DARPA STOW SYNTHETIC ENVIRONMENTS[†]

George E. Lukes[‡]
Defense Advanced Research Projects Agency
Arlington, Virginia

ABSTRACT

The Synthetic Environments (SE) Program, a technology component of DARPA's Synthetic Theater of War (STOW) initiative, has developed novel technology to create and use digital battlespaces of increasing size, fidelity and complexity needed for large-scale distributed simulation at the Joint Task Force level. The technical objective was to model tactically significant battlefield detail and phenomenology that impact the performance and behavior of entity-level combat platforms, sensors and weapons (e.g., tanks, helicopters, ships, missiles, rounds). The developmental strategy was grounded on the transformation and rationalization of operational terrain, bathymetric, meteorological and oceanographic data products into an integrated environmental data base and the adaptation of environmental models to real-time operations.

Considerable progress has been achieved in a period of three years. The spatial extents of STOW environmental data bases have been systematically extended to support combined air, amphibious, ground, naval and special operations over large areas with geodetic rigor. Internally, 3D spatial topology has been developed to support multiple elevation surfaces including ocean surface and ocean floor, bridges, tunnels and multistory buildings. Mechanisms to represent and distribute dynamic meteorological and atmospheric fields have been incorporated into the synthetic battlespace.

Where the STOW Europe synthetic environment of 1994 was a static benign world populated by dynamic warfighters, the STOW 97 synthetic environment featured dynamic natural effects (e.g., time-of-day, wind, rain, fog, dust) as well as man-made environmental effects (e.g., smoke, flares, destroyed bridges and buildings). Progress in dynamic terrain, one of the most difficult issues in distributed simulation, has been exceptional to include terrain cratering. Real-world weather has now been introduced into distributed simulation within an architecture that support execution of nested feature and effects models.

ABOUT THE AUTHOR

George E. Lukes serves as Program Manager for Synthetic Environments and Image Understanding at the Defense Advanced Research Projects Agency (DARPA). Prior to joining DARPA, Mr. Lukes was a Physical Scientist at the U.S. Army Topographic Center, Alexandria, Virginia. His research interests include simulation and modeling, digital mapping, image understanding and autonomous navigation. His early work in Optical Power Spectrum Analysis led to the development of high-speed automated screeners for operational mapping and reconnaissance imagery. Subsequent work in Computer-Assisted Photo Interpretation Research led to state-of-the-art developments for interactive mapping. Mr. Lukes has pioneered applications of digital mapping and environmental technology to modeling and simulation. Serving as DARPA Agent, he was responsible for generation of terrain data bases for the Autonomous Land Vehicle, SIMNET, Project ODIN (Kuwaiti Theater of Operations), the 73 Easting Battlesite, Bosnia and STOW. He served as the first Chairman for Simulated Environment at the Workshop on Standards for the Interoperability of Distributed Simulation. Mr. Lukes holds a B.S. degree from the University of California, Berkeley and a M.S. degree from the American University, Washington, D.C.

[†] Approved for Public Release, Distribution Unlimited.

[‡] Significant contributions to this paper were made by senior members of the Synthetic Environments team: Dr. Paul Birkel (MITRE, Reston, VA); Dr. Dale Miller (Lockheed Martin, Bellevue, WA); Mr. Richard Schaffer (Lockheed Martin, Cambridge, MA); Mr. Tom Stanzione (TASC, Reading, MA); and Mr. David Whitney (TASC, Reading, MA).

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INTRODUCTION

Advanced Distributed Simulation

In the late 1980's, DARPA pioneered distributed simulation technology with the Simulation Networking (SIMNET) Program. In partnership with the United States Army, SIMNET led to fielding several hundred manned Abrams M-1 tank and Bradley Fighting Vehicle simulators in the first crew-level virtual training network system. In the early 1990's, the Aggregate Level Simulation Protocol (ALSP) was developed to link large-scale constructive simulations (e.g., Corps Battle Simulation (CBS) and Air Warfare Simulation (AWSIM)) for a loosely-coupled joint simulation capability. Today, DARPA's efforts continue under the Advanced Distributed Simulation (ADS) initiative.

ADS seeks to create a highly realistic, widely distributed, seamless synthetic battlespace for service and joint training, mission rehearsal, analysis, acquisition, doctrine development, test and evaluation. The goal is to resolve combat actions at the platform or weapons system level-of-detail within a realistic environment which integrates terrain, ocean, atmosphere and dynamic environmental effects. Command and control behaviors and architectures are realistically simulated along with intelligence sensors, interfaces to real world command and control systems and logistics functionality. Manned simulators, or live instrumented systems, may be incorporated within the battlespace as desired.

ADS builds on the development and integration of three key technologies:

- Synthetic Environments - digital battlespaces representing areas within the real world of increasing size, complexity and fidelity in which human warfighters and Synthetic Forces interact;
- Synthetic Forces - computer generated entities operating in Synthetic Environments programmed to employ the tactics, techniques and procedures of friendly and opposition forces including command and control (Feldmann and Muller, 1997);
- Networking - advanced communications technology linking human warfighters and Synthetic Forces in shared Synthetic Environments from distributed locations.

Synthetic Theater of War

Synthetic Theater of War, or STOW[1], applies the ADS vision and technologies to the demanding application of staff and command training and mission rehearsal at the Joint Task Force level. The objective is to faithfully represent the spectrum of conflicts that a Joint Task Force could encounter in conducting air, amphibious, ground, naval and special operations. The associated synthetic battlespace is constructed at appropriate levels of detail to support live, virtual and constructive simulations with provisions for human interaction at all command levels.

