3.1 NEXTGEN WEATHER REQUIREMENTS

Cheryl G. Souders
FAA Air Traffic Organization, NextGen and Operations Planning, Washington, DC
Steve Abelman
NOAA National Weather Service, Silver Spring, Maryland
Cecilia Miner
NOAA National Weather Service, Silver Spring, Maryland
Robert C. Showalter
CSSI Incorporated, FAA Support, Washington DC
James Tauss
CSSI Incorporated, FAA Support, Washington DC
Ernie R. Dash
AvMet Applications Incorporated, FAA Support, Hampton, Virginia
Jack May
AvMet Applications Incorporated, FAA Support, Webster, New York

1.0 Four Dimensional Weather Functional Requirements for NextGen Air Traffic Management

1.1 Background

The Next Generation Air Transportation System (NextGen) is focusing on a new direction in aviation weather information capabilities to help stakeholders at all levels make better decisions to mitigate weather situations impacting safety and efficiency. In the NextGen era, "the primary role of weather information is to enable the identification of optimal trajectories that meet the safety, comfort, schedule, efficiency and environmental impact requirements of the users and the system." Safe and efficient NextGen operations will depend on enhanced weather capabilities based on three major tenets:

• A common picture of the weather for all transportation decision-makers and aviation system users

• Weather integrated directly into sophisticated decision support capabilities to assist decision-makers

• Use of Internet-like information dissemination to enable flexible and cost-efficient access to all necessary weather information.

Air Traffic Management (ATM) personnel, aviation industry representatives, pilots, and weather experts studying the NextGen paradigm have determined that a network-enabled, four-dimensional weather data cube (4-D Wx Data Cube) is the best choice to ensure that accurate weather information is integrated into NextGen operational decision-making. A subset of this 4-D Wx Data Cube, known as the 4-D Wx Single Authoritative Source (4-D Wx SAS), provides seamless, consistent, de-conflicted weather information for ATM decisions. The 4-D Wx SAS facilitates the integration of weather information directly into operational decision support tools.

In June 2007, the Joint Planning and Development Office (JPDO) Senior Policy Committee approved a request for agency resources to form a JPDO Weather Working Group-sponsored study team to perform a weather functional requirements analysis. A functional analysis to the lowest level is an essential first step in developing the associated functional and performance requirements necessary for JPDO agencies to plan and implement NextGen. The functional analysis determines those activities that must be performed in order to meet stakeholder needs and results in a complete set of functional requirements that satisfies those stakeholder's needs. It facilitates improved integration, discourages predefined solutions, and enables the incorporation of new and innovative designs and solutions.

The Weather Functional Requirements Study Team included representatives from the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD) with subject matter expertise in meteorology, systems engineering and cost/budget analysis.

**Corresponding author address:* Cheryl Souders, FAA
800 Independence Ave., SW, Washington, DC 20591
Cheryl.Souders@faa.gov (202) 385-7235

The study team's primary task was to develop the necessary functional and limited performance NextGen weather requirements for the 4-D Wx SAS to support NextGen operations. For this task, the study team extracted operational needs from the NextGen ConOps v2.0 and then decomposed them until sufficient detail existed to determine the high-level weather functions. These high-level functions were iteratively decomposed to determine all required NextGen weather functions. The team translated the resultant functions into limited functional and performance requirements including data attributes (e.g., spatial and temporal resolution, data latency, refresh rates, reliability, integrity, and information content).

The team was also tasked to develop and document cost, schedule, and performance attributes at the task level for the 4-D Wx SAS. Subject matter experts estimated the rough order of magnitude (ROM) costs using two comparables for developing and implementing the 4-D Wx SAS. The National Weather Service's (NWS) National Centers for Environmental Prediction (NCEP) prepared the estimate for developing the capability to create the weather information in the 4-D Wx SAS and the operational cost associated with this capability. NWS/NCEP developed this cost estimate using today's model development and system operations to estimate the cost of meeting the 4-D Wx SAS functional and performance requirements detailed in the JPDO report, “4-D Weather Functional Requirements for NextGen ATM,” Version 0.1, January 18, 2008.

1.2 Single Authoritative Source (SAS)

One key study team accomplishment was establishing a definition for the 4-D Wx SAS. The definition was developed in conjunction with the JPDO Weather Policy Study Team.

