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FOR THE SAFETY OF AIR NAVIGATION

EUROCONTROL

SEVERE WEATHER RISK MANAGEMENT SURVEY

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Abstract

Effective management of severe weather impact on the ATM system and flight operations is of great significance for improving the safety and cost-efficiency of aircraft operations and ATC service provision in Europe, in particular in congested airspaces. Severe weather phenomena disrupt air traffic flows and generate significant delays. If not managed properly, hazards to aviation associated to severe weather can lead to unsafe, high level of workload of pilots and controllers, and ultimately to losses of separation and aircraft accidents.

In 2011, on stakeholder request a Network Severe Weather procedure project was established by the Network Manager in EUROCONTROL in order to improve the support provided to ATC centres in managing the risk to aircraft operations caused by severe convective weather. The development of an effective severe weather risk management and coordination procedure should take due account of local ATC centres' capabilities, infrastructure, procedures and practices for severe weather impact management and how these elements could support the network severe weather procedure. Therefore a dedicated severe weather risk management survey was carried out in 2012.

The survey scope covered the entire chain of severe weather impact and risk management starting with weather forecasting by meteorological offices, addressing pre-tactical management by FMPs and the Network Manager and concluding with the deployment of tactical measures by ATC and pilots.

Keywords

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meteorological product	flight safety risk	risk management	sector protection

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EXECUTIVE SUMMARY

Effective management of severe weather impact on the ATM system and flight operations is of great significance for improving the safety and cost-efficiency of aircraft operations and ATC service provision in Europe, in particular in congested airspaces. Severe weather phenomena disrupt air traffic flows and generate significant delays. If not managed properly, hazards to aviation associated to severe weather can lead to unsafe, high level of workload of pilots and controllers, and ultimately cause losses of separation and aircraft accidents.

In 2011, on stakeholder request a Network Severe Weather procedure project was established by the Network Manager in EUROCONTROL in order to improve the support provided to ATC centres in managing the risk to aircraft operations caused by severe convective weather. The development of an effective severe weather risk management and coordination procedure shall take due account of local (ATC centre) capabilities, infrastructure, procedures and practices for severe weather impact management and how these could support the network severe weather procedure. Therefore a dedicated severe weather risk management survey was carried out in 2012.

The survey scope covered the entire chain of severe weather impact and risk management starting with weather forecasting by meteorological service providers, addressing pre-tactical management by FMPs and the Network Manager, and ending up with the deployment of tactical measures by ATC and pilots. The survey included in particular:

- Analysis of all weather related hazards (except natural hazards) in terms of impact on commercial transport operations and ATS provision;
- Review of available and used meteorological products;
- Review of en-route, terminal and airport ATM procedures related to weather impact management;
- Review of existing severe weather impact assessment and decision support tools;
- Identification and analysis of aviation accidents and incidents in which severe weather and related atmospheric conditions were reported as either a significant causal and/or contributory factor.

The collection and analysis of the survey data was supported by the establishment of a conceptual model for severe weather risk management in ATM. The model identifies the risks associated to severe weather impact on flight operations and describes the generic risk management functions, the actors involved and their interactions (see Chapter 3).

The review of the available information sources related to severe weather risk management (see Chapter 2) and the dedicated meetings with ANSPs and interviews with relevant specialists provided for the accumulation of sufficient information to build a credible outline of the current practices for severe weather risk management in Europe. This outline is presented in Chapter 5, section 5.1 “Summary of survey findings”.

By applying the conceptual model to the survey findings it was possible to identify and analyse a spectrum of available and used strategies for en-route and TMA ATC severe weather impact management. The survey findings and the analysis of the strategies enabled the development of a risk summary table (see Figure 5-7) that presents the effect of applying different strategies on the risks associated to severe weather impact.

The information collected and analysed in the course of the survey revealed a number of potential areas for improvement of the meteorological products used in severe weather impact assessment and enabled the identification of important issues which need to be addressed in order to improve the management of severe weather impact on flight operations and ATM in Europe, notably:

- With a few exceptions operational staff responsible for severe weather risk management at ATC units use standard (Annex 3) weather forecasts and reports, weather radar data and some other meteorological products. Use of dedicated tools and models for assessment of severe weather impact on ATC and flight operations is rather an exception. ATM decision support systems making use of enhanced weather forecast products and ATC impact assessment algorithms are not yet in operational use.

- Meteorological products (forecasts and current weather reports) conform to standards (ICAO Annex 3). However, there are very few enhanced products providing better granularity and improved accuracy of weather forecasts, appropriate to support efficient pre-tactical severe weather impact assessment and decision making.

- Optimisation of ATM system performance at network level as opposed to optimisation at 'local" level (optimal operation of network components does not mean optimal operation of the network) would require review of the current set of performance indicators and implementation of incentives for ANSPs.

The major conclusions from the survey are as follows:

Sufficiently managed Hazard Encounter Risk and Knock-on Flight Safety Risk. It can be argued within the context of this project that the Hazard Encounter Risk and Knock-on Flight Safety Risk, although not consistently managed at pre-tactical and tactical level, are sufficiently mitigated by the long standing procedures and the capabilities for in-flight avoidance. The in-flight Hazard Encounter Risk and Knock-on Flight Safety Risk are consistently managed in accordance with ICAO PANS-ATM and PANS-OPS provisions, aircraft operating procedures and other applicable national regulatory provisions. However, it can be argued within the context of this project that the risk of controllers' excessive workload (associated with the Knock-on Flight Safety Risk) is not sufficiently managed.

Inconsistent pre-tactical and tactical strategies. The severe weather hazard encounter prevention strategies and measures are applied inconsistently at pre-tactical and tactical level. The European ANSPs have developed and deployed different capabilities. In the majority of cases severe weather risk management is not applied at pre-tactical level. Some ANSPs have built the needed capability and competence but the lack of incentives and of an established process to capitalise on the available capabilities prevents the implementation of an enhanced and more effective severe weather risk management. This leads to sub-optimal ATM efficiency and increased air traffic controllers' workload, in particular in the critical time period before the tactical ATC measures take effect.

Non-interoperable pre-tactical and tactical strategies. In the rare cases of application, the risk prevention and mitigation strategies are based on locally developed capabilities, definitions and processes that are specific (not following common definitions, criteria, format, etc) and do not support an efficient communication and collaboration at Network level.

Sub-optimal performance of the European ATM Network. With respect to severe weather risk management the operation of the European ATM Network is suboptimal when applying the following criteria: (1) missed opportunities and (2) use of the available best practices. A risk management approach with adaptive incremental decision making presents a major opportunity for reducing weather related delays. The reasons for the sub-optimal performance can be found in the following groups of impediments:

- Lack of technical capabilities - tools to enable improved functioning of the risk management chain;
- Insufficient competence (e.g. lack of appropriate training) of involved actors;
- Lack of procedures - with few exceptions, operational supervisors are required to exercise their best judgment regarding the need to manage the anticipated impact of severe weather on the ATC operations;
- Lack of or inefficient incentives due to institutional and organisational reasons, such as: insufficient incentives for the ANSPs to introduce risk-based severe weather impact management and strategies that are optimised for the efficient operation of the Network; insufficient incentives for the meteorological service providers to go beyond the provisions of ICAO Annex 3 and provide information better supporting risk-based impact assessment and decision making; insufficient incentives for the FMPs to apply strategies at the pre-tactical level.

The detailed analysis of the survey findings and its conclusions can be found in Chapter 5.

1. Introduction

1.1 Survey objectives

Effective management of severe weather impact on the ATM system and flight operations is of, great significance for improving the safety and cost-efficiency of aircraft operations and ATC service provision in Europe, in particular in congested airspaces. Severe weather phenomena disrupt air traffic flows and generate significant delays. If not managed properly, hazards to aviation associated to severe weather can lead to unsafe, high level of workload of pilots and controllers and ultimately to losses of separation and aircraft accidents.

In 2011, on stakeholder request a Network Severe Weather procedure project was established by the Network Manager in EUROCONTROL in order to improve the support provided to ATC centres in managing the risk to ATC and aircraft operations caused by severe weather. Two operational trials of the procedure were conducted during the summer months of 2011 and 2012 with the participation of several European ACC units.

Moreover, the analysis of the operational trials' results and findings revealed the need of a more in-depth knowledge of the capabilities and practices deployed by the European ANSPs for management of severe weather impact on the safety of their operations. Hence, it was decided to carry out a dedicated severe weather risk management survey in order to:

- Reviewing the local (ATC unit) capabilities, infrastructure and practices/procedures for severe weather management and assessment how these could support the network severe weather procedure;
- Facilitating the experience sharing between ANSPs on managing the impact of severe weather on operations;
- Explicitly reviewing of the safety risk (created by severe weather) management, including factors, such as controller training, system support, procedures/practices, ATC/crew interaction;
- Improving safety knowledge management by making the information available and accessible on SKYbrary;
- Support the development of Network playbooks.

The survey has been conducted in the autumn of 2012.

1.2 Scope

The survey scope covers the entire chain of severe weather impact and risk management starting with weather forecasting by meteorological (MET) service providers, addressing the pre-tactical management by FMPs and the Network Manager and ending up with the deployment of tactical measures by ATC and pilots, and includes in particular:

- En-route, terminal and airport ATC provisions related to severe weather impact management;
- All weather related hazards and involved actors such as ATC controllers, pilots, aerodrome operations entities, etc; however natural hazards, such as volcanic ash, flooding, etc and mitigation of their impact is outside the survey scope;
- A focus on commercial transport operations - the survey does not address the non-commercial General Aviation weather risk management related issues;
- Review of available meteorological products;
- Review of existing impact assessment and decision support tools;
- Identification and analysis of aviation accidents and incidents in which severe weather and related atmospheric conditions were reported as either a significant causal and/or contributory factor.

1.3 Survey approach

The following basic principles were followed in the data collection and analysis:

- **Risk based** data collection and analysis process – risk to aircraft in flight caused by severe weather and its impact on the safety of ATC services is the main reason for all the activities undertaken by the concerned individuals and organisations, and therefore the management of this risk is the main objective and connecting element of all related activities by the different actors taking part in this collaborative process;
- **Objectivity** - provision of a factual snapshot of the current procedures, practices and system support related to severe weather impact management in Europe;
- **Focus on the information flow** irrespective of the organisational and institutional arrangements, e.g. some ANSP receive the MET services from external providers, while other provide MET services bundled with the basic ATS services;
- **Best practices driven** – the compliance with the applicable regulatory requirements was within the survey scope, but was not the survey priority;
- **Structured data collection** process based on a pre-defined survey protocol.

The data collection phase included meetings with ANSP, typically of half a day duration. The method of workshops was applied for exploring questions and topics that allowed for establishing of a comprehensive picture of organisation's capabilities and severe weather risk management practices. The information provided by the respondents helped obtain qualitative, and in some cases quantified data that provides the baseline of the expert analysis.

A guide for the workshop moderators was developed. The guide contained instruction for the interviewer, interview scenario, questionnaire, and report format for the interviewer's report. The interview scenario and the set of questions were reviewed before each meeting in order to reflect the local environment and particularities as far as possible.

The meeting summary reports reflected the discussions, current severe weather risk management arrangements and practices (deployed by the particular service provider) and proposed solutions to the issue, if any. The summary reports were subsequently analysed, the main issues and conclusions captured and outlined in the main report body. The detailed information collected during the survey workshops with ANSPs can be found in the meeting summary reports in Annex 6 – Survey Meeting Reports.

1.4 Document structure

This severe weather safety risk management survey document comprises the following Chapters and Annexes:

a) **Chapter 1** presents the survey objectives, scope and approach.

b) **Chapter 2** contains a short review of used information sources, inter alia regulatory material, MET products and weather related hazards, accident and incident reports, publications related to severe weather impact assessment and management.

c) **Chapter 3** describes the conceptual model for ATM severe weather risk management.

d) **Chapter 4** provides a summary of the data collection process including survey topics and information related to the conduct of data collection workshops.

e) **Chapter 5** contains the analysis of collected data and presents the survey findings.

f) **Chapter 6** contains a list of abbreviations and acronyms used in the document.

g) **Chapter 7** contains a list of reference documents.

h) **Annex 1** presents the hazard assessment cards and related description of actors' roles. The cards are based on the conceptual model for ATM severe weather risk management.

i) **Annex 2** provides a description of meteorological products made available to aviation users in accordance with ICAO Annex 3.

j) **Annex 3** provides information about specific meteorological products available for use by ATC and aircraft operators (best practices in USA).

k) **Annex 4** provides more detailed information about available decision support tools used in severe weather risk management.

l) **Annex 5** presents the detailed data collection protocol for the meetings with ANSPs.

m) **Annex 6** contains the detailed data collected during the meetings with ANSPs.

n) **Annex 7** contains a summary of aviation accidents and incidents in which severe weather and related atmospheric conditions were reported as either a significant causal and/or contributory factor.

1.5 Intended audience

This document describes and analyses the severe weather impact and risk management chain in Europe and refers to existing best practices throughout Europe and elsewhere in the world.

The document is intended for use by operational staff of ANSPs and the Network manager. It has been developed explicitly to support:

- Operational experts;
- Operational managers;
- Flow managers;
- Network managers,

when evaluating current practices and procedures and the options for improved management of severe weather impact on ATC operations.

2. Review of available information sources

The information sources reviewed and referred to in this report can be grouped into several categories:

Regulatory materials – documents produced by rulemaking organisation; mostly ICAO documents are used in this report, but EU legislation and some FAA documents have been reviewed as well.

Accidents and serious incident reports – reports produced by official aircraft accident investigation bodies. SKYbrary Accidents and Serious Incidents database was used to trace down the reports related to a particular weather hazard.

Research papers – materials published by universities or other scientific organisations, which reveal the latest trends in weather risk management research.

Project reports – materials describing the results of projects undertaken by non-scientific organisations (EUROCONTROL, private companies), having well defined objectives and well defined practical applications.

Technical descriptions - detailed description of the operation of a particular product or system.

Magazine articles – materials dedicated to both professional and wider audience.

Advisory materials – materials that are non-mandatory in nature, but serve to inform, educate and raise awareness on particular weather hazard.

Websites – various information available on the World Wide Web.

The distribution of reviewed and used information sources is as follows:

Source type	Number
Regulatory material	27
Accidents and serious incidents reports	25
Research papers	12
Project reports	9
Technical descriptions	3
Magazine articles	2
Advisory materials	13
Websites	33

2.1 Regulatory material

The following regulatory documents were reviewed and used in the scope of the project:

Annex 2	**Rules of the Air** Differentiates IFR and VFR conditions and stipulates relevant flight rules
Annex 3	**Meteorological Service for International Air Navigation** Arranges the provision of necessary meteorological information to operators, flight crew members, air traffic services units, search and rescue units, airport management and others concerned with aviation. Describes the liaison between those supplying the information and those using it.
Annex 6	**Operation of Aircraft** Defines standards and recommended practices in respect of operating minima based on the aircraft and environmental factors found at each aerodrome. Describes how factors such as aircraft type, aircraft equipment, characteristics of the approach and runway aids, skill of flight crew interrelate in order to carry out procedures involved in operations in all weather conditions
Annex 11	**Air Traffic Services.** Spells out basic requirements for flight information service provision (including dissemination of weather information to aircraft) as well as specifications for operation flight information service (ATIS, D-ATIS etc.)
Annex 14	**Aerodrome Design and Operations** Contains a broad range of subjects, including planning and maintenance of runway surfaces and visual aids and requirements for accurate information on the conditions at the airport (e.g. condition of runway surfaces).
Annex 15	**Aeronautical Information Services** Contains requirements to ensure the flow of information necessary for the safety, regularity and efficiency of international air navigation. Requirements for SNOWTAM and PIB are of a particular interest for the present study
4444	**Air Traffic Management** Contains procedures for weather deviation, issuing of information of adverse weather and weather reporting
014	**SIGMET/AIRMET**
8168	**Procedures for Air Navigation Services (vol I)** Application of certain procedures and rules (e.g. noise abatement, minimum safety altitudes) with regard to adverse weather conditions, mandates inclusion of weather in pre-flight briefings
7030	**Regional Supplementary Procedures** Contains regional procedures on how to proceed in certain adverse meteorological procedures (e.g. forecast or non-forecast turbulence)
7910	**Location indicators**

8896	**Manual of Aeronautical Meteorological Practice** Contains a broad range of procedures on provision of meteorological service in aviation – met observations and reports, forecasts, SIGMET, AIRMET, briefings etc.
9328	**Manual of Runway Visual Range Observing and Reporting Practices** Details practices on RVR assessment
7488	Manual of the ICAO Standard Atmosphere
9837	Manual on Automatic Meteorological Observing Systems at Aerodromes
9377	**Manual on Coordination between Air Traffic Services, Aeronautical** **Information Services and Aeronautical Meteorological Services** Details coordination procedures between ATS units and Meteorological services providers to enable ATSU to provide the necessary MET information in-flight as well as carry out air traffic control functions
9817	**Manual on Low-level Wind Shear** Describes characteristics of wind shear, meteorological conditions and phenomena that cause it, effect on aircraft performance ,observing, forecasting and reporting as well as related training
9873	Manual on the Quality Management System for the Provision of Meteorological Service to International Air Navigation
9640	**Manual of Aircraft Ground De- icing/Anti-icing Operations** Provides summary of information essential to the planning and execution of de-icing/anti-icing operations during conditions which are conducive to airplane icing on the ground
9137	**Airport Services Manual** Details the appropriate use of various manufacturers' friction testing devices
9365	**Manual of All- Weather Operations.** Defines the principles of the Low Visibility Procedures and All Weather Operations.
WMO Publication No. 306	Manual on codes, volume i.2, part b — binary codes

2.2 Accident and incident reports

The review of the weather related accidents and serious incidents[1] included in Annex 7 – Summary of accidents and incidents shows that most fatal and high risk occurrences related to severe weather happen during the **approach** and **landing phases** of the flight. The same weather hazards can be encountered during the **climb** and **en-route** phases, however the consequences are usually less severe due to availability of more effective mitigation means. During the approach and landing phases of flight the workload in the cockpit is very high and any weather hazard evasive or impact mitigation actions are time critical.

1 As per the definition provided in ICAO Annex 13.

The severe weather related accidents and incidents can be attributed to the following weather related hazards:

- In-flight icing;
- Severe air turbulence (convective cloud origin[2]);
- Hail damage;
- Lightning strike;
- Low visibility due to fog or precipitation;
- Strong low level/surface winds and windshear.

The consequences of the **in-flight icing** hazard (ice accretion both with rime and clear ice) include but are not limited to: control difficulties due to degradation of aircraft performance which ultimately could result in loss of control; limited visibility; communication problems; blockage of pitot-tubes and static vents and ice shedding.

The consequences of the **severe air turbulence** hazard include but are not limited to: abrupt changes in attitude and altitude with large variations in airspeed; temporary loss of control (there may be periods where effective control of the aircraft is impossible); level busts attributed to abrupt changes in altitude and subsequent loss of separation; loose objects may move around the cabin and cause injuries to passengers and crew and damage to aircraft structure.

The consequences of the **hail damage** hazard include but are not limited to: considerable damage to aircraft which may not be immediately apparent to the crew including cracked and glazed windshields and windows which in turn can hinder visibility from the cockpit and ultimately may lead to loss of control and controlled flight into terrain (CFIT).

The consequences of the **lightning strike** hazard include but are not limited to: aircraft/airframe damage (mostly affected airframe parts are the radomes, tail fins together with the control mechanisms and surfaces); crew incapacitation due to blindness from the lightning flash; interference and damage to the avionics and the on-board electronic equipment; engine shutdown due to transient airflow disturbance associated with lightning which cause shutdown on both FADEC[3] and non-FADEC engines with close-spaced engine pairs.

The consequences of the **fog** and **low visibility hazard** include but are not limited to: impaired visibility from cockpit which affect take-off and landing operations; aquaplaning; runway incursion and excursion; CFIT.

The consequences of the **strong surface winds hazard,** applicable to aircraft at low altitude (approach, landing and climb phases of flight) can be particularly dangerous as

[2] This document addresses severe air turbulence only as a function of air movement associated with convective activity, especially in or near a thunderstorm which may occur in cloud or clear of cloud.

[3] FADEC - Full authority digital engine (or electronics) control is a system consisting of digital computer, called an electronic engine controller (EEC) or engine control unit (ECU), and its related accessories that control all aspects of aircraft engine performance.

any loss of control may occur sufficiently close to terrain to make recovery difficult or impossible. Such surface air movements include but are not limited to: windshear related to thunderstorms and extreme down-bursts (microbursts) which occur below the base of cumulonimbus and towering cumulus clouds which may lead to loss control.

Further high risk situations may be created by the flight crew actions to avoid a severe weather encounter or mitigate its impact on the flight. Such situations include: loss of separation (which ultimately could result in mid-air collision) and controlled flight into terrain (CFIT).

2.3 Meteorological (MET) products

Annex 2 – MET Products according to ICAO Annex 3, provides an overview of the various aviation specific meteorological products used in aircraft operations and ATS for anticipation of weather related hazards and identification of appropriate risk mitigation strategies and plans. Each product is presented in a tabular format with reference to its operationally meaningful parameters, including: short description, product type, data source, validity period, update rate, usage by ATC and pilots, probability (forecasts only), etc.

Annex 2 to this report includes presentation of the following current weather reports and forecasts:

- Meteorological Terminal Aviation Routine Weather Report - METAR;
- Aviation special weather report - SPECI;
- Local Routine (MET Report);
- Special Report;
- Aerodrome forecast (TAF);
- Landing forecast (TREND);
- Forecast for take-off;
- GAMET area forecast;
- SIGMET warning.
- AIRMET warning;
- Aerodrome warning;
- Upper air forecast;
- Significant weather (SIGWX) forecast chart;
- Volcanic ash advisory information chart;

- Tropical cyclone advisory information.

However, it is important to note that there is a big difference between the ICAO Annex 3 defined information/products, and their intended use and how this information/products are used in practice. For instance, METAR/SPECI, TAF, TREND and to some extent AIRMET/GAMET are specified to meet flight preparation requirements. They were never designed to be used in an airport and/or ATS decision making environment. And as such will de-facto never deliver the best 'service' for these operating environments.

Furthermore, the literature review and the meetings with European ANSPs have supported the identification of a number of additional MET products used for severe weather hazard anticipation and impact assessment. Such products are often bespoke or customized current weather reports or forecasts and can be considered as "best practice" in the field (refer to ANSP meeting reports in Annex 6). The list of "best practice" products is constantly growing and keeping it up-to-date would be a challenging task.

Annex 4 - MET products available to ATC and Operators (USA) provides a short overview of five further products:

- The Thunderstorm product;
- Ceiling and visibility product;
- Graphical Turbulence Guidance (GTG);
- The Icing product;
- Winter Weather Research Product (WSDD).

2.4 Impact assessment and decision support tools

Presently, it is generally accepted that adverse weather development processes are forecasted with a certain degree of limitation, often expressed by the probability factor (the probability factor may differ depending on the type of adverse weather). Ultimately, the successful forecasts models are likely to be probabilistic, taking account of the uncertainties in both the large and small scale atmospheric processes. The success of designing an optimal forecasting system entirely depends on understanding of the roles and interactions of the various scales of atmospheric motion involved in the initiation of convective events.

Significant progress in assessing the impact of forecasted convective weather has been made in recent years due to mainly FAA directed research for the integration of high resolution probabilistic 4D forecasting models into ATM collaborative decision support systems. These models have still certain limitations to be accounted of. A number of models are briefly described in Annex 3 – Decision support tools.

Most, if not all of severe weather impact assessment models described briefly in Annex 3, are developed and tailored for the U.S National Airspace System. The majority of the models, including the most mature ones, are designed to estimate the impact of convective weather on the ATM resources and performance parameters. Currently, there is a lack of well-developed impact assessment models for oceanic/remote areas' weather and volcanic ash, as well as for assessment of space weather impact on aircraft operations and ATM.

Most models use as input various weather forecasting and reporting methods and products and translate the forecasted/reported weather to aviation constraints and threshold events. The output is used further for operational impact assessment and decision support by taking due account of declared ATM system performance parameters (e.g. sector capacities). Many impact assessment models use a rectangular grid (e.g. 4 km) covering the area of interest to estimate the impact of severe weather on the planned operations within the affected airspace. This approach enables the estimation of capacity reduction per individual ATC sector. To date, the impact assessment and decision support tools are at different level of maturity – some are in operational use, while others are still in research phase.

Models and 'storm prediction' programmes used by the FAA include the Weather Research and Forecasting (WRF) Model which is a mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It features multiple dynamical cores, a 3-dimensional variational (3DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometres. Various European users have adopted this model.

The Corridor Integrated Weather System (CIWS) appears to be among the most mature modelling tools. It acquires data from FAA terminal weather sensing systems, and National Weather Service sensors and forecast products, and automatically generates convective weather products for display on existing systems in both terminal and en route airspace within the CIWS domain. CIWS products are provided to Air Traffic Control (ATC) personnel, airline systems operations centres, and automated air traffic management decision support systems in a form that is directly usable without further meteorological interpretation.

In October 2010, CIWS became the first ATC system to share information via the USA application of System Wide Information Management (SWIM) interface. SWIM compliance enables sharing of weather information provided by CIWS to US en-route centre traffic management units with external users, such as airline operations centres, and creation of a common situational awareness.

Another mature decision support tool is the Route Availability Planning Tool (RAPT). It is intended to help air traffic controllers and airline dispatchers determine which departure routes will be affected by operationally significant convective weather up to 90 minutes into the future (a 30 minute planning window plus 60 minutes flight time). RAPT assigns a departure route status to future departures (e.g clear of impact, low impact, caution or blocked) by combining CIWS precipitation and echo tops forecasts. RAPT became operational in US in August 2002, and has evolved in response to feedback from operational users and post event performance analysis.

Another tool with high potential is the Weather Impacted Traffic Index (WITI) which is intended for quantifying actual and forecast weather impact on air traffic. The WITI measures the number of flights impacted by weather. Each weather constraint is weighted by the number of flights encountering that constraint in order to measure the impact of weather on U.S National Airspace System (NAS) traffic at a given location.

Historically, WITI has focused on en route convective weather, but the approach is now applied to other weather hazard types as well (e.g. snow at an airport).

A further product which deserves attention is the Convective Weather Avoidance Model (CWAM). It is a model which helps assess the convective weather impact on traffic in en route airspace. The CWAM model was built by analysing historical traffic and weather data to determine when pilots choose to deviate or penetrate convective weather.

A web based tool that can be accessed over a CDM net in US is the Common Constraint Situation Display (CCSD). It allows participants (such as airlines) to view a graphical display of information which can be used to monitor the state of the NAS and to manage their operations. The data displayed on the CCSD comes from the Enhanced Traffic Management System (ETMS), which is the main automation system that the Federal Aviation Administration (FAA) uses for traffic flow management. It uses selected weather information, such as the current intensity of precipitation. The CCSD manages flow-constrained areas (FCAs) and provides a number of rerouting options. It uses weather forecast data from 3 different sources.

The Dynamic Airspace Rerouting Tool (DART) developed in 2010 under NASA sponsored research features flight rerouting algorithms that take into account both actual and forecast weather. It employs an original “stepout- and-scan” algorithm to find an economical reroute around dynamic convective weather (it can combine diagnostic and forecast) and, if a reroute is not possible, adds a small ground delay and retries until either a reroute is found or the delay exceeds some threshold and the flight has to be cancelled. As part of this research the concept of Probe Reroutes, has been developed: areas of airspace can be “probed” (tested) for permeability using series of probe flights, which can be initiated and terminated at any Lat/Long location.

A prototype set of tools is The Collaborative Routing Coordination Tools (CRCT). It is developed to help the Federal Aviation Administration (FAA) detect traffic flow problems in advance, generate problem resolutions, and evaluate the resolution strategies. CRCT does this by modelling four-dimensional aircraft trajectories and using them to predict traffic demand per ATC sector. Developed by the Centre for Advanced Aviation System Development (CAASD) at the MITRE Corporation as part of its Traffic Flow Management Research and Development activities, CRCT currently exists on a research platform.

A further research programme established by the FAA is the Consolidated Storm Prediction for Aviation (CoSPA). The objective is to integrate the currently used experimental systems into one high-quality expert system. It is a collaborative effort between the following US organizations: Federal Aviation Administration (FAA), the Massachusetts Institute of Technology (MIT), National Centre of Atmospheric Research (NCAR), National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), National Aviation and Space Agency (NASA), Department of Defence (DoD), universities and private organisations. The programme goal is to integrate and evaluate existing prototype products such as Corridor Integrated Weather System (CIWS), Integrated Terminal Weather System (ITWS), Collaborative Convective Forecast Product (CCFP), Convective SIGMETS, Numerical Weather Prediction (NWP), AutoNowcaster, and National Convective Weather Forecast (NCWF). The CoSPA display leverages the CIWS display capabilities and associated functionalities, which allows users familiar with CIWS to easily utilize CoSPA.

Furthermore, from 2010 to 2014, the FAA is planning to establish capability enhancements in the context of NEXTEN Work Package 2 which includes the integration of high confidence two hour weather predictions onto the primary display used by Traffic Managers and into Traffic Flow Management System (TFMS) through CIWS.

The above short product description demonstrate the enormous effort that has gone into the R&D on MET-ATM convective weather issues in the USA. The descriptions shall not be interpreted as an evidence of the actual use of these products, services and impact models in day-to-day operations. The majority of the projects mentioned are still projects in the experimental phase and their fitness for operational use is still to be validated.

In Europe, the development of weather translation models[4] and their integration within ATM decision support systems is lagging behind in comparison to the US.

The MET bulletin produced by the BELGOCONTROL MET office can be considered as a “best practice” forecast product in ATM for the European region. It provides enhanced explanation and presentation of the weather phenomena, such as thunderstorm, snow and icing, low cloud ceiling and low visibility, and strong and/or gusty winds. The MET data is easily understood by the concerned operational staff and is used for assessment of severe weather impact on ATC and capacity risk management. The information about the forecasted events/threats (time period, event type, probability) is provided per ATC sector.

Further, examples of tailor made weather forecast products are the “OpenRunway” and “WeatherWindows” developed by UK MET office. “OpenRunway” is an online weather forecasting package providing essential weather information regarding the RWY conditions and alerts to changing conditions for major UK airports around London. “WeatherWindows” is a specific forecasting and planning tool that enables decision makers to plan efficiently up to 15 days ahead weather dependant tasks such as RWY maintenance tasks, airport infrastructure changes, construction works. The product covers a wider area, i.e. 5-10 NM around the airport. The information is presented in graphical form, using colour coding.

[4] Models and algorithms for conversion and processing of weather inputs (forecast and current weather products) and other inputs (ATC system parameters) in order to produce aviation constraints and threshold events.

3. Conceptual model for severe weather risk management in ATM

3.1 Description of risk management functions

The severe weather impact can be associated to two different, yet interdependent, risks, notably **Flight Safety Risk** and **Flight Efficiency Risk.**

The **Flight Safety Risk** is the ultimate driver for the existence of the severe weather impact management. Flight Safety Risk can have different sources and manifestations:

- **In-flight Safety Risk** (impact on flight crew):
  - **Hazard Encounter Risk** – this risk is originating from the probability of a flight being exposed to severe weather and from the possible effects of this encounter. For example, possible effects of a flight being exposed to severe turbulence are level bust, aircraft damage, aircraft power loss, passenger injuries, crew incapacitation and loss of control in flight.
  - **Knock-on Flight Safety Risk** – this risk, the crew is exposed to, is originating from the "side" effects of the prevention and mitigation measures, undertaken to reduce the hazard encounter risk. For example, prolonged deviation to an alternate airport may contribute to a situation of fuel shortage. Another example is crew preoccupation and distraction which contribute to a less efficient threat and error management.
- **ATCO Excessive Overload Risk**. Similarly to the knock-on flight safety risk the ATCO excessive overload risk is a by-product of the measures undertaken to prevent or mitigate the hazard encounter risk. The difference is that the effect is on ATC and not directly on flight crew. It is important to note that ATC sectors may or may not be overloaded (current traffic demand exceeding declared sector capacity) but the ATCO can have an excessive subjective workload.

The **Flight Efficiency Risk** is associated to the likelihood and potential extent of incurred flight delays or even cancellations made due to severe weather risk management.

It has been decided to put the Hazard Encounter Risk at the core of the model as it is the original reason for the existence of the array of activities associated to severe weather risk management. Therefore decomposing the activities, starting with those associated to hazard encounter risk management is considered a truly systematic approach to revealing the reasons (or lack of reasons) for the existence of certain activities.

For the purposes of this model, the management of the Hazard Encounter Risk is described using two generic risk management functions: ***risk prevention*** and ***risk mitigation***.

Risk prevention is understood as any action aimed at avoiding the materialisation of the risk. These actions are further assigned to three time phases:

- **Pre-tactical prevention** – all actions taken before the day of operation (D-1);

- **Tactical prevention** – all actions taken on the day of operation, but before the commencement of the flight (off-block);
- **In-flight prevention** – all actions taken after commencement of the flight (off-block) but before hazard encounter.

Risk mitigation could be described as the actions taken by the concerned actors to contain the impact and minimise potential adverse safety effects on ATM and flight operations following hazard encounter or when encounter is imminent.

For both generic risk management functions**,** impact of prevention and mitigation actions on the operational environment is studied and described in order to be able to trace risk propagation throughout the system. The description of the generic risk management functions is done by means of a number of **specific functions**:

- Flight Trajectory Prediction – 4D prediction of the future position of the aircraft along the flight route;
- Traffic Forecast – flights expected to be within a given airspace volume (e.g. ATC sector) within a given time interval (e.g. 15 min or 1 hour); enhanced traffic forecast may include flight trajectories within the given airspace volume;
- Weather Anticipation – foreseeing the presence of a weather phenomenon that may endanger the safety of flights within a given airspace volume within a given time interval; weather anticipation is based on weather forecast(s), current weather reports and observation(s), and any other source of meteorological information;
- Weather Detection – determining the location of hazardous weather phenomenon, for example by means of weather radar products;
- Weather Network Warning – notification by an ATC unit to the Network (the Network Manager and/or adjacent ATC units) of expected severe weather within its area of responsibility;
- Weather Translation – use of models, algorithms and tools to convert the weather forecast and current weather report products and other inputs (ATC system parameters) in aviation constraints and threshold events;
- Integration of Weather and Airspace Information – a technical function (e.g. a tool) allowing for an integrated graphical display of forecasted/reported severe weather phenomena and affected airspace structures;
- ATC Impact Assessment – assessing the impact of severe weather on the ability of the ATC system (ATC unit) to ensure safe and efficient handling of forecasted traffic (the assessment could be supported by tool(s) for integrated processing of weather, airspace and traffic information);
- Impact Network Warning - notification by an ATC unit to the Network of expected impact (e.g. affected traffic flow, unavailability of an ATC sector's airspace or flight level layer, or of a runway on an airport for a given period of time) of severe weather within its area of responsibility; it may be combined with either Weather Network Warning or Intent Network Warning;
- Capacity & Demand Balancing Decision – decision at Network and/or local ATC unit level for the implementation of measures (e.g. flow regulation) for mitigation of severe weather impact on ATC operations;

- Intent Network Warning - notification by an ATC unit to the Network about planned measures (e.g. flow regulation) for mitigation of severe weather impact on ATC operations;
- ATCO Overload Prevention – implementation by an ATC unit of the planned or other appropriate measures for mitigation of severe weather impact on ATC operations;
- Flight Efficiency Effect Management - actions taken by the model actors (AO, pilot, ATC, etc) to minimise the adverse impact of weather hazard encounter prevention and of mitigation measures on flight efficiency;
- Knock-on Effect Management – actions taken by the flight crew (with or without coordination with AOC) and ATC to mitigate the Knock-on Flight Safety Risk;
- Weather Encounter Forecast – flight crew (AO) using the planed trajectory and weather data to determine the likelihood of severe weather encounter;
- Weather Encounter Avoidance – actions taken by the flight crew (with or without coordination with AOC) to prevent weather hazard encounter;
- Weather Encounter Mitigation - actions taken by the flight crew (with or without coordination with AOC) to mitigate the effects of encountered weather hazard.

The above are the functions are generic and do not necessarily represent current procedures and practices. The functions are used to characterise a conceptualised situation. The functions, interacting with each other, ensure the appropriate management of severe weather risks to ATM and aircraft operations. In order to optimise the severe weather risk management the main study question to be answered is: **"Are these functions and their interaction optimal for the given operational environment?"** In order to examine the potential answers to this question, for the purposes of this survey, the interaction of the functions has been described by means of a model.

The model was established by using the notion of **probabilistic directed acyclic graph with qualitative designation of the influences**. It is possible to quantify such a model, for example by using Bayesian or Markov probabilistic networks but this is beyond the scope of the current project. However, it is considered important to use a model that allows for further expansion and multiple use. The model is depicted on Figure 3.1 overleaf.

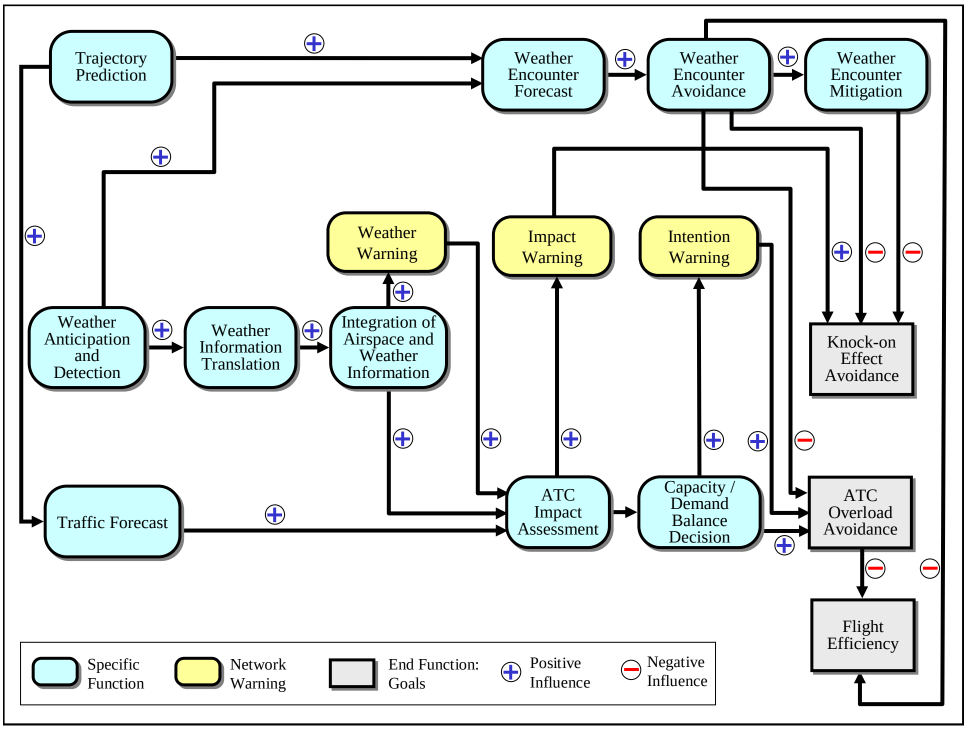


Figure 3-1: **Hazard encounter risk management model**

3.2 Description of model actors

Model actors are generic ATM system and flight operations roles who, through their actions, accomplish the goals of severe weather risk management functions. In this model eight (8) major actors have been identified: pilot, air traffic controller, operational supervisor (OPS SUP), local air traffic flow manager (FMP), aircraft operator, airport operator, network manager (NM), meteorological services provider (MET office). A generic description of each role's task and responsibilities with regard to severe weather risk management is provided below:

Pilot is understood as the crew of a particular flight. Most often this means the flight-deck crew, but in certain cases it may include cabin crew as well. These are the personnel that have direct responsibilities for the in-flight operation of aircraft systems, navigation and flight safety. At the tactical prevention phase the pilot anticipates probable weather hazards by reviewing weather data (forecasts and reports) and planned route, and then acts accordingly, for example by changing planned flight parameters, such as delaying departure, carrying extra fuel, changing route etc. In-flight prevention includes scanning for and detecting of adverse weather using various information sources (such as weather radar) and then changing flight trajectory, as needed, in order to avoid the affected area. At the mitigation phase pilot manages aircraft's state in best possible way in order to reduce exposure to and minimise the effects of encountered adverse weather hazard. Pilot's actions, both preventive and mitigatory, directly impact on the air traffic control function. The pilot does not participate at the pre-tactical phase.

Air traffic controller (ATCO) is used as a generic term to describe the ATC team responsible for managing a particular airspace sector. Normally this is the executive-planner pair, but could include an assistant controller or other, depending on local organisation. Main duties include (among others): provision of separation between aircraft, flight information service and provision of efficient flight trajectories within the area of responsibility. At the tactical prevention phase ATCO anticipates probable weather hazards using information from various available sources (e.g. weather radar, pilot reports) and plans for possible changes in operational environment (e.g. change in airspace/runway configuration, operational constraints, etc). At the in-flight prevention phase ATCO scans for and detects weather hazards using various information sources, plans for possible alternative prevention options and disseminates this information to pilots, as required. Prevention actions may address both safety of flight (crew warning or avoidance advice) and ATS system (notification of OPS SUP and/or adjacent sectors/unit). The mitigation actions include assistance to pilots and measures to minimise adverse impact on ATS, for example increased separation minima. As a general rule, the latter are coordinated with the OPS SUP. The ATCO does not participate at the pre-tactical prevention phase.

The operational supervisor is the ATCO on duty, who is in charge of the ATS provision by an air traffic control unit. In smaller units this could be a single person, but could be a team of supervisors in the case of large ACC centres, where each sector family has its own assistant supervisor. The OPS SUP would normally be responsible for managing sector configurations, assigning controllers to sectors, deciding on introduction of low visibility operations (LVP) and any other measures to contain the adverse impact of severe weather on ATS system and ensure the required level of safety of provided services. At the tactical prevention phase OPS SUP anticipates probable weather hazards using information from various sources, and plans for and decides on possible change in airspace/runway configuration, sector staffing, working procedures or traffic flow restrictions. A set of alternative options is considered and the most appropriate are selected and activated, as appropriate, during the tactical and in-flight prevention phase. At the mitigation phase OPS SUP monitors the situation and actively manages sector configurations and staff, or changes procedures (e.g. separation on approach) in accordance with the evolving situation. OPS SUP works closely with FMP and sector controllers, and coordinates with airport operator and adjacent ATS units, as appropriate.

Flow Manager's role is, in partnership with Network Manager, to support the most efficient use of available ATM resources through a timely and effective ATFCM process. FMP area of responsibility is usually limited to the AoR of parent ACC, but in certain cases a FMP may cover the AoR of several ACCs. FMPs provide network manager with "local knowledge" including any data or information which could be considered as necessary or useful in the effective and efficient execution of the ATFCM task, such as sector configurations and activation/de-activation schedules, monitoring values, taxi times, runway configurations etc. The FMP intervenes at the pre-tactical and/or tactical prevention phases by: anticipating adverse weather hazards using various information sources, assessing potential impact on local ATC operations, planning for possible prevention strategies and advising OPS SUP of potential mitigation measures, coordinating traffic flow regulations and disseminating network warnings. In general, traffic flow regulations are issued following coordination with the OPS/TWR SUP and Network Manager. The airport operator may be consulted if departures are affected.

Airport operator is the holder of the airport certificate and all its representatives, employees or agents that are directly responsible for the safe and efficient conduct of airport land-side operations. At the pre-tactical and tactical prevention stages airport operator anticipates adverse weather conditions using various information sources and plans for additional resources (e.g. de-icing fluid) or prevention measures (e.g. fixing light aircraft). Particular actions taken depend on the type of weather hazard, but are most often related to the management of pavement conditions and/or change in working procedures. Mitigating actions taken by airport operator are mostly related to the management of airport surface conditions, aircraft stand management, and dissemination of relevant information. Airport operator coordinates with OPS/TWR SUP, ATCO and aircraft operators.

Aircraft operator is any organisation or enterprise engaged in or offering to engage in an aircraft operation. In the context of this survey the aircraft operator's responsibility is defined with regard to the pre-flight preparation (provision of required MET and aeronautical data, flight planning) and provision of in-flight assistance to flight crews. In many cases the aircraft operator may outsource the information provision and flight planning tasks to other specialised organisations. The aircraft operator may participate at the pre-tactical and tactical prevention phases through review of weather forecasts, anticipation of weather hazards and change to the flight schedule/flight plan, or even cancellation, if appropriate. Aircraft operator may provide assistance to pilots at the in-flight prevention phase by advising on possible mitigation measures, such as alternate aerodrome or route. The aircraft operator carries out these tasks by means of an airline operations centre or dispatch centre. The aircraft operator coordinates with the NM, airport operator and pilot.

Network Manager (NM) is the EUROCONTROL network operations team that is responsible for the delivery of operational service in the domains of flow and capacity management, flight planning, information management, crisis and contingency management. NM enables all actors involved in flow management to share a common view of the airspace situation. Other tasks NM is dedicated to are the central collection, processing and distribution of flight plans and ensuring the balance of traffic demand and available airspace capacity over the long and short term. At the pre-tactical and tactical prevention phase the NM: anticipates adverse weather hazards using various information sources; coordinates with local FMPs on possible ATS impact mitigation strategies, consolidates all information available into a single network view; facilitates information flows between network players; assesses network impact and coordinates with FMPs local traffic flow regulations. Flow regulations are issued by NM at the tactical prevention phase and in rare cases at pre-tactical phase. The NM does not participate at the mitigation phase. NM coordinates with FMPs and aircraft operators.

Meteorological service provider within the scope of this survey shall be understood as aerodrome meteorological office, meteorological watch office as described in ICAO Annex 3 or any other public or private entity engaged in weather forecasting and reporting. A MET office maintains a watch/continuous survey of the meteorological conditions within its area of responsibility, prepares and disseminates SIGMET and AIRMET information, prepares and obtains forecasts on local aerodrome conditions, provides briefings and consultations and supplies meteorological information to aeronautical users. The MET office participates at the pre-tactical, tactical and in-flight prevention phases by continuously providing information on expected and actual meteorological conditions to all other actors. The contents, granularity and accuracy of supplied information is of paramount importance and influences the decision taken by all actors in this risk management model.

Figure 3-2 overleaf represents the interrelationship between different model actors.

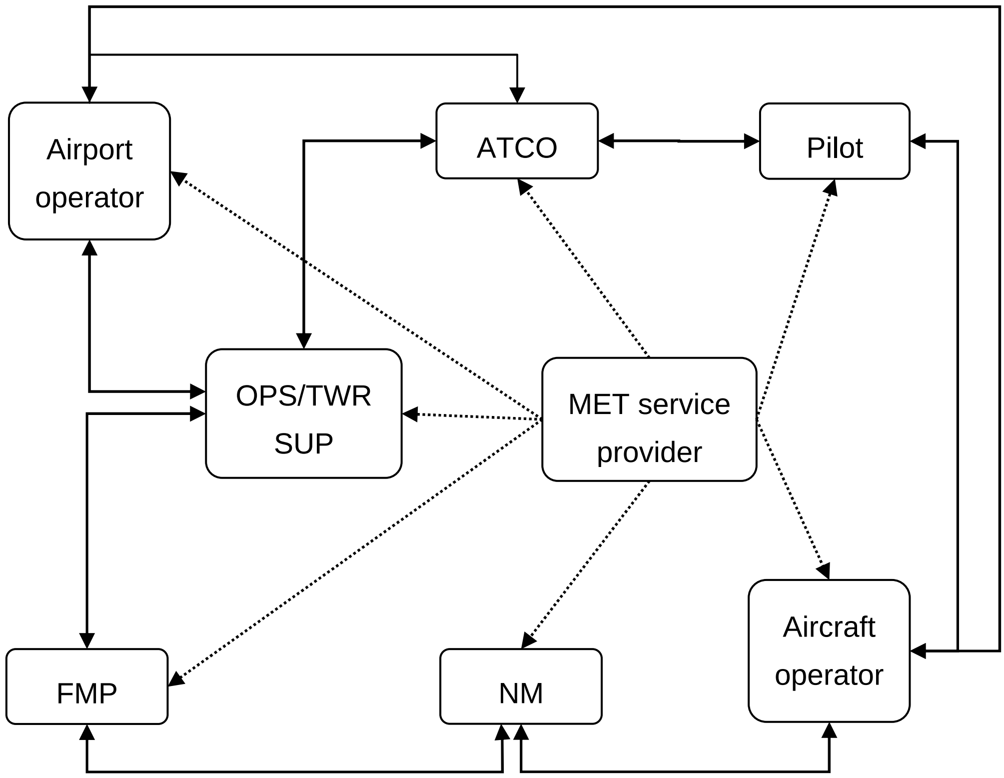


Figure 3-2: Model actors' interaction

3.3 Tabular model presentation and best practices

An alternative means of depicting tasks and relationships of model actors is the tabular format as presented on page 24. The table is titled "Hazard Assessment Card" as it enables a qualitative assessment of the potential weather hazard effects on exposed flight, as well as the direct and indirect impact on ATS provision.

The vertical axis of the table lists the model actors and horizontal axis describes the possible prevention measures per phase, as established in 3.2 above, the mitigation measures and the impact of both prevention and mitigation measures on flight operations and ATS provision.

The tabular form of the conceptual model has been used to present the collected knowledge about existing and currently used measures for severe weather risk management. The generic model table is presented on pages 25-26.

The seven (7) tables developed at Annex 1 titled "Hazard Assessment Cards", together with their detailed textual description, contain the procedures and best practices for management of risk related to the following weather hazards:

- Low visibility;
- Strong low level & surface winds, windshear and microburst;

- Severe turbulence;
- Lightning;
- In-flight icing;
- Heavy precipitation causing runway contamination.

Hazard Assessment Card

Wx Hazard:	Potential effects on a flight exposed to the Wx hazard
hazard name	*description of effects*

Actor / Description	Pre-tactical prevention (D-1)	Tactical prevention (D0 till departure)	In-flight prevention	Impact of the prevention measures	Mitigation of exposure to hazard	Impact of the mitigation measures	Related regulatory requirements
Pilot	N/A	anticipate weather hazards change planned flight parameters	detect weather hazard change flight trajectory	flight delay reduced flight efficiency	manage aircraft state to reduce exposure and mitigate effects	Increased workload; reduced flight efficiency	ICAO Annex 6
ATC controller	N/A	anticipate weather hazards plans for change in ops environment	anticipate weather hazards provide avoidance advice notify concerned actors	no adverse impact	assist pilot increase separation	reduced flight efficiency	ICAO Doc 4444
OPS SUP	anticipate weather hazards coordinate mitigation strategies	anticipate weather hazards change airspace/RWY configuration, manage sectorisation decide on flow measures	monitor situation change airspace/RWY configuration, manage sectorisation	flight delay reduced flight efficiency	monitor situation change ATC procedures manage sectorisation	reduced flight efficiency	ICAO Annex 11 Doc 4444
FMP	anticipate weather hazards identify prevention strategies propose flow measures	monitor situation propose re-sectorisation coordinate flow measures	N/A	flight delay	N/A	N/A	CFMU Handbook
Airport Operator	anticipate weather hazards plan for additional resources and prevention measures	monitor situation Adapt aircraft service procedures manage airport surface conditions	N/A	flight delay	monitor situation de-ice aircraft manage airport surface conditions	reduced flight efficiency	ICAO Annex 14

Aircraft Operator	anticipate weather hazards change flight schedule/flight plan	monitor situation change flight schedule/flight plan cancel flight	monitor situation advise pilot on alternate aerodrome or route	flight delay reduced fleet efficiency	advise pilot on alternate aerodrome	reduced flight efficiency	ICAO Annex 6 EU IR/OPS
Network Manager	anticipate weather hazards Coordinate impact mitigation strategies	anticipate weather hazards coordinate impact mitigation measures publish flow regulations coordinate alternate routes	N/A	flight delay reduced flight efficiency	N/A	N/A	EU NM IR
MET service provider	survey meteorological conditions produce and disseminate forecasts	survey meteorological conditions produce and disseminate current weather reports adjust and disseminate forecasts;	N/A	N/A	N/A	N/A	ICAO Annex 3

4. Data collection

4.1 Survey protocol

The survey protocol was developed with the objective to enable structured and systematic collection of data for analysis. The survey protocol is consistent with the conceptual model described in Chapter 3 and covers the following main topics:

A. Standards and/or regulations and/or national requirements to be complied with by the ANSP in management of severe weather impact on ATC and flight operations.

B. MET products and data made available, and actually used by responsible ANSP actors (e.g. OPS SUP, FMP, ATCO):

a) weather forecast products;

b) current weather reports;

c) weather radar data;

d) weather satellite data;

e) pilot reports;

f) any other sources.

C. MET data flow in the ATC unit:

a) from / to: MET office (if applicable) ; ATC unit controllers (TWR, APP and ACC); OPS SUP; FMP; any line managers;

b) MET data transmitted to airport operators (e.g. runway related data), pilots and/or airlines;

c) any dedicated MET data exchange tools and means for intra- and inter-centre coordination.

D. Procedures, guidance and practices for management of severe weather impact, including:

a) tactical ATCO procedures/guidance;

b) OPS SUP procedures/guidance;

c) FMP procedures/guidance.

E. Decision making loop and responsibilities, in particular:

a) how is decision taken (process) and who is involved (roles and responsibilities);

b) is an explicit risk assessment required;

c) are measures prescribed (e.g. by a procedure) or taken on a case by case basis.

F. Tools and models used for:

a) weather translation (presenting the MET data to the concerned operational staff at the required granularity and identifying constraints and threshold events in an easy to comprehend way);

b) ATC impact assessment (supports assessment on the impact on ATM system performance parameters, such as safety level, sector capacities, etc);

c) decision support (assistance to OPS SUP in identifying the most appropriate and proportionate risk prevention and mitigation measures to be applied);

G. Measures used to mitigate impact of severe weather - en-route and terminal/airport operations

H. Notification of severe weather impact and coordination of measures to be taken:

a) inter-sector and inter-unit (within the ANSP);

b) inter-centre (with other ANSPs);

c) with airport operators, aircraft operators and NMC.

I. Incident and accidents, if any, where weather was reported to be a factor

K. ATC contribution to severe weather risk: any reports about flights being forced into bad weather as the result of an ATC restriction (for example, use of “level cap” due to insufficient capacity in a sector).

The detailed survey questionnaire establishing all survey topics and used in the data collection process is provided at Annex 5 – Survey questionnaire.

Data was collected by means of dedicated survey meetings (workshops) with several ANSPs.

4.2 Data collection workshops

The method of workshop interview was considered the most appropriate for collecting qualitative data. Firstly, the persons being interviewed are members of a team (in some cases formally established) responsible for the achievement of a goal or set of goals. Secondly, the purpose of the interview is to gather information about a particular topic and related issues guided by a set of focused questions. Participants hear and interact with each other and the moderator, which yields different information from that obtained if people were interviewed individually.

