TRANSLATING AN ENSEMBLE WEATHER FORECAST INTO OPERATIONAL DISRUPTION FOR THE NATIONAL AIRSPACE SYSTEM

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1. INTRODUCTION

Thunderstorms are responsible for many air traffic delays across the National Airspace System (NAS) each year. They are also considered a threat to aviation safety due to their ability to produce both en route and terminal weather-related hazards such as lightning, hail, turbulence, microburst's, and wind shear. The Federal Aviation Administration (FAA) plans traffic flows to avoid thunderstorms utilizing a 6 hour forecast product designed for aviation.

The MITRE Corporation's (MITRE) Center for Advanced Aviation System Development (CAASD) analyses have demonstrated that thunderstorm impact to the NAS can be forecast reliably well beyond 6 hours and even up to 72 hours before the event in some cases. However, available forecasts are not useable to FAA traffic managers because they are designed for meteorologists and do not depict traffic flow impact.

MITRE is partnering with the FAA's Air Traffic Control System Command Center (ATCSCC), and the National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS)/Storm Prediction Center (SPC) and Aviation Weather Center (AWC), to develop a prototype forecasting capability that shows a greater than 6 hour forecast thunderstorm effect on traffic flows. This work supports Next Generation Air Transportation System (NextGen) weather integration initiatives set forth by the Joint Planning and Development Office's (JPDO) documentation titled: *Air Traffic Management (ATM) Weather Integration Plan* version 1.0. (JPDO 2009)

The primary objective for this collaborative research effort is to provide the FAA with a reliable aviation centric convective weather forecast for timescales greater than 6 hours. In doing so, the research has demonstrated the ability to correlate a meteorological forecast with historical air traffic demand, producing a unique aviation weather forecast capability. This prototype capability allows traffic managers to view forecasted impact to aviation from thunderstorms, not the thunderstorm forecast itself.

The capability requires no meteorological interpretation by the end user and provides a longer range planning horizon for the FAA and its customers. Longer range adverse weather impact information enables all stakeholders to plan their operations to make the best of available resources. With longer lead times, the FAA can request and have a greater opportunity to obtain the use of available resources they do not control such as Canadian or military airspace. Longer lead times also allow the FAA's customers to plan for complex logistics such as fleet and crew assignments.

This paper describes the collaborative research effort that resulted in the development of longer range convective weather forecasts tailored to the aviation community. It additionally includes a proposal for use in the Traffic Flow Management strategic planning process.

2. INITIAL RESEARCH

The basis of this research stems from MITRE observations and analyses from the operations floor at the ATCSCC. Those analyses showed that some convective events could be forecast up to 3 days before an event using longer range weather products such as the Storm Prediction Center's Convective Weather Outlook. Conclusions from that research were provided in the form of recommendations suggesting that a longer-term planning approach is feasible and should be considered by the FAA for implementation (Duquette et al. 2007).

3. COLLABORATIVE EFFORT

The purpose for the FAA, MITRE, SPC and AWC collaboration was to develop a way to provide useable and longer-range convective weather forecast information to FAA flow managers. Over the past few years, MITRE has made several visits to the SPC and

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AWC for information gathering and data collection. Subsequently, an invitation by the SPC to participate in their annual Spring Experiment gave MITRE the opportunity to explain the challenges the FAA has when dealing with convective weather and allow SPC researchers to understand how SPC's ongoing convective weather research may benefit aviation operations.

These meetings resulted in the exploration of a weather forecast to highlight the juxtaposition of convective weather and where aircraft normally fly in the NAS; SPC's Short Range Ensemble Forecast (SREF), post processed and calibrated for convective weather guidance was selected.

4. SHORT RANGE ENSEMBLE FORECAST

The SREF is a 21-member modeling system that is run four times daily at the NWS National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC) in Camp Springs, Maryland. SPC has incorporated guidance from ensemble prediction systems into all of its forecast program areas (e.g., Bright et al. 2008). Since almost 90 percent of all SPC products are for forecast periods three days or less, the NCEP SREF is well suited to meet the operational demands of the SPC (Bright and Grams 2009).

