J6.2 FLYSAFE - AN APPROACH TO FLIGHT SAFETY - USING GML/XML OBJECTS TO DEFINE HAZARDOUS VOLUMES SPACE FOR AVIATION

Andrew K. Mirza *, Christian Pagé **, Sébastien Geindre **
* Met Office, Exeter, Devon, EX1 3PB, ** Météo France, 31057 Toulouse, France

Abstract

World-wide air traffic is expected to double or triple within the next 20 years. With the existing on-board and on-ground systems, this could lead to an increase of aircraft accidents, in the same, or a higher proportion

In this paper, an account of the scope and objectives of the FLYSAFE project is described, this aims to develop a Next Generation Integrated Surveillance System (NG-ISS) on-board the aircraft and a supporting Ground-based network of Ground Weather Processors (GWP) and Weather Information Management Systems (WIMS). This paper will describe the state of development of the WIMS, the Ground-based Weather Processor architecture; examples of gridded data converted to GML data objects; and the data model used to exchange data. These developments are placed into the context of other developments with respect to availability of data for the aviation sector.

Although adverse weather is seldom the exclusive cause of accidents, it is nevertheless one of the most disruptive factors in aviation.

1. INTRODUCTION

Worldwide air traffic is expected to double or triple present day levels within the next 20 years (EC, 2001; JPDO, 2006). With the existing on-board and on-ground systems, this could lead to an increase of aircraft accidents, in the same, or a higher proportion. Despite the fact that accidents are rare, this increase is perceived as unacceptable by society and new systems and solutions must be found to maintain the number of accidents at its current low level. Although adverse weather is seldom the exclusive cause of accidents, it is nevertheless one of the most disruptive factors in aviation (FAA, 2007).

Weather phenomena can evolve at rapid rates, over a wide spatial extent when compared to other factors that may affect the safe conduct of flight, apart from aircraft mechanics, e.g., runway status, airspace sector access, support services. Thus, within the spectrum of aeronautical information, meteorological data or weather information is an important component for the safe conduct of a flight; and in the future for the efficient management of air traffic (EC-ATM, 2006).

This paper gives an account of the FLYSAFE project. Section 2 provides a description of the vision, the scope and objectives of the project. Section 3 describes the current state of development of the ground based architecture to support the FLYSAFE concept. Section 4 outlines FLYSAFE's perspective on the consequences for an increase in air traffic density and how its developments may mitigate such effects. Section 5 describes the meteorological data exchange model developed as part of the project. Section 6 describes the process used within FLYSAFE to create GML-Objects that describe weather phenomena, in particular those that effect aviation operations. Section 7 illustrates the results obtained after applying the data model and data processing described in sections 5 and 6. Section 8 illustrates the spatial and temporal selection of GML-Objects. Section 9 considers FLYSAFE's developments in the context of developments elsewhere within the aviation industry. Finally, section 10 draws conclusions and provides brief details for the evaluations to be undertaken during the final phase of the project.

2. FLYSAFE – VISION, SCOPE AND OBJECTIVES

FLYSAFE is a consortium of thirty-six small and medium sized enterprises based within Europe. The project is part funded under the European Commission's 6th Framework for research and development. The project timeframe is four years; having started at February 2005, (EU-FLYSAFE, 2008).

The objective of the project is to develop innovative solutions for systems and services to meet the needs of the aviation community not just today and tomorrow but also for the day after tomorrow.

* Corresponding author address:
Andrew K. Mirza,
Met Office, Exeter, Devon, UK, EX15 1HA;
email: andrew.mirza@metoffice.gov.uk

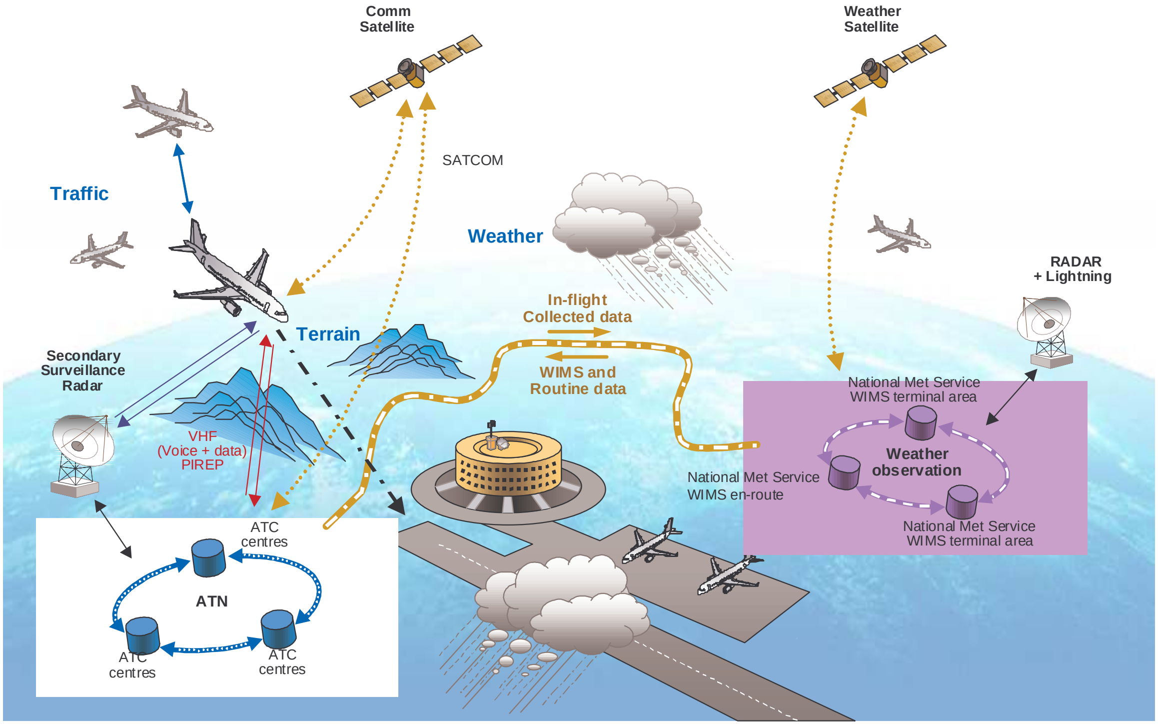

Figure 1: FLYSAFE's vision for an integrated framework of operation that conveys information on hazards to aviation users.

To achieve this objective the project is partitioned into four domains of activity, which defines the scope. The first three domains each address one of the main hazards to daily operations within the aviation community: traffic, terrain and atmospheric hazards. The fourth domain integrates these developments to demonstrate a cohesive framework of operation. Figure 1 is an illustration of such an integrated framework of operation – the FLYSAFE vision.

FLYSAFE aims to develop a Next Generation Integrated Surveillance System (NG-ISS) on-board the aircraft and a supporting Ground-based network of Ground Weather Processors (GWP) and Weather Information Management Systems (WIMS).

Aboard the aircraft the NG-ISS solution enhances the flight crew's situation awareness by providing consolidated information with respect to surrounding traffic, underlying terrain, weather conditions (current and forecast) and its own flight path. A variety of systems and services are employed to make available the data to support the NG-ISS solution.

