXXM can be used by systems that provide a range of tailored information for ATC, flight planning and other aerodrome and airline uses. It can contain increased spatial and temporal information and a greater range of data types compared to the traditional alphanumeric code form. As an example, an area of hazardous weather is often depicted by a polygon and in the alphanumeric code is recommended to be depicted by seven points or less, which may incur some conservatism on the part of the meteorologist. IWXXM can accommodate a more accurate depiction of the geographical area as it is able to use many more points. Further information regarding IWXXM is given in *Manual on Codes* (WMO-No. 306), Volume I.3 and ICAO Doc 10003.

9. INFORMATION MANAGEMENT

9.1 INFORMATION EXCHANGE

9.1.1 Meteorological information exchange

9.1.1.1 The exchange of meteorological information should be undertaken in the most secure, expedient, and economical manner possible, in a format that enables interoperability with other aviation systems and easy interpretation and application to aviation operations. This should not be to the detriment of the quality and integrity of the data. It is vital that the possibility of errors occurring in the data is reduced to an absolute minimum.

9.1.2 Communications networks

9.1.2.1 Suitable telecommunications facilities are required to ensure that meteorological information is securely exchanged between the aeronautical meteorological service provider and aviation users, including ATS units, AIS offices and SAR service units, as well as national, regional and international Operational Meteorological (OPMET) Centres and databanks.

9.1.3 Aeronautical fixed service

9.1.3.1 Time critical, OPMET information should be exchanged using the aeronautical fixed service (AFS). The AFS includes the use of the aeronautical fixed telecommunications network (AFTN) and the aeronautical message handling system (AMHS). The AFTN is being phased out and does not support the IWXXM format. The AMHS does support IWXXM but only if file transfer body part has been implemented, which enables the inclusion of a file attachment.

9.1.3.2 More information on telecommunications for aviation can be found in the *Manual on Detailed Technical Specifications for the Aeronautical Telecommunication Network (ATN) using ISO/OSI Standards and Protocols* (ICAO Doc 9880) and ICAO Annex 10, *Aeronautical Telecommunications*.

9.1.4 Use of the Internet

9.1.4.1 Internet technology is used extensively for the exchange of meteorological information through AFS Internet-based services, including the exchange of WAFS products and OPMET information as specified in Annex 3. This is regarded as a particularly efficient and flexible method, as it combines excellent quality with relatively low-cost, user-friendly receiving equipment. More information is available in *Guidelines on the Use of the Public Internet for Aeronautical Applications* (ICAO Doc 9855).

9.1.4.2 The WAFCs, both London and Washington, each operate a secure Internet-based service, namely SADIS and WIFS respectively, for the easy provision of OPMET and WAFS information. These systems offer a data library and do not process or visualize data. Rather, they make data available for extraction, processing and/or visualization by end-user systems. Further information on these services can be obtained in the *Secure Aviation Data Information Service (SADIS) User Guide* (ICAO) and *The World Area Forecast System (WAFS) Internet File Service (WIFS) Users Guide* (WAFC Washington).

9.1.4.3 Increasingly, meteorological information is made available via Internet-enabled smartphones and other handheld devices such as tablets using apps that present to the user a variety of graphical and alphanumeric data, often configurable to the user's needs. Such technology makes meteorological information available "in the palm of the user" and "on the go", and without the need for users to access other aviation-specific communication infrastructures.

9.1.4.4 Pre-flight systems also make use of Internet technology to supply and display meteorological information to operators and flight crew members for self-briefing and flight documentation purposes. Electronic flight bags, typically in the form of hand-held electronic devices, are now becoming commonplace on the flight deck, with the potential for in-flight updates via satellite-based Internet connectivity.

9.1.5 **Voice communication**

9.1.5.1 Communicating meteorological information via telephone can be labour intensive and may lead to relay errors or misinterpretations; however it should be considered as a backup system during contingency arrangements. The use of telephone and, more commonly, videoconferencing for aviation briefings and CDM is encouraged. Consideration should be given to recording operational conversations (voice or video) between the meteorologist and the aviation user, since these may be of relevance or significance in the event of an aviation incident or accident, or post-flight analysis.