Specialized post-processing of the SREF is performed at SPC to extract information relevant to the SPC mission. It is this specialized post-processing and calibration that are unique in order to extract information relevant to innovative applications such as translating weather forecasts to NAS impact and to refine the likelihood of an event by isolating information specific to the hazard of interest.

For example, beginning in 2009, EMC began providing SREF output at 1-hour intervals through the first 39 hours of the 87 hour forecast period. SPC took advantage of the higher time resolution output and produced post-processed, hourly SREF forecasts through 39-hours. Previously, the SREF output was available in 3-hour increments. The production of hourly SREF-based guidance is being performed in conjunction with AWC to help support their Collaborative Convective Forecast Product (CCFP) development, and in collaboration with MITRE, to explore temporal guidance that may be useful for TFM strategic planning at the ATCSCC beyond 6 hours.

Figure 1 represents a sample output from the SPC SREF probabilistic thunderstorm forecast. It is presented as a gridded plot, interpolated from a 40 kilometer (km) output grid down to 20 km to better align with the air traffic data. 20 km was used so air traffic routes can be resolved more clearly.

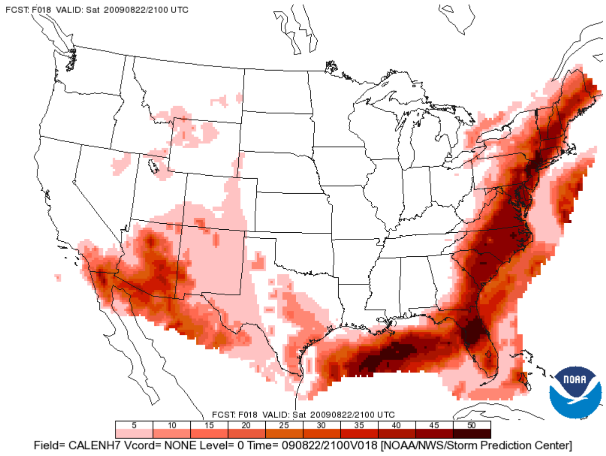

Figure 1: Actual model output of the SPC SREF with 20 km interpolation and no air traffic

4.1 SREF POST-PROCESSING BY SPC

The SPC post-processes the NCEP SREF to create a suite of customized ensemble products specifically for thunderstorm and severe thunderstorm prediction (Bright et al. 2004).

Production of the SPC SREF is performed by post-processing all 21 members of the NCEP SREF mentioned in Section 4 plus the addition of the 3-hour time lagged, operational NAM-WRF model (for a total of 22 members) at each 6-hourly SREF run cycle (03, 09, 15, and 21 UTC) (Bright and Grams 2009). Output from the SPC SREF is now available at both 1-hour increments and 3-hour increments. The 1-hour forecast intervals are available through 39 hours then 3-hour intervals afterwards through 87 hours.

Post-processing of the SREF was developed to provide diagnostics specifically relevant to the prediction of SPC mission-critical high-impact, mesoscale (small-scale) weather including: thunderstorms and severe thunderstorms, large-scale critical fire weather conditions, and mesoscale areas of hazardous winter weather.

5. COLLABORATION RESULTS

Based on the collaboration and the subsequent changes that SPC had made to the SREF to suit the challenges for aviation, SPC wanted to further understand the dynamics of air traffic in the NAS. To accomplish this, a composite of historical aircraft locations was initially developed to learn about the temporal and spatial norms across the NAS. This was performed by utilizing a 5-year sample set of historic air traffic data from the NAS that was gathered by MITRE using 1 January 2004 through 31 December 2008 as the sample set. The sample set consists of aircraft position messages (TZ) +/- 30 sec from the top of each hour of the day. TZ messages provide the 3D profile of each airborne flight. The locations and times of these TZ messages were then plotted by hour and day of week onto a 20 km grid of the NAS.

