U.S. Government Environmental Data Cube (4D Cube) Harmonization

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ABSTRACT

Through a cooperative inter-agency effort, the Departments of Commerce (DoC), Transportation (DoT), and Defense (DoD) are developing a 4-Dimension (x, y, z, and t) Weather Data Cube (4-D Wx Data Cube) to meet the significantly increased automation and machine-to-machine (M2M) aviation weather requirements of the Next Generation Air Transportation System (NextGen). The 4-D Wx Data Cube can be described as a data abstraction that allows one to process aggregated data from a number of perspectives. Each agency will fuse their existing efforts to meet their agency's aviation weather requirements into a mutually supportable national aviation weather data cube. The goal of this focused federal effort is to merge the majority of public and private sector aviation weather needs into the overall air transportation management process. While the US Government data cube will satisfy the vast majority of aviation weather requirements, agencies will maintain an independent capability to satisfy agency unique requirements such as homeland defense (DoD), non-aviation weather requirements such as flood forecasting and warning (DoC), and national surface traffic flow support (DoT). In the end-state, the 4-D Wx Data Cube will benefit from complimentary agency research and development focused on improved numerical weather prediction, aviation hazard prediction/detection, automated decision rules, and net-centric weather data standards.

1. Introduction

Just what constitutes an operational 4-Dimension Data Cube (4-D Data Cube)? Notwithstanding the nature of the specific weather data cube, in general, it is the complete and concise set of essential relevant elements of knowledge, information, and data required to support aviation operations. Inherent to the operational definition are the factors of data standardization, spatial and temporal relevancy, refresh rate, latency, accuracy, and consistency.

a. The 4-Dimension Weather Data Cube (4-D Wx Data Cube)Described

The 4-D Wx Data Cube has been developed to encompass the complete and concise set of essential relevant elements of knowledge, information, and data. The 4-D Wx Data Cube has to be both scalable and relocatable, depending on the needs of the moment. It also has to be precisely defined for each application, and it will necessarily be knowledge empowered (Oceanography 2002)

The elements that make up the 4-D Wx Data Cube are the following:

- It is located in an absolute geospatial and temporal frame of reference;
- It is updated at the frequency and timeliness required;
- It is shared;
- It is measurable and descriptive; and
- It is unique and unambiguous.

b. 4-D Wx Data Cube Characteristics

Characteristics of the 4-D Wx Data Cube include:

- Knowledge Empowered – the fundamentals of this knowledge empowerment are experienced and empowered decision makers benefiting from an enhanced understanding of the environment as well as the enhanced collaborative decision-making process.
- Networked – connected and synchronized in time and space with the specific purpose to facilitate integrated and interdependent operations across a domain.
- Interoperable – facilitates coordinated inter-agency operations.
- Adaptable/Tailorable – ensures that each specific agency can maintain agency unique responsibilities while adapting to rapidly changing environments and the data in such a format to allow users to build their own unique products and services in addition to NextGen "standard" products and services.
- Precise – knowledge gained within the 4-D Wx Data Cube needs to provide accurate, exacting information that impacts the user's ability to affect an outcome.
- Timely – right information needs to reach the right user(s) at the right time to favorably impact any operational outcome.

2. Requirements "Building the 4-Dimensional Weather Data Cube"

During the NextGen development process of the 4-D Wx Data Cube, it was apparent that each agency involved (Federal Aviation Administration, National Weather Service, Air Force and Navy) had their own perspective of what constituted a 4-D Wx

Data Cube. While many aspects of each agency weather cubes were very similar, the differences amounted to enough significance that no one model would suffice to meet all agency requirements. Historically, each agency supported its own proprietary data bases, data streams and operational implementations. This was a strict requirement prior to the explosion of network-centric operations. Even within a specific agency, levels of support (e.g. environmental support, logistics, security, etc.) were largely "stove-piped" acting as unique agents. With the advent of reliable communication bandwidth, increased data storage capability, and, most notably, the worldwide employment of the Internet, true network-centric collaboration is common throughout the communities. The idea that one could "data mine" information that was tied spatially and temporally to a common datum or frame, allows for truly coordinated decision making. It is instructive to see how each of the major agencies involved viewed their respective 4-D Wx Data Cubes.