The first operational demonstration of STOW technology occurred in October 1994 in conjunction with the Atlantic Resolve '94 Joint Training Exercise termed STOW Europe. In 1995, STOW was designated as the first DARPA Advanced Concept Technology Demonstration (ACTD) with the United States Atlantic Command (USACOM) as the operational partner. In 1996, the United Kingdom Ministry of Defence joined the STOW ACTD Program as a technology and operational partner. In October and November 1997, STOW ACTD developments culminated in an operational demonstration termed STOW 97 as part of the Unified Endeavor 98-1 Coalition Joint Task Force Training Exercise.

STOW Europe (or STOW-E) provides both an introduction to the STOW concept and a baseline against which to gauge subsequent progress. STOW-E was initially conceived in Fall 1993 as a brigade-level ground maneuver training exercise

[1] See http://www.stow.com/ on the World Wide Web.

linking three armor battalions, each in a different simulation modalities:

- one battalion in “live” simulation -- real soldiers in real tanks operating in the real world -- at the Combat Maneuver Training Center (CMTC), Hohenfels, Germany;
- one battalion in “virtual” simulation -- real soldiers in tank simulators operating on a synthetic version of that same real world -- from the 7th Army Training Center, Grafenwöhr, Germany;
- one battalion in “constructive” simulation -- synthetic forces using a tailored version of the synthetic world in the Brigade/Battalion Battle Simulation (BBS) – physically located and staffed at the CMTC.

Subsequently, the scope of STOW-E expanded dramatically to include air, ground and naval forces operating from sixteen sites located on two continents. The Defense Simulation Internet provided real-time connectivity employing novel High Performance Application Gateways. The actual STOW-E exercise supported 2100 entities including “live” tanks, ships and aircraft. It is important to note that commanders and combatants -- ranging from AWACS controllers to attack submarine crews to the operational brigade commander and his staff on the ground -- did not react differently to live, virtual and constructive forces.

Synthetic environments for STOW-E consisted of three geospecifc terrain data bases generated from operational Defense Mapping Agency (DMA)[2] products tailored in extent, content and data density to support ground, air and naval operations (see Figure 1). Application-specific compilations supported computer-generated forces via the ModSAF Compact Terrain Data Base (CTDB), several real-time 3D visual systems and 2D electronic maps ("plan view displays") for command and control. For ground operations, tailored Topographic Line Maps were produced to reflect the content of the synthetic battlespace.

The distributed simulation exercise was conducted with forces operating concurrently on the three terrain data bases. Entity locations were communicated using entity-state Protocol Data Units

[2] On October 1, 1996, DMA was incorporated into the new National Imagery and Mapping Agency (NIMA).

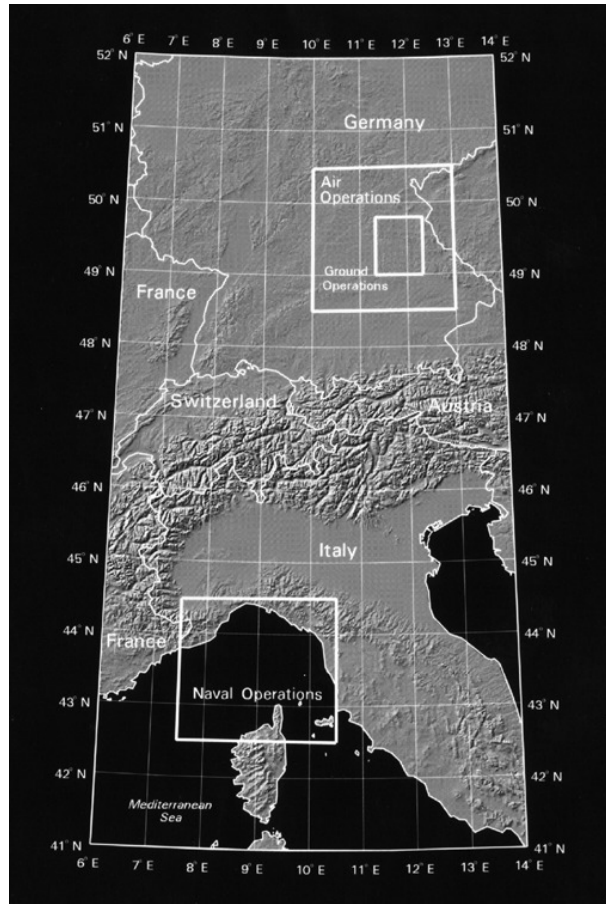


Figure 1. Location of STOW-E terrain data bases.

(PDU’s) referencing entity positions in Geocentric Cartesian Coordinates to provide consistent positions. As in previous Distributed Interactive Simulation (DIS) exercises, interaction between combatants was characterized by highly dynamic free-play while modeling of environmental phenomena was quite limited. All combat took place at constant time (mid-day) with unrestricted visibility. Dynamic environmental effects were not modeled.

Synthetic Environments Program

In terms of size and complexity, the synthetic environments for STOW-E represented a key benchmark at the time; moreover, it was the point of departure for focused investments to develop larger, more complex and, for the first time, dynamic environmental data bases and associated dynamic environmental processes.

STOW has required development of synthetic environments (1) far larger in terms of spatial extent,

(2) more realistic in terms of content and spatial representation, (3) with a higher degree of interoperability between diverse applications that (4) can be generated and shared faster to meet critical military applications. These dynamic synthetic environments needed to be affordable and supportable within disparate real-time simulators and simulations linked by high-performance local-area and wide-area networks.

