

REPORT DOCUMENTATION PAGE				<i>Form Approved</i> OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 10-02-2011		2. REPORT TYPE Technical Paper		3. DATES COVERED (From - To) FEB 2011 - MAR 2011	
4. TITLE AND SUBTITLE European and U.S. Perspectives on the Sharing and Integration of Weather Information into ATM Decisions				5a. CONTRACT NUMBER FA8720-05-C-0002	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) David Pace, Thomas Ryan, Aaron Braeckel, Dennis Hart, Oliver Newell, and Kajal Claypool				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) MIT Lincoln Laboratory 244 Wood Street Lexington, MA 02420				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Federal Aviation Administration 800 Independence Avenue, SW ATO-P Washington, DC 20591				10. SPONSOR/MONITOR'S ACRONYM(S) FAA	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Weather is a major source of operational air traffic delays, accounting for 25 to 70 percent of all delays dependent of the geographical region. In today 's Air Traffic Management (ATM) systems, a variety of weather information is available to help tactical and strategic planners better anticipate weather events that impact airspace capacity. Regretfully, the information is not always shared amongst all the stakeholders involved or well integrated into the existing ATM environment. This paper describes the high-level concepts for an improved sharing and integration or weather information into Air Traffic Management Decisions, as well as the current state and anticipated capabilities or the underlying information Management infrastructure.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF: U			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 6	19a. NAME OF RESPONSIBLE PERSON Zach Sweet
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (include area code) 781-981-5997

European and U.S. Perspectives on the Sharing and Integration of Weather Information into ATM Decisions*

FAA Contract Approved

2/10/11

David Pace
Aviation Weather Group, FAA
Washington, D.C.
david.pace@faa.gov

Thomas Ryan
Aviation Weather Group, FAA
Washington, D.C.
thomas.e.ryan@faa.gov

Aaron Braeckel
Research Application Laboratory, NCAR
Boulder, CO
braeckel@ucar.edu

Dennis Hart
Eurocontrol
Brussels
Dennis.hart@eurocontrol.int

Oliver Newell and Kajal Claypool
Weather Sensing Group
MIT Lincoln Laboratory
Lexington, MA
olivern@ll.mit.edu

Abstract— Weather is a major source of operational air traffic delays, accounting for 25 to 70 percent of all delays dependent of the geographical region. In today's Air Traffic Management (ATM) systems, a variety of weather information is available to help tactical and strategic planners better anticipate weather events that impact airspace capacity. Regrettably, the information is not always shared amongst all the stakeholders involved or well integrated into the existing ATM environment. This paper describes the high-level concepts for an improved sharing and integration of weather information into Air Traffic Management Decisions, as well as the current state and anticipated capabilities of the underlying information management infrastructure.

I. INTEGRATION OF WEATHER INFORMATION IN ATM

A. U.S. Perspective

Weather has a tremendous impact on aviation operations. A study of accident reports from the years 1994 through 2006 revealed that 20 percent of aviation accidents and 23 percent of fatal aviation accidents were weather related. Weather delays account for 70 percent of the \$41 billion annual cost of air traffic delays within the United States National Airspace System (NAS), or \$28 billion annually. Approximately two thirds (\$19 billion) of these delays are considered to be

avoidable. The Weather-Air Traffic Management (ATM) Integration Working Group of the NAS Operations Subcommittee of the Federal Aviation Administration's (FAA's) Research, Engineering and Development Advisory Committee conducted a 12-month study to examine the potential benefits of integrating weather and ATM. The report of this committee made several recommendations regarding integration of weather and the potential for weather integration to help reduce delays. The way to mitigate these delays and eliminate those that are avoidable is to improve the quality and method of use of weather information and integrate the weather support into NAS decisions. At the same time, the advantages and potential benefits of integrating weather and air traffic management will, in all likelihood, assist in reducing the number of weather related accidents.

The FAA has produced a NextGen ATM-Weather Integration Plan which provides the approach, scope, and implementation roadmap to achieve the NextGen vision; to enable decision makers to identify areas where and when aircraft can fly safely with weather assimilated into the decision making. It also addresses agency roles and responsibilities and includes resource requirements. The plan establishes an approach to deal with the integration of weather information into the ATM decision-making process. Integration as used here refers to the inclusion of weather information into the logic of a decision process or a decision aid such that weather constraints are taken into account when the decision is made or recommended. The goal of weather integration is to minimize the need for humans to gauge NAS weather constraints and to determine the optimum mitigation of these constraints.