From the work that has been done by the cooperative inter-agency's (Department of Commerce (DoC), Transportation (DoT), and Defense (DoD)) efforts, the following requirements have been identified.

a. Observations

Observations **(**or sensed data**)** are the cornerstone of any 4-D Wx Data Cube. They provide the current state of the environment. Observations can be obtained in three different methods, in-situ, remote, and automated.

b. Analysis

As defined in the AMS Glossary – Analysis is "A procedure to project the state of the atmosphere as known from a finite set of imperfect, irregularly distributed observations onto a regular grid or to represent the atmospheric state by the amplitude of

standard mathematical formulas" (AMS Glossary). Analysis includes data assimilation (to include quality assurance) and interpretation via numerical/statistical models or human assessment. An analysis of received data can provide a gridded data set for locations where there is not a direct source of information.

c. Forecasts

Forecasts provide the future state of the environment. Weather forecasted can be provided in four different formats, text, gridded, graphical, and even verbal.

d. Dissemination

Each governmental agency currently uses a different means of disseminating the observed, analyzed, and forecast weather data. When building the 4-D Wx Data Cube each of the following dissemination methods will need to be available to create a seamless common weather picture.

- DoC National Digital Forecast Database (NDFD) and the Aviation Digital Data Service (ADDS). The National Weather Service (NWS) provided NDFD consists of gridded forecasts of sensible weather elements. NDFD is a seamless mosaic of digital forecasts from NWS field offices working in collaboration with the National Centers for Environmental Prediction (NCEP). ADDS provided automated forecasts of icing, turbulence and convective hazards to aviation. These databases are available to the public for use in creating text, graphic, gridded, or image products of their own. Over time, NWS will offer a wider array of gridded forecast elements of hazards to aviation.

- DoT System-Wide Information Management (SWIM). SWIM is the technology that will make aviation systems and services interact in a seamless manner throughout the National Airspace System (NAS). SWIM manages network-enabled information flow and access among all the disparate air traffic operational systems. It will reduce the time and cost to distribute information and improve the agility of the NAS. It is like an Internet for air traffic systems, including a search-and-retrieval capability.
- DoD Global Information Grid (GIG). The GIG is the communications concept to achieve net-centric operations within the Department of Defense. The weather communities within the services are collaborating and building the Joint Meteorological and Oceanographic (METOC) Broker language (JMBL) (an extensible mark up language (XML) schema) to facilitate machine-to-machine (M2M) connectivity. This schema is currently in limited operational use. All segment development is expected to be complete by 2011.

e. Integration and Mitigation

Integration and mitigation are two accepts of the 4D Wx Data Cube that will relate the environment to the operational needs of the user. This can be in the form of ground to ground contact between the weather sensors, controllers, forecasters, and pilots; air to ground communication across aircraft networks and weather sensors; or air to air information being passed between pilots and aircraft sensorsin the form of urgent or routine weather updates. All these forms of communication requirements need to be flexible to take into account the every changing mission and many different types of the end user.

f. Policy and Training

As the 4D Wx Data Cube develops, the policies of the different agencies need to be gathered and consolidated into a single NextGen 4D Wx Data Cube policy frame of reference, and memorandum of agreement that everyone is committed to support.

As the 4D Wx Data Cube is created, training material will provide the framework to best utilize the information that is presented. This training material needs to address the needs of each agency to include those responsible for gathering the data (observations, analysis, and forecasts), disseminating the weather information within the 4D Wx Data Cube, and providing the end user information and instructions on how to use the weather data, information., and knowledge (integration). This training material can be formal classroom training or computer based training material and done just-in-time or as part of agency specific recurring training/certification.

3. Agencies Approach to NextGen Concept

a. Department of Commerce (NOAA, NWS)

The Department of Commerce, through NOAA, has been a strong supporter of NextGen since its inception. NOAA provides staffing for the leadership of the NextGen Weather Working Group and NOAA contributes technical expertise to development of key JPDO planning documents. NOAA staff participated in the formation of the Concept of Operations, the Enterprise Architecture, the Integrated Work Plan, and the NextGen Business Case. Additionally, the Weather Working group has established two study teams focused on NextGen Weather support – both with substantial participation by NOAA. The Weather Policy Team has assessed policies pertaining to implementation and operation of the weather support services. The Functional Requirements Study Team

is developing top level requirements for the 4-D Wx Data Cube for Air Traffic Management.

