WHAT CONSTITUTES A VERIFIED AND VALIDATED NATURAL ENVIRONMENT REPRESENTATION?

John R. Hummel[1] *and Donna W. Blake*[2]
[1]Advanced Computer Applications Center
Argonne National Laboratory
9700 S. Cass Avenue/DIS-900
Argonne, IL 60439-4832
630-252-7189
jhummel@anl.gov

[2]VisiTech, Ltd.
535A East Braddock Road
Alexandria, VA 22314-5884
703-725-9412
blake@visitech.com

The submitted manuscript has been created by the University of Chicago as Operator of Argonne National Laboratory ("Argonne") under Contract No. W-31-109-ENG-38 with the U.S. Department of Energy. The U.S. Government retains for itself, and others acting on its behalf, a paid-up, non-exclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public and display publicly, by or on behalf of the Government.

KEYWORDS:
Natural Environment Representation, V&V, consistency, fidelity

ABSTRACT: Models and simulations play an increasing role in the planning and training as well as the execution of successful military operations. The simulations depend on the ready availability of integrated natural environment representations for a wide range of scenarios. As the modeling and simulation (M&S) community works to develop the capability to produce the necessary representations (e.g., the Integrated Natural Environment Authoritative Representations Process [INEARP]), the terms "authoritative", "verified and validated", "consistent", and "fidelity" are used to indicate that these representations meet certain qualifications. In this presentation we discuss what these terms mean from both the producer and user viewpoints and how these qualifications can be determined within the context of developing an integrated environmental representation. Specific examples from recent efforts to generate such representations will be presented.

1. INTRODUCTION

Models and simulations are beginning to play an increasing role in the planning and training as well as the execution of successful military operations. As these models and simulation become more sophisticated, they are becoming able to include more realism in how the environment interacts with the rest of the simulation. In this paper we will discuss what constitutes a verified and validated natural environmental representation for modeling and simulation (M&S) applications.

The term "environmental representation" has different meanings within the M&S community. In Section 2, we explain the term within the context of a typical military simulation. In Section 3, we describe the manner in which environmental representations, especially those involving the ocean or atmosphere domains, actually are obtained. Section 4 explains what the term "authoritative" means with regard to the natural environment, especially when linked with "data sources" and "data representations." The terms "verification and validation" (V&V) are addressed in Section 5 with regard to how an environmental representation is developed. Finally, a process that can verify and validate an environmental representation is described in Section 6.

2. WHAT CONSTITUTES AN ENVIRONMENTAL REPRESENTATION?

An environmental representation used in M&S application has three different aspects: the environment phenomena included in the application, environmental effects the phenomena have on the other simulation entities, and impacts from the other simulation components on the natural environment components. These components are shown in the synthetic natural environment conceptual reference model that is represented in Figure 1 (Birkel, 1998.)

The environmental *phenomena* consist of those commonly observed in the real world, e.g., temperature, winds, currents, waves, aerosols, ion density, and topography. (This term normally precludes manmade objects, but in the case of terrain features can encompass human influences like canals, straightened rivers, etc.)

For military operations, however, it is the environmental *effects* on military systems that are important, rather than the natural environment components themselves. For example, a sensor may measure sound speed, which is calculated from temperature and salinity. Or, a sensor may measure an electromagnetic signal that is attenuated by aerosols or by water vapor. It is the *attenuation* of the signal that is important to the sensor, not the phe-

nomena performing the attenuating (e.g. the aerosols or water vapor).

Environmental *impacts* deal with the changes to the natural environment caused by the military systems themselves. Amphibious vehicles are affected by waves, but also generate wakes that alter the wave patterns in the littoral zone. Tanks churn the surface soil and can change the trafficability for following tanks.

The three aspects of an environmental representation are handled differently. The natural environment (i.e. the instantaneous values of the represented phenomena) is generally provided as a pre-runtime database for a particular simulation exercise. Environmental effects are generally calculated during simulation runtime. The environmental impacts occur during simulation runtime and are folded back into the pre-runtime natural environment database to update it as the simulation progresses.

