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Integration and Study of Chemical, Biological, Radiological, and Nuclear Plume Simulation in the Augmented REality Sandtable (ARES)

by Yasmina Raby, Christopher Markuck, Jeremy Sauer, Julian Abich IV, Morgan Eudy, Christopher Garneau, Nathan Vey, Charles Amburn

NOTICES

Disclaimers

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by Yasmina Raby
Computational and Information Sciences Directorate, ARL

Christopher Garneau
Human Research and Engineering Directorate, ARL

Nathan Vey, Charles Amburn
US Army Natick Soldier Research, Development and Engineering Center (NSRDEC)

Jeremy Sauer
National Center for Atmospheric Research (NCAR)

Julian Abich IV, Morgan Eudy
Quantum Improvements Consulting (QIC)

Christopher Markuck
Dignitas Technologies LLC

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14. ABSTRACT

This report discusses a project funded by the Defense Threat Reduction Agency to integrate the Augmented REality Sandtable (ARES) with the atmospheric transport and dispersion (AT&D) models developed by the National Center for Atmospheric Research for the purpose of generating realistic Chemical, Biological, Radiological, and Nuclear (CBRN) simulations on ARES. Additionally, the ARES team conducted an effectiveness study of ARES with the integrated AT&D simulation models for generating a CBRN plume on the sandtable modality of ARES.

15. SUBJECT TERMS

Augmented REality Sandtable, ARES, battlespace visualization, simulation and training, information visualization, multimodal interaction, human performance assessment, CBRN

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1. Introduction and Background

This project integrated the Augmented REality Sandtable (ARES) with the atmospheric transport and dispersion (AT&D) models developed by the National Center for Atmospheric Research (NCAR) for the purpose of generating Chemical, Biological, Radiological, and Nuclear (CBRN) simulations with realistic 3-D, terrain-aware, meteorology using modestly priced (non-supercomputer, non-networked) computing hardware resources at a performance rate suitable for training and operations applications. In addition to the technical requirements of initial development and customization of the AT&D models, and tight coupling of these models to ARES, an effectiveness analysis study was conducted to utilize qualitative and quantitative assessments to evaluate the benefit of this integration for CBRN defense training.

1.1 Augmented REality Sandtable (ARES)

ARES is a research and development testbed for investigating techniques in visualizing and interacting with complex battlespace information with the goal of providing a customized common operating picture (COP) at the point of need. ARES has been developed to have several modalities to visualize geospatial terrain information, which includes a physical sandtable augmented with commercial off-the-shelf (COTS) sensor and image projection technology, a mobile application for visualizing and interacting with the area of operations (AO), as well as head-mounted displays (HMDs) using augmented reality (AR) and virtual reality (VR).

1.2 Virtual Threat Response Emulation and Analysis Testbed

NCAR's Virtual Threat Response Emulation and Analysis Testbed (VTHREAT) utilizes AT&D models to generate realistic datasets and/or simulation capability for AT&D of chemical and biological agents. VTHREAT components coupled here include an ARES-customized version of the Weather Research and Forecasting[1,2] (WRF) model permitting passive scalar AT&D simulations for mesoscale domains (strategic perspective AOs between 10 and 1000 km) and NCAR's emerging GPU-accelerated Large Eddy Simulation (LES) model named "FastEddy" for microscale domains (tactical perspective AOs less than 100 km).

The WRF model was adjusted to target a simulation domain size of 50 to 200 km on the long side of the ARES table side, translating to a strategic-AO, mesoscale simulation capability of 1,200 km^2 to 20,000 km^2. The mesoscale simulation domain size and location, meteorological conditions, and time of day are exposed to the user as inputs directly through the ARES modality of choice. Depending on simulation domain size, a mesoscale simulation horizontal resolution between 0.5 km and 2 km will be automatically selected to ensure optimal performance on the modest hardware resources. One challenge was ensuring that the WRF model, which is typically executed in a high-performance computing (HPC) or supercomputing environment on thousands of CPU cores, could achieve robust and consistent performance on a much more restrictive 18 to 20 CPU cores, such that the simulation results would be streamed back to ARES at a rate commensurate with a training or operations experience. For the mesoscale range of domain sizes and corresponding resolutions above, this customized version of WRF is automatically configured on-the-fly to produce 3–6 simulated hours within a 30 to 60 min lesson plan or exercise window. Moreover, the first streamed results arrive as an ARES-projected image sequence within a few minutes. This initial delay is required to perform the automated configuration of simulation initial, boundary, and plume release conditions and a set of meteorology "spin-up" sequence procedures implemented specifically for the ARES-VTHREAT integration goals of this project.