FLYSAFE envisages that dedicated weather information management systems (WIMS) at airports provide nowcasts for meteorological conditions around a terminal manoeuvring area; National Meteorological Centres provide longer and medium term forecast data for atmospheric hazards: clear air turbulence, icing and parameter data to compute wake vortex. All data made available on-demand through a network of data-hubs, the GWP, accessible to *anyuser*, *anytime, anywhere* (the "*Martini Principle*").

3. GROUND WEATHER PROCESSORS

Figure 2 illustrates the components of the Ground based architecture. Each component is a node within the architecture. Point based observations are reported as measurements by a variety of sensing devices, which includes the aircraft. These are assimilated into numerical models of the atmosphere which generate fields (coverages) that forecast the future state of the atmosphere.

The scope of FLYSAFE's development for the ground segment is the Weather Information Management Systems and the Ground Weather Processor; for the airborne segment it is the on-board NG-ISS.

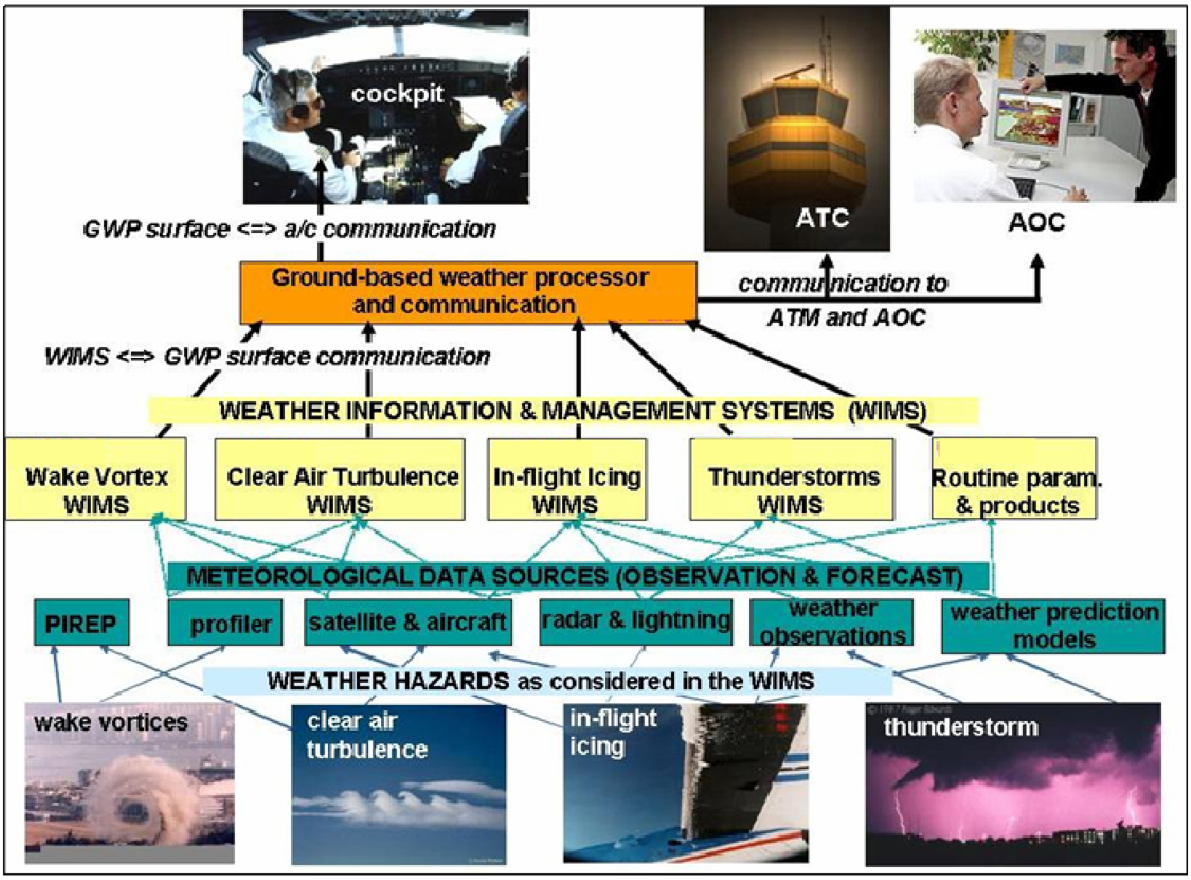

Figure 2: FLYSAFE's ground-based architecture comprising ground weather processors and weather information management systems.

Weather Information Management Systems (WIMS) take as input these forecasts to generate forecasts of atmospheric hazards that effect aviation operations: wake vortices, clear air turbulence, icing and convective activity (Gerz, 2006). The WIMS operate at specialist centres which maybe the National Meteorological Centre, a commercial operator or maybe an airport operations centre. A network of WIMS would generate forecasts for each of the atmospheric hazards at all spatial and temporal scales; ranging from low resolution, long range global forecasts; regional resolution, medium range forecasts to high resolution, local (TMA) nowcasts. It is anticipated that such spatial and temporal range will cover all phases of flight from planning, departure, en-route and arrival.

Each weather information service provider (WISP) converts its forecast fields into atomic data which we call a GML-Object, encoded using the Geospatial Mark-up Language (OGC, 2004). These GML-Objects are stored within a distributed network of data-stores. These data-stores are node points within the architecture and form the interface between aviation users and the WISPs. It is envisaged that two variants of these data stores would exist: a local weather processor to store data for the local TMA scale and a central weather processor to store data at regional and global scales. The essential difference between them exists only in the scale of data stored and the degree of spatial and temporal selection available.

Figure 2 seems to imply a one way flow of data – that is up-linked from the ground to the airborne user; however we anticipate that *in-situ* observations, e.g., AMDAR and PiREPS, would be down-linked to the ground weather processor where it could be made available for requests: to up-link; for local processing or by WISPs and NMCs. With this picture in mind it is a small step to imagine data circulating around the network.

4. ANTICIPATED CONSEQUENCES FOR AN INCREASE OF AIR TRAFFIC DENSITY

As noted earlier, commentators within the aviation industry anticipate significant growth in worldwide air traffic. This expansion ranges from twice to triple the current volume of air traffic c2000. Since optimal or favourable airspace is limited the consequence would be an increase in traffic density within these regions.

Despite advancements in aircraft design and technology, greater traffic density increases risks to: flight safety; traffic management; health and safety of the workforce; reduction in turn-around times on the ground; increased costs should disruption or delay occur; and the environmental impacts on local air pollution, noise and carbon emissions. FLYSAFE's developments are aimed at mitigating some of these effects by improving the situation awareness of the flight crew and improving the management of air traffic flow and flight planning.

It is recognised within the project that weather conditions could effect daily operations adversely – causing delays to departures, to en-route aviation traffic and to arrivals, not just for period caused by the impact of the preceding weather but also for the consequential effects due to misplaced assets which may continue for several days. As such, weather information processing is a key component within the FLYSAFE architecture.

For the on-board system, NG-ISS, weather information is integrated within its processing; data from the ground-based weather processor are fused with *in-situ* observations, the results are analysed by a strategic data consolidation component that provides enhanced situation awareness to the flight crew in terms of traffic, terrain, the atmospheric state and its current flight path.

The NG-ISS is coupled to the ground-based weather processor using a data exchange protocol. The NG-ISS generates automatically requests for data; such requests define the volume of space and temporal range of interest. The requests are sent to a portal which forwards it to the relevant ground weather processor.