As each military system is developed, it undergoes considerable testing and evaluation (T & E). During the T & E phase, numerical models and algorithms are developed to understand and supplement the real world testing. These models and algorithms include environmental effects models. When a given military system is incorporated into a simulation, the models used for that system, including the effects models, are commonly the ones developed during the T & E phase. Thus, effects models are "bundled" with the military system models, rather than being handled separately as shown in Figure 1. Therefore, military systems, especially legacy ones, may have different effects models for the same effect, such as propagation loss.

For the purposes of this paper, the natural environment or pre-runtime aspect of the environment representation is the one being examined.

3. HOW DO YOU OBTAIN AN ENVIRONMENTAL REPRESENTATION?

Many users of environmental data believe data are obtained solely from observations of the real world, especially using satellites. Observations from individual instruments are available, but even these are often processed by some type of numerical algorithm. But more importantly, the observational networks used to collect data for the atmosphere, ocean, and space domains are completely inadequate to provide the spatial and temporal coverages needed to provide the environmental information needed for most users, but especially for the M&S community. Furthermore, M&S applications require not only "real" (i.e. based on physics), but "realistic" environmental information to do "what if" scenarios based on possible environmental conditions - not actual, observed conditions.

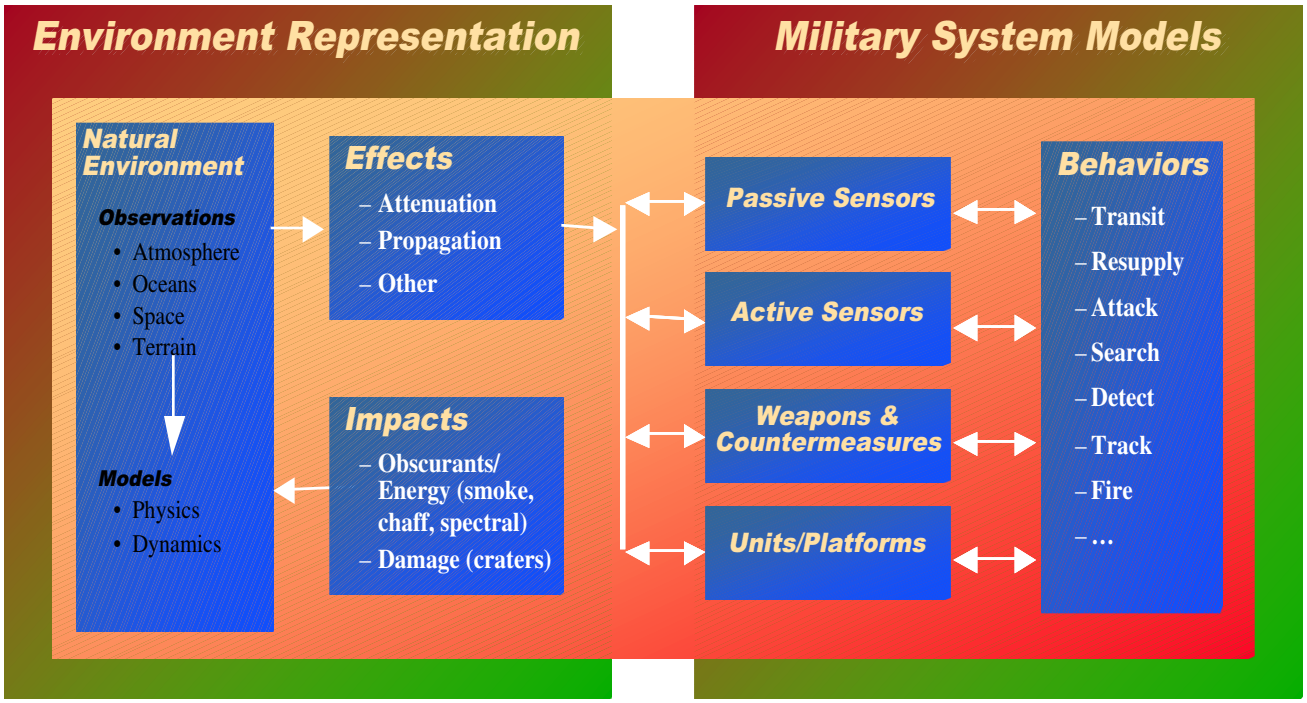

Figure 1. The Environment Representation Model, as Modified from the Original "Birkel" Model

Figure 2 gives an overview of some of the issues associated with developing a process to produce an integrated natural environment. The natural environment has four domains: atmosphere, ocean, space, and terrain. The first three are fluids and can vary considerably over a day while the terrain domain, aside from catastrophic events, can be considered to be static.