*This work was sponsored by the Federal Aviation Administration under Air Force Contract No. FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Government.

The ATM-weather Integration concept addresses the following problems:

- Most weather support to ATM is manual, with weather displays that must be interpreted by the user.
- Weather products do not have the maturity required for direct insertion without interpretation nor are they translated into constraint information.
- Rules for interpretation and use of weather data are generally based on the experience of the user.
- ATM decisions based upon today's weather products are inconsistent from user to user.

Figure 1 below illustrates the process of moving from raw current and forecast weather data through the creation of weather information that relates weather data to aviation constraints and on to the generation of rules for decisions to be made by ATM operators and other users and ultimately to the creation of automated Decision Support Tools (DSTs).

An analysis of the current state of weather integration was conducted and found weather integration opportunities in the NextGen Solution Sets: Initiate Trajectory Based Operations, Increase Arrivals/Departures at High Density Airports, Increase Flexibility in the Terminal Environment, Improve Collaborative ATM, Increase Safety, Security, and Environmental Performance, and Transform Facilities. Each solution set was broken down into Operational Improvements (OIs), with level Mid-Term capabilities, Mid-Term operational scenarios, and Mid-Term weather integration and needs analysis.

ATM will require DSTs that can access information from the 4-D Weather Data Cube (4-D Wx Data Cube) that has been

translated into NAS constraints and provide ATM with best choice options. The translation can be obtained by a network service for common use or by imbedding the translation capability in the DST for unique needs. The FAA ATM-Weather Integration Plan provides an overview of methodologies, the strategy for evaluation of the methodologies, and the initial identification of the best near-term strategies for further development. An appendix to the Plan provides a survey identifying technologies and methodologies for translating weather information into ATM constraints in the NAS and for using that information. The survey includes approaches for addressing weather-related uncertainty in ATM decision making and risk management processes.

The Plan presents a summary of each of the surveyed ATM constraint and impact models starting with models that were derived primarily for convection, and ending with a wide variety of models for several types of aviation hazards. It also contains an assessment of the maturity of the ATM constraint and impact models presented, and identifies gaps in technologies that must be addressed for NextGen.

Further research is required on the conversion of weather data into specific ATM constraints. It is expected that this research will be a collaborative effort involving the government, the private sector, and academia.

The execution of this Plan will occur in four steps. The steps will be executed in sequential order from the start, but the steps will be repeated many times as new weather techniques and ATM tools are developed and may be occurring simultaneously at some point in the future. The steps are as follows:

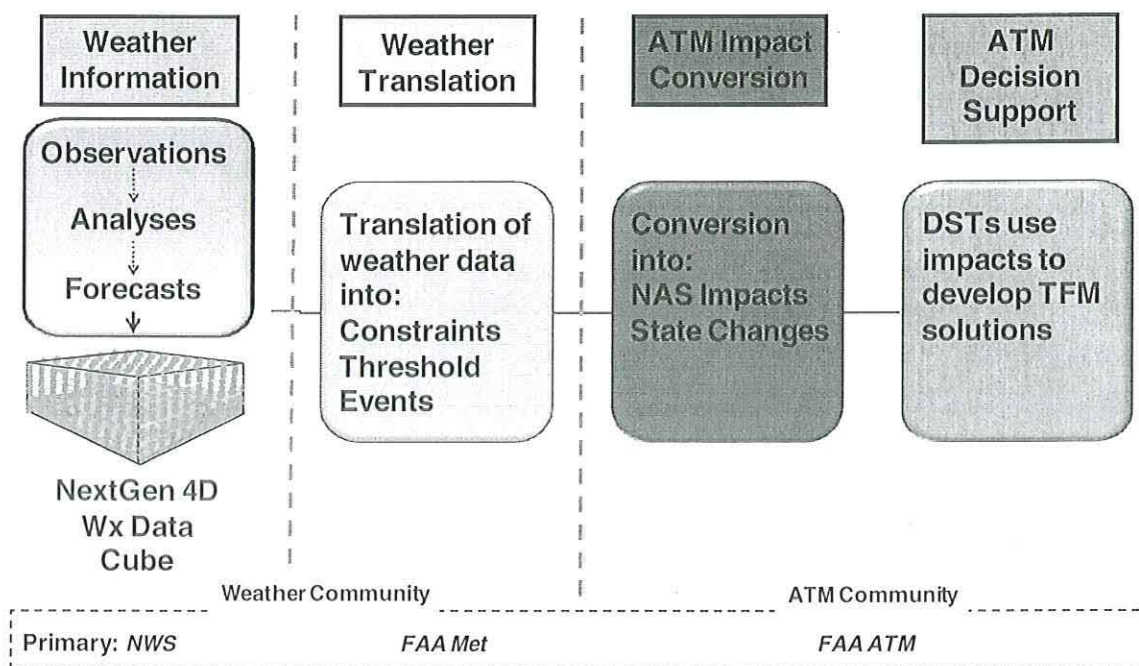


Figure 1 Conversion of weather information into ATM decisions.

1. Align teams with each solution set and analyze weather integration requirements for a service- and performance-based approach for weather integration as associated with operational relevance.

2. Identify the specific weather integration insertion points, including performance criteria and value, into ATM tool or decision platform functionality.

3. Identify and recommend the specific weather integration techniques and technologies that best fit the requirements of a particular traffic flow management tool under development and in particular, the insertion points identified in the previous step.

4. Serve as the Subject Matter Expert for the ATM tool development team to assist in integration of the weather methodologies and to evaluate test results.

To download the FAA ATM-Weather Integration Plan, go to <http://www.jpdo.gov/> and then in the top right corner choose "Knowledge Center" and "Library." From there, look under "Technical Documents" to find "Air Traffic Management-Weather Integration Plan v2.0."

B. European Perspective

Today's and future European ATM Network (EATMN) is little different to the US NAS and will continue to be subject to the same vagaries of weather phenomena that affect air transport today. EUROCONTROL's Performance Review Unit (PRU) and its Central Flow Management Unit (CFMU) estimated that over recent years, 25% of the airport and en-route delays in the EATMN were attributable to weather. Translating this to Airport performance, around 45% of delays had a direct relationship with the weather on or in the vicinity of airports. Whilst less impressive than the estimated associated costs in the US, the average annual costs for weather related delays in Europe is an estimated €900 million.

Within the context of the future EATMN, this considerable impact of weather on safety, capacity and efficiency and the potential to mitigate some of the environment impact of aviation must be examined in detail. The importance of timely, accurate and easily available meteorological information for decision support is emphasized in European ATM Master Plan and the Single European Sky ATM Research (SESAR) Programme.

Identified by all stakeholders are a number of key changes in support of the notion of utilization, management and interchange of meteorological information relevant for the future European and Global ATM system. These key changes identified are very similar to the US ones and address issues such as requirements for improved means to forecast and report wind shear, low level turbulence, wake vortex, low visibility procedure conditions, winter conditions, severe weather phenomena and similar occurrences to support user needs. In general, these products and services are in addition to the traditional requirements for Meteorological (MET) Information and Services as specified in ICAO Annex 3. This in itself requires a key change in how MET is harmonized, regulated and all stakeholders conjointly work towards global

interoperability. This is especially true in a European setting where MET Information and Services available for aviation today are almost exclusively dictated by the stated ICAO provisions.

Besides developing new capabilities, recent advances in meteorological observation and forecasting techniques have already raised the levels of accuracy of the predicted information at a European level significantly. But the use of these products by the European ATM community continues to be low. The reasons for this underutilization are far from clear. There is circumstantial evidence that a lack of awareness is a significant cause. However, the root cause could be that ATM today, with respect to weather, applies a reactive rather than proactive approach to decision making. 'Wait and see' appears to be the norm, as the perceived level of associated risk is considerably lower than in the proactive alternative.

To change this norm, it is clear that a significantly higher degree of understanding and cooperation between the user and supplier communities is required. The challenge is to identify the key data attributes required to assure a high degree of confidence in the information and the platform for decision making. Moreover, to start to work on this conversion of weather data into specific ATM constraints, it is crucial to understand, foster and develop the notion of uncertainty in ATM decision making.

The aim is to move towards the much desired holistic, cooperative and collaborative decision-making environment. In such an environment the diverging expectations and interests of all members of the Air Transport community are balanced to achieve equity, access and system efficiency. It is essential for the efficiency of ATM that a knowledge-based decision making is made inclusive of weather. Therefore the existing knowledge on the uncertainty of MET Information throughout the this decision making environment for ATM must be quickly and fully incorporated into operational procedures..