The data were then gridded for presentation to a 20 km CONUS grid, and composited hourly for every day of the week (e.g., traffic positions on a Tuesday at 22 UTC). By gridding aircraft data across the NAS, data can be viewed in many ways. For example, the probability of an aircraft within a 20 km grid at a specific time can be calculated. Furthermore, spatial correlations of air traffic in adjacent grids can be easily computed for additional statistical diagnostics.

The gridded aircraft position data (Fig. 2) are used to construct various composites that are then integrated with the calibrated SREF output. The composite of all air traffic is available on the NOAA/NWS grid 215 Lambert Conformal with 20 km grid lengths; see http://www.nco.ncep.noaa.gov/pmb/docs/on388/tableb.html for further grid information.

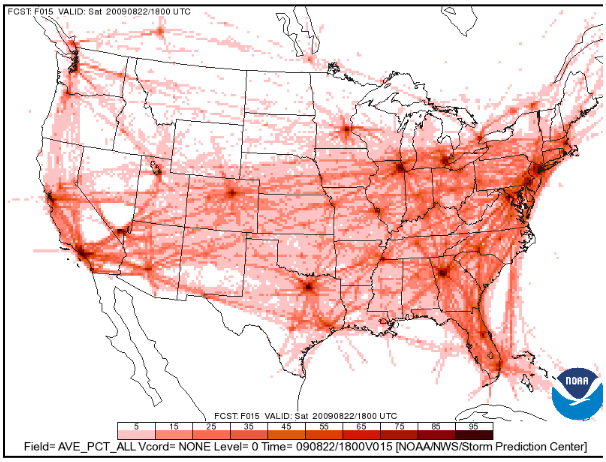

Figure 2: Gridded data composite of air traffic position data for 18 UTC on a Saturday at 20km grid lengths

6. INCORPORATING AIR TRAFFIC DATA INTO THE SREF

Once the SREF post processing is completed by SPC, that output is integrated with the appropriate day and time of the historical aircraft composite data to complete the final output of convective weather impact. The probability of convection in a specific grid box as well as the percentage of time historically an aircraft is in the same grid box produces the final probabilistic output of operational impact to the NAS.

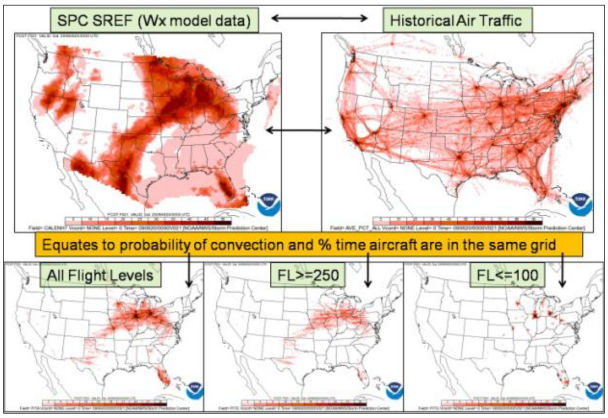

Figure 3: Example of translating a convective weather forecast into operational disruption to the NAS.

Figure 3 is an example of the SREF output (top left) and the corresponding historical air traffic position data (top right). The resultant output (bottom 3 maps) are forecasts depicting NAS disruption. This is the final result of combining a gridded probabilistic forecast (SREF) with the percent time an aircraft is historically in the same grid thus translating “weather” data into subsequent “disruption” data. The output is then parsed out by “ALL” flight levels (bottom left), the en route domain >=FL250 (bottom middle), and the terminal domain <=FL100 (bottom right).

The graphical map outputs are currently displayed as gridded plots and are detailed further in the next section. Gridded plots rather than contours are currently being utilized for the output as they appear better suited for traffic flow management purposes in order to visualize impact from convective weather and to extract the impacted routing structure within the NAS. The resultant effort of this collaborative research has produced the capability to now forecast NAS disruption or “impact” from a convective weather forecast and requires no meteorological interpretation by the user. The output is no longer an explicit convective weather forecast map, but is essentially a weather forecast that has been autonomously translated into a probabilistic forecast of air traffic disruption.

