Application of Military Weather Thresholding and Big Data Analytics to Civil Trajectory-Based Weather Avoidance Rerouting

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Key Words

NextGen, weather avoidance, route resolution, integration, trajectory-based, CSS-Wx, NWP

Introduction

This year, ATCA is co-locating its 59th Annual Conference & Exposition with the Civil/Military Aviation Conference (CMAC). While there are many operational issues faced by both civil and military air traffic management (ATM), weather will continue to impact efficient and predictable air operations in the civil side as well as successful mission objectives on the military side. Thus, the timing is right to consider weather avoidance and resolution technologies developed for the military to civil air traffic control challenges and vice-versa. The challenge with military systems is that, by their operational requirements, publication even of non-classified components such as weather decision support tools is not widely known. Review of related work shows that all three services (Army, Navy and Air Force) have each developed a version of a weather avoidance decision aid embedded in operational command and control systems. An encouraging aspect of this development is that these weather tools are open geospatial consortium (OGC) compliant data models and are built using web services so the potential for re-use is possible.

The purpose of this paper is to describe prior military weather decision aids development, highlight route weather thresholding technology development at General Dynamics and make the case for how civil and military weather decision aids development to date can and should be leveraged to benefit both civil and military weather hazard detection, avoidance and re-routing operations.

Brief Overview of Related Work in 4-D Grid based Weather Avoidance and Rerouting

Since 2005, there has been several published papers addressing weather detection, avoidance and rerouting undertaken by various organizations including General Dynamics, Lockheed Martin, the Army Research Laboratory (ARL), MIT Lincoln Laboratory, NASA Ames Research Center (ARC) and others. Some having been funded by government contracts and others funded with internal research funds.

NASA

In 2005, NASA published work on grid-based air traffic conflict detection [1]. This research investigated the use of 4-D space-time grids applied to strategic air traffic conflict detection and served as motivation for the authors' subsequent work in in grid-based trajectory weather conflict detection and resolution services prototype development at Lockheed Martin from 2008-2011. [2,3,4,5]

In 2012, NASA ARC published work on Dynamic Weather routes [6] whereby weather impacts on en route aircraft are continuously updated and evaluated. A ground ATC automation decision support tool was then employed for operators to manually create reroutes around the hazardous weather as defined by the convective weather avoidance model (CWAM).

Navy

From 2009 to 2012, The Navy Integrated Tactical Environmental System (NITES) 2nd Generation Redesign (N2R) and NITES-Next Generation (NITES-Next) - a component of the Global Command & Control System (GCCS) Operating Environment (GOE) developed by General Dynamics. See Figure 1. NITES is deployed to shipboard meteorological and oceanographic (METOC) offices and ashore at tactical support centers, Naval Meteorology and Oceanography Command activities, Marine Corps air station weather offices and Marine Corps meteorological mobile facilities. The objective of the NITES2 system is to provide the warfighter with access to METOC data sources and to perform predictions via Tactical Decision Aids (TDAs) that make use of the METOC data. See Figure 2.

Within NITES-Next is the Joint Thresholding Segment (JTS), which is an environmental analysis tool that combines the functionality of the Tactical Control Project (TCP) Thresholding Tool and the Integrated Weather Effects Decision Aid (IWEDA) developed by the Army Research Laboratory (ARL). JTS allows environmental data to be run against threshold rules or queries. Threshold rules allow the data to be evaluated against threshold values. The results are passed to the IWEDA software for display. A summary display of the weather impacts at the mission, system, subsystem, and component level is provided with the capacity to drill down to explore the metadata. Further analysis can be performed over an area or for sortie missions along a route.

