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Weather Effects Embedded within Net-Centric C2 System Workflows

Topic 10: Collaborative Technologies for Network-Centric Operations

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Abstract

Weather impacts military operations, sometimes adversely. Currently, including weather advice within on-going deliberations relies largely on time consuming and disconnected mental fusion of various sources and systems to gain a shared understanding of the "natural" battlespace. As a result, weather advice is often ignored, misrepresented, or overlooked in the heat of battle. This will only worsen as computer-augmented decision-support improves over time.

To manage operational risk effectively, decision-makers need weather-effects guidance embedded within their existing workflows. C2ISR application developers would benefit greatly having a Software Developers' Toolkit (SDK) to help them incorporate what is needed and to ensure that there is consistency across all net-centric collaboration spaces. The Air Force Research Laboratory Information Directorate, Rome, NY, is researching how to build just such a toolkit; the Weather Software Toolkit for Operational Risk Management (WxSTORM). This toolkit will offer a scalable, component-based, service-oriented, and integration-ready solution that can be transitioned into C2ISR systems needing contextual weather-effects information within their collaboration processes. This paper provides an overview of why including weather has been so hard, examples of how weather affects military operations, how an SDK will provide an easy-to-incorporate solution, and a sample of how including advice helps.

Introduction

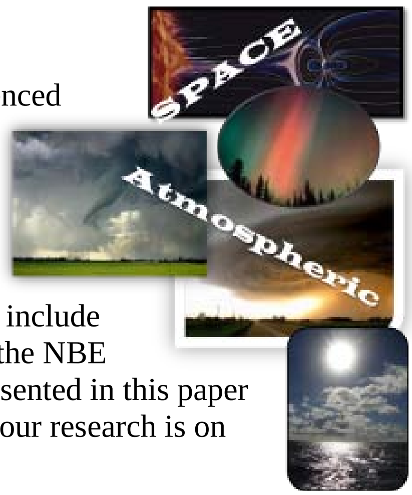

Figure 1: Air and Space focus

Military operations are conducted in, and are thus influenced by, the natural elements; the Natural Battlespace Environment (NBE). The NBE is an all-encompassing term meant to represent atmospheric, space, oceanic, littoral, land, and biological environments. All military forces are susceptible to adverse conditions of the NBE. [1,2,3] For this reason, military planners need to include situational awareness of the current and future states of the NBE within their decision workflows. While the concepts presented in this paper are equally applicable to all NBE domains, the focus of our research is on the atmospheric and space environments (Figure 1).

Joint Publication 3-59, *Joint Doctrine, Tactics, Techniques, and Procedures for Meteorological and Oceanographic* (METOC) *Operation*s points out that, "Properly applied, joint meteorological and oceanographic (METOC) operations can provide air, land, maritime, space, and special operations forces with a significant, even decisive, advantage over our enemies."[4] The U.S. Air Force and Navy are highly adept at measuring, reporting and accurately predicting the state of the NBE.[5] Joint Pub 3-59 also defines METOC "… as a term used to convey all meteorological, oceanographic, and space environmental factors as provided by the Services, support agencies,

[1] Fuller, 1990

[2] Eliot, 1993

[3] Demmert, et. al., 2005

[4] Joint Pub 3-59, Overview, p. vii

[5] Demmert, et. al., 2005

and other sources."[6] The Joint METOC community has a well trained, highly professional cadre and sophisticated infrastructure for providing tailored, excellent quality, high fidelity forecast information to commanders and their staffs.

Decision-makers, at all echelons, strategic through tactical, strive to use this information in a variety of ways in planning and directing operations. Including "weather" advice within on-going deliberations, however, has heretofore largely relied on the time consuming and disconnected mental fusion of both Command & Control (C2) and METOC sources and systems. We have consistently failed at incorporating it within our computer-augmented decision-support. As a result, weather advice has often been ignored, misrepresented, or overlooked in the heat of battle. Ironically, when weather is at its worst, things go badly and decision-makers get too busy reacting to weather problems and have no time to contemplate exploiting what we know about it; which would have kept them out of the mess in the first place. As Command & Control Intelligence, Surveillance, and Reconnaissance (C2ISR) system developers succeed at making the decision-making process more and more automated, it will be increasingly difficult to make use of weather advice unless we figure out how to incorporate it within our automation.

The need exists, therefore, to advance our ability to exploit our superior understanding of the NBE within computer-augmented decision-making C2ISR applications.[7] We require capabilities that afford C2ISR applications the ability to "visualize-to-utilize" NBE influences directly within their applications so that decision-makers can readily manage operational risk. Incorporating NBE influences directly within decision workflows is the key to enabling decision-makers at all command levels to quickly and seamlessly acquire NBE situational awareness and to accurately assess its affects on current and proposed military operations.[8]

Doing this requires more than just machine-to-machine NBE data transfers, as, for example, already provided by the Air Force's Joint Environmental Toolkit (JET). It also requires a long list of processing capabilities internal to C2ISR applications to deal with the complexities of the data and correct application of the advice. The Air Force Research Laboratory Information Directorate's Weather Software Toolkit for Operational Risk Management (WxSTORM) project has conducted research into what capabilities are needed. Because there are many ways to misinterpret and misuse the weather information provided to C2ISR users, we need the C2ISR development community to depend on a standardized, verified, validated set of access, analysis, and visualization components, ideally made available as a software toolkit (SDK) to all C2ISR application development programs.

Component-based software solutions that can be readily integrated into existing and emerging C2ISR applications provide the flexibility and affordability to achieve the necessary advances across the broad spectrum of diverse environments, tools, applications and systems in use within the C2ISR community. The effectiveness of these solutions must be based on the ease of incorporation of components into developing and

[6] Joint Pub 3-59, Overview, p. vii

[7] Lanicci, 1998

[8] Heckman, 2008

evolving systems, the understandability of the advice presented, the rapidity of response within decision response cycles and, ultimately, an increase in mission success rates.