Definition: The 4-D Wx SAS represents the machine-readable, network-enabled, geo- and time-referenced weather information available via network-enabled communications and has the following characteristics:

• Includes current observations, interpolated current conditions, and predictions of future conditions

• Supports probabilistic decision aids

• Provides a seamless, consistent, de-conflicted common weather picture for integration into operational decisions that is available to all ATM decision makers.

The figure below illustrates that the 4-D Wx SAS is only a portion of the overall 4-D Wx Data Cube. The 4-D Wx SAS contains grid point data of observed and forecast weather information that is formed by the merger of model data, automated gridded algorithms, climatology, observational data, and meteorologists’ input/data manipulation to ensure consistency and accuracy. Each SAS grid point will contain the “official” meteorological value of a particular aviation parameter at the same location, altitude and timeframe.

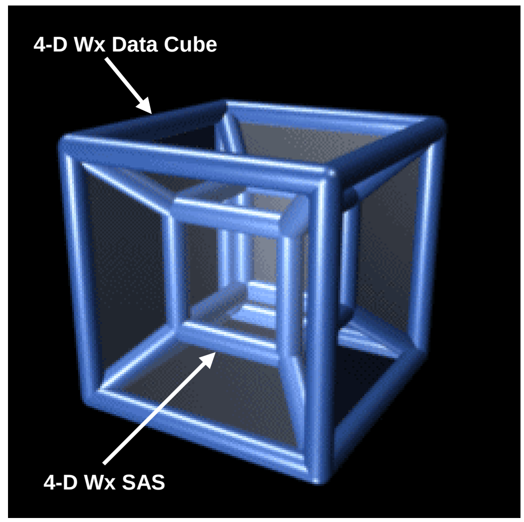

Figure 1 – 4-D Wx Data Cube / SAS

1.3 NextGen 4-D Weather SAS Functional Requirements

The following are examples of 4-D Wx SAS functional requirements developed by the JPDO study team.

The 4-D Wx SAS shall provide:

- Forecasts for all airspace designated as Terminal with 0.5-km resolution. [Note: The team updated this value from the original 1.0 km resolution.]
- Non-convective forecasts for airspace designated as Terminal at:
  - o 15-minute increments for time 0-4 hours;
  - o 1-hour increments from 4 to 60 hours;
  - o 6-hour increments from 60 hours to 14 days
- Convective forecasts for airspace designated as Terminal in 10-minute increments out to 2 hours

- Non-convective forecasts for all airspace designated as En route at 4-km resolution
- Convective forecasts for all airspace designated as En route at 1-km resolution

2.0 PRELIMINARY PERFORMANCE REQUIREMENTS (pPR) - DEVELOPED FOR THE NEXTGEN CONCEPT REQUIREMENTS AND DEFINITION (CRD) PHASE

2.1 4-D Weather Cube – SAS

Using the JPDO developed functional requirements, the FAA developed its NextGen weather performance requirements for the 4-D Wx SAS portion of the 4-D Wx Data Cube. The participants in the requirements development team included representatives from the FAA terminal, en route, system operations, NextGen and operations planning offices; three GA pilots (two with multi-engine experience); one controller with both terminal and en route experience; two people with flight service station experience and two NWS representatives.

The team determined the spatial and temporal resolution required in these performance requirements primarily based on NextGen concepts (e.g., super density operations (SDO) and trajectory based operations (TBO)) and air traffic domains. These end-state performance requirements include both observed and forecast weather parameters and will be validated by all NextGen decision-makers early in 2009. Afterwards, the FAA will use modeling and simulation with decision-maker participation to produce a final NextGen set of weather performance requirements.

Before developing the weather performance requirements, the team determined the appropriate accuracy values for the functional spatial and temporal resolutions for the surface and aloft and for each air traffic domain (i.e., designated terminals, en route and global). An initial step in this process was a review of tables 4-1 and 5-1 in the *Four Dimensional Weather Functional Requirements for Next Generation Air Transportation System (NextGen) Air Traffic Management*. To ensure that each air traffic domain and forecast time period had been addressed, a matrix was drafted as a reference. During the review process, it became obvious that there were many common functional and performance criteria that applied to the 4-D Wx SAS information within any given air traffic domain. Thus, tables were created that included common Observation Performance Requirements and Forecast Performance Criteria. Three examples of the Forecast Performance Criteria tables are included below in Section 2.2.