This weather forecast for aviation is based on the composited aircraft location and the calibrated probability of a thunderstorm (Bright et al. 2005) being independent. The product of the two represents a first-order proxy for the gridded probability of en route aircraft encountering thunderstorms. Under the assumption of independence, joint probabilities of aircraft at a specific location and thunderstorms (or convective cloud tops) can be estimated by taking the product of the calibrated thunderstorm guidance with the normal probability of aircraft occupying that grid cell.

7. AVIATION IMPACT MAPS FOR TFM

The graphical output format of the convective weather impact maps can be tailored for the needs of flow managers. Several examples and descriptions of how this information is depicted for different altitude strata follow: Those examples include:

- Aviation Impact at "All" Flight Levels
- Aviation Impact >= FL250 (En route Domain)
- Aviation Impact <= FL100 (Terminal Domain)
- Aviation Impact from Convective Echo Tops >= FL370

7.1 AVIATION IMPACT AT "ALL" FLIGHT LEVELS

Figure 5 shows a map of the impact to air traffic at all flight levels based on the forecast from the SPC SREF in Figure 1. This translation shows convective weather impact on traffic flows at all flight levels. These aviation impact maps represent the percentage of time aircraft are contained within a grid box at the specified time along with the probability of convection in that same grid.

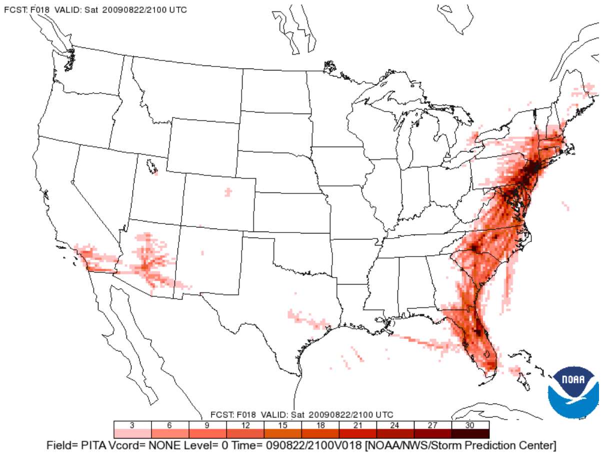

Figure 5: Combined SPC SREF output with air traffic at all flight levels illustrates the resultant impact to air traffic from the SREF model forecast

7.2 AVIATION IMPACT >=FL250

Figure 6 is the translation of the weather forecast into operational disruption based on the historical flow of air traffic in the NAS at Flight Level 250 and higher. By using the Aviation Impact >= FL250 (En route Domain) a traffic manager can visually see a refined view of what particular routes or routing structure within a certain region will be disrupted by convective weather from FL250 and higher at a particular hour.

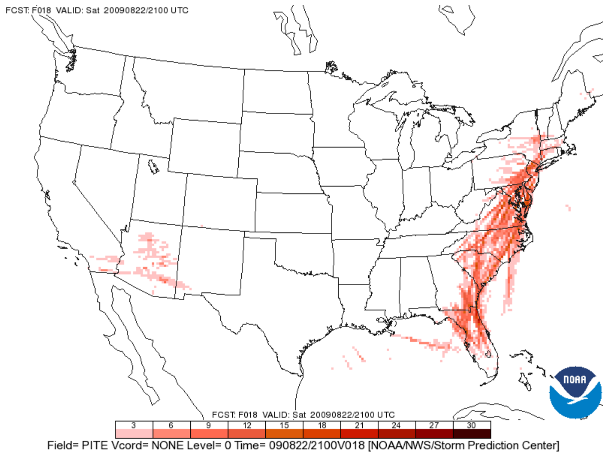

Figure 6: Combined SPC SREF forecast with air traffic >= FL250 (25,000 feet) illustrates the resultant impact to air traffic for the en route domain.