This paper provides a quick perspective on how Joint METOC supports C2ISR, what makes it so difficult to include METOC products within computer-augmented decision-support, and how atmospheric and space weather impact military operations. It describes how the WxSTORM project is tackling the problem of incorporating METOC guidance head-on, and finishes with a sample use cases of how decision-makers can manage operational risks with embedded METOC support. The essential first step to doing that is to understand Joint METOC support.

Joint METOC Support

Many countries expend resources to routinely measure the physical conditions, the attributes, of the NBE using space, air, and ground based measuring devices. These measurements are shared throughout the World Meteorological Organization. Militaries expend resources to measure their respective natural battlespace environments and other data-denied areas of interest. The multitudes of sources are calibrated, interpolated, interpreted, fused and assimilated by our METOC strategic centers to create running analyses of the state of our various NBEs. These analyses are disseminated to decision-makers to provide a reasonably current, albeit old, status of their NBE, and are also injected into sophisticated computer models to project the NBE's state into the future. The Air Force Weather Agency (AFWA) and the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC) run Numerical Weather Prediction (NWP) models on a cyclical basis to produce forecast products of applicable attributes wherever and whenever the DoD needs them. These are also disseminated to subscribers as they are produced. The end-to-end process of collecting, analyzing and predicting the state of the NBE and publishing accurate, consistent, timely and relevant products is laid out in AF Doctrine 2-9.1 (Figure 2).[9]

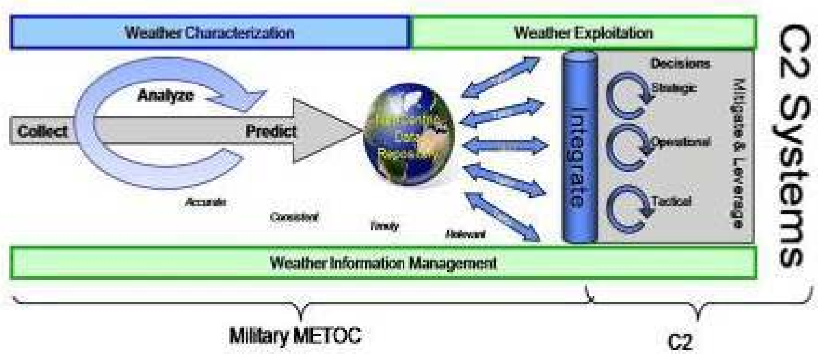

Figure 2: Air Force Weather doctrine conceptual model

Characterizing the weather is extremely difficult, but just as challenging is finding ways of exploiting our hard earned weather understanding within computer-augmented decision making. To succeed, we need to answer many hard questions. Working with the well-honed weather data model, for instance, is extremely complicated; how do we integrate NBE data models within C2ISR decision-support? When we do succeed in incorporating weather advice, how do we ensure all collaborators use the same authoritative source? But it is not really the raw weather data that we need; what we need is to understand what it is going to do to us and

[9] Air Force Doctrine 2-9.1, 2006, p. 15

our adversaries. Translating predicted NBE state into impacts to operations has proven to be non-trivial.[10] There are many degrees of freedom that are sensitive to the context of the situation. How do we dynamically determine impact? When we dynamically determine impact, how do we not clutter the screens or overload decision-makers with our results? And finally, is it beneficial to represent uncertainty and, if it is, how should we do it? Solutions to incorporating NBE understanding have to have solid, executable answers to these questions.

The primary question is how to deal with the extremely complex weather data model that is used to capture the state of the NBE. Meteorologists have invented thousands of attributes to describe the state of the atmosphere. Fortunately, only a few dozen are relevant to military operations (e.g., temperature, moisture, pressure, winds, precipitation, icing, aerosol concentration and type). Some of the characteristics that make it so difficult to work with include:

1. 5-Dimensions (latitude, longitude, altitude, time, and attribute)
2. Multiple units of measure (e.g., Celsius, Fahrenheit; millibars, hectopascals; feet, meters)
3. Data types (text bulletins, text code, raster, vector, numerical)
4. Data formats (e.g., GRIB, netCDF, GIF, Shape, NITF)
5. Projections (Mercator, Lambert Conformal, Lat/Lon) with multiple geodetic datums (e.g., WGS 84, spherical Earth with differing earth radius standards)
6. Multiple, nested horizontal resolutions (AF: 55/45/15/5 km, Navy: 27/9/3 km)
7. Multiple vertical resolutions represented in several different coordinate systems (e.g., pressure, height, geopotential height, sigma)
8. Many nested windows (Figure 3) with overlaps and coverage gaps (Figure 4)[11]
9. Update schedules, model run cycles, and many different models.

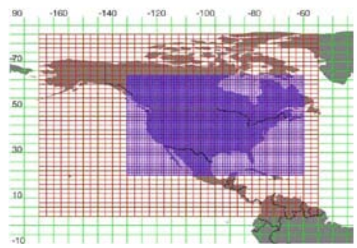

Figure 3: Nested Grid Example

Perhaps the most complicating characteristic of all is the fact that Joint METOC publishes their forecasts in a uniformly gridded data field (UGDF) format using World Meteorological Organization standard gridded binary (GRIB) format.[12] GRIB is a specification for storing multiple grid datasets within a single compressed and compacted file for efficient storage. Despite the obvious advantages in reduced storage and bandwidth required for transmission, the complexity of GRIB has made it extremely difficult for C2ISR systems to ingest it. In particular, the GRIB format requires a priori knowledge of how the information is packaged in order to “degrib” (i.e., decode) it into a form that can be used within decision support systems.