9.1.5.2 Meteorological information from automatic weather observing systems may make use of text-to-speech technology to enable the user to access real-time meteorological observations via a telephone or radio service. This provides an advantage for users in that the information is updated when required, repeated continuously, available over a relatively large area and available simultaneously for everyone. For example, at many aerodromes the local meteorological information is integrated into the ATIS message, along with other information about the aerodrome such as the runway(s) in use, runway surface conditions, transition level and other important operational information. Further information regarding ATIS can be found in ICAO Annex 11 and PANS-ATM (ICAO Doc 4444).

9.1.5.3 Meteorological information is provided to aircraft in flight (VOLMET) through HF and/or VHF broadcasts and datalink (for D-VOLMET) (refer to ICAO Annex 3). VOLMET and D-VOLMET are operated in accordance with regional air navigation agreements. They make use of technology that converts the textual meteorological information into speech (refer to ICAO Doc 9377).

9.2 **OPMET EXCHANGE**

9.2.1 **OPMET exchange system**

9.2.1.1 The national, regional and international exchange of meteorological information is achieved through a network of OPMET centres (see Figure 2). These include:

- National OPMET Centres (NOCs);
- Regional OPMET Centres (ROCs);
- Regional OPMET databanks (RODBs);
- Interregional OPMET gateways (IROGs);
- SADIS and WIFS services.

9.2.1.2 Further information is provided in the ICAO Regional OPMET Bulletin Exchange Handbooks (ROBEX Handbooks). Information on the exchange of IWXXM is provided in the ICAO *Guidelines for the Implementation of OPMET Data Exchange using IWXXM*.

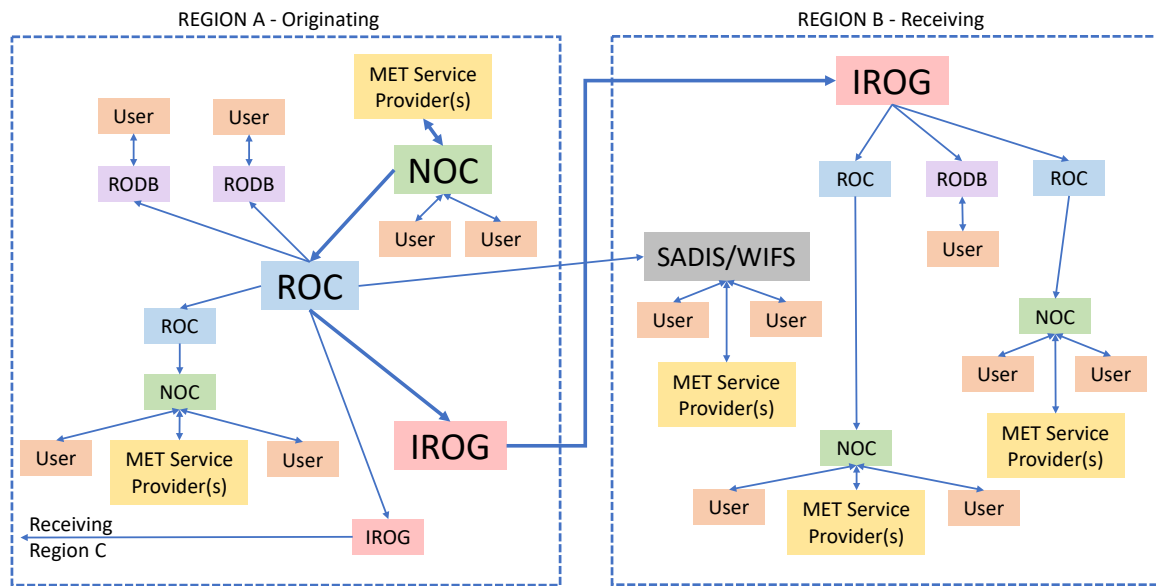


Figure 2. OPMET exchange

9.2.2 National OPMET Centre

9.2.2.1 The role of the NOC is to gather OPMET messages from the aeronautical meteorological service provider, compile national OPMET information into bulletins, validate the bulletin structure and distribute them according to the regional distribution schema. As necessary, the NOC will add the WMO bulletin header and send the OPMET information to its associated ROC via the AFS, State briefing services and other users within its national AOR. The NOC will also distribute OPMET information gathered from other areas to users, depending on the user requirements.