Requirements Definition – apart from direct support to the JPDO, NOAA has begun to develop the technologies to enable the generation of NextGen weather forecast information. The 4-D Wx Data Cube concept has passed the first gate in formal requirements definition process of the NWS and a project team will now produce a NOAA 4-D Wx Data Cube Concept of Operations and coordinate with the Functional requirements Study Team to ensure compatibility of NOAA's detailed plans with other agency contributions to the NextGen 4-D Wx Data Cube.

Human Forecaster Integration – the methodology for human forecaster integration is a critical element of the NextGen weather concept to enable digital weather information to become the primary means to fulfill regulatory requirements. NWS is evaluating approaches to this issue. This year NOAA established a pilot program in its Alaska Aviation Weather Unit and a prototype effort in the Dallas/Ft Worth area to test tools and concepts for human forecaster participation applicable to NextGen weather support.

Weather model Improvements – at the National Centers for Environmental Prediction (NCEP), there has been significant progress in the development of Short Range Ensemble Forecast (SREF), which provides a probabilistic forecast of aviation weather elements. Work this year has focused on the update frequency of localized high resolution statistical guidance. These numerical weather prediction model improvements will all contribute to more accurate forecasts in the NextGen environment and aid the development of the needed probabilistic forecasts described in the *NextGen Operations Concept.*

Improved Access to Observations – increased access to observations of current weather is critical to produce more accurate weather forecasts. Atmospheric moisture is one of the least measured, most highly variable element in the atmosphere. In 2007, NOAA awarded the first contract to acquire a network of aircraft based water vapor sensors that will allow observations from commercial aircraft to serve as complete atmospheric profiles, including humidity. The increased frequency and resolution of the resulting atmospheric soundings will enable much more accurate forecasts, especially in the areas of ceiling, visibility, icing and convection. This capability and the associated data communications systems will enable all equipped aircraft to serve as weather nodes on the Net-Enabled Operations information grid.

b. Department of Transportation (FAA)

The FAA approach to the NextGen concept for weather is built around the end user decision process in the civil aviation arena. Unlike the Department of Defense, where the weather cube precepts were built primarily for force employment and transit of US civil airspace is of secondary concern, the FAA has increased capacity, efficiency, and safety of the NAS as its primary focus. The enabling FAA infrastructure is the System-Wide Information Management (SWIM) program which will enable network-enabled weather operations. The FAA concept hinges on systematically developing, disseminating, and integrating quality weather information into operational decision making, both manual and automated, in air traffic management, airline operation centers, and the aircraft flight deck. The agency will develop improved weather observation capabilities, improved weather forecasts, and provide automated decision-support tools (DST) with weather data that helps comprehend and manage the risks to their operations

posed by weather. The realization of the benefits in the FAA Flight plan – increased capacity and margin of safety in the face of large anticipated increases in demand – depends on providing these improved weather observation and forecasting capabilities and integrating that weather information into DSTs.

The 4-D Wx Data Cube enables the point-to-multipoint, networked access of observational and forecast weather information by all NextGen users, service providers, military planners, security personnel, and the flying public, of observational and forecast weather information from the distributed sources. The 4-D Wx Data Cube will enable net-centric access by system users to consistent tactical and strategic level weather information. The 4-D Wx Data Cube will also employ Networked-Enabled Operations (NEO) compatible data management techniques to enable information to be accessible across varied space and time scales. Changes to weather information will be rapidly disseminated and all categories of weather users will have improved access to timely and accurate flight information at their homes, businesses, airports, and in the air to support improved decision making for increased capacity and enhanced safety.