The SE Program met these challenges through the following principles:

- transforming operational terrain, bathymetric, meteorological and oceanographic data sources into integrated environmental data bases of sufficient fidelity and currency for live, virtual and constructive simulations;
- adapting operational and research models into real-time environmental processes for Synthetic Forces reflecting tactically significant impacts of the environment on military operations and tactically significant impacts of military operations on the environment;
- developing real-time, three-dimensional (3D) visualization capabilities of the environmental data bases, environmental phenomena and Synthetic Forces for humans;
- and generating associated two-dimensional (2D) electronic and paper maps for command and control of Synthetic Forces.

The general flow of operational environmental data to generate and manage a dynamic synthetic environment using simulation-specific tools and services is shown in Figure 2. Geographic information systems are used to assess, intensify and transform digital bathymetic and terrain data with current imagery. Operational (and research) meteorological and oceanographic data are collected in a repository such as the Master Environmental Library (MEL[3]) then incorporated in simulation-specific environmental data bases. Networking technology and protocols for Distributed Interactive Simulation (DIS) and the High Level Architecture (HLA[4]) Run-Time Infrastructure (RTI) are used to share static and dynamic data with ModStealth for 3D visualization, Synthetic Forces and other real-time applications.

[3] http://www-mel.nrlmry.navy.mil/.
[4] See http://www.stow.com/.

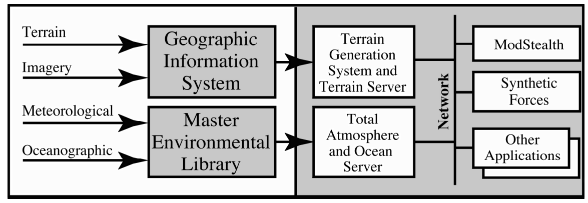


Figure 2. Transformation of operational source data to generate large-scale dynamic battlespace.

STOW required a distributed capability for real-time 3D visualization of the battlespace that would support emerging STOW networking technology including the HLA/RTI and novel SE capabilities such as dynamic atmospheric phenomena and dynamic terrain. ModStealth Openscene (Cauble et al, 1997) was developed within the SE Program using the ModSAF network interface libraries to support network operations under DIS or HLA/RTI protocols. ModStealth Openscene has been designed to support one or more image generators (IG) by encapsulating IG-specific interfaces within three well-defined agents: an agent for modeling atmospheric phenomena termed Virtual World Environment System (VWES); an agent for terrain data base paging; and an agent supporting dynamic terrain and objects. The ModStealth has been demonstrated using the Vistaworks™ visualization software running on a Silicon Graphics Onyx RE^2, the GT200 image generator and a new Performer-based visualization back-end on a variety of Silicon Graphics workstations[5].

The SE Program[6] has been organized to support four related technology developments entitled (1) Improved Computer Generated Forces (CGF) Terrain Data Base, (2) Dynamic Terrain and Objects, (3) Total Atmosphere Ocean Services and (4) Dynamic Virtual Worlds as well as a focused effort in environment data base generation. The following sections summarize each effort, provide a summary of progress achieved in environmental data base generation for STOW and conclude with remarks on technical progress and continuing challenges.

[5] Perspective illustrations in this paper are single frame images generated by ModStealth.
[6] See http://svl.tec.army.mil/SE/.

IMPROVED CGF TERRAIN DATA BASE

The Improved Computer Generated Forces Terrain Data Base (ICTDB) project has led to significant improvements to the internal ModSAF terrain data base representation. Following a rigorous requirements analysis, the ICTDB project focused on four areas for improved terrain representations.

Integrated Triangulated Irregular Networks

Large-scale support of computer generated forces requires advances in both the adequacy and efficiency of large, complex terrain data bases. New spatial data base representations integrating feature and elevation data in triangulated irregular networks provide flexibility and economy in representing complex natural and man-made surfaces (Figure 3). Critical spatial constraints are introduced by terrestrial features such as shorelines, ridgelines, cut-and-fill roadbeds, streambeds and banks, as well as rice paddies and dikes (Gifford et al, 1996). Two major advantages of iTINs over traditional TINs lie in the ability to model roads on the terrain preserving road beds with proper cut-and-fill characteristics and the ability to constrain drainage networks to local terrain minimums.

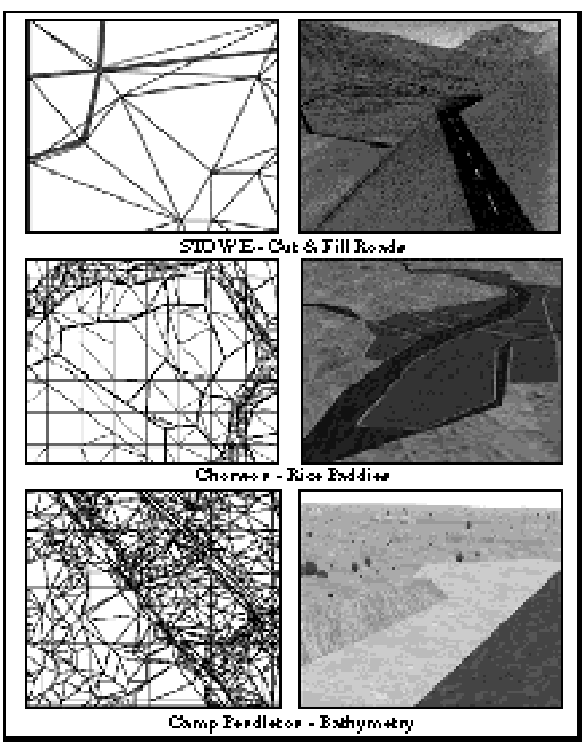


Figure 3. Integrated Triangular Irregular Networks.