The ground weather processor returns data that is spatially and temporally relevant. Weather phenomena that may affect one flight may have no relevance to a flight that follows by ten minutes later but it may affect a different flight which it may encounter in the same time frame.

Using the same data exchange protocol the same data would be accessible to other users or applications, e.g., local and regional air traffic control centres, airline operation centres or ground-based services.

5. GWP DATA EXCHANGE MODEL

We have so far described the architecture proposed by FLYSAFE for the delivery of meteorological data to the flight deck. However, for data exchange to occur a mechanism to request data and return data needs to be agreed. To facilitate this process a meteorological data exchange model (MEMO) has been designed and developed. At present this model is to be used to deliver meteorological data developed within the project; the data model is backwards compatible to a selection of ICAO Annex 3 products (ICAO, 2007) insofar that these are encoded using GML envelopes; we anticipate that developments elsewhere within the industry will provide an appropriate data model for ICAO products.

FLYSAFE's MEMO is expressed using the Unified Modelling Language (UML). Figure 3 depicts the high level packages used to define MEMO. The red (left) <leaf> contain the specification for the atmospheric hazards of interest to this project; the blue (right) <leaf> contain the specifications that encode, using GML, a selection of ICAO Annex 3 messages. The yellow (centre) <leaf> specify the common attributes and metadata to be associated with GML objects and ICAO messages. Figure 4 depicts the GML feature types that define GML objects for the atmospheric hazards: Ice, CAT and Cb activity.

A number of off-the-shelf tools are used to convert this UML data model to GML. Enterprise Architect (Sparx, 2007) is used for the modelling environment and XMLSpy (Altova, 2006) the editor used to tweak the resulting GML schema. The Hollow World GML Application Schema (SEEGRID, 2007) is used to express the data model; ShapeChange (Portele, 2005), modified by the Met Office and Météo France, is used to translate this data model into a GML schema. The GML schema derived is used to encode the objects derived from the post-processing step that converts gridded data into contour values.

The GML encoded data is then used by a variety of applications. The primary application is FLYSAFE's NG-ISS, in particular the data fusion component, which integrates the data into its data processing that provides the flight crew with guidance on the atmospheric state in relation to their flight path. The GML encoding also affords other applications to use the same data, for example, geospatial information systems.

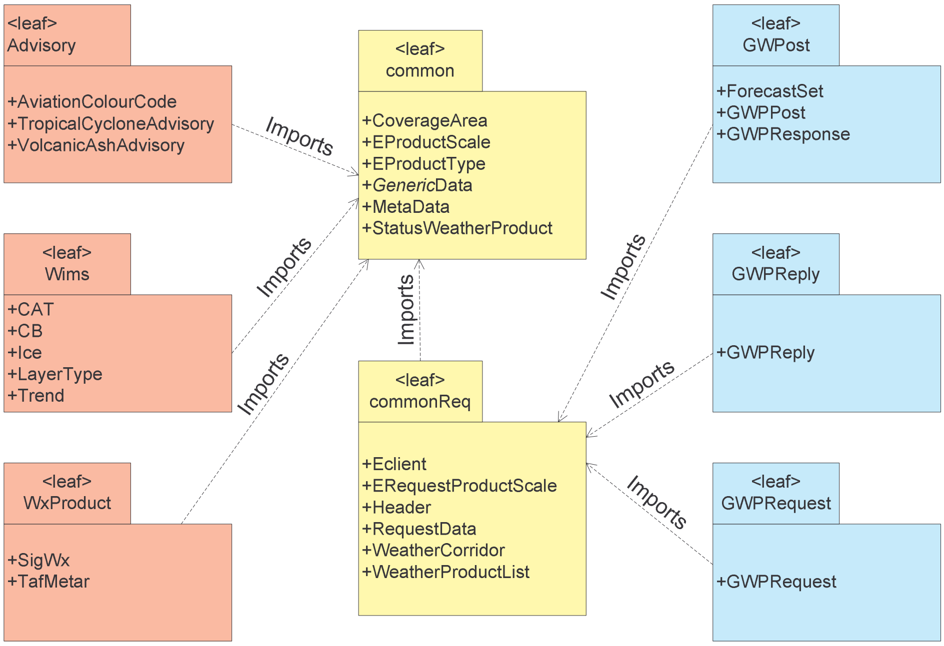

Figure 3: Top level view of FLYSAFE's meteorological data model.

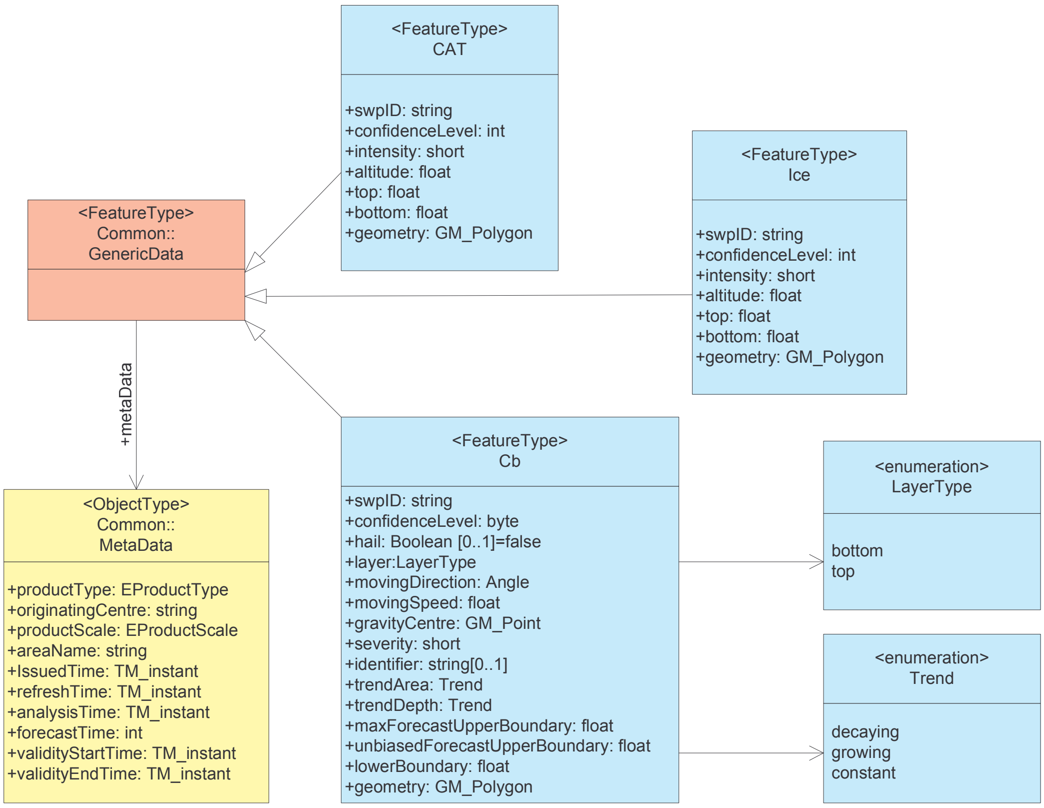

Figure 4: The GML feature types defined within the meteorological data model

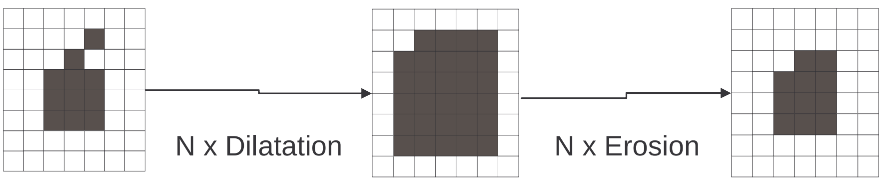

Figure 5: Smoothing filter applied to candidate objects.