While the FAA concept focuses on the use of weather information, to some degree the FAA will provide and host a component of the 4-D Wx Data Cube, at least initially. For example, such legacy systems as the Terminal Doppler Weather Radar (TDWR), the Integrated Terminal Weather System (ITWS), and the Corridor Integrated Weather System (CIWS) will publish their information as part of the 4-D Wx Data Cube until such time as their functions are allocated elsewhere. The implementation for SWIM Segment 1 will begin in 2009, including network publication of ITWS products (with TDWR information embedded) and CIWS products. Also included in the SWIM

Segment 1 will be publication of PIREP information as received by the FAA Weather Message Switching Center –Replacement system from the agency's en-route modernization system and other sources. In the NextGen era, such publication will merge with that from NOAA and the DOD to collectively become the distributed 4-D Wx Data Cube.

c. Department of Defense (Air Force, Navy)

The DoD will work within the NAS to protect the Homeland, train to maintain readiness and be prepared to successfully accomplish missions worldwide. Because the FAA has the operational lead for the NAS and the NWS has the lead for providing public weather data and information for the United States, the DoD will continue to supplement DoC and DoT to meet its unique mission.

One of the primary weather contributions to NextGen is the Joint Meteorological and Oceanographic (METOC) Broker Language (JMBL) written as a joint effort by the United States Air Force and Navy. JMBL is in use today providing weather data and information to plan and execute military operations. This weather data exchange format can be easily adapted for worldwide peacetime operations as well. Once all of the segments are complete, users and decision-makers will be able to integrate all weather data into automated tools to facilitate decision making and provide repeatable outcomes. Repeatable processes provide a level of consistency necessary for safe, effective operations when multiple users for different functional areas require a consistent answer, i.e. a Common Weather Picture (CWP). Within the DoD, the Joint Vision 2020 addresses the CWP from which strategic, operational and tactical decision-makers will plan operations. DoD operates on a global perspective and relies heavily on the National

Geospatial Intelligence Agency (NGA) for geospatial information referenced to a common data framework (US Navy Geospatial Roadmap). This common rectified meteorological, oceanographic, hydrographic and precise time information passes through DoD communication networks and will directly support the automated, Air Traffic Management architecture envisioned by NextGen.

4. NexGen 4-Dimensional Weather Data Cube.

Today weather data are not well integrated into either manual procedures or automated decision support systems, are not readily available to all decision makers, and are not sufficiently accurate. Thus, improvements are needed to support the increased number of air traffic operations envisioned in the future. More importantly, unpredicted changes in weather cause significant impacts and disruptions; the current systems are not responsive to unpredicted weather.

The goal is to determine the impact of weather and use that information for better decision-making. Using integrated weather information, along with probabilistic forecasts, to influence system decisions will minimize the effects of weather on NextGen operations. This solution set proactively plans operations based on the predicted impact, rather than attempt to mitigate impacts once the weather has changed.

Two different models of the NextGen weather system were developed: (1) a functional model needed to describe the roles and responsibilities for the interested parties and (2) a description of various uses of the information contained within the 4-D weather data cube to divide NextGen weather information into types of information that have different implications for policy – especially with regard to data rights.

At the core of the NextGen weather capability is the 4-D Wx Data Cube that contains all relevant aviation weather information formed from the merger of observations, automated gridded products, models, climatological data, and human forecaster input from both public and private sources. Figure-1 represents the agreed upon version of the NextGen 4-Dimension Weather Data Cube.