ICTDB developed an efficient representation utilizing a virtual grid technique for organizing the iTIN polygons along with polygonal topology information which supports directed search. These techniques provide efficient elevation and intervisibility calculations over iTIN without degrading performance on gridded terrain (Stanzione et al, 1995).

Global Coordinate System

ICTDB developed a rigorous global coordinate system for use within CGF systems. The most widely used terrain data bases supporting ground forces have had spatial extents of 100 km by 100 km or less. Over these distances, effects of earth curvature are sufficiently small to permit use of simplifying "flat earth" projection representations. For larger exercise areas required for STOW, the effects of earth curvature on line-of-sight can not be ignored. A Global Coordinate System (Stanzione et al, 1996) has been developed in the ModSAF Compact Terrain Data Base (CTDB) which partitions the earth into one degree by one degree tiles. As seen in Figure 4, a local Cartesian coordinate system is instantiated within each tile to support efficient real-time operations while maintaining full geodetic rigor with respect to the shape of the earth. GCS libraries support real-time conversion to conventional coordinate systems (e.g., geographic latitude and longitude or MilGrid coordinates as well as operations between tiles such as piecewise linear distance and vector operations.

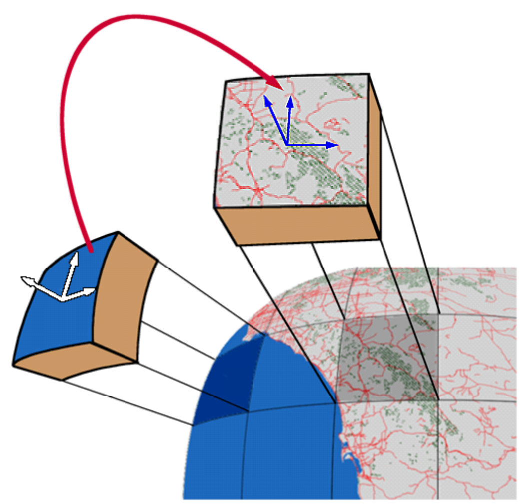


Figure 4. Global Coordinate System divides the Earth into tiles and provides transition operators between tiles while maintaining geodetic rigor.

Multiple Elevation Surfaces

ICTDB addressed the problem of multiple elevation surfaces and structures. While simple 2.5D terrain surfaces (one and only one elevation value for any horizontal location) are sufficient for many simulation applications, STOW has several instances where it is essential to represent multiple elevation surfaces (Buettner et al, 1996a): naval operations with explicit representation of ocean surface and ocean floor (Buettner et al, 1996b; ground operations with traffic on bridges as well as underpasses and tunnels; and individual combatants operating in multistory buildings. Under ICTDB, explicit data structures and methods have been implemented to represent and operate on true three-dimensional terrain with provisions for multiple elevation surfaces. MES structures, which include buildings and bridges, provide the representation for exterior and interior geometric information, as well as topological information for route planning and navigation within these structures.

Advanced Features and Attributes

ICTDB has addressed the identification and representation of advanced features and attributes to include all features and attributes normally found in operational terrain sources such as Interim Terrain Data (ITD) and Tactical Terrain Data (TTD). Feature and Attribute Coding Catalog (FACC) codes have been added to all terrain features which allows the storage of FACC classification and attribute data on a per-feature basis. Thus, feature attribution can be tailored for specific applications without necessitating a change in the CTDB format. A polygon attribute table (PAT) has also been added to the ModSAF terrain representation for storage of performance critical terrain characteristics beyond simple mobility indices. The PAT allows attribute groups, such as standard soil types, soil wetness and surface material category attributes, to be associated with individual polygons. These capabilities support rapid prototyping and changing user requirements as well as run-time modification of features and attributes.

DYNAMIC TERRAIN AND OBJECTS

Dynamic terrain development has provided the means to damage or destroy buildings and bridges, crater roads and runways, and emplace anti-tank ditches, vehicle survivability positions and infantry trenches. The challenges of this effort were:

- arbitrating simultaneous changes to the terrain from multiple applications (e.g., bulldozer simulator and cratering munitions);
- serializing changes;
- communicating changes (abstractly and/or polygonally);
- minimizing network bandwidth requirements;
- real time operation;
- and addressing the needs of a large scale distributed simulation on an arbitrary TINed terrain surface.

An architecture addressing these challenges was developed (Miller et al, 1996a and 1996b). Changes are communicated via a new type of interaction called an Environmental Change Notice which communicates state and polygonal information. An application known as the DT Scribe was developed to arbitrate and serialize changes requested by other applications. Another application, the DT Sim, assesses munitions damage to cultural features and creates and repairs runway craters. Each application (e.g., ModSAF, ModStealth, DT Sim) includes a DT Agent which inte-