6. GRIDDED DATA TO GML OBJECTS

In this section we describe briefly the post-processing step that creates GML-Objects.

Gridded data containing coverages or fields that represent meteorological phenomena which present a hazard to aviation is created by the WIMS. Usually this gridded data is supplied in GRIB format (WMO, 2003), although this is not strictly required.

Gridded fields are first read and thresholds applied to create categorical fields. A temporary boarder is applied to the category field to bind any potential objects with a complete boundary. A flood fill algorithm is used to smooth boundaries of potential objects (category fields are dilated then eroded, figure 5) finally a binary mask is generated indicating the location of candidate field objects.

For each object represented in the binary mask a contour algorithm is applied. The result is each object is represented as polygon. To represent objects more fully, exterior and interior boundaries of the polygon are identified. Any candidate objects that do not contain a minimum number of points are rejected. To reduce the number of points used to represent an object a polygon reduction algorithm is applied – this smoothes corners and sharp angles (> 85°) and reduces the number of points required to represent the object. Finally, each closed polygon is expressed using an ordered list of geographic co-ordinate points. The combination of metadata and the polygon are encoded using the GML schema the result constitutes the GML-Object, which is written to a file for later use.

Figure 6 depicts an extract from a file that contains GML-Objects for clear air turbulence. The top part of the figure contains a reference to the XML schema document; the middle section contains the metadata that describes the object's properties and attributes; the bottom section contains the geographic co-ordinates that define the bounded region of space to which the object's properties apply.

7. EXAMPLES OF GRIDDED DATA TO GML OBJECTS

The GML encoding described in section 5 and the post-processing described in section 6 has been applied to data generated from Météo France's SIGMA system (FME); the UK Met Office Unified Model (UKMO); University of Hanover's (UNI) post-processing of ADWICE

GML Encoded CAT Field Object

Reference to the GML Schema document

```
<?xml version="1.0" encoding="UTF-8"?>
<wims:GWPPost xsi:schemaLocation="http://www.flysafe-eu.org/wims memo.xsd"
xmlns:wims
---------------------------------------
<wims:swpId>swp_catg.200701250000000000_1</wims:swpId>
<wims:confidenceLevel>1</wims:confidenceLevel>
<wims:intensity>1</wims:intensity>
<wims:altitude>7185</wims:altitude>
<wims:top>8117</wims:top>
<wims:bottom>7185</wims:bottom>
<wims:catType>0</wims:catType>
<wims:geometry>
<gml:Polygon srsName="urn:ogc:def:crs:EPSG:4326">
  <gml:exterior>
   <gml:LinearRing>
    <gml:posList>   -89.44 162.28 -89.44 162.28 -89.81 165.09 -89.81 167.34
     -89.81 171.84 -89.81 174.09 -89.81 176.34 -89.44 178.03 -89.44 176.34
     -89.44 171.84 -89.44 169.59 -89.44 167.34 -89.44 162.28 -89.44 162.28
    </gml:posList>
   </gml:LinearRing>
  </gml:exterior>
</gml:Polygon>
</wims:geometry>
```

GML Object Meta Data for CAT Object

GML Object - closed polygon that defines, in this case, the area of moderate to severe CAT.

Figure 6: A GML-Object representing a region of clear air turbulence.

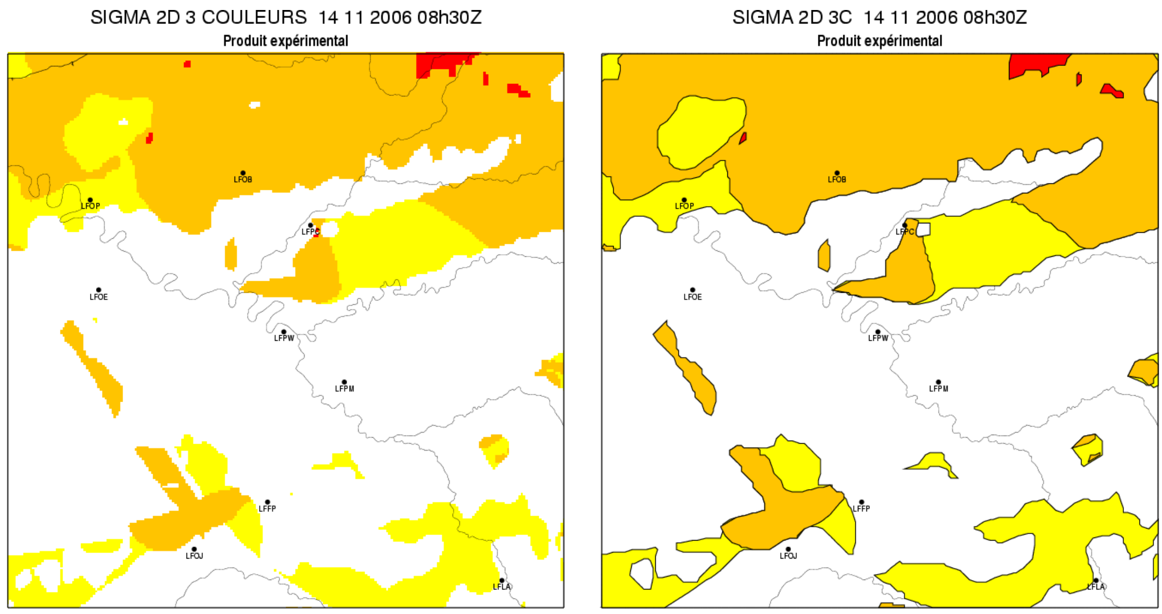

Figure 7: SIGMA Atmospheric ice forecast. The image on the left is generated using the source gridded field; the image on the right is generated using GML-Objects.

data from Deutscher Wetterdienst's (DWD); and forecast products from Deutsches Zentrum für Luft- und Raumfahrt e.V (DLR).

Figure 7 shows a gridded field for icing generated using Météo France's SIGMA system. The figure on the left is generated using gridded data whereas the figure on the right is generated using the object data derived from the grid.

The grid-to-objects post processing was applied to a SIGMA output file with 200 x 200 grid points at 1 kilometre resolution, ten vertical levels and at one time step. (This coverage is representative of an airport's terminal manoeuvring area.) The file size of the original gridded data using the GRIB format was ~1.7 MB; the corresponding GML-Object file containing similar information was found to be ~ 35 KB, which on compression was reduced to 5 KB. This reduction in file size is sufficient to make it feasible to uplink this data to the NG-ISS in terms of the time to uplink and the cost of transmission.

Figure 8 shows the gridded field for forecast clear air turbulence generated from the Met Office Global Unified Model. The upper (green) figure is generated using the gridded field whereas the lower (orange) figure is generated using the object data derived from the grid.

The grid-to-objects post processing was applied to a Unified Model output with 640 x 480 grid points with an approximate 40 kilometre resolution, five vertical levels and at one time step. The file size of the original gridded data is 4.4 MB; the corresponding GML-Object file containing similar information was found to be 4.0 MB, which on compression was reduced to ~200 KB. It was found that compression of the GRIB file achieved the same reduction in file size.

