Abstract

Generally, military training exercises use weather to control exercise pace. The effects of weather, however, should be a factor when training decision makers and operational planners. The Air and Space Natural Environment Modeling and Simulation Executive Agent office recently spearheaded an effort to integrate realistic weather effects into military training exercises with great success. However, the experience also highlighted the need to make weather consistent across all aspects of an exercise. Thus, the office kicked off a project to provide a coherent suite of products—the Environmental Data Cube (EDC). This could revolutionize the way weather plays in future military training exercises.

Introduction

The visualization of weather in simulations occasionally takes the form of clouds or rain with intermittent lightning. More often than not, skies are clear and models operate unimpeded by weather. However, much can occur behind the scenes if the visual displays and the calculated effects of weather are consistent. For instance, vehicles may lose traction when traversing wet ground, aircraft infrared sensors often perform poorly in fog, and people sometimes get sick on ships tossed about by large waves. Decision makers must understand weather-induced effects in order to make appropriate choices. The

Vision

The ASNE MSEA office envisions a simple interface that provides exercise planners with a way to design weather scenarios based on training objectives. The resulting data set would then be used to generate a menu-selectable suite of products to support exercise participants and controllers. Preparation and distribution of these products would get done via the net-centric architecture supporting operational warfare.

Goal

Simply stated, an event coordinator would determine objectives for an exercise or training event. Those objectives would be rendered into a corresponding environmental scenario through a tool called the Environmental Scenario Generation. As an option, exercise planners could choose “typical”, “benign” and/or “poor” conditions for the exercise timeframe and area of interest. The data would then be distributed to event participants (federates and staffs) in products to suit each end user. Any changes to
the scenario would similarly affect all simulations and displays/briefings. In general, ASNE MSEA proposes to integrate weather into exercises by less manpower intensive means.

Environmental Data Cube (EDC)

A wide range of Department of Defense (DoD) modeling and simulation applications require access to environmental representations (atmosphere, space, ocean, time-sequenced terrain) to satisfy operational requirements. The Environmental Scenario Generator satisfies this need by generating representations in various formats to fit the need of the model or simulation. However, data alone does not ensure consistency across a federation. Some simulations do not accept weather data. Other federates require visual products. Hence the need for a system to provide a comprehensive set of information derived from that basic scenario. This requirement led to the development of the EDC.

EDC is fundamentally about the production and delivery of a full suite of consistent products. As an example, the EDC capability can be used to support an exercise to include thematic data cubes with content derived for specific federates, pre-computed effects/performance data, visual products to support decision makers and analysts, as well as a tailored set of system impact rules that may be utilized during the exercise. The EDC will also ensure that the right mix of information is delivered to each participant of the exercise, in whatever mechanism is standard for their community. This implies the entire spectrum of delivery options, from pre-exercise distribution of information to runtime distribution over both operational and simulation protocols.

The Genesis of EDC

Austere Challenge 2006 (AC06) was a Chairman, Joint Chiefs of Staff (CJCS) exercise to test the ability of US Air Forces in Europe (USAFE) to rapidly transition from peace-time to “warfighting headquarters”. Since mission success is highly dependent on weather, AC06 planners decided early to include an objective to force exercise participants to make decisions to mitigate or exploit the effects of weather when generating the Air Tasking Order (ATO) or battle plan. While not a novel concept, this objective would be supported through more rigorous, realistic, and automated processing than previous exercises. Besides weather officers briefing the forecast to ATO planners, simulations would enforce proper planning by affecting the outcome of appropriate missions. In addition, exercise controllers would not have to manually manipulate simulation results to account for weather. The only simulations in the federation affected by weather included Air Warfare Simulation (AWSIM), Air Force’s premier operational-level training simulation, and Joint Conflict and Tactical Simulation (JCATS), a US Joint Forces Command simulation for training ground forces in tactical missions.

AC06 stands out as the first operational-level exercise in which the weather injected into the computer simulation driving the exercise was the same as that provided net-centrically to the exercise participants. This brought realistic dynamic targeting and execution due to simulated changing weather. The employed process set a paradigm for realistic weather play in future exercises.