The purpose of workshops is to develop a broad and deep understanding rather than a quantitative summary. The hallmark of workshop is the explicit use of the group interaction to generate data and insights that would be unlikely to emerge without the interaction found in a group. The technique inherently allows observation of group dynamics, discussion, and first hand insights into the respondents’ behaviour, attitudes, language, etc. It is not necessary for the group to reach any kind of consensus, nor is it necessary for people to disagree. The objective is to get high-quality data in a social context where people can consider their own views in the context of the views of others, and where new ideas and perspectives can be introduced.

Six (6) data collection workshops were held in total, notably with representatives of five European ANSPs and the FAA. In addition, FMP and operational specialists from further European ANSPs were interviewed in order to collect information on the procedures and practices used to manage severe weather impact on ATS operations.

Workshop participants may be assigned to the following main groups:

- Operational supervisors;
- Flow managers;
- Safety experts/managers.

The survey protocol was used to ensure not only the structured collection of data during the workshops, but to enable a meaningful post-workshop data analysis and conclusions. Moreover, the workshop participants were given the opportunity to provide any further information considered relevant.

The data collected at the survey workshops were captured in workshop reports that were subsequently coordinated and agreed with the workshop participants. The workshop reports are provided in Annex 6 – Survey meetings reports.

5. Findings, analysis and conclusions

5.1 Summary of survey findings

The findings of the severe weather risk management survey were gradually accumulated as work on the project tasks progressed. The review of the available information sources related to severe weather risk management (see Chapter 2) enabled the survey team to identify a couple of important issues which need to be addressed in order to improve the management of severe weather impact on flight operations and ATM in Europe:

1. Use of dedicated tools and models for assessment of severe weather impact on ATC and flight operations is rather an exception. ATM decision support systems making use of enhanced weather forecast products and ATC impact assessment algorithms are not yet in operational use.

2. MET products (forecasts and current weather reports) conform to standards (ICAO Annex 3). However, there are very few enhanced products providing better granularity and improved accuracy of weather forecasts, appropriate to support efficient pre-tactical severe weather impact assessment and decision making.

The dedicated meetings with the ANSPs and interviews with relevant specialists provided for the accumulation of sufficient information to build a credible outline of the current severe weather risk management practices in Europe. This outline is presented below using the basic structure of the survey protocol, as described in 4.1 above. The conclusions and findings hereafter are formulated as generic statements, applicable to the ATS provided by the European ANSPs, without referring each time to the surveyed population:

A. Standards and/or regulations and/or national requirements to be complied with by the ANSP in management of severe weather impact on ATC and flight operations

ICAO standards and recommended practices concerning the provision of ATS in adverse weather conditions (e.g. low visibility) and provision of meteorological information to flight crews are followed in all States. In some States controllers are required (i.e. it is mandatory) to pass available information about hazardous weather phenomena (e.g. severe turbulence) to concerned flights. Specific national rules related to severe weather risk management are rather an exception. In the case of Belgocontrol safety assessment of the dedicated severe weather management procedure was requested by the NSA.

B. MET products and data made available, and actually used by responsible ANSP actors

In all ATC centres operational staff[5] are provided with the aerodrome forecasts (TAFs) for the area of interest and in most the en-route centres controllers have access to the upper wind forecasts. In some centres operational staff can consult further weather

[5] Air traffic controllers, operational/tower supervisors and flow managers

forecast products, such as GAFOR, GAMET and general regional forecasts, accessible on the intranet or internet. Few ANSPs receive enhanced forecast products (exceeding Annex 3 requirements) which enable an improved ATS provision in adverse weather conditions and more efficient decision making by the responsible actors – OPS/TWR SUP and FMP. Examples of such products are the “OpenRunway” and “WeatherWindows” in UK and Belgocontrol MET bulletin.

Current weather reports (i.e. METAR, SPECI) and ATIS are available to the operational staff in all surveyed ATC units.

In the vast majority of ATC units controllers have access to weather radar information at their working positions either integrated with the operational (radar and flight plan) data or on a separate display. This enables controllers to provide information about location of hazardous areas (e.g. CBs) or avoidance advice on pilot request.

In difference to the weather radar data, satellite weather data are not commonly available at the operational working positions. In some ATC centres satellite weather maps and animation products (showing the direction of movement of detected weather) are available at the OPS SUP and FMP positions.

Pilot reports are important source of information about weather hazards, in particular regarding the severity of impact and current location of hazardous weather. However this information is not always pro-actively sought by controllers (or shared by the flight crew). Upon reception of a pilot report, controllers pass the information to other flights in the affected area and in some cases (e.g. severe turbulence, windshear) to the MET office in line with requirements of Annex 11 and 3.

Often, OPS/TWR SUP has access to more MET data products and more detailed meteorological information than sector controllers. Such information may include enhanced forecasts of aerodrome conditions, weather radar products, possibility to consult the MET office providing meteorological services to the ANSP, etc.

The meteorological information is usually accessible at the operational positions by means of a separate information display system. In some centres, weather radar data and data from the weather channel of ATC radars can be displayed in the main radar situation display window. In one ATC units a MET portal is currently being developed with the aim to provide all operational users with customised meteorological information.

The meetings with ANSPs revealed several potential areas for improvement of the MET products to support safe, more efficient and expeditious ATS provision:

- improved weather radar data presentation - as an overlay on the actual airspace structure, including also possibility to display a vertical plan view allowing for estimation of affected altitudes and flight levels;
- better predictability of severe weather;
- improved estimation of phenomenon probability allowing for a shift to a more pre-tactical management of severe weather impact in the long term, thus reducing the impact of unwanted diversions.

C. <u>MET data flow in the ATC unit</u>

In the majority of ATC units controllers are briefed about hazardous weather at shift start and position handover. However, in some centres there is no dedicated weather briefing; according to the local regulations controllers are responsible to brief all elements of the air situation at the start of their duty. In some centres, the OPS SUP is provided with the capability to insert and send weather related information to all CWP to be observed on a separate display.

In most ANSPs, OPS SUP would contact the FMP and inform them about expected weather impact and need of flow measures. However, in a few cases weather briefing and decision on implementation of flow measures is a collaborative process.

In general, ANSPs do not use dedicated tools for exchange and dissemination of meteorological information – MET data are distributed on the local area network (LAN). The meteorological information is displayed at the operational positions either on a dedicated display and/or on a multi-purpose display.

A good practice identified by the survey is that airport ATC units inform the airport operators about expected disturbances of traffic flow due to severe weather and related traffic management decisions (e.g. use of holding patterns) and restrictions.

D. Procedures, guidance and practices for management of severe weather impact

With a very few exceptions ANSPs do not have dedicated severe weather risk management procedure, but follow applicable generic procedures as per the applicable operational manuals and existing guidance material.

Tactical ATCO procedures include:

- use of increased separation minima;
- suspension or limited use of parallel headings;
- coordination of changes to flight trajectories with adjacent sectors;
- passing of pilot reports about significant weather (e.g. severe turbulence) to concerned flights and to the MET office, as appropriate;
- controllers do not provide proactively to flight crews avoidance advice (e.g. vectoring around CB), but upon request can inform pilots about the weather they observe on the CWP displays and the avoiding actions implemented/reported by other crews.

The OPS/TWR SUP procedures include:

- monitoring of current and predicted weather conditions and sector loads and assessment of the need to implement sector protective measures;
- implementation of flow measures (e.g. reduces rates);
- coordination with adjacent units and implementation of traffic restrictions at the Transfer of Control (ToC) points and/or affected airports;
- taking decision on the use of and changes to holdings and STARs depending on the location and evolution of the weather phenomenon;
- implementation of increased minimum departure intervals (MDI), increased separation on approach and traffic prioritisation;
- implementation of low visibility operations (LVO);
- regulating departures at closely situated airports;
- suspension of RVSM operations.

The FMP procedures include:

- assessment of potential impact of severe weather using available weather forecasts, predicted traffic data and their expertise;
- coordination of possible traffic flow measures with OPS/TWR SUP and NM;
- monitoring traffic counts / sector occupancies and notifying the OPS/TWR SUP of expected capacity issues.

E. Decision making loop and responsibilities

In the majority of States decision for the implementation of traffic flow measures is taken by the OPS/TWR SUP. The OPS/TWR SUP may or may not consult the FMP. In some ATC units the decision for implementation of flow regulations is the result of a collaborative process with the participation of the OPS SUP, team supervisors (e.g. ACC, APP), FMP and operational experts, as applicable.

In most ANSPs there is guidance for the OPS/TWR SUP on capacity reduction, acceptance rates and other sector protection parameters to be implemented depending on the type and severity of impact of weather hazards. Values are recommended and the OPS/TWR SUP has to exercise his/her judgment when making decision.

In general, implementation of traffic flow measures is postponed as much as possible until sufficient confidence is build that ATC services will be adversely affected. Due to the specific European environment (size of airspace and closely situated airports) implementation of traffic flow measures 1 to 2 hours in advance proves often to be effective. In case decision for implementation of flow regulation at an airport is based on the weather forecast, the respective traffic regulation is issued typically 3 to 4 hours in advance.

Some ANSP representatives indicated that the EU imposed ANSP performance management and indicators is not conducive to making decision at corporate level for the implementation of pre-tactical severe weather risk management.

In general, a dedicated risk assessment of severe weather impact is not required and not performed at tactical level.

The following examples of good practices are worth a wider dissemination:

- In one ANSP at pre-tactical level the FMP manager carries out risk assessment, determines the mitigation strategy, files a dedicated template and distributes it to the concerned actors. The possible mitigation strategies have been described in detail and include sets of measures and related implementation scenarios. The strategies are implemented at tactical level by the FMP controllers. FMP controllers have received appropriate training and are all ACC supervisors.
- In another ANSP the morning briefing of the ACC, APP, TWR supervisors and FMP staff include assessment of the situations and decision on the use of particular sectorisation schemes and/or implementation of flow regulations, if needed. The latter may be taken or postponed for a later moment depending on the forecasts, current weather reports and the development of the situation.

F. Tools and models for weather translation, ATC impact assessment and decision support:

With a few exceptions (e.g. a few ANSPs use enhanced weather forecast products) operational staff responsible for severe weather risk management use standard (Annex 3) weather forecasts and reports, weather radar data and some other meteorological products. A tool for integrated display of the available meteorological and airspace data, and assessment of the impact on the ATC elements (sectors, traffic flows, etc) is not yet in operational use. Such tools are under development in few ATC centres.

G. Measures used to mitigate impact of severe weather

The following pre-tactical and tactical measures are being applied by the ANSPs:

- defensive controlling techniques (at sector level);
- sectorisation management;
- additional controller at sector position;
- opening positions that were previously bandboxed at the ATC airport units;
- traffic flow regulation;
- tactical flight re-routing;
- use of holding patterns;
- traffic prioritisation;
- increased separation on approach;
- reduced arrival rate;
- diversion to alternate airport;
- implementation of departure rates - minimum departure intervals;
- increased departure intervals (used to alleviate issues in the terminal sectors);
- departure traffic restriction (e.g. delay or temporary ban);
- regulating departures at closely situated airports;
- low visibility operations.

H. Notification of severe weather impact and coordination of measures (to be) taken

Internally, within the ATC unit: Avoidance routes and/or holdings are coordinated between ACC sectors and with TMA / TWR sectors.

With adjacent ATC units: In general, a dedicated notification/coordination procedure related to severe weather impact coordination and management does not exist. However unusual and emergency situations and traffic restrictions on entry points are communicated by the OPS SUP. In some cases coordination with airport ATC units is triggered by pilot reports of areas avoided due to weather (CBs).

With airport operators: OPS/TWR SUP passes information about traffic flow measures affecting airport operation. The severe weather risk management procedure of Belgocontrol includes two daily conferences with the airport operator.

With aircraft operators: In general not performed. In the case of NATS, the FMP sends on D-1 a brief on expected ATC capacity for the next day to a list of aircraft operators.

With the Network Manager: Carried out in line with the established procedures and agreements.

I. Incident and accidents in which weather was reported to be a factor

Severe weather contribution to incidents can be considered limited. The typical descriptions of such incidents are:

- Separation infringement caused by unexpected deviation of a flight from its planned route due to avoiding action without previously notifying the sector controller.

- Separation infringement on final approach due to variation in wind direction and speed.

Most often weather appears as factor in ATC incident reports related to sector overload.

K. ATC contribution to severe weather risk

One report was received about several flights asked to plan their flight trajectory through airspace affected by CB activity due to ATC restriction, notably implementation of level cap to protect upper sectors. Following coordination safe trajectories were agreed.

L. Potential improvements identified during the data collection workshops

- Improved traffic predictions and weather forecast; however the existence of limiting factors for predictability improvement is recognised;

- Improved management of resources to the limit possible, including monitoring quality of service and implementing improvement measures;

- Improved presentation of the weather information, in particular: vertical extent, reliable presentation of hazardous weather behind weather radar return layer (presentation in depth), precision and granularity;

- Improved impact assessment and decision support tools, including workload and complexity modelling, as well as tagging of flights to be acted upon;

- Optimisation at network level as opposed to optimisation at ‘local” level (optimal operation of network components does not mean optimal operation of the network); such process should be supported by incentives; potential incentives to consider might be “network delay attribution” and “missed opportunity to reduce the network delay”;

- Improved strategic and tactical management of potential diversions to alternate aerodromes at local and network level, taking into account recent trends in aircraft operating policies to minimise reserve fuel carried and the capacity of airports filed as alternate by the flights affected by adverse weather at the destination airports.

- Further optimisation of the performance scheme to ensure that service providers implementing measures to optimise/improve network performance are not unduly penalised; however it should be recognised that there is a limit to what can be done in severe weather scenarios.

- Optimisation of traffic flow measures, and respectively of ATC network, as a central service.

- Change in methods used for flight efficiency calculation (last filed route) may motivate wider implementation of severe weather risk management procedure.

5.2 Analysis

The process of managing severe weather impact on aviation operations can be characterised as:

- **Safety-driven** – the ultimate reason for aircraft in flight to avoid exposure to severe weather is because it is potentially unsafe.
- **Multi-disciplinary** – there are various actors involved, both at organisational and individual role level, including: pilots, air traffic controllers, flow managers, ATC supervisors, ANSPs, aircraft operators, airport operators, meteorological services providers and the Network Manager.
- **Proportionate** – the scale of intervention strategies is proportionate to the magnitude of the severe weather impact.
- **Time critical** – in a time sequence the following, sometimes overlapping, conceptual steps can be outlined:
  - Weather hazard anticipation;
  - Weather hazard detection;
  - Assessment of potential impact (on flight) of weather hazard encounter;
  - Identification of possible encounter prevention and mitigation measures;
  - Assessment of potential impact on the flight and on the ATM network of the weather hazard encounter prevention and mitigation measures;
  - Weather hazard exposure prevention (managing Hazard Encounter Risk);
  - Weather hazard exposure mitigation (managing Hazard Encounter Risk and Knock-on Flight Safety Risk);
  - Prevention and mitigation measures impact management (managing ATCO Excessive Overload Risk and Flight Efficiency Risk).
- **Risk-based** – The severe weather impact is associated with two different, yet interdependent: **Flight Safety Risk** and **Flight Efficiency Risk**.

For the purpose of analysing the survey findings the survey scope is divided into two separate groups:

- En-route and TMA ATC severe weather impact management;
- Airport ATC severe weather impact management.

This grouping is considered appropriate due to the commonality of the hazard encounter preventive and mitigation approaches. It is to be noted that the Airport ATC severe weather impact management often affects the terminal operations (e.g. use of holding patterns, increase separation on approach, etc).

The survey determined that for the en-route and TMA ATC the most relevant weather hazards are: severe turbulence, lightning and in-flight icing. Typically, these hazards are associated with the existence and the development of convective weather.

By applying the conceptual model to the survey findings it was possible to identify and analyse a spectrum of available and used strategies for en-route and TMA ATC severe weather impact management. The strategies are differentiated depending on the degree of accomplished notification and communication regarding the forecasted/actual weather, its potential/actual impact on ATC operations and the application of flow measures:

- **Strategy A** is characterised by: lack of communication at network level (with other ATC units or the Network Manager) about the forecasted/reported severe weather and related impact; traffic flow measures or STAM are not implemented; severe weather risk is managed locally at tactical ATC level.
- **Strategy B** is characterised by: systematic communication at network level (with other ATC units or the Network Manager) about the forecasted/reported severe weather and the related impact; traffic flow measures or STAM are not implemented; severe weather risk is managed locally at tactical ATC level.
- **Strategy C** is characterised by: lack of communication at network level (with other ATC units or the Network Manager) about the forecasted/reported severe weather and related impact; implementation of traffic flow measures or STAM in addition to tactical ATC mitigation measures.
- **Strategy D** is characterised by: systematic communication at network level (with other ATC units or the Network Manager) about the forecasted/reported severe weather and related impact; implementation of traffic flow measures or STAM in addition to tactical ATC mitigation measures.

According to the above definitions traffic flow regulations or STAM are not used in strategies A and B. The survey identified that in such situations successful management of weather hazard encounter risk depends on the correct and timely pilot decision for and execution of in-flight weather avoidance. Thus, the avoidance flight trajectory ❷ is a deviation from the flight planned trajectory ❶ (see Figure 5-2). In the worst case, identified by the survey, the trajectory of the avoiding flight penetrates the adjacent sector’s (Y) airspace without prior coordination. In case Strategy A is applied, both affected ATC sectors (X and Y) are not protected against ATCO excessive overload risk. In case Strategy B is applied, sector X is not protected but the protection of sector Y is possible.

The time needed by the aircraft to travel the additional distance on the avoidance flight trajectory ❷ constitutes an “in-flight avoidance” delay. This delay affects the flight efficiency but is not captured and monitored through the delay indicators established in the context of the European ATM performance scheme.

Figure 5-2 overleaf illustrates graphically strategies A and B.

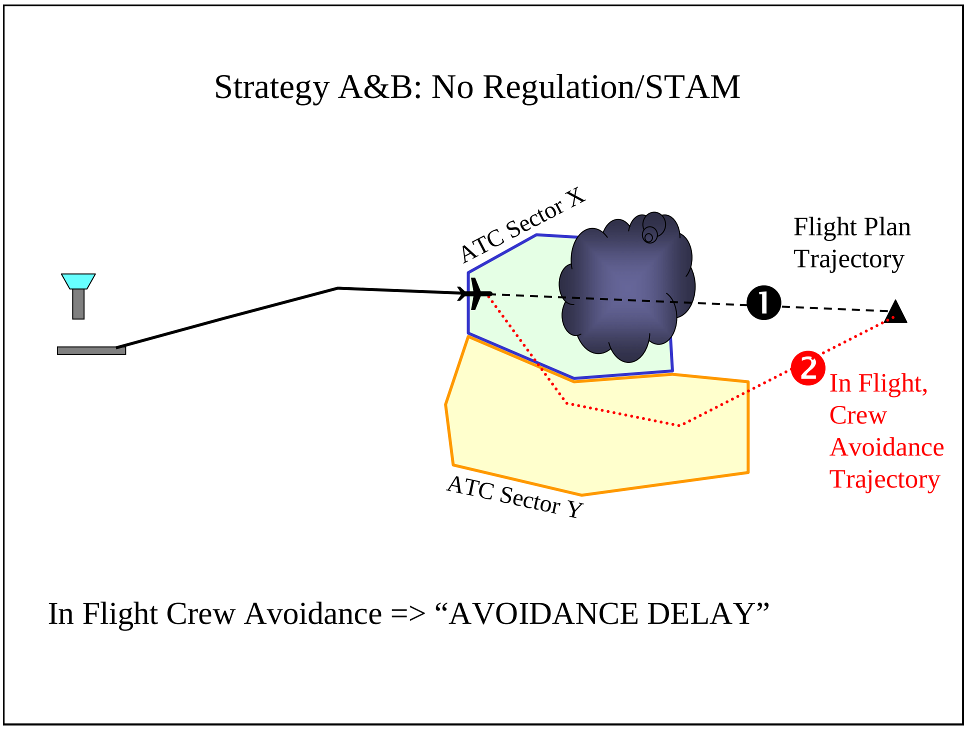


Figure 5-2: Strategies A & B – In-flight crew avoidance

On the other hand, in line with the provided strategy definitions, traffic flow regulation or STAM are used in strategies C and D. The entry of the flights, affected by the traffic measures, into the weather impacted sectors is either delayed by forced holding on the ground at the airport of departure or, in rare cases, avoided by re-routing before departure. The application of traffic flow measures generally causes "capacity" delay that is captured and monitored through the delay indicators established in the context of the European ATM performance scheme.

Figure 5-3 overleaf illustrates graphically strategies C and D for flights affected by traffic flow regulation measures or STAM.

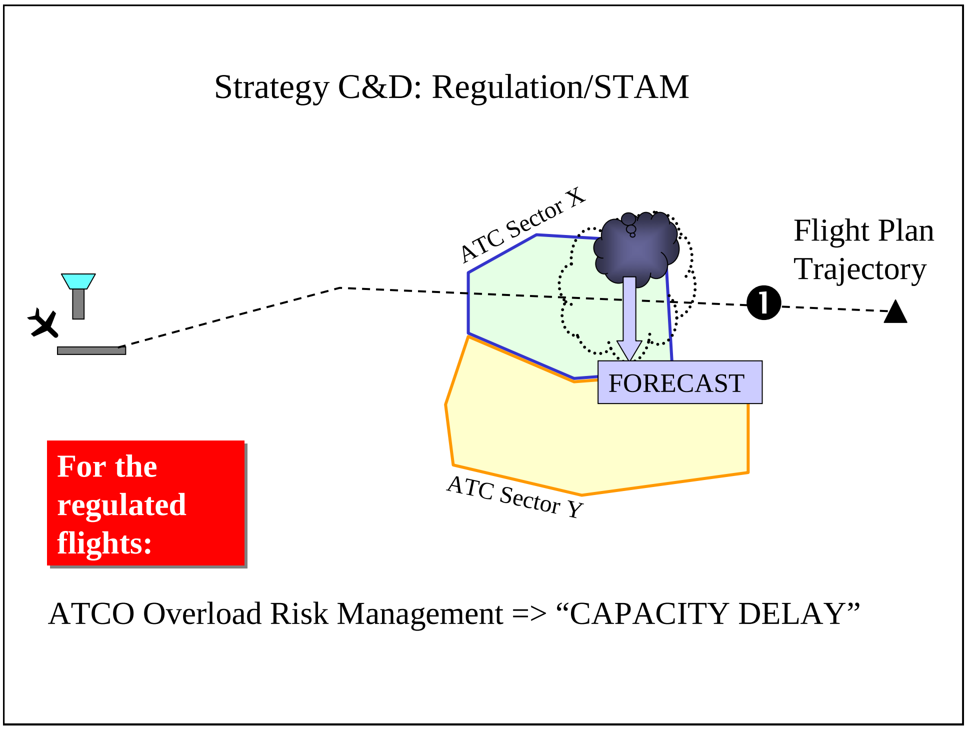


Figure 5-3: Strategies C & D – Flow regulation & STAM

In strategies C and D the trajectories of flights not affected by flow measures or STAM are similar to Strategy A or B in-flight avoidance trajectory and, consequently, such flights incur similar "in-flight avoidance" delay.

Figure 5-4 below illustrates graphically strategies C and D for flights not affected by flow regulation measures or STAM.

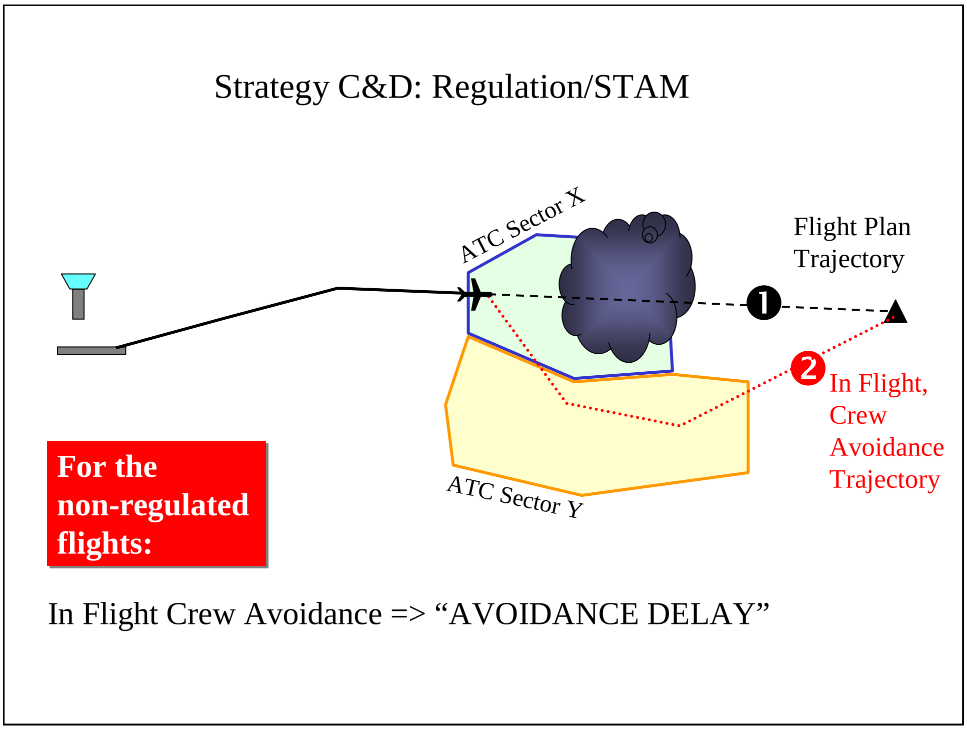


Figure 5-4: Strategies C & D – Flights not affected by flow measures

In Strategy C the lack of communication about the impact on Sector X, can result in Sector Y overload, in particular when more than one unplanned and unknown flight enters its airspace. A summary of the ATCO excessive overload risk analysis for all the strategies is presented on Figure 5-5 below.

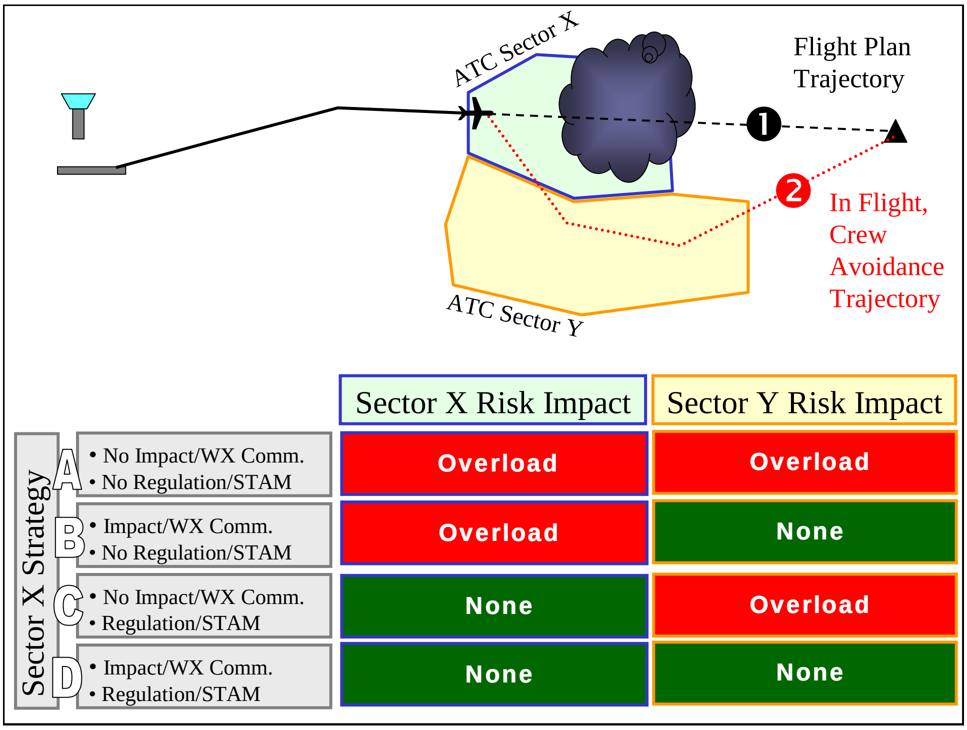


Figure 5-5: All strategies – ATCO excessive overload risk

In Europe, currently, a strategy for optimisation of in-flight avoidance is not applied. Such a strategy would reduce the in-flight “avoidance delay” of airborne flights affected by severe weather and therefore would minimise the impact on the flight efficiency.

The review of the existing literature and the findings from a dedicated visit revealed that FAA is using **Strategy E** (an upgrade of Strategy D) that can be characterised by: systematic communication at network level about the forecasted/reported severe weather and related impact; implementation of traffic flow measures or STAM. Additionally, based on a collaborative decision making process, the in-flight weather avoidance by affected flights may be optimised.

Figure 5-6 overleaf illustrates graphically Strategy E.

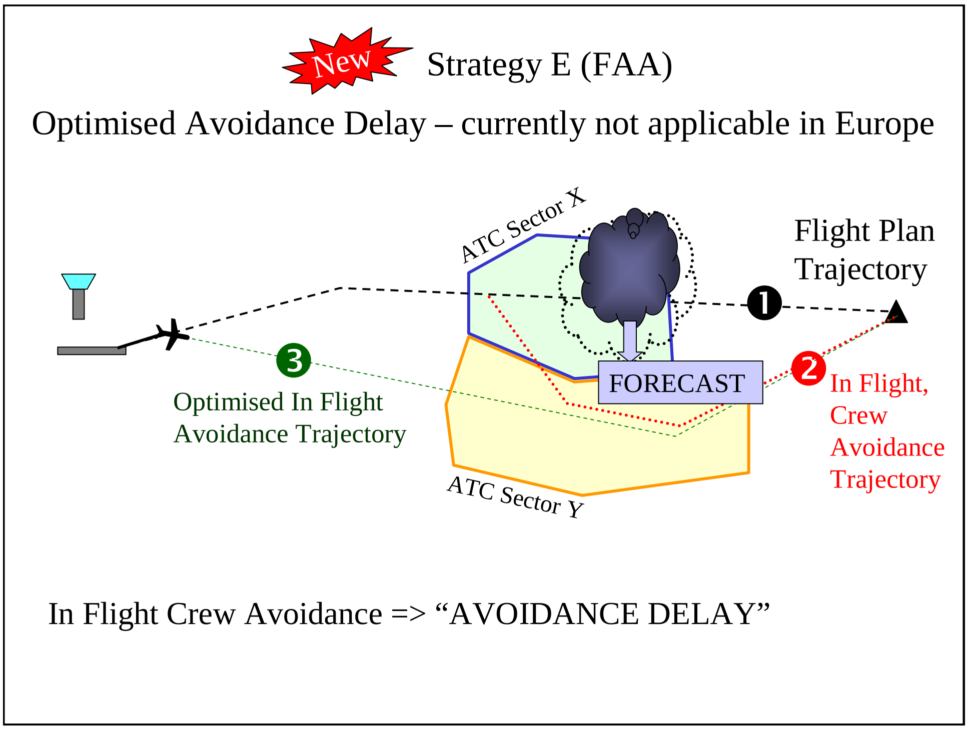
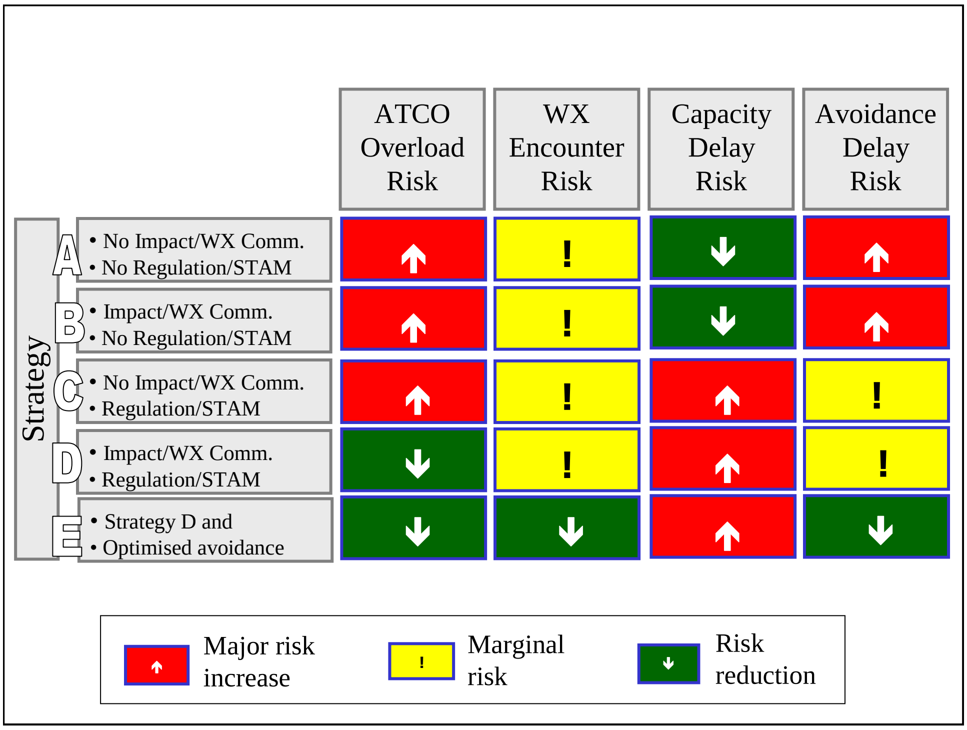


Figure 5-6: Strategy E– In-flight avoidance delay optimisation

ATCO excessive overload risk is one of the two main risk components of Flight Safety Risk, together with In-Flight Safety Risk, as established by the risk breakdown in Chapter 3. The survey findings and the analysis of the strategies discussed above enabled the development of a risk summary table (see Figure 5-7 below) that presents the effect of applying different Strategies on the formulated risks.



Strategy		ATCO Overload Risk	WX Encounter Risk	Capacity Delay Risk	Avoidance Delay Risk
A	• No Impact/WX Comm. • No Regulation/STAM	↑	!	↓	↑
B	• Impact/WX Comm. • No Regulation/STAM	↑	!	↓	↑
C	• No Impact/WX Comm. • Regulation/STAM	↑	!	↑	!
D	• Impact/WX Comm. • Regulation/STAM	↓	!	↑	!
E	• Strategy D and • Optimised avoidance	↓	↓	↑	↓

↑ Major risk increase — ! Marginal risk — ↓ Risk reduction

Figure 5-7: Risk summary table – Impact of mitigation strategies

The weather encounter risk is reliably reduced only by Strategy E because this is the only strategy removing the need for ad-hoc in-flight severe weather avoidance by pilot and hence significantly reducing the likelihood of pilot acting on limited or insufficient weather information available in-flight (the limitations of on-board weather radars has been well documented in the literature).

Additionally, in strategies C, D and E (use of flow measures and STAM) the ATCO overload risk in the severe weather impacted sector will be strongly dependant on the efficiency of a number of elements of the weather management chain and their characteristics, in particular:

- Availability and accuracy of weather anticipation and detection;
- Credibility and reliably of weather data translation into operationally meaningful terms (constraints, threshold events) and calculating associated probabilities;
- Sound impact assessment (including integration of weather, airspace and traffic data);
- Capacity / demand balancing and decision making.

The survey determined that for the Airport ATC severe weather management the most relevant hazards are low visibility, strong surface winds, runway contamination, severe turbulence on final approach, lightning and (heavy) precipitation. Alike the en-route and TMA environment, the risks associated with the en-route and TMA ATC severe weather impact management are also valid with the following particularities:

- The affected adjacent ATC sector (Y) is, most of the time, the APP sector, associated with the Terminal airspace.
- The effect on the adjacent APP sector is even stronger compared to the en-route adjacent sector scenario. The reason is that all or significant part of the traffic to/from an airport passes through the associated APP sector. The impact of low visibility operations is very much indicative of this effect. During the survey it was reported that during low visibility operations the workload of the TWR Controller is likely to reduce and the workload of the APP controller likely to increase compared to normal operations, provided that all other conditions are remain equal.
- An additional risk is affected by the applied strategies, notably the knock-on flight safety risk. During the survey it was reported that the provision of weather warning and, even more importantly, forecasted impact warning has a significant effect on the aircraft operator and crew planning. Available forecast weather information is often not sufficient to the flight crew for accurate estimation of expected in-flight delays and for an appropriate reserve fuel planning. Several aircraft emergency events were reported recently following unfold of similar scenarios.

The effect on the flight efficiency risk of the previously described elements of weather management process (availability of correct and appropriate weather information, its reliable interpretation; sound impact assessment and decision making) seems to be higher compared to the effect on flight safety risk. (The survey established that severe weather contribution to separation infringement incidents can be considered limited.) The more efficient is the severe weather impact management process the better will be aircraft operators' awareness of the forecasted severe weather and its impact on planned operations. This would help shift the decision making horizon more towards the pre-tactical phase (before departure) and would reduce the proportion of flights in need to divert to alternate aerodrome. During the survey it was reported that currently a diversion to alternate aerodrome is probably the worst case scenario with respect to the flight efficiency.

5.3 Conclusions

The survey conclusions are assigned to three major groups:

- conclusions on the severe weather risk management structure in Europe;
- conclusions on the coherence of severe weather risk management across Europe;
- conclusions on the performance of the European severe weather risk management structure.

5.3.1 Conclusions on the coherence of the severe weather risk management

Coherent in-flight avoidance procedures and practices. The in-flight Hazard Encounter Risk and Knock-on Flight Safety Risk are consistently managed in accordance with ICAO PANS-ATM and PANS-OPS provisions, aircraft operating procedures and other applicable national regulatory provisions.

Inconsistent tactical and pre-tactical strategies. The severe weather hazard encounter prevention strategies and measures are applied inconsistently at pre-tactical and tactical level. The European ANSPs have developed and deployed different capabilities. In the majority of cases severe weather risk management is not applied at pre-tactical level. Some ANSPs have built the needed capability and competence but the lack of incentives and of an established process to capitalise on the available capabilities prevents the implementation of an enhanced and more effective severe weather risk management.

Currently there is no consistent collaborative (across national borders) ATM response to and secure monitoring of severe weather events. This can be mainly attributed to the rather reactive approach to the management of severe weather impact on flight operations and ATS provision. This approach leads to sub-optimal ATM efficiency and increased air traffic controllers' workload, in particular in the critical time period before the tactical ATC measures take effect.

Non-interoperable tactical and pre-tactical strategies. In the rare cases of application, the risk prevention and mitigation strategies are based on locally developed capabilities, definitions and processes that are locally-specific (not following common definitions, criteria, format, etc) and do not support an efficient communication and collaboration at Network level.

5.3.2 Conclusions on the performance of the European severe weather management structure

Sufficiently managed Hazard Encounter Risk. It can be argued within the context of this project that the Hazard Encounter Risk, although not consistently managed at pre-tactical and tactical level, is sufficiently mitigated by the long standing procedures and capabilities for in-flight avoidance.

Management of Knock-on Flight Safety Risk can be improved. The strategic and tactical management of potential diversions to alternate aerodromes at local and network level can be improved, taking into account recent trends in aircraft operating policies to minimise reserve fuel carried and the capacity of airports filed as alternate by the flights affected by adverse weather at their destination airports.

Carriage of fuel is well regulated for any single flight, however in case of a common cause for diversion of multiple flights, for example caused by adverse weather, diversion becomes a traffic management safety issue. It includes holding delays and sequence for landing, as well as airport resources, such as parking stand availability. Obviously an optimisation strategy at flow management level would be beneficial for all actors involved.

Not sufficiently managed ATCO Excessive Overload Risk. It can be argued within the context of this project that the risk of ATCO excessive workload (associated with the Knock-on Flight Safety Risk) is not sufficiently managed.

Sub-optimal performance. With respect to severe weather risk management the operation of the European ATM Network is sub-optimal when applying the following criteria: (1) missed opportunities (all other conditions being equal) and (2) use of the available best practices. An analysis of the severe weather impact management in USA establishes that as much as two thirds of the weather related delay is avoidable. Another key finding of this analysis is that a risk management approach with adaptive incremental decision making presents a major opportunity for reducing weather related delay. A study published by NASA identifies the "attitude of resignation" (it is wrongly considered that weather presents unavoidable disruption to traffic flow) as a contributory factor to sub-optimal severe weather impact management.

The reasons for the sub-optimal performance can be found in following groups of impediments:

- ***Lack of capabilities*** (technical reasons). Lack of tools to enable proper functioning of the risk management chain, including:
    - ***Tailored MET products***. The ICAO Annex 3 MET products used currently were never designed to be used in an airport and/or ATS decision making environment. And as such will de-facto never deliver the best 'service' for these operating environments. There is a need that forecasting and reporting methods and products are tailored to reflect operationally meaningful aviation constraints and threshold events. "Custom" weather forecast and reporting products will better meet ATM needs, i.e. supporting correct impact assessment and timely decision making.
    - ***Accuracy of the forecast***. As a general rule the weather forecast accuracy is increasing as the time is getting closer to the forecasted event, however the opportunities (and available time) for the application of traffic management strategies are diminishing until, finally, the window of opportunity is closed and only in-flight risk management strategies are possible.
    - ***Precision of the detection***. Lack of reliable information about the exact location, dimensions and evolution in time of the hazardous weather phenomenon is a major factor for abstention from timely implementation of risk management strategies.
    - ***Granularity of the referenced airspace***. The scale used shall be appropriate and meaningful to support traffic management decision making and sufficiently small in size to reduce the uncertainty about the volume of airspace affected by the forecasted weather.
    - ***Better vertical plan view***. Enhanced information about the vertical extent of the reported weather.

  - ***Indication of the probability***. Includes probability of occurrence of the forecasted meteorological phenomena and probability of the different types of impact (encounter, knock-on effects and ATCO excessive overload).
  - ***Impact assessment***. Models and tools to estimate the impact of convective weather on the ATM resources and performance parameters.
  - ***Decision support***. Integrated processing and display of the meteorological, airspace and traffic data, including generation and/or validation of potential solution strategies and measures.

- ***Insufficient competence*** (human performance reasons), e.g. lack of training;

- ***Lack of procedures***. With few exceptions, OPS supervisors are required to exercise their best judgment regarding the need to manage the anticipated impact of severe weather on the ATC operations*.*

- ***Lack of or inefficient incentives*** (institutional and organisational reasons)

  - Insufficient incentives for ANSPs to introduce risk-based severe weather impact management, which would, by definition, lead to some traffic management interventions that would be unnecessary in hindsight. For example, if a service provider introduces a traffic management procedure based on a 60% probability of severe weather, for a sufficient large number of trials, the results will include some 40% “unnecessary” interventions. Because of this 40 % “unnecessary” interventions service providers refrain from acting at strategic level in principle. This is in spite of the opportunity to achieve more efficient operations by acting on both the “unnecessary” 40% and on the needed 60% of flights compared to not acting at all in all cases. This particular lack of incentive originates in the difficulty to communicate and justify the use of risk-based strategies externally and even sometimes to the public and press.

  - Insufficient incentives for ANSPs to introduce strategies that are optimised for the efficient operation of the Network but have a negative effect on the local performance. An in-flight weather avoidance by aircraft affects flight efficiency but the incurred “in-flight avoidance delay” it is not attributed to the ANSP’s performance (accountability for the delay vs. no accountability for missed opportunities to assist other parties improve their performance).

  - Insufficient incentives for the ANSPs to accept traffic management strategies and measures implemented by another actor (e.g. NM), but which have an impact on their own performance. For example, the capacity and flight efficiency targets are cascaded down from the network level to FABs and ANSPs – i.e. targets are directly allocated to the ANSPs. However, the severe weather impact management strategies may in some cases change (e.g. decrease) traffic flows through the airspace served by a particular ANSPs and this will have an impact on its cost-efficiency indicators.

  - Insufficient incentives for the MET services providers to go beyond the provisions of ICAO Annex 3 and provide information better supporting risk-based severe weather impact assessment.

  - Insufficient incentives for the FMPs to apply strategic flow management at pre-tactical level.

6. Abbreviations and acronyms

This table contains all abbreviations and acronyms used throughout the document.

Abbreviations & Acronyms	
ACC	Area Control Centre
AIP	Aeronautical Information Publication
ANSP	Air navigation Service Provider
AO	Aircraft Operator
AOC	Airline Operations Centre
AoR	Area of Responsibilities
APP	Approach
A-SMGCS	Advanced - Surface Movement Guidance and Control System
ATC	Air Traffic Control
ATCC	Air Traffic Control Centre
ATCO	Air Traffic Controller
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATS	Air Traffic Service
CAASD	Centre for Advanced Aviation System Development
CCFP	Collaborative Convective Forecast Product
CCSD	Common Constraint Situation Display
CDM	Collaborative Decision Making
CFIT	Controlled Flight Into Terrain
CIWS	Corridor Integrated Weather System
CoSPA	Consolidated Storm Prediction for Aviation
CRCT	The Collaborative Routing Coordination Tools
CWAM	Convective Weather Avoidance Model
DART	Dynamic Airspace Rerouting Tool
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
FAB	Function Airspace Block
FIR	Flight Information Region
FMP	Flow Management Position
FPL	Flight Plan
GA	General Aviation
GTG	Graphical Turbulence Guidance
ICAO	International Civil Aviation Organisation
ITWS	Integrated Terminal Weather System

Abbreviations & Acronyms	
LVP	Low Visibility Procedure
MET	Meteorological
MIT	Massachusetts Institute of Technology
NAS	U.S. National Airspace System
NASA	National Aeronautics And Space Administration
NCAR	National Centre of Atmospheric Research
NCWF	National Convective Weather Forecast
NM	Network Manager
NMC	Network Management Centre
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
NWS	National Weather Service
OPS	Operational (Services)
PANS ATM	Procedures for Air navigation Services – Air Traffic Management
PANS OPS	Procedures for Air navigation Services – Aircraft Operations
RAPT	Route Availability Planning Tool
RN	Route Network
RWY	Runway
STAM	Short Term ATFCM Measures
SUP	Supervisor
SWIM	System Wide Information Management
TFMS	Traffic Flow Management System
TMA	Terminal Control Area
TWR	Tower
WAFC	World Area Forecast Centres
WITI	Weather Impacted Traffic Index
WRF	Weather Research and Forecasting
WSDD	Winter Weather Research Product
WX	Weather
VAAC	Volcanic Ash Advisory Centre

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Annex 1 – Hazard Assessment Cards

1. Low Visibility

Hazard Assessment Card

Hazard:	Potential effects on a flight exposed to the hazard:
Low Visibility (Fog)	*Loss of situational awareness, Runway Incursion, Runway Excursion, CFIT*

Actor / Description	Pre-tactical Prevention (D-1)	Tactical Prevention (D0 till departure)	In-flight Prevention	Impact of the Prevention Measures	Mitigation of exposure to hazard	Impact of the Mitigation Measures
Pilot	▪ nil	▪ Adverse WX anticipation after review of MET forecasts & current weather reports ▪ Flight delay ▪ Plan for contingencies (e.g. alternate destination and extra fuel)	▪ Adverse WX detection through: current weather reports; automatic broadcast (VOLMET, ATIS); pilot reports; ATC advise; Visual observation ▪ Holding for WX improvement ▪ Diversion	▪ Inefficient flight profile; ▪ Longer flight; ▪ Increased pilot workload ▪ Landing at alternate aerodrome	▪ Follow AFM procedures and manufacturers limitations ▪ Go around ▪ Engage AP ▪ Autoland ▪ Reduced taxi speed	▪ Increased flight duration; ▪ Pilot fatigue ▪ Pilot distraction ▪ Possible reduced separation to other aircraft
ATC controller	▪ nil	▪ Adverse WX anticipation and detection through:, MET reports; pilot reports, visual observation; RVR and visibility measuring equipment ▪ Change of DEP RWY ▪ Change ARR RWY and APP type	▪ WX detection through: , MET reports; pilot reports; visual observation; RVR/Visibility indicators ▪ Early warning to pilots; ▪ Clear arrivals to Holding areas ▪ Use of appropriate RWY configuration and STARs ▪ Information on alternate	▪ Increased workload; ▪ Increased frequency occupancy time; ▪ Increased coordination; ▪ Increased missed approach rates ▪ Increased probability of separation loss/RWY incursion ▪ Reduced taxi in/out	▪ Frequent RVR checks as necessary ▪ Increased separation; ▪ Use of Surface Movement Radar/A-SMGCS ▪ Traffic Information and warnings to increase pilots' situational awareness ▪ LVP	▪ Reduced throughput; ▪ Flight delays; ▪ Increased coordination ▪ Increased Frequency occupancy time ▪ Increased RWY occupancy times ▪ Reduced availability of traffic management techniques (e.g. multiple

			aerodrome conditions and availability	flexibility		line-ups)
OPS SUP	▪ nil	▪ Adverse WX anticipation through: MET forecasts & reports; RVR and visibility indicators; visual observation ▪ Warn NM and adjacent centres of adverse WX at airport ▪ Decide on appropriate RWY configuration and SID/STARs ▪ Decide on traffic restrictions – e.g. reduced departure rate; priority to arrivals ▪ Introduce LVP	▪ Warn NM and adjacent centres of reported adverse WX ▪ Tactical flow management; minimum departure intervals; miles in trail on final approach ▪ Application of LVP	▪ Increased workload (complexity assessment; Wx monitoring; coordination) ▪ Suspension of RWY ops	▪ RWY configuration management ▪ Assigning additional staff / sectors ▪ Implement increased separation (e.g. miles in trail) ▪ Application of LVP ▪ Flow measures – arrival rate	▪ Reduced throughput; ▪ Flight delays; ▪ Flight cancellations ▪ ATC service suspension
FMP	▪ Adverse WX anticipation through MET forecasts and other MET data ▪ Initial ATC impact assessment; ▪ Decision (CDM) on prevention strategy ▪ Provide network warning in case of potential capacity reduction	▪ Adverse WX anticipation and detection through MET forecasts and reports and other MET data ▪ Flow regulation ▪ Traffic and MET conditions monitoring and regulation adjustment, if needed	▪ nil	▪ Reduced runway capacity ▪ Runway zero rate regulations ▪ Flight delays ▪ Flight cancelations	▪ nil	▪ nil
Airport Operator	▪ nil	▪ Implement ground operations restrictions in accordance with LVP requirements	▪ Provide Follow Me services ▪	▪ Disruption of airport operations (flight schedules) ▪ Suspension RWY ops	▪ nil	▪ nil
Aircraft Operator	▪ Adverse WX anticipation through MET forecasts ; ▪ Review of flight schedule and ANSPs response intentions (NOP) and decision on departure time change ▪ Revise crew roster to provide pilots with needed low visibility qualifications ▪ Change in a/c rotation plan to provide an a/c suitably equipped for low	▪ Adverse WX anticipation through MET forecasts and reports; ▪ Flight delay; ▪ Flight cancelation; ▪ Flight rerouting to alternate destination	▪ Nil, or ▪ In case of dispatch office – assistance with alternate aerodrome options and/or rerouting to alternate destination	▪ Disruption of planned daily schedule; ▪ Increased cost ▪ Less efficient fleet use	▪ Changes to seasonal schedule (arrival and departure times; frequencies)	▪ Disruption of planned schedule; ▪ Increased cost; ▪ Less efficient fleet use

	visibility operations					
Network Manager	▪ Adverse WX anticipation through MET forecasts and other MET data; ▪ Consolidates forecast data, updates NOP; makes list of affected airports; ▪ Initial Network impact assessment in view of expected demand, runway/ capacity data, and ANSPs response intentions; ▪ Coordinates with FMPs local prevention strategies ▪ Facilitates the dissemination of potential capacity reduction warnings ▪ Prepares traffic scenarios activation	▪ Adverse WX anticipation through MET forecasts and reports; ▪ Consolidates MET data; updates NOP; makes list of affected airports and airspaces; ▪ Network impact assessment (planned demand, capacity data, and ANSPs response intentions) ▪ Coordinates with FMPs for local prevention strategies and measures ▪ Issues Flow regulations ▪ Facilitates the propagation through the network of the adverse WX warnings	▪ Facilitates the propagation through the network of the adverse WX warnings ▪ Facilitates flight re-routings, as needed	▪ Increased workload ▪ Increased coordination ▪ Increased number of flow regulations ▪ Increased number of SLOT assignments ▪ Increased number of FPL change and cancelations processing	▪ nil	▪ Increased need of Slot revision;
MET office / MET service provider	▪ Adverse WX forecasting; ▪ In some cases customized forecasts and weather translation	▪ Adverse WX forecasting; ▪ Adverse weather detection and reporting ▪ In some cases customized forecasts/reports and weather translation	▪ Adverse WX detection and/or reporting (visual observation, PILOT REPORTS, RVR measuring equipment etc.)	▪ nil	▪ nil	▪ nil

1.1 Description

Low visibility at airports may be caused by a number of weather phenomena, but most often it is associated with fog.

Fog is a collection of liquid water droplets or ice crystals suspended in the air at or near the earth's surface. There are different types of fog depending on the mechanism of its formation: radiation fog, advection fog, frontal fog, steam fog etc. Regardless of the mechanism of formation, fog brings significant risks to aircraft operations. Hazards related to fog are:

- *Loss of situational awareness* – during reduced visibility operations, risk of situational awareness loss exists not only for pilots and tower controllers, but also for ground staff operating vehicles on the movement area

- *Runway incursion* – Risk of runway incursions is significantly increased during low visibility operations, especially when combined with other factors (e.g. manoeuvring area complexity)

- *Runway excursion* – if sight of runway visual aids is lost during the final stages of approach and landing a runway excursion is likely to occur

- *CFIT* – Controlled flight into terrain is often associated with the combination of low visibility conditions and non-precision approaches

Low visibility can be also associated with intense showers (rain, snow) but unlike fog these conditions are much more transient in nature. Sandstorms and dust storms may also cause significant reduction in ground visibility but they are not typical for the European region.

1.2 Actors, Prevention and Mitigation

Meteorological service provider is usually the initiating actor of any adverse weather risk management process. Meteorological forecasts of adverse weather would normally be available several days before the day of operations; however forecast confidence would be rather low until short time before occurrence of the forecasted weather. A large variety of tools and computational models are available to MET officers, but forecast accuracy may vary according to local conditions and peculiarities. Not only Annex 3 forecasts and weather reports, but direct assistance to other actors is sometimes provided (e.g. enhanced weather forecast bulletins, pre-shift and pre-flight briefings, customized forecasts or MET reports) on request by ATC service providers, airport operators or aircraft operators.

Flow Management Positions anticipate adverse weather using input from MET service providers. Forecast weather severity and probability are used to estimate the potential impact on ATC operations in the airspace for which FMP is responsible. Advice on risk management strategies is provided to Ops supervisor using mostly experience and knowledge on local specifics. In certain cases decision support tools or a predefined set of strategies might be available to facilitate planning and reduce overall response time. In case capacity reduction is provisioned, a relevant warning should be disseminated to airspace users and adjacent ATC units (usually via NM). FMPs continually monitor updates of weather and traffic forecasts and adjust the response strategies accordingly in close coordination with Ops supervisors.

Network Manager uses Information from MET service providers to anticipate adverse weather in certain portions of airspace. Often information from more than one source needs to be consolidated in order to obtain a global network view. NM identifies the airspace and airports which might be directly affected by expected meteorological conditions, contacts relevant FMP for details on planned measures and, if required, issues flow regulations. NM facilitates propagation through the network of adverse weather warnings and their expected effect on operations. NM will be impacted by an increased workload and coordination, as well as an increased number of regulations, slot assignments and revisions.