9.2.3 Regional OPMET Centre

9.2.3.1 The ROC is responsible for the collection of the OPMET information from the NOCs within its Region and for validation of the message format. The ROC will then disseminate the OPMET information, via AFS, to the RODBs and IROGs within its Region, to all other ROCs within its Region and to both WAFCs for dissemination on SADIS and WIFS. When an ROC receives OPMET information from other Regions via their IROG, they will distribute this OPMET information to all its associated NOCs.

Note: There are currently nine ICAO Regions: Africa-Indian Ocean (AFI), Asia (ASIA), Caribbean (CAR), European (EUR), Middle East (MID), North American (NAM), North Atlantic (NAT), Pacific (PAC), and South American (SAM). Appendix 1 of the *Directives of Regional Air Navigation Meetings and Rules of Procedure for their Conduct* (ICAO Doc 8144) refers to the ICAO regional structure. There is a high degree of congruence between ICAO Regions and WMO Regional Associations, and the States and Territories therein, although congruence is not complete.

9.2.4 Interregional OPMET gateway

9.2.4.1 The IROGs facilitate interregional exchange and are responsible for collecting and disseminating meteorological information from their own Region and forwarding this to their partner IROGs in other Regions. Any OPMET formation received by an IROG from another Region will be disseminated to the ROCs and RODBs within its own Region.

9.2.5 **Regional OPMET databank**

9.2.5.1 RODBs store meteorological information and provide the capability for users to interrogate this information. Replies to these requests are described in the regional OPMET databank interface control documents (ICAO RODB ICD). Reply reports of a request will be aggregated into one or more messages. The RODBs are also responsible for providing OPMET data and associated requests monitoring and the calculation of monitoring statistics.

9.2.6 **SADIS and WIFS**

9.2.6.1 SADIS, hosted by the United Kingdom of Great Britain and Northern Ireland, and WIFS, hosted by the United States, make available to registered users WAFS forecasts and OPMET information to be used in pre-flight planning and flight documentation.

9.3 **VALIDATION AND STATISTICS**

9.3.1 **Quality control of OPMET data**

9.3.1.1 OPMET data QC is performed at national, regional and international OPMET centres and databanks, where messages are checked for formatting and coding errors, as well as for time and space consistency, in as close as possible to real time. However, it is the responsibility of the originating office, as part of their properly organized QMS, to apply robust QC procedures during data processing and preparation of meteorological information, to eliminate the main sources of errors and thus reduce the downstream likelihood of rejection by a system or misinterpretation by a user that could result in an aviation incident or accident.

9.3.1.2 Erroneous messages found by the OPMET databanks should be either rejected or corrected by reference back to the source or by the databank itself. Data corrected by the databanks should be flagged in the database.

9.3.1.3 The RODBs compile information about errors that were found in messages and bulletins, and compile records and reports, such as the numbers and types of errors detected during QC, to help States identify problems in OPMET issuance or coding.

9.3.1.4 Further information can be found in the ICAO ROBEX Handbooks.

9.3.2 **OPMET validation**

9.3.2.1 When validating messages, the OPMET centres and databanks should not modify the content of the meteorological data, for example visibility, wind and the like. Checks should be made on the following:

- WMO header;
- ICAO location indicator and originating centre;
- Report or message type;
- Date and time of issuance and validity;
- End of message format.

9.3.3 **OPMET monitoring statistics**

9.3.3.1 Performance indicators are used by OPMET databanks to look at the compliance, availability and regularity of meteorological information.

9.3.3.2 The compliance index assesses the level of compliance of the OPMET information exchanged. It looks at the total number of reports received during the monitoring period compared with what was expected.

9.3.3.3 The availability index is a measure of the current coverage of OPMET distribution against the exchange requirements. The availability index is performed daily from the data captured during the monitoring period. If at least one non-nil report is received from the aerodrome during the 24-hour period, that aerodrome is considered to have been available.