In establishing the production process shown in Figure 2, decisions are made about the types of observations, models, and historical data that will be included, as well as they way in which they will be combined. These decisions will determine the type of output: what parameters are included or omitted, the temporal and spatial resolutions, the format, coordinate systems, map projections and, most important, the context for which the output is appropriate. (See Hummel and Christiansen [2000] for a discussion of the importance of context in simulations.) The instance data output from this process are the pre-runtime integrated natural environment representation that will be used as input data for a given simulation exercise. Therefore, the simulation requirements for the integrated natural environment should drive the production process developed to provide such information.

The simulation developers and users frequently provide natural environment requirements in terms of specific scenarios. Then the environmental data providers may respond with instance environmental databases for the few scenarios, rather than developing and documenting a process to meet the general need for environmental input data for that simulation. Simulations can be run hundreds of times with different scenarios for each run , e.g., Korea in the winter or Saudi Arabia in the summer. Rather than building a specialized instance data set for each scenario or, worse, using the wrong environment database, thereby increasing risk of failure, it is more effective and efficient to develop the production process to provide the required input environment data for the simulation, regardless of what the scenario is. If simulations and components of simulations are reused and combined into federations, the documentation of the original production processes for environmental representations forms the basis for quickly determining environmental requirements for the new system as well as developing the production process to meet them.