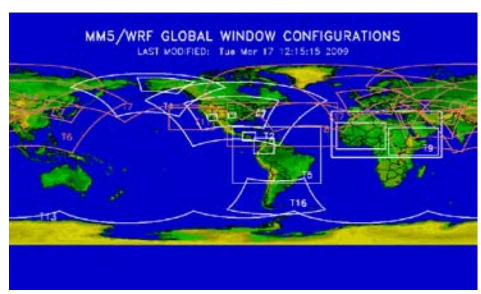

Figure 4: Current AFWA Window

[10] Shirkey and Gouveia, 2002

[11] JAAWIN

[12] WMO GRIB website

The fact that visualization and geospatial information system experts treat gridded data values differently than meteorologists adds an interesting complication. GIS systems normally interpret gridded data as the value in the center of a uniformly valued box (or triangle) the size of the data resolution (i.e., a raster). Gridded weather data, on the other hand, is the value at a specific geometric point. When a weather attribute value is needed for a specific location, complicated algorithms use the available, surrounding data points to interpolate to the point requested. The proper interpolation scheme is a function of attribute. It turns out that it is not trivial to infer how many pixels can be uniformly "colored" based on the point data provided. WxSTORM will have the documented code to get developers through the gauntlet.

The concept of compound time is another complicating factor that must be handled when working with weather data. Not only is there normal date/time; there is past, present, and future; model run time (i.e., yesterday's forecast for tomorrow, today's forecast for tomorrow, and tomorrow's forecast for tomorrow); and different ways of thinking about windows of time (Figure 5).

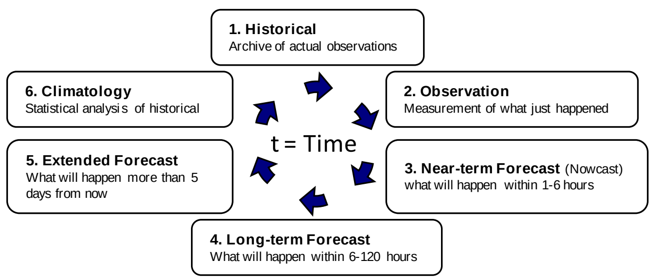

Figure 5: NBE Time Categories

Which product category should C2ISR developers use to support specific decisions? For example, do decision-support systems use extended forecasts or climatology to support particular decisions about operations weeks or months away? In current operations, should "old" observations or "uncertain" Nowcasts be used? Each of these different categories of time has different inherent accuracies. WxSTORM will have the code and documentation to help developers decide what is best for their specific decision-points.

Because of the nature of NWP, NBE future state is available at discrete points of time (i.e., time steps). METOC centers generate very high fidelity datasets, but to mitigate bandwidth consumption, they currently limit dissemination to snapshots of time as a function of spatial resolution. As an example, Table 1lists forecast data currently published by AFWA.[13] Figure 6 graphically depicts availability as discrete points in time.

Model	Spatial		Temporal		Time steps (# of points)
	Coverage	Resolution (km)	Coverage (hours)	Resolution (hourly)	
GFS	Global	55	180	6	31
MM5	Regional	45	72	3	25
WRF	Nested region	15	48	3	17
WRF	Nested area	5	30	1	31

Table 1: Current AFWA Gridded Forecast Product Availability

Because the data is in time steps, not only do decision-support systems need to interpolate between spatial data points, they need to interpolate between

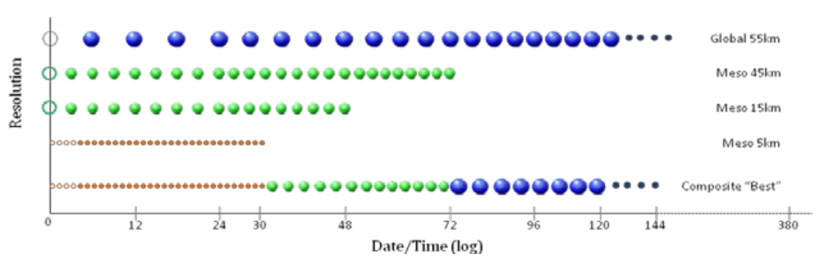

Figure 6: Discrete Points of Time Availability

[13] AFWA JAAWIN Website

discrete points in time. Because higher resolution is better, a general “composite best” rule, as depicted in Figure 6, could be automated to use the highest resolution data available at any particular time for the point or area that is needed.

Recognizing the complexities of their data and understanding future operational requirements to collaborate in a joint environment, Joint METOC worked out the DISA certified Joint METOC Conceptual Data Model (JMCDM), a fully documented database schema of geo-located NBE data to support interoperable data transfers.[14]

Joint METOC deliberations also include a set of XML schemas for access and exchange of weather data, the Joint METOC Broker Language (JMBL).[15] It allows any system to request NBE data in the same way regardless of who is providing the data. Both the AF and Navy are using JMBL to provide true net-centric access to their data. The AF is deploying the Joint Environmental Toolkit (JET) to designated C2ISR centers to disseminate their data and provide a data service interface. JET is the official Net-Enabled Command Capability (NECC) Weather Data Service.[16]

As we progress at getting NBE information to the decision-maker and they depend on incorporated situational awareness and advice, it will be critical to unity of effort and effective collaboration that the advice be consistent.

> Contradictory information frustrates attempts to collaborate and self-synchronize since collaborators must resolve conflicts before working on the decision at hand. All decision makers in an operations area must get their weather information from a consistent and authoritative source to prevent disruption of coordinated operations. To cite a simple example, a fighter mission launches, expecting marginal [weather] conditions in a refueling track, but the tanker cancels since its information shows conditions out of (the tanker’s) limits. Although this scenario is manageable, imagine decision makers involved in a complex joint and/or coalition operation attempting to plan their part of the overall operation and trying to avoid or mitigate the effects of weather. One of the four principles of [Joint METOC] operations, consistency serves as the basis of the call for “one theater, one forecast,” found in Joint Publication 3-59.[17]

Joint METOC will exercise a process consistent with Joint Publication 3-59 to appoint domain authorities who will dynamically determine the authoritative sources and publish THE forecast that all will use. Data service requests will automatically point to the “model of the moment.” Net-centric, service oriented operations will enable them to do it.