During the exercise, controllers distributed weather products at times to agree with the inputs to the federation. Questions from participants were addressed via the exercise chat system. Discussions included possible consequences of weather.

Overall, weather play turned out to be a huge success in AC06. Not only was the scenario realistic and challenging, it generally had consistent results across almost all aspects of the exercise. The participants did generate an ATO that mitigated the effects of “bad” weather and exploited “good” weather. For a few of the missions, they chose to accept the risk of betting against weather and had consequences—missions returned with unexpended ordnance because the weather effect precluded detection of their assigned targets. What’s more, this occurred without any external controller manipulation.

For the first time ever in a major exercise, there was a systematic connection established between the data being played inside the simulations and that being briefed by the weather personnel supporting the exercise. This was accomplished through the provision of consistent modeled data, historical observations, and archived graphics.

Post exercise analysis revealed some areas for improvement. First, there was a need to automate generation of exercise products (i.e., environmental data, graphics, and weather effects). Currently, ASNE MSEA subject matter experts must work through the Environmental
Scenario Generator to find specific cases where appropriate weather parameters (i.e., temperature, pressure, humidity) exist in the database and generate a data set in the right format. Then they have to go to other organizations such as the Operational Weather Squadrons and hopefully find the other data that complements the scenario. Meanwhile, these same subject matter experts work with contractors to generate effects data. The process in AC06 was laborious and time consuming. In the future, with EDC, exercise planners will be able to generate the entire suite of gridded, observational, effects, and graphical data sets required to support an exercise.

Secondly, AC06 uncovered problems with distribution of products. One of the simulations required manual entry of the weather during the exercise. During one period in particular, the simulation was “stuck” on bad weather, while the script had moved on to improved weather conditions. The ground became saturated and trafficability was degraded by 80%, much worse than what should have been caused by the weather scenario. Ground forces became bogged down. The result was that ground entity behaviors during this period were not consistent with the weather being briefed or that being played in the air simulation. The disparity resulted in a decision to default to “benign weather” for a short time. Regrettably, the ATO being executed was planned for marginal weather so planners were a little upset about their wasted efforts. While this sort of decision is often a reality in exercises, it shows the need for a centralized weather server to ensure all federates receive a change. This would help alleviate the problem encountered in AC06 caused by disparate inputs/outputs between simulations and exercise participants.

EDC Components

Environmental Scenario Generator (ESG). ESG enables models and simulations to incorporate representations of the environment (i.e., atmosphere, space, and ocean) in order to produce effects caused by the environment. It searches historical or modeled environmental databases to find user-defined scenarios. To do this, ESG employs “fuzzy logic” techniques to locate the best matches to the desired scenario. It then generates a dataset in various formats, to include Synthetic Environmental Data Representation & Interchange Specification (SEDRIS), gridded binary (GRIB), comma separated value (CSV), and a couple of model-unique formats. Due to its power and flexibility, it easily supports new resources (i.e., databases and transforms), customer-unique requirements, and external standards (i.e., Joint METOC Broker Language (JMBL)). It also integrates with other applications, such as Joint Weather Impact System (JWIS). ESG technology was developed to be domain neutral, and can easily be applied to new data and model resources, or be extended to support new data types and formats.

Registered users can access a web-based version of ESG and generate datasets, but ASNE MSEA recommends customers go through subject matter experts until they gain an understanding of the tool’s purpose, capabilities, and limitations. Basic information and account application exists at the AFCCC web site. Currently, only government persons and those contractors working on DoD projects can get ESG accounts.

ESG is also designed to facilitate the Integrated Natural Environment Authoritative Representation Process (INEARP), which tries to ensure consistency and coherency between environmental domains (i.e., atmosphere, ocean, terrain, and space). For instance, rain produces wet ground; seas aren’t calm when in windy conditions.

The data from ESG can be used by physics models to produce effects and/or drive realistic behavior models within simulations. In the case of distributed exercises, the data can be pre-distributed to each simulation, or can be distributed at runtime by a federate. However, ESG technology does not directly address these issues; its focus is on providing physically consistent representations of the natural environment, in a form ready for use in simulations.