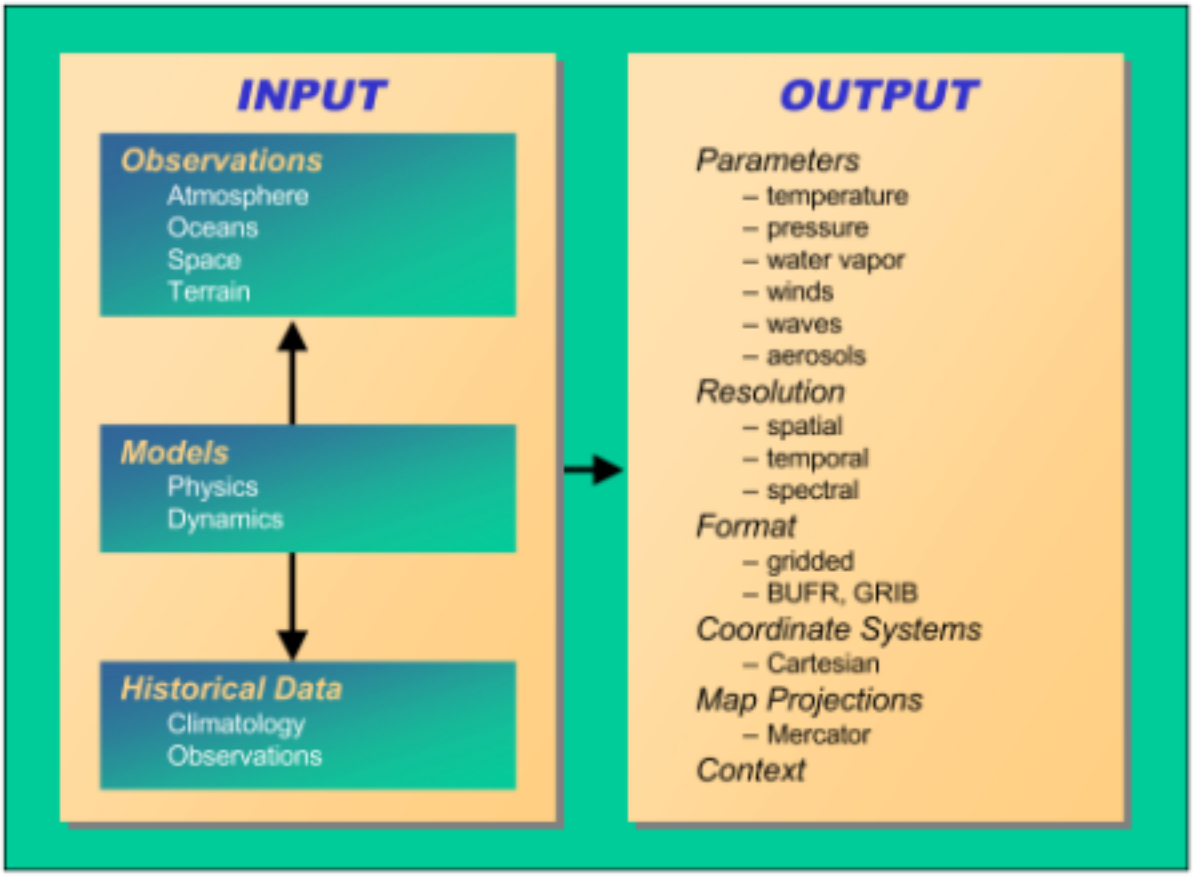

Figure 2. A Representation of Some of the Issue Associated with Developing a Process to Generate an Integrated Natural Environment

4. WHAT MAKES AN ENVIRONMENTAL REPRESENTATION AUTHORITATIVE?

The terms "authoritative" and "authority" frequently are heard with regard to environmental information. First, consider the dictionary definitions for the terms (Morris, 1976):

- Authoritative – "…having arisen from proper authority, official"
- Authority – "…an accepted source of expert information or advice as from a book or person"

As an example of an "authoritative source" of weather information, consider what NOAA says about the National Weather Service (NWS):

> "The National Weather Service is the primary source of weather data, forecasts and warnings for the US…The NWS is the sole United States official voice for the issuing warnings during life-threatening weather situations." (http://www.noaa.gov)

The statements clearly indicate that NWS has been "authorized" by the United States (US) to provide warnings and that not only is the NWS an official (authoritative) source of weather warnings, it is the only official source so designated by the US. That is why radio and television will state that "The *NWS has issued* a severe storm warning…." No other producer, group or agency is authorized to issue such warnings in the US. Note the relationship between the US government and the NWS. The NWS is an agency of and funded by the US. Furthermore, the statement only applies to the US and not to any other country. Both the US and NWS have agreed with the published statement. One group cannot unilaterally designate another as authoritative; there must be clear agreement of the responsibilities and limitations.

What then is an "authoritative data source," especially for the natural environment? From the Glossary of the Defense Modeling and Simulation Office (DMSO) Verification, Validation, and Accreditation (V&A) Recommended Practices Guide (RPG) (Youngblood, 2000):

> Authoritative Data Source – A data source whose products have undergone producer data verification, validation and certification activities.

The terms "verification" and "validation" are more commonly used by the M&S community than the producers of environmental data. At this time, no producer of environmental data certifies that the data produced has been verified and validated for use in M&S applications. Thus, by the above definition, there are no authoritative *environmental* data sources.

Although there are no "authoritative data sources" for environmental data, there are producers of environmental data who are considered "authorities" by the second dictionary definition. Usually these producers have an established reputation and provide data sets with clear documentation as to the process by which the data sets have been produced as well as the testing and evaluation that have been done on the process.

The term "authoritative data representation" is also defined in the Glossary of the DMSO VV&A RPG (Youngblood, 2000):

> Authoritative Data Representation – Models, algorithms, and data that have developed or approved by a source which has accurate technical knowledge of the entity or phenomenon to be modeled and its effects.

Thus, the natural environment representations created by a production process can be "authoritative" if the production process is developed and approved by appropriate Subject Matter Experts (SME). Presumably such SMEs would, as producers of environment information, ensure that the production process did undergo producer V&V.

5. WHAT IS VERIFICATION & VALIDATION FOR AN INTEGRATED NATURAL ENVIRONMENT REPRESENTATION?

Verification and Validation are considered to be both necessary and difficult by the M&S community. The V&V should not be reserved to the very end of simulation development but planned and executed throughout the simulation development process. (In many programs, the requirement for V&V is detailed in the Federal Acquisition Regulations.) But what is V&V for an integrated natural environment representation and where and how should it be performed?

Verification is frequently defined as answering the question, "Did I build it right?" For the producer of an environmental representation, the answer is "yes", if the result is internally consistent, that is, if it satisfies the physical and dynamic constraints to the appropriate level.