The LES high-fidelity simulation capability integrated into the ARES-VTHREAT system, named FastEddy, is intended for smaller AOs (~100 km^2) that require higher fidelity in both space and time (~50–100 m horizontal resolution, and temporal evolution at timescales on the order of seconds) to achieve turbulence-resolving flow field simulation and resultant AT&D effects from the small-scale, scenario-specific, tactical perspective. Small-scale, scenario-specific effects include highly resolved topographic features (ingested automatically from ARES) leading to flow splitting around peaks, flow drainage into valleys, and atmospheric-stability-regime dependent near/far-field turbulent forcing effects on agent transport and dissipation.[3–5] The critical benefit of LES simulations for AT&D over traditional AT&D models is the removal of uncertainty associated with empirically derived parameterizations for these turbulence effects required by fast-running unresolved flow condition (nonLES, pseudo-steady-state, reduced sophistication) meteorology models. As stated above for the WRF mesoscale simulation capability, a substantial research and development challenge was the implementation of a performant WRF capability on modest hardware commensurate with training and exercise time constraints. For the microscale ARES-VTHREAT capability this, challenge is even greater due to the substantial and multifaceted increase in computational burden of high-fidelity LES simulations. To overcome this challenge, the FastEddy model was designed and implemented directly on graphics processing unit (GPU) hardware. The execution of FastEddy in a GPU-accelerated mode is accomplished by targeting a resident-GPU algorithm written directly in NVIDIA's CUDA language library. With this salient feature of the FastEddy model, LES simulations of sub-100-m resolution can be performed over tactical perspective AOs faster than real time on a single GPU, and within a wall clock timeframe appropriate for training and operations exercises. Without GPU-acceleration an LES simulation of the same specifications would require thousands of CPU cores.

As with the mesoscale modeling capability, there is an initial delay from initiating the plume simulation process to visualizing the plume on the table. This delay is again required to set the automated simulation initial, boundary, and plume release conditions, and to permit a meteorological spin-up phase where an initially laminar flow condition evolves into a turbulence-resolved flow field driving embedded constituent transport and dispersion. Ideally, a simulated hour of initialization leads to a more stable plume simulation, but can be reduced to a half hour to reduce initial wait-time. The LES model generates a half hour of simulation results in approximately 6.5 min of wall clock time.

These models are not part of the Joint Effects Model (JEM)/Joint Warning and Reporting Network (JWARN) system. The WRF and FastEddy-based CBRN simulations are fully integrated within ARES such that topography of a mapped area (as measured by the ARES camera using the user-shaped sand as a proxy to map terrain) is ingested into the simulations, directly affecting simulated plume transport and dispersion. Additionally, meteorological and source conditions including time-of-day dependent stability regime, configurable source location, and size are available as integrated user inputs through the ARES modality of choice.

1.3 Effectiveness Study

We performed an effectiveness study with the initial mesoscale integration of ARES and VTHREAT for the Maneuver Support Center of Excellence's (MSCoE) CBRN Captain's Career Course (CBRNC3) at Fort Leonard Wood, Missouri. In this study, a class was divided into a team that used ARES for their Tabletop Exercises (TTX) and a team that used traditional methods for the TTXs. These teams were compared using course assessments, knowledge acquisition tests, and self-reported questionnaires.

2. ARES–VTHREAT Integration

The ARES team and NCAR collaborated to integrate the VTHREAT simulation models using a service-oriented architecture (SOA). NCAR developed a Docker container-based platform named SimBox and Python-based model-view-controller (MVC) application programming interface (API) exposing the WRF and FastEddy simulation models, and automated configuration-launch-streaming services. The collaboration yielded a protocol for SimBox to communicate simulation information over ARES' messaging system (RabbitMQ). This protocol enabled SimBox to consume ARES' starting parameters and depth data as terrain data required to run the simulation, enabling the sandtable topography to be used as simulation terrain. SimBox uses the parameters and terrain to generate a simulation and that streams back results of embedded agent transport and dispersion as a sequence of images to be projected by ARES into the user modality environment.

Within ARES, a new service was developed to render a 2-D image from the plume concentration and velocity field information generated by SimBox. This image can then be consumed, allowing the plume to be projected on the sandtable. SimBox sends a series of binary results output frames to ARES and ARES converts output data to rendered image frames at an independently configured frame rate, displaying the images as an animation on the sandtable using a buffered rendering service that mitigates inconsistencies due to network latency or computation time.

To allow users to set up and display a plume, modifications to ARES' Tactical Planner Android application user interface (UI) were required. These modifications allow the user to set the starting parameters (plume release time-of-day and location, wind speed and direction, mass size, and simulation duration).

Once the user defines the simulation in the Tactical Planner application and starts the simulation, ARES captures the terrain information and sends this information and the starting parameters to SimBox. SimBox initializes a simulation 30 min to 1 h prior to the release time, allowing for flow field minimal development prior to the release time. When the simulation reaches release time, frames of the plume are sent to ARES and the 2-D plume simulation displays on the table and Tactical Planner application simultaneously. The colored contours indicate the concentration levels of agent species. The near-surface flow field is intuitively visualized by wind quivers ("arrows") showing the horizontal wind direction, and wind speed (arrow length), and indicate ascending (red arrows) or descending (blue arrows) air mass.