Aircraft operators receive information about possible weather deterioration through standard aviation forecasts and current weather reports issued by MET service providers. Some large operators may have their own meteorological departments (or contracts with MET service providers). Operators would review their own flight schedules and ANSPs response plans and decision on departure time change or diversion to alternate destination might be taken. Ultimately some flights might be cancelled. Crew roster might be revised in order to provide pilots with appropriate qualifications for low visibility operations. Similarly aircraft rotation plan might be changed in order to execute the flight with a suitably equipped aircraft. Some airlines may provide in-flight assistance with choosing best possible alternate options. Airlines will suffer from a significant disruption of planned daily schedule, less efficient fleet use and overall increase in operating costs.

Airport operator will implement ground operations restriction in accordance with local low visibility procedure requirements. Follow me services might be provided (usually where taxiways are not equipped with centreline lights). Significant disruption of airport operations may occur. Sometimes runway operations might be suspended for days due to visibility conditions being below operating minima.

Ops supervisor will obtain information on adverse weather through available MET forecasts and reports (TAFs, METARS etc.), runway visibility measurement and display equipment or a direct visual observation. Normally it is the responsibility of Ops supervisor to warn adjacent ATC units on any potential influence that adverse weather may have on operations and request activation of relevant LoAs' provisional clauses (specific transfer of control conditions or other). Ops supervisor will warn also NM (directly or through FMP) of any planned response actions that may have an effect on network operations. Runway configuration will be carefully selected according prevailing conditions. Increased separation might be introduced in all affected approach sectors as well as minimum departure intervals/increased final approach separation. Flow regulations, such as arrival rate restrictions might be also introduced. Supervisor may initiate the introduction of low visibility procedures. Supervisor's workload would be significantly increased due to the need to constantly monitor weather development and assess traffic complexity. Airport throughput will be significantly reduced, flights might be delayed and/or cancelled. When visibility conditions are below operating minima runway operations might be suspended.

Pilots receive information on possible weather deterioration or expected improvement at their pre-flight briefings through review of available meteorological forecasts and reports. At this stage a change in departure time is possible in order to avoid any potential adverse weather encounter. Contingency measures would be taken by the PIC (e.g. additional fuel) in order to be able to hold for longer periods or divert to distant alternate aerodromes. There may be a need to replace the flight crew, if encountered delay is too high. Pilots will incur increased workload due to the need to continuously assess adverse weather and possible alternate options, which may result in fatigue and distraction and an increase in probability of operational errors. Any deviation (e.g. go around) would make flight profile less efficient, increasing distance and time flown. Mitigation options available to pilots are a missed approach (when airborne) or reduction of taxi speed and proceeding with caution (on the ground).

Air traffic controllers obtain usually early information about possible weather deterioration at routine pre-shift briefings. Additional sources of information are local weather reports and current weather reports (METAR), pilot reports, visibility and RVR and direct visual observation. ATCOs may use change of routings (e.g. change in SID/STAR or runway in use) in order to minimise and/or mitigate the effects of low visibility on operations. Arrivals into busy airports might be cleared to hold for weather improvement, and runway configuration might be changed. Early warnings to pilots will be given in order to prepare for the possible encounter of low visibility conditions. Information on alternate aerodromes' conditions and availability will be provided. ATCOs would incur increased workload, coordination and frequency occupancy time. Missed approach rates will be increased as well. Larger separations and surface movement radar/A-SMGCS would be extensively used in order to mitigate the increased probability of separation loss. Low visibility procedures may be applied. Runway occupancy times might be increased significantly and therefore capacity reduced. Some of the traffic management techniques normally used by controllers may not be available anymore (e.g. multiple line-ups).

1.3 Related accidents and incidents

A343, Nairobi, Kenya, 2008

April 2008 an Airbus A340-300 being operated by Virgin Atlantic on a scheduled passenger flight from London had carried out a night auto ILS approach to Runway 06, Nairobi airport, Kenya. Just prior to touchdown, the aircraft entered an area of fog and the PF lost sight of the right side of the runway and the runway lights.

Causes/Findings:
Loss of visual reference during the flare

Safety Recommendations:
Five recommendations are made related to the training of ATCOs, compliance of runway lightning system with ICAO standards and implementation of routine testing of runway friction levels.

B742/B741, Los Rodeos Tenerife, 1977

March 1977, a KLM B747-200 commenced its daylight take off at Los Rodeos airport, Tenerife in very poor visibility, recorded as 300 meters three minutes earlier, after receiving only a departure clearance and continuing the take-off roll even after ATC advised "standby for take-off". Collision with a Pan American Airways Boeing 747-100 which was taxiing on the runway in accordance with its ATC clearance issued on the same radio frequency.

Causes/Findings:
Main cause is departure without proper clearance of KLM B747-200. Contributory are poor visibility conditions, inadequate language skills, overlapping transmissions, loss of situational awareness (due visibility), and traffic congestion

Safety Recommendations:
There are three recommendations related to the use of standard, concise and unequivocal aeronautical language and compliance with ATC clearances

T154, Smolensk, Russian Federations, 2010

April 2010, a Tupolev Tu-154M being operated by the Polish Air Force Special Transport Regiment on a pre-arranged VIP fight from Warsaw to Smolensk Severny impacted ground obstacles and terrain during approach in thick fog.

Causes/Findings:

The immediate cause of the accident was the failure of the crew to take a timely decision to proceed to an alternate aerodrome, although they were not informed that the actual weather conditions at Smolensk “Severny” Airdrome were significantly lower than the established aerodrome minima. A number of contributory factors are cited in the investigation report.

Safety Recommendations:

Recommendations are related to the pre-flight preparation, development of SOP emphasizing crew interactions as well as development and implementation of the procedure of recurrent simulator training for the crews of the Tu-154M aircraft.

MD87/C525, Milan Linate, 2001

October 2001, in thick fog at Milan Linate airport, Italy, an MD87 on its take-off roll collided with a Cessna Citation which had taxied onto the active runway.

Causes/Findings:

Immediate cause is runway incursion during low visibility conditions. A long list of additional causes is provided in the investigation report.

Safety Recommendations:

The investigation report provides a long list of safety recommendations related to controller qualifications, AIP publications, Low visibility procedures, introduction of safety management system, creation of European action plan for the prevention of runway incursion and others.

2 Strong low level & surface winds, windshear and microburst

Hazard Assessment Card							
Hazard:		**Potential effects on a flight exposed to the hazard:**					
Strong low level&surface winds, windshear, microburst		*Loss of Control; RWY excursion*					
Actor	**Description**	**Pre-tactical Prevention** (D-1)	**Tactical Prevention** (D0 till departure)	**In-flight Prevention**	**Impact of the Prevention Measures**	**Mitigation of exposure to hazard**	**Impact of the Mitigation Measures**
Pilot		▪ nil	▪ Adverse WX anticipation after review of MET forecasts & current weather reports ▪ Flight delay ▪ Plan for contingencies(e.g. diversion and additional fuel)	▪ Adverse WX detection through: current weather reports; pilot reports; ATC advise ▪ Holding for WX improvement ▪ Diversion	▪ Inefficient flight profile; ▪ Longer flight; ▪ Increased pilot workload	▪ Follow AFM procedures and manufacturers limitations ▪ Request most favourable RWY/APP type ▪ Monitor speed ▪ Go around ▪ Max TO thrust ▪ Monitor headwind/tailwind vs. surface wind ▪ Choice of flap settings ▪ Increased speed on approach	▪ Increased flight duration; ▪ Increased workload ▪ Pilot Fatigue ▪ Pilot Distraction ▪ Possible reduced separation to other aircraft
ATC controller		▪ nil	▪ Adverse WX anticipation and detection through: WX and/or Doppler Radar, current weather reports, pilot reports, visual observation, LLWAS; wind sensors & display	▪ WX detection through: , MET reports, pilot reports, visual observation; TWR wind indications, Doppler Radar, LLWAS; wind sensors	▪ Increased workload; ▪ Increased frequency occupancy time; ▪ Increased coordination; ▪ Increased missed approach rates ▪ Increased probability of	▪ Frequent wind checks as necessary ▪ Increased separation; ▪ Request frequent pilot reports and advise following aircraft	▪ Reduced throughput; ▪ Flight delays; ▪ Go around(s) ▪ Diversions ▪ Increased coordination

		▪ Change of RWY	▪ Early warning to pilots; ▪ Clear arrivals to Holding areas ▪ Use of appropriate RWY configuration	separation loss;		
OPS SUP	▪ nil	▪ Adverse WX anticipation through: MET forecasts & current weather reports; WX and Doppler radar; visual observation, LLWAS; wind sensors ▪ Warn NM and adjacent centres of adverse WX ▪ Decide on appropriate RWY configuration and SID/STARs ▪ Decide on traffic restrictions	▪ Warn NM and adjacent centres of reported adverse WX ▪ Tactical flow management; minimum departure intervals; miles in trail on final approach	▪ Increased workload (complexity assessment; coordination)	▪ RWY configuration management ▪ Assigning additional staff / sectors;(Split TWR into TWR/GND positions, ▪ Implement increased separation (e.g. miles in trail)	▪ Reduced throughput; ▪ Flight delays; ▪ Diversions
FMP	▪ Adverse WX anticipation through MET forecasts and other MET data ▪ Initial ATC impact assessment; ▪ Decision (CDM) on prevention strategy ▪ Provide network warning in case of potential capacity reduction	▪ Adverse WX anticipation and detection through MET forecasts and current weather reports and other MET data ▪ Flow regulation ▪ Traffic monitoring and regulation adjustment, if needed	▪ nil	▪ Reduced runway capacity ▪ Flight delays	▪ nil	▪ nil
Airport Operator	▪ nil	▪ Implement restrictions on ground operations (e.g. halt boarding, detach and secure jet ways once wind speed exceeds prescribed operating maximum)	▪ nil	▪ Disruption of airport operations (flight schedules)	▪ nil	▪ nil
Aircraft Operator	▪ Adverse WX anticipation through MET forecasts ; ▪ Review of flight schedule and ANSPs response intentions (NOP) and decision on FPL change, if applicable	▪ Adverse WX anticipation through MET forecasts and current weather reports; ▪ Flight delay; ▪ Flight cancelation;	▪ Nil	▪ Disruption of planned daily schedule; ▪ Increased cost ▪ Less efficient fleet use	▪ nil	▪ Disruption of planned schedule; ▪ Increased cost; ▪ Less efficient fleet use

Network Manager	▪ Adverse WX anticipation through MET forecasts and other MET data; ▪ Consolidates forecast data, updates NOP; makes list of affected airports; ▪ Initial Network impact assessment in view of expected demand, runway/ capacity data, and ANSPs response intentions; ▪ Coordinates with FMPs local prevention strategies ▪ Facilitates the dissemination of potential capacity reduction warnings	▪ Adverse WX anticipation through MET forecasts and current weather reports; ▪ Consolidates forecast data; updates NOP; makes list of affected airspaces; ▪ Network impact assessment (planned demand, EAUP, capacity data, and ANSPs response intentions) ▪ Contacts FMPs for local prevention strategies and measures ▪ Issues Flow regulation ▪ Facilitates the propagation through the network of the adverse WX warnings	▪ Facilitates the propagation through the network of the adverse WX warnings	▪ Increased workload ▪ Increased coordination ▪ Increased number of flow regulations ▪ Increased number of SLOT assignments	▪ nil	▪ Increased need of Slot revision
MET office / MET service provider	▪ Adverse WX forecasting; ▪ In some cases customized forecasts and weather translation	▪ Adverse WX forecasting; ▪ Adverse weather detection and reporting ▪ In some cases customized forecasts/ current weather reports and weather translation	▪ Adverse WX detection and/or reporting (WX/Doppler radar, visual observation, pilot reports, LLWAS etc.)	▪ nil	▪ nil	▪ nil

2.1 Description

Wind is a term that refers to the lateral and/or vertical flow of air relative the earth surface, caused by a difference in pressure between one region and another. Localised meteorological phenomena may result from a variety of causes e.g. orographic wind, katabatic wind, anabatic wind etc. Convective weather is associated with strong up and down drafts and local surface gusts of rapidly changing speed and direction. Cumulonimbus clouds are also associated with downbursts – an area of significantly cooled descending air that, when hitting the ground, spreads out in all directions producing strong winds. When the Downburst is contained within an area of 4 km diameter or less it is commonly referred to as a **microburst.**

Low level **windshear** is defined as a sudden change in wind speed and/or direction and can have a significant effect on aircraft's performance during early climb-out or final approach.

Strong cross-winds or tail-winds exceeding AFM limits may cause runway excursion, especially in gusty conditions or when combined with other factors as negative runway slopes or runway contamination. Windshear and microbursts are associated with the possibility of uncommanded airspeed loss and subsequent loss of control.

2.2 Actors, Prevention and Mitigation

Meteorological service provider is usually the initiating actor of any adverse weather risk management process. Meteorological forecasts of adverse weather would normally be available several days before the day of operations; however forecast confidence would be rather low until short time before occurrence of the forecasted weather. A large variety of tools and computational models are available to MET officers, but forecast accuracy may vary according to local conditions and peculiarities. Not only Annex 3 forecasts and weather reports, but direct assistance to other actors is sometimes provided (e.g. enhanced weather forecast bulletins, pre-shift and pre-flight briefings, customized forecasts or MET reports) on request by ATC service providers, airport operators or aircraft operators.

Flow Management Positions anticipate adverse weather using input from MET service providers. Forecast weather severity and probability are used to estimate the potential impact on ATC operations in the airspace for which FMP is responsible. Advice on risk management strategies is provided to Ops supervisor using mostly experience and knowledge on local specifics. In certain cases decision support tools or a predefined set of strategies might be available to facilitate planning and reduce overall response time. In case capacity reduction is provisioned, a relevant warning should be disseminated to airspace users and adjacent ATC units (usually via NM). FMP continually monitor updates of weather and traffic forecasts and adjust their response strategies accordingly.

Network Manager uses Information from MET service providers to anticipate adverse weather in certain portions of airspace. Often information from more than one source needs to be consolidated in order to obtain a global network view. NM identifies the airspaces and airports which might be directly affected by expected meteorological conditions, contacts relevant FMP for details on planned measures and, if required, issues flow regulations. NM facilitates propagation through the network of adverse weather warnings and their expected effect on operations. NM will be impacted by an increased workload and coordination, as well as an increased number of regulations, slot assignments and revisions.

Ops supervisor will obtain information on adverse weather through available MET forecasts and reports (TAFs, METARS etc.), observation of weather (or ATC) radar or a direct visual observation. Normally it is the responsibility of OPS supervisor to warn adjacent ATC units on any potential influence that adverse weather may have on operations and request activation of relevant LoAs' provisional clauses (specific transfer of control conditions or other). OPS supervisor will warn also NM (directly or through FMP) on any planned response actions that may have an effect on network operations. In order to mitigate the effects of increased controller workload OPS supervisor will manage dynamically sector and runway configuration, possibly opening new control positions, changing runways in use and assigning additional controllers. Runway configuration will be carefully selected according prevailing conditions. Increased separation might be introduced in all affected approach sectors as well as minimum departure intervals/increased final approach separation. Flow regulations might be also introduced.

Aircraft operators receive information about possible weather deterioration through standard aviation forecasts and reports issued by MET service providers. Some large operators may have their own meteorological departments (or contracts with MET service companies). Operators would review their own flight schedules and ANSPs response plans and decision on departure time change might be taken. Ultimately some flights might be cancelled. Airlines will suffer from a significant disruption of planned daily schedule, less efficient fleet use and overall increase in operating costs.

Airport operators may implement restrictions on ground operations during strong wind conditions – boarding may be halted and jetways detached from aircraft and secured. This would result in delays and significant disruption in flight schedules.

Pilots receive information on possible weather deterioration at their pre-flight briefings through review of available meteorological forecasts and reports. At this stage a change departure time is possible in order to avoid any potential adverse weather encounter. Contingency measures would be taken by the PIC (e.g. additional fuel) in order to be able to hold for longer periods or divert to distant alternate aerodromes. Pilots will incur increased workload due to the need to continuously assess adverse weather and possible alternate options, which may result in fatigue and distraction and increase in probability of operational errors. Any deviation (e.g. go around) would make flight profile less efficient, increasing distance and time flown.

There are a number of mitigation techniques available to pilots to mitigate the effects of strong wind and gusts/ windshear. A few are listed:

- Follow AFM procedures and manufacturer limitations on maximum crosswind and tailwind values
- Request from ATC most favourable type of approach or runway
- Monitor closely airspeed and airspeed trend in order to detect any evidence of impending windshear
- Monitor headwind and tailwind components vs. surface wind to detect any potential windshear
- Select appropriate flap setting (e.g. minimum flaps configuration compatible with take-off requirements to maximize climb-gradient capability)
- Maintain high speed on approach in order to have adequate stall margin

Air traffic controllers obtain early information about possible weather deterioration at routine pre-shift briefings. Additional sources of information are ground weather radar (sometimes also ATC radar), MET reports (METAR, SIGMET), pilot reports, runway wind indicators, LLWAS (Low Level Windshear Alert System) and direct visual observation. ATCOs may use change of routings (e.g. change in SID/STAR or Runway in use) in order to minimise and/or mitigate the effects of strong wind/windshear/microbursts. Arrivals into busy airports might be cleared to hold for weather improvement, runway configuration might be changed. Early warnings to pilots will be given in order to prepare them for the possible encounter of wind hazards. Frequent surface wind checks will be given to pilots on final approach, information from pilot reports on actual conditions will be updated as often as practical and passed on to following aircraft. Increased separation will be applied on final approach or between arrivals and departures in order to mitigate the increased probability of separation loss. ATCOs working in windshear/strong wind conditions are likely to incur increased workload, coordination and frequency occupancy time. Missed approach rate may be higher than usual. Runway throughput will be reduced and flight delays might be significant.

2.3 Related accidents and incidents

DC10, Tahiti French Polynesia, 2000

December 2000, a Hawaiian Airlines DC10 overran the runway at Tahiti after landing long on a wet runway having encountered crosswinds and turbulence on approach in thunderstorms.

Causes/Findings:

The accident was caused by the failure, during the preparation for the approach, to take into account the risk of a storm passing over the airfield at the time of landing.

Safety Recommendations:

- Operators ensure that crews are made aware of the importance of specifically planning, during the arrival briefing, for circumstances that would lead to a modification in the approach strategy, where the meteorological situation warrants it;
- The DGAC study the possibility of equipping all aerodromes on French territory used for public transport with runway centreline lighting;
- Operators systematically ensure that the documentation used by aircrew is in accordance with the relevant national regulatory documentation.

MD-11, Dublin Ireland, 2002

February 2002, a Delta Airlines MD-11 encountered a sudden exceptional wind gust (43 knots) during the landing roll at Dublin, Ireland. The pilot was unable to maintain the directional control of the aircraft and a runway excursion to the side subsequently occurred.)

Causes/Findings:

The cause of the runway excursion was that the aircraft was subjected to an unexpected and sudden wind gust during the initial stages of the landing rollout, inducing a rate of yaw to the left, which could not be controlled by the pilot flying.

Safety Recommendations:

A number of safety recommendations to ICAO, airport authority and the aircraft operator mostly related to the post-incident response.

MD81, Kiruna Sweden, 1997

In March 1997, a McDonald Douglas MD 81 left the runway during the night landing at Kiruna performed in a strong crosswind.

Causes/Findings:

Gusting winds not reported; exceedance of the recommended crosswind speed; touchdown more than 9 m left of centreline; runway braking action coefficient was less than reported;

Safety Recommendations:

- Air traffic control personnel to be given more in-depth operational flight instruction, and the possibility of joint training with flight crew personnel.
- Ensure that routines and equipment are developed to enable ATC personnel to report information concerning actual crosswind component upon request.

B738, Limoges France, 2008

In March 2008, a Boeing 737-800 landing at Limoges, overran the runway during heavy rain and with a strong crosswind

Causes/Findings:

The crew were not fully aware neither of the intensity of the precipitation and condition of the runway, nor of the change in the wind direction.

Safety Recommendations:

None

A320, Hamburg Germany, 2008

On 1 March 2008, an Airbus A320 experienced high and variable wind velocity on short finals during the attempt at landing on runway 23 at Hamburg. With a strong crosswind component from the right, a bounced contact of the left main landing gear with the runway was followed by a left wing down attitude which resulted in the left wing tip touching the ground.

Causes/Findings:

- Unexpected left wing down attitude which was not expected by the crew.
- Crosswind exceeding the maximum demonstrated for landing.
- Deficiencies in operating manual, FCOM and aircraft standard documentations.

Safety Recommendations:

A number of safety recommendations are made to German CAA, aircraft manufacturer, aircraft operator, EASA and ICAO.

A343, Toronto Canada, 2005

On 2 August 2005, an Airbus A340-300 landed at Toronto in daylight during a thunderstorm and failed to stop before reaching the end of the runway. It exited the airport perimeter and crossed a main road before ending up in a ravine approximately 300 m beyond the end of the runway. Although an intense post-crash fire began immediately and smoke began to enter the cabin, all 309 occupants were able to evacuate before the fire took significant hold.

Causes/Findings:

The crew conducted an approach and landing in the midst of a severe and rapidly changing thunderstorm. There were no procedures within the aircraft operator related to distance required from thunderstorms during approaches and landing, nor were these required by regulations.

Safety Recommendations:

- Establish clear standards limiting approaches and landings in convective weather.
- Improve training in order to enable pilots to make better decisions for landing in deteriorating weather conditions.

DC93, vicinity of Charlotte NC USA, 1994

On 2 July 1994, a DC-9 collided with trees and a house shortly after attempting a missed approach at Charlotte Airport, USA, in heavy thunderstorms.

Causes/Findings:

- Flight crew's decision to continue an approach into severe convective activity that was conducive to a microburst;
- The flight crew's failure to recognize a windshear situation in a timely manner;
- The flight crew's failure to establish and maintain the proper airplane attitude and thrust setting necessary to escape the windshear;
- The lack of real-time adverse weather and windshear hazard information dissemination from air traffic control.

B735, vicinity Billund, Denmark,1999

On 3rd December 1999, a Boeing 737-500 diverting from Copenhagen made a successful lnding at Billund after two approaches and an earlier unsuccessful one at the intended destination. The aircraft landed with less than Final Reserve Fuel having declared an emergency on that account. Windshear warnings during the second approach were ignored because of the low fuel status.

Causes/Findings:

- Significant information concerning flight safety was not passed on to the flight crew with a minimum delay; the adverse weather condition with strong winds and severe turbulence; the weather forecasts were significantly different from the actual weather observations.

- The crew did not have complete airport information about the Danish airports that were considered to be suitable for the operator; The NOTAM system was not effective and not useful for aircraft in-flight;

Safety Recommendations:

- Vital information concerning flight safety to be made available to all aircraft operating within Copenhagen FIR with a minimum of delay;
- ATC radar operators to be equipped with real time display indicating adverse meteorological phenomena;
- The Danish Civil Aviation Administration ensures that NOTAMs can be easily reconstructed for accident and incident investigation purposes

B734, Brisbane Australia, 2001

On 18th January 2001, a Boeing 737-400 encountered a Microburst shortly after commencing a go-around from 500 ft during an approach to runway 19 at Brisbane due to the onset of severe weather.

Significant factors:

There was an intense thunderstorm overhead Brisbane aerodrome at the time of the occurrence. The thunderstorm produced a microburst, hail and heavy rain, which the aircraft encountered during the go-around. Air traffic control and Bureau of Meteorology staff did not mutually exchange information regarding the thunderstorm as it approached Brisbane aerodrome. The controllers did not advise the crew of, and nor did the crew request, details of the lateral limits, direction of travel and ground speed of the thunderstorm. The terminology and language used by air traffic controllers in the R/T exchange with crew and between each other did not convey their concerns about the intensity of the thunderstorm to the crew until the aircraft was on final approach. The aircraft was not fitted with a forward-looking windshear warning system, nor was it required to be.

Safety Recommendations:

A number of recommendations concerning training of air traffic control personnel, development of a standard thunderstorm intensity scale, integration of MET radar information on ATC radar screens.

MD82, Little Rock USA, 1999

On 1 June 1999, an MD82 overran the end of the runway during landing in severe weather conditions

Causes/Findings:

Probable cause was the flight crew's failure to discontinue the approach when severe thunderstorms and their associated hazards to flight operations had moved into the airport area and the crew's failure to ensure that the spoilers had extended after touchdown. Among the contributory factors was the continuation of the approach to a landing when the company's maximum crosswind component was exceeded.

3. Severe Turbulence

Hazard Assessment Card						
Hazard:	**Potential effects on a flight exposed to the hazard:**					
Severe Turbulence (due to convective weather)	*Level bust; A/C damage; Power loss; Injuries; Crew incapacitation; Loss of Control;*					
Actor / **Description**	**Pre-tactical Prevention** (D-1)	**Tactical Prevention** (D0 till departure)	**In-flight Prevention**	**Impact of the Prevention Measures**	**Mitigation of exposure to hazard**	**Impact of the Mitigation Measures**
Pilot	▪ nil	▪ Convective WX anticipation after review of MET forecasts & current weather reports ▪ FPL route change ▪ Flight delay	▪ Convective WX detection through: aircraft radar; current weather reports; pilot reports; visual observation or ATC advise ▪ Lateral deviation ▪ FL change ▪ Holding or diversion (In case of turbulence situated over destination airport)	▪ Inefficient flight profile; ▪ Longer route; ▪ Increased pilot workload ▪ Possible reduced separation to other aircraft	▪ Reducing aircraft speed; ▪ Maintain clean configuration as long as possible ▪ Fit seat belts / harnesses ▪ Suspend cabin service ▪ Select penetration FL/altitude ▪ Expedite leaving the affected area ▪ Follow AFM turbulence procedures ▪ Actions to asses and mitigate any damage and/or injury	▪ Route and/or FL change; ▪ Increased flight duration; ▪ Pilot Fatigue ▪ Pilot Distraction ▪ Possible reduced separation to other aircraft
ATC controller	▪ nil	▪ Adverse WX anticipation and detection through: WX and/or ATC radar, current weather reports, pilot reports, visual observation ▪ Change of SID/departure clearance	▪ Adverse WX detection through: WX and/or ATC radar, current weather reports, pilot reports, visual observation; ▪ Early warning to pilots; ▪ Convective WX avoidance advice and assistance;	▪ Increased workload; ▪ Increased frequency occupancy time; ▪ Increased coordination; ▪ Increased need of system updates (e.g. route); ▪ Non-standard traffic flows and new conflict points;	▪ Convective WX avoidance assistance ▪ Increased separation; ▪ Flight level allocation	▪ Reduced throughput; ▪ Flight delays; ▪ Unexpected aircraft deviation from cleared trajectory ▪ Unanticipated aircraft conflicts ▪ Holding patterns not

			▪ Clear arrivals to Holding areas ▪ Use of appropriate RWY configuration and STARs	▪ Increased probability of separation loss; ▪ Reduction in available airspace for conflict resolution; ▪ Increased probability of unknown traffic entering the sector; ▪ Limited applicability of radar vectoring and lateral separation		available
OPS SUP	▪ nil	▪ Adverse WX anticipation through: MET forecasts & current weather reports; WX and ATC radar; visual observation ▪ Warn NM and adjacent centres of Adverse WX ▪ Decide on appropriate RWY configuration and SID/STARs ▪ Decide on traffic restrictions	▪ Warn NM and adjacent centres of reported Convective WX ▪ Tactical flow management: coordinate tactical ATC avoidance routings; minimum departure intervals;	▪ Increased workload (complexity assessment; coordination)	▪ Sectorisation management; ▪ Assigning additional staff on sectors; ▪ Implement increased separation (e.g. miles in trail)	▪ Reduced throughput; ▪ Flight delays;
FMP	▪ Convective WX anticipation through MET forecasts and other MET data ▪ Initial ATC impact assessment; ▪ Decision (CDM) on prevention strategy ▪ Provide network warning in case of potential capacity reduction	▪ Convective WX anticipation and detection through MET forecasts and current weather reports and other MET data ▪ Flow regulation ▪ Traffic monitoring and regulation adjustment, if needed	▪ nil	▪ Reduced sector capacity ▪ Flight delays ▪ Flight re-routings	▪ nil	▪ nil
Airport Operator	▪ nil	▪ nil	▪ nil	▪ Disruption of airport operations (flight schedules)	▪ nil	▪ nil
Aircraft Operator	▪ Convective WX anticipation through MET forecasts ; ▪ Review of flight schedule and ANSPs response intentions (NOP) and decision on FPL change, if	▪ Convective WX anticipation through MET forecasts and current weather reports; ▪ FPL route change; ▪ Flight delay; ▪ Flight cancelation;	▪ Nil, or ▪ In case of dispatch office - assistance to pilots on Convective WX avoidance	▪ Disruption of planned daily schedule; ▪ Increased cost ▪ Less efficient fleet use	▪ nil	▪ Disruption of planned schedule; ▪ Increased cost; ▪ Less efficient fleet use

	applicable					
Network Manager	▪ Convective WX anticipation through MET forecasts and other MET data; ▪ Consolidates forecast data, updates NOP; makes list of affected airspaces; ▪ Initial Network impact assessment in view of expected demand, airspace/ capacity data, and ANSPs response intentions; ▪ Coordinates with FMPs local prevention strategies ▪ Facilitates the dissemination of potential capacity reduction warnings	▪ Convective WX anticipation through MET forecasts and current weather reports; ▪ Consolidates forecast data; updates NOP; makes list of affected airspaces; ▪ Network impact assessment (planned demand, EAUP, capacity data, and ANSPs response intentions) ▪ Contacts FMPs for local prevention strategies and measures ▪ Issues Flow regulation ▪ Facilitates the propagation through the network of the convective WX warnings	▪ Facilitates the propagation through the network of the convective WX warnings	▪ Increased workload ▪ Increased coordination ▪ Increased number of flow regulations ▪ Increased number of SLOT assignments	▪ nil	▪ Increased need of Slot revision
MET office / MET service provider	▪ Convective WX forecasting (CB, TS, CAT); ▪ In some cases customized forecasts and weather translation	▪ Convective WX forecasting (CB, TS, CAT); ▪ Convective weather detection (e.g. WX radar) and reporting ▪ In some cases customized forecasts/current weather reports and weather translation	▪ Convective WX detection and/or reporting (WX radar, visual observation, pilot reports, etc.)	▪ nil	▪ nil	▪ nil

3.1 Description

Turbulence is caused by the relative movement of disturbed air through which an aircraft is flying. Its origin may be thermal or mechanical and it may occur either within or clear of cloud.

- Thermal – for example associated with convective activity such as thunderstorms, or close to the boundary between air masses where a Jet Stream exists.
- Mechanical – associated with passage of air masses over terrain of significant vertical extent causing, for example, mountain wave activity and rotors.

The absolute severity of turbulence depends directly upon the rate at which the speed or the direction of airflow (or both) are changing although perception of the severity of turbulence which has been encountered will be affected by the mass of the aircraft involved.

For the purpose of reporting and forecasting of air turbulence, it is graded on a relative scale, according to its perceived or potential effect on a 'typical' aircraft, as Light, Moderate, Severe and Extreme.

Light turbulence is the least severe, with slight, erratic changes in attitude and/or altitude.

Moderate turbulence is similar to light turbulence, but of greater intensity - variations in speed as well as altitude and attitude may occur but the aircraft remains in control all the time.

Severe turbulence is characterised by large, abrupt changes in attitude and altitude with large variations in airspeed. There may be brief periods where effective control of the aircraft is impossible. Loose objects may move around the cabin and damage to aircraft structures may occur.

Extreme turbulence is capable of causing structural damage and resulting directly in prolonged, possible terminal loss of control of the aircraft.

When severe turbulence is encountered it may cause:

- *Aircraft damage* when structural load limits are exceeded
- *Injuries* to crew members or passengers- either when an unrestrained person impacts internal aircraft structures or when a person is hit by non-firmly attached objects in the cabin
- *Level bust* – severe turbulence may abruptly displace aircraft from intended flight path and may require substantial control input to compensate
- *Loss of control* – Severe turbulence may cause momentary loss of control. This may represent a significant danger if experienced at low levels when chances of recovery are low
- *Crew incapacitation* – during severe turbulence encounters even simple tasks as reading instruments may become nearly impossible

- *Power loss* – Selecting continuous ignition ON is a typical procedure during turbulence penetration to avoid engine flame-out.

Severe and/or extreme turbulence is often caused by convective weather (e.g. CB).

3.2 Actors, Prevention and Mitigation

Meteorological service provider is usually the initiating actor of any adverse weather risk management process. Meteorological forecasts of adverse weather would normally be available several days before the day of operations; however forecast confidence would be rather low until short time before occurrence of the forecasted weather. A large variety of tools and computational models are available to MET officers, but forecast accuracy may vary according to local conditions and peculiarities. Severe mechanical turbulence caused by terrain may be commonplace in some locations when the winds are from a particular direction. Not only Annex 3 forecasts and weather reports, but direct assistance to other actors is sometimes provided (e.g. enhanced weather forecast bulletins, pre-shift and pre-flight briefings, customized forecasts or MET reports) on request by ATC service providers, airport operators or aircraft operators.

Flow Management Positions anticipate adverse weather using input from MET service providers. Forecast weather severity and probability are used to estimate the potential impact on ATC operations in the airspace for which FMP is responsible. Decision on risk management strategies is taken using mostly experience and knowledge on local specifics. In certain cases decision support tools or a predefined set of strategies might be available to facilitate planning and reduce overall response time. In case capacity reduction is provisioned, a relevant warning should be disseminated to airspace users and adjacent ATC units (usually via NM). FMP continually monitor updates of weather and traffic forecasts and adjust their response strategies accordingly.

Network Manager uses Information from MET service providers to anticipate adverse weather in certain portions of airspace. Often information from more than one source needs to be consolidated in order to obtain a global network view. NM identifies the airspace and airports which might be directly affected by expected meteorological conditions, contacts relevant FMP for details on planned measures and, if required, issues flow regulations. NM facilitates propagation through the network of adverse weather warnings and their expected effect on operations. NM will be impacted by an increased workload and coordination, as well as an increased number of regulations, slot assignments and revisions.

OPS supervisor will obtain information on adverse weather through available MET forecasts and reports (TAFs, METARS etc.), observation of weather (or ATC) radar or a direct visual observation. Normally it is the responsibility of OPS supervisor to warn adjacent ATC units of any potential influence that adverse weather may have on operations and request activation of relevant LoAs' provisional clauses (specific transfer of control conditions or other). OPS supervisor will warn also NM (directly or through FMP) on any planned response actions that may have an effect on network operations. In order to mitigate the effects of increased controller workload OPS supervisor will manage dynamically sector configuration, possibly opening new sectors and assigning additional controllers. Increased separation might be introduced in all affected sectors as well as minimum departure intervals/increased final approach separation. Flow regulations might be also introduced.

Aircraft operators receive information about possible weather deterioration through standard aviation forecasts and reports issued by met service providers. Some large operators may have their own meteorological departments (or contracts with met service companies). Operators would review their own flight schedules and ANSPs response plans and decision on FPL or departure time change might be taken. Ultimately some flights might be cancelled. Some operators may provide in-flight assistance to pilots on best possible weather avoidance options. Airlines will suffer from a significant disruption of planned daily schedule, less efficient fleet use and overall increase in operating costs.

Airport operators can take no prevention or mitigation actions to counteract the effects of turbulent conditions. Nevertheless they will suffer indirectly from a significant disruption in flight schedules as a result of airborne and ground delays.

Pilots receive information on possible weather hazards at their pre-flight briefings through review of available meteorological forecasts and reports. At this stage a change in flight plan route and/or departure time is possible in order to avoid any potential adverse weather encounter. Contingency measures would be taken by the PIC (e.g. additional fuel) in order to be able to fly a profile which will avoid turbulence (including diversion to alternate airport). Once airborne convective weather and associated turbulence will be detected by aircraft weather radar (typically up to 150 NM ahead), or advance information will be received from ATC advise, pilot reports, automatic broadcast services (VOLMET, ATIS) or direct visual observation. Change in course (most often) or flight level change (rarely) would be initiated by flight crew in order to avoid any conditions of severe turbulence. In case that an approach or landing to destination aerodrome is not possible or not recommendable decision will be taken to hold for weather improvement or divert to an alternate aerodrome.

Pilots will incur increased workload due to the need to continuously assess adverse weather and possible alternate options which may result in fatigue and distraction and increase the probability of operational errors. Any deviation (lateral or vertical) would make flight profile less efficient, increasing distance and time flown. In the event of a lateral/vertical deviation that was not planned for and/or properly communicated to ATC, reduction in separation from other aircraft may occur.

A number of mitigation techniques are available to pilots in turbulent conditions – reduction in aircraft speed in order to reduce stress on the airframe, maintain clean configuration on approach for as long as possible, fit seatbelts and harnesses, suspend cabin service etc. When penetration in an adverse weather area is unavoidable, penetration altitude has to be carefully selected in order to be able to maintain adequate terrain clearance at all times.

Air traffic controllers usually obtain early information about possible weather deterioration at routine pre-shift briefings. Additional sources of information are some weather radar products, MET reports (METAR, SIGMET), pilot reports, and in the case of tower controllers, direct visual observation. ATCOs may use change of routings (e.g. change in SID/STAR) in order to prevent penetration into adverse weather areas. Early warnings will be given to pilots and advance information on possible deviation actions will be requested from pilots in order to build a traffic management plan as early as possible. Allocation of different flight levels might be applied on closely spaced routes or in congested portions of airspace in order to prevent reduction in separation between deviating aircraft. Arrivals into busy airports would be cleared to hold for weather improvement if the turbulence is connected to convective activity, runway configuration might also be changed in order to mitigate some of the adverse weather effects

In such conditions air traffic controllers would incur increased workload, coordination and frequency occupancy time. Need for frequent updates of ATC system may arise (update of flight trajectories/FL). In cases where significant portions of airspace are blocked by weather, controllers may face a significant reduction in space available for conflict resolution. Intensive weather deviation creates non-standard traffic flows and new conflict points at unanticipated position. Larger separations will be applied by ATCOs in order to mitigate the increased probability of separation loss. Depending on the location of adverse weather some standard (published) holding patterns may not be available.

3.3 Related accident and incidents

A333, en-route, Kota Kinabalu Malaysa, 2009

22 June 2009, an Airbus A330-300 on a flight from Hong Kong to Perth encountered an area of severe convective turbulence at night in IMC in the cruise at FL380 and 10 of the 209 occupants sustained minor injuries and the aircraft suffered minor internal damage.

Causes/Findings:

The crew did not detect the convective area either visually or by radar. The area of convective turbulence comprised ice crystals, which the aircraft radar had limited capability to detect.

Safety Recommendations:

Upgrade weather radar on all fleet in order to increase detection capability.

DHC2, Sqwau Lake Quebec, Canada, 2005

1 September 2005, a DHC-2 Beaver, crashed near Squaw Lake, Quebec, Canada, following loss of control in adverse weather and moderate to severe turbulence

Causes/Findings:

The pilot attempted to cross a mountain ridge in adverse weather, and the aircraft stalled at an altitude from which recovery was not possible. Loss of visual references, strong updrafts, moderate to severe turbulence and possible wind shear likely contributed to the onset of the aerodynamic stall.

Safety Recommendations:

Only recommendations related to the effectiveness of SAR operations were issued.

4. Atmospheric electricity and lightning

Hazard Assessment Card						
Hazard:	**Potential effects on a flight exposed to the hazard:**					
Atmospheric electricity and lightning	*Aircraft damage, Communication problems; Avionics problem; Power loss; Crew Incapacitation*					
Actor / **Description**	**Pre-tactical Prevention** (D-1)	**Tactical Prevention** (D0 till departure)	**In-flight Prevention**	**Impact of the Prevention Measures**	**Mitigation of exposure to hazard**	**Impact of the Mitigation Measures**
Pilot	▪ nil	▪ WX anticipation after review of MET forecasts & current weather reports ▪ FPL route change ▪ Flight delay ▪ Refuelling delay ▪ Request alternative RWY ▪ Plan for contingencies (e.g. diversion and additional fuel)	▪ WX detection through: aircraft radar; current weather reports; pilot reports; visual observation or ATC advise ▪ Lateral or vertical deviation ▪ Diversion or hold for Wx improvement (In case of adverse weather situated over destination airport)	▪ Inefficient flight profile; ▪ Longer route; ▪ Increased pilot workload ▪ Possible reduced separation to other aircraft ▪ Departure / approach delay	▪ Expedite leaving the affected area ▪ Turn on cockpit lights ▪ Optimise holding speed ▪ Review fuel endurance ▪ Request EAT	▪ Route and/or FL change; ▪ Increased flight duration; ▪ Pilot Fatigue ▪ Pilot Distraction ▪ Possible reduced separation to other aircraft
ATC controller	▪ nil	▪ WX anticipation and detection through: WX and/or ATC radar, current weather reports, pilot reports, visual observation, pre-shift briefings ▪ Departure suspension ▪ Change of SID/departure clearance	▪ WX detection through: WX and/or ATC radar, current weather reports, pilot reports, visual observation; ▪ Early warning to pilots; ▪ WX/TS avoidance advice and assistance; ▪ Clear arrivals to holding areas ▪ If needed provide info on	▪ Increased workload; ▪ Increased frequency occupancy time; ▪ Increased coordination; ▪ Increased need of system updates (e.g. route and level); ▪ Increased probability of separation loss; ▪ Reduction in available	▪ WX avoidance assistance ▪ Increased separation; ▪ Use of appropriate RWY configuration and STARs	▪ Reduced throughput; ▪ Flight delays; ▪ Unexpected aircraft deviation from cleared trajectory

			alternate aerodrome conditions and availability	airspace for conflict resolution; ▪ Reduced airport throughput		
OPS SUP	▪ nil	▪ WX anticipation through: MET forecasts & current weather reports; WX and ATC radar; visual observation ▪ Warn NM and adjacent centres of adverse WX ▪ Decide on appropriate RWY configuration and SID/STARs ▪ Decide on traffic restrictions – e.g. departures suspension	▪ Warn NM and adjacent centres of reported adverse WX ▪ Tactical flow management: coordinate tactical ATC avoidance routings; minimum departure intervals; increased final approach separation	▪ Increased workload (complexity assessment; coordination)	▪ Sectorisation management; ▪ Assigning additional staff on sectors; ▪ Implement increased separation (e.g. miles in trail)	▪ Reduced throughput; ▪ Flight delays;
FMP	▪ Adverse WX anticipation through MET forecasts and other MET data ▪ Initial ATC impact assessment; ▪ Decision (CDM) on prevention strategy ▪ Provide network warning in case of potential capacity reduction	▪ Adverse WX anticipation and detection through MET forecasts and current weather reports and other MET data ▪ Flow regulation ▪ Traffic monitoring and regulation adjustment, if needed	▪ nil	▪ Reduced sector capacity ▪ Flight delays ▪ Flight re-routings	▪ nil	▪ nil
Airport Operator	▪ nil	▪ Lightning hazard preventions measures on the ground (e.g. restrictions on re-fuelling operations) ▪ Refuelling delays	▪ nil	▪ Disruption of airport operations (flight schedules)	▪ nil	▪ nil
Aircraft Operator	▪ Adverse WX anticipation through MET forecasts ; ▪ Review of flight schedule and ANSPs response intentions (NOP) and decision on FPL change, if applicable	▪ Adverse WX anticipation through MET forecasts and current weather reports; ▪ FPL route change; ▪ Flight delay; ▪ Flight cancelation;	▪ Nil, or ▪ In case of dispatch office - assistance to pilots on adverse WX avoidance	▪ Disruption of planned daily schedule; ▪ Increased cost ▪ Less efficient fleet use	▪ nil	▪ Disruption of planned schedule; ▪ Increased cost; ▪ Less efficient fleet use

Network Manager	▪ Adverse WX anticipation through MET forecasts and other MET data; ▪ Consolidates forecast data, updates NOP; makes list of affected airspaces; ▪ Initial Network impact assessment in view of expected demand, airspace/ capacity data, and ANSPs response intentions; ▪ Coordinates with FMPs local prevention strategies ▪ Facilitates the dissemination of potential capacity reduction warnings	▪ Adverse WX anticipation through MET forecasts and current weather reports; ▪ Consolidates forecast data; updates NOP; makes list of affected airspaces; ▪ Network impact assessment (planned demand, EAUP, capacity data, and ANSPs response intentions) ▪ Contacts FMPs for local prevention strategies and measures ▪ Issues Flow regulation ▪ Facilitates the propagation through the network of the adverse WX warnings	▪ Facilitates the propagation through the network of the adverse WX warnings	▪ Increased workload ▪ Increased coordination ▪ Increased number of flow regulations ▪ Increased number of SLOT assignments	▪ nil	▪ Increased need of Slot revision
MET office / MET service provider	▪ Adverse WX forecasting (CB, TS and lightning); ▪ In some cases customized forecasts and weather translation	▪ Adverse WX forecasting; ▪ Adverse weather conditions detection and reporting ▪ In some cases customized forecasts/ current weather reports and weather translation ▪ Assistance in pre-flight briefings	▪ Adverse WX detection and/or reporting (WX radar, visual observation, pilot reports, etc.)	▪ nil	▪ Frequent updates on WX development to ATC staff (in-between routine reports)	▪ nil

4.1 Description

Lightning is an electrostatic discharge caused by imbalance of atmospheric charge inside clouds, between clouds (usually Cumulonimbus clouds) or between a cloud and the ground. Lightning is accompanied by a brilliant flash of light and thunder noise (sometimes not heard depending on the observer's location). Lightning rarely threatens the safety of aircraft; nevertheless. cases of physical damage or interference with aircraft systems have been reported. The potential effects on a flight exposed to lightning are:

- *Aircraft damage* – structural damage to aircraft as a result of a lightning strike is rare. However occasions have been reported when lightning strikes leave punctures in the radomes or tail fins of aircraft (entry and exit points).
- *Crew incapacitation*- Momentary blindness from the lightning flash, especially at night, is not uncommon.
- *Interference with avionics* - A lightning strike can affect avionics systems, particularly compasses.
- *Communication problems* - Static electricity may affect performance of VHF radio reducing readability.
- *Engine shutdown* - Transient airflow disturbance associated with lightning to cause engine shutdown on both FADEC and non-FADEC engines with close-spaced engine pairs.

4.2 Actors, Prevention and Mitigation

Meteorological service provider is usually the initiating actor of any adverse weather risk management process. Meteorological forecasts of adverse weather would normally be available several days before the day of operations; however forecast confidence would be rather low until short time before occurrence of the forecasted weather. A large variety of tools and computational models are available to MET officers, but forecast accuracy may vary according to local conditions and peculiarities. Not only Annex 3 forecasts and weather reports, but direct assistance to other actors is sometimes provided (e.g. enhanced weather forecast bulletins, pre-shift and pre-flight briefings, customized forecasts or MET reports) on request by ATC service providers, airport operators or aircraft operators.

Flow Management Positions anticipate adverse weather using input from MET service providers. Forecast weather severity and probability are used to estimate the potential impact on ATC operations in the airspace for which FMP is responsible. Decision on risk management strategies is taken using mostly experience and knowledge on local specifics. In certain cases decision support tools or a predefined set of strategies might be available to facilitate planning and reduce overall response time. In case capacity reduction is provisioned, a relevant warning should be disseminated to airspace users and adjacent ATC units (usually via NM). FMP continually monitor updates of weather and traffic forecasts and adjust their response strategies accordingly.

Network Manager uses Information from MET service providers to anticipate adverse weather in certain portions of airspace. Often information from more than one source needs to be consolidated in order to obtain a global network view. NM identifies the airspace and airports which might be directly affected by expected meteorological conditions, contacts relevant FMP for details on planned measures and, if required, issues flow regulations. NM facilitates propagation through the network of adverse weather warnings and their expected effect on operations. NM will be impacted by an increased workload and coordination, as well as an increased number of regulations, slot assignments and revisions.

Aircraft operators receive information about possible weather deterioration through standard aviation forecasts and reports issued by met service providers. Some large operators may have their own meteorological departments (or contracts with met service companies). Operators would review their own flight schedules and ANSPs response plans and a decision on FPL or departure time change might be taken. Ultimately some flights might be cancelled. Some operators may provide in-flight assistance to pilots on best possible weather avoidance options. Airlines will suffer from a significant disruption of planned daily schedule, less efficient fleet use and overall increase in operating costs.

OPS supervisor will obtain information on adverse weather through available MET forecasts and reports (TAFs, METARS etc.), observation of weather (or ATC) radar or a direct visual observation. Normally it is the responsibility of OPS supervisor to warn adjacent ATC units on any potential influence that adverse weather may have on operations and request activation of relevant LoAs' provisional clauses (specific transfer of control conditions or other). OPS supervisor will warn also NM (directly or through FMP) on any planned response actions that may have an effect on network operations. In order to mitigate the effects of increased controller workload OPS supervisor will manage dynamically sector configuration, possibly opening new sectors and assigning additional controllers. Increased separation might be introduced in all affected sectors as well as minimum departure intervals/increased final approach separation. Flow regulations might be also introduced.

Airport operators may implement measures related to the prevention of ignition and fire on the ground due to lightning hazard. Normally all re-fuelling operations would be halted if there is thunderstorm activity within 5 NM of the airport. This may generate significant delays on departing traffic and cause disruption on flight schedules and airport operations.

Pilots receive information on possible weather deterioration at their pre-flight briefings through review of available meteorological forecasts and reports. At this stage a change in flight plan route and/or departure time is possible in order to avoid any potential adverse weather encounter. Contingency measures would be taken by the PIC (e.g. additional fuel) in order to be able to hold for longer periods or divert to distant alternate aerodromes. Once airborne, convective weather activity will be detected by aircraft weather radar (typically up to 150 NM ahead), or advance information will be receive by ATC advise, pilot reports, automatic broadcast services (VOLMET, ATIS) or direct visual observation. A change in course would be initiated by flight crew in order to avoid in-flight the convective weather. In a situation where an approach or landing at destination is not possible or not recommended, a decision will be taken to hold for weather improvement or divert to an alternate aerodrome.

Pilots will incur increased workload due to the need to continuously assess adverse weather and possible alternate options, which may result in fatigue and distraction and an increased probability of operational errors. Any deviation (lateral or vertical) would make flight profile less efficient, increasing distance and time flown. In the event of an expeditious lateral/vertical deviation that was not planned for and/or properly communicated to ATC, reduction in separation minima with other aircraft may occur.

During lightning activity cockpit lights would be turned on in order to mitigate the blinding effect of flashes.

Air traffic controllers usually obtain early information about possible weather deterioration at routine pre-shift briefings. Additional sources of information are some weather radar products, MET reports (METAR, SIGMET), pilot reports, and in the case of tower controllers, direct visual observation. ATCOs may use change of routings (e.g. change in SID/STAR) in order to prevent penetration into adverse weather areas. Early warnings will be given and advance information on possible deviation actions will be requested from pilots in order to build a traffic management plan as early as possible. Arrivals into busy airports would be cleared to hold for weather improvement, runway configuration might be changed in order to mitigate some of the effects of heavy thunderstorm and lightning activity. When needed information on possible alternate aerodrome conditions and availability would be provided. In heavy thunderstorm and lightning conditions air traffic controllers would incur increased workload, coordination and frequency occupancy time. Need for frequent updates of ATC system may arise (update of flight trajectories/FL). Both airspace and airports will suffer from reductions in capacity with their respective increase on flight delays. Larger separation will be applied by controllers in order to mitigate the increased probability of unexpected deviation from cleared trajectory and separation loss.

4.3 Related Accidents and incidents

D228, Bodo Norway, 2003 (Lightning damage)

On 4 December 2003, a Dornier-228 approaching Bodo, Norway, was struck by Lightning and suffered damage to the elevator control. The crew were temporarily blinded and momentarily lost control of the aircraft but managed to crash land just short of the runway threshold.

Causes/Findings:

- Crew had insufficient training in the use of weather radar.
- Airborne weather radar was not functioning correctly.
- Ground weather radar was not available at the time of the accident.

Safety Recommendations:

- Improve weather radar training and maintenance.
- Consider integrated presentation of weather radar information on air traffic control services radar displays.

B752, Girona, Spain, 1999 (Lightning damage)

On 14 September 1999, a Boeing 757 crash landed and departed the runway after a continued unstabilised approach in bad weather to Girona airport, Spain.

Causes/Findings:

- Detailed information on weather development and intensity was not provided by ATC to the flight crew.
- The electrical power supply of the airport failed immediately before the aircraft touched down due to heavy rain and storm activity and runway lights went out.
- The main cause was the destabilisation of the approach below decision height due to loss of external visual reference.
- Contributory causes were the impairment of runway visual environment due to heavy thunderstorm activity and the extinguishing of runway lights, the mental shock of loss of RWY lights that prevented flight crew from initiating a go-around as well as inefficient evaluation of the movement and severity of the storm affecting the aerodrome.