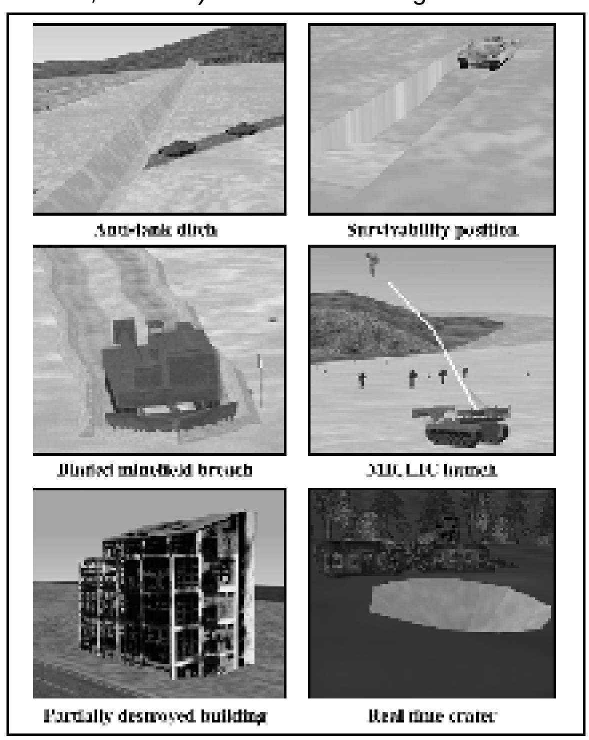


Figure 5. Typical dynamic terrain capabilities.

grates each change into its client's run-time data base in real time. Run time induced changes to the terrain surface and cultural features are shown in Figure 5.

TOTAL ATMOSPHERE OCEAN SERVICES

Total Atmosphere Ocean Services or TAOS provides dynamic meteorological and oceanographic (METOC) data to the battlespace. In STOW, TAOS distributes high-fidelity, tactically significant atmosphere, ocean and surf zone data on demand to networked simulation clients including Synthetic Forces and ModStealth. TAOS has been developed within a modular architecture for collection, assimilation, integration, distribution, and management of METOC data that supports both the HLA/RTI and DIS communications protocols (Whitney, Schaffer et al, 1996).

TAOS ingests, stores and distributes gridded atmosphere-ocean-surf data which varies in three spatial dimensions and time. Authoritative gridded forecasts products, from both operational and research models can be combined by the TAOS Integrator and stored in a data base as consistent environmental data for distribution (Whitney and Stoltz, 1997). Drawing largely from the Master Environmental Library (MEL), hundreds of different base gridded environmental variables from a wide range of volumetric gridded data sets are available and others can be easily added by extending the TAOS library of data receivers. Table II lists some of the model/receiver pairs implemented in TAOS. For STOW 97, mesoscale meteorological data from the United Kingdom Meteorological Office for the Persian Gulf was the authoritative data source.

In addition, TAOS can link to a variety of real-time sources to collect and distribute the latest hourly field observations that are available from both public and authoritative DoD data sources. Surface, upper atmosphere, aircraft, ship, and ocean buoy observations are provided via the AWN (Automated Weather Network) of 15,000 global sites managed by the US Air Force. Precipitation information in the U.S. can be derived from data collected every 15 minutes from National Weather Service weather radars, through a linkage via a commercial radar data provider (Weather Services International).

Given a data base of gridded volumetric data fields, TAOS enables this data base to be supplemented with localized high resolution environmental features, or more abstract aggregate features such as the CSSM (Cloud Scene Simulation Model) for high-resolution cloud products, atmospheric extinction coefficients for specific wavebands, aggregated precipitation data to drive hydrologic models, spectral tide models, and ocean acoustic sound velocity profiles. Libraries of feature and transform objects enable such existing models to be embedded in TAOS to provide a extensible set of derived features and products (Whitney et al, 1997a).

TAOS provides a range of data products to meet individual user needs. For distribution of data over a simulation network, any variable can be distributed as a data objects that ranges from fully-gridded to spatially uniform, depending on the resolution of data needed by the client. Specialized coordinate transforms, derived variables, and varying distribution rates are all provided by the TAOS Distributor. The TAOS Network Monitor allows this environmental network traffic to be monitored through a GUI for load and reliability analysis. TAOS is also implementing a capability to provide traditional weather graphics for human exercise players that are consistent with the environmental data being supplied to the network simulations (Whitney et al, 1997b).

DYNAMIC VIRTUAL WORLDS

The Dynamic Virtual Worlds (DVW) addressed enhancement of the STOW battlespace with tactically significant, real world environmental effects that vary in both space and time (Suliman, 1997). Correlated, real-time environmental feature models were implemented in both Synthetic Forces and ModStealth. Effects added to the virtual battlefield include the variation of illumination with time-of-day, illumination due to flares; obscuration due to atmospheric clouds, tactical smoke munitions, artillery-generated dust, vehicle dust, smoke from burning vehicles, fog, atmospheric haze, rain, and snow; and an ocean wave and ship response model (see Figure 6).

The DVW environmental architecture was carefully designed to provide the JointSAF application a unified interface to environmental effects). The interface isolates the application from the details of the underlying models, and allows these models to be upgraded without impacting the application. In addition, the architecture allows the selection of the environmental models to be used in a particular federation execution, to meet the fidelity computation and communication constraints of that execution. In ModStealth, the architecture also isolates the environmental models from the peculiarities of the underlying image generator (Li et al, 1996).

The goal of the DVW effort was not to develop new environmental models. A wide range of environmental models already exist, developed by organizations with specialized knowledge in the relevant environmental domains. Instead, the goal was to identify appropriate existing models and, where necessary, adapt them to the requirements of large-scale, real-time distributed simulation. This adaptation typically required adding support for dynamic, network-driven state updates and partitioning algorithms to allow as much off-line precomputation as possible. A few of the models adapted in this effort are briefly described below.

The Environment Editor supports user specification of uniform, homogeneous atmospheric conditions. A graphical user interface allows setting time-of-day, temperature, wind velocity, precipitation type and rate, cloud cover, and many other parameters. In STOW, 3D gridded and uniform data supplied by TAOS is normally used instead of the editor; however, the editor is convenient tool for localized model testing and small scale exercises.