Consistent with other ARES modalities, the CBRN simulation can also be displayed in a 3-D grid of agent particle concentrations. This 3-D grid can be visualized in both AR and VR modalities, allowing users to see the height of the particles above the terrain (modeled in the sand).

2.1 ARES Integration Architecture

We integrated SimBox into the ARES SOA as a service, with minimal changes to the existing ARES infrastructure. We coordinated with NCAR to align the SimBox communication protocol with the ARES messaging system, allowing SimBox to consume terrain data already generated by existing services. Figure 1 shows the relevant services and communication channels supporting plume modeling.

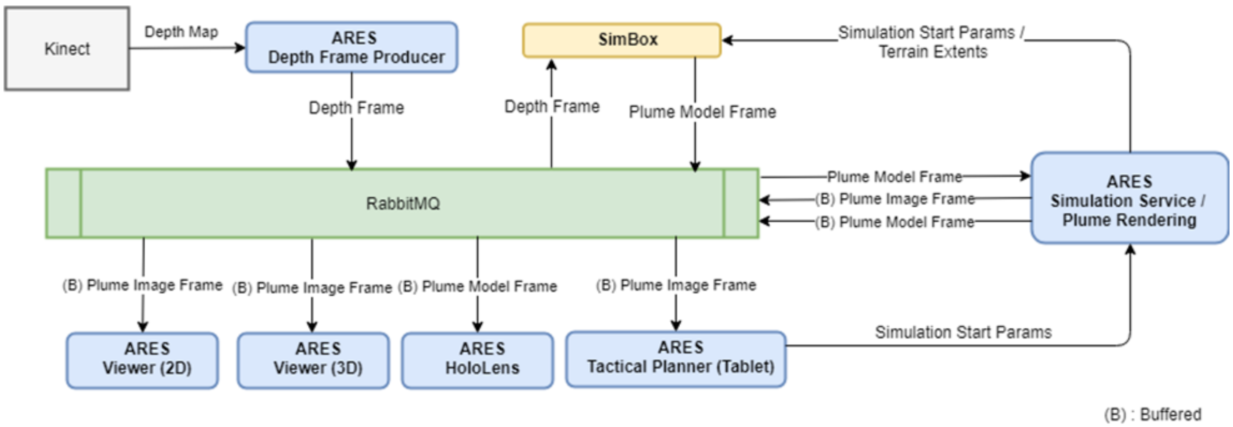

Fig. 1 SimBox integration with the ARES service-oriented architecture

As depicted in Fig. 1, the Kinect captures depth information from the sandtable topography. The ARES Depth Frame Producer service translates the depth data into a Depth Frame message and publishes it to RabbitMQ. The newly added SimBox service consumes these Depth Frames and produces a Plume Model Frame, representing the state of the CBRN plume at a given instant in time (see Table 1). We developed a new ARES service that renders a 2-D image from the Plume Model Frame and publishes the resultant Plume Image Frame to consumers. Many existing ARES services already have the capability to generically consume image frames from the message queue, which simplifies the process of consuming image frames from the plume simulation.

Table 1 Plume Model Frame message packet

Byte offset	Type	Byte count	Field name	Notes
0	Byte	1	Version	…
1	Integer	4	Nx	Number of elements x-dimension
5	Integer	4	Ny	Number of elements y-dimension
9	Integer	4	Nz	Number of elements z-dimension
13	Integer	4	Time stamp	Epoch time UTC
17	Byte array (float)	4*Nx*Ny*Nz	Plume concentration	3-D array of plume concentrations
17+4*Nx*Ny*Nz	Byte array (float)	4*Nx*Ny*Nz	Zonal velocity (U)	3-D array of wind velocities (m/s)
17+2*4*Nx*Ny*Nz	Byte array (float)	4*Nx*Ny*Nz	Meridional velocity (V)	3-D array of wind velocities (m/s)
17+3*4*Nx*Ny*Nz	Byte array (float)	4*Nx*Ny*Nz	Vertical velocity (W)	3-D array of wind velocities (m/s)

Figure 2 shows the ARES 2-D viewer, which is a consumer of image frames, projecting the simulated plume onto the sandtable modality. The generated image frame is composed of four parts: plume concentration, current simulation time, color bar showing the scale of concentration colors, and wind quivers showing wind direction and vertical velocity (blue/red = descending/ascending).