9.3.3.4 The regularity index is a measure of the consistency in the number of reports provided by an aerodrome. It assumes that the number of reports follows a normal distribution and attempts to ascertain the distribution characteristics (mean and standard deviation) from a set of data. These characteristics are used to determine if the subsequent number of reports from an aerodrome is "regular".

9.4 **ARCHIVING**

9.4.1 **Archive requirements**

9.4.1.1 Aeronautical meteorological information should be stored securely by the aeronautical meteorological service provider and, on request and to the extent practicable, should be made available to any authority, service provider, operator or others concerned with the application of meteorology to international air navigation. It is important to provide and maintain or to lease secure repositories (databases) for both en-route and aerodrome meteorological information and that the stored information can be readily retrieved upon request.

9.4.1.2 Aeronautical meteorological information is needed for many purposes, including for:

- Climatological studies;
- Accident and incident investigations;
- Research programmes;
- Forecast and warning verification;
- QC.

9.4.1.3 The following aerodrome observational elements, where available, should be archived:

- Surface wind direction, speed and gusts;
- Visibility and RVR;
- Present weather;
- Cloud amount, height of cloud base, cloud type and vertical visibility;
- Air and dew-point temperature;
- Atmospheric pressure;

- Wind shear;
- Sea surface temperature and significant wave heights.

9.4.1.4 It is important to also include information regarding the location of the observation, the date and time, units of measurement, QC flag and intensity of the meteorological element (where relevant). Information on sensor and system types and the dates of installation, commissioning, changes and decommissioning should also be archived.

9.4.1.5 For the purposes of accident and incident investigations, basic meteorological information concerning the approach and climb-out area, and conditions en route should also be stored, along with any meteorological information supplied to ATS units. This may include radar data, satellite imagery, NWP information and wind shear measurements.

9.4.2 **Data storage**

9.4.2.1 The period over which aeronautical meteorological information is to be stored should be agreed upon between the meteorological service provider and the meteorological and/or aviation authority. There may also be national (domestic) archive requirements that will need to be met. It is recommended that aeronautical meteorological information be stored in a central digital database with a separate off-site back-up facility.

9.4.2.2 ICAO Annex 3 states that information supplied to flight crew members shall be retained for a period of at least 30 days from the date of issue and made available for inquiries or investigations, then held until the inquiry or investigation is finished. This is considered to be the minimum requirement for data storage, whereas best practice is to store meteorological information for much longer periods of time, in particular for climatological purposes.

9.4.2.3 Aerodrome meteorological observations should ideally be stored indefinitely for the preparation of long-term time series as it is recommended that aerodrome climatological information be based on data series covering at least five years. In addition, these observations should be stored for a suitable period at the observation site (or nearby) so that it is possible to recover information in the event of data loss in central storage facilities.

9.4.2.4 Any meteorological observations, forecasts, advisories or warnings documented in written or hand-drawn chart form should be archived for at least the period until they can be scanned and stored securely in an electronic database. Derived information does not need to be archived as long as the information can be reconstructed using the original data. Any telephone or video recordings from the operational aviation meteorologist should be stored for an agreed period to ensure that any information required for accident or incident investigations can be recovered.

9.4.2.5 Information disseminated via national, regional or international communication networks should be stored by the responsible OPMET centre or databank.

9.5 **SYSTEM-WIDE INFORMATION MANAGEMENT**

9.5.1 **The SWIM concept**

9.5.1.1 Currently the majority of meteorological information consumed by aviation users requires a large element of human interaction from the initial provision to the transfer of the data, to the interpretation by the end user. The introduction of SWIM will see fewer human interactions and a move towards increasing machine-to-machine communications for meteorological information, which is expected to improve data distribution and accessibility as well as quality and reliability.

9.5.1.2 SWIM uses concepts described in the *Manual on System Wide Information Management (SWIM) Concept* (ICAO Doc 10039). The SWIM concept consists of standards, infrastructure and governance that enable the exchange of aeronautical information, including meteorological information, via SWIM-enabled applications and services. Interoperability is achieved globally through common information exchange models that describe the logical format and structure of the data elements that make up these domains. The agile delivery model uses simpler, more cost effective systems that enable greater flexibility with information exchange.