2.2 Draft Preliminary Performance Requirements (pPR)

The weather performance requirements team focused on the 4-D Wx SAS functional requirements, developing a preliminary subset of FAA performance requirements as part of the Concept Requirements and Definition (CRD) phase documents required to enter Investment Analysis (IA) for the NextGen 4-D Wx Data Cube. CRD and IA are phases of the FAA acquisition process which lead to implementation. The Preliminary Performance Requirements (pPR) address the observed and forecast weather information, including probability forecasts, needed by NextGen decision-makers in the year 2025.

The following are pPR examples that correspond to the 4-D Wx SAS functional requirements listed in paragraph 1.3 above. The pPR examples reference the Tables 1-3 on the following pages; an overall example plus a specific (highlighted) example is provided for each Table.

Table 1 – Forecast Horizontal (Location) Accuracy

- Overall: The NextGen Forecast horizontal accuracy shall be plus or minus values specified in Table 1 below for each respective time period and domain.
- Specific: The NextGen Forecast horizontal accuracy shall be plus or minus 1/4 km in latitude and longitude location for 0-2 hour forecasts in the Terminal Air Traffic Domain.

Table 2 – Forecast Vertical (Base/Tops) Accuracy

- The NextGen Forecast vertical accuracy shall be plus or minus values specified in Table 2 for each respective time period, domain, and altitude stratum.
- The NextGen Forecast vertical accuracy shall be plus or minus 50 ft for all 0-2 hour forecasts for conditions between AGL to 2900 ft in the Terminal Air Traffic Domain.

Table 3 – Forecast Begin/End Time Accuracy

- The NextGen Forecast Begin/End time accuracy shall be plus or minus values specified in Table 3 for each respective time period and domain.

- The NextGen Forecast Begin/End time accuracy shall be plus or minus 2.5 minutes for all 0-2 hour convective forecasts in the Terminal Air Traffic Domain.

<table>
<tr><th rowspan="3">Forecast Valid Period</th><th colspan="4">Air Traffic Domain</th></tr>
<tr><th rowspan="2">Terminal</th><th colspan="2">En Route</th><th rowspan="2">Global</th></tr>
<tr><th>Convective</th><th>Other Wx</th></tr>
<tr><td>0-2hrs</td><td rowspan="2">1/4 km</td><td>1/2 km</td><td rowspan="5">2 km</td><td rowspan="5">5 km</td></tr>
<tr><td>2-4hrs</td><td>1 km</td></tr>
<tr><td>4-10 hrs</td><td rowspan="2">1/2 km</td><td rowspan="3">2 km</td></tr>
<tr><td>10-24hrs</td></tr>
<tr><td>24-60 hrs</td><td>1 km</td></tr>
<tr><td>60hrs - 14 days</td><td>TBD</td><td>TBD</td><td>TBD</td><td>TBD</td></tr>
<tr><td>Long Range Outlook</td><td colspan="4">TBD</td></tr>
</table>

Table 1 Forecast Accuracy - Location (Lat/Long)

<table>
<tr><th rowspan="2">Forecast Valid Period</th><th colspan="3">Air Traffic Domain</th></tr>
<tr><th>Terminal</th><th>En Route</th><th>Global</th></tr>
<tr><td colspan="4">0-2 hrs</td></tr>
<tr><td>5,000 ft - Top of NAS</td><td>250 ft</td><td rowspan="3">250 ft</td><td rowspan="3">250 ft</td></tr>
<tr><td>3,000 - 4,750 ft</td><td>125 ft</td></tr>
<tr><td>AGL to 2,900 ft</td><td>50 ft</td></tr>
<tr><td colspan="4">2-4 hrs</td></tr>
<tr><td>5,000 ft - Top of NAS</td><td>250 ft</td><td rowspan="3">250 ft</td><td rowspan="3">250 ft</td></tr>
<tr><td>3,000 - 4,750 ft</td><td>125 ft</td></tr>
<tr><td>AGL to 2,900 ft</td><td>50 ft</td></tr>
<tr><td colspan="4">4-10 hrs</td></tr>
<tr><td>5,000 ft - Top of NAS</td><td>500 ft</td><td rowspan="3">500 ft</td><td rowspan="3">500 ft</td></tr>
<tr><td>3,000 - 4,750 ft</td><td>250 ft</td></tr>
<tr><td>AGL to 2,900 ft</td><td>100 ft</td></tr>
<tr><td colspan="4">10-24 hrs</td></tr>
<tr><td>5,000 ft - Top of NAS</td><td>500 ft</td><td rowspan="3">500 ft</td><td rowspan="3">500 ft</td></tr>
<tr><td>3,000 - 4,750 ft</td><td>250 ft</td></tr>
<tr><td>AGL to 2,900 ft</td><td>100 ft</td></tr>
<tr><td colspan="4">24-60 hrs</td></tr>
<tr><td>5,000 ft - Top of NAS</td><td>1,000 ft</td><td rowspan="3">1,000 ft</td><td rowspan="3">1,000 ft</td></tr>
<tr><td>3,000 - 4,750 ft</td><td>500 ft</td></tr>
<tr><td>AGL to 2,900 ft</td><td>150 ft</td></tr>
<tr><td colspan="4">60 hrs - 14 days</td></tr>
<tr><td>5,000 ft - Top of NAS</td><td rowspan="3">TBD</td><td rowspan="3">TBD</td><td rowspan="3">TBD</td></tr>
<tr><td>3,000 - 4,750 ft</td></tr>
<tr><td>AGL to 2,900 ft</td></tr>
<tr><td>Long Range Outlook</td><td colspan="3">TBD</td></tr>
</table>