Knowing what the weather is going to be is necessary but nowhere near sufficient for knowing what it will do to our operations. Determining and representing impact has proven to be quite complicated as it is very sensitive to the context of the operation and has many degrees of freedom. The WxSTORM project is researching how to present 5-D weather data with a dozen or so degrees of freedom on a 2-D screen within the context defined within a given C2ISR systems.

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[14] Joint METOC Public Data Administration Website

[15] JMBL Website

[16] NECC TRA, 2008

[17] Heckman, 2008, pg. 3

Weather impact advice is currently calculated outside the C2ISR system by mostly manual processes. Great progress has been made in making METOC products available machine-to-machine, through the use of JET for example. The WxSTORM project is reviewing METOC webpages and existing product generation applications to determine the types of weather-advice products that warfighters prefer and have come to depend on. The software modules to dynamically generate those preferred products from base data are being collected, re-factored, and absorbed into the SDK as we can afford it.

When it comes to determining rules-based weather impact, the preferred tool has been the Integrated Weather Effects Decision Aid (IWEDA). IWEDA was developed by the Army Research Laboratory, in the mid-90s and has continuously evolved over the years. [18,19] It is now the Tri-Service IWEDA (T-IWEDA).[20] T-IWEDA is an application designed to assist decision-makers by calculating weather effects on military systems and, by aggregation, military operations. Weather impacts are derived by evaluating predicted weather attributes against vetted environmental-threshold values for platforms, systems, subsystems, and components (Table 2). These values are determined from published weapon system specifications, collected operator experience, and negotiations with warfighters. ARL stores and manages the vetted threshold values in the Centralized Rules Database (CRDB).[21] T-IWEDA is being integrated into the Distributed Common Ground System-Army (DCGS-A)[22] and is currently planned for integration in a future increment of JET.[23]

Weather Attribute	Critical threshold/ rule	Weather Impact
Wind speed = 50 knots	Winds > 45 kts	Unfavorable: Exceeds Helicopter's hover operating limits
Temperature = - 6 C	Temperature < 15 F	Unfavorable: Severely degrades personnel land operations
Visibility = 2.5 miles	Visibility < 2 miles	Marginal : degrades UAV flight operations
Wind speed = 30 kts	Wind speeds > 25 kts	Unfavorable: significant impact on the AAV's ability to maintain speed and maneuverability

Table 2: Sample of thresholds in the CRDB

Historically, weather impact has been rated as favorable (green), marginal (amber/yellow), or unfavorable (red) depending on the asset's critical-threshold-rule definition.[24] Current research is suggesting that a better way of thinking about this is to call them operational thresholds and stay away from "rules" and "go/no go" language. METOC is not giving decision-makers rules that they have to follow; it really is just guidance. Warfighters react negatively when presented with "weather rules."

No matter what we call them, it has proven useful to display weather impacts as a Weather Effects Matrix (Figure 7).[25] This matrix has proven to be a useful tool but

[18] Sauter,2000

[19] Shirkey and Gouveia, 2002

[20] Ingham, et. al, 2006

[21] ARL, 2003

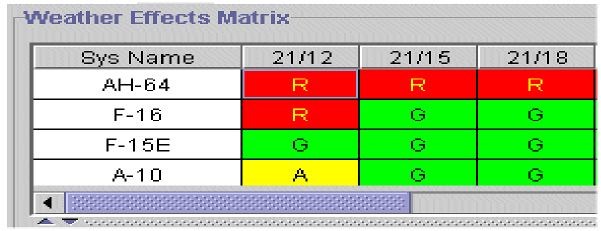
[22] Malapit, 2007

[23] JET TRD, 2008

[24] Shirkey and Gouveia, 2002

[25] ARL T-IWEDA, 2003

would be more useful if it was integrated directly into C2ISR applications. We need to figure out how to incorporate this outstanding impact advice directly within C2ISR decision processes.


Weather Effects Matrix

Sys Name	21/12	21/15	21/18
AH-64	R	R	R
F-16	R	G	G
F-15E	G	G	G
A-10	A	G	G

Figure 7: Sample Weather Effects Matrix

The WxSTORM project is also finding that it is better to talk about degree of risk and stay away from favorable/ unfavorable language. Although the difference between "unfavorable" and "high risk of failure" may be subtle, it has been helping convey what we really mean when the matrix says "red," and has been fitting better when we discuss managing operational risk.

When we figure out how to best convey impact, an obvious concern as decision-makers increase their use of weather effects advice, is the need to relay to them the uncertainty inherent in the information they're using. Forecasts are extremely accurate and are getting ever more so with each new advance in NWP but, some days are more predictable than others. Unfortunately, and perhaps ironically, NWP models have the most uncertainty when the weather is most likely to affect operations. Advances, such as ensemble modeling, are helping to quantitatively analyze and convey the uncertainty in the forecasts. Somehow, this uncertainty information has to be translated into terms that operators understand.

Weather Effects - Current

Weather impacts to military operations occur in many ways, at many levels. The T-IWEDA CRDB currently has over 10,400 thresholds. Knowing how the weather may limit what they hope to do can help decision-makers at every level of command. Examples include:

1. **Strategic**
   a. Wait until after monsoon rainy season to begin campaign.
   b. Win before severe winter sets in.
   c. Build weapons that work in extreme cold.
   d. Move troops forward in January across a frozen lake.
   e. Wait two years after Solar Maximum to pick a fight where collateral damage is very sensitive because GPS is consistently degraded during that time.
2. **Operational**
   a. Ensure parkas arrive in desert before August for night time ops.
   b. Use IR sensor X in morning (fog); visible sensor Y in afternoon (clear).
   c. Expect/plan on slow sortie regeneration rates because it's so hot.
   d. Reserve airspace to east of city to ensure cloud free line of sight.
   e. Reserve air refueling airspace to east in morning and west in afternoon to synchronize with frontal passage (aviation hazards).
   f. Ionospheric scintillation in the tropic theater rules out HF during the day.