9.5.2 Meteorological information exchange in SWIM

9.5.2.1 The exchange of meteorological information is enabled using the following concepts, as detailed in the ICAO Plan for Aeronautical Meteorological (MET) Information in System-Wide Information Management (SWIM) (ICAO MET-SWIM Plan):

Information: The MET information contents being utilized and exchanged in SWIM. Information is exchanged using a data exchange format, of which one type is an Information Exchange Model. ... Data exchange formats are typically returned from information exchange services (request/reply) or sent as a portion of publish/subscribe messages. In the latter case, the payload must be small or a reference (e.g. uniform resource locator (URL)). The primary information exchange model in MET-SWIM is IWXXM.

Information Service: A web service which provides information consumers access to one or more applications or systems by means of the SWIM core services. It encapsulates a distinct set of operations logic within a well-defined functional boundary.

MET Information Services: An information service which is used to exchange MET information. An information exchange service enables interoperability by following well-defined standards and governance specifications agreed upon by stakeholders and implemented via commonly agreed means. In the MET-SWIM system, information exchange services are used to distribute, filter and transform MET information for use in SWIM.

Information Service Overview: the information service metadata intended to promote service discovery and an initial evaluation of an information service. It is the responsibility of service providers (e.g. MET service providers, ANSPs, etc.) to ensure that Service Overview information is available to describe the SWIM information services.

Information Service Definition: An agreement that documents the similarities of provided services when information service providers decide to align their services. A Service Definition is intended to be a template for certain service categories addressing general descriptive elements of one service that can be reused, as well as a template for same services that address features and technical aspects that should be equally applied.

9.5.3 Transition to a SWIM environment

9.5.3.1 The implementation and transition of meteorological information exchange into a SWIM environment will follow the aviation system block upgrade schedule outlined in the ICAO GANP. The ICAO Roadmap for Aeronautical Meteorological (MET) Information in System-Wide Information Management (SWIM) (ICAO MET-SWIM Roadmap) provides more detail on the timelines and strategies required for this transition.

9.5.3.2 It is recognized that the exchange of OPMET via the AMHS requires bulletins; however, the SWIM architecture offers a range of alternative, innovative approaches for exchanging meteorological information. In a SWIM environment it is recommended that

individual reports be made available as part of the basic aeronautical meteorological service so that additional SWIM services can then be built upon these. If a bulletin is still required, a service provider could collate these individual reports into bulletins.

9.5.3.3 In summary, the exchange of meteorological information in a SWIM environment is likely to include the following transitional components:

- The provision of meteorological information in IWXXM as the primary data form;
 - The provision of meteorological information via SWIM information services, including web feature service, web coverage service and web map service;
 - Additional data types beyond IWXXM, including gridded data;
 - Replacement of the AFTN and AMHS “message push” communications with advanced message queuing protocol.
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10. RESEARCH AND DEVELOPMENT

10.1 SCIENCE TO OPERATIONS

10.1.1 The benefits of research

10.1.1.1 Atmospheric research programmes are aimed at improving the quality and accuracy of weather, climate and environmental observations, prediction, service delivery and scientific assessments of national, regional and global environmental conditions. The application of advances in science to service delivery results in improved advanced warning of meteorological phenomena (such as cyclones) and other naturally occurring hazardous events (such as volcano eruptions) and allows all users, people and organizations, to better prepare and limit the loss of lives and property.

10.1.1.2 Research to improve aeronautical meteorological observations, forecasts and service delivery benefits the aviation industry by enhancing safety and efficiency during all phases of flight, and for other specific outcomes such as reducing fuel burn to reduce atmospheric pollution. Research is critical to gaining a better understanding of the effects of hazardous weather, climate extremes and air-quality issues on the aviation industry, and to developing strategies for adaptation and mitigation to climate change and variability, including extreme weather events.

10.1.2 Research to operations

10.1.2.1 With the rapid advancement in both science and technology, there is a growing demand for research that will ensure that aeronautical meteorological services are interoperable, fit for purpose and of high quality. A direct link needs to be established between research efforts and the long-term strategic plans related to the aviation industry, including strategies outlined in the ICAO GANP and the WMO *Long-term Plan for Aeronautical Meteorology* (AeM Series No.5).