Over the past fifty years, the environmental sciences communities have amassed considerable information: observations, numerical models, algorithms, historical databases, reports and journal articles. Most of these components have undergone considerable testing and evaluation to insure physical and dynamical consistency or, in the case of documentation, peer review. Most of this testing and evaluation has addressed the question of internal consistency so that this testing and evaluation information can be used to verify the components. These components are available in various repositories. The reuse of these components is common and is facilitated by careful documentation.

A production system, such as one described in Figure 2, is a linked and ordered process that can involve the reuse of components from the repositories. The process must be verified even if the components have themselves been individually verified. As stated in the DMSO VV&A RPG (Youngblood, 2000):

> "If either a product or its intended use is changed, then new V&V must be performed."

The output from the production process or the instance data must also be verified. However, if the production process has been verified then the verification of the instance data or output is trivial. If the production process has not been verified or if the process changes with each scenario, the verification of each instance data set is indeed time consuming and difficult. Again, risk mitigation dictates that a production process be developed and V&V'ed to provide the integrated natural environment scenarios needed by a simulation or federation.

Validation is frequently defined as answering the question, "Did I build the right thing?" The "right thing" is determined by user requirements. Most data sets, algorithms and models that are available in repositories were built to satisfy users not in the M&S community. That does not mean that they are not suitable for M&S applications, just that no validation has been done for those M&S requirements.

User requirements for the integrated natural environment representation focus on the output, not the production process, in Figure 2. However, the production system will be designed and developed to provide the integrated natural environment representation required by the simulation. The production process should be validated for the simulation; then validating each instance of the integrated natural environment is easy. The instance data just needs to be checked to see that it is appropriate for the scenario. For example, is this instance data for Korea in the winter?

A critical factor in validation of environmental representations is the existence of robust requirements. That is, user requirements for the natural environment must be developed in sufficient detail to insure that the goals of the simulation can be met.

6. A PROCESS TO VERIFY AND VALIDATE AN ENVIRONMENTAL REPRESENTATION

DMSO is developing a process and enabling technologies that are intended to provide DoD modeling and simulation customers with authoritative environmental representations. The process that will be used is called the Integrated Natural Environment Authoritative Representation Process (INEARP) and consists of a series of detailed steps, summarized in Figure 3, that cover the analysis of the customer's requirements to determine the context and need of the simulation, retrieving (when appropriate) data from available archives, producing a Just-in-Time (JiT) authoritative environmental representation, and delivering the resultant authoritative representation to the customer.

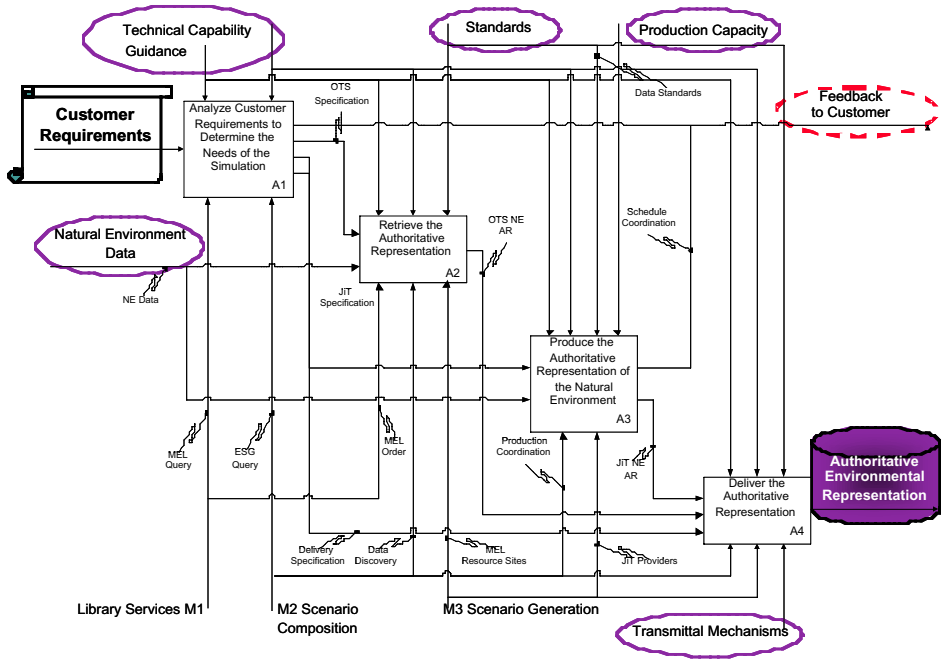

Figure 3. High Level Representation of DMSO's Integrated Natural Environment Authoritative Representation Process