7.3 Aviation Impact <=FL100

For the terminal domain, the Aviation Impact <= FL100 maps illustrated in Figure 7 have shown utility, especially at the major airports. MITRE researchers have been working with FAA traffic management personnel to review the outputs of these maps in a "pre-event" and "post-event" capacity as a way to determine potential value. Some of the trials have included modeling Ground Delay Program (GDP) rates for an airport up to 48 hours prior to the event, then comparing those to the actual Traffic Management Initiative (TMI) that was issued and the timing of that initiative. GDP's manage demand arriving at a capacity-constrained airport by delaying flights at their departure airport. The most common reason for a reduction in arrival rate for an airport is adverse weather. In fact, studies show that the NAS will net the greatest potential benefits from improved identification and prediction of weather and its impacts on the terminal area (Souders et al. 2004). In addition, thunderstorms at or in the vicinity of the terminal domain can directly influence an airport's arrival and departure rate, therefore making them positively correlated to a substantial number of flight delays each year (Huhn 2005).

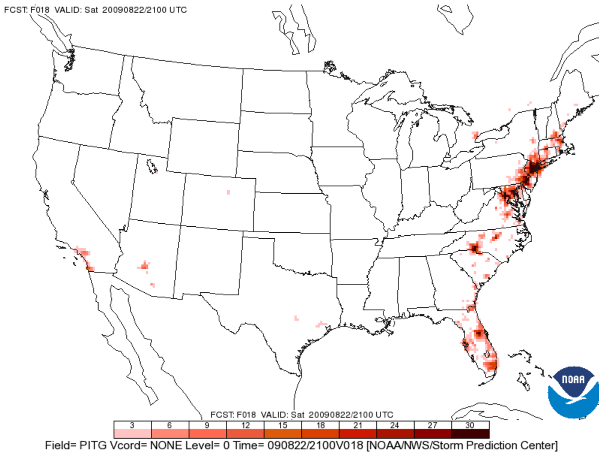

Figure 7: Combined SPC SREF forecast with air traffic <=FL100 (10,000 feet) illustrates the resultant impact to air traffic for the terminal domain.

7.4 Aviation Impact from Echo Tops >=FL370

Figure 9 illustrates the impact to air traffic from echo tops >=FL370 and indicating vertical extent. For example, in other cases there has been widespread impact at FL250 and higher yet very little impact from echo tops at FL370 and greater. This allows a traffic manager to isolate the scope of the disruption and determine the vertical extent of the impact to the en route domain.

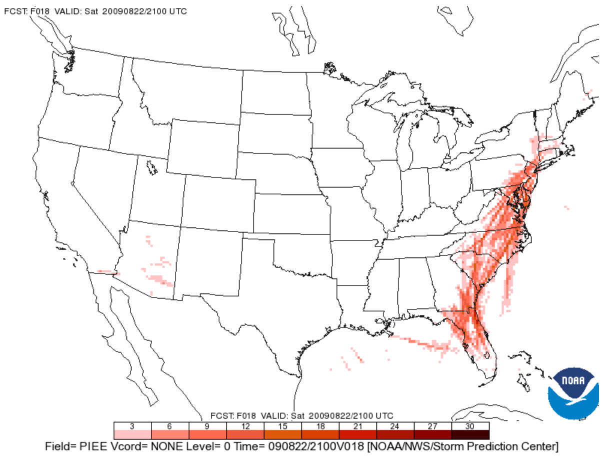

Figure 9: Combined output of the SREF Echo Tops with air traffic >=FL370 (37,000 feet) illustrates the resultant impact to air traffic to the en route domain from Echo Tops.

8. ALTERNATIVE PRESENTATION USING A TIME SERIES FORMAT

The time series format of the convective weather impact maps (Figure 10) is another useful way of illustrating the data output from the graphical maps discussed earlier.

Similar to the graphical maps, the time series displays are available daily on the same schedule as the NCEP SREF and can be accessed by a traffic manager for impact guidance out to 39 hours. The time series maps are set up to display the Maximum Probability (Red Line), the Median Probability (Blue), and Minimum Probability (Purple) of convective weather impact to the entire NAS or to a specific region. This is only a first step towards displaying impact data values in this format and will most likely be refined to display other parameters with future research.