10.1.2.2 However, research on its own is not enough. Being able to transfer this research into operations is the critical step in realizing the benefits of this research. Best practice involves identifying the need; engaging the stakeholders; using project management principles to undertake the research and implement the outcomes into operations; and employing the appropriate research, project management and implementation teams. It is important to plan and budget appropriately, thereby helping to ensure that research can be incorporated into operations and be sustainable.

10.1.3 National and international collaboration

10.1.3.1 National and international collaboration can be very beneficial when undertaking research. It allows for greater diversity of knowledge, skills and processes. Cost- and risk-sharing can help reduce the burden of costs and risks that may otherwise be attributable to a country or organization that conducts research in isolation.

10.1.3.2 Other benefits to be derived from collaboration include:

- The access to different technologies;
- The ability to run larger-scale projects;
- Building relationships and mentoring others;
- Sharing lessons learned from previous projects;

- Stimulating discussion and looking at alternative ways to solve problems;
- Capacity-building and overall motivation of the research and implementation teams.

10.1.3.3 The return time on the investment associated with a collaborative research effort may be faster compared with individual research efforts and the output may possess wider utility.

10.2 PROJECT PLANNING

10.2.1 Project life cycle

10.2.1.1 Project management is integral to research and development activities and deliverables. It aims at improving productivity, collaboration, accountability, performance and customer satisfaction, while reducing costs and workload. It is used to deliver the desired results by ensuring that projects are consistent with objectives and by providing sustainable benefits to the customer. There are a variety of different project management principles and methodologies. Choosing the right model will depend on the type, size and complexity of the project.

10.2.1.2 The WMO Project Management Guidelines and Handbook outlines the following stages within the project life cycle:

- Identification;
- Preparation;
- Implementation;
- Completion and evaluation;
- Post-completion follow-up.

10.2.2 Project identification

10.2.2.1 The reasons for undertaking a project may originate from the needs of the aviation industry; an opportunity to improve services; and/or by a legal or organizational requirement. The project identification phase consists of defining the project idea and undertaking a preliminary assessment of its relevance and feasibility. Research and consultation with stakeholders are required to establish the need and define the problem, and to identify the rationale for undertaking a project. This phase will result in the formulation of a project concept note (or similar) that outlines the project objectives, expected results, cost implications, funding sources, general implementation schedule, key risks and alternate solutions or options. It should enable prioritization of the project with respect to the overall objectives and strategic priorities of the organization.

10.2.3 Project preparation

10.2.3.1 After approval of the project concept note, typically by a project board or similar, the project needs to be properly designed and planned in the form of a project plan. During the project preparation phase a designated project manager, in consultation with stakeholders, will justify and describe the project, including its objectives, benefits, synergies with other projects, expected results, activities, deliverables, risks and risk-mitigation measures, and consistency with strategic priorities. This phase will also define the implementation plan and include the project management structure, project timelines and milestones, financial plan, how success will be measured, project reporting arrangements and details of post-project completion sustainability.

The project manager will secure approval and funding as well as identify the composition of the project team taking into consideration the skills and knowledge and the expected number of people required to successfully execute the project within the prescribed budget and timeline.

10.2.4 **Project implementation**

10.2.4.1 During the project implementation stage, planned activities are implemented and tracked against the agreed objectives, performance indicators, project timeline and associated milestones. The project manager will ensure that project personnel are recruited, goods and services are procured, and that progress and finances are monitored and routinely reported on. Risks must be continuously monitored, mitigated and documented. It is recognized that not everything will go exactly to plan, so the project manager must ensure that the project remains viable and achievable. The project manager will also need to assess the need for any revisions of the implementation plan and associated timelines, along with any changes to the financial agreements.

10.2.5 **Project completion and evaluation**

10.2.5.1 During the project completion and evaluation phase the project manager is required to prepare a project final report (or similar). This will include an assessment of the implementation milestones against the agreed targets and their sustainability into the future. The final cost of the project must be compared to the initial project budget to ensure accounting transparency. This stage may involve user testing or other means to evaluate the product, service or system in a trial environment against clearly defined evaluation criteria. The report will be the basis of final project acceptance prior to completing operational acceptance.