Key to the success of the INEARP is having a well-defined and documented set of customer requirements. These requirements should be developed as an iterative process involving the customer, environmental subject matter experts, and representatives from the operational environmental data providers. During this iterative process, the customer's requirements can get translated from "wants" to "needs" and then mapped against specific data products that are generated by known technical capabilities using established (and documented!) standards and guidance policies. This process would also result in the establishment of an agreed upon schedule, based on available production capacity, and transmittal formats and mechanisms. This process would also involve providing

the customer with continuous feedback throughout the entire process.

The importance of "process" in verifying and validating an environmental representation can be demonstrated by taking examples from two current environmental programs, the Integrated Ocean Architecture (IOA) (Hummel et. al., 2000a) and the Weather Effects for the Warfighter (WxFX) programs (Hummel et. al., 2000b) The IOA is currently being used to generate surf zone data to support potential beach landing operations, while the WxFX is designed to support analyses of the impact of the environment on military systems.

The physics that govern what happens in the surf zone are driven by processes that begin in the open ocean and in the atmosphere. There are a series of well understood and validated scientific models that describe the physics that are involved in describing a surf zone representation. Historically, these models were run individually and the data linkages between models were handled via a human "sneaker net." This can be a labor intensive - and potentially inefficient – process. The IOA program was developed to automate this process, as summarized in Figure 4, in order to reduce the time required to perform an analysis as well as reduce the chances for the introductions of errors.

From the perspective of the INEARP, the IOA is both a user of authoritative environmental data and a potential producer of authoritative environmental data to other programs. The IOA is being developed to support an operational Navy requirement and so will have requirements for authoritative atmospheric and bathymetric data. In addition, the IOA is also being considered as a provider of surf zone data within the INEARP. One of the values of the IOA from the perspective of the INEARP is that it will have a verified and validated process of how data are generated so that the user will be able to obtain the necessary information to make an assessment of how well the data generated using the IOA matches the requirements.