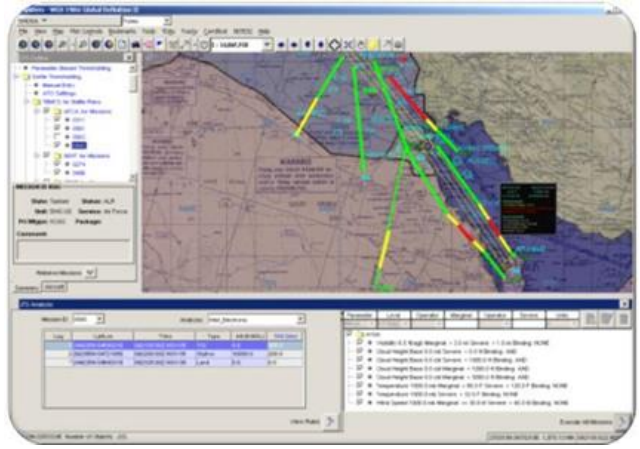

Figure 1 NITES-Next Thresholding Function showing mission impacts of weather hazards on multiple flight trajectories

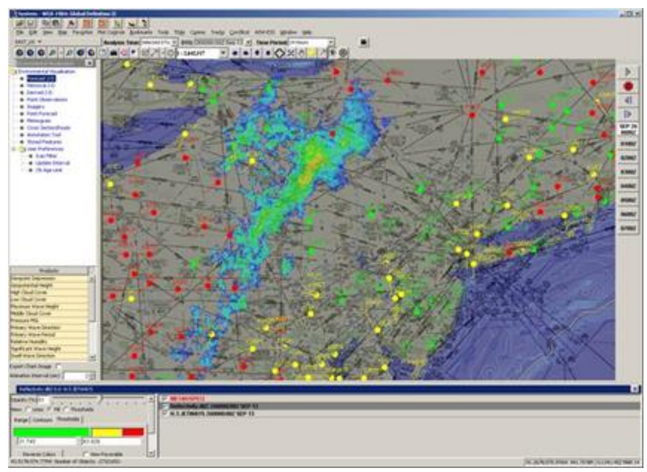

Figure 2 Google Earth ™ Visualization of NITES-Next METOC data

Army

In 2008, ARL published work on an Aviation Weather Routing Tool (AWRT) which addressed the complexity of routing aircraft around adverse weather conditions [7]. In 2011, ARL published work on Atmospheric Impacts Routing (AIR) – an Army decision aid, described in report ARL-TR-5792 [8]. The AIR application is a replacement to the technology described in [7]. Because of the IWEDA component incorporation into the NITES JTS, AIR and NITES, JTS uses a weather effects matrix, where the effect of a given weather hazard on a flight is rated in one of three categories" favorable, marginal and unfavorable).

Lockheed Martin

In 2008 under a FAA funded NextGen Demonstration project at the Daytona, FL NextGen Test Bed, with an Embry-Riddle Aeronautical University (ERAU)-led industry team, Lockheed Martin developed a concept of integrating 4-D predictive weather with the Traffic Management Advisor (TMA) and En-Route Automation Modernization (ERAM) prototypes of an ERAM D-Position weather re-routing trial planning tool whereby en route controllers could evaluate hazardous weather routes by using a rubber-band scheme to manually create a trial re-route [9]. From 2009 to 2010, in collaboration with Ensco, Inc., Lockheed Martin developed a grid-based hazardous weather detection prototype and later, a grid-based hazardous weather conflict resolution service prototype. Like the ARL AIR/IWEDA weather effects matrix, the Lockheed Martin weather conflict detection service used the concept of a 4-valued convective weather avoidance field (WAF) developed by Ensco, Inc., not to be confused with the WAF based on the convective weather avoidance model (CWAM) developed by MIT Lincoln Lab [10,11]. In 2011, a grid-based weather conflict resolution service prototype was developed that included aircraft-to-aircraft conflict probe to ensure weather re-routes did not create a flight conflict as a result. [4]. The weather conflict detection service was then later used in a 2011 FAA NextGen Demo project at Daytona where TMA was modified to display convective weather as well as integrating the output of the weather conflict service data into TMA decision support algorithms with delay impacts shown on the TMA Timeline Graphical User Interface (TGUI) display [5]

Both the military-focused AIR work and the author's previous civil ATC focused research on grid-based trajectory weather resolution methods approached the problem of weather avoidance and re-routing in similar ways, but with different constraints on objectives.