It is observed that in many domains of Air Transport and ATM, a state of having limited knowledge and where it is impossible to exactly describe the future outcome of things can be handled. Risk management methodologies inclusive of cost-loss analysis provide the mechanisms to address uncertainty in decision making processes. It is accepted that a transatlantic flight approaching the outer bounds of radar coverage will appear on the ATCO screen in defined space and time but not exactly on position A, or time B. However, ATM finds it difficult to, for instance, incorporate a spot wind forecast of 2 meter per second at FL350, into the calculation of the associated intended track.

It should be recognized that the level of uncertainty in domains other than meteorology is in most cases of a different order. Therefore, it could be perceived as difficult to apply in a straightforward manner by ATM. This comes back to the intrinsic stochastic nature of weather -thus meteorology- compared to other information types and domains used by ATM. These are potentially reasons why it is not possible to handle the uncertainty associated with meteorological information in an ATM context across the EATMN. The exact reasons are however not completely understood.

Further research is required to improve the level of understanding and confidence within the MET and ATM communities to tackle issues associated with meteorological uncertainty. It is expected that this research will be a collaborative effort throughout the SESAR Programme.

II. WEATHER INFORMATION MANAGEMENT INFRASTRUCTURE

The U.S. and European plans for integration of weather information into ATM in the 2013-2025 time frame presume the existence of a robust ATM information management infrastructure inclusive of weather information. At a high-level, both the FAA and Eurocontrol and the regional ATM improvement programmes NextGen and SESAR are addressing the issue using a similar, Service-Oriented Architecture (SOA) approach that relies on standardized data exchange models and data access services. A key goal is to move away from stove-piped weather systems that are not inherently interoperable and are, as a consequence, difficult to maintain and extend and moreover hindering common situational awareness amongst all relevant stakeholders.

The need for standardized data models and data access services is certainly not unique to the weather domain, or the FAA or EUROCONTROL as organizations. In the U.S., numerous other government agencies, such as the Department of Defense (DoD), Department of Homeland Security (DHS), are pursuing a similar strategy. In Europe, organizations such as the Infrastructure for Spatial Information in Europe (INSPIRE), serve a similar role.

A. Data models

The focus over the last few years has been on creating data models that leverage existing standards, such as the spatial data standards supported by the International Standardization Organization (ISO) or the Open Geospatial Consortium (OGC). The weather information exchange model (WXXM), developed jointly by the FAA and EUROCONTROL, is an example of a modular data model based on core components defined by the ISO and OGC standards. The benefits of standards include interoperability between a wide variety of

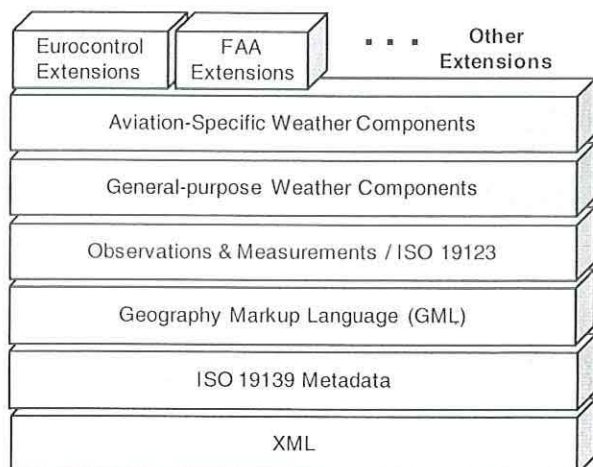


Figure 2 Layered, composable, WXXM XML Schema

weather data providers and consumers, as well as shared software component libraries.

Following guidance in the NextGen and SESAR Enterprise Architectures, WXXM separates the abstract conceptual model from the physical implementation(s) of the model. In WXXM, the abstract conceptual model is defined using Universal Modeling Language (UML) and is commonly referred to as the Weather Information Conceptual Model (WXCM). Currently, WXXM includes a physical implementation of the conceptual model in the form of an Extensible Mark-up Language (XML) schema, which itself leverages XML schema components available from ISO and OGC and is automatically generated from the UML model. This XML schema is referred to as WXXS. The modular, component-based design of the WXXM XML schema is shown below in figure 2. Note that the XML schema is one physical realization of the conceptual model, and other representations are possible.