10.2.5.2 This phase also involves handing over the deliverables and documentation, cancelling supplier contracts, releasing staff and equipment, and informing stakeholders of the closure of the project. A report on lessons learned should be completed soon after the closure of the project so that future projects can be guided by what worked well and where improvements were needed.

10.2.6 **Project post-completion follow-up**

10.2.6.1 The post-completion follow-up is a critical stage in the life cycle of a project because it allows for the continuation of benefits to be derived after a project has been completed. This should be conducted when the benefits provided by the project have begun to be realized; for example when a new product or service is being actively used by aviation users. Such follow-up may take place several months to a year after the project closure. It is essential that the follow-up is conducted in consultation with the beneficiaries of the project. Any need for corrective action should be identified and actions taken accordingly. The project post-completion follow-up may also include the identification of maintenance and evolution actions, which could form the basis of a follow-up programme or project.

11. THE NEXT 10 YEARS

11.1 Chapter 1 (Introduction) highlights that meteorology is important to all phases of aircraft operations, and the provision of aeronautical meteorological services contributes to aviation safety, air navigation capacity and efficiency, economic air transport and environmentally responsible civil aviation.

11.2 Consistent with the move towards a globally harmonized, interoperable ATM system, the next 10 years will see traditional products – such as METAR, TAF and SIGMET – replaced by contemporary information services. SWIM will be central to the new operating environment.

11.3 Information on meteorological phenomena that are unconstrained by artificial boundaries (such as FIRs) will be exchanged via SWIM.

11.4 SWIM will enable the provision of new and innovative meteorological decision-support tools and impact-based services. These will be critical to common situational awareness and CDM amongst aviation users through the 2020s and beyond.

11.5 Continued scientific and technological advancement, and the implementation of these advances into operational services, should ensure that the aeronautical meteorological community – providers and consumers – remains ready to harness opportunities and overcome challenges wherever and whenever they emerge.

11.5 The responsibilities of aeronautical meteorological personnel will change as service delivery modalities evolve. There will be a need, for example, for observers and forecasters to adapt to continued advances in science and technology, including increased automation of observations at aerodromes, and to shifting engagement with aviation users that will result in roles that are more consultative or advisory in nature compared with today.

11.6 The validity (or shelf life) of formal training and assessment resources, the transferability of personnel between multiple competency frameworks, and the proficiency levels or dimensions of skills will be key considerations over the next 10 years.

11.7 The impacts of climate change and variability, manifesting through unseasonal or extreme weather events, may result in new or renewed demand for enhanced meteorological forecast and warning services as well as seasonal or sub-seasonal climate forecasts.

11.8 The provision of services on a multinational (multi-State) basis may become commonplace as aeronautical meteorological service providers seek to increase efficiency and reduce costs through the implementation of shared infrastructure and shared service delivery. Moreover, the establishment of such services may become a prerequisite for the provision of information on meteorological phenomena that is not constrained by any artificial boundary and is harmonized in space and time.

11.9 The next 10 years will be a time of great change within the aeronautical meteorology community. Changes that have been under careful consideration and planning over the past few years or longer will become a reality. Aeronautical meteorological service providers must embrace the challenges, maximize the opportunities and better mitigate and manage the risks associated with change. This will ensure that the best science, technology and expertise are used to deliver a safer, more efficient, economic and environmentally responsible aviation ecosystem.

ACRONYMS AND GLOSSARY

AD WRNG	aerodrome warning
AFS	aeronautical fixed service
AFTN	aeronautical fixed telecommunications network
AIM	aeronautical information management
AIP	aeronautical information publication
AIREP	air-report
AIRMET	Information concerning en-route weather phenomena which may affect the safety of low-level aircraft operations
AIS	aeronautical information service(s)
AIXM	aeronautical information exchange model
AMDAR	aircraft meteorological data relay
AMHS	aeronautical message handling system (or air traffic services message handling services (ATSMHS))
ANSP	air navigation service provider
AOR	area of responsibility
ARFOR	area forecast
ARS	special air-report(s)
ASECNA	Agency for Aerial Navigation Safety in Africa and Madagascar
ATC	air traffic control
ATIS	automatic terminal information service
ATM	air traffic management
ATN	Aeronautical Telecommunication Network
ATS	air traffic services
BIP-M	Basic Instruction Package for Meteorologists
BIP-MT	Basic Instruction Package for Meteorological Technicians
BKN	Broken, as related to cloud amount, 5 to 7 oktas
BUFR	binary universal form for the representation of meteorological data
CAVOK	Visibility, cloud and present weather better than prescribed values or conditions (“cloud and visibility are OK”)
CDM	collaborative decision-making