The Case for Big Data

With as much that has been published about "Big Data" in recent years, sorting through the hype for relevant application of Big Data methods to a given problem can be challenging. The evolution of Information Technology (IT) has rapidly changed the way organizations move, store, process, and access information. With increasing data storage requirements, high levels of security risks and the complexity of data being collected, government and industry are seeking new and innovative ways to turn massive amounts of structured and unstructured data into actionable information. General Dynamics Information Technology (GDIT) has deployed Big Data technologies for government programs including:

- US Navy FNMOC – Integrated secure NoSQL feature store with spatial data plug-ins and delivery of meteorological OGC Web Feature Service (WFS) and Web Mapping Service (WMS) services across multiple network security enclaves
- Naval Tactical Cloud – Implemented with Open Geo-spatial Consortium GeoServer and Cloudbase Accumulo, Ozone Widget Framework (OFW) Touch and OWF Inter Widget Communication (IWC) See Figure 3

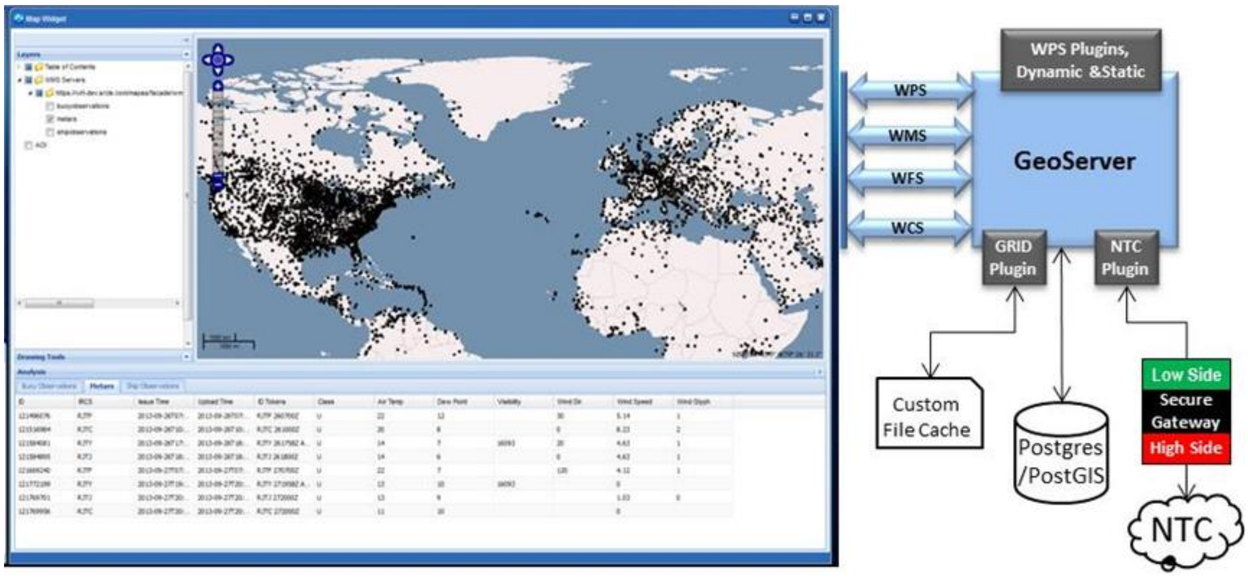

Figure 3. Naval Tactical Cloud Big Data METOC Application

So, why would a real-time big data analytics approach make sense for weather detection, avoidance and re-routing services? When considering grid-based approaches described [1] and [3], where a volume of airspace containing weather, aircraft and route restrictions is "digitized" into cells of some specified dimension, there are several considerations, chief among which include:

1. Size of the volume of airspace in the region of interest (ROI)
2. Grid cell resolution in the ROI
3. Update rate of aircraft trajectories
4. Amount of and intensities of weather phenomena in the ROI
5. Probabilistic value of the weather phenomena in the ROI
6. Number and variety of aircraft in the AOI
7. Various ATC route restrictions and constraints
8. Special Use Airspace schedules

Consider the volume of airspace for an Air Route Traffic Control Center (ARTCC). The ARTCC airspace includes many general aviation airports, several large commercial airline served airports, one or more military air bases, special activity airspace. Thus, within this airspace are a variety of military and civil flight operations including en route flyovers (flights transiting the ARTCC's airspace), military aircraft entering, exiting and operating within military operations areas (MOAs) and aircraft departing and descending through multiple altitude layers.