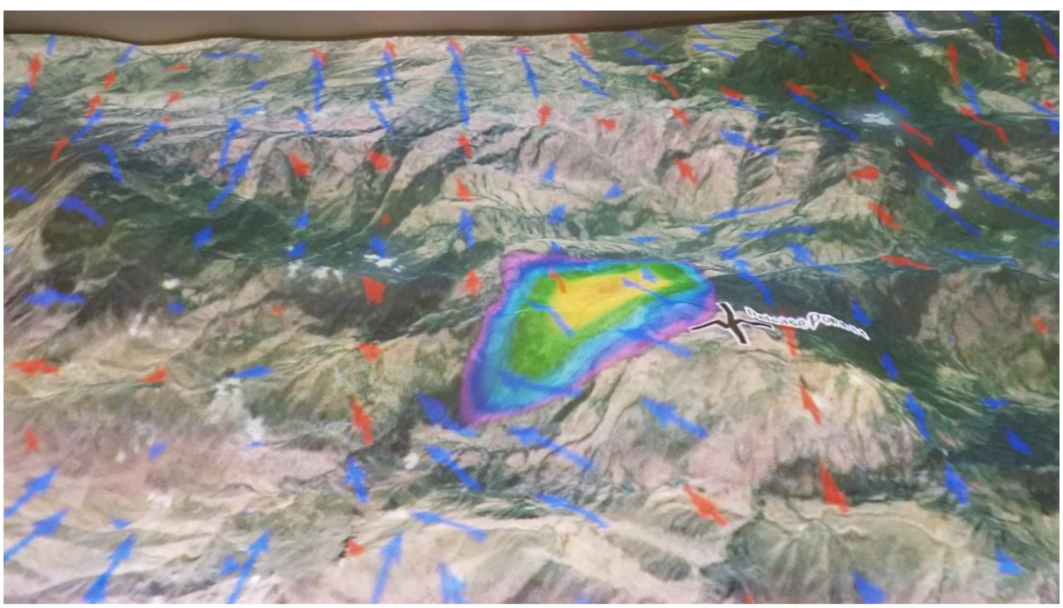

Fig. 2 CBRN plume projected onto the sandtable modality

We also implemented functionality to display the plume dispersion motion onto the sandtable modality. The ARES rendering service outputs image frames at a configured frame rate. All image frame consumers, such as the ARES 2-D viewer, use this data to form an image stream of the entire simulation. The frame rate used within ARES is independent of the SimBox frame rate for Plume Model Frames, as the rendering service implements buffering to mitigate the impact of network latency or spikes in model computation time, allowing for consumers (and ultimately, end-users) to receive a consistent image stream. Furthermore, the rendering service buffers and streams Plume Model Frames with their Image Frame counterparts. This allows consumers that require the raw Plume Model Frame (e.g., HoloLens, Mobile AR) to remain in-sync with image frame consumers.

2.1.1 Settings and Configuration

The new rendering service supports several configurations for the output image frames, as noted in Table 2. These configurations are stored on disk using the JavaScript Object Notation data format and may be modified dynamically (i.e., during a simulation) through a Representational State Transfer API. Figure 3 shows examples of the plume image with and without wind quivers enabled.

Table 2 Configuration parameters for plume images

Parameter	Type	Notes
plumeAlpha	Float	Plume transparency [0.0, 1.0]
showColorbar	Bool	Show colorbar legend
plumeColorbarLabelColor	Object {a: 0, r: 1.0, g: 0, b: 0}	ARGB floats for colorbar
showQuivers	Bool	Show wind quivers
quiverAlpha	Float	Quiver transparency [0.0, 1.0]

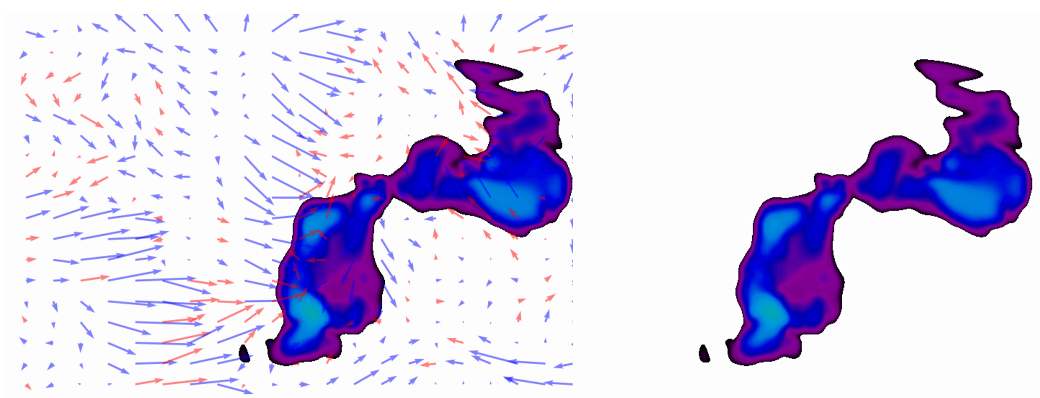

Fig. 3 Plume image with and without wind quivers

Additional plume configuration data are stored in another settings file but are not changeable dynamically. These configurations are read only when booting up the rendering service. Table 3 lists a sample of the settings provided.