Natural illumination due to the sun, moon, and stars is calculated based on standard celestial ephemera and the U.S. Army Research Laboratory-Battlefield Environment Directorate (ARL-BED) ILUMA model. The Ephemeris model accurately computes the position of the sun and moon, and the phase of the moon at a given location and time. Simulation exercises can now operate around the clock, with illumination conditions dynamically ranging from full daylight to an overcast, moonless night.

A model developed by the U.S. Army Night Vision Laboratory calculates the inherent contrast between a target vehicle and its background. The Inherent Contrast Model feeds the target acquisition model and allows target detection probability to depend on the target type, background type, illumination source, and sensor spectral response.

Obscuration of the battlefield due to smoke from burning vehicles, smoke munitions, smoke generators, artillery dust and muzzle dust are based on ARL-BED's Combined Obscuration Model for Battlefield Induced Contaminants (COMBIC). COMBIC models production, transport, and diffusion battlefield obscurants, and effects of these obscurants on atmospheric transmission in several wavebands (Gardner et al, 1996).

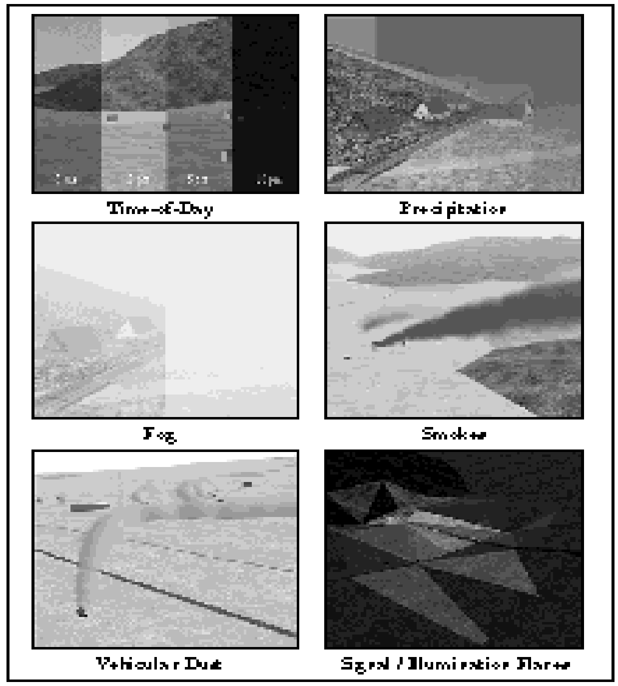


Figure 6. Typical dynamic environmental effects.

Three-dimensional fractal cloud fields that evolve in time and space are modeled based on a simplified version of the Cloud Scene Simulation Model (CSSM) developed by the U.S. Air Force Phillips Laboratory. Low resolution cloud descriptions (e.g., cloud type and cloud cover percentage) supplied by TAOS are used to generate consistent, high resolution 3D cloud fields. The techniques used require little network bandwidth to convey cloud state and support very efficient transmission calculations within Joint SAF (Kukolich et al, 1996).

Separate parameters for the open ocean and surf zone are supported in STOW. Supported parameters include current velocity, temperature, salinity, and tide level. Waves in the ocean and surf zone are represented by up to 25 spectral coefficients. A parameterized wave response model for displacement hulls has been implemented.

ENVIRONMENTAL DATA BASES

To meet STOW requirements, environmental data representations have increased dramatically in terms of size, content and functionality. Progress in both environmental representation and environmental data base generation for STOW is summarized in Tables I and II. Key data points are the capabilities demonstrated at STOW-E in October 1994, a series of STOW Engineering Demonstrations in 1996 and 1997 and the STOW 97 ACTD in the fall of 1997.

STOW Europe

Terrain data bases for ground operations covered a 64 km by 84 km area including the Combat Maneuver Training Center at Hohenfels and the 7th Army Training Center at Grafenwöhr. Primary source materials were DMA Digital Terrain Elevation Data (DTED) Level 2 and Interim Terrain Data (ITD). For the first time, the full exercise area was represented as an integrated Triangulated Irregular Network (iTIN) with roadbeds built into the 2.5-dimensional terrain surface. Previous data bases had been generated by projecting two-dimensional features (e.g., road “ribbons”) onto a simple gridded terrain surface.

To support air operations over and adjacent to the ground operations area, a larger terrain data base (232 km by 232 km) was generated using the traditional gridded terrain representation with projected cartographic features. Here again, primary source materials were DMA DTED Level 2 and ITD.

A third terrain data base was generated to support naval and associated air operations in the northern Mediterranean. DMA DTED Level 1 and Digital Chart of the World (DCW) were used to generate a 244 km by 244 km area in a gridded 2.5D representation of the land and sea surface; bathymetry was not modeled. Cartographic features were projected on the terrain surface.

Southwest United States

While the three terrain data bases fielded in 1994 for STOW-E were large and ambitious for the time, growing demands of Joint Task Force training and mission rehearsal required generation of terrain data bases over significantly larger spatial extents to support combined exercises while maintaining sufficient detail for entity-level simulation.

STOW engineering developments in 1995-1997 focused on generation of environmental data bases in the Southwest United States (SW/US). Operational military and civil agency products were tailored in extend, content and data density to support air, amphibious, ground, naval and special operations (see Figure 7). As in STOW-E, application-specific compilations supported computer-generated forces, 3D visualization and 2D electronic maps. For amphibious and ground operations, paper maps and charts were produced reflecting the content of the synthetic battlespace.