Safety Recommendations:

- Aircraft operator to review flight planning and clearance procedures in order to take into account probable meteorological conditions including thunderstorms.
- Improve ATCO training to determine what meteorological information to provide to flight crews.
- National Meteorological Services in collaboration with air traffic services to establish a standardised system to inform flight crews on the evolution and intensity of storms

5. In-flight Icing

Hazard Assessment Card						
Hazard:	**Potential effects on a flight exposed to the hazard:**					
In-flight Icing	*Loss of control; Communication problems; Avionics problem; Power loss; Loss of engine-out capability; Ice shedding; CFIT*					
Actor / **Description**	**Pre-tactical Prevention** (D-1)	**Tactical Prevention** (D0 till departure)	**In-flight Prevention**	**Impact of the Prevention Measures**	**Mitigation of exposure to hazard**	**Impact of the Mitigation Measures**
Pilot	▪ nil	▪ WX anticipation after review of MET forecasts & current weather reports ▪ FPL route change, including cruising levels if needed ▪ Flight delay ▪ De-icing on the ground ▪ Plan for contingencies (e.g. diversion, additional fuel)	▪ WX detection through: aircraft systems; broadcasted current weather reports; pilot reports; visual observation or ATC advise ▪ Lateral deviation ▪ FL change ▪ Diversion or Hold for WX improvement (In case of adverse weather situated over destination airport)	▪ Inefficient flight profile; ▪ Longer route; ▪ Increased pilot workload ▪ Possible reduced separation to other aircraft ▪ Time pressure to expedite departure within holdover time	▪ Manage aircraft speed and power accordingly; ▪ Expedite leaving the affected area ▪ Follow AFM icing procedures ▪ Operate anti/de-icing systems	▪ Route and/or FL change; ▪ Increased flight duration or emergency landing ▪ Increased fuel consumption ▪ Increased workload ▪ Pilot Fatigue ▪ Pilot Distraction ▪ Possible reduced separation to other aircraft ▪ Reduced aircraft performance
ATC controller	▪ nil	▪ WX anticipation and detection through: WX and/or ATC radar, current weather reports, pilot reports, visual observation, pre-shift briefings	▪ WX detection through: WX and/or ATC radar, current weather reports, pilot reports, visual observation; ▪ Early warning to pilots; ▪ WX avoidance advice and	▪ Increased workload; ▪ Increased frequency occupancy time; ▪ Increased coordination; ▪ Increased need of system updates (e.g. route and	▪ WX avoidance assistance ▪ Increased separation; ▪ Use of appropriate RWY configuration and STARs	▪ Reduced throughput; ▪ Flight delays; ▪ Unexpected aircraft deviation from cleared trajectory ▪ Possible reduced

		▪ Change of SID/departure clearance	assistance; ▪ Clear arrivals to Holding areas ▪ Provide info on alternate aerodrome conditions and availability	level); ▪ Increased probability of separation loss; ▪ Reduced airport throughput ▪ Increased taxi time ▪ Time pressure (expedite departures within holdover time limits)		separation to other aircraft ▪ Reduction in available conflict resolution techniques (e.g. no speed control);
OPS SUP	▪ nil	▪ WX anticipation through: MET forecasts & current weather reports; WX and ATC radar; visual observation ▪ Warn NM and adjacent centres of adverse WX ▪ Decide on appropriate RWY configuration and SID/STARs ▪ Decide on traffic restrictions	▪ Warn NM and adjacent centres of reported adverse WX ▪ Tactical flow management: coordinate tactical ATC avoidance routings; minimum departure intervals; increased final approach separation	▪ Increased workload (complexity assessment; coordination)	▪ Sectorisation management; ▪ Assigning additional staff on sectors; ▪ Implement increased separation (e.g. miles in trail) ▪ Runway configuration management	▪ Reduced throughput; ▪ Flight delays;
FMP	▪ Adverse WX anticipation through MET forecasts and other MET data ▪ Initial ATC impact assessment; ▪ Decision (CDM) on prevention strategy ▪ Provide network warning in case of potential capacity reduction	▪ Adverse WX anticipation and detection through MET forecasts and current weather reports and other MET data ▪ Flow regulation ▪ Traffic monitoring and regulation adjustment, if needed	▪ Nil	▪ Reduced sector capacity ▪ Flight delays ▪ Flight re-routings	▪ nil	▪ nil
Airport Operator	▪ Adverse WX anticipation through MET forecasts and other MET data ▪ Plan for de-icing of aircraft	▪ De-icing of aircraft prior to departure	▪ nil	▪ Disruption of airport operations (flight schedules)	▪ nil	▪ nil
Aircraft Operator	▪ Adverse WX anticipation through MET forecasts ; ▪ Review of flight schedule and ANSPs response intentions (NOP) and decision on FPL change, if applicable	▪ Adverse WX anticipation through MET forecasts and current weather reports; ▪ FPL route change; ▪ Flight delay; ▪ Flight cancelation;	▪ Nil, or ▪ In case of dispatch office - assistance to pilots on adverse WX avoidance	▪ Disruption of planned daily schedule; ▪ Increased cost ▪ Less efficient fleet use	▪ nil	▪ Disruption of planned schedule; ▪ Increased cost; ▪ Less efficient fleet use

Network Manager	▪ Adverse WX anticipation through MET forecasts and other MET data; ▪ Consolidates forecast data, updates NOP; makes list of affected airspaces; ▪ Initial Network impact assessment in view of expected demand, airspace/ capacity data, and ANSPs response intentions; ▪ Coordinates with FMPs local prevention strategies ▪ Facilitates the dissemination of potential capacity reduction warnings	▪ Adverse WX anticipation through MET forecasts and current weather reports; ▪ Consolidates forecast data; updates NOP; makes list of affected airspaces; ▪ Network impact assessment (planned demand, EAUP, capacity data, and ANSPs response intentions) ▪ Contacts FMPs for local prevention strategies and measures ▪ Issues Flow regulation ▪ Facilitates the propagation through the network of the adverse WX warnings	▪ Facilitates the propagation through the network of the adverse WX warnings	▪ Increased workload ▪ Increased coordination ▪ Increased number of flow regulations ▪ Increased number of SLOT assignments	▪ nil	▪ Increased need of Slot revision
MET office / MET service provider	▪ Adverse WX forecasting (CB, TS or icing conditions); ▪ In some cases customized forecasts and weather translation	▪ Adverse WX forecasting; ▪ Adverse weather conditions detection and reporting ▪ In some cases customized forecasts/ current weather reports and weather translation ▪ Assistance in pre-flight briefings	▪ Adverse WX detection and/or reporting (WX radar, visual observation, pilot reports, etc.)	▪ nil	▪ nil	▪ nil

5.1 Description

In-flight icing refers to the accretion of ice on aircraft wings, engines or their inlets when super cooled water droplets come into contact with aircraft surface. In-flight icing could potentially cause:

6. *Loss of control* – Accumulation of ice on wing surfaces changes an airfoil's contours, increases drag and reduces lift. Aircraft weight is also increased. As a result wing stall, tail plane stall or lateral control overbalance may occur.
7. *Communication problems* - ice accretion on unheated aerials may affect radio performance
8. *Avionics problems* - Blockage of pitot tubes and static vents may render airspeed indications unreliable. Loss of artificial stall warning may also occur.
9. *Power loss* – induction icing (also called carburettor icing) is the build-up of ice in the fuel induction system of a piston engine and may reduce available power or cause the engine to stop. In turbine engines the only ice produced is near the first compressor stage. This is rarely an insurmountable problem as there is sufficient heat in the area from hot air bleed or hot oil. There might be a problem with ice ingestion on high performance turbine engines as a sudden slug of slush may cause engine flame-out.
10. *Loss of engine-out capability* – Icing may result in change in the shape of power required vs. power available curves which, should one engine fail, may render the aircraft incapable of maintaining safe altitude.
11. *Ice shedding* - Accrued ice may shed from aircraft near the aerodrome posing threat to property or people on the ground (or even other aircraft when hazardous-sized pieces are shed on the runway prior or just after touchdown). Ice shed from wings may also be ingested into tail mounted engines causing engine failure or flame-out.
12. *Terrain Impact* - If the drag increase and/or thrust decrease due to ice accretion is excessive, continued level flight may not be possible, and a descent will be required in order to maintain airspeed. This has resulted in impact with terrain in mountainous areas.

12.1 Actors, Prevention and Mitigation

Meteorological service provider is usually the initiating actor of any adverse weather risk management process. Meteorological forecasts of adverse weather would normally be available several days before the day of operations, however forecast confidence would be rather low until short time before occurrence of the forecasted weather. A large variety of tools and computational models are available to MET officers, but forecast accuracy may vary according to local conditions and peculiarities. Not only Annex 3 forecasts and weather reports, but direct assistance to other actors is sometimes provided (e.g. enhanced weather forecast bulletins, pre-shift and pre-flight briefings, customized forecasts or MET reports) on request by ATC service providers, airport operators or aircraft operators.

Flow Management Positions anticipate adverse weather using input from MET service providers. Forecast weather severity and probability are used to estimate the potential impact on ATC operations in the airspace for which FMP is responsible. Decision on risk management strategies is taken using mostly experience and knowledge of local specifics. In certain cases decision support tools or a predefined set of strategies might be available to facilitate planning. In case capacity reduction is provisioned, a relevant warning should be disseminated to airspace users and adjacent ATC units (usually via NM). FMP continually monitor updates of weather and traffic forecasts and adjust their response strategies accordingly.

Network Manager uses Information from MET service providers to anticipate adverse weather in certain portions of airspace. Often information from more than one source needs to be consolidated in order to obtain a global network view. NM identifies the airspaces and airports which might be directly affected by expected meteorological conditions, contacts relevant FMP for details on planned measures and, if required, issues flow regulations. NM facilitates propagation through the network of adverse weather warnings and their expected effect on operations. NM will be impacted by an increased workload and coordination, as well as an increased number of regulations, slot assignments and revisions.

Aircraft operators receive information about possible weather deterioration through standard aviation forecasts and reports issued by met service providers. Some large operators may have their own meteorological departments (or contracts with met service companies). Operators would review their own flight schedules and ANSPs response plans and decision on FPL or departure time change might be taken. Ultimately some flights might be cancelled. Some operators may provide in-flight assistance to pilots on best possible alternate options. Airlines will suffer from a significant disruption of planned daily schedule, less efficient fleet use and overall increase in operating costs.

Airport operators anticipate weather deterioration through available standard aviation forecasts and reports. At D-1 plans can be reviewed in order to enable efficient conduct of aircraft de-icing procedures. Scheduled airport operations may be affected by in-flight icing hazards due to the delays caused by aircraft de-icing prior to departure.

OPS supervisor will obtain information on adverse weather through available MET forecasts and reports (TAFs, METARS etc.), observation of weather (or ATC) radar display or a direct visual observation. Normally it is the responsibility of OPS supervisor to warn adjacent ATC units on any potential influence that adverse weather may have on operations and request activation of relevant LoAs' provisional clauses (specific transfer of control conditions or other). OPS supervisor will warn also NM (directly or through FMP) on any planned response actions that may have an effect on network operations. In order to mitigate the effects of increased controller workload OPS supervisor will manage dynamically sector configuration, possibly opening new sectors and assigning additional controllers. Increased separation might be introduced in all affected sectors as well as minimum departure intervals/increased final approach separation. Flow regulations might be also introduced. During adverse weather operations OPS supervisor's workload will be significantly increased.

Pilots receive information on possible weather deterioration at their pre-flight briefings through review of available meteorological forecasts and reports. At this stage a change in flight plan route and/or departure time is possible in order to avoid any potential adverse weather encounter. Contingency measures would be taken by the PIC (e.g. additional fuel) in order to cater for additional fuel burn when using anti/de-icing systems. Once airborne, advance information on icing conditions will be receive by ATC advice, pilot reports, automatic broadcast services (VOLEMT, ATIS). Direct visual observation and on-board warning system assist recognition of icing conditions in-flight. Change in course or flight level change would be initiated by flight crew in order to avoid the adverse conditions. In cases where continuation of flight to destination aerodrome is not possible, a decision will be taken to divert to an alternate aerodrome.

Pilots will incur increased workload due to the need to continuously assess adverse weather and possible alternate options. Any deviation (lateral or vertical) would make flight profile less efficient, increasing distance and time flown. In the event of any lateral/vertical deviation (weather avoidance action) that was not planned for and/or properly communicated to ATC, reduction in separation from other aircraft may occur. In case aircraft was de-iced prior to take off there will be a time pressure on flight crew to execute departure within the holdover time limits.

In case an area of severe icing is penetrated pilots would use appropriate flying techniques in order to mitigate any adverse effects on aircraft performance (increase in speed and power, selection of fastest way out of the area, operation of de-icing system, turning on continuous ignition etc.). The increased flight duration, need for route/FL change may cause pilot fatigue and distraction and increase the probability of operational errors.

Air traffic controllers usually obtain early information about possible weather deterioration at routine pre-shift briefings. Additional sources of information are some weather radar products, MET reports (METAR, SIGMET), pilot reports, and in the case of tower controllers - direct visual observation. ATCOs may use change of routings (e.g. change in SID/STAR) in order to prevent penetration into adverse weather areas. Early warnings will be given to pilots and advance information on possible deviation actions will be requested in order to build a traffic management plan as early as possible. Aircraft encountering in-flight icing in the hold may request an expedited approach. Arrivals would be cleared into holding patterns as needed and information on possible alternate aerodromes' conditions and availability would be provided. In the cases when ground de-icing procedures are implemented, there might be a time pressure on air traffic controllers to expedite departures within the limits of hold-over time. In icing conditions air traffic controllers would incur increased workload, coordination and frequency occupancy time. Need for frequent updates of ATC system may arise (update of flight trajectories/FL). In cases where large portions of airspace are blocked by weather, controllers may face a significant reduction in space available for conflict resolution. Some of the techniques used for conflict resolution may not be available (e.g. no speed control during icing conditions). Both airspace and airports will suffer from reductions in capacity with their respective influence on flight delays.

12.2 Related accidents and incidents

B712, Union Start MO, USA, 2005

On 12 May 2005, a Boeing 717-200 on a flight from Kansas City to Washington National and climbing in night IMC experienced a sudden loss of control from which recovery was only achieved after a prolonged period of pitch oscillation involving considerable height variation.

Causes/Findings:

Loss of reliable airspeed indication due to an accumulation of ice on the air data / pitot sensors. Contributing to the incident was the flight crew's improper response to the erroneous airspeed indications, their lack of coordination during the initial recovery of the airplane to controlled flight, and icing conditions

Safety Recommendations:

None

AT72, Roselawn IL, USA, 1994

On 31 October 1994 an ATR 72 crashed near Roselawn, Indiana, USA, following loss of control due to airframe icing.

Causes/Findings:

Loss of control, attributed to a sudden and unexpected aileron hinge moment reversal, that occurred after a ridge of ice accreted beyond the deice boots while the airplane was in a holding pattern during which it intermittently encountered super cooled cloud and drizzle/rain drops, the size and water content of which exceeded those described in the icing certification envelope. The airplane was susceptible to this loss of control, and the crew was unable to recover**.**

Safety Recommendations:

A number of safety recommendations are made related to the distribution of information (pre-flight and in-flight) of hazardous weather conditions, amendments in federal regulations, development of icing certification procedures, development of new weather forecast methods and others.

ATP, Oxford UK, 1991

On 11 August 1991, a British Aerospace ATP, during climb to flight level (FL) 160 in icing conditions, experienced a significant degradation of performance due to propeller icing accompanied by severe vibration that rendered the electronic flight instruments partially unreadable.

Causes/Findings:

- The rapid accumulation of clear ice, which was not evident to the crew, but which produced significant aerodynamic degradation.
- The difficulty of assessing visually the thickness of ice on the wing leading edges from the flight deck.
- The BMA standard procedure to use a maximum TIT of 720°C in the climb discouraged the commander from applying power to counteract the loss of performance.
- Use of autopilot in the pitch mode during climb, which hampered recovery from the subsequent loss of control.
- The propeller vibration which disguised the onset of the stall.

Safety Recommendations:

14 Recommendations are made concerning institutional, organizational and training issues.

AT43, Folgefonna Norway, 2005

On 14 September 2005, an ATR 42-320 experienced a continuous build-up of ice in the climb and, despite the activation of de-icing systems,, entered an uncontrolled roll and lost 1500ft in altitude.

Causes/Findings:

No immediate cause was given, however the report states that: “[…] the investigation has proven a clear connection between the icing incident and latent contributing factors, such as deficiencies in the airline’s quality system and flight safety programme. […] this case illustrates how important a well-functioning regulatory oversight is to flight safety. The failure of the CAA-N follow-up contributed to deficiencies in the operator’s quality system and flight safety programme not being corrected in time.[…]”

Safety Recommendations:

A number of safety recommendations were made concerning operation of this aircraft type in icing conditions.

6. Heavy precipitation causing runway contamination

Important note: For the purpose of this survey weather related hazards are defined at the boundary of aircraft operations. Runway contamination is a result of the meteorological phenomenon "precipitation", the properties of the runway surface and the availability and timely application of measures for removal of runway contamination factors.

Hazard Assessment Card

Hazard:	**Potential effects on a flight exposed to the hazard:**
Heavy precipitation causing RWY contamination	*Loss of control; Runway Excursion; Loss of situational awareness*

Actor / Description	Pre-tactical Prevention (D-1)	Tactical Prevention (D0 till departure)	In-flight Prevention	Impact of the Prevention Measures	Mitigation of exposure to hazard	Impact of the Mitigation Measures
Pilot	▪ nil	▪ WX and RWY conditions anticipation after review of forecasts & current weather reports, SNOWTAM; automatic broadcasts ▪ De-icing procedure on the ground (when snowing) ▪ Flight delay ▪ Plan for contingencies (e.g. diversion, additional fuel)	▪ RWY condition anticipation through: SNOWTAM; automatic broadcasts (VOLMET, ATIS); ATC advise ▪ Diversion or hold for change in RWY conditions ▪ Divert or hold for WX improvement (in case precipitation area is situated over destination airport ▪ Diversion if a/c not	▪ Inefficient flight profile; ▪ Longer route (in case of diversion); ▪ Increased pilot workload ▪ Time pressure to expedite departure/arrival (in-between snow removal gaps) ▪ Operate de-icing system (if equipped and applicable for precipitation type)	▪ Manage aircraft speed ▪ Request longest RWY possible ▪ Use max reverse thrust immediately after touchdown ▪ Monitor auto brakes ▪ Use appropriate directional control and braking techniques	▪ Increased pilot workload ▪ Pilot Fatigue ▪ Pilot Distraction ▪ Increased flight duration and fuel consumption

			equipped properly (e.g. anti-skid or one thrust reverser inoperative) ▪ Go around			
ATC controller	▪ nil	▪ WX and RWY condition anticipation and detection through: SNOWTAM, current weather reports, pilot reports, visual observation, pre-shift briefings, RWY friction measurement	▪ WX and RWY conditions detection through: current weather reports, pilot reports, visual observation; RWY friction measurements ▪ Warning to pilots; ▪ Clear arrivals to Holding areas, when RWY closed for inspection or decontamination ▪ Coordinate RWY re-open times and advise crews ▪ Provide info on alternate aerodromes conditions and availability	▪ Increased workload; ▪ Increased frequency occupancy time; ▪ Increased coordination; ▪ Reduced airport throughput ▪ Increased taxi time ▪ Flight delays ▪ Time pressure (expedite departures within snow removal gaps)	▪ Have precipitation areas avoidance assistance ▪ Increased separation; ▪ Use of appropriate RWY configuration ▪ Manage RWY/TWY lights intensity ▪ Use of SMR / SMGCS ▪ Coordinate RWY re-open times and advise pilots	▪ Controller fatigue ▪ Increased probability for error
OPS SUP	▪ nil	▪ WX and RWY conditions anticipation through: MET forecasts & current weather reports; visual observation; RWY friction measurement reports; SNOWTAM; pilot reports ▪ Warn NM and adjacent centres of adverse WX and anticipated impact on arrival/departure traffic ▪ Decide on appropriate RWY configuration and SID/STARs ▪ Decide on traffic restrictions	▪ Warn NM and adjacent centres of possible airport restrictions/ flow measures /closure ▪ Tactical flow management; increased separation approach; minimum departure intervals, etc	▪ Increased workload (complexity assessment; coordination) ▪ Flight delays;	▪ APP sectorisation and RWY configuration management; ▪ Assigning additional staff/opening new positions; ▪ Implement increased separation (e.g. miles in trail, departure intervals) ▪ Maintain coordination with airport operator's staff on RWY conditions and snow removal progress	▪ Reduced throughput; ▪ Flight delays;
FMP	▪ WX and RWY conditions anticipation through MET forecasts and other MET data ▪ Initial ATC impact assessment; ▪ Decision (CDM) on	▪ WX and RWY conditions anticipation and detection through MET forecasts and current weather reports; SNOWTAM and other data ▪ Flow regulation ▪ Traffic monitoring and	▪ nil	▪ Reduced APP sector capacity ▪ Reduced RWY capacity ▪ Flight delays	▪ nil	▪ nil

	prevention strategy ▪ Provide network warning in case of potential RWY capacity reduction	regulation adjustment, if needed				
Airport Operator	▪ WX and RWY condition anticipation through MET forecasts and other MET data ▪ Plan additional staff and technical resource for RWY de-contamination ▪ Plan for aircraft de-icing procedures	▪ WX and RWY conditions anticipation and detection through current weather reports, visual observation, RWY friction measurement, RWY temperature indicators ▪ Provide timely information to ATC on current and expected RWY conditions ▪ Decontaminate RWY and TWYs as needed ▪ Implement de-icing procedures	▪ Monitor RWY and TWY conditions and close runway if needed ▪ Organise RWY decontamination in close coordination with ATC	▪ Disruption of airport operations (flight schedules) ▪ Flight delays ▪ Increased turnaround time	▪ Monitor RWY and TWY conditions and provide timely information to ATC ▪ Organise RWY braking action measurements and distribute results (SNOWTAM) ▪ Close RWY for de-contamination ▪ Advise ATC on RWY decontamination progress and update RWY re-open times as necessary	▪ Disruption of airport schedule; ▪ Flight delays ▪ Increased fuel burn
Aircraft Operator	▪ WX and RWY conditions anticipation through MET forecasts ; ▪ Review published RWY de-contamination plan (AIP) ▪ Review of flight schedule and ANSPs/airports response intentions (NOP) and decision on departure time change, or revised destination, if applicable ▪ Advise airport/ground handling of possible requirement for aircraft de-icing services	▪ WX and RWY conditions anticipation through MET forecasts and current weather reports; SNOWTAM ▪ Flight delay; ▪ Change of destination; ▪ Flight cancelation;	▪ Nil, or ▪ In case of dispatch office - assistance to pilots with selection of appropriate alternate options (e.g. diversion)	▪ Disruption of planned daily schedule; ▪ Increased cost ▪ Less efficient fleet use	▪ nil	▪ nil
Network Manager	▪ Adverse WX anticipation through MET forecasts and other MET data; ▪ Consolidates forecast data, updates NOP; makes list of affected airports;	▪ Adverse WX anticipation through MET forecasts and current weather reports; ▪ Consolidates forecast data; updates NOP; makes list of affected airspaces and airports	▪ Facilitates the propagation through the network of the adverse WX warnings	▪ Increased workload ▪ Increased coordination ▪ Increased number of flow regulations ▪ Increased number of SLOT assignments	▪ nil	▪ nil

	▪ Initial Network impact assessment in view of expected demand, capacity data, and ANSPs /airports response intentions; ▪ Coordinates with FMPs local strategies ▪ Facilitates the dissemination of potential capacity reduction warnings	▪ Network impact assessment (planned demand, EAUP, capacity data, and ANSPs and airport response intentions) ▪ Contacts FMPs for local prevention strategies and measures ▪ Issues Flow regulation ▪ Facilitates the propagation through the network of the adverse WX warnings				
MET office / MET service provider	▪ Adverse WX forecasting (snow or icing conditions); ▪ In some cases customized forecasts and weather translation	▪ Adverse WX forecasting; ▪ Adverse weather conditions detection and reporting ▪ In some cases customized forecasts/ current weather reports and weather translation ▪ Assistance in pre-flight briefings	▪ Adverse WX detection and/or reporting (visual observation, pilot reports, etc.)	▪ nil	▪ nil	▪ nil

a. Description

Precipitation is any product of the condensation of atmospheric water vapor that falls under gravity. This includes drizzle, rain, sleet, snow, small pellets and hail. Any of these may adversely affect aircraft operations to one extent or another. Heavy precipitation, and hail in particular, may cause:

- *Aircraft damage* – significant damage may be caused by hail on aircraft front surfaces including radome, windshield and slats. Aircraft damage on the ground is also possible, and even though this may not pose a direct risk to safe operations, the aircraft might be unserviceable for an extended period of time.
- *Loss of control* – depending on damage extent loss of control in-flight may occur – e.g. windshield damage may impair visibility from the cockpit thus leading to a loss of situational awareness. Ice accretion which is not removed before flight will lead to loss of control.
- *Communication problems* – a sharp increase in noise levels inside the cockpit during penetration into a hail-storm may prevent effective communication with ATC or between crew members (A321, en-route, Vienna, Austria, 2003)
- *Avionics problems* –Hail damage to radome and the antenna it protects may cause loss of weather radar which is an indispensable tool in mitigating the risk in convective weather related scenarios.
- *Power loss* – there is a limit on the amount of water that may be ingested by aircraft engines before flame- out occurs
- *Reduced visibility* – Precipitation may reduce visibility. See Low Visibility section for related risks.
- *Runway excursion* – strong precipitation can result in runway contamination and reduced braking action. In addition, precipitation and related deposits may cover runway visual aids and markings making.

Runway contamination is a term related to the presence of water, slush, snow or ice on the runway surface. Runway contaminants adversely affect braking performance and directional control by reducing the friction forces between tires and the runway. As a result loss of control and runway excursion may occur. In addition runway contaminants obscure ground markings or render other runway visual aids less discernible, making it difficult for pilots to assess the position of the aircraft on the runway, which may ultimately lead to a loss of situational awareness.

b. Actors, Prevention and Mitigation

Meteorological service provider is usually the initiating actor of any adverse weather risk management process. Meteorological forecasts of adverse weather would normally be available several days before the day of operations, however forecast confidence would be rather low until short time before occurrence of the forecasted weather. A large variety of tools and computational models are available to MET officers, but forecast accuracy may vary according to local conditions and peculiarities. Not only Annex 3 forecasts and weather reports, but direct assistance to other actors is sometimes provided (e.g. enhanced weather forecast bulletins, pre-shift and pre-flight briefings, customized forecasts or MET reports) on request by ATC service providers, airport operators or aircraft operators.

Flow Management Positions anticipate adverse weather using input from MET service providers. Forecast weather severity and probability are used to estimate the potential impact on ATC operations in the airspace for which FMP is responsible. Decision on risk management strategies is taken using mostly experience and knowledge on local specifics. In certain cases decision support tools or a predefined set of strategies might be available to facilitate planning. In case capacity reduction is provisioned, a relevant warning should be disseminated to airspace users and adjacent ATC units (usually via NM). FMP continually monitor updates of weather and traffic forecasts and adjust their response strategies accordingly.

Network Manager uses Information from MET service providers to anticipate adverse weather in certain portions of airspace. Often information from more than one source needs to be consolidated in order to obtain a global network view. NM identifies the airspaces and airports which might be directly affected by expected meteorological conditions, contacts relevant FMP for details on planned measures and, if required, issues flow regulations. NM facilitates propagation through the network of adverse weather warnings and their expected effect on operations. NM will be impacted by an increased workload and coordination, as well as an increased number of regulations, slot assignments and revisions.

Airport operators obtain information on expected weather conditions from meteorological service providers. Expected runway condition are not part of the standard aerodrome forecast (TAF), so potential effect on runway surfaces and braking action is deduced from forecast weather conditions using local knowledge and experience. Some airport operators may benefit from a custom meteorological forecast. Such forecasts will help determine expected runway surface conditions. If required, additional staff and technical resource will be mobilized for expected RWY de-contamination.

Runways and taxiways will be closely monitored during periods of heavy rain and certain areas might be closed, e.g. runway operations might be temporarily suspended due to runway flooding.

Often the resource needed for runway de-contamination operations (e.g. snow removal) is contracted externally on a seasonal basis and specific arrangements have to be made at D-1 to ensure its availability at the day of operations. Airport operator monitors runway conditions continually through visual observation, reports by pilots on estimated braking action or direct friction measurements using specialized vehicles. Where fitted, runway conditions monitoring is assisted by runway surface temperature indicators. Any possible deterioration in runway conditions, runway closures for snow/ice removal or friction measurements need to be coordinated in a timely manner with ATC in order to minimize the impact on efficiency and safety of runway operations. ATC needs to be continuously updated on runway de-contamination progress and expected re-opening time, so that this information might be re-distributed to awaiting aircraft.

In such condition airport operators are likely to face a significant disruption in flight schedules which may hinder efficient conduct of airport operations.

Aircraft operators use input from MET service providers to determine possible weather deterioration and potential impact on runway conditions. Expected runway contamination is not part of any standard aviation forecast, so potential deterioration in runway condition may need to be deduced from the weather forecast. In the case of smaller/seasonal airports the published in AIP snow clearing plan may be reviewed (or the airport operator directly contacted) in order to estimate the ability of the airport to cope efficiently with forecast situation. A review of ANSPs response strategies (flow regulation) will also be taken into account in order to decide on best possible strategy – change of departure time to avoid the risk of excessive airborne delay, depart on time accepting the risk of an airborne delay or a diversion or, ultimately, flight cancellation. In case the flight is conducted, aircraft operator (through its dispatch office) will continue to support crew in-flight providing information on best possible alternate options. Significant disruption in airlines daily schedule is possible, as a delayed flight may cause delay for another flight on a different destination if the same aircraft is used. The domino effect propagates delay throughout the day causing significant increase in airlines' operating costs.

OPS Supervisor assesses probable deterioration in runway conditions through available meteorological forecasts, braking action reports from pilots, runway friction measurement reports, SNOWTAMs or direct visual observation. Taking into account other factors (prevailing wind, traffic patterns at time of day, runway clearing plan) supervisor decides on most appropriate runway configuration and possible traffic restrictions. Adjacent ATC units have to be warned if affected (directly or through NM).Close contact will be maintained with airport operations supervisor on runway clearing plan and progress. Other response actions available to OPS supervisor are miles-in-trail restrictions on final approach, or opening additional sectors/working positions in order to mitigate the effect of increased controller's workload and reduced capacity. At times of contaminated runway operations workload for OPS supervisor will be high due to the need to continuously assess swiftly changing situation and the need for increased coordination.

Pilots receive information on possible degradation in runway surface conditions during pre-flight briefings through available met forecasts and reports, and SNOWTAMs. Information on current runway conditions also might be available via automatic broadcast services (e.g. ATIS via telephone). It is the responsibility of the captain to assess current conditions and, if needed, delay the flight and/or plan for possible contingencies (e.g. additional fuel to be able to hold for longer periods). In-flight, information about runway conditions might be received through ATIS or from ATC. SNOWTAMs or other reports also might be available if aircraft is suitably equipped to receive such messages in-flight. Pilots may decide to hold for conditions improvement or divert to an alternate aerodrome. If the decision to land is taken, pilots are likely to request the longest possible runway. Once on the ground it is likely that speed will be reduced as much as possible before initiating any turn off the runway. Maximum reverse thrust will be used immediately after touchdown (thrust reversers are more efficient at higher speeds). Auto brakes need to be monitored as on a contaminated runway the selected deceleration rate may not be achieved. Rudder pedals may be used for directional control instead of the nose wheel steering tiller.

Landing on a contaminated runway requires additional workload and may result in pilot fatigue or distraction. Often during heavy snowfall, a runway will be available only for short periods of time between two snow removal closures, which may put pressure on pilots to expedite departure or arrival within snow clearing gaps (increased probability of omissions/error).

Air traffic controllers usually receive information on possible deterioration on runway conditions through meteorological forecasts and current weather reports, pilot reports, SNOWTAM messages, runway friction measurement reports or direct visual observation. Information on runway conditions is also provided at routine pre-shift briefings. Any information on change in runway conditions, that comes to the attention of controllers, will be immediately passed on to pilots on frequency. Where a runway is closed for snow removal, TWR ATCO will delay start-ups and approach controllers will clear all arrivals into holding patterns by keeping track of the order in which aircraft requested clearance, so that a first-in-first-out service can be provided once the runway is re-opened. Any urgency (e.g. critical fuel status) will be given a priority. TWR ATCO normally will have a direct contact with the runway snow clearing team and updates of expected runway re-open times will have to be disseminated to awaiting pilots. Often conditions will be deteriorating at near-by airports as well and ATC may be requested to provide assistance with information on alternate aerodrome conditions and availability. Runway contaminants may obscure ground markings and appropriate runway lights intensity will have to be selected by controllers in order to assist pilots of arriving/departing aircraft. At smaller airports ATCOs may need to decide on appropriate runway configurations and implementation of increased separation. At larger airports this task will be taken over by ops supervisor.

During contaminated runway operations air traffic controllers will incur increased workload, increased frequency occupancy time, extensive coordination. Airport throughput will be reduced as a result of increased runway occupancy times, increased taxi time and increased final approach separations. Often during heavy snowfall runways will become available only for a short period of time before the snow removal process is restarted and controllers will be put under a lot of pressure to expedite as many departures/arrivals in these gaps as possible, which may result in fatigue and increased risk for operational errors.

c. Related accident and incidents

E135, George South Africa, 2009

On 7 December 2009, after a relatively normal touchdown at destination in unexceptional daylight conditions, an EMB 135 failed to decelerate normally and overran the end of the runway resulting in major damage to the aircraft and injuries to 7 of the 30 passengers on board and to all three aircrew. Having found that aquaplaning had been the cause of the failure to decelerate, the investigation noted that a significant runway rehabilitation programme had been completed the previous month and that the rain which had occurred on the day of the accident was the first after a long period of drought. It was then found that the runway surface friction, when wet, was very poor and that this could be readily attributed to the application of a bitumen emulsion, or ‘fog-spray’ sealant, to the runway surface during the rehabilitation programme. The EMB 135 had been especially vulnerable to the poor surface friction when wet because, in the absence of thrust reversers, it was dependent for deceleration almost entirely on wheel braking.

Causes/Findings:

The use of the fog spray sealant was considered to have been the primary probable cause of the occurrence of aquaplaning to such an extent that the crew was unable to decelerate the aircraft to a safe stop in the certificated distance.

Safety Recommendations:

- The use of sealants on runway surfaces to be prohibited.
- The certification status of runway 11/29 at (George Airport) to be reviewed with special emphasis on water drainage (proper grooving) and friction characteristics, as well as a macro and micro structure evaluation of the runway.
- The Aerodrome Department of the SACAA be strengthened to ensure adequate skills and knowledge to enable the comprehensive safety oversight over the certification of aerodromes and the maintenance of certification standards.
- The revision of Part 139 of the Civil Aviation Regulations of 1997 and its associated CATS document to ensure compliance with the provisions as contained in Annex 14, Volume I and international best practice.

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Annex 2 – MET Products according to ICAO Annex 3

METAR

MET product required by ICAO Annex 3	METAR
Description	METAR shall contain the information due to actual condition of meteorological elements.
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	C(R)
Working system/ method and/or source	Automated weather observation system on each aerodrome (AWOS)
Timeframe/Validity	Every 30 min or 1 h and shall be disseminated to international OPMET data banks and to other aerodromes in accordance with regional air navigation agreement.
Update rate	30 min or 1 h
Used by ATC	Yes, shall be transmitted to (and used by) local ATS units and be available to operators and users at the aerodrome
Used by pilots	Yes, for pre- flight planning information
GEO use (global, USA, EU, other)	Global
Probability	N/A
Other information	METAR is a part of information in VOLMET and D VOLMET

SPECI

MET product required by ICAO Annex 3	SPECI								
Description	SPECI shall contain the information due to actual condition and reaching special limitations for one or more meteorological elements.								
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	C(I-R)								
Working system/ method and/or source	Automated weather observation on each aerodrome system (AWOS).								
Timeframe/Validity	When special meteorological conditions occur. Reference: Annex 3 ICAO Appendix 3. Technical specifications related to meteorological observations and reports, 2.3.Criteria for issuance of SPECI	**Wind** SPECI should be issued whenever changes in accordance with the following criteria occur: a) when the mean surface wind direction has changed by 60° or more from that given in the latest report, the mean speed before and/or after the change being 20 km/h (10 kt) or more; b) when the mean surface wind speed has changed by 20 km/h (10 kt) or more from that given in the latest report; c) when the variation from the mean surface wind speed (gusts) has increased by 20 km/h (10 kt) or more from that given in the latest report, the mean speed before and/or after the change being 30 km/h (15 kt) or more; d) when the wind changes through values of operational significance. The threshold values should be established by	**Visibility** SPECI should be issued whenever changes in accordance with the following criteria occur: when the visibility is improving and changes to or passes through one or more of the following values, or when the visibility is deteriorating and passes through one or more of the following values: 1) 800, 1 500 or 3 000 m; and	**Runway visual range** SPECI should be issued whenever changes in accordance with the following criteria occur: when the runway visual range is improving and changes to or passes through one or more of the following values, or when the runway visual range is deteriorating and passes through one or more of the following values: 150, 350, 600 or 800 m;	**Present weather** SPECI should be issued whenever changes in accordance with the following criteria occur: when the onset, cessation or change in intensity of any of the following weather phenomena or combinations thereof occurs: freezing precipitation — moderate or heavy precipitation (including showers thereof) — duststorm — sandstorm; h) when the onset or cessation of any of the following weather phenomena or combinations	**Cloud base** SPECI should be issued whenever changes in accordance with the following criteria occur: when the height of base of the lowest cloud layer of BKN or OVC extent is lifting and changes to or passes through one or more of the following values, or when the height of base of the lowest cloud layer of BKN or OVC extent is lowering and passes through one or more of the following values: 1) 30, 60, 150 or 300 m (100, 200, 500 or 1 000 ft); and 2) 450 m (1 500 ft), in cases where	**Cloud amount** SPECI should be issued whenever changes in accordance with the following criteria occur: when the amount of a cloud layer below 450 m (1 500 ft) changes: 1) from SKC, FEW or SCT to BKN or OVC; or 2) from BKN or OVC to SKC, FEW or SCT; k) when the sky is obscured and the vertical visibility is improving and changes to or passes through one or more of the following	SNOWTAM	

		the meteorological authority in consultation with the appropriate ATS authority and operators concerned, taking into account changes in the wind which would: 1) require a change in runway(s) in use; and 2) indicate that the runway tailwind and crosswind components have changed through values representing the main operating limits for typical aircraft operating at the aerodrome;	2) 5 000 m, in cases where significant numbers of flights are operated in accordance with the visual flight rules;		thereof occurs: — ice crystals — freezing fog — low drifting dust, sand or snow — blowing dust, sand or snow — thunderstorm (with or without precipitation) — squall — funnel cloud (tornado or waterspout);	significant numbers of flights are operated in accordance with the visual flight rules; .	values, or when the vertical visibility is deteriorating and passes through one or more of the following values: 30, 60, 150 or 300 m (100, 200, 500 or 1 000 ft); and l) any other criteria based on local aerodrome operating minima, as agreed between the meteorological authority and the operators		
Update rate	When special meteorological conditions mention above occur.								
Used by ATC	Yes, shall be transmitted to (and used by) local ATS units and be available to operators and users at the aerodrome as operational meteorological information..								
Used by pilots	Yes, for pre-flight information for departure aerodrome when weather condition has changed.								
GEO use (global, USA, EU, other)	Global.								
Probability	N/A								
Other information	SPECI issue in case of special meteorological condition and limitation. According Annex 3 SPECI shall be disseminated for aerodromes where METAR disseminated with frequency of 1 h or as it is defined in ANP								

Local routine (MET report)

MET product required by ICAO Annex 3	Local routine (MET report)
Description	Local routine shall contain the information due to actual condition of meteorological elements. The difference between METAR and local report are defined by average period of meteorological elements. (2min for LOCAL and 10 min for METAR).
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	C(R)
Working system/ method and/or source	Automated weather observation on each aerodrome system (AWOS).
Timeframe/Validity	Every 30 min or 1 h and shall be disseminated to ATS, operators and users at the aerodrome
Update rate	Every 30 min.
Used by ATC	Yes, shall be transmitted to (and used by) local ATS units.
Used by pilots	Yes, shall be transmitted and be available to operators and users at the aerodrome by ATIS.
GEO use (global, USA, EU, other)	Global
Probability	N/A
Other information	Local reports, only for dissemination at the aerodrome of origin intended for arriving and departing aircraft and it is broadcasted by ATIS.

Special reports

MET product required by ICAO Annex 3	Special reports	
Description	SPECIAL shall contain the information due to actual condition and reaching special limitations for one or more meteorological elements. The difference between SPECI and special report are defined by average period of meteorological elements. (2min for Special and 10 min for SPECI).	
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	C(I-R)	
Working system/ method and/or source	Automated weather observation on each aerodrome system (AWOS).	
Timeframe/Validity	When special meteorological conditions occur. There is a possibility to add more than specified conditions for meteorological elements as they defined in Annex 3 ICAO. These possibility are recognized and defined by local agreements b/n MET and ATS and usually are connected more and less to operational minimums for aerodromes	**<u>The list of criteria for the issuance of local special reports shall include the following:</u>** a) those values which most closely correspond with the operating minima of the operators using the aerodrome; b) those values which satisfy other local requirements of the air traffic services units and of the operators; c) an increase in air temperature of 2°C or more from that given in the latest report, or an alternative threshold value as agreed between the meteorological authority, the appropriate ATS authority and the operators concerned; d) the available supplementary information concerning the occurrence of significant meteorological conditions in the approach and climb-out areas as given in Table A3-1 of Annex 3; and e) those values which constitute criteria for SPECI. (please see table.1.2)
Update rate	When special meteorological conditions mention above occur	
Used by ATC	Yes, shall be transmitted to (and used by) local ATS units and be available to operators and users at the aerodrome.	
Used by pilots	Yes, by ATIS	
GEO use (global, USA, EU, other)	Global	
Probability	N/A	
Other information	Local special reports, only for dissemination at the aerodrome of origin (intended for arriving and departing aircraft) and it is broadcasted by ATIS. Difference b/n two types - SPECI and SPECIAL are in average period. In general for SPECI average period for meteorological elements are 10 min; for SPECIAL are 2 min.	

Aerodrome forecast (TAF)

MET product required by ICAO Annex 3	AERODROME FORECAST (TAF)	
Description	Aerodrome forecasts and amendments shall be issued as TAF[6] and include the information of forecasting value of meteorological elements representing weather condition on airport and expected significant changes to one or more of these elements during the period of validity.	
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F	
Working system/ method and/or source	NWPM Numerical Weather Prediction Models – Mesoscale model with resolution on approximately 3x3km.	
Timeframe/Validity	The period of validity of a routine TAF should be not less than 12 hours nor more than 24/30hours 12h/24h/30h	
Update rate	3h/6h/6h	**<u>Clarification:</u>** TAF is means the Terminal Aerodrome Forecast. The period of validity of a routine TAF should be not less than 12 hours nor more than 30 hours; this period should be determined by regional air navigation agreement. Routine TAF valid 12 hours should be issued every 3 hours and those valid for 24 or 30 hours should be issued every 6 hours. The requirements for TAF for each country and aerodrome are defined in Doc 7754. Reference: DOC 7754; **EUR ANP,** Part VI — Meteorology (MET)
Used by ATC	Yes, as additional information for aerodrome.	
Used by pilots	Yes, pre-flight planning information.	
GEO use (global, USA, EU, other)	Global.	
Probability	There is possibility for using of probability of 30% and 40%. A probability of an alternative value or change of less than 30 per cent should not be considered sufficiently. A probability of an alternative value or change of 50 per cent or more, for aviation purposes, should not be considered as probability but instead should be indicated, as necessary, by use of the change indicators “BECMG” or “TEMPO „significant to be indicated. A probability of an alternative value or change of 50 per cent or more, for	

[6] *Guidance on methods to keep routine forecast (TAF) under continuous review is given in the* Manual of Aeronautical Meteorological Practice *(Doc ICAO 8896).*

	aviation purposes, should not be considered a probability.
Other information	1. An aerodrome forecast shall be issued at a specified time and consist of a concise statement of the expected meteorological conditions at an aerodrome for a specified period. 2. Aerodrome forecast amendments shall be issued as TAF – AAA, AAB and etc.

Landing forecast (TREND)

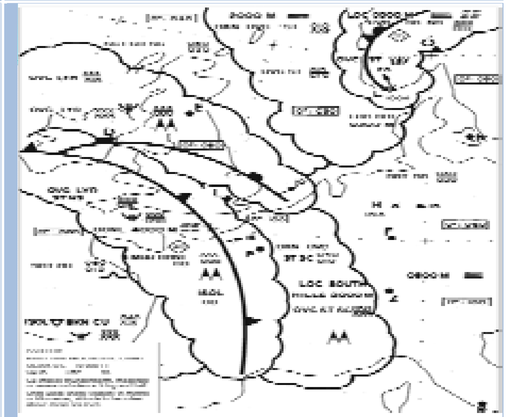
MET product required by ICAO Annex 3	LANDING FORECAST (TREND)
Description	Aerodrome forecasts for landing issued by special limitations of meteorological elements.
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F (R)
Working system/ method and/or source	NWPM Numerical weather prediction models – Mesoscale model with resolution on approximately 3x3km.
Timeframe/Validity	The period of validity of should be not less than 2 hours.
Update rate	If necessary every 30 minutes.
Used by ATC	Yes, as a part of LOCAL/SPECIAL ROUTINE (MET REPORT).
Used by pilots	Yes, pre-flight planning information.
GEO use (global, USA, EU, other)	Global.
Probability	N/A
Other information	LANDING FORECAST (TREND) is part of METAR and LOCAL/SPECIAL ROUTINE (MET report).

Forecasts for take-off

MET product required by ICAO Annex 3	FORECASTS FOR TAKE-OFF
Description	FORECASTS FOR TAKE-OFF should refer to a specified period of time and should contain information on expected conditions over the runway complex in regard to surface wind direction and speed and any variations thereof, temperature, pressure (QNH), and any other elements as agreed locally.
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F (R)
Working system/ method and/or source	NWPM Numerical weather prediction models – Mesoscale model with resolution on approximately 3x3km.
Timeframe/Validity	The period of validity of should be not less than 2 hours.
Update rate	A forecast for take-off should be supplied to operators on request within the 3 hours before the expected time of departure.
Used by ATC	N/A
Used by pilots	A forecast for take-off should be supplied to operators and flight crew members on request within the 3 hours before the expected time of departure.
GEO use (global, USA, EU, other)	Global.
Probability	N/A
Other information	NOTE: Entirely LANDING FORECAST is part of METAR and LOCAL/SPECIAL ROUTINE (MET report).

GAMET AREA FORECAST

<table>
<tr><th>MET product required by ICAO Annex 3</th><th colspan="2">GAMET AREA FORECAST</th></tr>
<tr><td>Description</td><td>GAMET AREA FORECAST shall be prepared in two different ways:
• abbreviated plain language;
• when chart form is used, the forecast shall be prepared as a combination of forecasts of upper wind and upper-air temperature, and of SIGWX. The phenomena cover the layer between the ground and flight level 100 (or up to flight level 150 in mountainous areas, or higher, where necessary) and d shall contain information on en-route weather phenomena hazardous to low-level flights.
When prepared in GAMET format, area forecasts shall contain two sections: Section I related to information on en-route weather phenomena hazardous to low-level flights, prepared in support of the issuance of AIRMET information, and Section II related to additional information required by low-level flights. Additional elements in Section II shall be included in accordance with regional air navigation agreement. Elements which are already covered by a SIGMET
message shall be omitted from GAMET area forecasts.</td><td><u>Example 1:GAMET abbreviated plain language</u>
YUCC GAMET VALID 220600/221200 YUDO
YUCC AMSWELL FIR/2 BLW FL100
SECN I
SFC WSPD: 10/12 65 KMH
SFC VIS: 06/08 3000 M BR N OF N51
SIGWX: 11/12 ISOL TS
SIG CLD: 06/09 OVC 800/1100 FT AGL N OF N51 10/12 ISOL TCU 1200/8000 FT AGL
ICE: MOD FL050/080
TURB: MOD ABV FL090
SIGMETS APPLICABLE: 3, 5
SECN II
PSYS: 06 L 1004 HPA N5130 E01000 MOV NE 25 KT WKN
WIND/T: 2000 FT 270/70 KMH PS03 5000 FT 250/80 KMH MS02 10000 FT 240/85 KMH MS11
CLD: BKN SC 2500/8000 FT AGL
FZLVL: 3000 FT AGL
MNM QNH: 1004 HPA
SEA: T15 HGT 5M
VA: NIL</td></tr>
<tr><td>Type
(forecast (F), current weather(C), regular (R) and irregular (I-R))</td><td>F (R)</td><td><u>Meaning:</u>
An area forecast for low-level flights (GAMET) issued for sub-area two of the Amswell* flight information region (identified by YUCC Amswell area control centre) for below flight level 100 by the Donlon/International* meteorological office (YUDO); the message is valid from 0600 UTC to 1200 UTC on the 22nd of the month.
Section I:
surface wind speeds: between 1000 UTC and 1200 UTC 65 kilometres per hour; surface visibility: between 0600 UTC and 0800 UTC 3 000 metres north of 51 degrees north (due to mist); significant weather phenomena: between 1100 UTC and 1200 UTC isolated thunderstorms without hail; significant clouds: between 0600 UTC and 0900 UTC overcast base 800, top 1 100 feet above ground level north of 51 degrees north; between 1000 UTC and 1200 UTC isolated towering cumulus base 1 200, top 8 000 feet above ground level; icing: moderate between flight level 050 and 080; turbulence: moderate above flight</td></tr>
</table>

			level 090 (at least up to flight level 100); SIGMET messages: 3 and 5 applicable to the validity period and sub-area concerned. **Section II:** pressure systems: at 0600 UTC low pressure of 1 004 hectopascals at 51.5 degrees north 10.0 degrees east, expected to move north-eastwards at 25 knots and to weaken; winds and temperatures: at 2 000 feet above ground level wind direction 270 degrees; wind speed 70 kilometres per hour, temperature plus 3 degrees Celsius; at 5000 feet above ground level wind direction 250 degrees; wind speed 80 kilometres per hour, temperature minus 2 degrees Celsius; at 10 000 feet above ground level wind direction 240 degrees; wind speed 85 kilometres per hour, temperature minus 11 degrees Celsius; clouds: broken stratocumulus, base 2 500 feet, top 8 000 feet above ground level; freezing level: 3 000 feet above ground level; minimum QNH: 1 004 hectopascals; sea: surface temperature 15 degrees Celsius; and state of sea 5 metres; volcanic ash: nil.
Working system/ method and/or source	NWPM Numerical weather prediction models – Mesoscale model with resolution on 3x3km.		**<u>Example 2: GAMET chart form</u>**
Timeframe/Validity	When chart form is used for area forecasts for low-level flights, the forecast of upper wind and upper-air temperature shall be issued for points separated by no more than 500 km (300 NM) and for at least the following altitudes: 600, 1 500 and 3 000 m (2 000, 5 000 and 10 000 ft), and 4 500 m (15 000 ft) in mountainous areas. 1. When chart form is used for area forecasts for low-level flights, the forecast of SIGWX phenomena shall be issued as low-level SIGWX forecast for flight levels up to 100 (or up to flight level 150 in mountainous areas, or higher, where necessary). Low-level SIGWX forecasts shall include the following items: a) the phenomena warranting the issuance of a SIGMET as given in Appendix 6 and which are expected to affect low-level flights; and b) the elements in area forecasts for low-level flights as given in Table A5-4 except elements concerning: 2. upper winds and temperatures; and 3. forecast QNH.	Please see example 1	

Update rate	Every 6 h	
Used by ATC	N/A	
Used by pilots	Area forecast addressed to pilots from GA and VFR	
GEO use (global, USA, EU, other)	Globally, in respect of two type as mention above. Some countries use the first one format, another the second one.	
Probability	N/A	
Other information	Area forecasts for low-level flights GAMET prepared in support of the issuance of AIRMET information or significant weather and conditions below flight level 100 (or up to flight level 150 in mountainous areas, or higher, where necessary).	

SIGMET

MET product required by ICAO Annex 3	SIGMET	
Description	SIGMET information shall be issued by a meteorological watch office and shall give a concise description in abbreviated plain language concerning the occurrence and/or expected occurrence of specified en-route weather phenomena, which may affect the safety of aircraft operations, and of the development of those phenomena in time and space.	
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F	
Working system/ method and/or source	NWPM Numerical weather prediction models: 1. Global and regional model with resolution on approximately 25x25km. 2. Mesoscale model with resolution on approximately 3x3km.	
Timeframe/Validity	1. The period of validity of SIGMET should be not less than 4 hours. 2. SIGMET messages for volcanic ash and tropical cyclones shall be updated at least every 6 hours.	
Update rate	If it need every 4 hours	
Used by ATC	Yes, SIGMET should be supplied to ATC for support en-route planning and operations; Coordination shall be maintained between the meteorological watch office and the associated area control centre/flight information centre to ensure that information on volcanic ash included in SIGMET and NOTAM messages is consistent	**Clarification:** There is special procedure in case of volcanic ash. MET prepared SIGMET based of information disseminate from VAAC. The next step based on SIGMET and affected areas, AIS disseminated NOTAM regarding information above. Those two types of messages are obligatory in case of presence of volcanic ash. *REMARK: NOTAM is in responsibility of AIS not MET.*
Used by pilots	Yes, for pre-flight planning information.	
GEO use (global, USA, EU, other)	Global.	
Probability	N/A	
Other information	1. SIGMET messages concerning volcanic ash cloud and tropical cyclones should be based on advisory information provided by VAACs and TCACs. 2. SIGMET information shall be cancelled when the phenomena are no longer occurring or are no longer expected to occur in the area.	

AIRMET[7]

MET product required by ICAO Annex 3	AIRMET	
Description	AIRMET information shall be issued by a meteorological watch office in accordance with regional air navigation agreement, below flight level 100(or up to flight level 150 in mountainous areas, or higher, where necessary). AIRMET information shall give a concise description in abbreviated plain language concerning the occurrence and/or expected occurrence of specified en-route weather phenomena, which may affect the safety of low-level flights, and of the development of those phenomena in time and space.	YUCC AIRMET 2 VALID 221215/221600 YUDO YUCC AMSWELL FIR MOD MTW OBS AT 1205Z AND FCST N48 E10 FL080 STNR NC
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F (I-R)	***Meaning:*** The second AIRMET message issued for the AMSWELL flight information region (identified by YUCC Amswell area control centre) by the Donlon/International* meteorological watch office (YUDO) since 0001 UTC; the message is valid from 1215 UTC to 1600 UTC on the 22nd of the month; moderate mountain wave was observed at 1205 UTC at 48 degrees north and 10 degrees east at flight level 080; the mountain wave is expected to remain stationary and not to undergo any changes in intensity
Working system/ method and/or source	NWPM Numerical weather prediction models: 1. Global and regional model with resolution on approximately 25x25km. 2. Mesoscale model with resolution on approximately 3x3km.	.
Timeframe/Validity	The period of validity of an AIRMET message shall be not more than 4 hours.	
Update rate	If it needed.	
Used by ATC	N/A	
Used by pilots	Yes, AIRMET is used for flight planning and in-flight monitoring	
GEO use (global, USA, EU, other)	Locally	

[7] Reference: ICAO EUR DOC 014/2010, EUR Basic ANP, DOC 7754 , Part VI and FASID Table MET 1B, MET 2B and MET 3B.

Probability	N/A		
Other information	AIRMET information shall be disseminated only for one specified en-route weather phenomena. If there is more than one, AIRMET for each should be issued. AIRMET information shall be cancelled when the phenomena are no longer occurring or are no longer expected to occur in the area. SIGMET and AIRMET are warning information, hence they are of highest priority among other types of OPMET information provided to aviation users. The primary purpose of SIGMET and AIRMET is for in-flight service, which requires timely transmission of the SIGMET and, where available, AIRMET messages to pilots by the ATS units and/or through VOLMET and D-VOLMET.	**Clarification** As mention in 1.8 GAMET is a forecast refers to area forecast for low flight levels addressed to General aviation. AIRMET is form of warnings (as SIGMET for IFR) due to significant weather events affecting VFR.	

AERODROME WARNINGS

MET product required by ICAO Annex 3	AERODROME WARNINGS
Description	Aerodrome warnings shall be issued by the meteorological office and shall give concise information of meteorological conditions which could adversely affect aircraft on the ground, including parked aircraft, and the aerodrome facilities and services.
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F (I-R)
Working system/ method and/or source	NWPM Numerical weather prediction models: 1. Global and regional model with resolution on approximately 25x25km. 2. Mesoscale model with resolution approximately 3x3km.
Timeframe/Validity	If special meteorological condition might occur.
Update rate	If it needed.
Used by ATC	Aerodrome warnings should be disseminated to ATC as additional information regarding special meteorological condition and expected effect of taxis.
Used by pilots	Aerodrome warnings should be disseminated to operators and local aerodrome services.
GEO use (global, USA, EU, other)	Global
Probability	N/A
Other information	Aerodrome warnings are in base of A-CDM especially in USA regarding pre-flight information and future planning of all activities at airports. Aerodrome warnings should be cancelled when the conditions are no longer occurring and/or no longer expected to occur at the aerodrome.