Table 2 Forecast Accuracy - Bases/Tops

<table>
<tr><th rowspan="3">Forecast Valid Period</th><th colspan="5">Air Traffic Domain</th></tr>
<tr><th colspan="2">Terminal</th><th colspan="2">En Route</th><th rowspan="2">Global</th></tr>
<tr><th>Convective</th><th>Other Wx</th><th>Convective</th><th>Other Wx</th></tr>
<tr><td>0-2hrs</td><td>2.5 min</td><td rowspan="2">5 min</td><td rowspan="3">15 min</td><td rowspan="3">15 min</td><td rowspan="3">15 min</td></tr>
<tr><td>2-4hrs</td><td>5 min</td></tr>
<tr><td>4-10 hrs</td><td>15 min</td><td>15 min</td></tr>
<tr><td>10-24hrs</td><td rowspan="2">30 min</td><td rowspan="2">30 min</td><td rowspan="2">30 min</td><td rowspan="2">30 min</td><td rowspan="2">1 hour</td></tr>
<tr><td>24-60 hrs</td></tr>
<tr><td>60hrs - 14 days</td><td>1 hour</td><td>1 hour</td><td>1 hour</td><td>1 hour</td><td>3 hours</td></tr>
<tr><td>Long Range Outlook</td><td colspan="5">TBD</td></tr>
</table>

Table 3 Forecast Accuracy - Begin/End Times

Note: The pPR do not currently cover the performance requirements for model-output data. Those performance requirements will be developed in the next phase. Also, it needs to be emphasized that the pPR are end state requirements (year 2025) and are not related to existing weather products which are part of a planned 2013 Initial Operating Capability (IOC) demonstration of the 4-D Wx Data Cube functionality.

3.0 4-D WX SAS PROBABILITY FORECASTS

3.1 SAS Data - Basis for Weather Decision Criteria

The content of most NextGen weather forecasts will change from deterministic to probabilistic. Probabilistic forecasts will quantify the uncertainty of operationally significant weather[1]. Many of the efficiencies and capacity improvements in the NextGen concepts such as TBO and Collaborate Air Traffic Management (C-ATM) will not be fully realized without reducing the impact of weather uncertainties.

The 4-D Wx SAS will contain four-dimensional (x, y, z, and time) probabilities to enable Air Navigation Service Providers' (ANSPs) and flight operations decision support tools (DSTs) to aid decision makers in managing operational risk due to adverse weather. TBO and C-ATM DSTs will use weather information from an integrated, de-conflicted 4-D Wx SAS to provide quantitative assessments of risk in weather categories that have an adverse impact on aviation: convection, wind shear, turbulence, in-flight icing, reduced ceiling and visibility, volcanic ash, space weather, winds, and precipitation type and intensity. These probabilities will be provided for all time periods ranging from the near-immediate (e.g., a 1-minute forecast analyzed from the latest observations) to the long-term (determined from climatological data and seasonal forecasts) to support decision maker risk assessments.