The layered, modular nature of the model provides obvious benefits in the form of software reuse. Less obvious is the fact that design also allows for modular governance of the model. This is particularly useful in the context of the more rapidly changing aspects of the model driven by new NextGen or SESAR requirements. Community-specific extensions provide the necessary agility for organizations such as the FAA and Eurocontrol to independently innovate, while still remaining true to the overall WXXM framework.

It is interesting to contrast the WXXM data model with the aeronautical information exchange model (AIXM) and other models under development for data typical used in the ATM environment (Flight Objects, etc.) from the perspective of Weather-ATM integration. As for WXXM, AIXM is based on GML and the ISO/OGC spatial standards stack. A diagram illustrating the composition of the AIXM XML schema is shown below in figure 3.

The leveraging of common underlying standards between WXXM, AIXM and other data domains under development provides a number of benefits to the ATM community. Shared software infrastructure and tooling across the weather and aeronautical information domains will simplify application development and reduce overall development costs. For example, a single GML software library can be used, assuming that the models are synchronized to use the same version of GML. Also cross-references between domains, such as a reference to an AIXM runway description from a WXXM airport weather report, also become more straightforward due

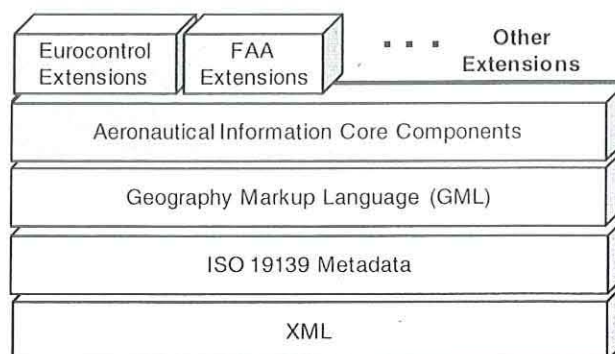


Figure 3 AIXM XML Schema Components

to the common approach shared by the two models. The use of cross references is important to minimize duplication of data, with its associated bandwidth requirements and quality assurance issues. Within the SESAR Programme, these commonalities which respect to common rules and common components for all the models used in the different data domains is also made abstract. This common layer is represented as an abstract Information model inclusive of a set of rules with respect to the underpinning data domains. This model is referred to as the ATM Information Reference Model (AIRM).

The sharing of XML components at the physical exchange level is, however, not a magic bullet in terms of providing seamless interoperability between two or more information domains. In practice, there is still a fair amount of manual domain-specific labor involved, placing limits on software component reuse. Weather information, for example, tends to be highly dynamic when compared with aeronautical information such as runway and airspace geometries. The temporality models of AIXM and WXXM evolved somewhat separately, and are quite different. As a result, software components used to handle the temporal aspects of weather data cannot currently see significant reuse with respect to handling the temporal aspects of AIM data. The possibility of increased alignment of the models with respect to temporality and other features will be the subject of ongoing research in the 2011-2015 time-frame, some of which will be conducted under the auspices of the OGC interoperability program.

B. Information Services

The second major piece of the interoperability puzzle is the set of interfaces, or *services*, used to access the data. History has shown that large-scale interoperability is best achieved by leveraging a relatively small number of interfaces that are, to the extent possible, data type agnostic (analogous to the use of HTTP and FTP on the Internet). The OGC Web Feature Service (WFS) and Web Coverage Service (WCS) have been selected as a set of standardized interfaces for access of non-gridded and gridded weather data products, when used in near real time user applications. These interfaces provide standardized query semantics to allow data to be filtered by product type, as well as by specifying spatial and temporal constraints.

Neither the WCS or WFS services, as currently specified by the OGC, support publish/subscribe message exchange semantics. This is considered to be an important service pattern in an ATM environment. A key activity within NextGen has been to develop publish/subscribe extensions for WCS and WFS, based on the OASIS WS-Notification specification. This capability has been successfully demonstrated, and the responsible NNEW team will be working on standardizing the approach within the OGC over the next two years.

The OGC interfaces, including the planned publish/subscribe extensions, are not specific to the weather domain, and are capable of supporting spatial and temporal query access to other data types such as aeronautical information, flight information or other relevant information for ATM. The WFS and WCS interfaces serve as an abstraction layer, allowing for a variety of underlying data stores (SQL,

Flat-File, etc.) to be used in support a variety of data types, such as weather, aeronautical information, and flight data.