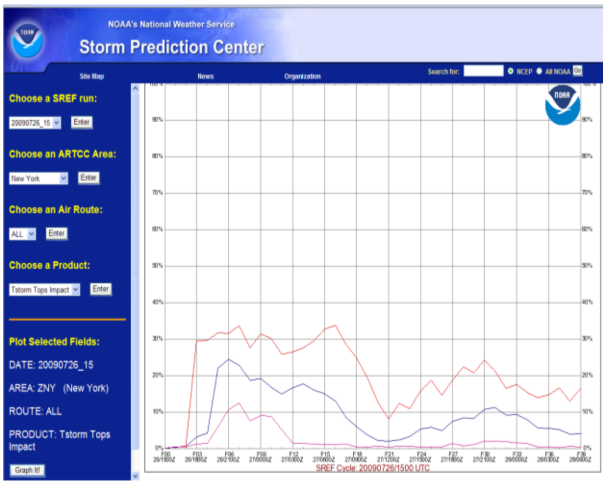

Figure 10: Example of a time series map of impact for New York Center (ZNY) as a function of time.

The primary utility and benefit of the time series maps is that a traffic manager can view a regionalized impact of convective weather at the Air Route Traffic Control Center (ARTCC) or “Center” level. By viewing forecasted convective weather impact at this level, a traffic manager can begin to move away from a NAS wide systemic problem-solving scenario if the impact will be regionalized in scope.

Use of the time series format can help traffic managers better understand the convective weather scenario for the day. Convective weather impact is illustrated as a function of time on a single display rather than on multiple graphical maps. For example, convective weather impact illustrated as a function of time can clearly depict a scenario in which morning convection would be followed by additional convection during the afternoon hours. This is illustrated as a double peak (Figure 11) to the impact curve (red trend line).

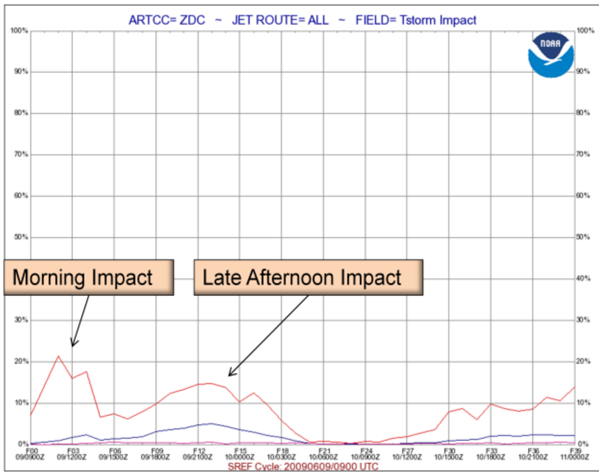

Figure 11: Example of a double peak in the impact curve due to convective weather that is forecast to impact all jet routes within Washington Center (ZDC) as a function of time.

Because the time series format indicates numeric values for operational impact as a function of time, this format is well suited for automated TFM decision support systems in the future.

9. OPERATIONAL IMPLEMENTATION PROPOSAL

FAA use of a collaborative strategic planning process with lead times of 24 hours and greater will require a revised strategic planning process. To meet this need, MITRE proposed an approach that is similar to the NWS multi-tiered concept for alerting their customers and partners who need considerable lead-time to prepare for hazardous weather. Their vernacular uses the terms "Outlook," "Watch," and "Warning," (or "Advisory" if warning thresholds are not met) products to alert for potentially significant weather; see http://www.wrh.noaa.gov/slc/productguide/CH4.php for further information.

Based on this, MITRE developed the TFM Weather Management Matrix model (Figure 13) which was designed for use in a longer-term strategic planning process. It proposes the use of a multi-tier approach based on the increasing risk of disruption to the NAS as a function of time. The graphical NAS impact forecast maps described in Section 7 were intended for use with the matrix decision model.