AD WRNG	aerodrome warning
Chicago Convention	The Convention on International Civil Aviation
CMA	continuous monitoring approach
CRC	China–Russian Federation Space Weather Consortium
DART	deep-ocean assessment and reporting of tsunami
D-VOLMET	datalink VOLMET
EFOD	electronic filing of differences
EUROCONTROL	European Organisation for the Safety of Air Navigation
FEW	Few, as related to cloud amount, 1 or 2 oktas
FIR	flight information region
FIXM	flight information exchange model
GAMET	area forecast (for low-level flights)
GANP	ICAO Global Air Navigation Plan
GASP	ICAO Global Aviation Safety Plan
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRIB	gridded binary or general regularly distributed information in binary form
HF	high frequency
IATA	International Air Transport Association
IAVW	International Airways Volcano Watch
ICAO	International Civil Aviation Organization
ICCAIA	International Coordinating Council of Aerospace Industries Associations
ICD	interface control document
IFALPA	International Federation of Air Line Pilots' Associations
IFATCA	International Federation of Air Traffic Controllers' Associations
IROG	interregional OPMET gateway
ISO	International Organization for Standardization
IWXXM	ICAO meteorological information exchange model
LIDAR	light detection and ranging

AD WRNG	aerodrome warning
Member (of WMO)	WMO Member State or Territory
MET	meteorological or meteorology
METAR	aerodrome routine meteorological report
MET REPORT	local routine meteorological report
NetCDF	network common data form
NMHS	National Meteorological and Hydrological Service
NOC	National OPMET Centre
NOTAM	Notice distributed by means of telecommunication containing information concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations
NSC	nil significant cloud
NWP	numerical weather prediction
OPMET	operational meteorological (information)
OVC	Overcast, as related to cloud amount, 8 oktas
PANS	procedures for air navigation services
PANS-ATM	Procedures for Air Navigation Services – Air Traffic Management (ICAO Doc 4444)
PECASUS	Pan-European Consortium for Aviation Space Weather User Services
QA	quality assurance
QC	quality control
QFE	Atmospheric pressure at aerodrome elevation or at runway threshold
QM	quality management
QMS	quality management system
QNH	Altimeter subscale setting to obtain elevation when on the ground
ROBEX Handbooks	ICAO Regional OPMET Bulletin Exchange Handbooks
ROC	Regional OPMET Centre
RODB	regional OPMET databank
ROFOR	route forecast
RVR	runway visual range

AD WRNG	aerodrome warning
SADIS	Secure Aviation Data Information Service
SAR	search and rescue
SARPs	standards and recommended practices
SCT	Scattered, as related to cloud amount, 3 or 4 oktas
SIGMET	Information concerning en-route weather and other phenomena in the atmosphere that may affect the safety of aircraft operations
SIGWX	significant weather
SMS	safety management system
SPECI	aerodrome special meteorological report
SPECIAL	local special meteorological report
SWIM	system-wide information management
SWXA	space weather advisory
TAF	terminal aerodrome forecast (in meteorological code)
TCA	tropical cyclone advisory
TCAC	Tropical Cyclone Advisory Centre
TEMP	temperature
TREND	landing forecast
USOAP	ICAO Universal Safety Oversight Audit Programme
VAA	volcanic ash advisory
VAR	volcanic activity report
VHF	very high frequency
VOLMET	meteorological information for aircraft in flight
WAFC	World Area Forecast Centre
WAFS	World Area Forecast System
WIFS	WAFS Internet File Service
WS WRNG	wind shear warning

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