3. **Tactical**
   a. Swing left around fields because the ground is soaked (Trafficability).
   b. Ascend to get out of the icing; descending would be worse.
   c. Move UAV south to avoid the approaching line of thunderstorms.
   d. Descend to find favorable tailwind (fuel consumption).
   e. Ingress target from the NE – take advantage of enemy radar ducting.
   f. Move ground troops during fog when enemy can't see.
   g. Turn space sensors away during coronal mass ejection events.

In an attempt to manage the complexity, the bulk of adverse effects can be summed up in the following types of limitations (of both blue and red forces):

1. **Sensor performance** – fog, cloud, dust, and haze obscure ability of ISR sensors on satellites, aircraft and human eyes, to see the target, runway, other aircraft, etc. Space weather affects GPS accuracy.
2. **Personnel performance –** extreme cold or hot inhibits prolonged work/combat. Personnel are also vulnerable to chemical, biological, radiological, and nuclear effects whose flow depends on winds and stability, for example.
3. **Equipment Performance –** weapons or communications systems are less effective under extreme temperatures, winds, ionospheric scintillation, electron flux densities, and heavy precipitation conditions. Turbulence makes it hard to refuel in the air.
4. **Mobility –** ground-based mobility and logistics timelines are affected by soil types, precipitation history, snow accumulations, etc. Air-based mobility is affected by aviation hazards, strong winds, ice and snow on the taxi/runway, etc.
5. **Safety –** safety of flight is impacted by turbulence, icing, and thunderstorm hazards in the route of flight. Cross-winds, tailwinds, gusts, and wind-shear also cause safety of flight issues on and near the ground.

Most C2ISR programs have indeed recognized the importance of needing to mitigate weather impacts to operations and consequently have documented many METOC support integration requirements.[26] The WxSTORM project undertook the challenge of collecting these requirements and, after extracting the NBE-specific requirements of each C2ISR system, organized them into a centralized collection. Focusing on just AF and USSTRATCOM programs, we reviewed 2,250 pages of C2 system requirements and extracted 1,170 weather requirements. These customer requirements were then used to derive a set of Functional Requirements and Software Specifications for the WxSTORM toolkit. So far, we have derived 241 functional requirements and 627 software specifications. The substantial requirements/specifications activities of the WxSTORM project have resulted in a well-defined toolkit that will answer an estimated 80-90% of all C2ISR weather requirements in the DoD.[27]

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[26] STORM External Requirements Appendix Doc, 2009

[27] STORM Functional Requirements & Software Specification, 2009

Over the last ten years, AFRL has had many C2ISR development programs with weather advice incorporation requirements discover that the difficulties in figuring it out far exceeded their proposed cost and schedule. As depicted in Figure 8, each individual C2ISR program would have had to build its own weather components. Or worse, they assumed that METOC support automation was sitting on a shelf ready to be incorporated, only to find that the shelf was filled with things they couldn't use. Since they did not make adequate plans to work the issue, they ended up with no means of getting the required functionality incorporated. No program yet has been given the resources to take on the challenge of METOC advice incorporation themselves. WxSTORM is striving to tackle this once for everyone.

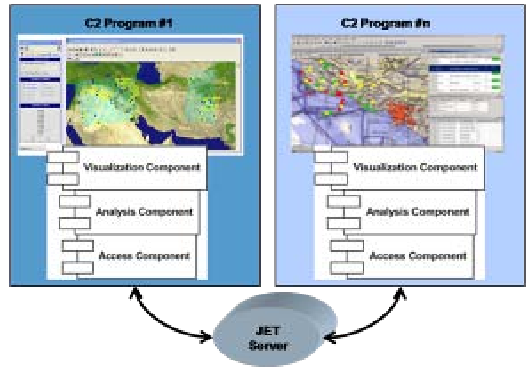

Figure 8: Component Development Overhead for each C2ISR System

For Joint METOC to successfully participate within the automated C2ISR Enterprise, automation developers must be provided a repository of software components within the format of a Software Developers' Toolkit.[28] In this way, developers may plug to play any or all Joint METOC support capabilities without spending much of their own program funds creating it or even having to figure out how to meet their levied requirements (Figure 9).

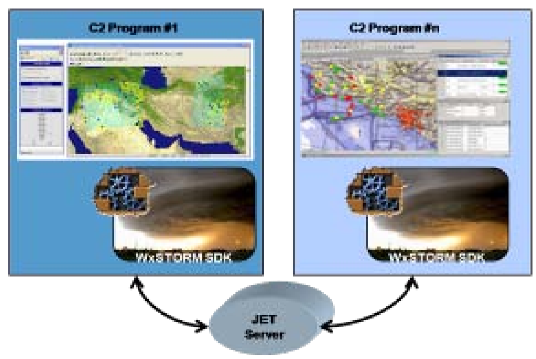

Figure 9: Synergistic Reusability of Components by Multiple C2ISR Systems

Weather Effects - Future

The C2ISR Enterprise consists of everything needed to provide Information Superiority, including a professional corps of C2 Warriors. It is the comprehensive, integrated system of systems, from sensors to decision makers to shooters (Anticipate, Find, Fix, Track, Target, Engage, Assess — Anyone, Anytime, Anywhere)[29], that will achieve Information Superiority. In this quest, the DoD is automating as much of the C2ISR Enterprise as possible. It is important to note that the C2ISR community is automating the decision-making processes, not the decisions. No one yet trusts computers to make the decisions, so operators insist on "decision-support" tools that present the data, information, and knowledge in a concise, coherent, and user-friendly way. Decision-makers have been consistently emphatic that they be made aware of the facts and be given the means to quickly enter their decisions. Situational data/ information can automatically be presented, options generated, and decisions automatically disseminated, but the decisions themselves must be made by humans in the loop.