Environmental Hypercube. Ultimately, for weather to be included in exercises, simulations must ingest environmental data, produce effects, and modify behaviors accordingly. In an operational exercise, the outcome would show the correct response to planner decisions when considering the weather (i.e., a poor weapon/weather combination would have a marginal chance of success). Weather influences sensor effectiveness, route selection, transit time, logistics, and a myriad of other factors. Alas, very few simulations have the ability to deal with weather data. Producing realistic effects can be prohibitively expensive in terms of runtime
performance, and modifying entity behavior algorithms can become very complex. As a means to assist simulation developers in incorporating environmental effects, ASNE MSEA sponsored the development of the Environmental Hypercube.

The Environmental Hypercube captures the effects of the environment on a particular class of weapon system by providing a performance metric as a function of tactical parameters. For example, an IR sensor system might be characterized by its Probability of Detection ($P_d$) as a function of viewing angle, sensor altitude, target type and location, and time of day. A physics model is then used to pre-compute the $P_d$ values for each combination of parameters, storing the result in a multi-dimensional lookup table, or Hypercube. In this example, the influence of weather is introduced through the target location (Latitude and Longitude) and time of day dimensions as inputs to the physics model computing the IR sensor performance. This Hypercube then enables simulations to access a realistic performance metric in milliseconds that is based on realistic physics applied against a realistic environment representation.

While in development, the Environmental Hypercube project leveraged the physical models provided in the Target Acquisition Weather Software (TAWS) mission planning application as the basis for generating Hypercubes representing IR, Laser, and TV sensor performance. However, the Hypercube technology itself is completely independent of the physics model chosen for use. Additional Hypercubes for performance metrics, such as Probability of Kill ($P_k$), trafficability, and Cloud Free Line of Sight (CFLOS) are all being investigated.

In order for the Hypercube to be used, the simulation must modify some aspect of its behavior algorithm for the weapon system of interest. Referring again to the example above, the IR sensor detection algorithm within the simulation would have to be modified to query the Hypercube for a $P_d$ value, providing values from the simulation for the tactical dimensions on which the Hypercube was constructed. The Hypercube can be accessed via an extremely small C application programming interface (API).

The Hypercube Display tool is a Microsoft Windows application for the graphical inspection of a Hypercube. It allows the user to manually set values for one or more dimensions and then visualize the performance metric as a function of the unconstrained dimensions. The current version supports the optional inspection of the weather data files that were used by the TAWS models in producing the Hypercube, resulting in the ability to inspect both the performance metric and the weather that impacted it. Simulation operators can use the Hypercube Display tool to aid in determining weather-affected sorties. The tool could also be used by exercise white cells when adjudicating or justifying results.

Web Services. The Web Services will include tools and a graphical user interface (GUI) to support net-centric enterprise initiatives based on XML transactions. This web service will be rapidly modifiable to conform to multiple standards. The web services are intended to provide access to the core production components of the EDC, which will include an interface to define and generate thematic sub-cubes from the base representation delivered from ESG; to produce Hypercubes through the use of physics-based models; to produce and access visualization products; and to define and access system-impact-rule data sets.

The EDC Web Portal will make a machine-to-machine interface possible and allow easy interaction between modeling and simulation users and environmental representation subject matter experts. This requires an intuitive graphical user interface (GUI) for modeling and simulation users unable to work in machine-to-machine mode. Some of these interfaces will need to be configured to meet specific user interfaces and designs.

Visual Data Cube (VDC). ASNE MSEA is developing the VDC to generate products to support visual representation of the data. The tool will include the means to create simulated observations, Terminal Area Forecasts (TAF), satellite data, and radar charts directly from the scenario data. In addition, the VDC has the potential to derive other graphics to support weather presentations. Thus, data and products would all be consistent with the modeled data as this is the source for constructing them.

The products created under the VDC will be compatible with Geographic Information System (GIS) mapping services for easy analysis or integration with existing display systems.