WIND SHEAR WARNINGS AND ALERTS

MET product required by ICAO Annex 3	WIND SHEAR WARNINGS AND ALERTS
Description	Wind shear warnings shall be prepared by the meteorological office for aerodromes where wind shear is considered a factor, in accordance with local arrangements with the appropriate ATS unit and operators concerned. Wind shear warnings shall give concise information on the observed or expected existence of wind shear which could adversely affect aircraft on the approach path or take-off path or during circling approach between runway level and 500 m (1 600 ft) above that level and aircraft on the runway during the landing roll or take-off run. Where local topography has been shown to produce significant wind shears at heights in excess of 500 m (1 600 ft) above runway level, then 500 m (1 600 ft) shall not be considered restrictive.
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F (I-R)
Working system/ method and/or source	NWPM Numerical weather prediction models: 1. Global and regional model with resolution on approximately 25x25km. 2. Meso-scale model with resolution on approximately 3x3km
Timeframe/Validity	If special meteorological condition as wind shear might occur. There is a possibility to include and disseminate alerts based on air/special reports from pilots There is different automated system for earlier warning as following: • Low level wind shear warning system; • LIDAR; • Doppler Radar.
Update rate	If it needed.
Used by ATC	Wind shear warnings shall be prepared for aerodromes where wind shear is considered a factor, in accordance with local arrangements with the appropriate ATS unit.
Used by pilots	Wind shear warnings shall be prepared for aerodromes where wind shear is considered a factor, in accordance with local arrangements with the appropriate operators concerned.
GEO use (global, USA, EU, other)	Locally, depend of geographical features on airport and orography.
Probability	N/A
Other information	1. Wind shear warnings and alerts is a part of **METAR** and **LOCAL/SPECIAL ROUTINE** (MET report) ad broadcast to users by ATIS and VOLMET. 2. Wind shear warnings for arriving aircraft and/or departing aircraft should be cancelled when aircraft reports indicate that wind shear no longer exists.

UPPER-AIR FORECASTS

MET product required by ICAO Annex 3	UPPER-AIR FORECASTS
Description	The forecasts of upper wind; upper-air temperature; and humidity; direction, speed and flight level of maximum wind; flight level and temperature of tropopause, and geopotential altitude of flight levels shall be prepared four times a day by a WAFC and shall be valid for fixed valid times at 6, 12, 18, 24, 30 and 36 hours after the time (0000, 0600, 1200 and 1800 UTC) of the synoptic data on which the forecasts were based.
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F (I-R)
Working system/ method and/or source	WORLD AREA FORECAST SYSTEM
Timeframe/Validity	00 h/06 h/12 h/18 h/(time in UTC)
Update rate	If it needed.
Used by ATC	Yes, for ACC regarding areas with strong winds and jet streams
Used by pilots	Yes, regarding areas with strong winds and jet streams
GEO use (global, USA, EU, other)	Globally
Probability	N/A
Other information	1. The foregoing grid point forecasts shall be issued by a WAFC in binary code form using the GRIB code form prescribed by WMO. 2. The foregoing grid point forecasts shall be prepared by a WAFC in a fixed grid with a horizontal resolution of 140 km. Note.— 140 km represents a distance of about 1.25° of latitude.

SIGNIFICANT WEATHER (SIGWX) FORECASTS

MET product required by ICAO Annex 3	SIGNIFICANT WEATHER (SIGWX) FORECASTS
Description	Significant weather forecast charts shall be prepared four times a day by a WAFC and shall be valid for fixed valid times at 6, 12, 18, 24, 30 and 36 hours after the time (0000, 0600, 1200 and 1800 UTC) of the synoptic data on which the forecasts were based. Significant en-route weather phenomena directly affect to plane on different flight levels.
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F (R)
Working system/ method and/or source	**WORLD AREA FORECAST SYSTEM** • Types of SIGWX forecasts SIGWX forecasts shall be issued as: a) high-level SIGWX forecasts for flight levels between 250 and 630; and b) medium-level SIGWX forecasts for flight levels between 100 and 250 for limited geographical areas, as determined by regional air navigation agreement. • Items included in SIGWX forecasts. High-level and medium-level SIGWX forecasts shall include the following items: a) tropical cyclone provided that the maximum of the 10-minute mean surface wind speed is expected to reach or exceed 63 km/h (34 KT); b) severe squall lines; c) moderate or severe turbulence (in cloud or clear air); d) moderate or severe icing; e) widespread sandstorm/duststorm; f) cumulonimbus clouds associated with thunderstorms and with a) to e); g) flight level of tropopause; h) jet streams; i) information on the location of volcanic eruptions that are producing ash clouds of significance to aircraft operations comprising: volcanic eruption symbol at the location of the volcano and, at the side of the chart, the volcano eruption symbol, the name of the volcano, latitude/longitude, the date and time of first eruption, if known, and a reference to SIGMET and NOTAM or ASHTAM issued for the area concerned; and j) information on the location of an accidental release of radioactive materials into the atmosphere, of significance to aircraft operations, comprising: the radioactivity symbol at the site of the accident and, at the side of the chart, the radioactivity symbol, latitude/longitude of the site of the accident, date and time of the accident and a reminder to users to check NOTAM for the area concerned.
Timeframe/Validity	Forecasts of significant en-route weather phenomena shall be prepared as SIGWX forecasts four times a day by a WAFC and shall be valid for fixed valid times at 24 hours after the time (0000, 0600, 1200 and 1800 UTC) of the synoptic data on which the forecasts were based.
Update rate	The dissemination of each forecast charts shall be completed as soon as technically feasible but not later than 11 hours after standard time of observation.
Used by ATC	Yes, for of Jet stream
Used by pilots	Yes , for pre-flight briefing information

GEO use (global, USA, EU, other)	Globally
Probability	N/A
Other information	SIGWX charts issued in the same time and cover the same period as Upper wind and temperature charts. SIGWX forecasts shall be issued in binary code form using the BUFR code form prescribed by WMO.

TROPICAL CYCLONE ADVISORY INFORMATION

MET product required by ICAO Annex 3	TROPICAL CYCLONE ADVISORY INFORMATION
Description	The advisory information on tropical cyclones shall be issued for tropical cyclones when the maximum of the 10-minute mean surface wind speed is expected to reach or exceed 63 km/h (34 kt) during the period covered by the advisory.
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F (R)
Working system/ method and/or source	TROPICAL CYCLONE ADVISORY CENTRES (TCAC)[8]
Timeframe/Validity	The advisory information on tropical cyclones shall be issued for tropical cyclones when the maximum of the 10-minute mean surface wind speed is expected to reach or exceed 63 km/h (34 kt) during the period covered by the advisory.
Update rate	When and where applicable.
Used by ATC	As agreed b/n meteorological offices ant ATS. For operational uses SIGMET for tropical cyclone

[8] *The GRIB code form is contained in WMO Publication No. 306,* Manual on Codes, *Volume I.2, Part B — Binary Codes;*

Used by pilots	SIGMET for tropical cyclone available as a part of pre-flight planning information.
GEO use (global, USA, EU, other)	Locally, depend of geographical features on airport and orography
Probability	N/A
Other information	In SIGWX charts position of tropical cyclone is marked by special sign. Usually it may see it in Atlantic ocean SW direction close to costal of Spain moving to North direction. There is unique procedure and special message related to this event, despite of reason that tropical cyclone is not typical for climate.

VOLCANIC ASH ADVISORY INFORMATION

MET product required by ICAO Annex 3	VOLCANIC ASH ADVISORY INFORMATION
Description	The advisory information on volcanic ash issued in abbreviated plain language, using approved ICAO abbreviations and numerical values of self-explanatory nature. The information required to be sent by State volcano observatories to their associated ACCs, MWO and VAAC.
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F (R)
Working system/ method and/or source	**VOLCANIC ASH ADVISORY CENTRES (VAAC)** Issued recommendation information in plain language and in format of charts regarding volcanic ash dispersion in atmosphere. As a result of this information in FIRs where volcanic ash is presence, meteorological offices issue SIGMET for volcanic ash
Timeframe/Validity	The format of charts regarding volcanic ash dispersion in atmosphere issued every sixth hours.
Update rate	When and where applicable.
Used by ATC	Yes, there are coordinate actions b/n meteorological services and ATS regarding en-route planning and departures and landing of aircraft in affected areas and aerodromes.

Used by pilots	Yes, by issued SIGMETs and additional charts due to volcanic as presence in atmosphere.
GEO use (global, USA, EU, other)	Locally, depend of presence of volcanic ash resulting of volcanic eruption.
Probability	N/A
Other information	N/A

NWPM - The Numerical Weather Predicting Models are suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometres. In case of resolution (usually 3kmx3km) they called mesoscale numerical weather prediction model and are designed to serve both operational forecasting and atmospheric research needs. It features multiple dynamical cores, a 3or 4-dimensional variational (3or 4 DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. See additional detailed information below:

Model	Grid length in mid-latitudes	Grid points	Vertical levels	Forecast length	Run times (UTC)
Global	25 km	1024 x 76970	70 (lid ~80 km)	144 hrs	00, 06, 12, 18
North Atlantic European (NAE)	12 km	600 x 36070	70 (lid ~80 km)	48 hrs	00, 06, 12, 18
Mesoscale models (ALADIN, WRF)	3km -7km	300x18035	70 (lid ~80 km)	36 hrs	00, 03,06, 09,12, 18,21

Reference:

1. Annex 3 ICAO/2010
2. Manual of Meteorological practice, ICAO Doc 8896/2011
3. Manual of Coordination b/n ATC, AIS and MET ICAO Doc 9377/2008
4. SIGMET/AIRMET, Doc 014, ICAO Doc014
5. Location Indicators ICAO Doc 7910
6. WMO Publication No. 306, Manual on Codes, Volume I.2, Part B — Binary Codes

Annex 3 – Decision support tools

1. Data Assimilation Research Testbed (DART) /WRF/CAM

Description

DART is a data assimilation method developed at the National Centre for Atmospheric Research (NCAR) which could be used for many different weather prediction models. It features easy to use software. It can address small and large scale weather models.

Weather translation

DART has incorporated the US National Centre of Atmospheric Research (NCAR) atmosphere models such as Weather Research and Forecasting (WRF) and Community Atmosphere Model (CAM). It provides analysis that is comparable in skill to the National Centres for Environmental Prediction (NCEP) reanalysis.

Weather Research and Forecasting (WRF)

The Weather Research and Forecasting (WRF) Model is a mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It features multiple dynamical cores, a 3-dimensional variational (3DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometres.

The effort to develop WRF has been a collaborative partnership, principally among the National Centre for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (the National Centres for Environmental Prediction (NCEP) and the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA). WRF allows researchers the ability to conduct simulations reflecting either real data or idealized configurations. WRF provides operational forecasting a model that is flexible and efficient computationally, while offering the advances in physics, numeric, and data assimilation contributed by the research community.

WRF has a rapidly growing community of users, and workshOPS and tutorials are held each year at NCAR. WRF is currently in operational use at NCEP, AFWA and other centres.

Community Atmosphere Model (CAM)

The Community Atmosphere Model (CAM) is the latest in a series of global atmosphere models developed at NCAR for the weather and climate research communities. CAM also serves as the atmospheric component of the Community Climate System Model (CCSM).

CAM latest version 5.0 is the seventh generation of the NCAR atmospheric General Circulation Model (GCM) and has been modified substantially with a range of enhancements and improvements. In particular, the combination of physical parameterization enhancements makes it possible to simulate full aerosol cloud interactions including cloud droplet activation by aerosols, precipitation processes due to particle size dependant behaviour and explicit radiative interaction of cloud particles. As such the CAM 5.0 represents the first version of CAM that is able to simulate the cloud-aerosol indirect radiative effects. More generally CAM 5.0 forms the main atmosphere component of the Community Earth System Model, version 1 (CESM1).

ATC impact assessment

The adaptation of WRF Model is part of FAA NextGen focus to develop an advanced mesoscale forecast & assimilation system to promote closer ties between research & operations.

The **WRF** in turn is used in **Consolidated Storm Prediction for Aviation (CoSPA)** programme – operated by MIT Lincoln Laboratory. WRF is located online at: http://cospa.wx.ll.mit.edu/nciws_servlets/

The final CoSPA forecast aims to optimally combine extrapolation heuristics with high resolution NWP output. Forecasts that accurately depict storm evolution and morphology are critical for making well informed decisions related to routing air traffic across the NAS.

Information used (inputs)

Data Assimilation Research Testbed (DART) based interface.

Problems solved

WRF and CAM are improved forecasting products which use DART methodology. WRF is used in CoSPA programme which is further discussed in the [CoSPA] section of this document.

Advantages

WRF - next generation mesoscale model used in both operational forecasting and atmospheric research needs.

WRF is suitable for a broad spectrum of applications (e.g. Grell convective parameterization; KF cumulus scheme; ETA TKE PBL scheme; Thompson/NCAR microphysics; RRTM long wave radiation; Dudhia shortwave radiation; Smirnova-RUC land-surface parameterization; 13 km grid length, 50 vertical levels etc.)

Limitations

The data source for many EU-wide observations (See *Applicability in Europe*) is taken from the U.S. Weather Service. (Not being a local European source could be a limitation)

Operational use of model

WRF is currently in operational use at Air Force Weather Agency (AFWA).

An experimental version of the Weather Research and Forecasting (WRF) model, called the High Resolution Rapid Refresh (HRRR), is run at NOAA's ESRLIGSD laboratory.

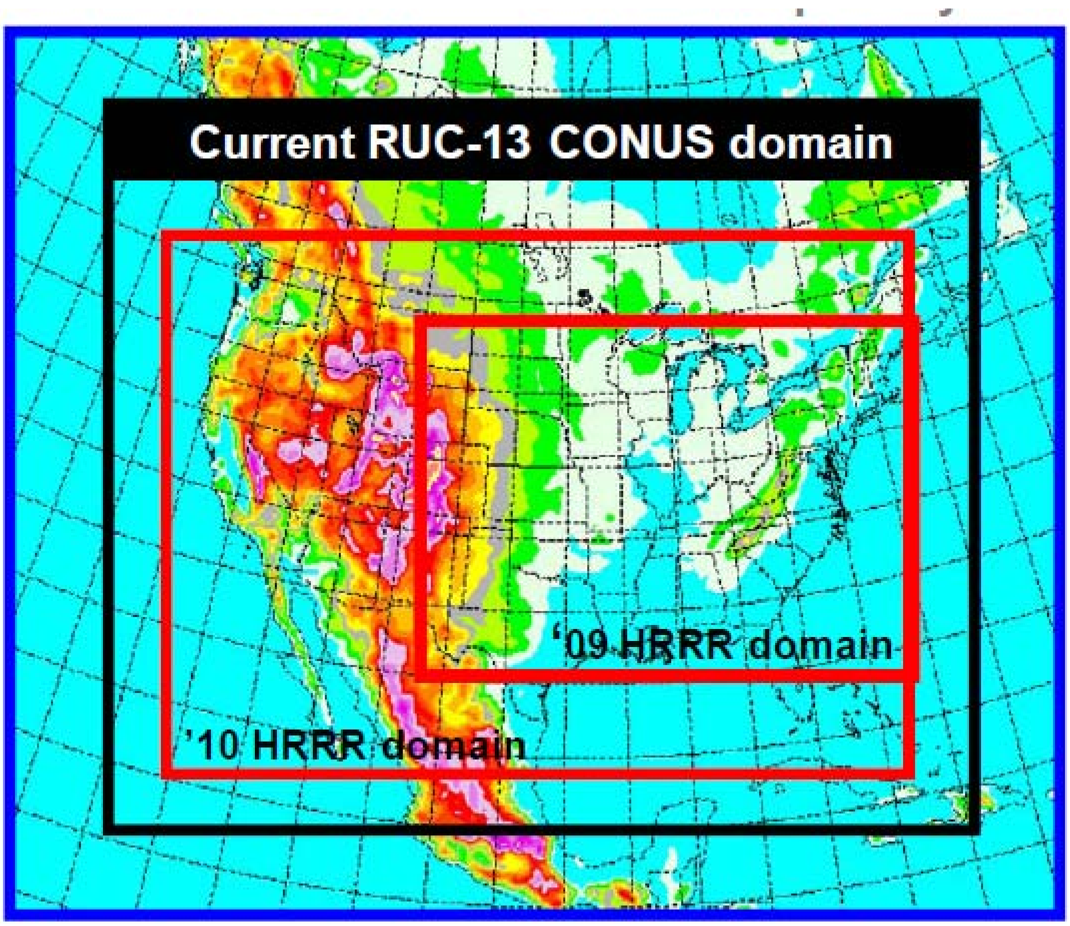


Figure 1: HRRR model nested in the WRF Rapid Refresh (RR) and Rapid Update Cycle RUC-13[9] models. Depicted are the experimental Northeast domain over which the HRRR[10] was run during 2008 and the expanded Midwestern and Eastern domain model for 2009. Beginning in 2010 the HRRR has been covering the Continental US (CONUS).

There are number of organisations, including several European which are using WRF in real time. The comprehensive list is available at this location:
http://www.mmm.ucar.edu/wrf/users/forecasts.html

Applicability in Europe

European users:

1. WRF forecasts for Europe at the National Observatory of Athens
2. WRF forecasts for Italy by Institute of Atmospheric Sciences and Climate (ISAC) of the Italian National Research Council (CNR), Lecce Section, and Italy.
3. WRF forecasts by Slovenian Meteorological Amateur Research Team (in Slovenian).
4. WRF forecasts by youmeteo.com, with real-time forecasts for Italy and Europe.
5. WRF forecast for North Atlantic and Iceland by the Institute for Meteorological Research, Reykjavik, Iceland.

[9] Rapid Update Cycle – 13Km (RUC-13) - Resolution improved from 20 to 13Km. Improved accuracy for jet- level winds, temperature, In-flight icing, convection, turbulence, and ceiling and visibility

[10] High-Resolution Rapid Refresh (HRRR) - Storm-resolving (3-km) model; updated every 30-60 min including latest radar data

6. WRF forecast by Earth Sciences Department, Barcelona Supercomputing Centre, Spain.

7. WRF forecast by students at University of Athens, Greece (Department of Physics and Department of Meteorology) at 21 and 7 km.

8. WRF forecast by MeteoNetwork of Italy.

9. WRF forecast by the Meteorological Service of Catalonia at 36/12/4 km grid sizes.

2. Consolidated Storm Prediction for Aviation (CoSPA)

Description

The Consolidated Storm Prediction for Aviation (CoSPA) programme was established by the FAA's Aviation Weather Research Program (AWRP) in order to integrate the currently used experimental systems into one high-quality expert system.
CoSPA is a collaborative effort between the following US organizations: Federal Aviation Administration (FAA), the Massachusetts Institute of Technology (MIT), National Centre of Atmospheric Research (NCAR), National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), National Aviation and Space Agency (NASA), Department of Defence (DoD,) universities and private organisations whose aim is to integrate and evaluate existing prototype products such as Corridor Integrated Weather System (CIWS), Integrated Terminal Weather System (ITWS), Collaborative Convective Forecast Product (CCFP), Convective SIGMETS, Numerical Weather Prediction (NWP), AutoNowcaster, and National Convective Weather Forecast (NCWF).

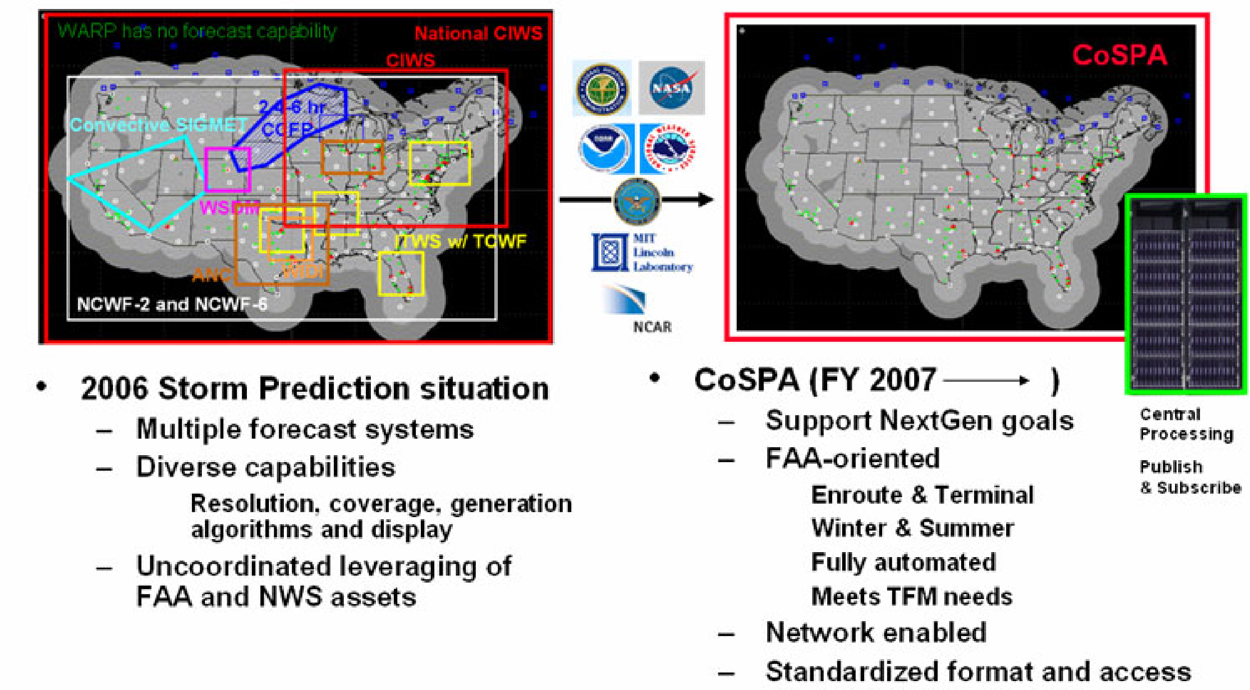


Figure 2: Illustration of the problem of multiple forecasts for use in aviation since 2006.

Weather translation

The motion prediction used in CoSPA consists of three fundamental steps, namely: (i) filtering and tracking, (ii) interpolation of motion fields, and (iii) advection of the weather. To create the raw motion vectors from the observed data, the input precipitation (VIL) images are filtered with a set of mean filters, followed by cross correlation on a time series of the images. Three scales are used for the extrapolation-these are the cell, envelope, and synoptic scales. Two of the three motion scales have been developed for the CIWS system: the cell scale, a 13 km diameter circular mean filter with a 6 min correlation time, and the envelope scale, a 13x69 km rotated elliptical filter with an 18 min correlation time. A new scale needed to be created particularly for the longer time horizons of CoSPA 2-8 hour forecasts: the synoptic scale, a

101x201 km filter with a 45 min correlation time. For the interpolation step, each set of raw motion vectors is interpolated to create a smooth vector map for each scale.

The *advection* process uses two steps to move the separate scales. First, rotation advection is applied to the cell and envelope motions, and second, an Eulerian advection step (or translation) is applied to the synoptic scale. For the first step, the synoptic motion is subtracted from the cell and envelope scales, and the resulting field is applied in a pseudo-Lagrangian sense to the forecast image. The method works as follows: a pixel is advected with a small time step, and then placed at a new location. The pixel is then advected again for the next time step with a motion field representing the area of its new location. The pixel therefore should approximately follow a streamline of the small-scale (rotational) motion field. The cell vectors are used out to a 10-min time horizon, then the advection process transitions to the envelope vectors that are used out to a 90min time horizon, at which point their influence is progressively diminished. After the rotation step is complete, an Eulerian step is applied using the synoptic-scale motion vectors to accomplish the final translation step.

The CoSPA display leverages the CIWS display capabilities and associated "touch and feel". Thus, users familiar with CIWS will find it easy to look at and utilize CoSPA.

ATC impact assessment

The near-term goal of CoSPA is to provide 0–2 hr. tactical CIWS weather forecasts blended with high-resolution numerical forecasts of convective storms out to 6 hours (e.g., 3 km spatial resolution updating every hour).

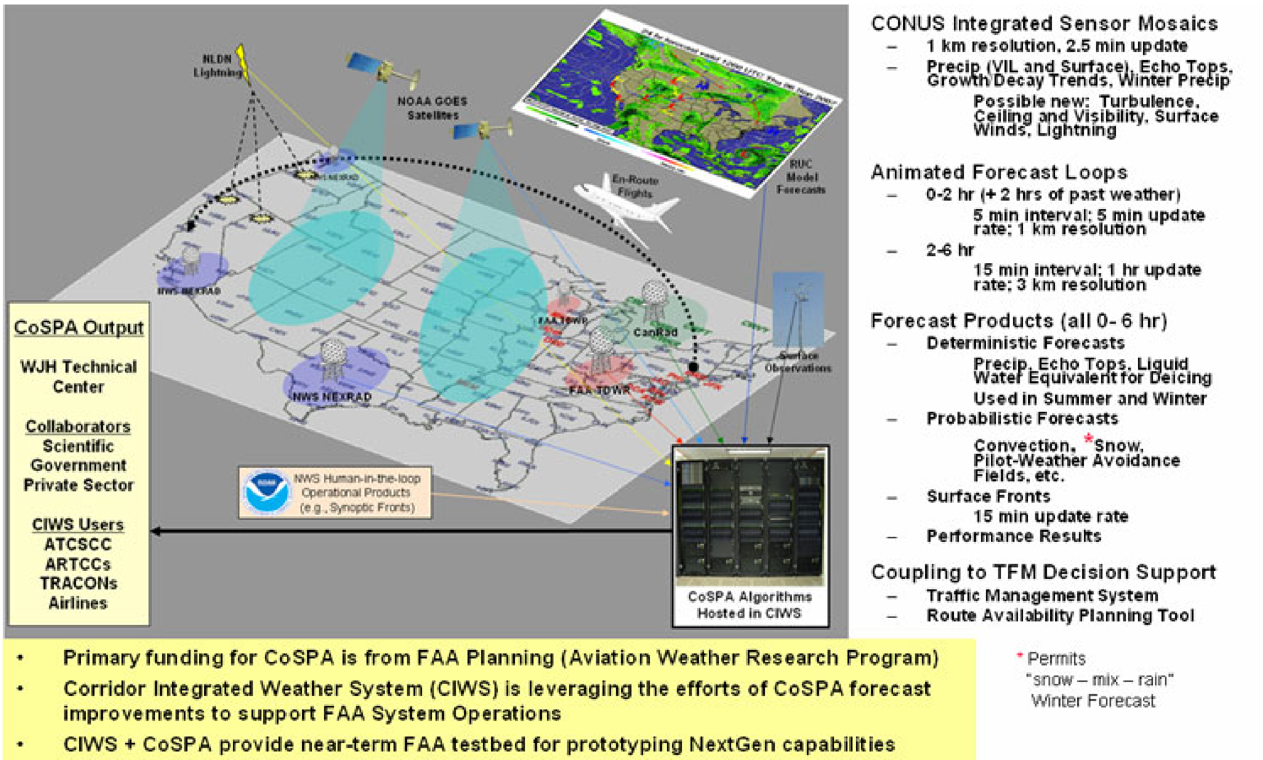


Figure 3: Specification of CoSPA capabilities for the NextGen initial operating capability in 2012.

Decision support

N/A – CoSPA is a weather prediction collaboration programme. Its long-term objectives (2018) are to provide blended forecasts out to 12 hours that are integrated into automated ATM decision support systems.

Information used (inputs)

CoSPA forecast system builds upon technologies of the Corridor Integrated Weather System (CIWS; and the 6-hour forecast version of the National Convective Weather Forecast (NCWF); Moreover, CoSPA uses the model forecasts from NOAA's Rapid Update Cycle (RUC) and the High Resolution Rapid Refresh (HRRR).

CoSPA's design methodology is to use feedback from operational users through open software architecture which will ensure that new and updated modules can be introduced on a regular basis. Modules are contributed by several organizations and then integrated into processing units according to the latest industry design and coding standards. Nationwide integrated sensors including radar, satellite, lightning, surface observations and aircraft are being utilised. Weather products are constructed from the fusing of this data and used in displays, automated tools or other derived products. Data products will be transmitted using the NextGen Network Enabled Weather (NNEW) web services currently being developed by the FAA. CoSPA concepts and goals are in line with the Next Generation Air Transportation System (NextGen), which is targeted for 2025.

Problems solved

Successful blending of heuristic and numerical weather forecasts.
CoSPA expansion to CONUS provides a basis for CoSPA forecast products to be evaluated by aviation traffic flow managers in the field in real time.

Advantages

The heuristic extrapolation forecasts are blended with the HRRR forecasts of VIL and ETOP to produce a seamless and rapidly updating, high-resolution 0-8 hour forecast of weather intensity and storm top heights. This is done through (i) a calibration of the model data to reduce intensity biases, (Ii) a phase correction to reduce location errors in the predicted precipitation field, and (Iii) a statistically-based weighted averaging of the heuristic extrapolation forecast and phase corrected numerical prediction. In CoSPA, heuristic extrapolation forecasts of VIL and ETOP from MIT/LL are thus blended with VIL and ETOP predictions from the HRRR model.

Open software architecture, many organisations are participating and have input (last could be disadvantage also as the input should be validated and closely monitored)

Limitations

Slow to implement; during 2018 is planned for the programme to provide blended forecasts up to 2 hours that are integrated into automated ATM decision support systems.

Operational use of model

A prototype version of CoSPA has been running in real time since 2008. The website of CoSPA is available at:

http://cospa.wx.ll.mit.edu/nciws_servlets/ - the site undergoes further development that leads to enhanced capabilities and improved performance.

Applicability in Europe

CoSPA is US specific programme which consists of several consolidated weather forecast products supported by different organisations and it is not available in Europe.

3. Corridor Integrated Weather System (CIWS)

Description

CIWS acquires data from FAA terminal weather sensing systems, and National Weather Service sensors and forecast products and automatically generates convective weather products for display on existing systems in both terminal and en route airspace within the CIWS domain. CIWS products are provided to Air Traffic Control (ATC) personnel, airline systems operations centres, and automated air traffic management decision support systems in a form that is directly usable without further meteorological interpretation. Using these products, traffic managers may achieve more efficient tactical use of the airspace, reduce controller workload, and significantly reduce air traffic delay. These tactical traffic flow management products complement the longer-term (two- to six-hour) national forecasts that are needed for flight planning and traffic flow management. The zero- to two-hour tactical forecasts also help bridge the gap between the current weather picture and the strategic plan.

Weather translation

The CIWS 3D weather depiction is composed of two main product types: Precipitation: vertically integrated liquid (VIL) and Echo Tops. Within these two categories there are overall six products.

Precipitation (VIL) mosaic product with storm motion vectors and storm top height tags (Kft) all overlaid on the visible satellite image:

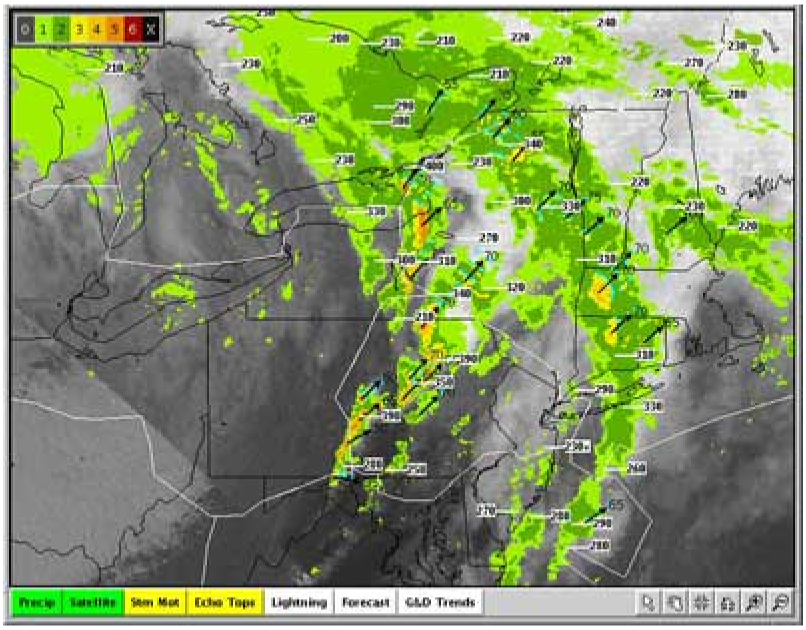


Figure 4: CIWS Precipitation (VIL) mosaic

CIWS 0-2 hour Precipitation Forecast - An animated loop shows 120 minutes of past weather, then advances the forecast in 5 minute increments to the maximum forecast time of 120 minutes:

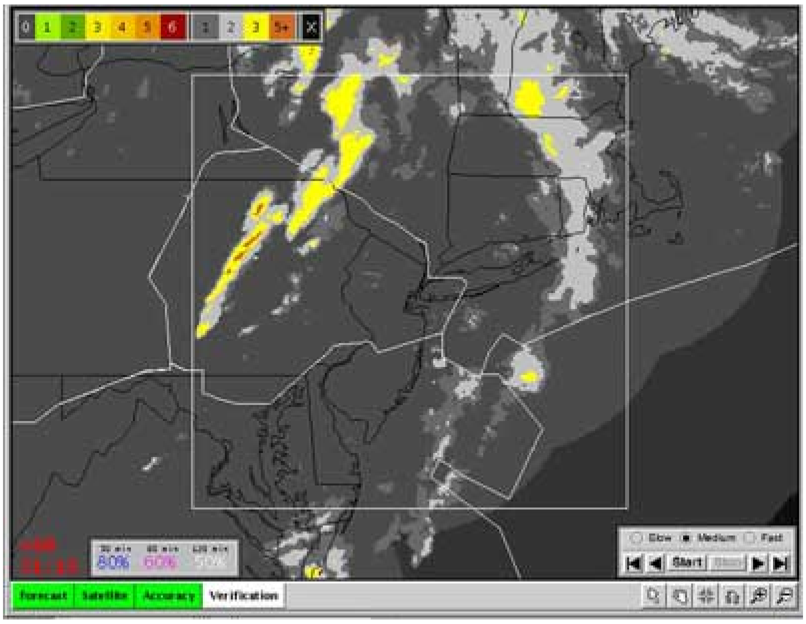


Figure 5: CIWS 0-2 hour Precipitation Forecast

CIWS Growth and Decay Trends - Displays current regions of storm growth (red/brown) and storm decay (blue) trends:

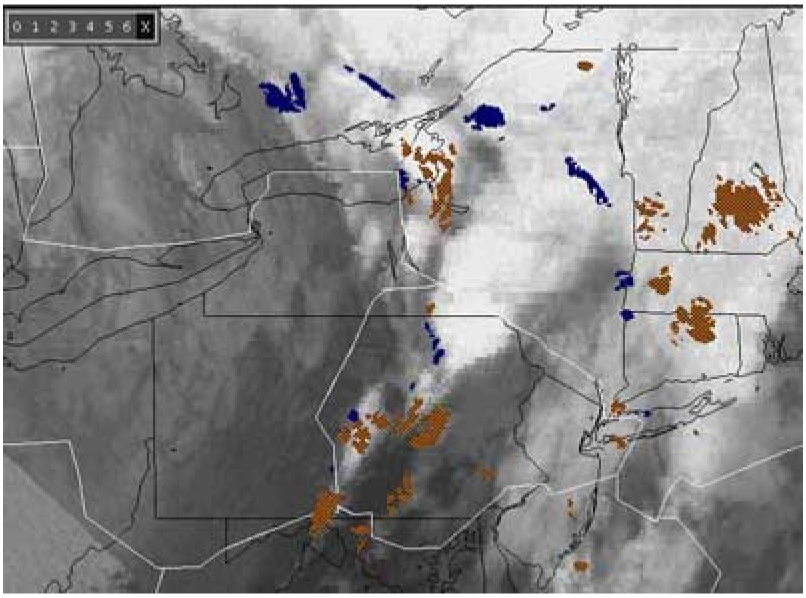


Figure 6: CIWS Growth and Decay Trends

CIWS winter weather forecast - conveys more information about cold-season aviation impacts by depicting snow, frozen precipitation, and rain:

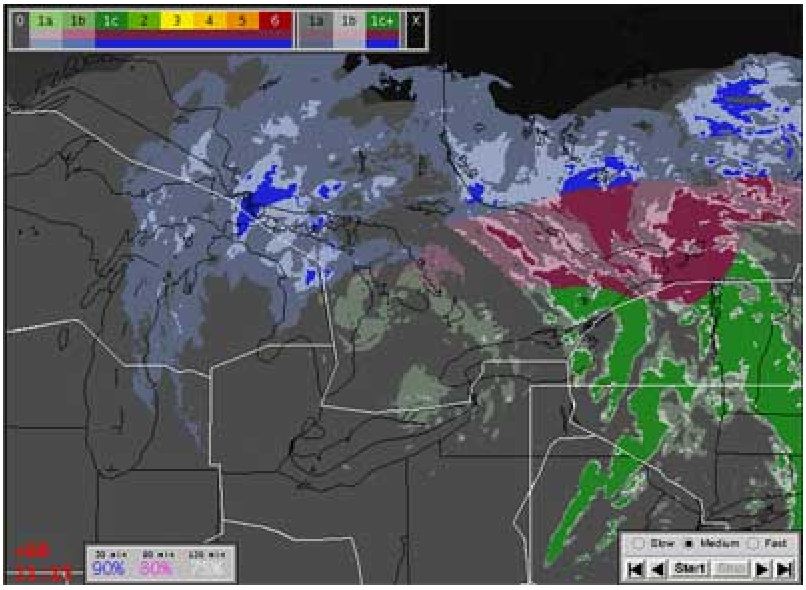


Figure 7: CIWS Winter weather forecast

CIWS Echo TOPS Mosaic - Displays the current storm echo tops:

Figure 8: CIWS Echo TOPS Mosaic

CIWS Echo TOPS forecast:

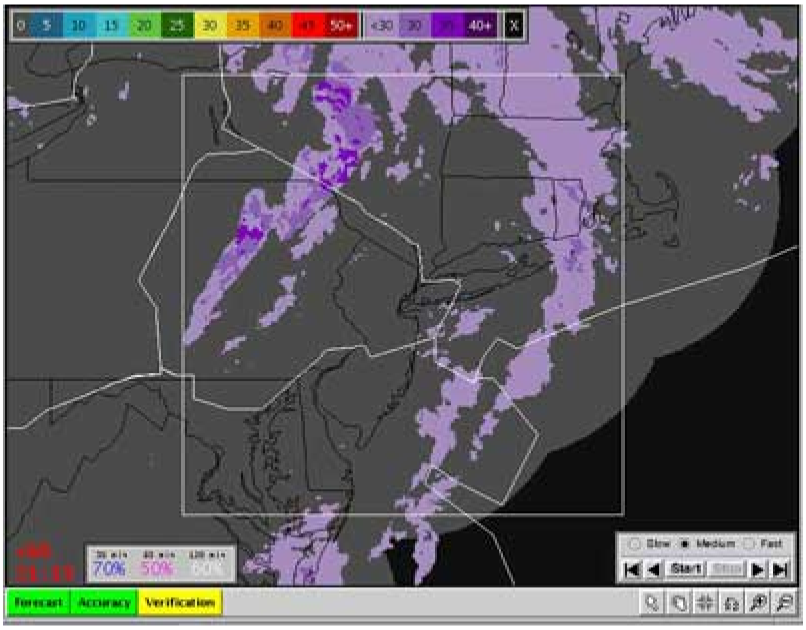


Figure 9: CIWS Echo TOPS Forecast

CIWS is located online at:
http://ciwswww.wx.ll.mit.edu/nciws_servlets/

ATC impact assessment

In addition to further improvements in both tactical and automated strategic convective weather forecasts especially the Consolidated Storm Prediction Algorithm (CoSPA), CIWS is being used for integrated weather-air traffic management (ATM) decision support tools development and the National Airspace System operations benefits analyses. CIWS data is being used to develop models of pilot avoidance of storms as well as models for route and sector capacity in convective weather. The Route Availability Planning Tool (RAPT) accesses the CIWS forecasts to improve the ability to provide route availability guidance in en route airspace surrounding the New York (NY) terminal area. CIWS also supports other programs, such as the System Wide Information Management (SWIM) program and the NextGen Network Enabled Weather (NNEW) program. CIWS data is used broadly as an information source for NextGen Architecture prototype testing.

Decision support

CIWS is being used for (ATM) decision support tools development and the National Airspace System operations benefits analyses. CIWS data is being used to develop models of pilot avoidance of storms as well as models for route and sector capacity in convective weather. The Route Availability Planning Tool (RAPT) accesses the CIWS forecasts to improve the ability to provide route availability guidance in en route airspace surrounding the NY terminal area. CIWS also supports other programs, such as the System Wide Information Management (SWIM) program and the NextGen Network Enabled Weather (NNEW) program. CIWS data is used broadly as an information source for NextGen Architecture prototype testing.

Information used (inputs)

Data is acquires from FAA terminal weather sensing systems, and National Weather Service sensors and forecast products and automatically generates convective weather products for display on existing systems in both terminal and en route airspace within the CIWS domain.

Technical description of CIWS:
Project Report ATC-355 CIWS Product Description Revision 1.0, G. W. Rappa, and S. W. Troxel 27 May 2009 - This document provides description of CIWS data product files.

Problems solved

The delay reduction benefits of CIWS in 2005 exceeded 90,000 hours of direct delay with an airline direct operations cost savings in excess of $90 M per year.

Advantages

- Complement the longer-term (two- to six-hour) national forecasts that are needed for flight planning and traffic flow management.
- The information provided by CIWS will allow air traffic managers to maximize the amount of usable airspace during periods of severe weather.
- With low-topped storms as depicted by the CIWS echo tOPS and echo tOPS forecast products, traffic managers are also able to exploit over-the-top routing.
- The CIWS System Wide Information Management (SWIM) - Compliant Prototype Service will make CIWS data products available to all Airline Operations Centres (AOCs) and other approved subscribers. The Service will publish digital versions of the CIWS products to serve the needs of the consumers. The prototype includes a Java test client with a simple graphical interface that allows users to perform various operations. One of the important features of the CIWS SWIM-compliant prototype is that it uses SWIM standards for the creation of the necessary dissemination services so that it can keep pace with the evolution of NextGen.
- Stakeholder benefits include not having to re-learn technology - users can leverage the data in an industry standard format, and quickly incorporate it into their systems. This result in both cost avoidance and cost savings measures (e.g., less time spent on transforming the data). Standards-based weather product formatting will reduce integration costs, thereby making the distribution of CIWS SWIM-compliant products more available and economical to a wider user base.

Limitations

- 2 hour weather predictions are not integrated yet, planned to be achieved by 2014.

Operational use of model

In October 2010, CIWS became the first ATC system to share information via the System Wide Information Management (SWIM) interface. SWIM compliance means the weather information provided by CIWS to en route centre traffic management units can now be made available to external users, such as airline operations centres, to create a common situational awareness.

From 2010 to 2014, the FAA is planning to establish capability enhancements through CATMT[11] Work Package 2 (WP2) of NEXTEN which includes the integration of high confidence 2 hour weather predictions onto the primary display used by Traffic Managers and into Traffic Flow Management System (TFMS) through CIWS. That WP also locates departure opportunities through impending weather gaps and determines if a flight will encounter weather problems on its projected departure route RAPT enhancement;

Applicability in Europe

N/A – CIWS is currently not applied in Europe. CIWS is US specific system.

[11] Collaborative Air Traffic Management Technologies (CATMT) is a NextGen Transformational Program that provides enhancements to the existing Traffic Flow Management System (TFMS).

4. Route Availability Planning Tool (RAPT)

Description

The Route Availability Planning Tool (RAPT) is an automated decision support tool (DST) intended to help air traffic controllers and airline dispatchers determine which departure routes will be affected by operationally significant convective weather up to 90 minutes into the future (a 30 minute planning window plus 60 minutes flight time). RAPT assigns a departure route status – GREEN for clear, DARK GREEN for low impact, YELLOW for caution and RED for blocked – to future departures by combining CIWS precipitation and echo tOPS forecasts.

Weather translation

The Corridor Integrated Weather System (CIWS) provides forecast grids of precipitation intensity based on Vertically Integrated Liquid (VIL) and echo top heights that are used in the RAPT blockage calculation. Pixel values in the VIL forecast range from 0 to 254 and represent a feature interest level that is mapped into Video Integrated Processor (VIP) levels of precipitation intensity for display (Troxel, 1990). Note that the VIL forecast provides greater resolution of precipitation intensity than the 6 levels of the VIP scale. The echo tOPS forecast predicts echo top heights at each pixel in the grid to the nearest 1000 feet. Forecasts have a spatial resolution of 1 km and a temporal resolution of 5 minutes. Forecasts are updated every 5 minutes. RAPT uses forecasts out to 90 minutes into the future (30 minute departure look-ahead plus 60 minutes flight time).

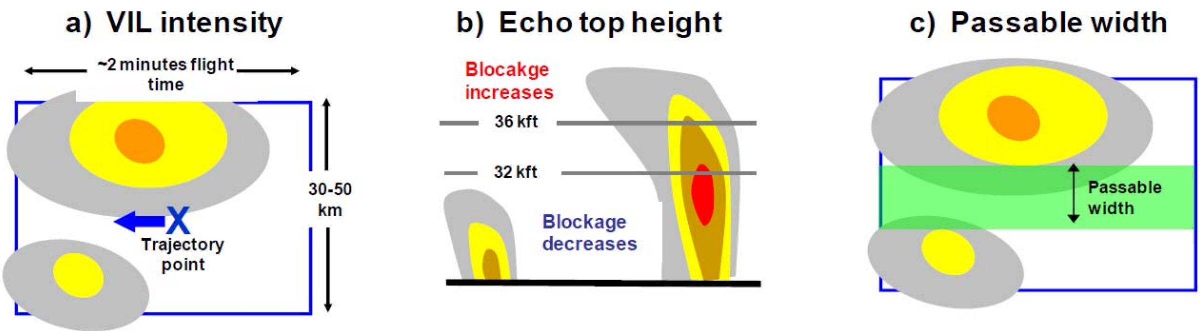


Figure 10: RAPT route blockage algorithm. Figures (a) is an overhead view of the departure route box (blue box) that surrounds a single trajectory point in a RAPT departure trajectory (the blue X in the middle of the box). The VIL intensity term in the blockage score a weighted average of the VIL values at each pixel in the box, with pixels near the centre having higher weights than those near the edges. Figure (b) illustrates the concept for echo top height contribution. Route blockage decreases linearly with echo top height where echo tOPS are less than 32 kft and increases linearly where they exceed 36 kft. Between 32 and 36 kft, the echo tOPS contribution to blockage is 0. Figure (c) illustrates the definition of the passable width, which is the widest longitudinal path that traverse the route box without any level 3 VIL pixels (shown as yellow regions in the figure).

Route blockage is calculated at each trajectory point based on the weather inside the route box cantered on the trajectory point. It is a linear combination of three factors: VIL intensity (I), echo top height (H) and passable width (W).

Intensity is a spatially weighted average of all VIL pixels greater than or equal to VIP level 1, where the weights are higher toward the centre of the route box and lower toward the edges. Weights are an algorithm parameter[12].

ATC impact assessment

RAPT calculates route blockage along departure routes that are based on statistically averaged, 60 minute, four-dimensional (4D) departure flight trajectories. Trajectory points are calculated at one minute intervals. Flight trajectories have four phases – climb, transition, near enroute and enroute – that reflect flight altitude and airspace complexity. Routes are defined by boxes cantered on the trajectory points, whose length and width are functions of the flight phase. The lengths are set to approximately two minutes flight distance and the widths reflect the route density and the ability of air traffic control to manoeuvre flights around convective weather in the region traversed during the flight phase. Typically, routes are wide during the climb and transition phases (inside the TRACON), become narrower in the near enroute phase where departure and arrival routes are densely packed (ZNY and northern ZDC) and widen again in the enroute phase where routes are not so densely packed (ZOB and southern ZDC).

[12] W = Passable width – Greatest width between level 3 VIL pixels
The calculated blockage is
$B = a * I + b * E + c * W$
where a, b and c are algorithm parameters that are functions of the departure trajectory phase, and B is clipped to the [0,1] interval.

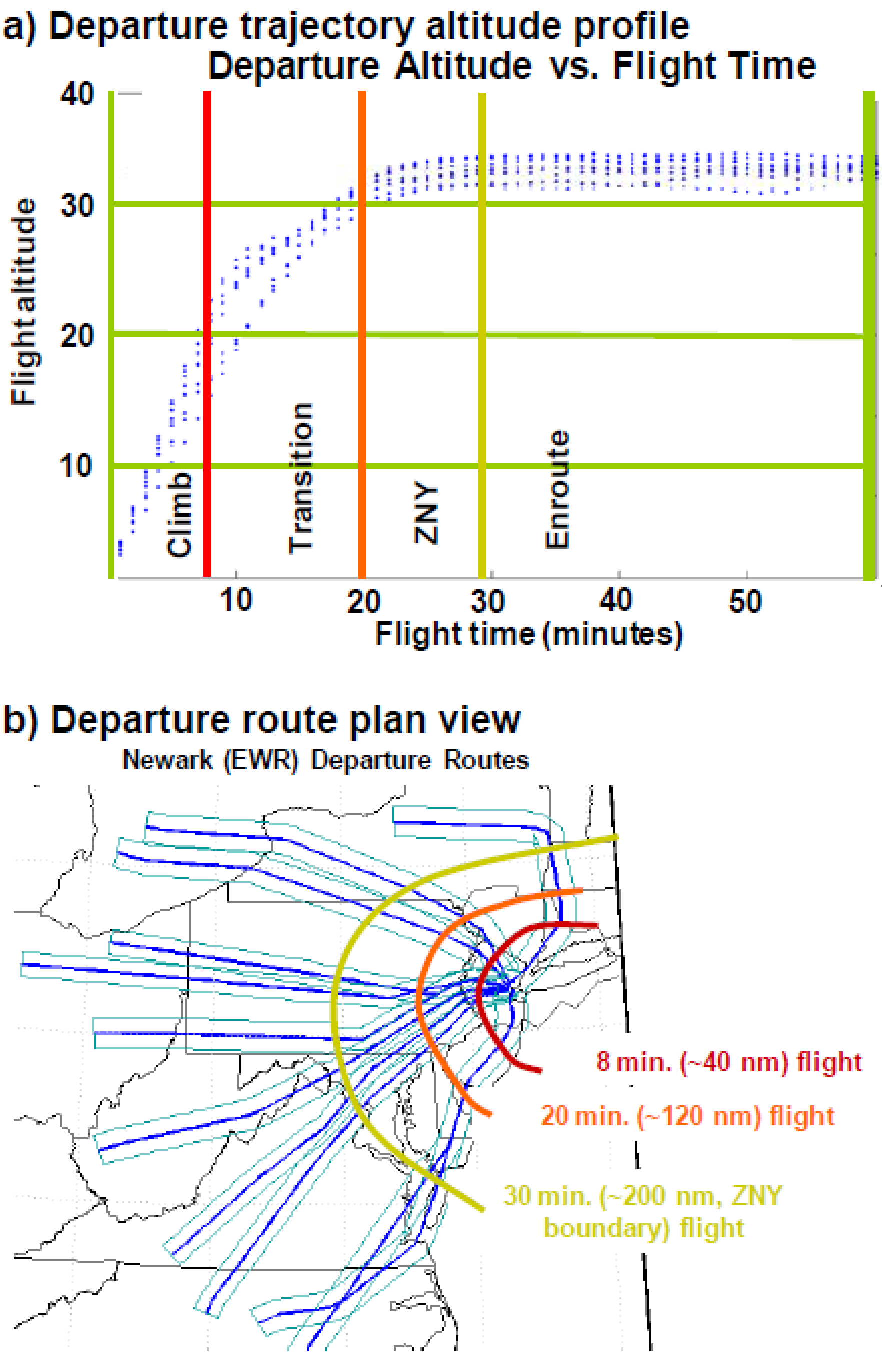


Figure 11 illustrates the RAPT departure trajectory definitions. Departure trajectory altitude vs. time profile (a) and departure route plan view (b) are illustrated.

Route blockage, a number between 0 and 1, is calculated for each box along a given route and thresholded to one of the four blockage status colours. The status for a particular departure route at a given departure time is the highest blockage encountered by the flight trajectory that starts at the departure time.

The RAPT display provides a departure status table and a weather forecast animation window.

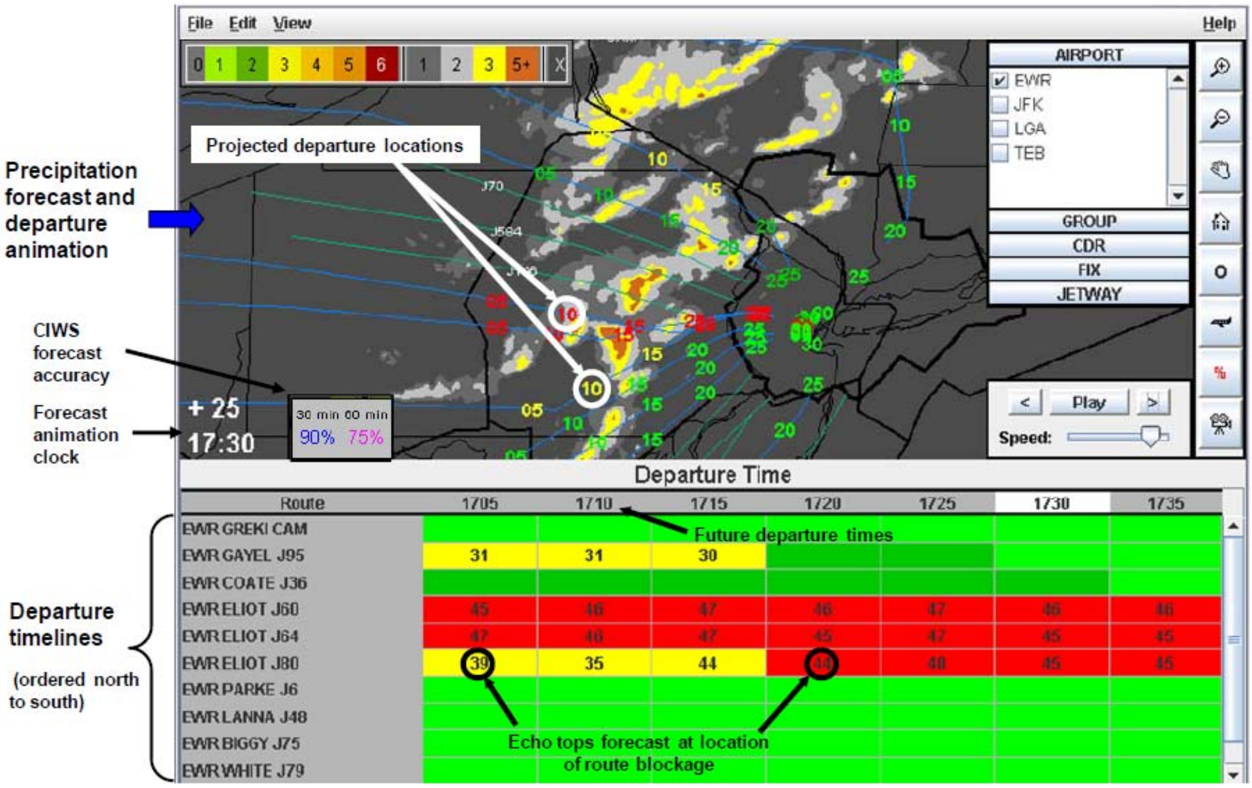


Figure 12: RAPT display. RAPT could be available to users as a window on the CIWS situational display or as a stand-alone web-based client application.