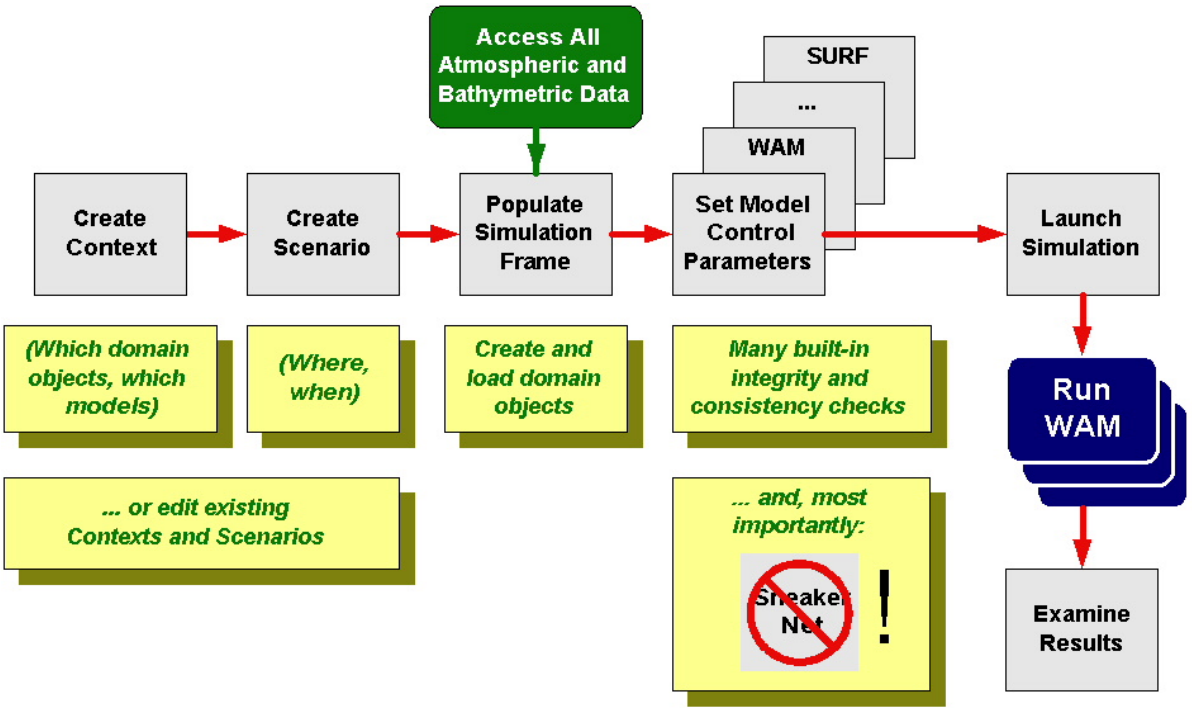

Figure 4. A Schematic Representation of the Process Used to Generate Surf Zone Representations Using the Integrated Ocean Architecture

The WxFX system is intended for use by the operational community as a part of the mission planning and analysis cycle. The set of military systems and supported operations encompasses Joint applications and, as a result, a WxFX study could require an integrated natural environment that includes land, ocean, atmosphere, and space domains. Figure 5 lists the environmental data requirements in the environmental domains and discusses some of the issues associated with the generation of the environmental data.

In an earlier version of the WxFX system, all of the required data could be provided by one operational provider, the Advanced Climate Modeling and Environmental Simulations (ACMES) system that is operated by the Air Force Combat Climatology Center. When the set of supported systems grew and included systems used by Navy and Marine operators, the data requirements in-

creased to the point where no single data provider could generate all of the required data. Now, a minimum of three separate data providers will be required and so the V&V process will have to encompass the generation of the individual data in each domain as well as the process used to integrate the individual domains into an internally self-consistent representation.