Depending on the ARTCC, weather conditions, particularly convective activity in the midwest, south and eastern regions of the continental United States (CONUS) can have a large impact on the ARTCC airspace as a whole. For example, the Denver ARTCC is approximately 198,000 square nm. Then, the altitude span of control extends, depending on the ARTCC sector, as low as the surface and up to 60,000 ft. The severest of convective storms can exceed 70,000 ft.

Grid cell resolution is a consideration because grid-based weather products such as Corridor Integrated Weather System (CIWS) precipitation and echo tops products can be quite large with a resolution dimension of 1 km x 1 km x 1000 ft. The amount of weather grid cell coverage along with the variety and probability of weather intensities in the ROI can result in very large data sets.

In ERAM, while there are a number of events and triggers which cause an aircraft trajectory to be rebuilt - the highest rate is determined by the rate of aircraft track updates – either from 12 sec long range surveillance radar (ARSR) or 5 sec short-range (Terminal ASR) track updates. In the 2012 Weather-ATM Integration demonstration at the Florida NextGen Test Bed, the 4-D trajectory grid was sampled at approximately every 6 seconds to ensure no long range radar track updates were missed. Thus, the trajectory grid was rebuilt every 6 seconds at the highest rate. The weather grid was rebuilt every 2.5 min per the CIWS update rate.

The density and types of aircraft in the AOI are a key consideration because, as indicated in [4], any weather avoidance or rerouting strategy is incomplete without an aircraft-to-aircraft conflict probe when evaluation weather avoidance routes to ensure that flights rerouting around weather are not rerouted such to create a potential conflict with each other. In a grid-based scheme, there is the weather grid and the aircraft trajectories grid. When a weather conflict is determined, a resolution grid will also be generated. The resolution grid is essentially a 4-D pathfinding problem using a grid-based tree search. The grids are all each 4-D data representations where there are points in space associated with a time value.

The hazardous weather reroute application includes each of the three big data characteristics including volume, variety and velocity [12].

Big Data solutions such as Hadoop and Accumulo were implemented for the FNMOC project. Given the vast amount of data that many weather sensors and systems generated along with the degree and rate of change of that data, an architecture that was needed that would handle the data as well as scale with the ever increasing amounts of data generated. Thus, Apache™ Hadoop® was the platform selected for data storage and processing. Its characteristics include scalability, fault tolerance, Open source, flexibility to store and mine any type of data. Using Hadoop, we can generate queries across structured and unstructured data that were previously impossible to ask or solve. [13] This will be needed especially in the case of extensive 4-D tree searches for weather reroute alternatives. Accumulo™ is a Not Only SQL (NoSQL) solution originally developed by the National Security Agency (NSA) works in collaboration with Hadoop in providing fast random read/write access. Accumulo™ is basically an efficient multi-dimensional map. The fact that weather is 4-D makes Accumulo™ particularly well suited for weather data analytics. Internal research and & development at General Dynamics has been extended to include the application of big data weather analytics techniques to grid-based hazardous weather detection and resolution advisories.

Opportunities for Collaboration

There are several options to pursue civil/military ATM collaboration including NASA Space Act agreements, FAA Small Business Innovation Research, and Other Transaction Agreements (OTAs). Collaboration efforts would likely make use of either an existing NextGen Demonstration Test Bed such as the Florida NextGen Test Bed in Daytona Beach, FL or the FAA's NextGen Integration and Evaluation Capability located at the William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. If the NIEC was chosen, the existing SE2020 System Engineering contract vehicle for NIEC support could be used to execute this project.

OTAs are covered under the Other Transaction (OT) Authority contract vehicle. An OTA is a special type of vehicle used by federal agencies for research and development purposes, and only those agencies that have statutory authority to engage in OTAs may do so [14]. The FAA, DoD and NASA all have OT Authority. In previous FAA OTAs utilizing the Daytona NextGen Test Bed, ERAU was the managing agent for government-industry teams developing a specific concept demonstration. For this collaboration opportunity, FAA could execute an OTA with ERAU coordinating industry and government research labs such as NASA, ARL and FNMOC to come together to demonstrate 1) a common hazardous weather detection service and 2) a common weather reroute resolution service that could be used by both FAA and military functions – each operating with independent thresholding rule sets. See Figure 4 for a notional architecture for this demonstration. In the long term, this service could eventually become part of CSS-Wx or may evolve to a separate development under the SWIM office. The weather conflict and resolution services would be common services that could benefit other military tactical planning aids as well as clients using the evolving Aircraft Access to SWIM (AAtS) services.