Based upon these early results, clearly the benefit of the grid-to-objects post processing as applied to the Unified Model output is questionable. Further evaluation will be undertaken during the implementation phase of FLYSAFE project. However, it is noted that GML imposes an extra data overhead in the use of tagged values and parameters which may detract from the advantage gained by the SIGMA output. Furthermore, the number of objects created for the global scale was greater, and there were more objects with larger boundaries. However, within the FLYSAFE vision, only data relevant to the user's volume of interest would be required. In this respect, only objects that intersect this volume would be returned thus it is unlikely that all objects within the global field would be returned in response to a request from an airborne user.

We have noted that GML-Objects are features that describe regions of space; they are whole features with spatial and temporal attributes, they may also possess additional attributes such as speed, direction, growth, decay, etc. These

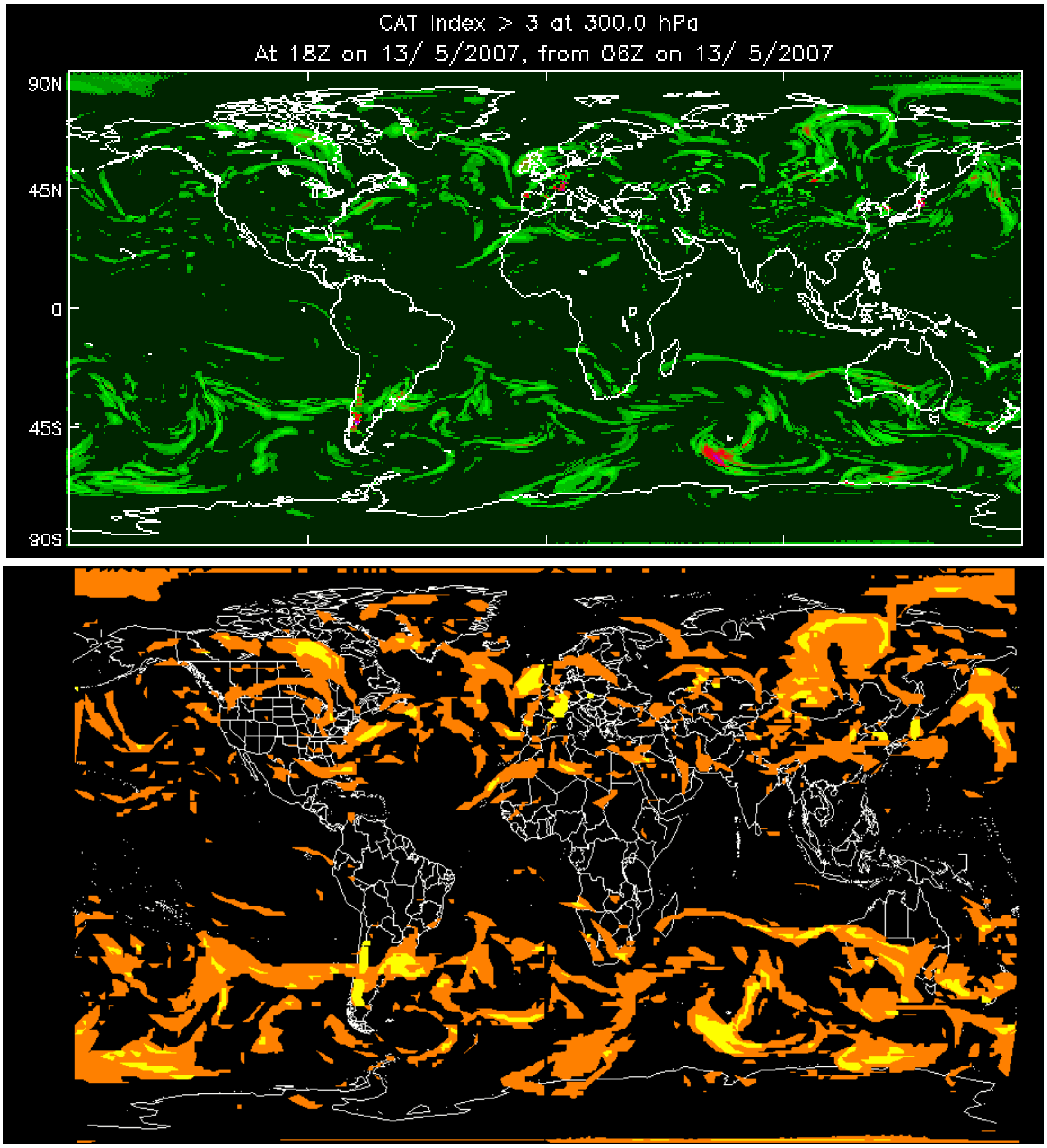

Figure 8: Unified Model atmospheric forecast for clear air turbulence. The upper (green) image is generated using the source gridded field; the lower (orange) image is generated using GML-Objects.

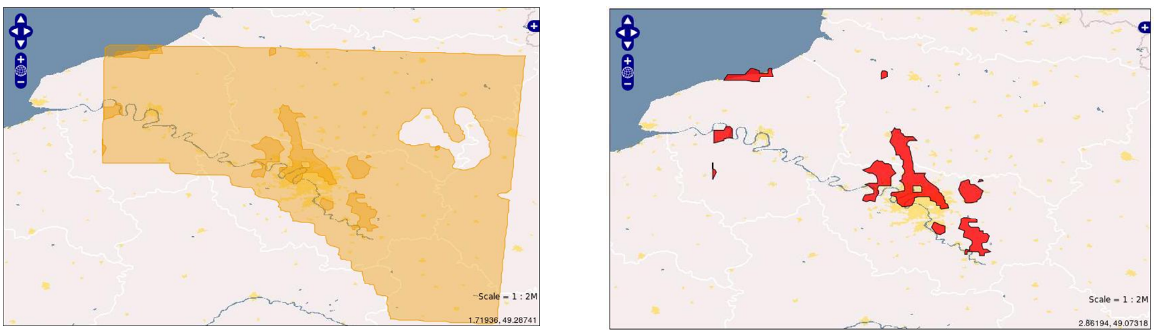

Figure 9: The image on the left shows region affected by moderate to severe ice. The image on the right shows only the region affected by severe ice.

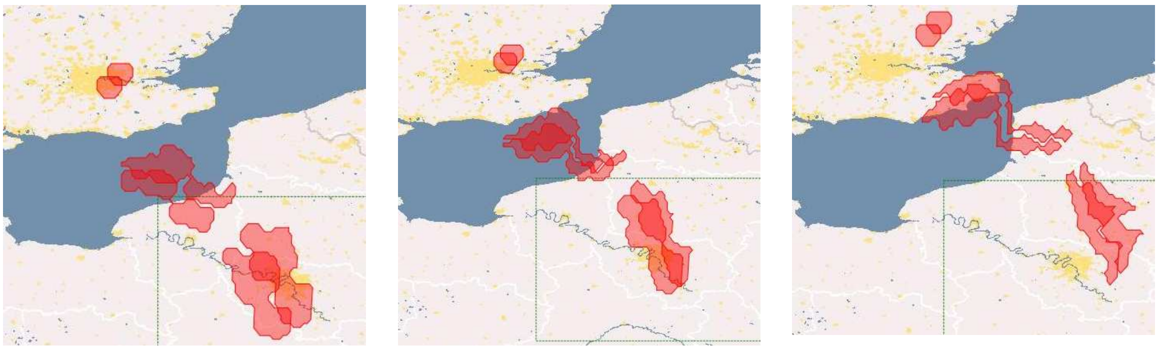

Figure 10: Cb objects selected at twenty minute intervals.