The purpose of probabilistic forecasts is to provide decision makers and DSTs with assessments of all the likelihoods of a weather parameter's risk of occurrence and magnitude. The integration of weather information into DSTs will remove limitations due to human cognitive processes. Probabilistic weather information will help multiple decision makers use the same weather information, applying their own operations parameter filters to determine the risk to their operation. For example, the visual flight rule (VFR) pilot needs to assess the risk of ceilings less than 3,000 feet en route. The instrument flight rule (IFR) pilot needs to assess the risk of ceilings less than 2,000 feet at touchdown. Another pilot, whether VFR or certified for IFR, may have a preference for no ceiling below 5,000 feet en route. Flight planning tools will apply a pilot or flight dispatcher's preference criteria to a complex assortment of weather probabilities and intensities to determine the most efficient and safe route.

Probabilistic weather enables the creation of a four-dimensional structure for each user that is defined by each user's specific operational thresholds. Composed of high resolution gridded weather information, a weather event such as the three-hour position of thunderstorms will have a high probability 3-D core representing the most likely volume where thunderstorm hazards will

[1] *Concept of Operations for the Next Generation Air Transportation System v2.0*, Joint Program Development Office, June 13, 2007, p. 5-4

occur. This high probability core will be surrounded by increasingly larger volumes of decreasing risk of thunderstorm hazards. Flight Planners will use DSTs to set up four-dimensional trajectories (4DTs) that will avoid this adverse volume defined by the flight's risk tolerance limits. The size of the weather structure (i.e., the volume containing the weather hazard) is defined by applying the user's stated risk tolerance to the probability field. Using this weather information, the user defines the 4-D "structure" for each weather hazard that is to be avoided by flight planning DSTs. Probabilities lower than the flight's risk tolerance form the airspace volume the DST will consider as available airspace for the flight.

TBO planning and in-flight navigation tools will use probabilistic forecasts to assess the risk of 4DT deviation and determine the most efficient 4DT, which meets individual flight tolerances for adverse or non-preferred weather conditions.

ANSPs will use probabilistic forecasts to minimize airspace capacity limitations by reducing the likelihood of overly conservative actions. In trajectory-based airspace, ANSPs use DSTs to assess weather constraint potential in the NAS. Capacity managers use probabilistic weather through DSTs to identify available NAS airspace. Flow control managers use probabilistic weather through DSTs to address large demand/capacity imbalances. Trajectory Managers use the latest in observation and near-term forecast improvement through DSTs to safely resolve aircraft conflicts in a complex environment.

3.2 Functional and Performance Criteria of Probability Forecasts

Describing the functional and performance requirements of probabilistic weather information is a challenge because of the lack of experience with using this type of information in decisionmaking. Final functional and performance requirements will rely on consistent interaction between researchers and the users of probabilistic weather information, in particular the developers of decision support tools.

A particular challenge describing the functional and performance requirements for probabilistic forecast information will be describing the content and reliability of probabilistic forecasts.

- Content – The probability of "*what*" is a question that will require research and testing. Is it the probability of severe turbulence at a point? Is it a probability distribution for a variety of turbulence magnitudes over an area larger than a point? How large? Are the probabilities expressed for discrete categories of turbulence (e.g., as in a probability mass function[2]), or as a continuous distribution of magnitudes (e.g., as in a probability density function[3]).
- Reliability – How good should probability forecasts be before they can be used operationally? Probability forecasts cannot be "*accurate*" as deterministic forecasts are measured. A "*reliable*" probabilistic rain forecast of 30% will produce rain 30% of the time. A forecast system that produces five rain events after 100 probabilistic forecasts of 30% is unreliable, and biased toward the low side. Research will have to determine the bias tolerance for each type of probabilistic forecast.

4.0 NEXT STEPS

To get to NextGen the FAA needs a transition plan that gets NextGen benefits to the users in the minimum time. Before this happens, however, a number of system engineering activities must occur.

First, the FAA's NextGen weather performance requirements, including the probabilistic requirements, need to be completed, which is estimated to be in March 2009. These requirements must then be validated within the weather and operational communities. During validation, the operational users will determine if the performance requirements are a correct translation of their operational needs (i.e., the NextGen ConOps v2.0), while the weather community will evaluate them for meteorological reasonableness. Even if the weather community determines that a performance requirement cannot be met, that doesn't mean it is not a valid performance requirement necessary to meet an operational need.

The FAA will then formally submit their NextGen weather requirements, which includes the performance requirements, the functional probabilistic forecast requirements, as well as

[2] A probability mass function is a function that gives the probability that a discrete random variable is exactly equal to some value.