Table 3 Plume service/render settings

Parameter	Type	Notes
Fps	Float	Number of frames per second
buffer_time	Int	Number of seconds of output to buffer prior to publishing
colormap	Class	Colormap for mapping plume concentration
quiver_colormap	Class	Colormap for mapping wind vertical velocity
colormap_normalization	String	"Logarithmic" or "linear" normalization for plume concentration
quiver_colormap_normalization	String	"Logarithmic" or "linear" normalization for quivers
quiver_subsample_x	Int	Scaling factor for subsampling wind quivers along x-dimension
quiver_subsample_y	Int	Scaling factor for subsampling wind quivers along y-dimension

2.1.2 User Interface (UI)

The Tactical Planner UI application allows end-users to start and stop a CBRN simulation from a tablet, as shown in Fig. 4. Users can add a release location on the map and specify the wind speed/direction, mass size, release time, and simulation duration before starting the simulation.

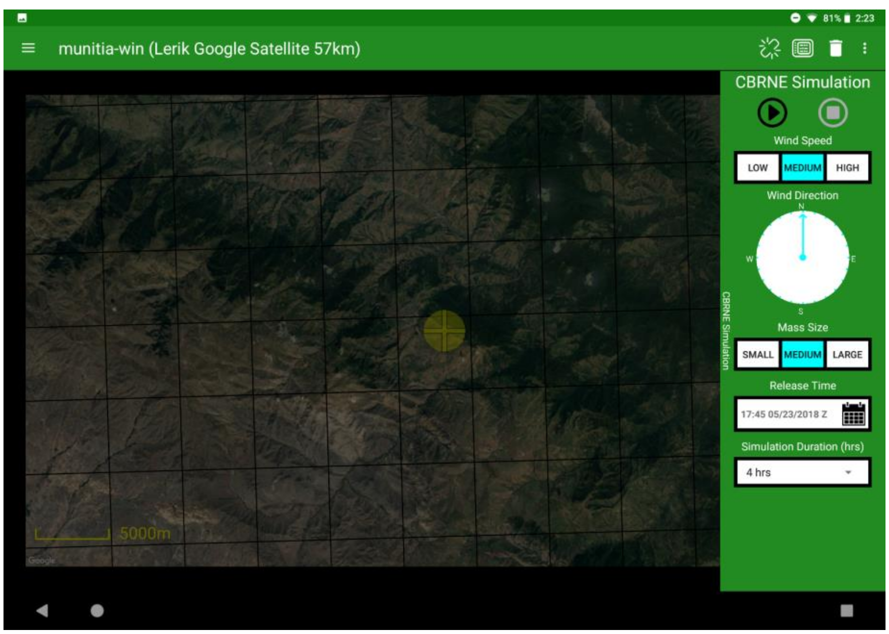

Fig. 4 Tactical planner UI for CBRN simulation

The simulation starts approximately one simulated hour prior to the release time to allow the weather simulation to stabilize. Once the simulation starts, users will see quivers depicting wind velocity and the current simulation time on the map. At the specified time of release, the plume will appear (see Fig. 5).

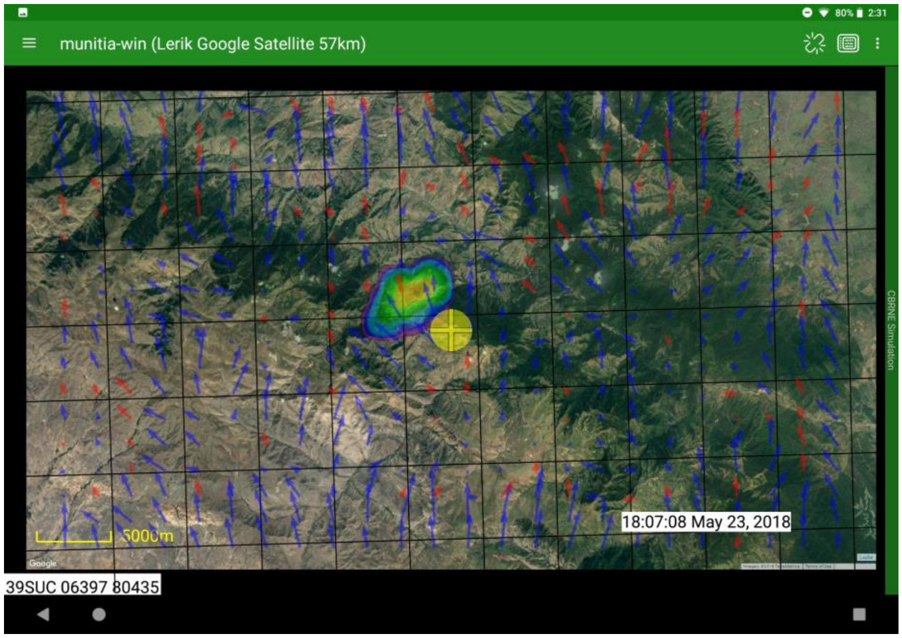

Fig. 5 CBRN simulation view on tactical planner UI, at time of release

Figure 6 shows the CBRN simulation synchronized across both the Tactical Planner UI and on the sandtable modality.