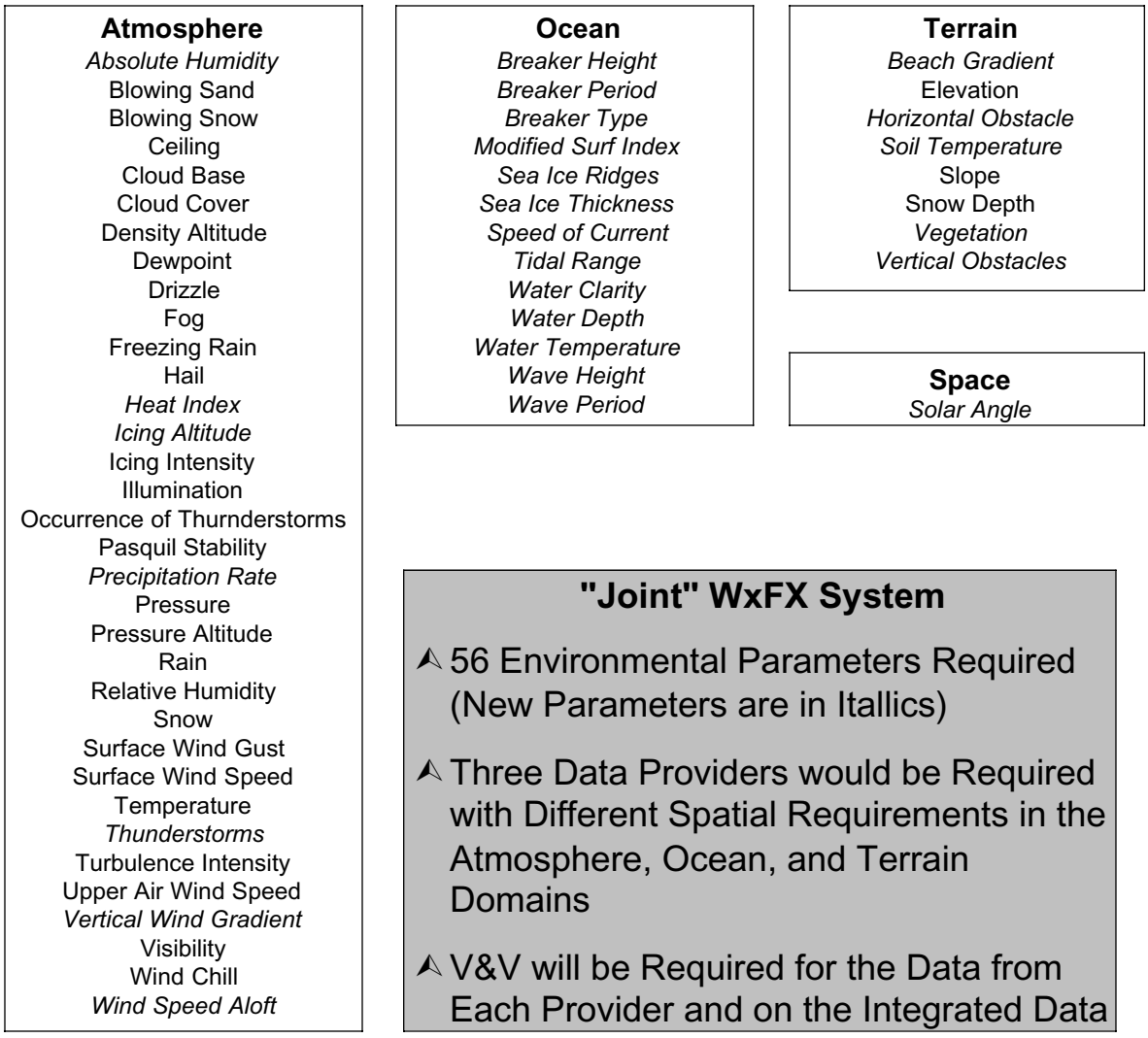

Figure 5. Summary of the Environmental Data Requirements and Associated Issues for the Weather Effects for the Warfighter System

7. SUMMARY AND CONCLUSIONS

Models and simulations are beginning to play an increasing role in the planning and training as well as the execution of successful military operations. As these models and simulation become more sophisticated, they are becoming able to include more realism in how the environment interacts with the rest of the simulation.

In this paper we have discussed the issues associated with developing an authoritative environmental representation for M&S applications. In particular, we have discussed what the terms "authoritative," "verified", and " verification" mean within the context of M&S applications. We have discussed the importance of having well defined customer requirements and well documented processes in order to determine if the environmental representation produced for a customer actually meet the expressed needs.

8. REFERENCES

Birkel, P. (1998) "SNE Conceptual Reference Model", Fall 1998 Simulation Interoperability Workshop, 14 - 18 September, Orlando, FL

Hummel, J.R. and Christiansen, J.H. (2000) "Defining, Expressing, and Using Context in a Simulation Environment," Spring 2000 Simulation Interoperability Workshop, March, Orlando, FL.

Hummel, J.R., Christiansen, J.H., Hield, C.W., Taxon, T.N. and Allard, R. (2000a) "The Integrated Ocean Architecture – A Framework for Generating Seamless Oceanic Representations for Modeling and Simulation Applications," 68th Military Operations Research Society Symposium, United States Air Force Academy, Colorado Springs, CO, 21 June.

Hummel, J.R., Baines, T.B., Hunsucker, M.S., and Walker, T.N. (2000b) "The Incorporation of High-Resolution Climatological Data to Support the Development of Environmental Tactical Decision Aids for the Warfighter," Fall 2000 Simulation Interoperability Workshop, 20 September, Orlando, FL.

Morris, W. Editor, (1976) The American Heritage Dictionary of the English Language, Houghton Mifflin Company.

Youngblood, S., Editor, (2000) The Defense Modeling & Simulation Office Verification, Validation & Accreditation Recommended Practices Guide, DoD 5000.61, http://www.dmso.mil/

9. ACKNOWLEDGMENT

This work is sponsored by the U. S. Department of Energy under contract number W-31-109-ENG-38

10. AUTHOR BIOGRAPHIES

JOHN R. HUMMEL is the Deputy Director of the Advanced Computer Applications Center in the Decision and Information Sciences Division at Argonne. He is the program manager for a number of applications using the Dynamic Information Architecture System (DIAS). He is a member of the SISO Synthetic Natural Environment and Logistics working groups.

DONNA W. BLAKE is a Senior Scientist with VisiTech, Ltd. in Arlington, VA, supporting the Navy MARVEDS and PRA programs. She is a former Chief of the Office of the M&S Ocean Executive Agent and has done research in both ocean and atmosphere modeling at several Navy laboratories. She has been a program manager for ocean sciences at NASA and for atmospheric sciences at NSF.