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[28] Farrell, 2000

[29] Air Force Research Laboratory's vision.

For this reason, we cannot just develop algorithms that handle the many complicated dimensions and degrees of freedom in the background. We have to figure out how to present them within user interfaces in a way that helps human decision-makers make decisions. Future capabilities to support decision-aiding visualizations must be able to combine weather and C2ISR data models to perform spatiotemporal analysis that includes but not limited to:

- Intersection/overlay between an airspace and forecasted weather
- Identification of regions (3D/4D) where weather-conditions pose a risk to the successful outcome of the mission
- Solution for achieving cloud free line of sight to a target at desired time
- Evaluation of sensor performance within expected weather conditions
- Interpolation/extrapolation of time and location for “weather” and “mission geometry” and assessment of intersection conditions at a certain location/time.

Incorporating METOC support within C2ISR systems has proved to be an overwhelming task. To more easily manage the task, NBE advice integration requirements can be divided into the following three categories: situational awareness, constraint-checking and context-sensitive decision support tools. All three are necessary for effective support, but each can be worked on separately.

The category most invested in, and hence closest to realization, is situational awareness. Very soon, command centers will have battlefield situational displays that show the situation in real-time, on a continuous basis. It will display terrain, location of friendly and enemy assets, threats, and the weather. Duty officers will be able to look at a screen to evaluate the current situation as they need it.

Most C2ISR systems under development have requirements to overlay weather information directly on their map displays. The main obstacle has been the incompatibility of METOC products with standard visualization formats. With the rapid progress in developing net-centric services and capabilities, duty officers will soon be able to toggle overlays of “weather” on their situational awareness displays.

As mentioned, general representations of basic weather are a necessity, but are not sufficient for getting the most out of Joint METOC support. Decision-makers at the force level, at the Coalition Air Operations Center for example, are making hundreds to thousands of decisions in short succession. There is just too much going on, too quickly for a human brain to maintain the connection between what is being planned, the hundreds of applicable weather-thresholds, and the anticipated weather. Continually comparing map overlays with intentions is simply too time consuming and prone to error. Hence, decision-support applications need to maintain the mission-to-weather correlations for the decision-maker.

As planners plan, they need help making sure that what they are planning is doable. As they define events, the application, in the background working on a non-interference basis, will need to compare the weather at the time and location of the event with thresholds specific to the context of the event. Thresholds are a function of things like role, mission, tactics, platforms, and weapon. If the expected weather is beyond a specified threshold, the application generates an alert and displays it on the decision-maker's screen. In some cases, aggregation of alerts and/or other forms of visual cueing are needed to avoid saturation. How this is to be done is the focus of WxSTORM research. Whether this monitoring is done within a given application or as an independent service (or agent) is under investigation.

As with any other threshold violation, like running out of fuel or tasking a sortie to fly faster than capable, duty officers will click on the alert representation to see what the problem is, as they have time. When the flag is clicked, perhaps a dialogue box will pop up to display the reason or reasons for the alert. They will have the opportunity to either ignore the alert or solve the problem. It is at this point that duty officers need decision support tools available to help work around the problem.[30]

C2ISR application developers must consciously work to avoid information overload. It is imperative that users only get the specific information necessary to solve the problem at hand. Hence, it is important that the tools available be sensitive to the context in which they are called upon. All of the information presented must be tailored to the problem at hand. This is the place for true, real-time, on-the-fly METOC support tailoring.

Another important concept is that NBE impact is only one of the parameters that planners have to contend with. Hence, it is necessary to think of METOC support as only one of the many feeds into a decision support system. Consequently, it is better to talk about context-sensitive decision support tools with integrated NBE information, not context-sensitive NBE tools.

So what the warfighter needs is interactive windows displaying all of the necessary information tailored to the problem at hand; all integrated within the planning process. To be of any use, these tools must contain information integrated, if not fused, from ALL knowledge domains (e.g., intelligence, weather, logistics, tactics, and command guidance).

The Roadmap to the Future

WxSTORM provides C2ISR application developers with the means to seamlessly incorporate METOC advice into their decision support applications so that weather considerations are directly included in decision-support workflows.

WxSTORM v1.0 is a highly documented software developer's toolkit (SDK) which will support two application development environments (.NET and Java). The toolkit is a scalable, component-based, integration-ready, service-oriented and government-owned solution that can be transitioned into C2ISR systems. Having this common SDK available to the C2ISR developer community will prevent each C2ISR program from having to build these capabilities from scratch. It has greatly simplified the complications.

Widespread use of WxSTORM will support the Joint METOC enterprise with new opportunities to efficiently and uniformly present METOC advice to the warfighter and will support the C2ISR developer community with a toolkit to incorporate METOC

[30] Farrell, 1996

advice more easily and seamlessly. It will also ensure proper use of the right METOC information from the right authoritative data sources using verified, validated algorithms and libraries. WxSTORM is the conduit that brings METOC information and impacts from the authoritative producer into the C2ISR computer-augmented decision-support application.

The WxSTORM Toolkit is organized into three functional components: access, analysis, and visualization. Each contains a variety of modules that can be used by developers in flexible configurations to meet the needs of their application. Figure 10 shows examples of the types of modules which are and will eventually be included within the SDK.