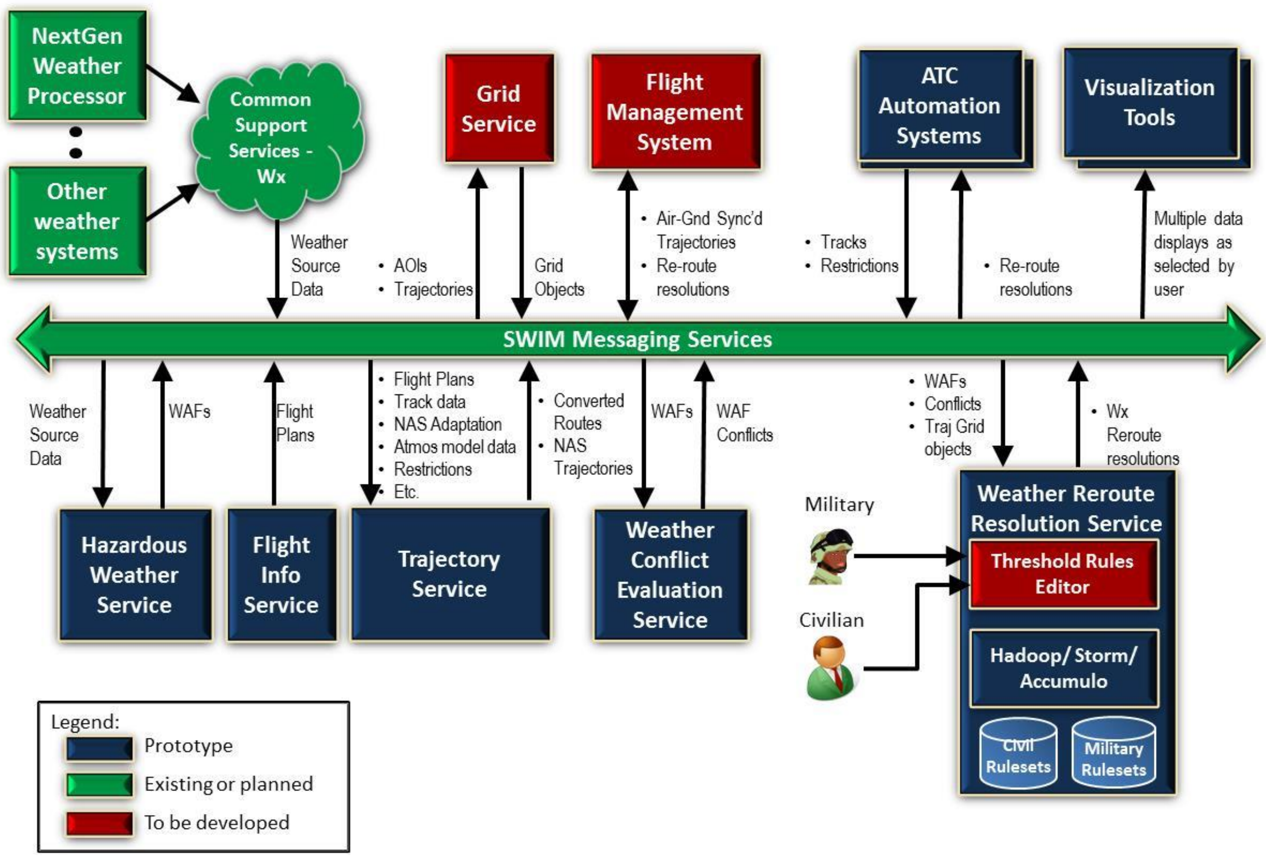

Figure 4 Civil-Military Collaboration Notional Demonstration Architecture For Grid-Based Weather Reroute Resolutions

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