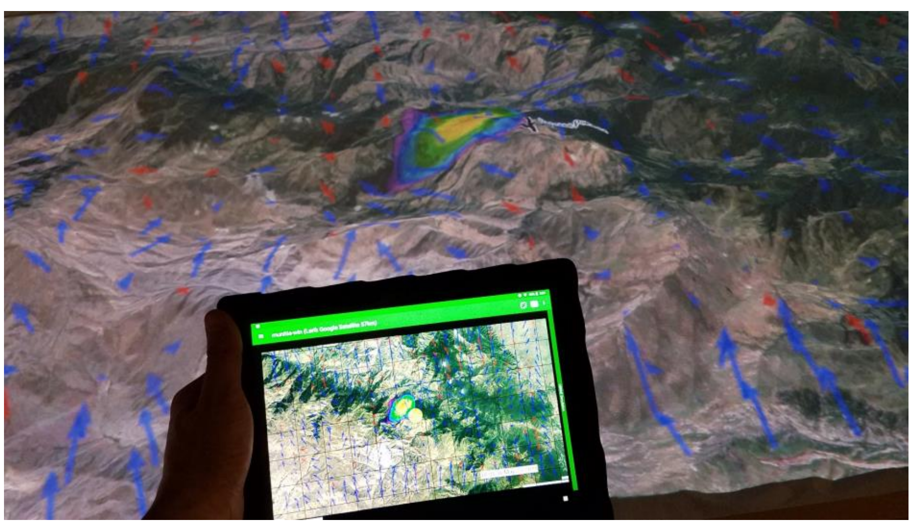

Fig. 6 CBRN simulation on the tactical planner UI and the sandtable modality

2.1.3 Augmented Reality

For viewing rendered 3-D visualizations of the CBRN simulation, ARES provides both a Microsoft HoloLens application and an Android AR application. Both applications construct a 3-D grid of emission positions from which plume particles originate, and particles are given velocity and coloring derived from plume concentration and wind speed data at the particle location. This velocity, along with fade-in/out transitions when particles are emitted/regenerated, gives the illusion of a moving plume. Figures 7 and 8 show examples of a 3-D plume rendered using the HoloLens and Android applications.