The full SW/US exercise area encompasses a 400 km by 400 km area providing maneuver space for air and naval components. Key data sources include DMA DTED, Digital Bathymetric Data Base (DBDB) and digital feature data from both DMA and the U.S. Geological Survey (USGS). The terrain surface and ocean floor is a gridded surface representation with a TIN shoreline. Higher resolution representations have been generated within this area to support amphibious, ground and special operations as described in the following paragraphs.

A 40 km by 60 km data base encompassing Camp Pendleton in southern California was generated to support amphibious operations. Primary source materials were USGS Digital Elevation Models, DMA DTED Level 2, Tactical Terrain Data and Digital Nautical Chart as well as 3” bathymetric data from

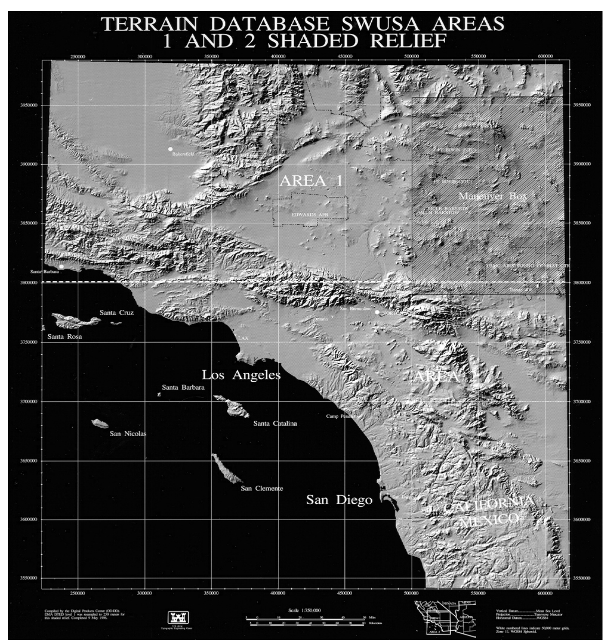


Figure 7. Southwest US terrain data bases.

the State of California. The full exercise area is represented as an integrated Triangulated Irregular Network (iTIN). With this data set, dynamic surf zone and tidal variations were implemented for the first time.

Terrain data bases for ground operations cover 111 km by 165 km area including the U.S. Army National Training Center at Fort Irwin and the U.S. Marine Corps Air Ground Combat Center at Twentynine Palms. Primary source materials were DMA Digital Terrain Elevation Data (DTED) Level 2 and Interim Terrain Data (ITD) transformed to form an integrated Triangulated Irregular Network (iTIN).

To support research with individual combatants in the DARPA/USMC Leathernet Project, a high resolution TIN data base was generated from a custom 1 meter digital elevation model for a 2.2 km by 3.3 km live fire range at Twentynine Palms. This Range 400 data set and an adjacent Delta Corridor data have been incorporated as an iTIN in a larger 25 km x 25 km terrain data base.

Meteorological and oceanographic data for the Southwest United States was ingested by TAOS from diverse sources assembled by the Master Environmental Library. Navy Operational Regional Atmospheric Prediction System (NORAPS) provided regional atmospheric data, while data from WAM and STWAVE were primary sources for ocean and surf-zone data.

Southwest Asia

The requirements of the STOW ACTD required generation terrain data base for a large region in southwest Asia (see Figure 8). Due to the considerable spatial extent (more than 500 km x 700 km) and the requirement to support naval, air, amphibious, ground and special operations, the data base was developed in the Global Coordinate System (GCS) with rigorously modeling earth curvature and the geoid (Lind et al, 1997).

NIMA source data included Digital Terrain Elevation Data (DTED) Level 1 (3 arc second grid posts), Digital Bathymetric Data Base, Controlled Image Base (10 m resolution satellite imagery), numerous digital feature data sets, digitized maps and paper maps with scales as large as 1:12,500. Interim Terrain Data, which was derived photogrammetrically with high geometric accuracy, included a rich obstacle layer (fences, berms, trenches, etc.) which was particularly valuable. The DTED contained artificial undulations know as “cornrows” which are an artifact of the stereo compilation process. These cornrows dominated the landscape in areas of very low terrain relief. Algorithms were developed and applied to minimize these artifacts while preserving the general shape of the terrain.

A geographic information system (GIS) was used to process the digital feature data prior to integration into the triangulated irregular network (TIN). Features integrated into the TIN included ocean high and low water marks, sea walls and other near shore escarpments, cut-and-fill roadbeds, rivers, canals, moats and berms.

This terrain data base contains numerous innovations: the first native GCS data base; the first to contain river bathymetry; the first to contain multiple states for all cultural features; the first to attribute the terrain with color, infrared, soil type, soil wetness, and surface roughness; and the largest terrain data base ever built to support ground ma-