Each row in the table ('departure status timeline') provides the status of future departures along a particular route. The routes are ordered from north to south. Each column in the table represents a future departure time. Each cell in the table is coloured according to the departure status for a particular departure time and route as described above. YELLOW and RED cells include a number that gives the median echo top encountered along the route at the point of blockage. They may also include an 'ENR' notation that indicates that the blockage occurred beyond the first 30 minutes of flight time, in 'enroute' airspace.

The weather forecast animation window shows an animated loop of the precipitation forecast, with the animation of RAPT departures overlaid. Each animated departure is represented as a 2 digit number, which gives the departure time as minutes after the hour. The colour of the number matches the RAPT status (GREEN, DARK GREEN, YELLOW or RED). The animation window provides users with additional information that can help them evaluate the reliability of departure status given in the RAPT departure status timelines.

Decision support

The operational model includes departure route definitions and a route blockage model that calculates the severity of convective weather impact on departure traffic along the first 60 minutes of flight time of the departure route.

Information used (inputs)

RAPT performance depends on forecasts made by CIWS.

Problems solved

The operational testing confirmed the validity of the RAPT operational concepts. Field observers noted successful RAPT usage at several facilities over the course of the study and found that RAPT guidance was operationally sound and timely in many circumstances. Overall, RAPT performance was best in circumstances where convection was embedded in larger regions of stratiform or low level precipitation.

Advantages/

RAPT assigns a departure route status to future departures by combining CIWS precipitation and echo tOPS forecasts.

Limitations

- In early stages of testing RAPT tended to fail, usually by over-warning, where small, strong isolated cells or high-gradient edges of larger cells were present near the edges of route boundaries[13].
- RAPT is oversensitive to small, strong weather features and the temporal correlation between successive weather forecasts is greater than RAPT expects.
- Critical characteristics of forecasts, such as the spatial correlation between forecast pixels and the relative magnitude of different forecast errors (motion, storm growth, decay, etc.), are not well understood. More research is needed to understand and characterize weather forecast uncertainty in a way that can be readily translated into route blockage uncertainty.

Operational use of model

RAPT became operational in August 2002, and has evolved in response to feedback from operational users and post event analysis of performance. The operational model and display was revised in 2007 to address shortcomings observed in the most recent RAPT performance evaluation.

The RAPT Evaluation and Post-Event Analysis Tool (REPEAT) is developed to support post-event analysis of New York-area departure operations, which indicates its level of operational maturity.

Currently, RAPT users include air traffic control personnel in the Newark (KEWR), LaGuardia (KLGA), Kennedy (KJFK) and Teterboro, NJ (KTEB) towers, the New York TRACON (N90), four ARTCCs - New York (ZNY), Washington, DC (ZDC), Cleveland (ZOB) and Boston (ZBW) and the FAA Command Centre (ATCSCC), as well as airline dispatchers at several commercial airlines (Continental, JetBlue, Northwest and Delta).

Research is on-going to improve the operational model and user display, account for forecast uncertainty, provide real-time performance scoring and extend RAPT to other terminal areas.

Applicability in Europe

N/A – RAPT is currently not applied in Europe. RAPT is US specific system.

[13] Since RAPT uses only valid pixels to characterize weather in the route box (pixels that are 'null', indicating lack of radar return, valid forecast or edited data, are not included in the intensity or echo top height calculations), it often overestimated the impact of such weather. This failure mode became more evident with the introduction of wider routes in 2007, as the route boundaries now extended several miles to either side of the centre of the route and severe weather at greater distance influenced the route blockage calculation.

5. Convective Weather Avoidance Model (CWAM)

Description

This model addresses how convective weather impacts traffic in en route airspace. The CWAM model was built by analysing historical traffic and weather data to determine when pilots choose to deviate and when to penetrate convective weather.

The capacity impact model combines weather avoidance fields (WAFs) from the Lincoln Laboratory developed convective weather avoidance model (CWAM) with en route airway geometry to estimate the capacity reduction due to convective weather along the route. Sector capacity reduction is calculated as the demand-weighted average of the route capacity reduction of all routes in the sector.

Weather translation

Both precipitation intensity as well as echo tOPS data is important factors in the decision. WAFs are computed as a function of observed and/or forecasted weather to determine 2D or 3D grids retaining either a probability of deviation (0% to 100%) or a binary deviation decision value (0 or 1).

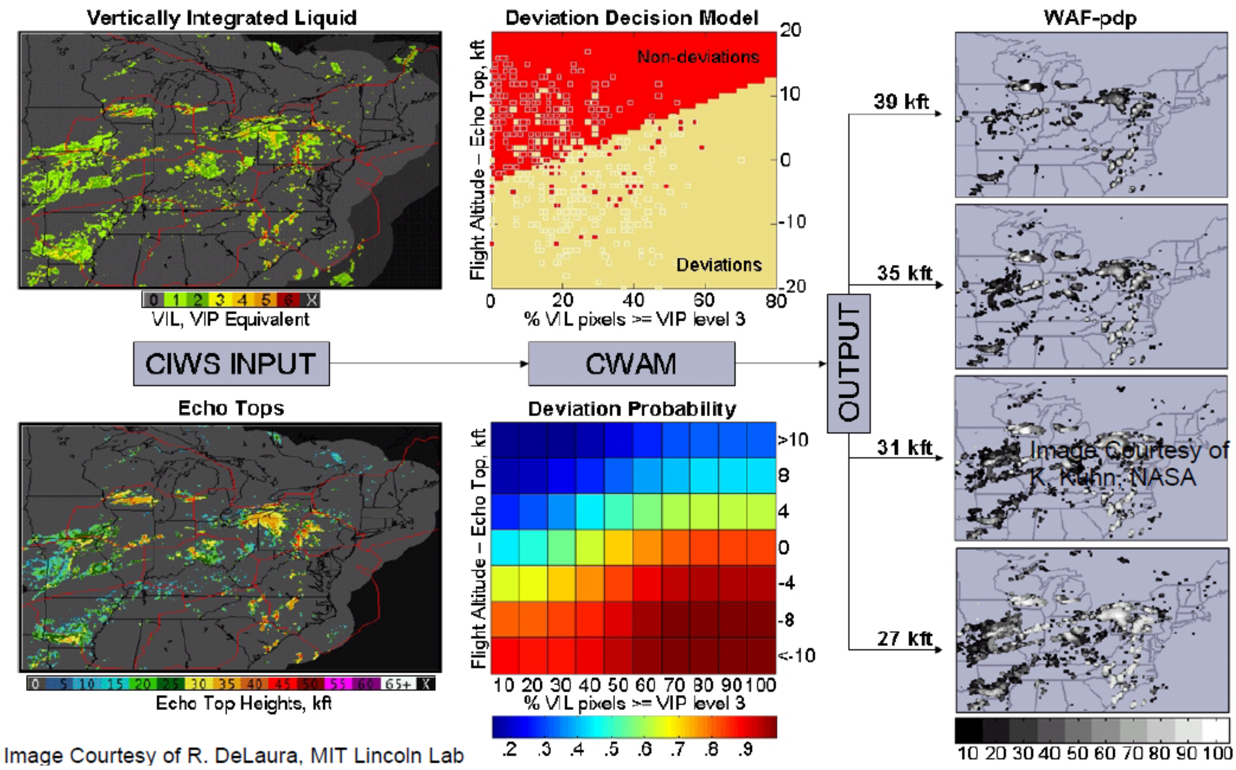


Figure 13: The translation of convective weather into Weather Avoidance Fields (WAFs). Source: Summary of Weather – ATM Integration Technology, Jimmy Krozel

CWAM requires both the inference of pilot intent from an analysis of trajectory and weather data and an operational definition of deviation. Two approaches have been taken to model and validate weather-avoiding deviations using trajectory and weather data: trajectory classification and spatial cross-correlation.

A second study (CWAM2) extended the analysis to additional Centres (ZDC, ZID and ZOB) and included several additional deviation predictors. The additional predictors captured information about storm growth and decay, vertical structure and weather type (convective or non-convective). Even with all the additional information, the difference between flight altitude and radar storm top was again the top predictor of pilot deviation to avoid convective weather.

ATC impact assessment

CWAM define 4D (three spatial dimensions and time) en route constraints applicable for both tactical and strategic look-ahead times, and offer advantages for ATC and for TFM, including identification of expected constraints in the NAS using state-of-the-art convective forecast data and building common situational awareness of weather impact between traffic managers and NAS users. CWAM is fairly mature weather integration technology at the implementation stage, and has been empirically validated.

In order to determine the impacts of convective weather on terminal air traffic operations, CWAM models must be modified to take into account the constraints of terminal area flight to calculate WAFs that apply specifically to terminal area operations. Each WAF grid point is assigned a probability and/or a binary value (0 or 1) that represents that likelihood that pilots will choose to avoid convective weather at a point location in the terminal area. For instance, departures and arrivals are constrained to follow ascending or descending trajectories between the surface and cruise altitude, leaving little flexibility to avoid weather by flying over it. Aircraft flying at low altitudes in the terminal area appear to penetrate weather that en route traffic generally avoids. The willingness of pilots to penetrate severe weather on arrival increases as they approach landing.

Decision support

CWAM is a model which when operational will be used in CIWS.

Information used (inputs)

The model used Corridor Integrated Weather System (CIWS) Vertically Integrated Liquid (VIL) and echo top fields and National Lightning Detection Network (NLDN) data to predict aircraft deviations and penetrations. The statistical results showed that the difference between flight altitude and the radar storm top was the most important factor in explaining pilot deviations. The second most important factor was the precipitation intensity.

Problems solved

The model accuracy is equally good for sectors with capacity reductions > 50%, although in sectors with higher impact the model tends slightly to overestimate impacts.

Advantages

Mature weather integration technology which have been empirically validated

CWAM translates convective weather information from CIWS into impact on aircraft by determining which convective regions pilots will choose to avoid.

Limitations

Observed flight tracks may not correctly represent pilot preference. In some instances, pilots may have penetrated airspace that they would rather have avoided or they may have avoided airspace that was easily passable.

Since the decision to deviate rests ultimately with the pilot, further research into human factors is needed to ensure that CWAM capture the critical elements of pilot decision making. It is important that automatically generated weather voiding reroutes be acceptable to pilots.

Operational use of model

CWAM is currently being tested. A third CWAM study (CWAM3) is being planned. It will be the first to include operational information, such as time of day (daylight, twilight, night), aircraft type, airline, airspace congestion, etc., as potential predictors of deviation. Lincoln Laboratory is also investigating the visual cues available in the cockpit to gain a better understanding of which aspect of the weather the pilot considers hazardous.

Applicability in Europe

CWAM – WITI is currently not applied in Europe.

6. NAS Weather Impacted Traffic Index (WITI)

Description

WITI is a tool for quantifying actual and forecast weather impact on air traffic. The WITI measures the number of flights impacted by weather. Each weather constraint is weighted by the number of flights encountering that constraint in order to measure the impact of weather on NAS traffic at a given location. Historically, WITI has focused on en route convective weather, but the approach is now applied to other weather hazard types as well.

WITI consists of the following components:

- WITI-B evaluates the extent to which a flight would have to reroute in order to avoid severe weather.
- En route WITI (E-WITI) for a flow is the product of its hourly flight frequency and the amount of convective reports in a region of airspace. Another approach apportions all en route WITI measures to origin and destination airports.
- Terminal WITI (TWITI) considers terminal area weather, ranked by severity of impact, and weights it by the departures and arrivals at an airport.

The National Weather Index (NWX) implements the WITI on a NAS-wide scale.

The National Airspace (NAS) Weather Index (NWX) is constructed as a weighted sum of the en-route and terminal components, and was used for weather impact assessment in the entire NAS. It showed good correlation with NAS-wide delay metrics.

Weather translation

In WITI's basic form, every grid cell of a weather grid W is assigned a value of 1 if above a severe weather threshold and a value of 0 otherwise The number of aircraft T in each grid cell of the weather grid W is counted. The WITI can then be computed for any time period (such as 1minute intervals) as the sum over all grid cells of the product of W and T for each grid cell. A WITI-B variation evaluates the extent to which a flight would have to reroute in order to avoid severe weather. If a planned trajectory encounters severe weather, the algorithm finds the closest point in a perpendicular direction to the flow where no severe weather is present. The WITI score for that route is then weighted by the number of cells between the original impeded cell and the unimpeded cell found for the reroute.

Various methods for determining the traffic count have been explored. WITI can use actual flight tracks from:

- Normal operation or “good weather days” as the traffic data source,
- current day flight plan trajectories,
- great circle tracks between the origin and destination airports as the ideal, shortest-path unimpeded flight trajectories.

Actual scheduled flight frequencies on these flows for the day in question are used. The En route WITI (E-WITI) for a flow is the product of its hourly flight frequency and the amount of convective reports in rectangular or hexagonal grid cells.

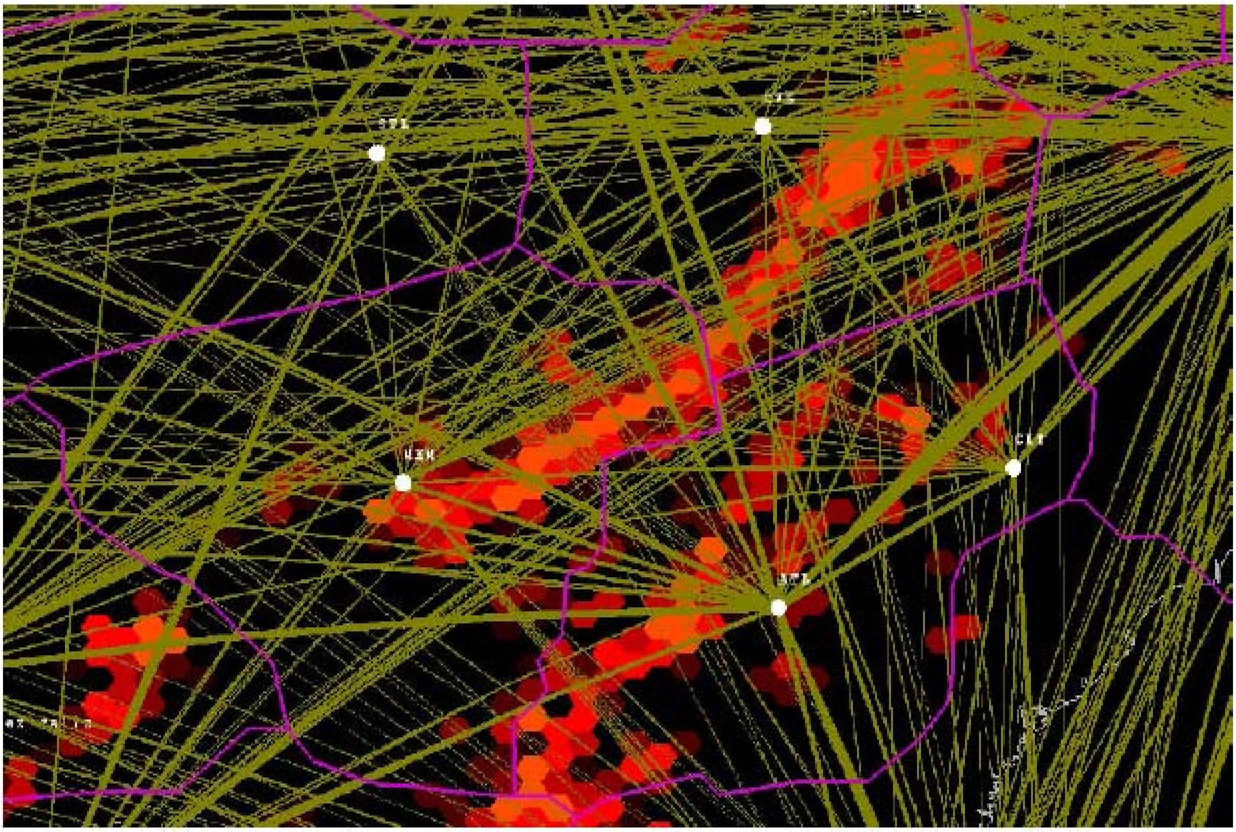


Figure 14: WITI Calculation Display

This is then aggregated to the NAS level and to a 24-hour day, as well as by centre, sector, or general airspace geometry. Another approach apportions all en route WITI measures to origin and destination airports. Even though en route delays may not be due to any local airport weather, the resulting delays will originate and/or eventuate at the departure or arrival airports. A grid cell's WITI score for a flow is apportioned to each airport proportional to the square root of the distance from the cell to those airports. The closer a weather cell is to an airport, the larger the portion of the WITI will be assigned to that airport. This provides a national WITI score broken out by airport – consistent with how NAS delays are recorded in ASPM today

The correlation between the WITI and delays has improved as additional types of weather besides en route convection have been considered. Terminal WITI (T-WITI) considers terminal area weather, ranked by severity of impact, and weights it by the departures and arrivals at an airport. Types of weather include local convection, terminal area winds (direction, severity, and altitude), freezing precipitation, and low ceilings/visibility. The impact of turbulence on en route flows is also being studied as an inclusion to WITI

ATC impact assessment

WITI is intended to allow for higher-fidelity analysis of weather impacts on the NAS and of the system's operational outcomes such as the strategies to mitigate the impacts, thus reducing delays, cancellations, operating costs etc.

Decision support

The NWX metric can be produced on an hourly, daily or monthly basis, NAS-wide or regionalized. It is planned to be used for the FAA's morning briefings, long-term post-season reviews, and future-NAS analyses. Future work includes developing methods for NAS outcome prediction based on weather forecast.

Information used (inputs)

Information from the two weather products is used: National Convective Weather Detection (NCWD) data and Collaborative Convective Forecast Product (CCFP)[14] data. NCWD is one of the approved aviation radar products and CCFP is one of the approved aviation forecast weather products used for air traffic planning by the FAA.

WITI also uses actual flight tracks from a "good weather day" as the data source for traffic. It also uses flight plan traffic for the particular day being analysed.

WITI Forecast Analysis (FA) uses actual weather data, for the following products:

En-route (E-WITI)

- En-route weather E-WITI uses actual convective weather data, e.g. NCWD
- E-WITI-FA uses convective forecast data, e.g. CCFP
- Both use the same scheduled traffic on major flows
- Convective forecast data is converted to "quasi-NCWD" format (probability or intensity of Weather converted to % max NCWD score for hexagonal grid cells)

[14] The Collaborative Convective Forecast Product (CCFP) is a graphical representation of expected convective occurrence at 2-, 4-, and 6-hours after issuance time. Convection for the purposes of the CCFP forecast is defined as a polygon of at least 3000 square miles that contains:
• A coverage of at least 25% with echoes of at least 40 dBZ composite reflectivity; and
• A coverage of at least 25% with echo tops of FL250, or greater; and
• A forecaster confidence of at least 25%.

All three of these threshold criteria combined are required for any area of convection of 3000 square miles or greater to be included in a CCFP forecast. This is defined as the minimum CCFP criteria. Any area of convection which is forecasted NOT to meet all three of these criteria will NOT be included in a CCFP forecast.

Comprehensive list of all CCFP, collaboration weather project between FAA, NOOA, Environment Canada and NAV Canada: http://aviationweather.gov/products/ccfp/info/

The chart below provides a comparison between the E-WITI (post-event) and E-WITI FA (forecast of 2, 4 and 6 hr.) values

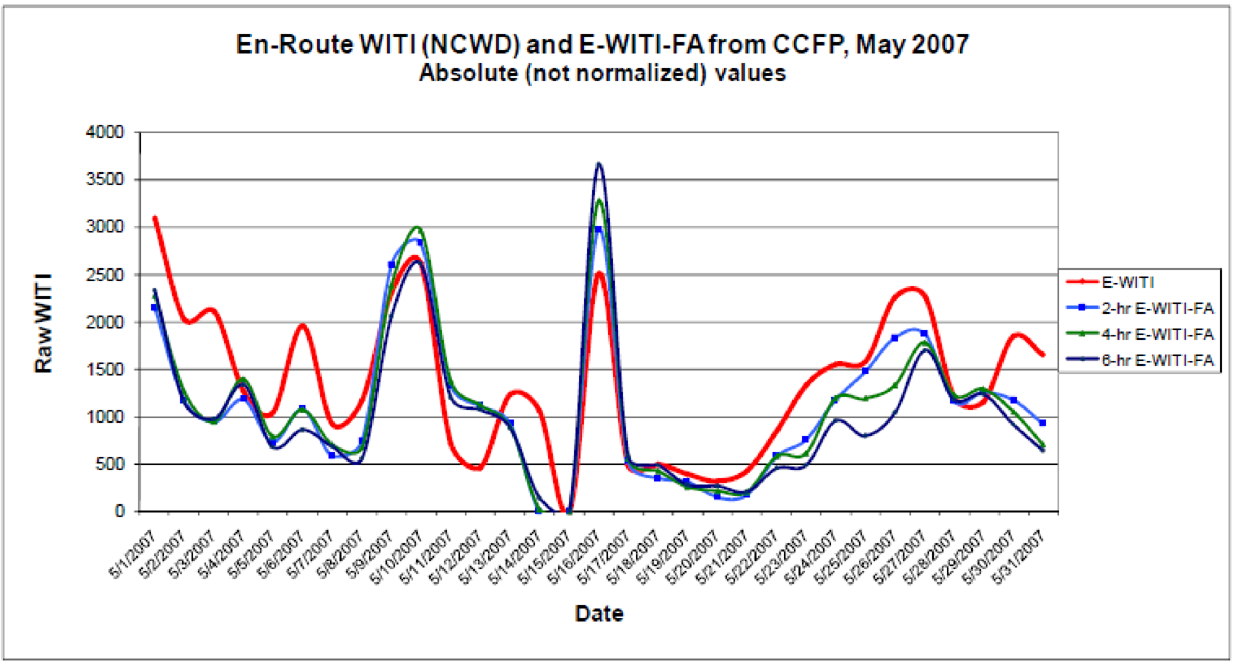


Figure 15: En-route Wx: E-WITI vs. E-WITI-FA (Source: http://www.aviationweather.gov/static/docs/forum/KleinAlexander.pdf)

Terminal (T-WITI)

- Terminal weather T-WITI uses actual surface Wx data (METARs)
- T-WITI-FA uses forecast data (TAFs)
- Both use the same scheduled traffic at major airports
- TAF converted to quasi-METAR form, “rolling look-ahead” stream

The chart overleaf provides a comparison between the T-WITI (post-event) and T-WITI FA (forecast of 4-hr look ahead) values

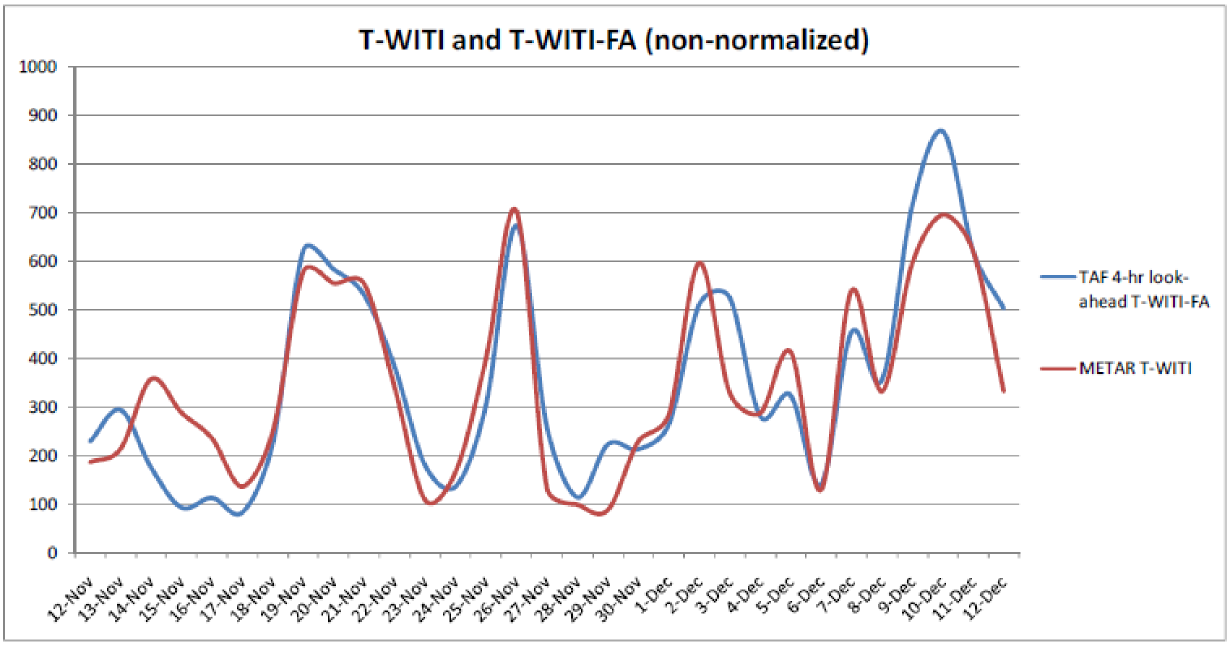


Figure 16: 30-Day T-WITI vs. T-WITI-FA (Nov-Dec 2007) (Source: http://www.aviationweather.gov/static/docs/forum/KleinAlexander.pdf)

Problems solved

The development of the NAS Weather Index (NWX) has established a common framework within which ATM System service performance discussions may be held. It provides the opportunity to segregate individual elements impacting performance that are interdependent with weather and supports analysis to elevate system performance at the best investment level.

The National Weather Index (NWX) implements the WITI for the FAA. In addition to calculating E-WITI and T-WITI, it considers the additional delays due to queuing during periods where demand exceeds capacity, both en route and at airports. This 4-component NWX is referred to as the NWX4. Current research is now exploring the use of the WITI for airline route evaluation, departure and arrival fix evaluation at TRACONs, and principal fix evaluation in ATM centres

Advantages

Tool for quantifying actual and forecast weather impact on air traffic and it measures the number of flights impacted by weather.

It could provide information on day-to-day (and consequently weekly, monthly, and seasonal) changes in traffic.

Given that the WITI is an estimation of NAS performance, WITI has also been used as a measure of NAS delays. Multiple years of weather, traffic, and delay data have been analysed, and a strong correlation exists between the WITI metric and NAS delays. Recent research considers other factors in addition to delay, such as the number of cancellations, diversions, and excess miles flown in reroutes.

According to its developers WITI could be customised and expanded to cover the following 7 factors:

En-route convective Wx, Volume and ripple effects, Local convective Wx, Wind, Snow, IMC (low ceilings/vis), Other such as minor Wx, unfavourable RWY configuration, etc.

FAA currently uses: EWITI, TWITI and Qdelay (US NAS is represented as a "sum" of 34 main airports)

Limitations

The WITI tool is still under development.

Operational use of model

Used by the FAA on a regular basis to measure system performance in an objective manner and to compare different seasons' Wx/traffic impact with outcomes (e.g. delays)

The animated weather viewer (web tool) is located at:
http://apps.avmet.com/animatedviewer/

The tool has the ability to combine, synchronise and animate two weather products on a single display. Users are given the ability to zoom, pan, and make specific date selections for dates between 2007 and present. Overlays include the airports, states, FAA Centres, as well as three CCFP forecasts.

Applicability in Europe

N/A – WITI is currently not applied in Europe. WITI is US specific product.

7. Common Constraint Situation Display (CCSD)

Description

The Common Constraint Situation Display (CCSD) allows collaborative decision making (CDM) participants such as airlines to view a graphical display of information that they can use to monitor the state of the NAS and to manage their operations. The CCSD is a web-based tool that can be accessed over the CDM net. The CCSD displays the following types of dynamic data.

- It shows the Enhanced Traffic Management System (ETMS) predictions of air traffic demand for the next fifteen hours, and it highlights the particular airports, sectors, and fixes where excess demand is forecast.
- It shows selected weather information such as the current intensity of precipitation.
- It shows flow-constrained areas (FCAs), which are volumes of airspace that are expected to be special trouble spots, possibly because of severe weather.
- It shows the reroutes that have been issued by the Air Traffic Control System Command Centre.
- It shows the Collaborative Convective Forecast Product (CCFP), which is used by the FAA and NAS users for traffic flow management strategic planning.

In addition, to help the user interpret this data, the CCSD allows the user to display static data such as airports, navaids, fixes, and political boundaries.

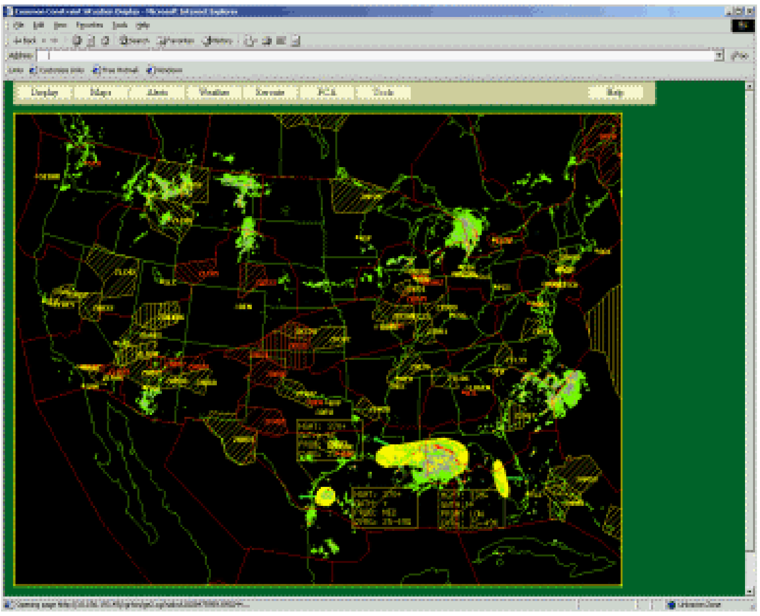


Figure 17: CCSD with translated weather across CONUS

Weather translation

The Federal Aviation Administration (FAA) receives data on flights that fly under Instrument Flight Rules (IFR). ETMS typically receives a position update on an airborne flight once a minute. The demand predictions are updated once a minute, with these predictions being based on the latest data that ETMS has received; these predictions are provided to the CCSD. Also, the CCSD receives an update on the precipitation data once every five minutes, on the CCFP once every two hours, and on FCAs and reroutes whenever an FAA traffic manager issues an update. The most recent data is shown on the CCSD every time its screen refreshes, which is once a minute (or whenever the user manually refreshes the screen).

ATC impact assessment

The data shown on the CCSD is exactly the same data that is seen by the FAA traffic flow managers that use ETMS, except that data on sensitive flights, lightning data, and aircraft icons are omitted. What is notable about the CCSD is that it provides access to this data in an inexpensive and easily supported way since a CCSD user only needs a browser and connectivity to the Air Traffic Control System Command Centre (ATCSCC), which hosts the CCSD web server. The user does not need any special software that needs to be installed or maintained.

Decision support

The FAA is strategically disseminating ETMS data over three platforms: Traffic Situation Display (TSD)[15], Web-based Situation Display (WSD), and CCSD. Each platform is aimed at a different audience, depending on the performance and functionality that is required and the cost that can be justified. This strategy promises to give all personnel the data needed for making decisions at the lowest feasible cost.

Although the WSD does not provide all the functionality of the TSD, it does provide the core functionality that is most needed. With the WSD a user can have access to ETMS data and can make decisions based on the data. Moreover, the WSD delivers this functionality at a much lower cost than the TSD since the WSD does not require that custom hardware and software be installed and supported at the user's site.

The WSD is aimed at not only the FAA but also at military and civilian agencies within the federal government. A side benefit of the web-based approach used for the WSD is that it can easily be modified to realize the long desired goal of providing more ETMS data to the NAS users, in particular the airlines.

Therefore, the FAA has developed CCSD, which is aimed at NAS users. The CCSD is, in effect, the same as the WSD except that certain data that is not appropriate for NAS users has been removed. In particular, the CCSD is the same as the WSD except for the following differences.

- The CCSD does not show flight icons since FAA policy is that showing flight icons is a function left to the private sector.

[15] Of roughly 190 TRACONs in U.S., only about 31 have the TSD. The reason is cost. The TSD is costly for the following reasons: The TSD runs on a high-end workstation (though the cost of the needed workstations has now dropped substantially). ; A great deal of custom ETMS software is installed on this workstation to support the TSD.; A high level of support, both local and remote, is needed to maintain the software and hardware for ETMS workstations at each site.

- The CCSD does not show lightning data since this data is very expensive; the NAS users are left to acquire lightning data, if desired, by other means.
- The CCSD does not show detailed data on sensitive flights, for example, military flights.
- The CCSD allows the FAA to share information with the airlines, especially information about constraints in the system such as congested airports or overloaded airspace, and to collaborate in effectively solving traffic flow problems.

Information used (inputs)

The data displayed on the CCSD comes from the Enhanced Traffic Management System (ETMS), which is the main automation system that the Federal Aviation Administration (FAA) uses for traffic flow management. Flight data, including reports of the current positions of airborne aircraft, comes to ETMS from the twenty-one air route traffic control centres (ARTCCs) and the roughly 190 Terminal Radar Approach Control facilities (TRACONs) in the United States. In addition, data comes from Canada, Great Britain, and Mexico.

The weather forecast data is obtained from the following sources/functions: NOWRAD[16], CCFP, NCWF[17]

The dialog box overleaf shows the weather overlays which can be used in CCSD:

[16] The **NOWRAD** command displays a color-coded graphic overlay of areas of precipitation.

The display, updated every five minutes, shows up to six levels of precipitation, ranging from very light to very heavy. Two NOWRAD options are available. NOWRAD (8km) uses the same weather data as used by the TSD and is recommended for display. The NOWRAD (2km) high-density weather data provides better resolution of weather information, but takes longer to display. Only one option may be selected at a time.

[17] The **NCWF** (National Convective Weather Forecast) uses polygons to depict a one-hour forecast of the location of currently existing thunderstorms. An arrow and a number that indicate the storm's current direction of motion and speed, in knots, accompany each polygon. The NCWF updates every five minutes.

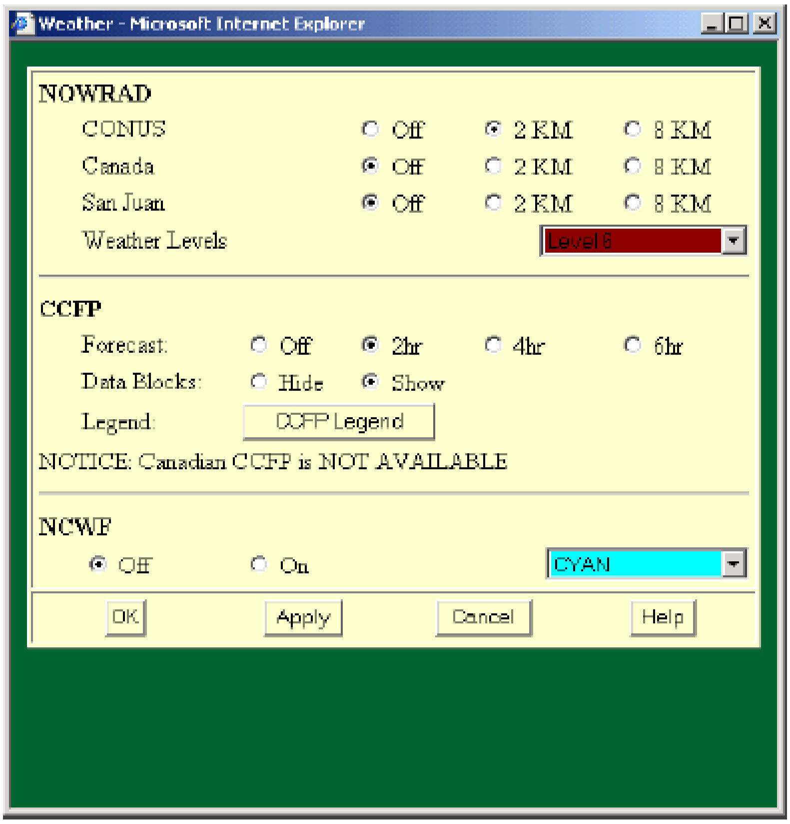


Figure 18: CCSD Weather dialog box (Source: Common Constraint Situation Display, User Manual Version 8.4, April, 2007, Volpe National Transportation Systems Centre, U.S. Department of Transportation)

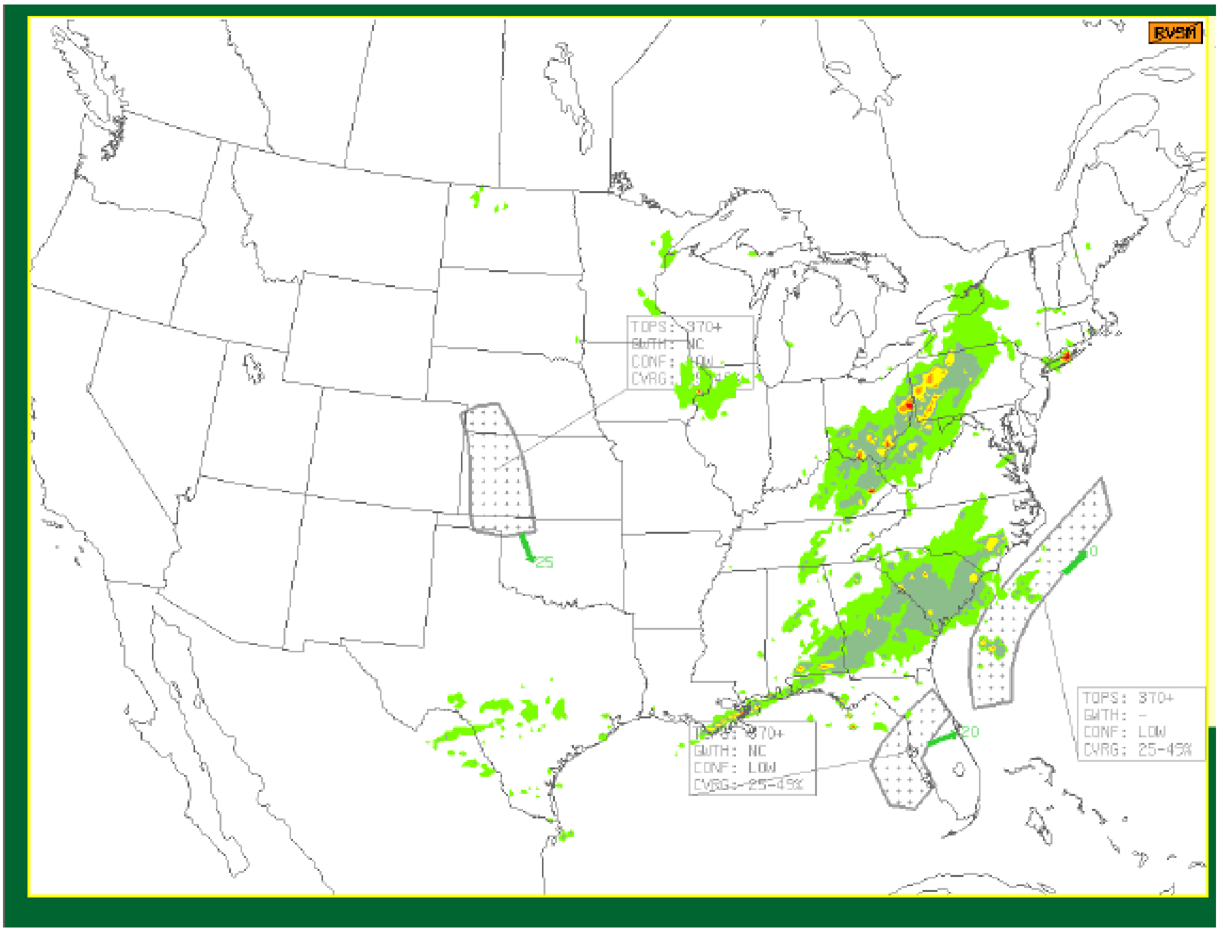


Figure 19: CCSD sample display of selected weather overlays (Source: Common Constraint Situation Display, User Manual Version 8.4, April, 2007, Volpe National Transportation Systems Centre, U.S. Department of Transportation)

Problems solved

Enhanced Traffic Management System (ETMS) predictions of air traffic demand for the next fifteen hours and highlights of the specific airports, sectors, and fixes where excess demand is forecast. It uses selected weather information, such as the current intensity of precipitation. It manages flow-constrained areas (FCAs) and provides plethora of rerouting options. It uses weather forecast data from 3 different sources NOWRAD, CCFP and NCWF.

Advantages

CCSD uses a collaborative tool that utilises 3 different sources for weather forecasts
Uses data from the existing FAA system: ETMS
Provides extensive reroute options [18]and has automated reroute advisory and reroute monitor.
CCSD Airline Operators (AO) users can view route information for their airline only.
Easy to install, configure and use (web-based application). It could be used on both Windows and Unix-based platforms.

[18] For extensive description of the CCSD Rerouting functionality consult: Common Constraint Situation Display, User Manual Version 8.4, April, 2007, Volpe National Transportation Systems Centre, U.S. DoT, pp. 61 - 98

Limitations

Limited functionality compared to TSD in order to reduce cost and technical customization and support

A low number of correct forecasts based on NCWF data. About 70% of the forecast by NCWF were false alarms (this data is based on 2002 analysis).

Operational use of model

Used widely across the United States by the Stakeholders. The data shown on the CCSD is exactly the same data that is seen by the FAA traffic flow managers that use ETMS, except that data on sensitive flights such as military flights is omitted.

Applicability in Europe

N/A

8. Collaborative Routing Coordination Tools (CRCT) - Weather Problem Resolution (WPR)

Description

The Collaborative Routing Coordination Tools (CRCT) is the prototype of a set of tools to help the Federal Aviation Administration (FAA) to detect traffic flow problems in advance, to generate problem resolutions, and to evaluate the resolution strategies. CRCT does this by modelling four-dimensional aircraft trajectories and using them to predict demand for sector usage. A methodology was developed and used to compare the prediction performance of CRCT under various software and data configurations. The methodology can be and has been used for other tools (e.g., the Enhanced Traffic Management System (ETMS)) that predict sector demand. The CRCT is an integrated collection of automation functions to assist traffic flow management in monitoring traffic flows, developing strategies to alleviate congestion and avoid severe weather, and analysing the impact of proposed strategies.

With the CRCT analysis capabilities, the traffic manager is able to visualize the impact of a proposed strategy on sector loading or on individual aircraft, and compare the potential effects of each strategy. Eventually, the traffic manager will be able to share this information not only with traffic managers from other facilities but also with airspace users. Thus, CRCT capabilities will help facilitate collaboration among NAS stakeholders to develop strategies that are most suitable for meeting their respective operating objectives when constraints in the NAS require traffic flow management action.

Developed by the Centre for Advanced Aviation System Development (CAASD) at The MITRE Corporation as part of its Traffic Flow Management Research and Development activities, CRCT currently exists on a research platform on which operational concepts and automation functions are developed in CAASD's laboratory and evaluated by traffic flow management personnel in their operational facilities. As a result of these evaluations, operational needs for capabilities are identified, desired capabilities are refined, and procedures for operational use are developed. When the FAA determines that a capability should be integrated into the Traffic Flow Management (TFM) System, CAASD assists the FAA in transferring the technology to the implementation team and, where appropriate, the private sector.

Weather translation

CRCT Traffic Display with generated Flow Constrained Areas (FCAs) use information derived from the NCWF forecast. The FCA polygons represent detections and predictions of severe convective weather extending out in half-hour intervals (0-, 30-, 60-, and 90-minute forecasts). Each weather FCA includes an altitude top and time range. CRCT automatically predicts which flights will intersect these FCAs using the aircraft trajectory and the 4-dimensional location of the FCA.

ATC impact assessment

The Traffic Management Specialist (TMS) can use CRCT-WPR to create a plan to reroute the flights that are in conflict with the FCAs around the weather. The TMS determines how aircraft will flow around the storms and through any holes between storms by generating TFM

Designated Reroutes (TDRs). TDRs are reroute paths created by clicking on locations on the display.

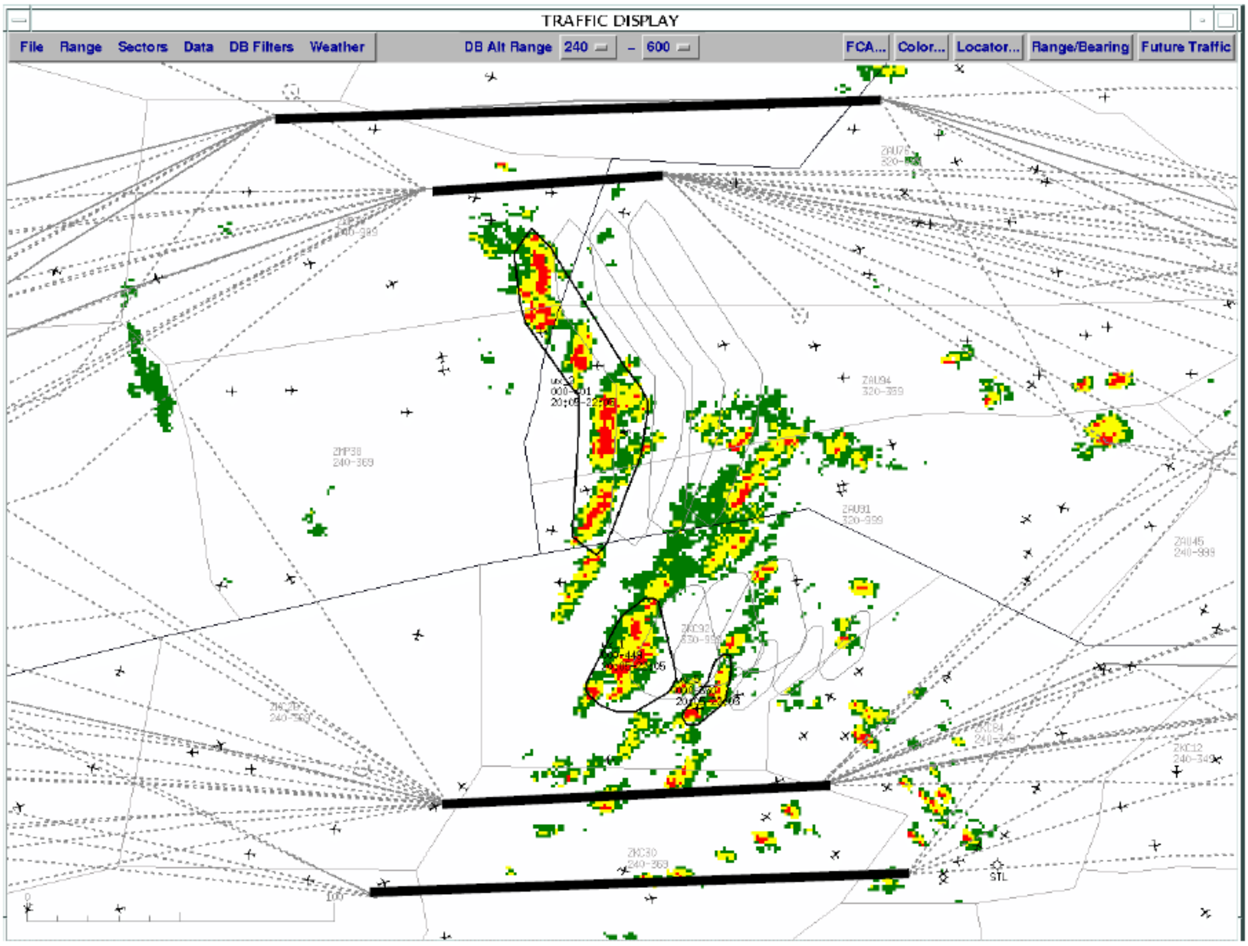


Figure 20: an example of four TDRs, two north and two south of the storm. Although these TDRs have only two nodes each, TDRs can have any number of nodes, any orientation, and can cross each other (Source: Traffic Flow Management (TFM) Weather Rerouting Decision Support, Stephen Zobell, Celesta Ball, and Joseph Sherry MITRE/CAASD, McLean, Virginia)

After the TMS creates an initial plan, CRCT-WPR (Weather Problem Resolution) evaluates the plan and attempts to find reroutes onto the TDRs for flights that are in conflict with weather. First, the TDRs that each flight could potentially use are determined based on the maximum turn angle, time range, and altitude limits of the TDRs. Then, CRCT-WPR performs an optimization to determine which flights will be assigned to each TDR based on minimizing arrival delays while staying within the rate limits of each TDR. Flights scheduled to take off after the plan start time can be delayed on the ground in order to fit into an available slot on a TDR.

The dotted lines on Figure 20 show the proposed reroutes generated by CRCT-WPR for this plan. Rerouting to one of the two TDRs closest to the storm would cause the least delay for most flights, but the rate limits on these TDRs have caused some of those flights to use the TDRs further north and south.

The plan in Figure 20 required less than 10 seconds for CRCT-WPR to evaluate. However, execution time increases as the number of conflict aircraft or TDRs increases. Since CRCT-WPR is designed for rapid processing, plans can be created, evaluated, modified, and re-evaluated quickly.

When the plan evaluation is complete, CRCT-WPR displays the plan results including statistics on flight delays and the number of aircraft rerouted. Information is also displayed about the flights that were not able to be incorporated into the plan, including the number of flights that could not find a slot on any TDR, and the number of flights that would have to turn too sharply to reach a TDR. CRCT also generates predicted sector loading based on the plan reroutes, so that the TMS can determine whether the reroutes might cause unacceptable workloads for sector controllers.

The ability to spread the work of handling merging and diverging traffic across several sectors is an important capability of CRCT-WPR.

CRCT also has a Future Traffic Display where the TMS can view the predicted locations of aircraft or weather. Using this display, the TMS can look at future periods of high congestion and assess whether the situation might be too complex for sector controllers.

If the TMS is unsatisfied with the results of the planned reroutes, the plan can be modified. The entry rates on TDRs can be lowered to reduce traffic through congested sectors, the rates can be raised for under-utilized TDRs, and new TDRs can be added to avoid congested areas or to increase the number of flights using the plan. The new plan is then evaluated, a new set of reroutes is produced, and the results of the new plan are assessed. This cycle can be repeated until the TMS is satisfied that the plan moves flights past the weather as efficiently and safely as possible.

Decision support

CRCT has been developed for the purpose of providing tools to traffic flow managers and airspace users to address the shortfalls experienced in the present system. Specifically, CRCT functions are designed to assist with the following:

- Visualizing future traffic flows, based on filed flight plan information.
- Identifying and analysing potential traffic flow management situations.
- Identifying the flights that are expected to be directly impacted by the situation.
- Defining candidate routes (either for traffic flows or specific flights) to alleviate the situation.
- Analysing the impact of a reroute strategy on sector loading for all the sectors across a region.
- Enabling traffic flow managers from all facilities and airspace users to gain common situational awareness and information about strategy alternatives.

- Facilitating the implementation of reroute strategies.

While CRCT-WPR is built specifically to handle weather, the tool can also work for other flow restriction problems. For example, an equipment failure disrupting ATC in a particular region can be handled using CRCT-WPR by manually generating an FCA around the region and building TDRs to route flights around the FCA.

Information used (inputs)

CRCT (Baseline) includes functionality for rerouting around manually-generated Flow Constrained Areas (FCAs), automatic identification of aircraft predicted to enter FCAs, manual rerouting of aircraft around FCAs, and automatic assessment of the impact of proposed reroutes on sector traffic volume. In baseline CRCT, a Traffic Management Specialist (TMS) manually draws an FCA polygon to represent an area impacted by weather or other factors that limit traffic flow. Manual FCA generation is practical only when few FCAs are needed and the weather is very stable and predictable. This is often not the case with convective weather, which can consist of many storm cells moving at various speeds and directions and involving complex cell growth, decay, splitting and merging.

CRCT-WPR adds to CRCT is automatic generation of weather FCAs using a weather forecast product. The forecast products currently available include the National Convective Weather Forecast (NCWF) and the Collaborative Convective Forecast Product (CCFP). The NCWF, is a computer model developed by the National Centre for Atmospheric Research (NCAR), which provides forecasts extending out one or two hours and is updated every five minutes. CRCT-WPR uses the NCWF; however, the use of CCFP or other forecasts is being investigated.

Problems solved

CRCT-WPR is on-going research.

CRCT-WPR has the potential to be an effective tool for dealing with large convective weather systems and other traffic flow problems. Continued research by CAASD and weather research organizations will improve the ability of CRCT-WPR to safely reduce flight delays caused by convective weather.

Advantages

With the CRCT analysis capabilities, the TMS is able to visualize the impact of a proposed strategy on sector loading or on individual aircraft, and compare the potential effects of each strategy. The collaboration CRCT capabilities will help facilitate coordination among NAS stakeholders to develop strategies that are most suitable for meeting their respective operating objectives when constraints in the NAS require traffic flow management action.

Limitation

Base-line CRCT manual generation is practical only when few FCAs are needed and the weather is very stable.

CRCT-WPR still needs to be expanded and improved in some areas. These areas of research include the following:

- Improved weather forecasts and understanding of forecast accuracy
- Expanded collaboration (including ATCSCC, ARTCCs, Airlines, and Pilots)

- Improved load balancing and resource rationing
- Improved controller workload predictions
- Improved management of forecasting inaccuracies

Operational use of model

CRCT currently exists on a research platform on which operational concepts and automation functions are developed in CAASD's laboratory and evaluated by traffic flow management personnel in their operational facilities.

Since 2005, CRCT has been installed for evaluation purposes at Kansas City Centre and the Air Traffic Control System Command Centre (the facility responsible for national traffic flow management), and will continue to be evaluated by traffic flow. The FAA and CAASD are jointly conducting these evaluations. Later this year, CRCT will be installed in the Indianapolis Centre to enable a broader evaluation. CRCT functionality has benefited greatly from past field evaluation efforts and, with input from on-going exercises and evaluations, continues to evolve. The purpose of the current set of evaluations is to validate the local and national traffic management requirements for CRCT capabilities that will be implemented in the NAS. These validated requirements will serve as the basis for technology transfer of CRCT to the FAA's implementation team.