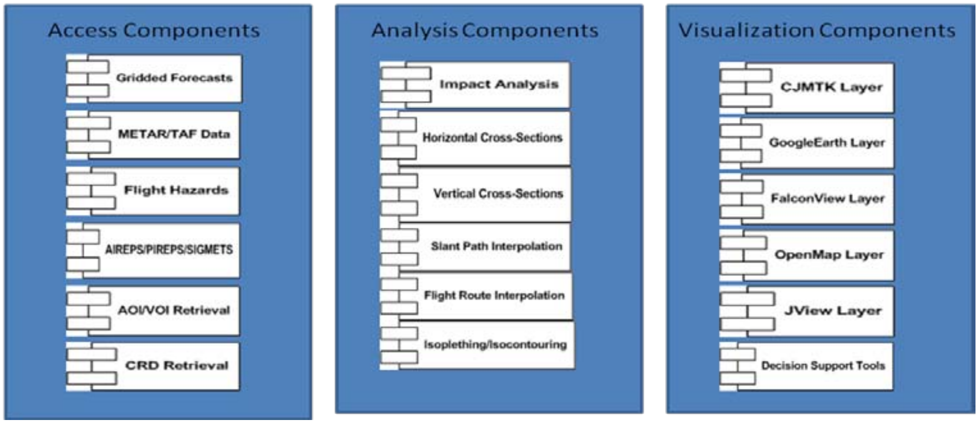

Figure 10: WxSTORM Components

Access Components provide the means of composing JMBL requests, retrieving data from authoritative METOC services, parsing the responses, and managing a local data cache. These components dramatically simplify JMBL use and local data management. WxSTORM v1.0 supports two data segments: current airfield observations (METAR) and gridded binary forecast data (GRIB). There will be other segments supported in subsequent spirals.

With the SDK, developers have the freedom to use JET as the cache and make a JMBL request every time weather is needed, or they can decide to subscribe to what they need and sustain a local cache. Such a local cache is advantageous for applications querying the same weather information repeatedly and for users that plug in, load up, and go.

Query performance is much better from local cache compared to constant reachback. Another advantage to using a cache is that developers can design their system to subscribe and sustain a cache as a separate thread in the background and not bother or bog down the decision-support application. A lot of the hard work may be proactively preprocessed. The disadvantage is that the data does get old and if connectivity is down for too long, decisions have the potential of being made using expired data.

Analysis Components link the C2ISR and NBE domains using knowledge of operational constraints and mission context, to model/analyze, and determine operational risk. The WxSTORM program is making a concerted effort to seek out existing capabilities, evaluate them, and negotiate with the owners to absorb them into the SDK; the goal being to make these libraries accessible to a wider C2ISR audience.

WxSTORM v1.0 does not include analysis components. This type of capability is planned for subsequent spirals, but note that future funding has been tenuous at best.

The WxSTORM solution is planning on implementing powerful and complex weather exploitation techniques, dynamically calculating NBE influences on missions and characterizing operational risk. WxSTORM v2.0 will provide these capabilities in a form that can easily be incorporated into a wide range of C2ISR programs having METOC advice requirements.

WxSTORM will provide the software to interface with and use authoritative weather threshold services for computation and/or display of impacts inside C2ISR applications. WxSTORM modules can be used to connect to impact services or to compute context-sensitive impacts directly in the application. To ensure consistency across an enterprise, WxSTORM will supply modules that pull the weather thresholds from authoritative sources such as from a CRDB service on JET. By locally caching these thresholds with the weather forecast data, a client application may analyze very complex combinations of role, mission, platform, location and time as decision-makers compose plans. It will allow C2ISR developers to store a local cache of impact information for timely access by their application. WxSTORM, through its geospatial visualization modules, will also help C2ISR applications render the calculated impacts on their displays.

Visualization Components provide modules to link the weather data model and impact products to many different geo-spatial visualization technologies (CJMTK[31], Google Earth[32], FalconView[33], STK[34], and JView[35]) and non geo-spatial visualizations (e.g., timeline, pie chart). WxSTORM v1.0 provides geospatial visualization modules; other types of visualization are scheduled for subsequent spirals. WxSTORM will have code to convert between map projections (e.g., Lambert Conformal, Polar Stereographic, and Mercator), coordinate systems, and geodetic reference systems. It has modules to extend existing geospatial libraries with a temporal dimension (from 2D/3D to 4D). These include specialized techniques and interfaces for visualization in the time dimension. It also will support Open Geospatial Consortium (OGC) standards for Web Feature Services (WFS) and Web Mapping Services (WMS); this will allow developers to add weather overlays to their OGC-compliant Common Operational Pictures (COPs).

Several previous efforts that successfully incorporated "weather on the COP" using various languages and visualization technologies have provided concrete lessons and modular capabilities that have been folded into the SDK:

- GAPS (Global Awareness Presentation Services)[36]
    - - .NET, GoogleEarth, AGI STK and CJMTK

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[31] CJMTK Website

[32] Goggle Earth Website

[33] FalconView Website

[34] AGI's STK Website

[35] AFRL's Java visualization software developers' toolkit; available through AFRL/RISF

[36] Loomis, et.al., 2008

- SOMPE (Special Operations Mission Planning Environment)[37]
  - - .NET, FalconView
- JASMAD (Joint Airspace Management and Deconfliction System)[38]
  - - Java, CJMTK, JView
- Weather Explorer[39]
  - - .NET, ArcGIS Desktop
  - - currently deployed within JET for display of weather in GIS

Figure 11 provides examples illustrating the incorporation of weather information in various applications. All of these capabilities have been absorbed into WxSTORM v1.0 and can now support rapid integration into any C2ISR project.

Sample use case:

Many C2ISR programs have documented requirements that decision-makers want to determine when a specified ISR sensor will be able to see a specified target or any and all targets within a specified area (e.g., AOC WS 10.2 CDD para. 6.4.1.1).[40] Current practice is to compare target locations on the “red COP” with satellite imagery from a weather website (e.g., JAAWIN, JET) (Figure 12).