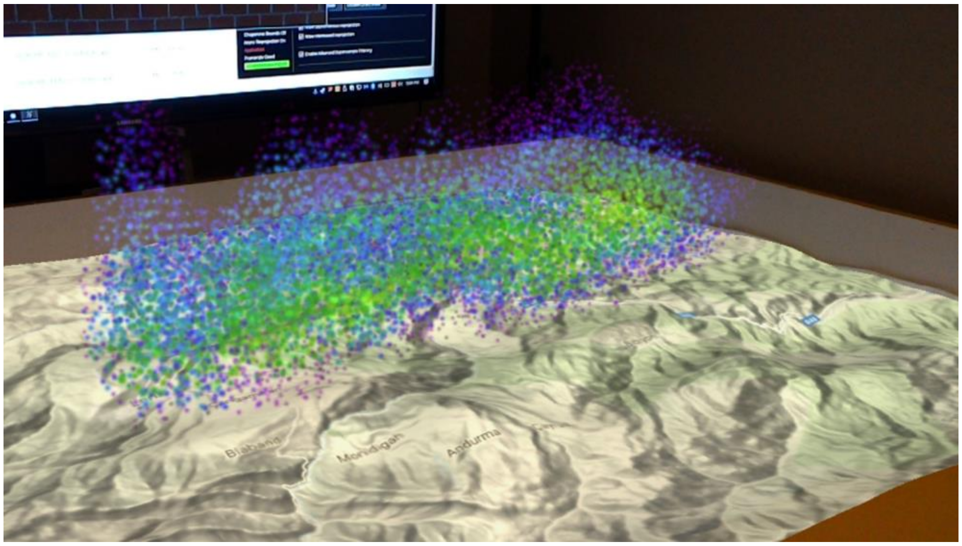

Fig. 7 Plume rendering viewed with AR HMD

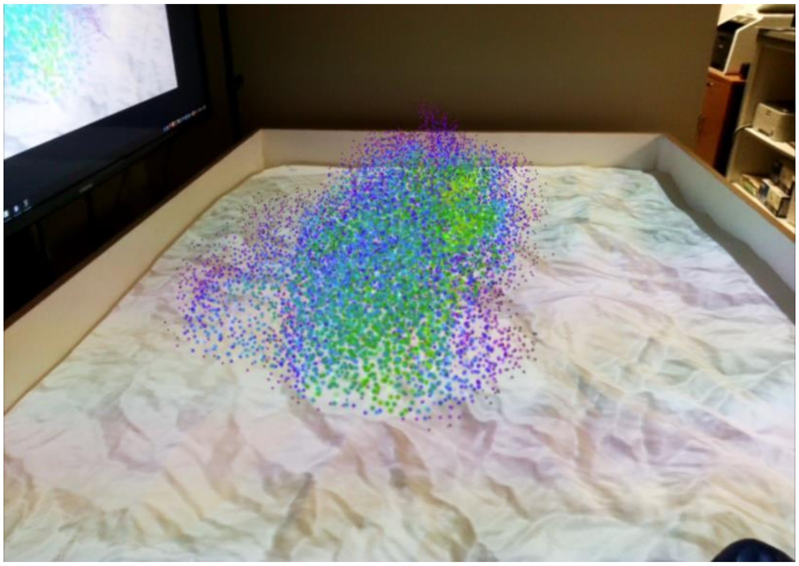

Fig. 8 Plume rendering viewed on Android tablet

The Android application renders the 3-D plume on top of the device's camera view (as shown in Fig. 8). When used in conjunction with an HTC Vive Tracker, the application can track the device position relative to the sandtable. Users of the Android application will see the correct orientation of the plume regardless of their physical position around the table.

2.2 Technical Challenges

During the integration phase, we encountered a significant issue with terrain steepness caused by the scaling of sand height based on the terrain scale. Using a fixed-size sandtable to represent arbitrarily large terrain, as is the case for the WRF plume model, the height of the sand becomes increasingly exaggerated relative to the area of the terrain (i.e., for a given height on the actual sandtable, the height of the virtual terrain increases with terrain size). This scaling makes it increasingly difficult to accurately portray the depth of larger terrain, and terrain that is too steep can be rejected by SimBox.

We addressed the issue by adding a "vertical exaggeration" slider to the ARES web interface, under Table > Settings > Terrain (see Fig. 9). This slider allows users to decrease the scaling value from table space to terrain space, causing the virtual terrain to be scaled down and thus reducing overall steepness.

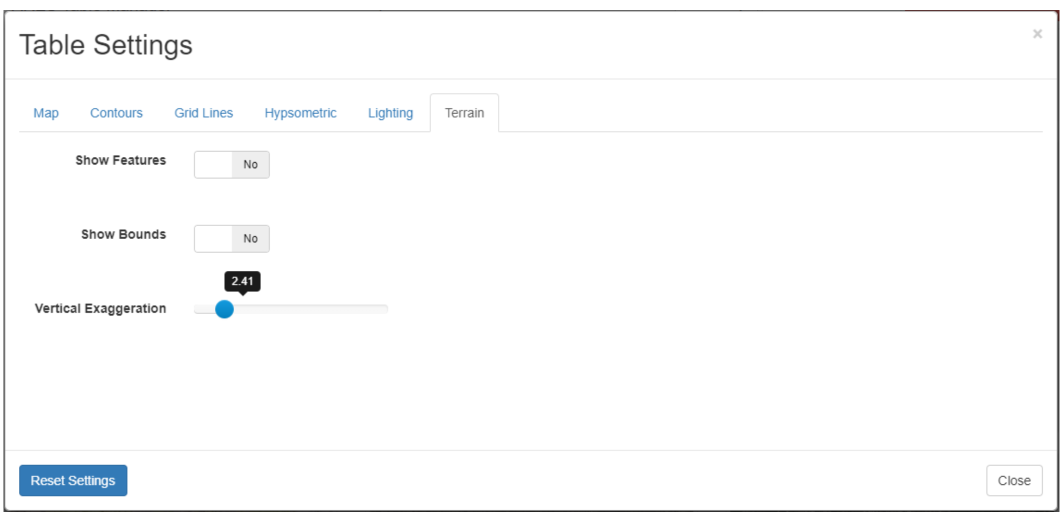

Fig. 9 Vertical exaggeration slider

3. Study of ARES and CBRN Simulation

3.1 Study Overview

We conducted an effectiveness study of ARES with the integrated AT&D simulation models for generating a CBRN plume on the sandtable modality of ARES.[6] This study was evaluated as an effective training tool for the CBRNC3 TTX where students are trained to use the military decision-making process (MDMP) and rapid decision-making and synchronization process (RDSP) to develop a course of action (COA) and operation plan to respond to a scenario involving potential CBRN use.