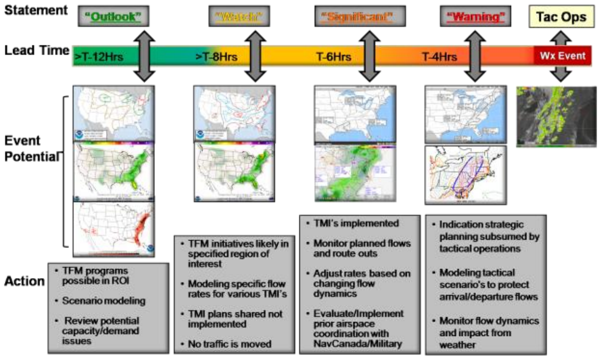

Figure 13: The TFM Matrix model enables traffic managers to plan against the increasing risk of disruption over time by referencing predefined supplemental weather information earlier in the planning process.

The intent of the matrix is to apply standard definitions and levels of response required by the system users based on identified weather trends and events. This could encourage proactive decision-making by all NAS stakeholders in anticipation of weather related constraints, build upon collected knowledge to incrementally raise system awareness of significant weather impact and subsequent mitigation plans. The matrix is the potential "process" that would utilize the "capability" to translate weather into impact at long-range timescales for the promotion of common situational awareness among stakeholders and a likely precursor to large-scale traffic initiatives

10. CAPABILITY USE AS A STEP TOWARDS NEXTGEN

Currently traffic flow managers must mentally integrate most weather information after viewing numerous stand-alone weather products before developing a response. A goal of NextGen is to minimize the need for human interpretation of weather impacts and for automated systems to determine the optimum mitigation strategy. This long range convective weather for aviation initiative discussed in this paper is a first step towards minimizing the need for humans to interpret aviation impact from convective weather and is well-positioned to provide an output for automated TFM systems to determine a strategic response.

10.1 NEXTGEN MID-TERM APPLICABILITY

The NextGen weather vision highlights the need for weather translated into operational impacts and is described in the NextGen Concept of Operations (2007), the NextGen Weather Concept of Operations (2006) and other documents produced by the JPDO. The concept of weather translated into operational impact is further refined by the FAA's NextGen Implementation Plan (2008), formerly called the Operational Evolution Partnership. Additionally, recommendations issued by the Weather – ATM

Integration Working group of the Research, Engineering and Development Advisory Committee (REDAC) concluded that traditional weather data translated into operational impact is necessary. In their report dated October 3, 2007. A key finding of this report was that a risk management approach with, incremental decision making and translating weather forecasts into air traffic impacts, presents a major new opportunity for reducing weather related delays in the future NAS (FAA 2007).

The “process” illustrated by the TFM weather management matrix and the “capability” demonstrated by translating weather data into operational impact for aviation is well suited to meet the needs of both the JPDO’s Air Traffic Management Weather Integration Plan as well as the REDAC’s findings on incremental decision-making and automatically translating weather forecasts. The data from this research is certainly applicable to NextGen initiatives in terms of temporal/spatial resolution, automated output, digital gridded data (GRIB), and is probabilistic. Therefore, the translated convective weather impact maps in this research are also potentially well suited for incorporation into the 4D Weather Cube in the future. The 4D weather cube will ultimately be a data repository for aviation weather information for use in decision support tools, automated TFM systems, and aircraft avionics utilizing the three spatial domains plus time. The current timeframe for initial operating capabilities of the 4D-weather cube is set for 2013.

11. SUMMARY

Providing longer range convective weather forecasts for aviation can show traffic managers the predicted convective weather impact to aviation without requiring the interpretation of meteorological data. The proof of concept capability described in this paper is available daily on an experimental basis using the four times daily NCEP SREF in both a graphical and time series format. The graphical formats highlight areas where thunderstorms are forecast to disrupt the historical flow of air traffic in the NAS while the intent of the time series format is for the direct insertion into automated TFM systems.

Using reliable aviation centric convective weather data that show operational impact permits the expansion of strategic planning timelines beyond 6 hours. It additionally provides common situational awareness and facilitates the synchronization of stakeholder planning initiatives to improve NAS efficiency.

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