[3] A probability density function is a function that represents a probability distribution in terms of integrals.

recommended updates to the JPDO's set of weather functional requirements. The JPDO will then distribute these NextGen weather performance requirements to the other agencies for their review. This review will include an evaluation to determine if this set of requirements is sufficient to meet their operational needs. In some cases, the JPDO functional analysis may need the functions decomposed to a lower-level with new functional and performance requirements added to the set submitted by the FAA.

Once the JPDO has the updated set of functional and performance requirements, the JPDO functional requirements study team will need to be reconstituted for short period to update the "4-D Weather Functional Requirements for NextGen Air Traffic Management" document. That update will insure living documentation of the NextGen aviation weather requirements.

It must be emphasized that all the NextGen weather performance requirements must be validated through modeling and simulation with ANSPs and operators to ensure the requirements are correct and sufficient. Once the JPDO has a complete set of requirements, a more detailed gap analysis can be performed and used to develop a detailed, achievable transition plan. However, before the requirements can be allocated to the individual agencies, a requirements' allocation process must be developed. The FAA is currently developing such a process; although one of the other JPDO agencies may already have a functioning process, which can be used by the JPDO.

Finally, any requirement that can't be met due to lack of current meteorological knowledge will be allocated to R&D. By providing performance requirements to the R&D community, new products will not be forwarded to the operational evaluation board until the requirement has been met or the operational community has determined that sufficient benefit can be obtained by a less capable product.

5.0 SUMMARY

The JPDO weather functional requirements study team performed a functional analysis of the NextGen ConOps V2.0 and the NextGen Weather ConOps to determine the functions that the NextGen weather services must perform to meet users' needs. This study team then developed the associated weather functional requirements. The FAA weather performance requirements team used the results of the JPDO functional analysis and the associated functional requirements as the baseline to develop the performance requirements, as well as the probabilistic forecast functional and performance requirements. After validation within the FAA, these requirements will be submitted to the JPDO, reviewed by individual agencies, and incorporated into the 4-D Weather Functional and Performance Requirements for NextGen Air Traffic Management report to document all NextGen weather requirements.

6.0 ACRONYMS

4-D = Four Dimensional (space and time)

4DT = Four Dimensional Trajectory

4-D Wx SAS = Four Dimensional Weather Single Authoritative Source

4-D Wx Data Cube = Four Dimensional Weather Data Cube

AMS = American Meteorological Society

ATM = Air Traffic Management

ANSP = Air Navigation Service Provider

C-ATM = Collaborate Air Traffic Management

ConOps = Concept of Operations

CRD = Concept and Requirements Development

DOD = Department of Defense

DST = Decision Support Tool

FAA = Federal Aviation Administration

GA = General Aviation

IOC = Initial Operating Capability

JPDO = Joint Program and Development Office

NAS = National Airspace System

NASA = National Aeronautics and Space Administration

NextGen = Next Generation Air Transportation System

NOAA = National Oceanic and Atmospheric Administration

NWS = National Weather Service

pPR = Preliminary Program Requirements

ROM = Rough Order of Magnitude

R&D = Research and Development

SDO = Super Density Operations

TBD = To Be Determined

Wx = Weather

7.0 Glossary

Designated Terminals = Locations where NAS operations demand more than usual weather coverage – High density operations associated with OEP sites, space ports, and low density terminals within challenging climates may qualify

- High Density Operations - NextGen super-density sites will be determined by future benefit-to-cost analysis
- Spaceports – Low density but special flight operations extend beyond typical aircraft operating parameters
- Airspace associated with Designated Terminals includes a volume of airspace out to 100 kilometers in horizontal extent from each designated terminal's central reference point and extending up to the top of terminal airspace and for spaceports to the top of the NAS

En Route Domain = Volume of airspace within the NAS over North America and adjacent coastal waters excluding volumes of Designated Terminals

Global Domain = Volume of airspace outside the NAS including NAS Oceanic Airspace

4-D Weather Data Cube = All unclassified weather information used directly or indirectly for aviation decision making.

4-D Weather Single Authoritative Source = represents the machine-readable, geo- and time-referenced weather information available via network-enabled communications and has the following characteristics:

- Includes current observations, interpolated current conditions, and predictions of future conditions
- Supports probabilistic decision aids
- Provides a seamless, consistent common weather picture for integration into operational decisions that is available to all ATM decision-makers
- Each SAS grid point will contain the "official" meteorological value of a particular aviation parameter at the same location, altitude and timeframe

8.0 REFERENCES

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*Documents available at JPDO/NextGen website (http:/www.jpdo.gov/library)