Weather Data and Effects Server. ASNE MSEA plans to create a weather data and effects
server, which will facilitate a machine-to-machine capability. It will act as host for all environmental information (i.e., modeled data, derived products, and Hypercube effects) with the ability to share and disseminate available data. It will also allow seamlessly embedded calls and facilitate remote access so all federates in an exercise could access the authoritative source data and have coherent outputs.

The runtime component of the EDC will be capable of maintaining the EDC data products and maintain a reach-back capability to the EDC Web Portal to facilitate real-time updates to those products. These runtime distribution modules are focused on specific simulation protocols such as High Level Architecture (HLA), Distributive Interactive Simulation (DIS), and Extensible Modeling and Simulation Framework (XMSF).

EDC Development

DoD recognizes the value of incorporating environmental representations into models and simulations in order to train decision makers to account for all factors that affect a decision, including the environment. The EDC will rapidly provide a consistent set of products to simulations and decision makers that can reinforce the effects of the environment on human behavior, system performance, command and control, intelligence, etc.

The purpose of this work effort is to supply a realistic and consistent environmental representation to DoD models and simulations. Specifically, this effort deals with facilitating generation, visualization, and distribution of the environment to allow DoD models and simulations to accurately produce results brought about by the effects caused by the environment.

EDC is a system for providing interoperable use of the natural environment and its effects within the DoD; further define and explore scalable, deployable environmental scenarios; integrate ESG capabilities into additional DoD agencies; and continue to provide access to environmental modeling and simulation capabilities to support the emerging requirements from various DoD entities.

Assumptions

EDC will use and leverage emerging enterprise-level architectures and infrastructure initiatives, and will deliver products to demonstrate the value of interoperability among models and simulations, command and control systems, and intelligence gathering platforms.

EDC will act as a bridge between Environmental Resources and simulations by providing ready-access and interoperability between the data and tools with the live, virtual, and constructive simulation environments used by DoD communities.

EDC will operate over a distributed, net-centric environment (e.g. Global Information Grid (GIG)) to provide access and discovery of environmental resources and production visualizations and effects for M&S customers; integrate required DoD and Industry-based resources for a consistent, authoritative environmental representation; and deliver data and effects in a timely manner.

Constraints

EDC will have to function within existing bandwidth limitations and communication methods. In addition, it must provide a simple interface for system administration, configuration, and standardization of data parameters.

Data handling will be accomplished via networked and web-based tools and technologies through linked databases. Those technologies and tools will enable and facilitate a more net-centric, machine-to-machine-based architecture and, therefore, allow rapid collaboration across modeling and simulation communities, and within and among users.

Capabilities

All DoD Communities and Services have identified the requirement for physically consistent environmental representations and effects and the tools to rapidly acquire, use, and share them. The EDC provides effects of the environment on human behavior and system performance, environment products to real-world command and control devices, and an underlying environmental representation to ensure consistency and fair fight. EDC will provide a capability beyond any currently available system.

The primary deliverable is a server framework and the software to build derived environmental products and effects as well as share and distribute that information. This system would promote a consistent
representation of the environment and its application and impacts across a simulation, multiple federations, or a distributed set of users by allowing access to a single authoritative suite of environmental information.

The deliverable will be able to generate derived environmental products and visualizations from a predetermined environmental dataset and act as host for all environmental information with the ability to share and disseminate all available data sets.

The EDC incorporates a set of web services that allow for the integration of environmental resources through the use of foundational metadata so that a robust order processing architecture can utilize the wide range of data resources in the production of customized, integrated environmental and effects databases. The databases created include static data repositories, dynamic physics or rule-based effects models, and static and dynamic visualization production. The data resources reside throughout DoD, government, and industry operational support centers and are virtually integrated through ESG distributed architecture and applications. A number of environmental data analysis applications have already been developed to consume ESG data and will gain access to these resources through EDC.

A typical EDC interaction involves the construction of an environmental package to meet a set of user-defined specifications and constraints (e.g. a particular temporal and spatial region and resolution with a list of required parameters plus the needed effects and visualizations). EDC enables users to capture and translate customer requirements into a complete environmental package specification, which can include environmental conditions making up a scenario, and the environmental effects consistent with that scenario along with the visualizations of both. The EDC will ultimately construct and deliver a package to that specification. If a static package is not sufficient, full physics and rule-based weather models can be used to produce subsets of the effects and visualizations during runtime.