Additional information on the NNEW program can be found on the NNEW Wiki at: <https://wiki.ucar.edu/display/NNEWD/The+NNEW+Wiki>

The SESAR Information Management activities inclusive of meteorology can be found at: <http://www.sesarju.eu/programme/workpackages/wp8>

III. CONCLUSION

The challenges associated with the global integration of weather into ATM decision making are significant not least from the institutional side. EUROCONTROL and the FAA are working closely together to ensure harmonization across the Atlantic and to support ICAO at the global and regional levels. This collaboration is reflected in Action Plan P29 of the Eurocontrol/FAA Memorandum of Cooperation which has already delivered WXXM. Work is ongoing with respect to the 4 D Weather Cube and the many other facets of aviation meteorology which are currently being considered or delivered. Harmonization is formally organized through biannual Technical Interchange Meetings (TIM) and the essential needs of global harmonization are not being ignored. ICAO, WMO and a limited number of States from other ICAO regions are invited to participate in the TIMs

AUTHOR BIOGRAPHIES

David J. Pace was born in Norfolk, Virginia, USA. He attended the University of Virginia, Charlottesville VA (BA mathematics 1969), St. Louis University, St Louis Missouri (graduate studies in meteorology 1970), and San Diego State University, San Diego California (MS Astronomy 1974).

He has had an extensive career in aviation meteorology in the US Air Force and for FAA aviation weather programs and the Next Generation Air Transportation System at FAA Headquarters in Washington DC.

Mr. Pace is a member of the America Meteorological Society (aviation committee chair) and the National Weather Association.

Dennis (L.M.) Hart was born in Amsterdam, the Netherlands. He attended the Royal Netherlands Air Force Academy (Meteorology, 1989). Besides experience in operational (aviation) meteorology both supporting military operations and civil use, he has an extensive career in the management and international cooperation aspects of meteorological service provision.

He joined EUROCONTROL in 2008 as the Agency's senior aviation meteorology expert.

Mr. Hart is a member of the Dutch Meteorological Society (NVBM), member of regional and International Civil Aviation Organization (ICAO) groups working on MET support to ATM, Observer to the World Meteorological Organization (WMO) Aeronautical Program, advisor to European institutions on aviation meteorology and active in OGC.

Thomas E. Ryan was born in Perth Amboy, New Jersey, USA. He attended Frostburg State University of Maryland (B.S. Mathematics, 1982).

He has extensive Program Management experience in the US Air Force, the computer industry, the US Agency for International Development, and the US Federal Aviation Administration. His wide ranging program experiences include wide-area network management, a 50,000 seat email system, building construction, runway safety, and the FAA's NNEW program.

Mr. Ryan is a member of the American Meteorological Society and the Air Traffic Control Association.

Oliver J. Newell was born in Boston, Massachusetts, USA. He attended the University of Massachusetts, Amherst (B.S. civil engineering, 1984).

He is a staff member at MIT Lincoln Laboratory in Lexington, MA. Since 1988, he has worked on a variety of weather radar and aircraft surveillance sensor research programs for the FAA. Recently he has been addressing information management challenges associated with NextGen.

Mr. Newell is a technical committee member in the Open Geospatial Consortium and the OASIS ebXML Registry/Repository working group.

Kajal Claypool was born in New Delhi, India. She received her B.Tech. degree in Computer Engineering from Manipal Institute of Technology, Karnataka, India, and a Ph.D. degree in Computer Science from Worcester Polytechnic Institute, Worcester, Massachusetts, USA.

She was a faculty member post her Ph.D at the University of Massachusetts, Lowell, and a staff member at Oracle Corporation.

Dr. Claypool is an assistant group leader at MIT Lincoln Laboratory in Lexington, MA. Since 2007, her research is focused on data management, particularly in information integration and modeling, and stream data management.

Aaron D. Braeckel was born in Denver Colorado. He attended Evergreen State College (B.S. computer science, 1999), and University of Colorado (M.S. computer science, 2010).

He is a software engineer with the National Center for Atmospheric Research, in Boulder, Colorado. He began his work at NCAR on the Aviation Digital Data Service (ADDS) in 2002, and has been working in aviation weather dissemination and visualization ever since. He is currently the technical lead for the NCAR NNEW team.

Mr. Braeckel is active in the Open Geospatial Consortium and is a founding member of the OGC Web Services Publish/Subscribe Standards Working Group.