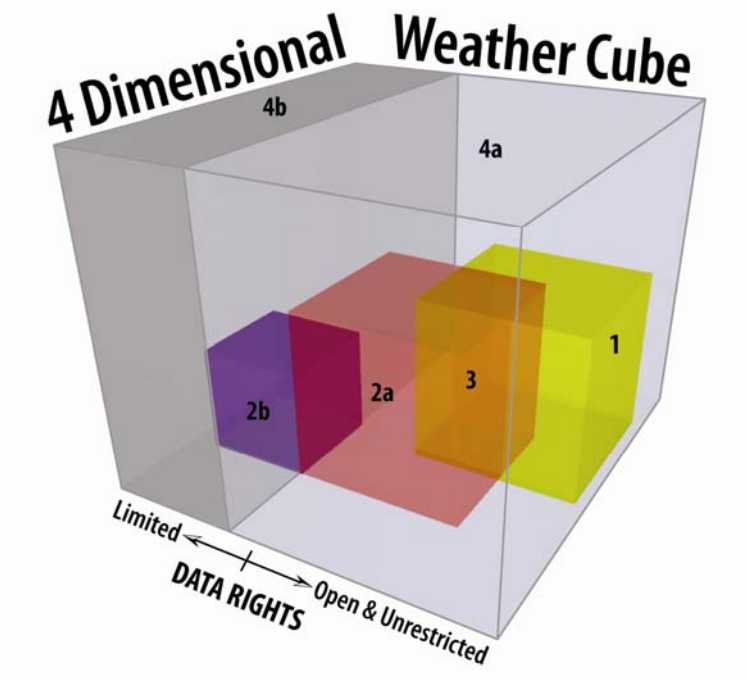

Figure-1 NextGen 4-Dimension Weather Data Cube

The production of the 4-D Wx Data Cube and its utilization by the NAS users' applications in an integrated, operational manner is the essence of NextGen weather capabilities. The 4-D Wx Data Cube is defined as all unclassified weather information used directly and indirectly for aviation decisions.

Data Rights describe the allowable uses of information. The term used to describe the data rights under which U.S. Government data are released is "open and unrestricted." Essentially all of the weather information provided by NOAA and provided to others is provided under "open and unrestricted" terms, and as a matter of policy, NOAA is

committed to supporting open and unrestricted data rights for environmental information worldwide. Other U.S. Government agencies are bound by the same basic policies with respect to data rights, with the exception of classified or security related information. On the other end of the spectrum are “limited data rights” that describe all information with terms of use other than “open and unrestricted” – understanding, that these limited rights are established on a case-by-case basis and may take a wide variety of forms. Also seen with Figure X, from an operational perspective, the 4-D Wx Data Cube is divided into several domains:

- Domain 1: Weather information used by the operator of the NAS for air traffic management decisions in the civil-use airspace portion of the NAS. The data information contained in this domain has open and unrestricted data rights (ex. Collaborative Convective Forecast Product).
- Domain 2a: Weather information approved for pilots and dispatchers to use in making operational decisions that meet regulatory requirements. This information contained in this domain has open and unrestricted data rights (ex. Government produced Terminal Aerodrome Forecast (TAF) for secondary and tertiary airports).
- Domain 2b: Weather information approved for pilots and dispatchers to use in making operational decisions that meet regulatory requirements. The information contained in this domain has limited data rights (ex. Commercially produced TAF).
- Domain 3: Any weather information that meets both of the functional descriptions in 1 and 2a (ex. Convective SIGMET).

- Domain 4a: All other weather information used by any NAS participant that has open and unrestricted data rights (ex. some Government produced numerical model output).
- Domain 4b: All other weather information used by any NAS participant that has limited data rights (ex. Commercial lightning data prior to government purchase and processing).

As indicated within the NextGen "*Weather Concept of Operations Version 1.0"* and the "*Concept of Operations for the Next Generation Air Transportation System Version 2.0*," weather concepts include a "Single Authoritative Source" (SAS) which provides a common weather picture for NAS participants.

All of the information in domains 1, 2a, 2b, and 3 (4-D Wx Data Cube) is "authoritative" in the sense that is approved for use by the Government for air traffic flow management purposes (domains 1 and 3) and/or approved for use to meet a regulatory purpose (domains 2a, 2b, and 3).

It is critical to the NextGen weather concept that *at least* the weather information in domains 1 and 3 be "single" in the sense that it forms a single, internally consistent depiction of current and predicted weather needed to guide air traffic management decisions in which controllers and operators participate collaboratively.

5. Outcomes

a. Benefits

- Common weather data, information, and knowledge will enable pilots and aircrews to engage in shared situational awareness and shared responsibilities with controllers,

dispatchers, flight service station specialists, and others, pertaining to safety and efficient preflight, en route, and post flight aviation decisions involving weather.

- Improved weather information, integrated into controller decision support tools, will improve the efficiency of controller decisions and greatly reduce controller workload during unfavorable weather.
- Improved weather data, information, and knowledge made accessible to pilots and Flight Operations Control (FOCs), will reduce fuel costs and costs of aircraft cancellations and diversions due to unforeseen, adverse weather.

b. Improvements

Improvements are categorized in 4 functional areas: weather information provided for integration into decision support tools; improvements in weather sensing capability, which is required to provide better forecasts; improved weather analysis, forecasting, and processing; and the universal and common access of that data, information, and knowledge by all users.

In the end-state, the 4-D Wx Data Cube will benefit from complimentary agency research and development focused on improved numerical weather prediction, aviation hazard prediction/detection, automated decision rules, and net-centric weather data standards.

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