Architecture

The EDC will be made up of two main protocol independent components: a system architecture to provide a backbone for distribution of products to various applications and events and a suite of programs to provide functionality and distribution capabilities. The suite of programs will include web services for orchestrating the production of EDC products, an EDC runtime component for integration of EDC products into simulation components (i.e., EDCFed for HLA), and an EDC web portal for activity management. The EDC infrastructure is based on metadata and provides a robust ordering architecture that treats data and display resources identically. It also provides process control to seamlessly link together sequences of resources. The EDC infrastructure components are domain and resource independent. They are not designed for specific environmental resources. In fact, the resources themselves are treated as entirely external (resource provider-owned) elements from the infrastructure. The ordering architecture will provide a flexible delivery mechanism that is tailored to a specific instance of a community’s runtime protocol.

Concurrent Efforts

In AC06, only one infrared sensor on the air side was affected by weather and only for air-to-ground missions. ASNE MSEA is working to expand models from a few sensors using TAWS to space models and weapons effects models.

ASNE MSEA will then integrate Hypercube into more simulations to make weather more realistic and consistent in exercises. Of the entire federation in AC06, only the air simulation was able to directly use weather effects data in an automated fashion through the use of Hypercube. Some effort was made to allow the ground simulation to see the same weather, but with limited success. In that case, data had to be input manually. In addition, intelligence platforms, air-to-air missions, air-to-ground missions (other than those with the affected sensor), etc. showed no effect with regard to weather. Thus, while weather could no longer be ignored by exercise participants, it was not fully integrated. It’s critical that all federates yield consistent outcomes. To achieve this, simulations will have to modify behavior algorithms to respond to weather effects. One efficient means of doing this is through the use of pre-computed Hypercube data sets. Current research is focusing on building hypercubes that provide weather effects to air fields and also provide weather effects to trafficability in ground simulations. With further funding, weather effects to air traffic routes, radar propagation, and human behavior are within our reach. Regardless of the how the weather effect and
resulting behavior is modeled in the simulation, it must be done based on a common underlying environment representation such as is provided by ESG. Buy-in from federate developers is the key to success; resources become the challenge. ASNE MSEA hopes to leverage the AC06 successes.

Conclusion

Based on the significant impacts it can have on the outcome of an operation, the environment should be a principle factor decision makers consider when weighing options. ASNE MSEA has been working to incorporate realistic weather into training exercises for some time, but recent successes with integrating realistic environmental effects that complement exercise objectives has spurred the desire to have consistent environmental inputs across the entire federation. The EDC will satisfy this requirement, and, by using the EDC suite of tools and interfaces:

1) Exercise planners will be able to automatically generate a set of products based on specific training objectives.
2) Products will be in a format appropriate for the federate.
3) Data can be displayed graphically in standard formats.
4) Data, graphics, and effects will be consistent across the federation.
5) Data will be distributed to federates at the proper time.

The infrastructure of this system is currently being developed and prototype tests are expected next year. This simple, flexible, and transparent system should enhance training exercises considerably.

Authors’ Biographies

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Mark Webb is a Staff Process Analyst/Meteorologist for DRC. He works in the ASNE MSEA Office. Mark is the ASNE MSEA technical and customer support lead. He has been actively involved with environment representation in the DoD M&S community to ensure a consistent environmental representation. Mark is retired from the U.S. Navy. His tours of duty included working with all four branches of DoD concluding with a tour at the Joint Special Operations Command. He is a graduate of Liberty University.

Steve Lowe is the manager of M&S programs, including ESG and Hypercube, at AER. He has been actively involved with environment representation in the DoD M&S community for over a decade. Mr. Lowe has performed research in environmental science through the development and applied use of numerical weather models, data exchange and analysis tools, and distributed computing systems. He received BS and MS degrees in Aerospace Engineering, with an emphasis on the study of fluid dynamics and the Marine Atmospheric Boundary Layer.