Applicability in Europe

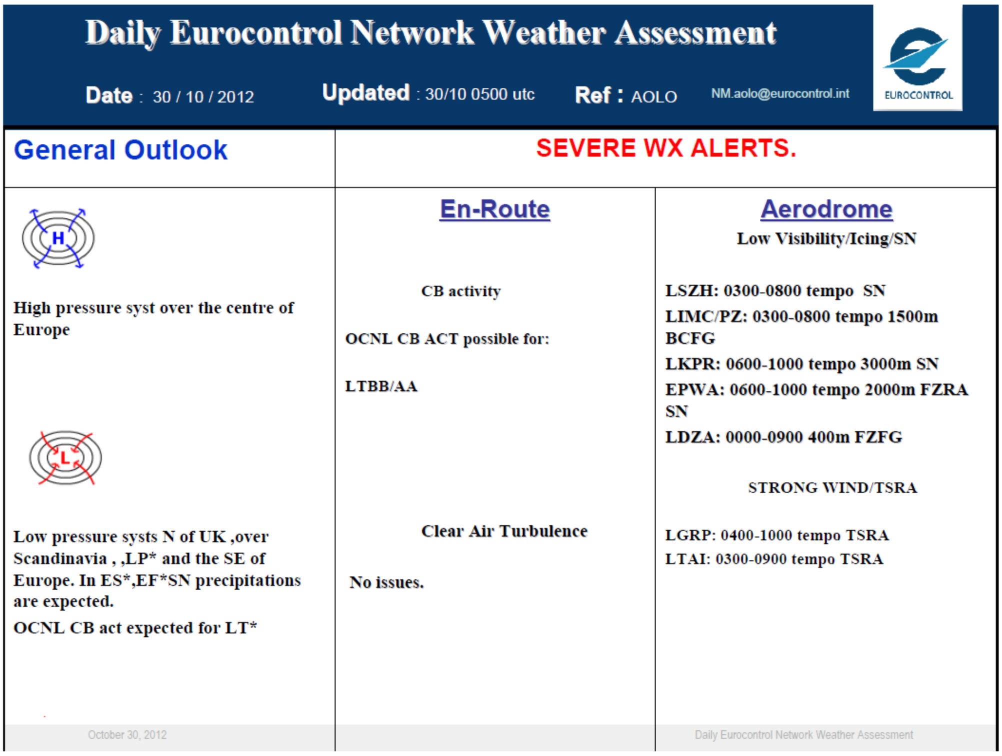
N/A

9. EUROCONTROL NOP

To date, in Europe collaborative ATM response to severe weather events is very limited in scope and geographical extent. The main contributory factors are inconsistent and reactive severe weather impact management procedures and practices across the region.

EUROCONTROL is taking the first steps towards collaborative proactive management of the severe weather impact on ATM and flight operations by embedding the weather information in the Network of Operations Portal (NOP). It supports Air Navigation Service Providers (ANSPs) and airspace users in anticipating, identifying, monitoring and planning for potential severe weather events that may impact ATM capacity and planned flight operations.

The NOP provides access to the Network Weather Outlook for the ECAC area, and Severe Weather alerts to which FMPs are to respond by conducting local assessments and mitigation actions if appropriate. FMPs communicate their assessment to the Network Manager.



Daily Eurocontrol Network Weather Assessment

Date : 30 / 10 / 2012 Updated : 30/10 0500 utc Ref : AOLO NM.aolo@eurocontrol.int EUROCONTROL

General Outlook	SEVERE WX ALERTS.	
	En-Route	**Aerodrome** Low Visibility/Icing/SN
High pressure syst over the centre of Europe	CB activity OCNL CB ACT possible for: LTBB/AA	LSZH: 0300-0800 tempo SN LIMC/PZ: 0300-0800 tempo 1500m BCFG LKPR: 0600-1000 tempo 3000m SN EPWA: 0600-1000 tempo 2000m FZRA SN LDZA: 0000-0900 400m FZFG
Low pressure systs N of UK ,over Scandinavia , ,LP* and the SE of Europe. In ES*,EF*SN precipitations are expected. OCNL CB act expected for LT*	Clear Air Turbulence No issues.	STRONG WIND/TSRA LGRP: 0400-1000 tempo TSRA LTAI: 0300-0900 tempo TSRA

October 30, 2012 Daily Eurocontrol Network Weather Assessment

Figure 21: Part of the EUROCONTROL daily Network weather assessment. The assessment contains[19]: General Outlook, Severe WX Alerts, Surface Pressure Forecast, Winds Forecast, Fog Risk Forecast, Temperatures, Significant Weather Forecast – Turbulence, Jetstreams, CBs., and Next day outlook. (Source: EUROCONTROL Network Operations Portal)

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19 The source used for the forecasts is WSI (Weather Services International) –business-to-business weather services, particularly for the media, aviation, and energy sectors.

Annex 4 - MET products available to ATC and Operators (USA)

The Thunderstorm product[20]

MET product	The Thunderstorm
Description	The Thunderstorm product (TCWF) states that the following capabilities are needed to aid decision-makers in mitigating avoidable weather delays: • Automatic detection of thunderstorm initiation, location, and severity • Location of precipitation and lightning (in-cloud, cloud-to-ground, and cloud-to-cloud) • Detection and measurement of thunderstorm attributes (e.g., hail, turbulence, echo tops, up/downdrafts, tornadoes, meso-cyclones) • Providing information on thunderstorm cell movement & direction • Providing regional (corridor), current, and forecast thunderstorm information • Integrating weather information with aircraft targets on controller displays • Automatic dissemination of information to pilots
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F(R)
Working system/ method and/or source	Weather sensors including surface sensors such as the Automated Surface Observing System (ASOS), radars such as the Terminal Doppler Weather Radar (TDWR), the Next Generation Weather Radar (NEXRAD), Airport Surveillance Radar (ASR) and weather processors such as WARP and CIWS, provide user displays. These displays give estimates of thunderstorm location and intensity using weather radar reflectivity information, including measures of some thunderstorm attributes (e.g., mesocyclones, hail, and echo tops).
Timeframe/Validity	The 2, 4, and 6-hour convective CCFP forecasts used for strategic TFDM.
Update rate	Forecast time resolution will be 5 minute increments for the first 2 hours, and 15 minutes increments from hours 2 through 8.
Used by ATC	Yes, shall be transmitted to (and used by) local ATS units and be available to operators and users at the aerodrome. This indirect supply of weather information will enable ATC to better manage sector volume/complexity, route capacity and aid in balancing controller workload.
Used by pilots	Yes, for pre- flight planning information. With weather information such as layered Composite Reflectivity (CR) information, precipitation intensity will be consistent with what the pilots see and experience at a given flight level.
GEO use (global, USA, EU, other)	USA
Other information	With NWP information, collaboration among NAS stakeholders and other stakeholders all with access to the same NWP information, air traffic decision-makers will be able to make more efficient use of available airspace. They will better anticipate where weather will constrain traffic and where traffic can be rerouted. NWP information will help ATCs mitigate adverse weather impact to the flying public. For example, if a general aviation pilot is in or near adverse weather without adequate on board weather sensing equipment, ATCs will better be able to provide assistance and navigate the pilot away from the weather, thereby mitigating a hazardous situation.

Notes:

NWP - Numerical Weather Product

NWPM - Numerical Weather Predicting Model

CCFP –Cloud Convective Forecast Product

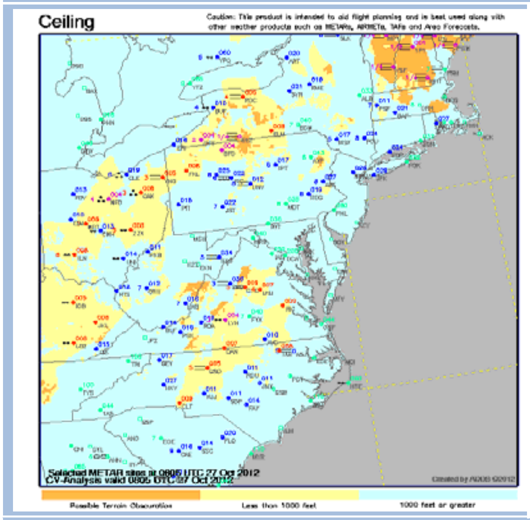
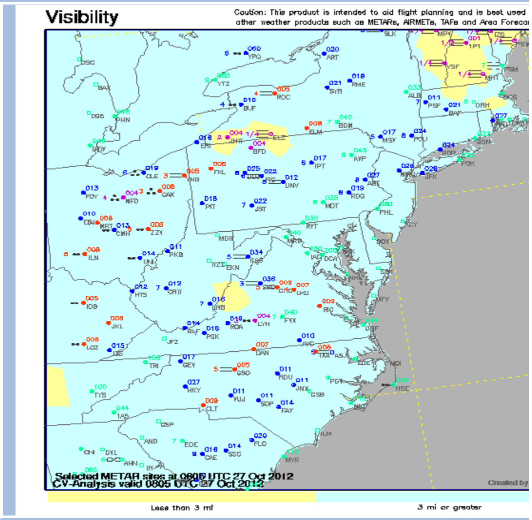
TCWF - Terminal Convective Weather Forecast

[20] Reference: **MODELING CONVECTIVE WEATHER AVOIDANCE IN ENROUTE AIRSPACE** Rich De Laura Mike Robinson Margo Pawlak, Jim Evans; Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, MA 02420

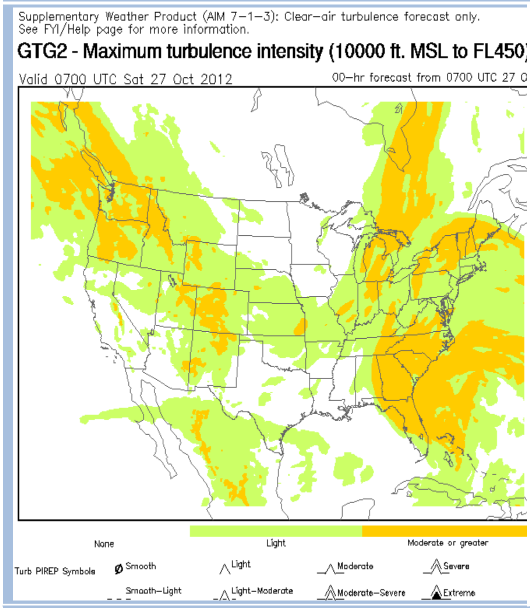
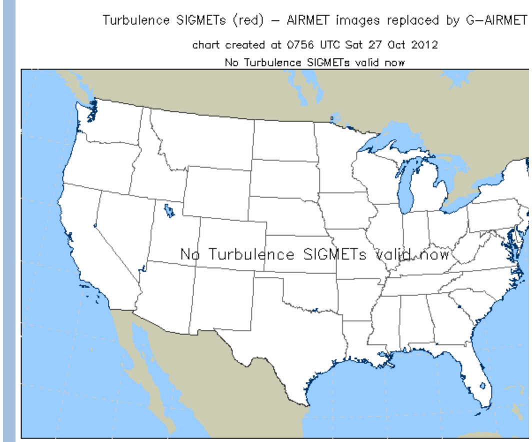
TDMF – Terminal Management Flights

All those products are support tools that translate the weather products and forecasts into forecasts of ATC impacts and then use those ATC impact forecasts to suggest air traffic management strategies. Aviation weather systems such as the Corridor Integrated Weather System (CIWS), (Klingle-Wilson and Evans,2005) and the National Convective Weather Forecast (NCWF) (Mueller, et al, 1999) provide weather products and forecasts that aid en route traffic managers in making tactical routing decisions in convective weather.

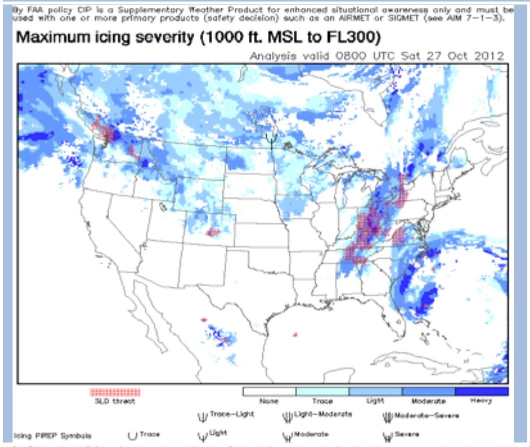
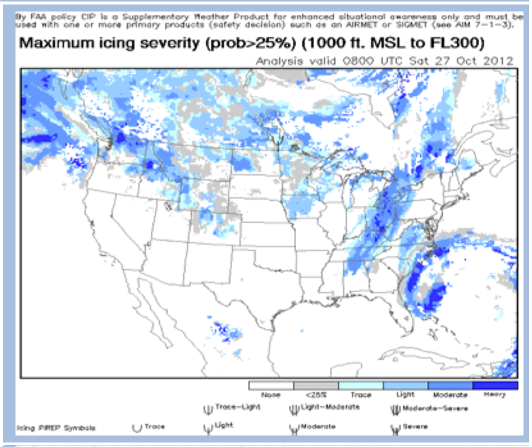
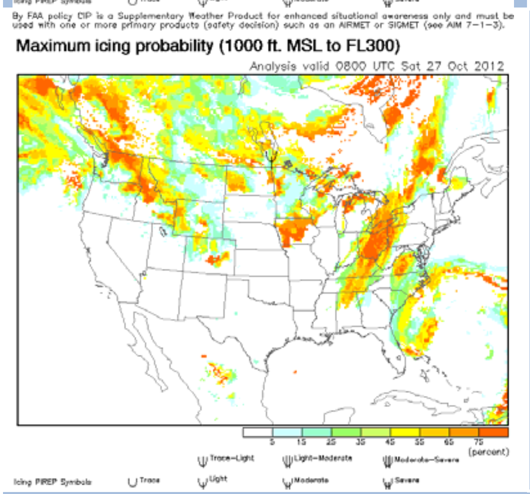
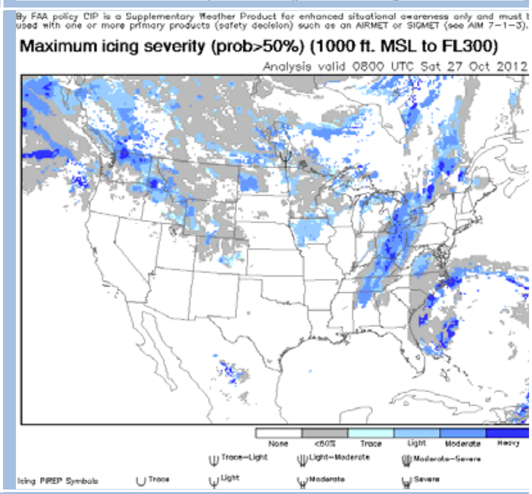
The Ceiling and Visibility

MET product	The Ceiling and Visibility
Description	This product is for flight planning purposes only and should always be used in combination with ceiling and visibility (C&V) information from official sources such as METARs, AIRMETs, TAFs and Area Forecasts. CVA (Ceiling and Visibility Analysis) is intended to aid situational awareness with a quick-glance visualization of current C&V conditions across an area or along a route of flight. CVA derives C&V for areas between METAR stations so may, as a function of distance from a METAR, misrepresent actual conditions.
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F(R)
Working system/ method and/or source	NWPM
Timeframe/Validity	24 h
Update rate	Every 1 h
Used by ATC	As additional information of VFR
Used by pilots	 
GEO use (global, USA, EU, other)	USA
Other information	

Graphical Turbulence Guidance (GTG)

MET product	Graphical Turbulence Guidance (GTG)
Description	The GTG is an automatically-generated turbulence forecast product that supplements AIRMETs and SIGMETs by identifying areas of turbulence. The GTG is not a substitute for turbulence information contained AIRMETs and SIGMETs. It is authorized for operational use by meteorologists and dispatchers.
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F(R)
Working system/ method and/or source	NWPM
Timeframe/Validity	24 h
Update rate	Every 1 h
Used by ATC	As additional information regarding SIGMET
Used by pilots	 
GEO use (global, USA, EU, other)	USA
Other information	

Icing

MET product	Icing
Description	The Icing product is an automatically-generated areas icing forecast product that supplements AIRMETs and SIGMETs by identifying areas of icing.
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F(R)
Working system/ method and/or source	NWPM
Timeframe/Validity	24 h
Update rate	Every 1 h
Used by ATC	As additional information regarding SIGMET and AIRMET
Used by pilots	   
GEO use (global, USA, EU, other)	USA
Other information	The main benefit of all graphical products are to support issue and understanding of meteorological products recommended by Annex 3

Winter Weather Research Product (WSDD)[21]

MET product	Winter Weather Research Product (WSDD)
Description	Integrated display system that depicts accurate, real time determinations of snowfall rate, temperature, humidity, wind speed and direction, called the "Weather Support to De-icing Decision Making" (WSDDM) system
Type (forecast (F), current weather(C), regular (R) and irregular (I-R))	F(R)
Working system/ method and/or source	NWPM
Timeframe/Validity	24 h
Update rate	Every 1 h
Used by ATC	For much better planning regarding de-icing procedure
Used by pilots	N/A
GEO use (global, USA, EU, other)	USA
Other information	It is generally agreed that effective management of winter weather requires decision support tools that translate the weather products and forecasts to suggest as a strategies of A-CDM. The weather data used by WSDDM include Doppler radars, surface weather stations, and snow gauges located near the airport, which accurately measure the amount of water in the snow.

[21] Reference: "Manual of aircraft ground de-icing/anti-icing procedure" ICAO Doc 9640 AN/940

Annex 5 - Survey questionnaire

1. **Standards/regulations applicable for severe weather scenarios**

1.1. Which ICAO standards are applicable?

1.2. Any national requirements related to the management of severe weather in addition to ICAO standards?

- 1.2.1. e.g. prohibition of landing clearance in case of visibility below airport minimum
- 1.2.2. runway or airport temporary closure
- 1.2.3. temporary avoidance of a certain area due to severe mountain waves etc.

2. MET products (incl. MET radar, SAT data, etc.)

2.1. Which weather forecast products are used?

- 2.1.1. TAFs - what is the validity period; how often is it updated; what is the geographical coverage?
- 2.1.2. En-route forecast?
- 2.1.3. Who is the user of this info (TWR, APP, ACC incl. AFIS)?

2.2. Current weather reports

- 2.2.1. METARs - what is the validity period; how often is it updated; what is the geographical coverage (e.g. all airports)?
- 2.2.2. SPECIs - what is the geographical coverage (e.g. all airports)?
- 2.2.3. Who is the user of this info (TWR, APP, ACC incl. AFIS)?

2.3. Weather radar data

- 2.3.1. What products (incl. forecast products based on extrapolation), how often is each product updated?
- 2.3.2. Geographical coverage (e.g. area, terminal)? Both
- 2.3.3. What is the data used for (for information only, for advice on avoidance, for ATC)?
- 2.3.4. Is OPS staff trained to “translate” it into ATC impact or who does it?
- 2.3.5. Any tools that help this process, how is the data displayed?
- 2.3.6. Who is the user of this info (TWR, APP, ACC incl. AFIS)?

2.4. Weather maps

- 2.4.1. What products (incl. resolution/ fidelity) and how often is each one updated?
- 2.4.2. Geographical coverage (e.g. area, terminal)?
- 2.4.3. What is the data used for (for information, for advice on avoidance, for ATC)?
- 2.4.4. Is OPS staff trained to “translate” it into ATC impact or who does it?
- 2.4.5. Any tools that help this process, how is the data made available at ATC working positions?
- 2.4.6. Who is the user of this info (TWR, APP, ACC incl. AFIS)?

2.5. Weather satellite data

- 2.5.1. What products and how often is each one updated?
- 2.5.2. Geographical coverage (e.g. area, terminal)?
- 2.5.3. What is the data used for (for information, for advice on avoidance, for ATC)?
- 2.5.4. Is OPS staff trained to “translate” it into ATC impact or who does it?
- 2.5.5. Any tools that help this process, how is the data made available at ATC working positions?
- 2.5.6. Who is the user of this info (TWR, APP, ACC incl. AFIS)?

2.6. Pilot reports

- 2.6.1. Are ATCOs actively seeking pilot reports or receiving them only on pilot initiative?
- 2.6.2. What is the data used for?
- 2.6.3. Any tools/procedures that help the process of pilots’ reports dissemination?
- 2.6.4. To whom is the info delivered - any procedures?

2.7. Data fusion products
- 2.7.1. e.g. MET radar data and forecasted data;
- 2.7.2. e.g. visibility (fog) forecast based on SAT data.

2.8. Any other sources?

3. MET data flow in the ATCC – from / to

3.1. MET office
- 3.1.1. Does the ANSP have own MET service?
- 3.1.2. If the MET service is outsourced how the data flow is ensured?
- 3.1.3. What data is output (to whom) and what data is input (by whom)?

3.2. TWR, APP and ACC controllers
- 3.2.1. What data is received (from whom) and what data is passed (to whom)?

3.3. OPS SUP
- 3.3.1. What data is output (to whom) and what data is input (by whom)?

3.4. FMP
- 3.4.1. What data is received (from whom) and what data is passed (to whom)?

3.5. Airport (e.g. runway related data)
- 3.5.1. What data is received (from whom) and what data is passed (to whom)?

3.6. Pilot
- 3.6.1. What data is received from pilots and what data is passed to pilots?

3.7. Any line managers
- 3.7.1. Is there any MET bulletin passed to line managers on daily basis?

3.8. Airlines and airspace users
- 3.8.1. What data is received (from whom) and what data is passed (to whom) to airlines and/or airspace users?

3.9. MET data exchange tools/means?

4. Procedures, guidance and practices

4.1. General

4.2. ATC Manual procedures for ATCOs.;

4.3. OPS SUP procedures related to:
- 4.3.1. Sectorisation configuration change;
- 4.3.2. Sector workload evaluation and airspace volumes capacity reduction;
- 4.3.3. Monitoring and complexity assessment;
  - 4.3.3.1. Any tools used;
- 4.3.4. Staffing;
- 4.3.5. Airspace closure and/or avoidance procedure;
- 4.3.6. Coordination with adjacent ATC sectors and/or ATS Units/Centres.

4.4. FMP procedures, related to:
- 4.4.1. Sectorisation configuration change;
- 4.4.2. Sector workload evaluation and airspace volumes capacity reduction;
- 4.4.3. Monitoring and complexity assessment.
  - 4.4.3.1. Any tools used.
- 4.4.4. Coordination with CFMU, adjacent ATC sectors and/or ATS Units/Centres.

4.5. Any guidance that is not mandatory?

4.6. Good practices?

5. Decision making loop and responsibilities

5.1. How is it decided to apply certain measures (clarify roles and responsibilities)?
- 5.1.1. What is the decision making coordination process and with whom?

5.2. Is there a change management procedure including explicit risk assessment of the weather conditions done and by whom?
- 5.2.1. Which risk mitigation means are applied?

5.3. Are the risk mitigation means prescribed for each typical severe weather scenarios or every time it is adapted (e.g. percentage of capacity cut decided by OPS SUP)?

6. Mitigation means of severe weather induced hazards

6.1. Severe turbulence (CB / TS) in area control and in terminal area
- 6.1.1. Measures by ATC
- 6.1.2. Measures by FMP
- 6.1.3. Measures by airport
- 6.1.4. Measures by AO
- 6.1.5. Measures by NM

6.2. Strong surface wind /wind shear at the airport
- 6.2.1. Measures by ATC
- 6.2.2. Measures by FMP
- 6.2.3. Measures by airport
- 6.2.4. Measures by AO
- 6.2.5. Measures by NM

6.3. Icing
- 6.3.1. Measures by ATC
- 6.3.2. Measures by FMP
- 6.3.3. Measures by airport
- 6.3.4. Measures by AO
- 6.3.5. Measures by NM

6.4. Strong precipitation (snow, rain, hail)
- 6.4.1. Measures by ATC
- 6.4.2. Measures by FMP
- 6.4.3. Measures by airport
- 6.4.4. Measures by AO
- 6.4.5. Measures by NM

6.5. Low visibility
- 6.5.1. Measures by ATC
- 6.5.2. Measures by FMP
- 6.5.3. Measures by airport
- 6.5.4. Measures by AO
- 6.5.5. Measures by NM

6.6. Runway contamination

6.7. Atmospheric electricity and lightning

7. Coordination

7.1. Inter-sector and inter-unit (within the ANSP)

7.2. Inter-centre (other ANSPs)
- 7.2.1. Any provisions in the LoA;
- 7.2.2. Dedicated coordination procedures;
- 7.2.3. Practices;
- 7.2.4. Ad-hoc.

7.3. with airport operator

7.4. with Airline Operator (is intent information shared)

7.5. with Network manager

7.6. What is coordinated?
- 7.6.1. MET data exchange;
- 7.6.2. Impact on ATC – forecasted and actual;
- 7.6.3. Severe weather management decisions - traffic restrictions;
- 7.6.4. Any other.

8. Any tools and models used for

8.1. Weather translation, (interpretation);
8.2. ATC impact assessment;
8.3. Decision support;
8.4. Exchange and coordination with adjacent units and Network Manager;
8.5. By whom are the tools used;
8.6. Any guidance on how to use the output from the weather data processing tools.

9. **Example scenarios for discussion**

9.1. Description of the severe weather type
- 9.1.1. Low visibility;
- 9.1.2. Strong wind;
- 9.1.3. Convective weather/turbulence - TS;
- 9.1.4. Wind shear;
- 9.1.5. Heavy precipitation (e.g. snow);
- 9.1.6. Mountain waves.

9.2. Impact on ATC operations and anticipated actions,
- 9.2.1. How is impact assessed?
- 9.2.2. What coordination will be done and with whom?
- 9.2.3. What actions are anticipated, in particular if weather is close to unit's AoR boundary?
- 9.2.4. With whom will be potential actions communicated and coordinated, and who will carry out this communication/coordination task?

9.3. Similar real events and actions taken in hindsight?

10. Incident/accidents with weather being a contributory factor

10.1. Where flights pushed into bad weather as the result of a ATC restriction (airspace, level cap scenario due to insufficient capacity in a sector, etc)?
10.2. What kind of Incident/accidents with weather being a contributory factor has happened recently?
10.3. What were the consequences in each case and what were the conclusions?
10.4. What were the recommendations and eventually groups of them?
10.5. What are the long-term trends of such events for 5 or 10 years if there is a statistical data?

11. Statistics - collect quantified (if not available, some qualitative) data, if available

11.1. Frequency of occurrence of the hazards;
11.2. Frequency of occurrence of local effect of the hazards;
11.3. Frequency of occurrence of Network Manager effect of the hazards.

Annex 6 – Survey Meeting Reports

ANSP 1

1. National requirements related to the management of severe weather in addition to ICAO standards

The NSA safety audits and their firm position that trade-offs between safety and other performance areas shall not be tolerated are considered a driver for the development and implementation of the en-route severe weather management procedure.

The NSA required proper risk assessment of the severe weather management procedure before the start of the live trial.

2. MET products and data made available and actually used

a. weather forecast products

- Dedicated tailor made MET bulletin produced by the ANSP MET office which:
    - provides better explanation of the weather phenomena
    - translates the Annex 3 products into a forecast that is easily understood by the concerned operational staff and can be used in the ATC impact assessment of severe weather (capacity risk management)
    - covers both terminal/airport and en-route sectors;
    - covers the following types of threats: CB (including CAT), TS, SN (included icing), LV (low ceiling and low visibility under a given threshold) and Winds (strong and/or gusty above given thresholds); the decision about threats to be covered has been taken based on archive data analysis
    - includes all MET data forecasted, i.e. no exclusion based on some thresholds (e.g. intensity, probability ,etc)
    - provides information about the forecasted events/threats (time period, event type, probability) per ATC sector
    - the time interval covered by the forecast (provided per sector) reflects the uncertainty about the exact time of weather/event manifestation; for highly probable events the operational preference is to have a greater time interval, rather than an incorrect one, if the exact time is difficult to predict
    - weather forecast issued in 2D (difficult to predict vertical extent of CBs)
    - uses the published (in the AIP) ATC sector/airspace identification codes as published in the CACD database, which makes it readable to the NM and airspace users (use of CACD sector/airspace identification code is essential if such product is to be made available at network level)
- The MET Supervisor issues 3 Severe weather assessment bulletins:
    - Pre-Tactical MET bulletin on D-1 at 10:00 UTC (summer) covering 24 hour period of the day of operation D 00:00 – 24:00 UTC
    - Tactical MET bulletin update on D-1 14:00 valid for the first 8 hours
    - Tactical MET bulletin update on Day of operation at 03:00 valid for the remaining16 hours
- The MET bulletin is updated as needed, based on certain criteria, i.e. updates are not limited by TAF schedule;
- The development and delivery of the enhanced MET bulletin did not require enhancement of existing or new tools and information sources used by the MET office
- Openness and trust between the MET office and OPS is a prerequisite for such MET bulletin
- TAF and TAFOR available

  - The MET office AoR (range = 300 NM) is wide enough to enable a high quality of the forecasts up to few hours in advance, based on the observed/reported events and estimation of their evolution (e.g. direction of movement)

b. current weather reports
   - METAR
   - SPECI

c. MET radar data
   - weather channels of terminal and en-route radars, integrated in the main situation display at CWP
   - MET radar data – on a separate display at CWP;
   - advisory use

d. weather maps

e. SAT data - available for display at CWP

f. pilot reports – as far as submitted by pilots (usually by phone after landing); there is no dedicate policy/procedure to actively seek/collect pilot reports on weather related hazards

g. data fusion products

- MET portal being developed with the aim to provide all users with customised MET info (TWR, APP, ACC, OPS SUP, FMP, regional airports)

3. MET data flow in the ATCC:

a. MET bulletin distributed PRETACT to:
   - FMP manager
   - OPS support ATFCM/ASM
   - ACC SUP (cc)
   - FMP (cc)
   - APP SUP
   - NM / AOLO

b. TACT updates are distributed to:
   - FMP manager (cc)
   - OPS support ATFCM/ASM (cc)
   - ACC SUP
   - FMP
   - APP SUP
   - NM / AOLO

c. MET data exchange tools/means
   - The MET bulletin – via email
   - Annex 3 products – standard means

4. Procedures, guidance and practices

- Before the start of the “Severe en-route weather network trial” flow regulations were issued to manage impact of bad weather on the ATC service provision to:
  - o arrivals/departures to/from Brussels airport following a CDM process involving ATS-MET-APT
  - o en-route traffic, but en-route weather impact management was not subject to ATS-MET CDM process
- Driver for implementing the procedure was past experience in OPS room of extremely difficult situations due to severe weather
- A task force set up to develop the severe weather risk management procedures. ANSP MET office was actively involved in procedure development, i.e. all involved ANSP units are procedure owners

- Important objective of the procedure objective is to increase awareness of the traffic managers of the risk the forecasted weather phenomenon can create to ATC and aircraft operations
- The purpose of the procedure is to anticipate severe weather events impacting capacity, providing time to develop, organize and coordinate ATC, Airport and Network Management Operations Centre responses to a potential ATC capacity limiting event.
- The application of the procedure is going to be continued after the trial.

- The severe weather risk management procedure includes:
  - Evaluation of probable capacity reduction by the FMP manager during the pre-tactical phase
  - Evaluation of the probable capacity reduction by the FMP controllers using dedicated guidelines
  - Risk assessment based on the worst case scenario, on the understanding that it is easier and faster to increase than to reduce capacity, as situation evolves
  - Update of the MET office on the changes of airspace sectorisation

- Severe weather risk management procedure for Brussels airport:
  - Total capacity reduction is based on the estimation of the reduction by aggregating all factors that may have impact (e.g. prevailing wind impacting on RWY configuration in use and low visibility)
  - The PRETACT/TACT severity assessment and respectively estimated capacity reduction is just a warning to the network, but does not mean that capacity will be reduced by the indicated percentage by means of a flow regulation
  - The PRETACT/TACT warning may be used by adjacent ATC units/NM/APT and AO to estimate possible impact on their systems/operations
  - The risk assessment uses a simple matrix to estimate % of capacity reduction based on: (1) expected impact of weather on the ATC elements, (2) the forecasted probability and (3) historic data (for calibration);
  - The assessment matrix can be represented by a table containing 3 columns: type of sever weather (e.g. CB), effect description (e.g. single RWY for landing) and risk assessment guideline (e.g. PRETACT: PROB 80% - Reduction 10%; TACT: PROB 80% - Reduction 25%)
  - For snow (SN) two periods, and respectively 2 sets of assessment parameters are used, notably snowfall and post-snowfall; in the latter case capacity reduction is lesser, but is still required
  - Radar approach interval between successive aircraft is determined in CDM process (includes APP SUP, airport, ACC) taking into account weather, but other factors too, such as RWY/TWY configuration, runway condition, etc.
  - Only arrival rate is regulated, never departure rate

- The guidelines for the estimation of the capacity reduction were developed by analysis of available operational and weather statistics for the last few years and tuned after consultation with operational staff; main criterion for estimating capacity reduction percentage is controller workload due to TS and CB activity)
- Post OPS analysis of the efficiency of flow measures implemented during the live trial period will be carried out with the objective to take decision for procedure permanent implementation
- Following procedure approval by NSA its geographical application scope will be extended to include regional airports

5. Decision making loop and responsibilities

- 5 parties participate: FMP manager, OPS support ATFCM/ASM, ACC SUP, FMP, APP SUP

- At pre-tactical level the FMP manager is responsible for traffic management; FMP manager:
    - Carries out risk assessment
    - Determines strategy
    - Files Excel template
    - Distributes the Excel sheet to concerned actors

- At tactical level FMP controllers are responsible for traffic management; FMP controllers have received appropriate training and are all ACC SUP

- The following decision making Strategies are in use:
    - Strategy 1 Wait and see (WX below certain probability PRETACT 50% and less 30% in TACT). There are 3 options
        - Considering to apply TACT measures when at the moment of the notification the Traffic Manager is considering TACT ATFCM measures but decision has not been taken
        - Considering to Apply a reduction in Monitoring Value when MET reports indicate that a lower monitoring value is required as alert threshold for decision making
        - Monitoring, but no action planned when MET report indicate that the capacity-demand balance shows that no ATFM regulation will be required
    - Strategy 2 Precautionary action when probability is between 50% to 70%PRETACT or 30% to 70%TACT. There are 4 options
        - Tactical measures are planned when MET reports indicate that there is reasonable assurance that TACT regulation will be required
        - Apply a reduction in Monitoring Value – when MET report indicate that a lower Alert threshold is required for decision making on regulation or not
        - Prepare TFV for regulation when MET reports indicate that ATFM regulation is imminent and that preparatory task are started for implementing the regulation
        - Plan reroutes or FL capping scenarios when rerouting or level capping scenario will be applied that can reduce the traffic demand to such a level that an ATFM regulation can be avoided
    - Strategy 3 Apply ATFCM measures in PRETACT when probability is more than 70% and in TACT. There are 3 options:
        - Apply a regulation at the declared capacity value when applying an ATFM regulation with an acceptable rate equal to the declared Monitoring Value
        - Apply a regulation at a reduced capacity when applying an ATFM regulation at acceptance rate which is x% lower than the declared monitoring value
        - Apply a reroute or FL capping

- AO will not take decision based only on the published MET bulletins, but are expected to carry out risk assessment according to the procedure in place and then decide; the message passed to the AO by the MET bulleting is: be prepared to take action, if this (forecasted event) happens

6. **Mitigation measures of severe weather induced hazards**)
    - The following Short Term ATFCM Measures (STAM[22]) are used to alleviate ATC sector overload: (linked to):
        - o Regulate departures tactically - manage departure rate by MDI (Minimum departure interval)
        - o Miles in trail – increased separation, however this measure are expected to increase workload in other adjacent upstream centers which are providing services to affected flights.
    - coordinated re-filing of FPL with AOs (done through the FOX[23], but not applied nationally)

7. **Coordination**
    a. inter-sector and inter-unit (TWR, APP, ACC) -
    b. inter-centre (other ANSPs) - nil
    c. with APT – 2 daily conferences
    d. AO and NMC – MET bulletin send by email

8. **Any tools and models used for**
    a. weather translation - dedicated MET bulletin
    b. ATC impact assessment – risk assessment matrix
    c. decision support :
    - Guidelines
    - Enhanced WX portal (tool) will be put in place to help improve the decision making including on tactical base (use of colour coding of the weather impact)
    d. exchange and coordination with adjacent units - nil

9. **Statistics and analysis**
    - Detailed and deep Post OPS analysis enabling identification of the real cause of the flow regulation issued. Currently, this is not possible at Network level due to the quality and scope of data available to the NM.

10. **Benefits and lessons learnt from the sever weather risk management**
    a. Benefits
    - Improved and timely decision making to protect controllers when needed
    - Improved severe WX awareness for FMP
    - Improved flight efficiency; delay did not get worse, improved customer satisfaction
    - Improved service to the users by improved predictability of operations (AO know what to expect and plan its response)
    - WX procedure is aligned with the principle requirement to move from ATC to ATM;

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[22] STAM typically include short ground delay, flight level capping or small re-routings

[23] The overall objective of the FOX operations was to address short ATFCM/ASM optimization within the FABEC area and to coordinate such optimization with the partners concerned during the period of the London Olympic Games. The goal was to optimize FAB-wide the capacity provision, the traffic flows and the use of airspace by civil and military users in close coordination with the Network Function, military units and local functions

b. Lessons learnt

- risk assessment matrix tuned following unnecessary delays
- critical success factor for the implementation of effective procedure is MET office understanding and cooperation
- implementation of severe weather risk management procedure is possible by a top down decision; it doesn't work the other way round
- if such procedure was to be implemented at network level the option for EC regulation may be considered
- change in the methods used for flight efficiency calculation (last filed route) may motivate implementation of severe weather risk management procedure

ANSP 2

1. National requirements related to the management of severe weather impact in addition to ICAO standards

- Related to low visibility operations –navaid sensitivity area protection; exemptions from the obligation to comply with noise abatement procedures (e.g. use of particular RWY configuration) in severe weather conditions
- Pilots are required to report severe turbulence to ATCOs, and ATCOs are required to pass this information to affected flights

2. MET products and data made available and actually used

2.1 Weather forecast products:

- TAF available at all CWP positions;
- Upper wind forecasts available at the en-route sectors;
- at some airports access is provided to more detailed MET information about the aerodrome conditions through a dedicated service:
  - o “OpenRunway” online weather forecasting package providing essential weather information regarding the RWY conditions and alerts to changing conditions for the 2 major capital airports; the product offers:
    - – Colour coded hour-by-hour summary detailing current and forecast weather specific for a given airport
    - – Bespoke thresholds that ATC can manage for a given airport and individual runways;
    - – Detailed graphs of current and expected conditions;
    - – Easy to use map viewer with satellite and weather radar overlays to visualise forthcoming weather;
    - – Access to information from runway sensors from MET Office installed systems or another existing provider;
    - – Optional 0 to 5 day summary prepared by one of the MET Office aviation forecasters who interprets the conditions at the airport (also available via email or fax);
    - – Round the clock access to aviation forecasters for advice and assistance in the decision making;
  - o “WeatherWindows” – specific forecasting and planning tool that enables decision makers to plan efficiently up to 15 days ahead weather dependant tasks such as RWY maintenance tasks, airport infrastructure changes, construction works; the product covers wider area, i.e. 5-10 NM around the airport; information is presented in graphical form, using colour coding; accessible at the SUP position; key features:
    - – Easy to interpret colour-coded display the likelihood of appropriate weather to carry out a task;
    - – Displays of opportunity up to 15 days ahead;
    - – Bespoke parameters and thresholds display only the weather information relevant to the specified tasks;
    - – WatchWindow function: monitoring key time periods to carry out tasks and alerting if weather conditions change;
    - – Confirmed Activity function: enables to keep an electronic record of information and decisions associated with each task;
    - – Task reports: printable PDF reports can be generated to record the key decisions;
    - – Weather alerts: definable weather alerts and thresholds specific to the airport operations providing users with specific alerts up to 15 days ahead;

- – Task verification: optional monthly analysis report detailing the accuracy of the product for the key tasks specified.

2.2 Current weather reports:
- available at all controller working positions in a separate information system;

2.3 Weather radar data
- most airports (ATC units) do not have access to weather radar data; pilot reports are main source of severe weather related information for the vicinity of the airport;
- The ACC has weather radar service, accessible at local SUP positions only; it includes historical and predicted data up to 2 hours in advance. The weather radar data is not shown graphically as an overlay on the current airspace structures (air routes, ATC sectors, etc).

2.4 Satellite weather data – not used in ATC operations;
2.5 pilot reports – see point 1 above;
2.6 typical severe weather phenomena:
- at airports: most often low visibility and snow, although there are only few cases over the last 5 years of disruption because of snow;
- TMAs are mostly impacted by CBs; worst impact is in the first hour. There is a knock-on effect on TMAs in case of airport impacted by, for example low visibility.

2.7 Potential areas for improvement of the MET products:
- better weather radar presentation with the actual airspace structure and in vertical plane;
- better predictability of severe weather elements;
- improved probability data would allow for a shift to a more pre-tactical management of the severe weather impact in the long term thus reducing the impact of unwanted diversions.

3 **MET data flow in the ATCC**:

3.1 from / to MET office;
- the ANSP does not provide MET services, such services are procured from the national MET office;
- Forecasts and current weather reports are available to all ATC unit (TWR, APP and ACC) controllers and operational supervisors; supervisors have access to further MET information - see point 2 above;
- FMP relies on the supervisors to be briefed about severe weather and potential impact;

3.2 any dedicated MET data exchange and tools/means
- Controllers are briefed about weather at shift start and at position handover;
- The morning briefing of the supervisors and FMP staff include assessment of the situations; decisions on the use of particular sectorisation schemes and/or implementation of flow regulations may be taken or postponed for a later moment depending on the forecasts, current weather reports and the development of the situation;
- On D-1 FMP participates to the pre-tactical briefing with NM providing outlook for the day of operation
- Airport ATC units inform the airport operators about expected disturbances of traffic flow due to severe weather

4 Procedures, guidance and practices for management of severe weather impact

4.1.1 Tactical ATCO procedures / guidance:
- controllers respond to pilot request; they are not encouraged to provide avoidance advice and there is no weather data (e.g. weather contours) available on the air situation display;

- controllers coordinate with adjacent sectors changes flight trajectories;
- in weather avoidance scenarios coordination with adjacent sectors may become an issue due to the sector shape and small size, and the need to modify FPL elements and notify the FPL/the changes to the adjacent sectors; the additional coordination and system update needs may raise considerably controller workload; possible means of mitigation is assignment of a support controller to help with the coordination tasks

4.1.2 OPS SUP procedures / guidance:

- monitors the weather radar data and sector loads, sectors,
- implements flow measures (e.g. reduces rates) if weather persists for a longer time;
- decides on the implementation and coordinates traffic restrictions with adjacent units; however there is no systematic coordination with adjacent centres of avoidance routes and scenarios – this is responsibility of sector controllers (see 4.1.1 above)
- decides on changes to holdings and STARs depending on the location and evolution of the weather phenomenon;
- supervisors at ATC airport units may implement: increased minimum departure intervals (MDI), increased arrival separation, traffic prioritisation; it is at supervisor's discretion when and which measures to implement;
- decision for implementation of flow regulation at an airport is taken based on the weather forecast, typically 3 -4 hours in advance;
- low visibility operations (LVO) at airports contribute to a reduced controller workload; however the workload of the TMA controller(s) may increase; implementation of LVO increases delays significantly (could reach 30 – 40 min per flight). TMA disruption is worst within the first hour when the traffic flow should be reduced. This is typically done by first imposing restrictions on departure flows originating at closely situated airports, like Paris, where the aircraft are still on the ground.
- safety of services in TMA sectors is supported by: regulating departures at closely situated airports, use of holdings, coordinating with airports about available stands; it is not a standard practice to implement TMA protective flow measures well in advance, unless it is confirmed that closely situated airport(s) will be closed;
- increased departure intervals (MDI) are also used to alleviate issues in the terminal sectors (use of parallel routes impeded by convective weather)
- en-route sectors: generally no action (implementation of flow measures) is initiated on forecasts , but situations is monitored closely by the OPS SUP in order to implement measures if need arises

4.2 FMP procedures/ guidance

The FMP participate to the briefings with operational supervisors and provide advice, as appropriate, on the implementation of sectorisation schemes and flow measures. FMP implement flow regulations in coordination with the NM upon supervisor's decision.

5 Decision making loop and responsibilities

5.1 how (process) and who (roles) is involved:

- the implementation of risk mitigation measures is a collaborative process, i.e. team decision is taken as a result of the consultation of FMP and team supervisors;
- in case of significant delays aircraft operators would cancel flights (AO decision without any ATC involvement)

5.2 is there any explicit risk assessment required: no

5.3 measures – prescribed (e.g. by a procedure) or taken on a case by case basis: guidance on acceptance rates implementation exist; type of severe weather,

separation and protection parameters are accounted of; values are recommended and the operational supervisor has to exercise his/her judgment when making decision
Note: The EU imposed ANSP performance management and indicators is in some cases impediment to making decision at corporate level for the implementation of pre-tactical severe weather impact management.

6 Tools and models used

6.1 weather translation (presenting the MET data in an easy to comprehend way to the ops staff) – see specific MET products description in 2.1 above;

6.2 ATC impact assessment (supports assessment of the ability to provide ATS in severe weather conditions): no dedicated tools;

6.3 decision support (about which measures to be applied):

- generic guidelines on capacity reduction exist, however the operational supervisor has to exercise his/her judgment following consultation with sector controllers and local SUPs (in the case of ACC 1);
- “WeatherWindows” tool described in 2.1 above.

6.4 exchange and coordination with adjacent units and NM:

- measures are coordinated between ACC and APP units and communicated to the affected airports (e.g. departure rate); in rare occasions TWR SUP may negotiate (with APP SUP) the suggested measures if severe impact is anticipated;
- flow measures are coordinated with NM and implemented in line with the approved procedures.

7 **Measures used to mitigate impact of severe weather** - per hazard (e.g. turbulence, strong surface wind) -

- sectorisation changes at ACC/APP level;
- opening positions that were previously bandboxed at the ATC airport units;
- implementation of departure rates; increased separation of arrivals; delayed and/or and stopped departures;
- potential area for improvement – reducing the time needed to open or bandbox sectors, e.g. to few minutes only.

8 **Coordination of possible severe weather impact and measures to be taken**

8.1 inter-sector and inter-unit (within the ANSP): information passed between sectors; the supervisor may inform sector controllers of severe weather cells (TS) observed on his weather radar display; coordination with airports triggered by pilot report of areas avoided due to weather (CBs); see also 6.4 above;

8.2 inter-centre (with other ANSPs): not really the case with adjacent ATCC, however traffic restrictions on entry points are communicated by the supervisor

8.3 with airport operators, aircraft operators and NMC – coordination with airport operator only, who will take care of the coordination with concerned aircraft operators

8.4 FMP sends on D-1 a brief on expected capacity for the next day to the aircraft operators

9 Incident/accidents with weather being a contributor

- Weather avoidance initiated manoeuvre led to loss of separation due to ATCO misjudging the rate of turn/descent
- Unwanted descent in downdraft led to loss of separation
- A fight was unable to stop descent due to windshear resulting in loss of separation;
- In 8 % of the reported cases of ATCO overload in 2011 weather was a factor;
- In 14 % of the reported separation infringements in 2011 weather was a factor.

10 ATC contribution:

Where flights pushed into bad weather as the result of a ATC restriction (airspace, level cap scenario due to insufficient capacity in a sector, etc)? – no such cases reported.

ANSP 3

1. Regulatory/national requirements to be complied with by the ANSP in management of severe weather impact

- standard (ICAO) provisions are applicable; controllers are required to pass available (e.g. by pilot reports) information to concerned flights,

2. MET products and data made available and actually used

2.1. weather forecast products:
- controllers can retrieve at the CWPs the TAFs for the area of interest (AoI); however TAFs are available for relevant aerodromes, even when far outside the AoI (AoI is a specific term to mean Area of Responsibility + 30NM);
- upper winds - available at the CWPs; information supplied by national MET office; updated every 6 hours;

2.2. current weather reports:
- controllers can retrieve at the CWPs the METARs for the AoI and relevant aerodromes outside the AoI; (see 2.1 above)

2.3. weather radar data:
- weather radar data are available for display in the main situation window at the CWPs (on/off position selectable by the controller); data is supplied by national weather services; data is updated every 5 minutes; two dimensional picture is provided, i.e. information about the vertical extent of the weather phenomenon is not provided;

2.4. weather satellite data:
- current weather maps available at SUP and FMP positions; supplied by national weather services;

2.5. pilot reports:
- as far as provided by pilots; controllers should seek such reports;

2.6. other sources
- the national MET service providers can be contacted for consultation and more detailed information, for example to clarify the vertical extent of a cloud build-up or to obtain information on the predicted evolution of the convective weather;
- FMP can retrieve various aviation weather products from the national weather services' web server; there are actually more sources available, but the national weather services' portal is the one commonly used.

3. MET data flow in the UAC

3.1. from / to: CWP. OPS SUP; FMP; line managers; airport operators;
- the electronic self briefing for controllers may include relevant weather information, however this is very unlikely;
- weather briefing, as necessary, at sector handover;
- OPS SUP is provided with the capability to insert and send weather related information to all CWP to be observed on a separate display;
- OPS SUP would contact the FMP and inform them about expected weather impact and need of flow measures;
- FMP would contact the OPS SUP and consult him about predicted severe weather and the possible impact on capacities;
- line managers are not involved, except in unusual circumstances (e.g. in case of strong wind affecting radars without radome protection);

3.2. any dedicated MET data exchange tools/means – no;

4. Procedures, guidance and practices for management of severe weather impact

4.1. tactical ATCO procedures / guidance:
- there are specific procedures for use in adverse weather conditions, for example increased separation minima;
- the use of parallel headings may be suspended/reduced;
- controllers should seek from crews information about hazardous weather;
- pilot reports to be passed to MET service provider(s) and concerned flights and neighbouring ATC centres;
- controllers do not provide proactively to flight crews avoidance advice (e.g. vectoring around CB), but can inform pilots about the weather they observe on the CWP display and the avoiding actions implemented by other crews;

4.2. OPS SUP procedures / guidance:
- responsible to check current/predicted weather conditions;
- may suspend RVSM operations;
- may lower capacity rates;
- coordinates with adjacent units, as needed, traffic flow measures to be implemented;

4.3. FMP procedures/ guidance
- Particular guidance for traffic flow / capacity management in severe weather conditions does not exist;
- Flow managers asses the potential impact of severe weather using predicted traffic data and their expertise, and coordinate with OPS SUP and neighbours (passing weather warning basically);
- Flow managers monitor occupancies and notify the OPS SUP of expected overloads;
- FMP may be informed of traffic flow measures to be implemented by the neighbouring centres, however this is not a formal procedure (e.g. provision in the LoA);

4.4. impact management scenarios:
- defensive control measures (at sector level);
- additional controller at position;
- tactical flight re-routing;
- re-sectorisation: technically 500 sector configurations are possible; a re-sectorisation requires 5 min to implement

5. Decision making loop and responsibilities

5.1. how (process) and who (roles) is involved:
- collaborative process with the participation of the FMP and OPS SUP; final authority rests with the OPS SUP;

5.2. is there any explicit risk assessment required – no;

5.3. measures – see 4.4. above;

6. Tools and models used

6.1. weather translation (presenting the MET data in an easy to comprehend way to the ops staff) – no dedicated tool;

6.2. ATC impact assessment (supports assessment on the ability to provide ATS);
- TMS showing predicted traffic and some weather information (e.g. predicted low visibility at an airport); further enhancement of MET data could be achieved by implementing the appropriate interface; the tool is still under development;
- currently the impact of severe weather is basically done by responsible roles using their best judgment;

6.3. decision support (about which measures to be applied); - no dedicated tool;

6.4. exchange and coordination with adjacent units and NM – no dedicated tool;

7. Measures used to mitigate impact of severe weather

- measures are implemented at tactical level (up to few hours in advance); typical timeframe for acting on TS is up to 1 hour in advance due to the high uncertainty of the TS evolution;
- re-sectorisation;
- acting on particular traffic streams and flights;
- implementation of STAM aiming to reduce the complexity in the sectors (occupancy monitored on a minute basis);

8. Coordination of possible severe weather impact and measures to be taken

8.1. inter-sector (within the ANSP)

8.2. inter-centre (with other ANSPs)

- if an impact on an adjacent centre is predicted it will be contacted at the OPS SUP level; theoretically the adjacent ATC centre would also receive AFP for affected flights;

8.3. with airport operators, aircraft operators and NMC

- occasionally affected airports in the ACC AoI may be contacted for more detailed information and clarification;

9. Incident/accidents with weather being a contributor

- Severe weather contribution to high severity (2/3) incidents can be considered infrequent - basically 1 per year;
- example incident: separation infringement caused by unexpected deviation of a flight from its planned route due to avoiding action without previously notifying the sector controller;

10. Potential for improvement

- Improved traffic predictions and weather forecast; however the existence of limiting factors for predictability improvement is recognised;
- Improved management of resources to the limit possible, including monitoring quality of service and implementing improvement measures;
- Improved impact assessment and decision making tools, including workload and complexity modelling, as well as tagging of flights to be acted upon;
- Optimisation at network level as opposed to optimisation at 'local" level (optimal operation of network components does not mean optimal operation of the network); such process should be supported by incentives; a potential incentive could be the implementation of "network delay attribution";
- Further optimisation of the performance scheme to ensure that service providers implementing measures to optimise/improve network performance are not unduly penalised; however it should be recognised that there is a limit to what can be done in severe weather scenarios;
- Optimisation of traffic flow measures, and respectively of ATC network, as a central service.