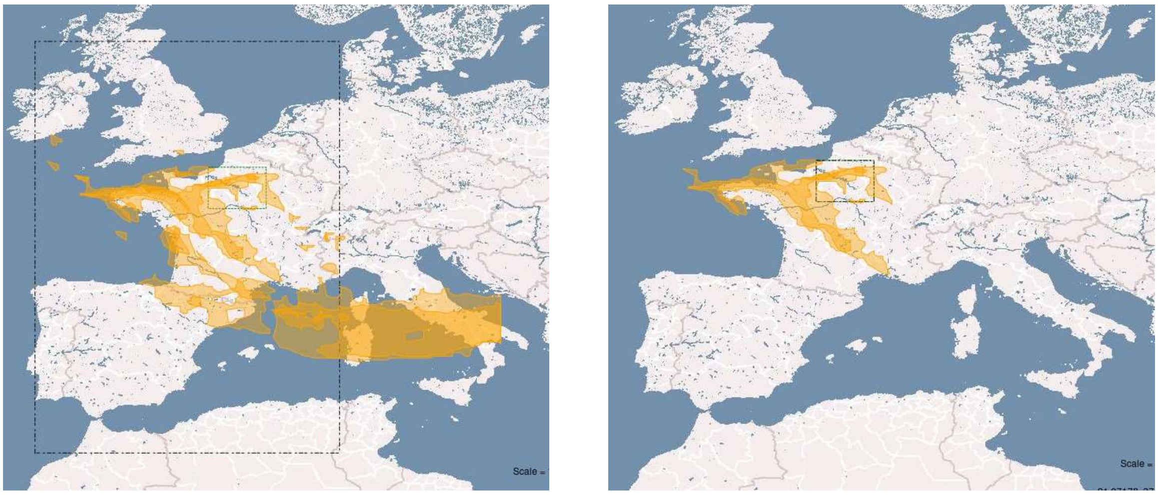

Figure 11: The image on the left shows Ice objects that intersect the large bounding box. The image on the right shows only the ice regions for the smaller bounding box.

attributes afford the opportunity to apply selection criteria to filter the objects.

8. SPATIAL AND TEMPORAL SELECTION OF GML-OBJECTS

Each object has at least metadata that describes its bounding box and contains temporal data for analysis and validity times. Each object has a unique code and is stored within an object database. This permits spatial and temporal selection. Figure 9 shows how data objects can be used within a geographic information system. The image on the left shows the area affected by conditions for moderate to severe ice formation; the image on the right, by selection, shows only the area for severe icing.

Figure 10 shows Cb objects selected by time. The image on the left is for the time period 1200-1220; the centre image is for the time period 1220-1240; the image on the right is for the time period 1240-1300.

Figure 11 is a further example for the spatial selection of Ice objects. The image on the left illustrates the intersection between the space occupied by the ice objects and the domain specified by the larger bounding box at one flight level for an en-route phase. Similarly, the image on the right is for the same flight level but for the small bounding box that represents the domain for Paris TMA. Only those objects that that intersect the volume or coverage of interest are selected and returned to the user.

It is possible to combine 3-D spatial co-ordinates (horizontal dimensions and flight levels) and temporal parameters to retrieve objects that make the intersection within the volume of interest and make the union within the specified time frame.

Figure 12 is a final illustration that shows the objects selected for an en-route phase of flight. The objects returned are regional scale Cb top (red), local scale Cb base (blue), regional scale CAT (black) and Ice objects (orange), which

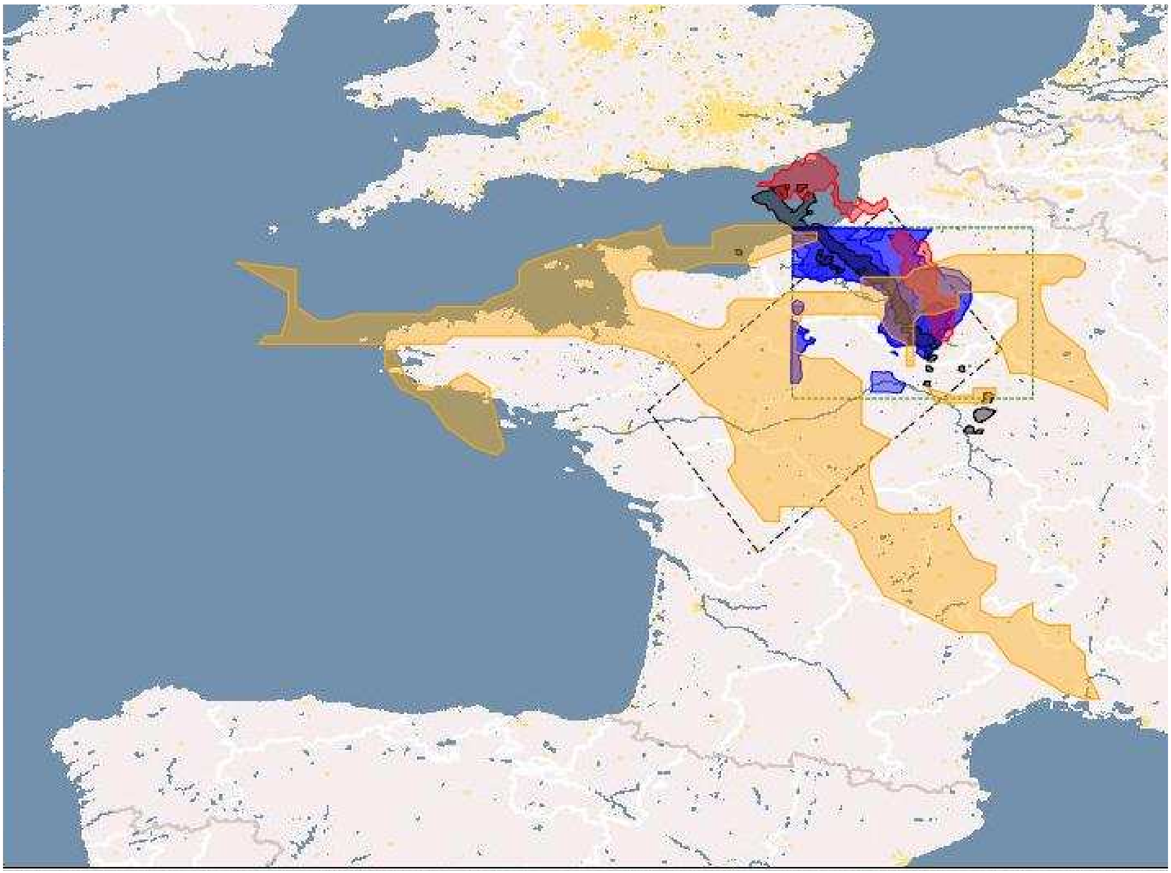

Figure 12: Forecast position of multiple objects for a single flight level: Cb top (red), local scale Cb base (blue), regional scale CAT (black) and Ice objects (orange).

make the intersection between the bounding box defined for one flight level.