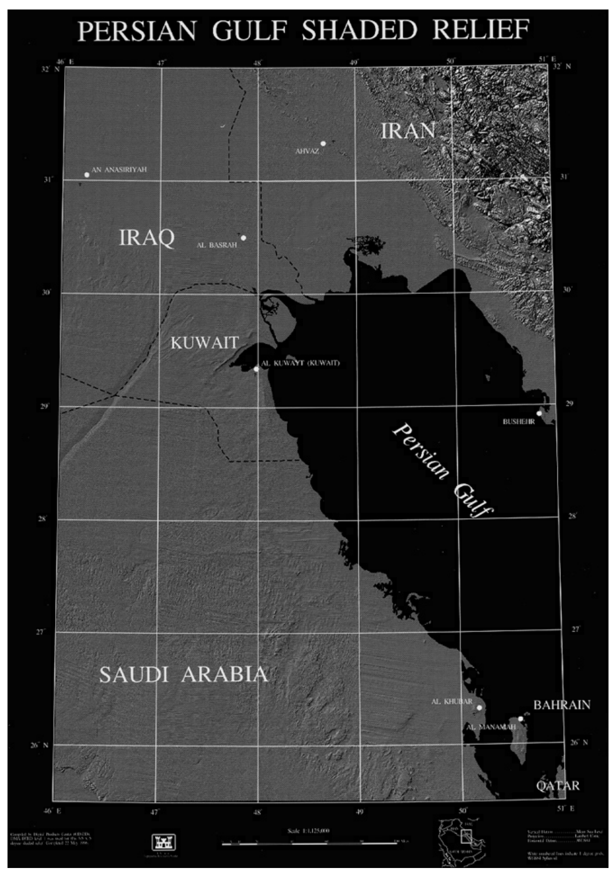
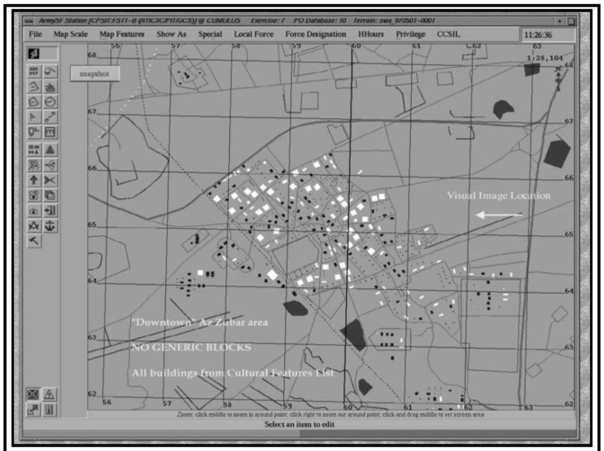
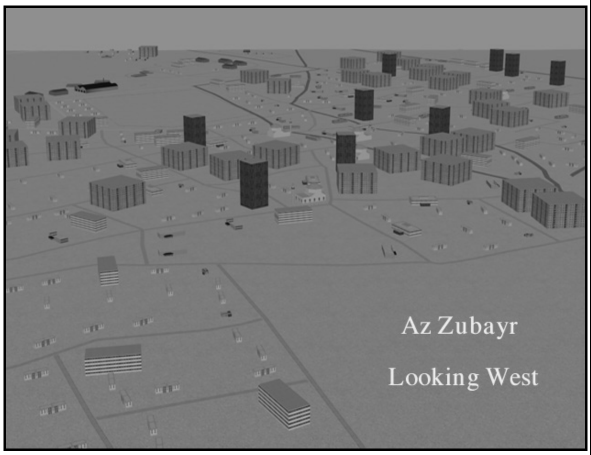


Figure 8. Southwest Asia terrain data base.



ModSAF map of special operations area



ModStealth view of special operations area

Figure 9. Special operations area at Az Zubayr.

neuver simulation. A ModSAF electronic map and ModStealth 3D view of the special operations area at Az Zubayr are shown in Figure 9.

To create an integrated meteorological and oceanographic environment for the south west Asia region, TAOS combined data from a variety of sources: mesoscale atmospheric data from the United Kingdom Meteorological Office; SWAFS ocean volumetric; XTide spectral tide model; and SWAPS and NSSM surf-zone data. Data from these models included 3D and 2D gridded volumes, uniform variables and spectral representations as appropriate for Synthetic Forces and ModStealth visualization. Atmospheric data was distributed at approximately 17 km spatial resolution at a one-hour update rate while surf and ocean data were distributed using a locally uniform model at a six-hour update rate.

CONCLUSIONS

The Synthetic Environments Program has developed revolutionary synthetic battlespaces of increased size, fidelity and complexity to support the spectrum of air, amphibious, ground, naval and special operations at the Joint Task Force level. A transformation strategy to generate environmental data bases for simulation from operational terrain, meteorological, oceanographic and bathymetric data was successfully conceived and executed. Dynamic processes for atmosphere, weather, obscurants, oceans and terrain have been adapted to represent and distribute tactically significant environmental changes within the computational and communications constraints of real-time, platform-level distributed simulation. In addition, new capabilities for dynamic terrain cratering have been developed, all with consistent run-time implementations in both Synthetic Forces and ModStealth.

Spatial representations can now support global applications with geodetic rigor. New functionality has been developed to support amphibious operations including near-shore bathymetry and to support individual combatants within high-resolution site models. Internally, 3D spatial topology has been developed to support multiple elevation surfaces including ocean surface and ocean floor, bridges, tunnels and multistory buildings.

Progress in incorporating dynamic environmental processes into the digital battlespace has been dramatic. Whereas the synthetic world of STOW-E was a static terrestrial stage that supported dynamic warfighters, the STOW 97 synthetic environment featured dynamic natural effects (e.g., time-of-day, wind, rain, fog, dust) as well as man-made environmental effects (e.g., smoke, flares, destroyed bridges and buildings).

Progress in dynamic terrain, one of the most difficult issues in distributed simulation, has been exceptional. All structures in the STOW 97 data base were destroyable. Dynamic cratering with real-time repolygonization in both the CTDB and the ModStealth visual data base was implemented in a generalized Dynamic Terrain Architecture. On-going efforts[1] build on this architecture to incorporate physics-based models from the Virtual Interactive Target (VIT) Program.

[1] with the Defense Special Weapons Agency (DSWA).