ANSP 4

1. Regulatory/national requirements to be complied with by the ANSP in management of severe weather impact

- standard (ICAO) provisions are applicable;

2. MET products and data made available and actually used

2.1. weather forecast products:
- controllers/OPS SUP can retrieve at their working positions TAFs for the area of interest (AoI);
- other forecast products, such as area forecast in plain language and GAFOR are also available;

2.2. current weather reports:
- controllers/OPS SUP can retrieve at their working positions the METARs for the AoI;
- ATIS for the major airport in the ACC AoR and GAMET are also available;

2.3. Minimum usable flight level correction:
- This is a specific product provided by the MET office (national government agency) to ensure a correct minimum usable flight level in the mountain region; level correction takes into account temperature and pressure; information is updated every 3 hours;

2.4. weather radar data:
- weather radar data are available for display in the main situation window at the CWPs (on/off position selectable by the controller); data is supplied by 2 ANSP radars (one for eastern part and one for western part of the served airspace); two dimensional picture is provided, i.e. information about the vertical extent of the weather phenomenon is not provided on the CWP display;
- in addition weather radar products are displayed on a dedicated screen at every operational position;

2.5. weather satellite data:
- not used;

2.6. pilot reports:
- as far as provided by pilots; controllers my seek information from pilots;

2.7. other sources
- OPS SUP / TWR SUP can contact the MET office for consultation and more detailed information, for example to clarify the vertical extent of a cloud build-up, the size of a turbulence area or to obtain information on the predicted evolution of the convective weather / low visibility;

3. MET data flow in the ATCC

3.1. from / to: CWP. OPS SUP; FMP; line managers; airport operators:
- there is no dedicated MET briefing of controllers; controllers are responsible to brief all elements of the air situation at the start of their duty;
- weather briefing, as necessary, at sector handover;
- all operational positions, including OPS SUP/TWR SUP, FMP, CWP are provided with the same MET information via the intranet;
- OPS SUP / TWR SUP would contact the FMP and inform them about expected severe weather impact and the traffic flow measures planned for implementations;
- depending on the needs, the OPS SUP can contact Geneva TWR SUP and coordinate a restriction of departing traffic (departure rate); in rare cases such restrictions can be coordinated with the TWR SUP of the closely situated to the national border, but in the adjacent country, airport

- line managers are not involved in management of severe weather impact;

3.2. any dedicated MET data exchange tools/means:

- no dedicated tools – MET information distributed on the intranet;
- two (2) dedicated MET data displays at each operational position: one for displaying weather radar data and one for displaying forecasts, current weather reports and ATIS data;

4. Procedures, guidance and practices for management of severe weather impact

4.1. tactical ATCO procedures / guidance:

- in case of low visibility operations at the major airport - increased separation minima on approach;
- controllers may seek from crews information about hazardous weather;
- pilot reports about significant weather (e.g. turbulence) to be passed to concerned flights; pilot reports about severe turbulence shall be passed to the MET office, too;
- controllers do not provide proactively to flight crews avoidance advice (e.g. vectoring around CB), but upon request can inform pilots about the weather they observe on the CWP displays and the avoiding actions implemented/reported by other crews;

4.2. OPS SUP / TWR SUP procedures / guidance:

- responsible to monitor current and predicted weather conditions and take decision on the need on sector protective measures;
- OPS SUP / TWR SUP may lower sector capacity in incremental rate in line with the existing guidance, for example 10%, 15%, 25% (or more in the case of arrival rate reduction)
- OPS SUP and TWR SUP will implement flow regulation up to several hours in advance of the forecasted severe weather (e.g. TS); for the regulation to be effective it shall be implemented at least 2 hours in advance;
- TWR SUP does not implement traffic regulations based on forecasted snow or low visibility, except when high degree of certainty exist; depending on the severity of severe weather effect arrival rate may be reduced significantly (more than 50 %);
- Flow rate is managed dynamically if severe weather persists for a considerable period of time (e.g. one day)
- TWR SUP may implement increased separation on approach;
- if needed, OPS SUP coordinates with TWR SUP tactical level restrictions for departing traffic from Geneva airport, and in some cases with the TWR SUP of the closely situated foreign country airport;

4.3. FMP procedures/ guidance

- flow managers implement flow regulations on OPS SUP or TWR SUP request;

4.4. impact management scenarios:

- flow regulation – sector capacity reduction;
- additional controller at position (in case of lack of controllers to open another sector);
- re-sectorisation;

5. Decision making loop and responsibilities

5.1. how (process) and who (roles) is involved:

- OPS SUP / TWR SUP assesses the possible impact of severe weather on sector workload using the available MET data and guidance, and takes decision on the implementation of appropriate measures;

5.2. is there any explicit risk assessment required – no;

5.3. measures:

- increased separation on approach;

- reduced arrival rate;
- departure traffic restriction;
- additional controller at sector position;
- re-sectorisation;
- traffic flow regulation;

6. Tools and models used

6.1. weather translation (presenting the MET reports and forecasts in an easy to comprehend, way to the ops staff, e.g. graphical image) – no dedicated tool;

6.2. ATC impact assessment (supports assessment on the ability to provide ATS);

- currently the impact of severe weather is basically assessed by the OPS SUP/ TWR SUP using his/her experience and best judgment;

6.3. decision support (about which measures to be applied) - no dedicated tool;

6.4. exchange and coordination with adjacent units – no dedicated tool;

7. Measures used to mitigate impact of severe weather

- measures are implemented at tactical level (up to few hours in advance); typical timeframe for acting on TS/CB activity is 2 hours in advance due to the uncertainty of the TS evolution;
- occasionally, flow measures are implemented to protect en-route sectors due to significant number of holdings caused by flow regulation implemented to manage the weather impact on TWR operations;
- acting on particular traffic streams and flights, e.g. major airport departures;
- see also 5.3 above;

8. Coordination of possible severe weather impact and measures to be taken

8.1. inter-sector (within the ANSP) - avoidance routes and or holdings are coordinated between ACC sectors and with TMA / TWR sectors;

8.2. inter-centre (with other ANSPs):

- normally coordination of avoidance routes done at ATC sector level per flight;
- coordination at OPS SUP level is rather an exception – only in unusual and emergency situations;

8.3. with airport operators, aircraft operators:

- not required for management of impact on ACC sectors;
- TWR SUP informs the airport operator about decision to implement flow regulation:

9. Incident/accidents with weather being a contributor

- typical hazards – severe turbulence, icing (in-flight and on the ground leading to emergency decent; difficulties to achieve correct sequence/spacing on approach and delays and incorrect departure sequence) and fog

10. Potential for improvement

- Improved presentation of the weather information, in particular: vertical extent, reliable presentation of hazardous weather behind weather radar return layer (presentation in depth), precision and granularity (e.g. development and implementation weather translation and decision support tools);
- Improved accuracy of weather forecast; however the existence of limiting factors for predictability improvement is recognised;

ANSP 5

1. **Regulatory/national requirements to be complied with by the ANSP in management of severe weather impact**
   - standard (ICAO) provisions are applicable;
   - LVP procedures and snow plan at the capital airport - developed by the ANSP and approved by the regulator (NSA)

2. **MET products and data made available and actually used**

   2.1. weather forecast products:
   - ACC SUP, TWR SUP and controllers have access at their working positions to the TAFs for the area of interest (AoI);

   2.2. current weather reports:
   - ACC SUP, TWR SUP and controllers have access at their working positions the METARs / ATIS for the AoI;

   2.3. weather radar data:
   - weather radar data are available for display in the main situation window at the CWPs according to the level of intensity (on/off position selectable by the controller); radar data is supplied by the airport weather radar; two dimensional picture is provided, i.e. information about the vertical extent of the weather phenomenon is not provided on the CWP display, but can be obtained from the MET office upon request;
   - TAF, METAR, ATIS nd wind information can also be called for display on a dedicated screen at every operational position (CWP);

   2.4. weather satellite data:
   - not used operationally, although it is available close to the SUP position;

   2.5. pilot reports:
   - as far as provided by pilots; controllers can also seek information from pilots;

   2.6. other sources
   - ACC SUP / TWR SUP can contact the MET office for consultation and more detailed information about expected adverse weather, for example to ask about forecast for a particular area or probability of the forecasted weather;

3. **MET data flow in the ATCC**

   3.1. from / to: CWPs,. ACC/TWR SUP; FMP; line managers; airport operators:
   - MET data are received by fax and printed on paper at the ACC and TWR SUP positions; ATCOs can display the MET data (e.g. METAR, ATIS) on a separate screen at the CWP
   - The ACC/TWR SUP provides a briefing to controllers about expected adverse weather before the start of the shift;
   - ATCOs familiarise themselves with current weather at sector takeover as part of the standard handover/takeover procedure;
   - line managers (e.g. Head of ACC) are not involved in management of severe weather impact on ATC operations, however are informed about the measures decided and implemented by the ACC/TWR SUP;

   3.2. any dedicated MET data exchange tools/means:
   - no dedicated tools – MET information distributed on the intranet to CWPs;

4. **Procedures, guidance and practices for management of severe weather impact**

   4.1. tactical ATCO procedures / guidance:
   - in case of low visibility operations at the capital airport - increased separation minima on approach depending on the RVR values and RWY(s) in use;

- controllers may ask from pilots to report hazardous weather;
- pilot weather reports (e.g. severe turbulence) are passed to concerned flights in the affected area and the MET office, and depending on the location of the area - to concerned adjacent ATC units;
- controllers do not provide to flight crews proactive avoidance advice (e.g. vectoring around TS or CB) – avoidance is done at pilot discretion; however upon pilot request ATCO can inform the pilot about the clutter he/she observes on the CWP display;

4.2. ACC SUP and TWR SUP procedures / guidance:

- SUP is responsible to monitor current and predicted weather conditions and take decision, if appropriate, to implement impact mitigation and sector protective measures;
- OPS SUP and TWR SUP will implement flow regulation few hours in advance of the forecasted severe weather (e.g. TS, fog, etc), according to the need; for the regulation to be effective (take effect on European flights) it shall be implemented at least 2 hours in advance;
- Flow rate / restrictions can be adjusted dynamically according to the developing adverse weather situation;
- Short term measures (such as shifted departures) are also used (see point 7 “Measures” below)

4.3. FMP procedures/ guidance

- flow managers implement flow regulations on ACC SUP and TWR SUP request;
- in some cases FMP are also involved in the collaborative process for management of sever weather impact

5. Decision making loop and responsibilities

5.1. how (process) and who (roles) is involved:

- ACC SUP and TWR SUP assess the possible impact of severe weather (e.g. fog, TS, etc) on the safe provision of ATC taking into account:
  - available MET data;
  - expected traffic demand;
  - existing procedures (e.g. LVP) and guidance in the manual,
  - availability of ATC resources (e.g. RWY configuration)

  and take decision on the implementation of appropriate and proportionate measures;
- SUP judgement and experience are very important factors in the decision making process, too
- decision is a result of a collaborative process and consultation with the participation of the ACC SUP, TWR SUP and the MET office; it takes place 4 times a day (24 hours)
- the percentage of probability of forecasted weather phenomenon is a very important parameter, in particular for TS, as different measures/solutions are implemented depending on this percentage;
- for the capital airport area visual observation is also used to support decision making;
- the SUP has to provide arguments (on paper) to justify the decision to implement flow regulation;
- sometimes FMP participates also to the coordination process: the departure times of some flights can be shifted (delayed) by max 15 min in order to prevent ATC sector overload; FMP coordinates with the concerned airports this shift of the departure times of affected traffic; principle agreement with local operators (Al Italia) is in place for the use of this measure;

- if decision is taken to implement flow regulation, the FMP coordinates the implementation with the Network operations centre of EUROCONTROL

5.2. explicit risk assessment for the implementation of traffic flow measures is not required

Note: An emerging issue nowadays is the airline operating policy and practice to fly with lawful minimum fuel for flight efficiency reasons which can have serious safety implications in case of complex situations, such as severe weather avoidance scenarios, which would require diversions to alternate aerodromes that flights can not execute due to shortage of fuel.

6. Tools and models used

6.1. weather translation (presenting the MET reports and forecasts in an easy to comprehend, way to the ops staff, e.g. graphical image) – no dedicated tool;
6.2. ATC impact assessment (supports assessment on the ability to provide ATS) – no dedicated tool;
6.3. decision support (about which measures to be applied) - no dedicated tool;
6.4. exchange and coordination with adjacent units – no dedicated tool;

7. Measures used to mitigate impact of severe weather

- measures are implemented at tactical level (up to few hours in advance); typical timeframe for acting on TS/CB activity is 2 hours in advance due to the uncertainty of the TS evolution;
- measures may focus on particular traffic streams and flights,
- measures can include as appropriate:
  - priority is to land the arrivals and manage departure flow
  - open all arrival positions (4 frequencies and 2 coordination positions) if needed;
  - delay departures to use more RWYs for arrivals (stand capacity of adjacent airports is quite low compared to the capital airport capacity)
  - holdings are used in case of need, but not as a preferred solution due to potential impact of severe weather on specific approach areas and/or fuel shortage problems (often flights arrive with lawful minimum fuel with reduced margins to wait for weather improvement)
  - departure traffic restriction – departure time shift by 5 to 10 min;
  - increase of taxi-time for departures;
  - increased departure interval;
  - additional EXC controller at sector position or OPS SUP to help
  - ATC sectorisation management;
  - traffic flow regulation;
  - RVSM suspension in part of the airspace in case of severe turbulence;
  - coordinate alternative levels with adjacent ATC units in case of severe turbulence
  - delay departures at regional airports in coordination with local TWR.

8. Coordination of possible severe weather impact and measures to be taken

8.1. inter-sector (within the ANSP) - avoidance routes and or holdings are coordinated between ACC sectors and with the ACC/TWR SUP;
8.2. inter-centre (with adjacent ATC units):
  - coordination of avoidance routes or any other traffic restriction is responsibility of the SUP; ATCOs shall inform the SUP in case of such need;
  - the SUP coordinates with the Military the opportunities to use active restricted areas to avoid hazardous weather;

8.3. FMP coordinates with the NOC (former CFMU)
8.4. with airport operators, aircraft operators:

- not required for management of impact on ACC sectors; (see also coordination of departure time shifting above)
- TWR SUP informs the airport operator (the main airport handling agent) about decision to implement restriction; and the airport operator coordinates further with aircraft operators as needed;

9. Incident/accidents with weather being a contributor

- typical hazards – an example is strong wind;

10. Potential for improvement

- More accurate weather forecasts, and in particular about the evolution of the weather phenomena, for example a more precise forecast of TS movement which will allow for better traffic planning;
- improved precision of the percentage of probability of forecasted weather because the measures/solution depends strongly on this parameter;
- improved granularity of weather forecast, i.e. availability of forecast not only for the airport area, but also for the TMA and ACC airspace, including on hourly intervals which will allow for an improved estimation of evolution and impact on ATC
- however the existence of limiting factors for an improved weather predictability is recognised;
- with regard to procedures - currently there is a exact guidance and provisions for LVP and snow plan implementation – such guidance is also desirable for the area control, however it is recognised that “hard” procedures for ACC are not feasible as ACC SUP has to exercise his judgement, experience and knowledge to take full account of evolving weather impact, controller skills; affected traffic demand and other environmental factors;

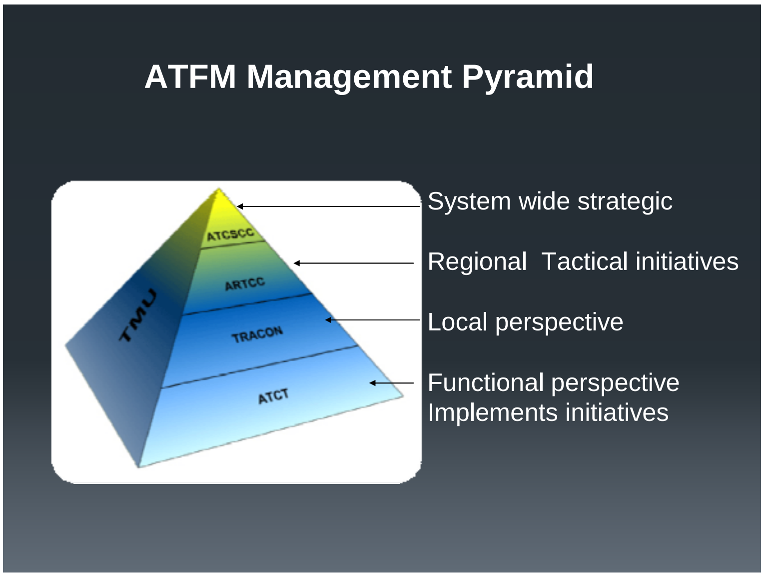
Improved cooperation between concerned actors and units is considered of paramount importance for the efficient and safe management of severe weather impact. Informed decisions shall be based on mutual trust and respect, and due consideration of potential impact of measures on the TWR, ACC and adjacent units’ operations.

FAA

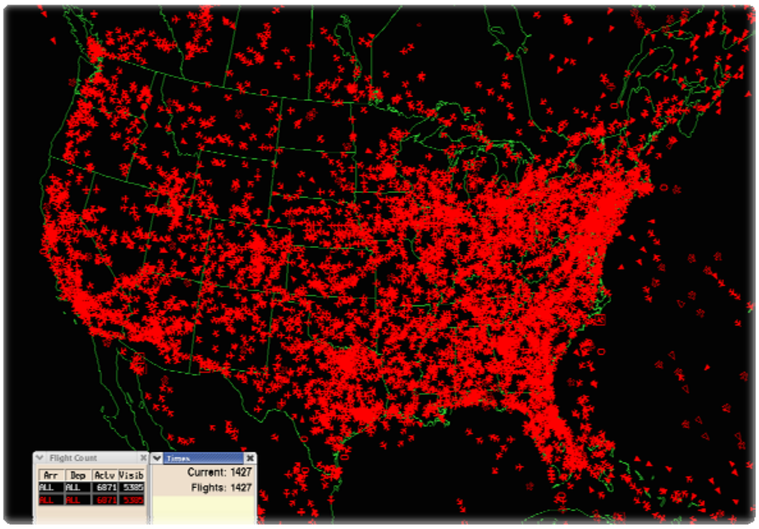
Air Traffic Control System Command Centre (ATCSCC), Virginia, 19 - 20 February 2013

1. Organisation and regulatory/national requirements of FAA in management of severe weather impact

- ATCSCC is part of 'ATFM Management Pyramid':



- ATCSCC mission is to serve as a focal point for National Airspace System and balance Air Traffic Demand, System Capacity and System Efficiency
- During peak traffic periods there are typically 6,000-7000 aircraft operating in the National Airspace System (NAS); about 55,000 aircraft operations daily



- Severe weather impact management is part of the Collaborative Decision Making; FAA and the Industry initiative aim at improving TFM through increased information exchange and improved collaboration
- Weather information supplier is the National Weather Service that forms part of the Department of Commerce. Currently, there is a new initiative within the NWS to bring meteorologists into the ATCSCC. This was the case in the 90s but was discontinued until a year ago.

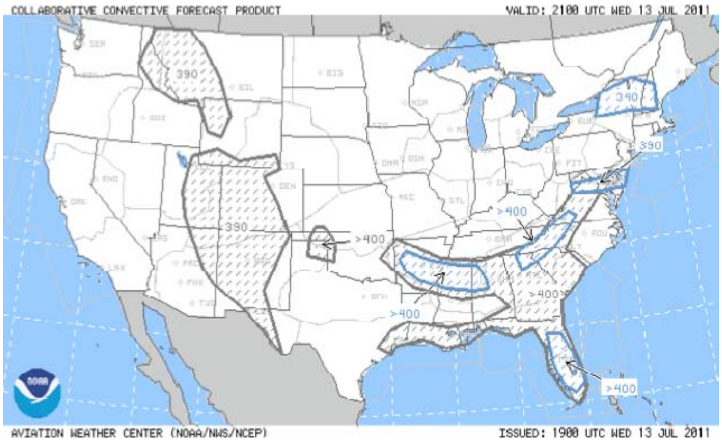
- NOAA/NWS provides aviation weather services around the clock. It includes:
  - 122 Weather Forecast Offices (WFOs)
  - 21 Center Weather Service Units (CWSUs)
  - 3 Meteorological Watch Offices: Aviation Weather Center (AWC) KC, MO, Alaska Aviation Weather Unit (AAWU), Anchorage, AK, WFO Honolulu, HI
  - 2 Volcanic Ash Advisory Centers: AAWU and National Centers for Environmental Prediction, Washington, D.C.
  - 1 World Area Forecast Center: AWC
  - Tropical Prediction Center, Miami, FL
  - Storm Prediction Center, Norman, OK
  - Space Weather Prediction Center, Boulder, CO
- The Center Weather Service Units offer reimbursed weather services provided by 4 meteorologists (3 officers + 1 manager) 16 hours a day to each of the 21 ACC Centres. This service was introduced after NTSB investigation into an accident in Georgia in 1978. The service includes en-route meteorological advisories and briefings, take-off and landing forecasts, warning briefings and tactical decision aid.
- Weather Forecast Officers (WFOs) produce airport forecasts for over **600** airports 4 times a day, including amendments and updates thereto. For the “core 30” airports a 2 hours update period is envisaged to achieve synchronization with the Strategic Planning Call concerning the following weather elements: clouds, visibility, thunderstorms, wind and precipitation.
- NWS in the ATCSCC operational focal point for all NWS products and services used by Traffic Managers. It works with entire NWS infrastructure that produces aviation forecasts to ensure NWS meets TFM requirements for accuracy, consistency and reliability, notably the Weather Forecast Offices (WFOs), Center Weather Service Units (CWSUs) and Aviation Weather Center (AWC). It provides daily assessment of NWS performance to both FAA and NWS leadership and represents a new concept, critical to continuous improvement.
- The CDM Weather Evaluation Team (WET) is a sub-team of CDM. It is a joint initiative of FAA and NAS Stakeholders to solve problems in the NAS through information sharing. The tasks are assigned by the CDM Stakeholders Group (CSG). CSG members and participants include FAA, stakeholders (Airlines, NBAA), NOAA/NWS, contractors and subject matter experts.
- ATCOs issue a weather avoidance advisory that is different from vectoring. It is not an ATC instruction but a clearance to deviate - e.g. “30 degrees to the right”.
- Approach separation is predefined and can be increased in case of adverse weather impact.
- The runway capacities are normally defined for visual separation/visual approach.
- NextGen vision of weather impact manageemnt and dealing with core concepts includes to date:
  - Single Authoritative Source (SAS);
  - Human-over-the-loop (forecast process);
  - Tracking performance of forecasts used for traffic management decisions;
  - Translation of weather to impact (on ATC and flight operations) and integration into Decision Support Tools (DSTs).

2. MET products, data, tools and decision support

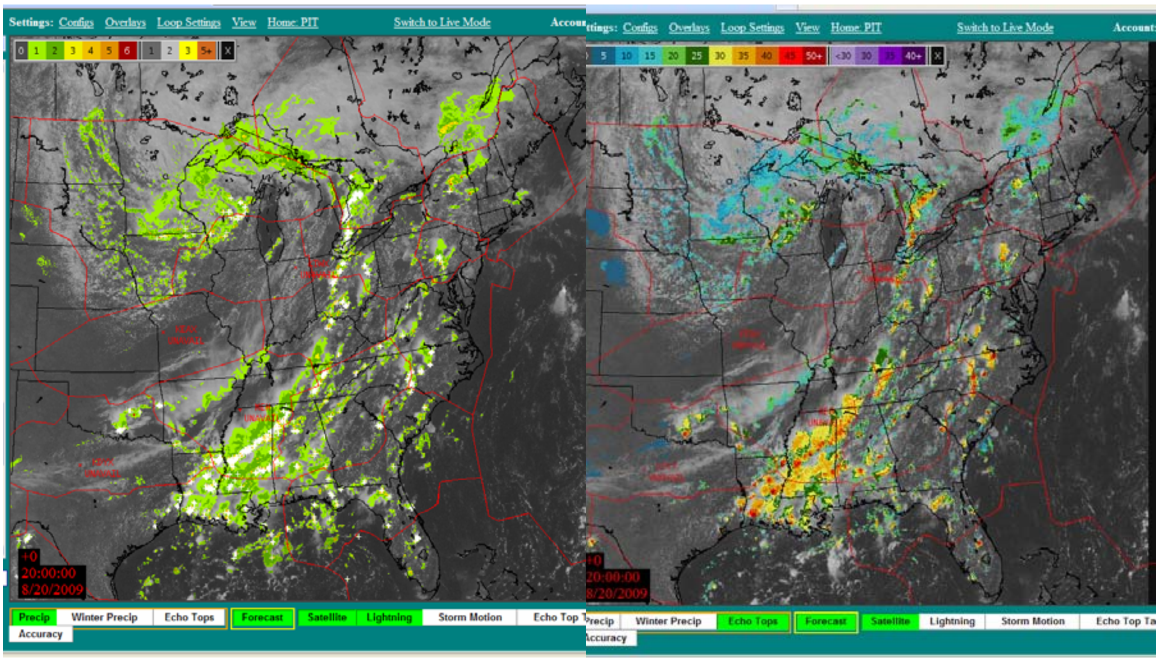
2.1. weather forecast products, translation and decision support tools:

- TAF, METAR, ATIS and wind information can be called for display on a dedicated screen at TRACON and en-route ACC positions;
- ATCSCC have access to Collaborative Convective Forecast Product (CCFP) produced by NWS AWC. NWS leads the collaboration between the 21 centres and the industry (including airlines) meteorologists. The CCFP is produced every 2

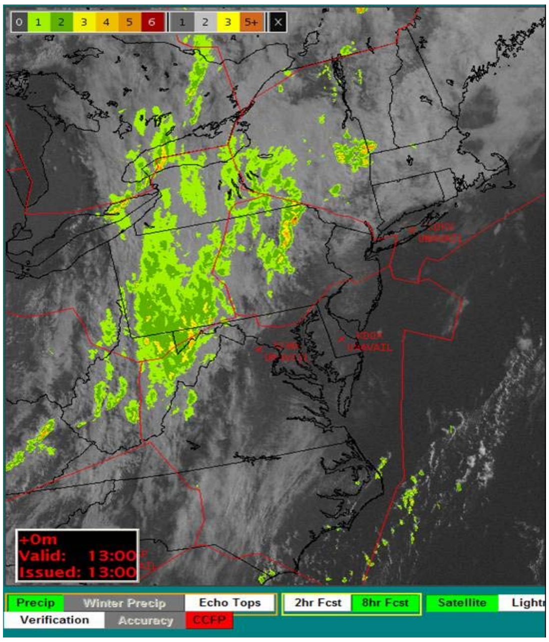
hours (1 March - end of October). It presents polygons for 2, 4, 6 hour forecasts of coverage (sparse, medium, solid) and forecast confidence (low, high).There is 51% vote for Aviation Weather Centre. The product is an early version of the Single Authoritative Source (SAS) envisioned for NextGen. Traffic Flow Managers use it to develop daily playbooks.

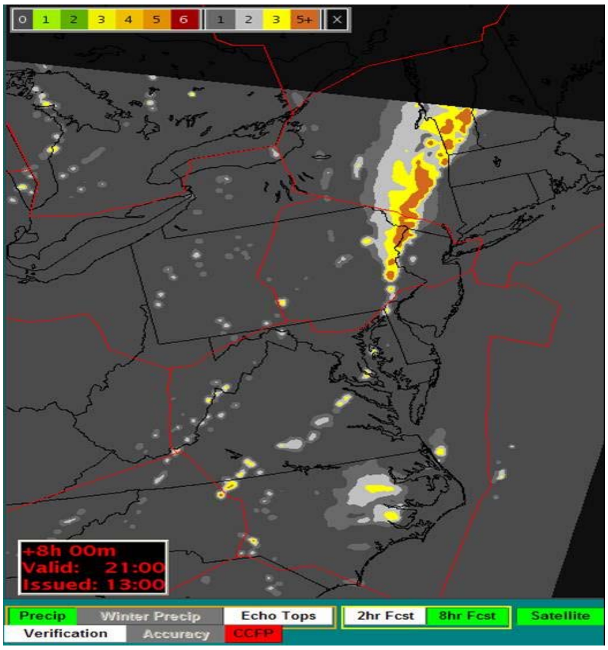


- The Corridor Integrated Weather System (CIWS) provides a forecast of precipitation and echo tops from 0 to 8 hours into the future, updated every 5 minutes. It blends high-resolution numerical weather model with storm extrapolations, while maintaining identical look and feel that is interpreted like radar reflectivity. CIWS is on Traffic Situational Display since 2012.

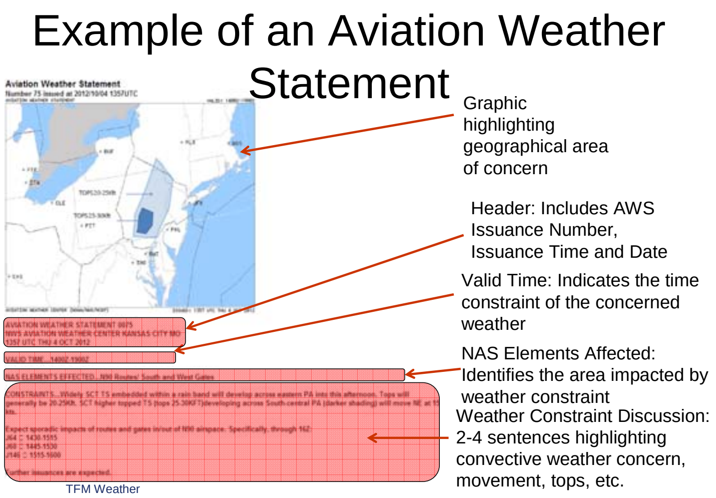


Consolidated Storm Prediction for Aviation (COSPA) (Experimental)

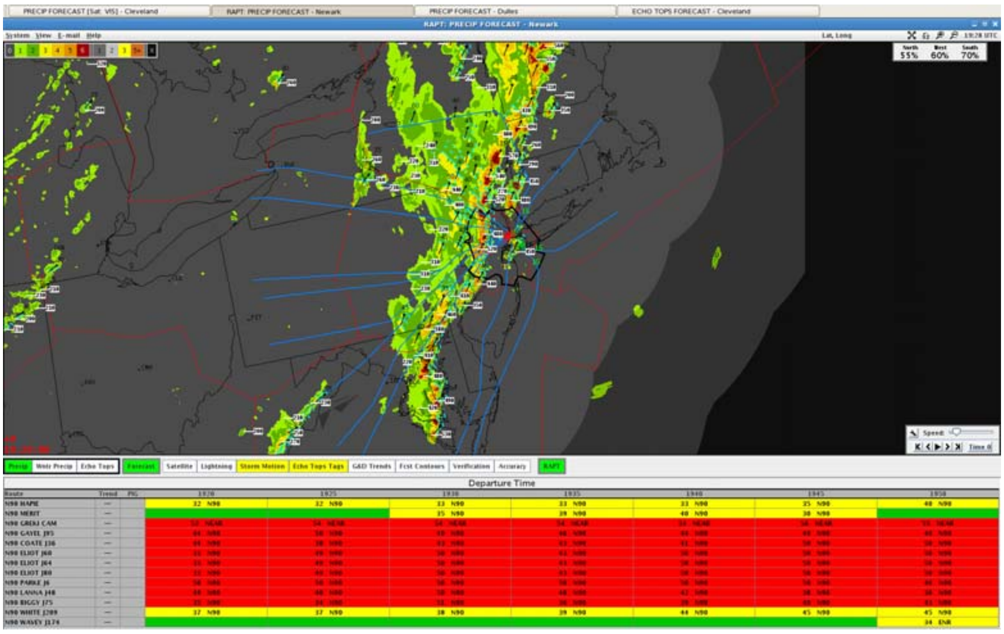




- Aviation Weather Statement is a Command Centre Advisory, focused on convective but also on winter weather. Event based type of product, experimented at NY and NAS wide in 2014. Information is presented to traffic managers only if it impacts traffic.



- The Route Availability Planning Tool (RAPT) is an example of ATM–weather integration (see overleaf). It is based on the CIWS (up to 2 hours convective weather forecast) and a pilot deviation model and presents the information in a 5 minute increment. The traffic is not displayed. It is considered Level 2 integration/translation. RAPT is a translation function, assisting in identification of traffic blockage, but still not a decision tool.

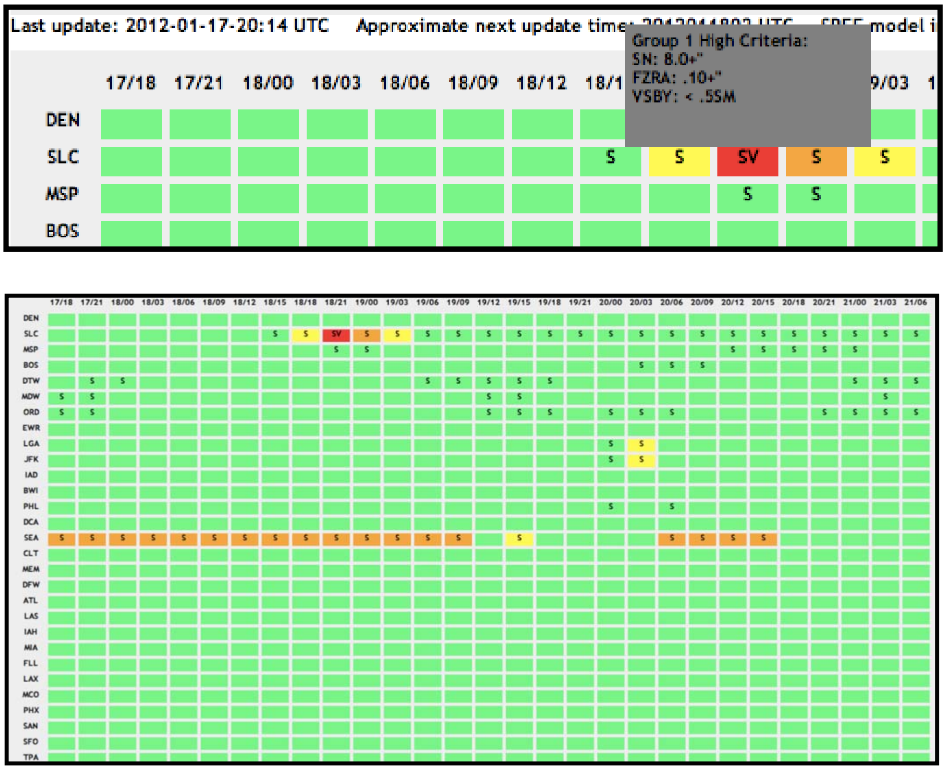


Example of RAPT screen shot

- Extended Convective Forecast Product (ECFP). Similar to CCFP, which is an instantaneous picture, ECFP displays polygons projected further into the future time. The prediction is not made by a meteorologist but automated (model based). The product is available all the time.

Example of Extended Convective Forecast Product

- Aviation Winter Weather Dashboard. The product is introduced last winter and represents a CDM / AWC collaboration dashboard approach. It is automation-driven and presents information for 29/30 “core” airports. The product includes use of terminal impact criteria (green/yellow/orange/red) adjusted by airport.



Example of Aviation Winter Weather Dashboard

2.2. current weather reports:

- ACC SUP, TWR SUP and controllers have access at their working positions to the METARs and ATIS

2.3. weather radar data:

- Weather radar data are available for display on the main situation window at the CWPs. The radar data are provide by FAA and National Weather Service radars. The update rate is 1 minute.

2.4. weather satellite data:

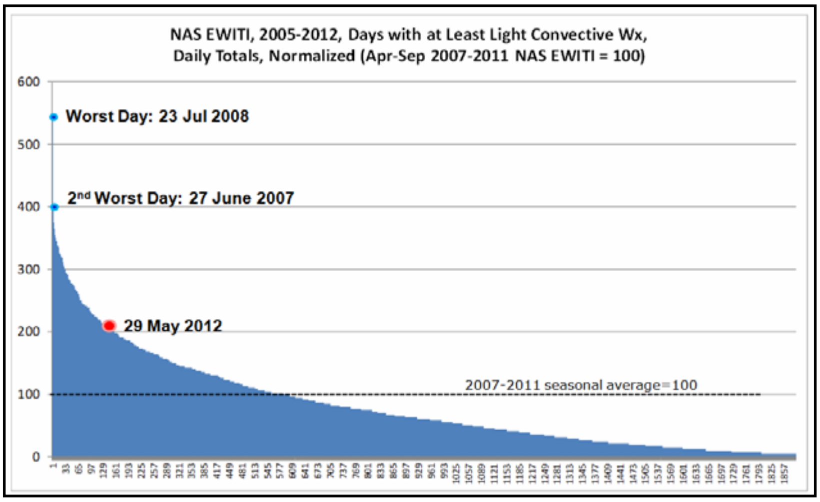
- weather satellite data is available as stand alone display only for ATCSCC;

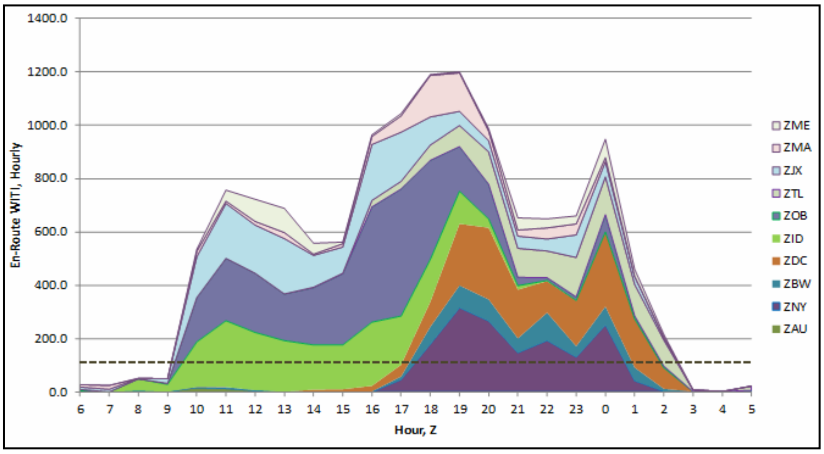
2.5. pilot reports:

- used as far as provided by pilots; controllers can also seek information from pilots;

2.6. R&D and experimental tools

- Weather Impact Traffic Index (WITI) and WITI-FA - provides objective, common frame of reference for weather impact on NAS. It can support historical comparison, i.e. of a reference day to a past day; support also alternative views of NAS constraints and indication of the forecast accuracy.

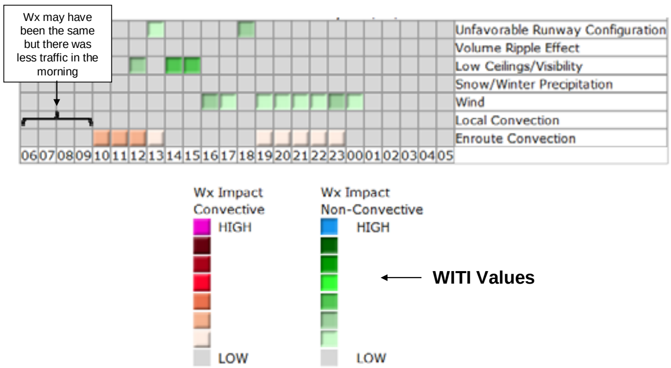




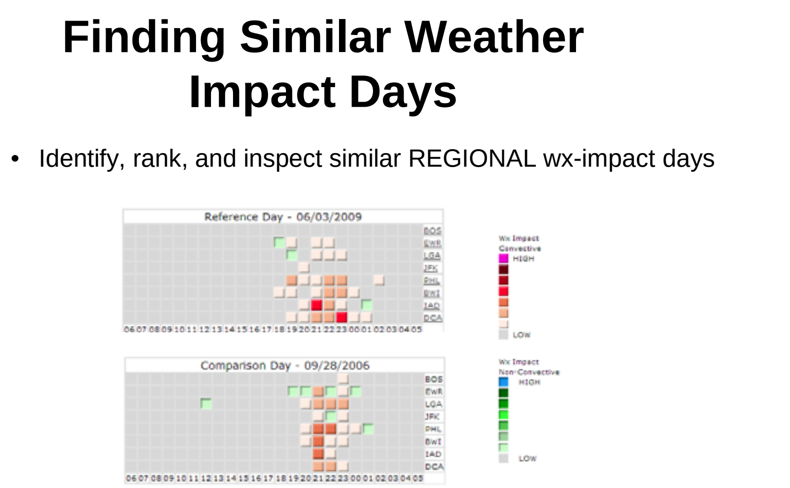
- Similar WX Impacts, Convective & Non-Convective

Similar Weather Impact Events (WX & Demand) **

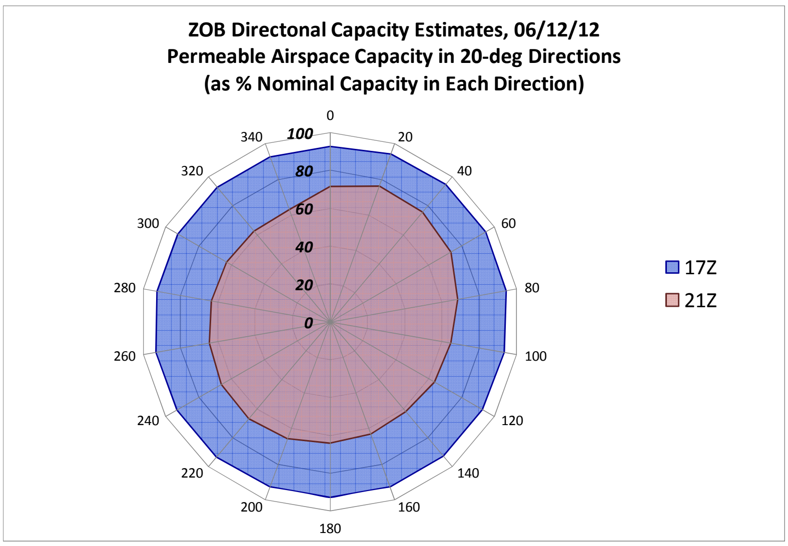
Example: ORD – Varying impacts throughout the day, both convective and non-convective



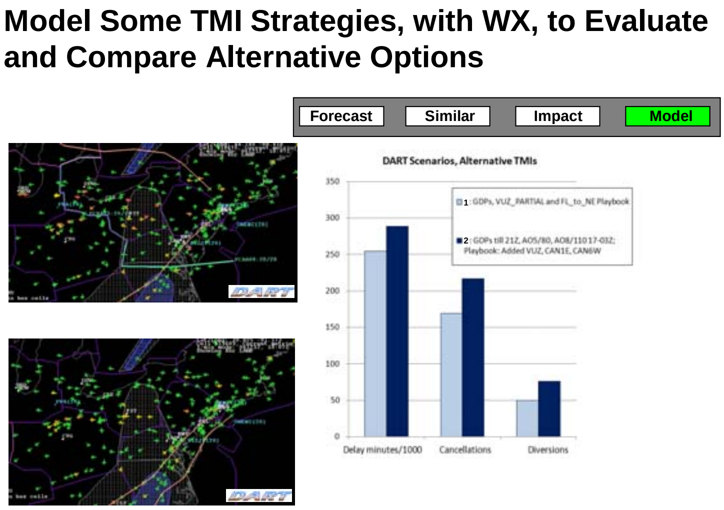
- Similar Weather Event Identification - an AvMet's Similar Weather Toolkit© that can search for and compare convective weather events that are similar in: organisation (line, cells, etc.), intensity, vertical extent (tops), location, coverage, evolution (strengthening, weakening), time of day occurrence.



- Capacity Degradation Caused by Weather – a tool that enables to define airspace availability as a set of the "capacity degradation" percentages along a predefined set of directions instead of a single "capacity degradation" percentage for the ATC center.



- The Dynamic Airspace Routing Tool (DART) is a weather-aware superfast-time NAS/ATM simulation model. The simulation integrates the ETMS flight plans, terminal WX (convective and non-convective), TRACON and en-route convective WX (actual and forecasts); airport RWY configurations and capacity (may be Wx-degraded), however does not include physical RWYs, airspace at sector and ATC center level, capacity (may be Wx-degraded), TMIs (Playbook, GDP, GS, AFP, MIT). The tool can blend historically enforced TMIs and simulated TMIs, reroutes, delays, Cnx, simulated airborne holding & diversions. There are user-definable rules, risk factors, equipage profiles, randomized WX, airport/airspace capacity, WX forecasts, traffic. It is a “superfast-time” NAS simulation tool to enable simulation of an entire “day-in-the-NAS” (50,000+ flights and all the above detail) on a desktop PC in 2-3 min.



3. Procedures, guidance and practices for management of severe weather impact

3.1. tactical ATCO procedures / guidance:

- in case of low visibility operations - increased separation minima on approach;
- controllers may ask pilots to report hazardous weather;
- pilot weather reports (e.g. severe turbulence) are passed to concerned flights in the affected area and the MET office, and depending on the location of the area - to concerned adjacent ATC units;

4. Decision making loop and responsibilities

4.1. how (process) and who (roles) is involved:

- Traffic managers do not close airspace or flows;
- Reducing capacities is a joint responsibility with the ATC facility;
- Flow measures include rerouting of flights but still allow some flights through the affected airspace;
- The ATCSCC can drive the decision

4.2. Monitoring

- A tool was developed that provided for the establishment (via a benchmark study) of key thresholds for each airports – e.g. SF below 3500, ceiling, visibility and wind speed and direction. A board on a secure website presents the automatically populated information and enables comparison against the thresholds. It can be seen on a calendar type of presentation with airports colour coded by TAF reliability (starting with 4 hour TAF), for example coded in red if two or more threshold levels were exceeded.

5. Measures used to mitigate impact of severe weather

- Measures are implemented at tactical level (up to few hours in advance);
- Active and airborne flight can be re-directed by using a re-route plan. The plan is executed trough the en-route facilities.
- Measures may focus on particular traffic streams and flights.

- Whenever a re-route is possible there is an attempt to inform the operator in advance to enable appropriate fuel management.
- When the airport is affected the arrival rates are a key factor.
- Currently there is a tendency for a higher aircraft load factors reaching 80-90%. This creates pressure for the operators as in case of flight cancelations the options are very restricted.
- Winter weather, especially snow forecast is a reliable decision making factor for cancelation and it is often used by the operators because the forecast impact is normally very credible.
- There is a warning announcing the level of cancelations at a given airport but without providing details which airlines cancelled flights because of commercial concerns.
- There is a new tool - Collaborative Trajectories Options Program – that is believed to be of particular importance by helping identify operator’s intent. This new traffic management tool helps operators understand what their options are – if the route is optimal they may want to keep it until the delay accumulates to a particular threshold.
- Operators are not proactively looking into the diversion options because they can change flight route after departure for business reasons. Currently, stakeholders are exploring the pertinent ways to introduce transparency – how do you push the information to concerned parties (e.g. operator) about flights that decided to divert.
- There is an advanced alert of the potential impact, and potential/planned traffic measures are incrementally announced by means of: putting in place of a “Possible Program” 6 to 8 hours in advance; then its status is changed to a “Probable Programme”, and finally to “Expected Program” that is to be implemented. The decision criteria used to establish and update the programme are: time in advance, probability of the weather and type of weather phenomena, however it is composed using best judgement and without strict criteria.
- Ground delay programme depends on the airport and the average duration of flights affected; it takes 1 to 1.5 hours before an update takes place and is notified to concerned parties, for SF – the time needed is 3 hours

6. Coordination of possible severe weather impact and measures to be taken

6.1. inter-sector (within the ANSP) ;

6.2. inter-centre (with adjacent ATC units):

- coordination of avoidance routes or any other traffic restriction is responsibility of the OPS SUP; ATCO shall inform the OPS SUP in case of such need;
- There are no explicit measures to protect the airspace/sectors adjacent to those affected by weather in case of traffic deviation. Normally it is left at flow managers’ discretion to inform the OPS SUP or controllers of adjacent units of deviation traffic but it is done ad-hoc and can not be always relied upon.

7. Potential for improvement

- Provision of probabilistic forecast – not only forecasting the probability of the phenomena but also the probability of given volume of airspace to be affected;
- Possibility to receive forecast information for the ‘outliers’, for example at SF 200 ft ceiling makes a big difference – it is an operational trigger;
- Weather integrated in the automation, i.e. at the aircraft level to determine the effect and communicate it to the dispatcher; integrating the weather in a standardised and objective way; set the system in a transparent way for all concerned stakeholders;
- Ensure availability of meteorological staff at all times – 24/7;
- Often acceptance rates are reduced because of compression and winds but it may not be objective (operationally justified). The weather information may be available but there is problem with its translation (e.g. operational impact estimation) for the

operational people. It will be beneficial to visualise the areas of compression, for example at 1000 ft increments; wind forecasts are pretty reliable.

- Winds aloft and the impact on the acceptance rate.
- More accurate weather forecasts and improved granularity of weather forecast about the evolution of the weather phenomena, for example a more precise forecast Multilevel forecast for wind;
- MET card in the aircraft for improved MET data collection;
- The TAF may become obsolete in the future – it is not updated fro a long period of time; it is a deterministic forecast, some other tools needed;
- Having a precise and reliable feedback how good the traffic management was in terms of avoiding/mitigating the impact of severe weather.

Annex 7 – Summary of accidents and incidents

The most common characteristics of severe avoidance weather scenario include:

Non-standard traffic flows – the traffic flow is irregular and not easy to anticipate because of:

- the changing intensity of cells, both vertically and horizontally;
- the situational awareness of the flight crew and routing decisions they take based on the display of the on-board weather radar;
- altitude of aircraft (often it is different than the FPL filed altitude/FL);
- deviating from the original planned route;
- the training and experience of the flight crews; and
- the difference in the airline operator's procedures for weather avoidance.

Reduction in available airspace – controllers will have less airspace volume available for conflict resolution tasks with a consequent impact on sector capacity;

New conflict points – new random crossing points are likely to occur as a result of the disrupted and non-standard traffic patterns;

Increased frequency occupancy time – radio-communication is likely to be prolonged due to the necessity to clarify the details associated with the avoidance actions as well as revised onward routing clearances. Usage of non-standard radio-telephony (RTF) is likely to increase;

Increased manual (telephone) coordination – telephone coordination with adjacent sectors or ATS units is likely to increase due to the necessity to coordinate the details associated with the avoidance actions (change of routes and flight levels);

Rapidly changing situation – isolated CB cells can quickly evolve into a squall line and make navigation through the line of CBs increasingly challenging for the pilots;

Degradation of RVSM capability – convective weather conditions are associated with moderate to severe turbulence, hence it might be advisable to downgrade the reduced vertical separation minima (RVSM) airspace and introduce 2000 ft vertical separation in areas with reported severe turbulence;

Lack of information about traffic in own sector (not on frequency) – situations may arise when traffic deviating from its planned/cleared flight route, due to bad weather, penetrates (or flies close to the boundary of) another sector's airspace without prior notification of the controller in charge of that sector who is not aware of crew's intentions;

Limited applicability of radar vectoring - use of radar vectoring to resolve potential traffic conflicts might be limited due to crew inability to maintain the required headings. This is a very significant factor in busy environments where controllers rely heavily on radar vectoring to provide separation;

Airspace constraints - ATC sector overloads can be aggravated by the combination of weather factors (majority of these are Cb-related) and airspace constraints in particular in busy TMAs.

The following list is a summary of aviation accidents and incidents in which severe weather and related atmospheric conditions were reported as either a significant causal and/or contributory factor.

This cumulative list will be used to present a more narrow perspective on weather related events related but not limited to the risks of loss of in-flight separation, loss of control, CFIT, runway incursion and runway excursion.

1. IN-FLIGHT ICING

- On 12 May 2005, a Boeing 717-200 on a scheduled passenger flight from Kansas City to Washington National and climbing in night IMC experienced a sudden loss of control from which recovery was only achieved after a prolonged period of pitch oscillation involving considerable height variation.
- On 31 October 1994, an ATR 72 crashed near Roselawn, Indiana, USA, following loss of control due to airframe icing.
- On 11 August 1991, a British Aerospace ATP, during climb to flight level (FL) 160 in icing conditions, experienced a significant degradation of performance due to propeller icing accompanied by severe vibration that rendered the electronic flight instruments partially unreadable.
- On 14 September 2005, an ATR 42-320 experienced a continuous build up of ice in the climb, despite the activation of de-icing systems aircraft entered an uncontrolled roll and lost 1500ft in altitude.

2. IN-CLOUD AIR TURBULENCE

- On 1 September 2005, a DHC-2 Beaver, crashed near Squaw Lake, Quebec, Canada, following loss of control in adverse weather and moderate to severe turbulence.
- On 22 June 2009, an Airbus A330-300 on a flight from Hong Kong to Perth encountered an area of severe convective turbulence in night IMC in the cruise at FL380 and 10 of the 209 occupants sustained minor injuries and the aircraft suffered minor internal damage.

3. HAIL DAMAGE

- On 26 May 2003, an A321 suffered severe damage from hail en route near Vienna. Some of the flight deck windows became crazed and other areas of the airframe suffered extensive damage although this was not apparent to the crew. The aircraft made a precautionary descent to FL230, in accordance with the required abnormal procedures, and continued the flight to its destination of Manchester. The crew had no indication or warning that the aircraft was about to enter an area of severe turbulence, associated with the upper levels of a Cumulonimbus cloud.

- On 9 June 2006, an Airbus 321-100, encountered a thunderstorm accompanied by hail around 20 miles southeast of Anyang VOR at an altitude of 11,500 ft, while descending for an approach to Gimpo Airport. The radome was detached and the cockpit windshield was cracked due to impact with hail.

4. LIGHTNING DAMAGE

- On 14 September 1999, a Boeing 757 crash landed and departed the runway after a continued un-stabilised approach in bad weather to Girona airport, Spain.
- On 4 December 2003, a Dornier-228 approaching Bodo, Norway, was struck by lightning and suffered damage to the elevator control. The crew were temporarily blinded and momentarily lost control of the aircraft but managed to crash land just short of the runway threshold.

5. FOG

- On 27 April 2008 an Airbus A340-300 on a flight from London carried out a night auto ILS approach to Runway 06, Nairobi airport, Kenya. Just prior to touchdown, the aircraft entered an area of fog and the PF lost sight of the right side of the runway and the runway lights.
- In March 1977, a B747-200 commenced its daylight take off at Los Rodeos airport, Tenerife in very poor visibility, recorded as 300 metres three minutes earlier, after receiving only a departure clearance and continuing the take-off roll even after ATC advised "standby for take-off". It collided with a Boeing 747-100 which was taxiing on the runway in accordance with its ATC clearance issued on the same radio frequency.
- On 10 April 2010, a Tupolev Tu-154M on a pre-arranged VIP fight from Warsaw to Smolensk Severny impacted ground obstacles and terrain.
- On 8 October 2001, in thick fog at Milan Linate airport, Italy, an MD87 on its take-off roll collided with a Cessna Citation which had taxied onto the active runway.

6. STRONG LOW LEVEL & SURFACE WINDS

- On 10 July 2002, a Saab 2000 on a flight from Basel to Hamburg encountered extensive thunderstorms affecting both the intended destination and the standard alternates and due to a shortage of fuel completed the flight with a landing in day VMC at an unmanned general aviation airstrip where the aircraft collided with an unseen obstruction.
- On 2 August 2005, an Airbus A340-300 on a flight from Paris CDG to Toronto landed at destination in daylight during a thunderstorm and failed to stop before reaching the end of the runway. It exited the airport perimeter and crossed a main road before ending up in a ravine approximately 300 m beyond the end of the runway.
- On 24 December 2000, a DC10 overran the runway at Tahiti after landing long on a wet runway having encountered crosswinds and turbulence on approach in thunderstorms.
- On 3 February 2002, a MD-11 encountered a sudden exceptional wind gust (43 knots) during the landing roll at Dublin, Ireland. The pilot was unable to maintain the directional control of the aircraft and a runway excursion to the side subsequently occurred.

- On 9 March 1997, a McDonald Douglas MD 81 on a flight from Stockholm Arlanda to Kiruna left the runway during the night landing at destination performed in a strong crosswind with normal visibility.
- On 21 March 2008, a Boeing 737-800 on a flight from Charleroi, Belgium to Limoges carried out a daylight approach at destination followed by a landing in normal ground visibility but during heavy rain and with a strong crosswind which resulted in runway overrun.
- On 1 March 2008, an Airbus A320 on a flight from Munich to Hamburg experienced high and variable wind velocity on short final in good daylight visibility. During the attempt to land on runway 23 with a strong crosswind component from the right, a bounced contact of the left main landing gear with the runway occurred which was followed by a left wing down attitude resulting in the left wing tip touching the ground.