The preceding figures show data as 2-D Hazardous Areas. This is a consequence of the model data used which itself is a 2-D representation of the atmosphere, with the third dimension achieved by stacking each 2-D layer. Display management of the data is outside the scope of the current development work package. Since digital data is supplied it is anticipated that its display would be managed by the end-user's application, should it be necessary. However, Figure 13 is an illustration of a display for icing that could enable flight crew (or ground crew) to make an informed decision about the forecast weather situation that affects their flight path. The top part of Figure 13 shows a scenario – a flight is on a path that will bring it to a volume of within which super-cooled liquid water content is forecast. The bottom part of Figure 13, left-side, shows two cross-sections of the forecast region; a horizontal cross-section at the current flight level with the spatial extent of the forecast weather event in relation to the current flight path (solid line) and the NG-ISS proposed solution (dotted line) to avoid the hazard. The bottom part of Figure 13, right-side, shows a vertical cross section of the same hazard. The flight crew could interrogate the data more closely to satisfy themselves of the recommended solution.

9. GENERAL TRENDS NOTED DURING DEVELOPMENTS WITHIN FLYSAFE

The choice to use GML arises due to several noted trends: primarily the use of GML for the exchange of geospatial information; emerging regulatory and industry standards for the exchange of data (EC-ATM, 2002, RTCA, 2007); the availability and maturity of standards for data exchange, e.g., IS0-19100 series; meta-data standards for quality assurance (EC-ATM, 2007); and the apparent adoption rate for encoding data using mark-up languages (Saunders, 2002, WMO, 2005, MOD, 2006, SITA and ARINC, 2006). In addition, consideration was given to the availability of open source standards and solutions, off-the-shelf tools for development, future interoperability with existing systems for

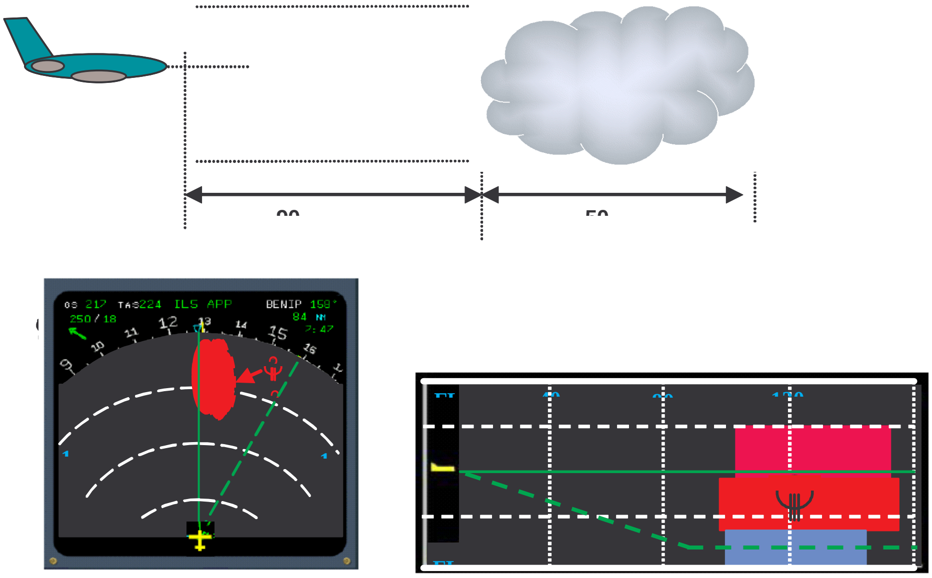

Figure 13: Top – Situation: aircraft approaching a forecast region of super-cooled liquid water. Bottom – 3-D representation of the hazard using 2-D horizontal and vertical cross-sections.

transparent data access (Sayadian, 2004, SWIM, 2005); and finally governance and maintenance of standards (EC-ATM, 2006).

We note recent developments for the exchange meteorological data and that there are a number of candidate XML models, for example, the data model developed by the Australian Bureau of Meteorology for use at the 2008 Beijing Olympics (Ebert and Brown, 2006); the US Defense Joint METOC exchange schema (EC-ATM, 2007a); US National Weather Service's dwGML application schema (EC-ATM, 2007a, Schattel, 2007); the Met Office developments for data exchange for the Joint Environmental Dynamic Data Server (MO, 2004, 2005; CWID, 2005) and the climate science exchange schema (Woolf 2005a, 2005b). However, for one reason or another none of these were deemed suitable for aviation weather information; the main reasons we found were lack or limited compliance to open standards; undue complexity, lack of extensibility or lack of applicability. However, one candidate model, WXXM, was considered but at the time of our development this model did not exist.

The WXXM model (EC-ATM, 2006, EC-ATM, 2007a, 2007b) is a member of a family of data exchange models under development by Eurocontrol (figure 14). This family of data models will each start from a conceptual data model expressed in UML, which is then converted into an XML schema. It is intended that this family of data models expressed in this form will afford interoperability with other systems and services that provide data to aviation users.

The decision was taken to develop the FLYSAFE data model using the data modelling techniques developed at the Met Office and Météo France; these techniques we believe are aligned to those used by Eurocontrol. This affords the opportunity for further development of the FLYSAFE data model by extension of the WXXM to incorporate the new categories and expressions of weather information.

10. CONCLUSIONS AND FUTURE

FLYSAFE has outlined a solution for meteorological data exchange between airborne and ground-based systems, which comprise of the NG-ISS, an on-board data processing unit, supported by a ground-based network collectively called the Ground Weather Processor.

The GWP is composed of a network of Weather Information Management Systems (WIMS) and data hubs. WIMS specialise in forecasts of hazardous weather phenomena specific to aviation at various scales and update rates: CAT, Wake Vortex, Icing and Cb Turbulence.

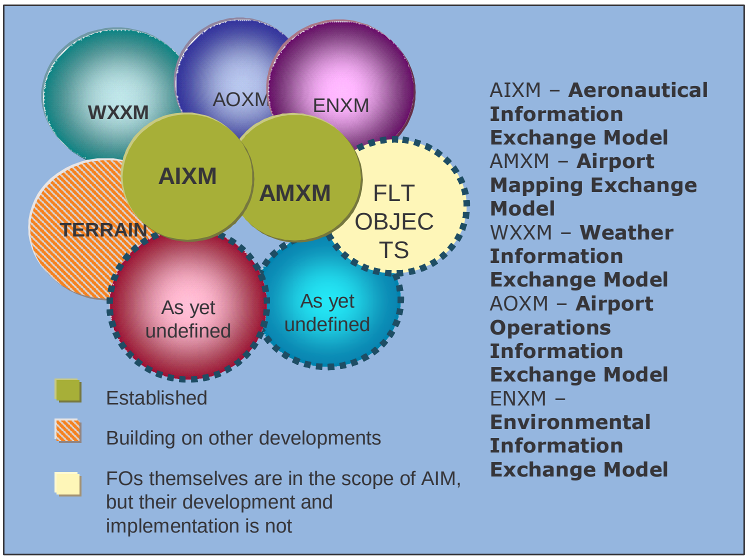

Figure 14: Eurocontrol's proposed family of interoperable models for data exchange within the aviation domain (EC-ATM, 2006).