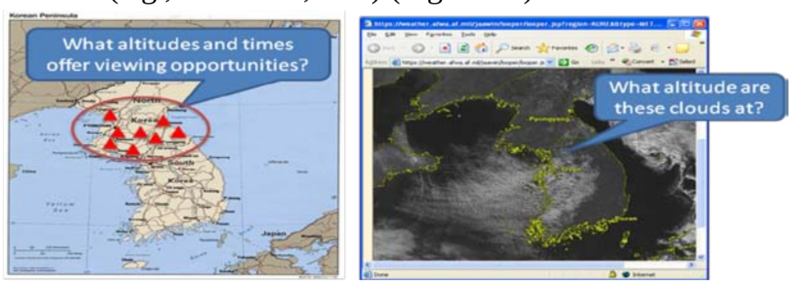

Figure 12: Current Webpage products

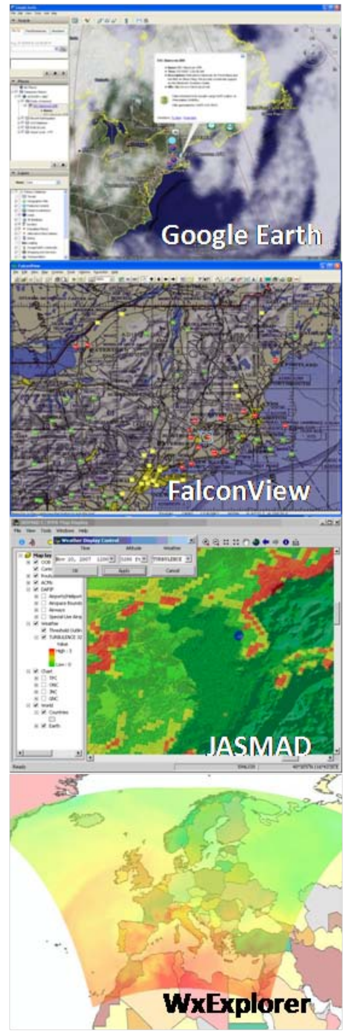

Figure 11: Display Samples

Using WxSTORM (Figure 13), a C2ISR developer would include modules in their application to access and manage applicable weather forecast data, calculate Cloud Free Line of Sight (CFLOS), and visualize advice within desired display capability.

If they also want/need to depict impact, developers may choose to include modules that ingest weather thresholds from the CRDB, calculate risk, and maintain user-specified color coding to depict what targets may be acquired

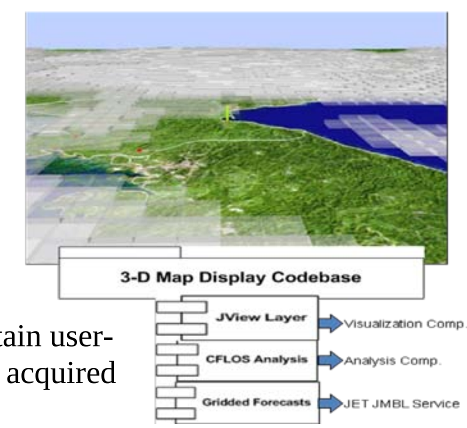

Figure 13: WxSTORM-enabled ISR Planning

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37 SOMPE Website

38 Griffith, et. al., 2006

39 Desai, et. al., 2006

40 AOC WS 10.2 CDD, 2006

by a specified platform and sensor. Adding slider bars to allow users to adjust altitude and time, decision-makers could see the problems and adjust mission parameters to find a viable solution.

For example, Figure 14 depicts a situation where a platform flying at 10,000 feet would be able to see some of the desired targets but not all, whereas a platform flying at 8,000 feet would be able to see all of them. Other information would be displayed that would inform the planner whether or not there is a platform available to fly that low, and to determine if it is allowed to fly that low in that area.

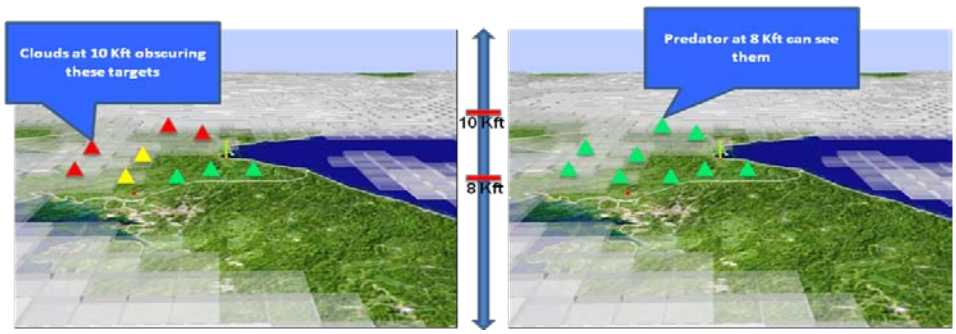

Figure 14: Integrated Visualization Samples

Using the various components and modules in different combinations will enable C2ISR developers to meet most, if not all, of their weather advice incorporation requirements.

Conclusion

This paper has suggested an approach to incorporating weather and its effects directly into C2ISR applications. Undertaking the creation of a common toolkit, WxSTORM, will leverage existing GOTS capabilities to offer ease of integration and synergistic reusability of common components across the DoD. With this toolkit, C2ISR systems will no longer have to take on the expensive overhead of figuring out how to meet their weather advice requirements. Using a standard SDK within net-centric service oriented operations will allow C2ISR application developers to quickly and efficiently incorporate METOC advice within their computer-augmented decision-support systems in a productive, unified way, thereby ensuring consistent collaboration across all net-centric nodes.

WxSTORM version 1.0 was released in April 2009. AFRL is still working out how to manage distribution and licensing but it will be similar to NGA's Commercial Joint Mapping Toolkit (CJMTK), free to qualified DoD C2ISR developers. [41]

As this project progresses, the design will be further defined and developed as we learn more and tackle more use cases. WxSTORM will spiral in interlocking blocks that provide a logical set of functions that support discovered/identified specifications (e.g., cloud free line-of-sight for ISR planning as depicted here within).

[41] CJMTK (http://www.cjmtk.com//About.aspx)

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