The data hubs will receive, store and forward weather information relevant to the volume of space specified by the user in a request. To accommodate the available aeronautical data link rates, a method has been developed to reduce the amount of data required to represent hazardous weather phenomena; this method converts gridded data into GML-Objects, which also affords the facility to select GML-Objects spatially and temporally. FLYSAFE's expression of meteorological data appears consistent with the trend towards greater interoperability for data exchange and for the use of machine-to-machine interaction to provide decision support within the aviation domain.

The final stage of the FLYSAFE project is the integration of developments undertaken to date, which will be done in two stages. The first stage is user evaluations using flight simulations at the Nationaal Lucht- en Ruimtevaartlaboratorium (NLR) facility in Amsterdam. The second stage will be flight trials during 2008. The flight trials will be used for verification of the WIMS forecasts using observations and measurements collected during two flight campaigns: February and August 2008.

Evaluation of the data link between the NG-ISS and the GWP will be part of the August 2008 flight campaign. A GWP node is being assembled at Météo France, it will use open source solutions: Geoserver (GEOS, 2008) for OGC compliant Web Feature Service, a Cocoon XML (Apache, 2008) interface to translates user requests to a WFS compliant format and a PostGIS (RR, 2008) spatial database to store weather objects. SaNTA , developed by Skysoft, based in Portugal, has been chosen as the protocol to support SATCOM air-to-ground communications; Rockwell Collins, based in France, will integrate the communication solution within NLR's aircraft, Metro Swearingen twin turboprop.

The flight trials will take place in and around the Paris TMA and selected routes between Amsterdam and Paris.

11. ACKNOWLEDGEMENTS:

This development work is part funded by the European Commission, EU Research 6th Framework, EC contract AIP4-CT-2005-516167.

Met Office
Bob Lunnon, Debi Turp, Angela Relle, Lauren Reid, Jeremy Tandy

Météo France
Patrick Josse, Agathe Drouin

DLR (Germany)
Thomas Gerz, Arnold Tafferner, Caroline Forster

University of Hannover
Thomas Hauf, Micheal Theusner, Jakob Tendel, Sonja Jirsch (DWD)

Rockwell Collins (France)
Frédérique Azum, Olivier Perrier, Marianne Ricart, Alain Brossard, Eric Itica

NLR (Netherlands)
Wilfred Rouwhorst, Con Kranenburg, Adri Marsman, Bart Heesbeen

Thales (France)
Laurence Mutuel

12. REFERENCES:

Altova, 2006, *XMLSpy2006*, website last accessed 2008-01-17, http://www.altova.com/download_archive.html

Apache, 2008, Cocoon, Apache Software Foundation, website last accessed 2008-02-14 http://cocoon.apache.org/

CWID, 2005, Coalition Warrior Interoperability Demonstration (CWID) 2005, p43.

Ebert, B and Brown, B, *et al* 2006; *Draft file format specifications for B08FDP v1.0*, Bureau of Meteorology Research Centre, Australia.

EC, 2001: *European Aeronautics – A Vision for 2020*, European Commission, Luxembourg.

EC-ATM, 2002, *AIXM-XML Primer*, Air Traffic Management Programme, Eurocontrol, Brussels, Belgium.

EC-ATM, 2006: *Aeronautical Information Management Strategy v4.0*, Air Traffic Management Programme, Eurocontrol, Brussels, Belgium.

EC-ATM, 2007: *Integrity of Aeronautical Information: Principles – Data and Quality Management v1.0*, Controlled and Harmonised Aeronautical Information Network, Air Traffic Management Programme, Eurocontrol, Brussels, Belgium.

EC-ATM, 2007a: *WXXM Workshop 15th – 16th May 2007*, Eurocontrol, Brussels, Belgium.

EC-ATM, 2007b: *WXCM Workshop 18th – 19th December 2007*, Eurocontrol, Brussels, Belgium.

EU-FLYSAFE, 2008; *FLYSAFE*, website last accessed 2008-01-08 http://www.eu-flysafe.org/Project.html.

FAA, 2007, *Report of the Weather-ATM Integration Working Group*, Research, Engineering and Development Advisory Committee, Federal Aviation Administration, October, 2007

GEOS, 2007, Geoserver, website last accessed 2008-02-14, http://docs.codehaus.org/display/GEOS/Home

Gerz, T, *et al*, 2006, Improved Weather Information for Cockpit and Tower, 25th International Congress of the Aeronautical Sciences, 2006.

ICAO, 2007, *Meteorological Service for International Air Navigation, Annex 3 to the Convention on International Civil Aviation, Sixteenth Edition, July 2007*, International Civil Aviation Organization, Montréal, Canada

JPDO, 2006, *Weather Concept of Operations v1.0*, Weather Integrated Product Team, Joint Planning and Development Office, Washington DC.

MO, 2004, Barometer, issue 1, p6, Met Office

MO, 2005, Barometer, issue 3, p3, Met Office

MOD, 2006; *Information Exploitation (IX), Ministry of Defence Policy on the Use of XML (Version 2.0),* November 2006, Director General Information, Central Data Management Authority, United Kingdom

OGC, 2004, *GML-3.1.0, ISO/TC 211/WG 4/PT 19136 Geographic information – Geography Markup Language (GML),* Open GeoSpatial Consortium.

Portele, C., 2005, *ShapeChange*, Interactive Instruments GmbH, Bonn, Germany, website last accessed 2008-01-16, http://www.interactive-instruments.de/ugas/

RR, 2008, Refractions Research, website last accessed 2008-02-14 http://postgis.refractions.net/

RTCA, 2007, *Met Data Link OSED Draft Specification*, Radio Technical Commission for Aeronautics (RTCA), (due to be published in 2007)

Saunders, C, *et al,* 2002, *Meteorological Data and XML*, Expert Team on Data Representation and Codes, World Meteorological Organisation, Geneva, Switzerland.

Sayadian, L. *et al*, 2004 *System Wide Information Management (SWIM): A proposed Global Implementation*, Aeronautical

Communications Panel, Working Group N - Networking, May 2004.

Schattel Jr., J. L., Taylor, A. A., Hershberg, P. R. and Bunge, R., 2007, *Disseminating National Weather Service Digital Forecasts Using Open Geospatial Standards*, 23rd Conference on IIPS, American Meteorological Society

SEEGRID, 2007, *Hollow World* GML Application Model, website last accessed 2007-01-15 https://www.seegrid.csiro.au/twiki/bin/view/AppSchemas/HollowWorld.

SITA and ARINC, 2006, *From legacy to open standards The benefits of XML messaging to the air transport industry*, whitepaper, website last accessed, 2008-01-14 http://www.sita.aero/

Sparx, 2007, *Enterprise Architect v6.0*, website last accessed 2008-01-17, http://www.sparxsystems.com.au/

SWIM 2005, *SIMDAT D.18.1.1 Consolidated Meteorology Requirements*, SWIM Consortium, 2005

WMO, 2003, *Introduction to GRIB Edition1 and GRIB Edition 2*, World Meteorological Organisation, Geneva, Switzerland.

WMO, 2005, *Meeting of the Expert Team on Data and Representation and Codes, Draft Report*, *Muscat, Oman, Dec 2005*, World Meteorological Organisation, Geneva, Switzerland.

Woolf, A, *et al*, 2005a, *Standards Based Data Interoperability in the Climate Sciences*, Meterol Appl 12 9-22 (2005)

Woolf, A, *et al*, 2005b, Climate Science Modelling Language: *Standards Based Markup for Metocean Data*, 21st International Conference on Interactive Information Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology, American Meteorological Society