In this between-groups study, the students were split into two groups with 14 members each. One team accomplished course exercises using traditional methods (digital maps, worksheets, Microsoft Office products, and JEM/JWARN. The other team also had access to the traditional tools but replaced JEM/JWARN with ARES to complete their exercises (Fig. 10). Each team was asked to complete five questionnaires designed to elicit subjective and objective feedback. The following is a list of assessments and corresponding questionnaires used to evaluate the groups:

- MDMP/RDSP deliverables and briefs: instructor grading rubric
- MDMP/RDSP knowledge acquisition: Knowledge Assessment Questionnaire (administered before and after the TTX)
- Team collaboration: Team Diagnostic Survey (TDS)
- Self-efficacy: Self-efficacy Questionnaire
- Technology acceptance: Technology Acceptance Measure (TAM)

Fig. 10 Study participants using ARES

3.2 Study Results and Discussion

Two-sample *t*-tests were used to assess the effects of utilizing ARES on CBRNC3 MDMP/RDSP outputs, knowledge acquisition, team collaboration, and self-efficacy compared to a traditional approach. Bonferroni corrections were made to determine significant differences between the two groups ($\alpha = 0.0125$). Sample size for each analysis varied as some participants were not present on the first and last day of data collection, but the minimum was $n = 27$.

3.2.1 CBRNC3 Briefs Grading Rubric

Two-sample *t*-test found no significant difference between the traditional ($M = 4.33$, $SD = 0.68$) and ARES ($M = 4.50$, $SD = 0.75$) teams on accuracy scores, $t(60) = –0.094$, $p = .17$. Similarly, two-sample *t*-test found no significant difference between the traditional ($M = 4.57$, $SD = 0.69$) and ARES ($M = 4.63$, $SD = 0.77$) teams on support scores, $t(62) = –0.300$, $p = 0.17$.

3.2.2 Knowledge Assessment

Percent difference scores for pre- and post-knowledge assessments were calculated for each team and then a two-sample *t*-test was run. No significant differences were found between the traditional ($M = 21.6$, $SD = 6.62$) and ARES ($M = 20.6$, $SD = 8.71$) on percent difference knowledge scores, $t(23) = 0.407$, $p = 0.34$.

3.2.3 Team Diagnostic Survey (TDS)

Two-sample *t*-tests were run for all 13 subscales of the TDS. A significant difference was found between the traditional (M = 2.52, SD = 0.65) and ARES (M = 1.88, SD = 0.66) teams on ratings for Knowledge and Skill Related Process Criteria, $t(26) = 2.59$, $p = 0.008$. No other significant differences were found for all other subscales ($p > 0.0125$).

3.2.4 Self-Efficacy Questionnaire

Two-sample *t*-tests were run on all items of the self-efficacy questionnaire. A significant difference was found between the traditional (M =86.8, SD = 7.8) and ARES (M = 94.3, SD = 8.5) teams on ratings for how confident they felt their team could develop a COA, $t(26) = –2.43$, $p = 0.011$ (Fig. 11).

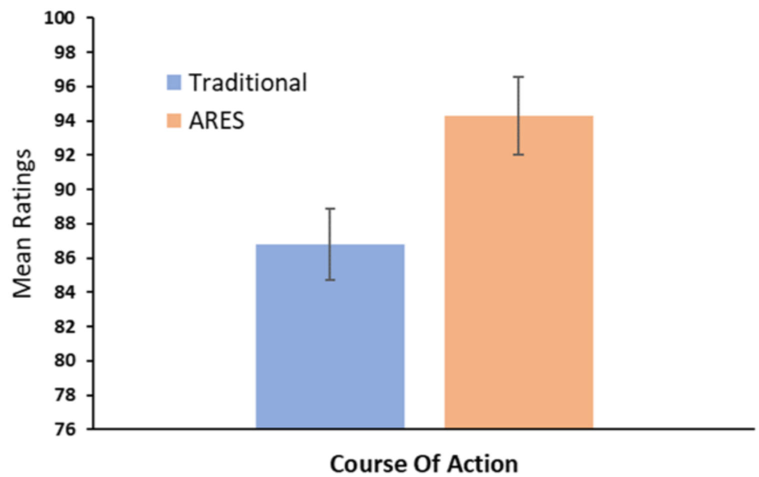

Fig. 11 Mean ratings for team self-efficacy regarding developing a COA

COA development requires extensive team communication and collaboration. Since the ARES team felt more confident in developing COAs as a team after utilizing the ARES platform, this suggests that the ARES platform facilitated a higher level of team communication and collaboration compared to the traditional team.

3.2.5 Technology Acceptance Measure (TAM)

This measure provides descriptive data and was focused specifically on ARES technology so only the ARES team completed this measure. The lowest rating was for elicited anxiety while using ARES (M = 3.4, SD = 0.7) and ranged to the highest rating, which was for perceived enjoyment while interacting with ARES (M = 4.9, SD = 1.1).

These results are important for two reasons. First, it demonstrates that new users with very little training were able to effectively employ the ARES system. Second, students who are less overwhelmed may have more cognitive resources available to allocate toward the acquisition of new knowledge, skills, and abilities, and thus, the system may positively impact performance outcomes.

3.2.6 After-Action Review (AAR)

An after-action review (AAR) following the TTX evaluation identified that the ARES team preferred using ARES over PowerPoint to create MDMP/RDSP output, citing that they were able to generate results more quickly and provide the same or better details for their briefings. Participants stated that they were impressed at being able to create all the COA overlays and evaluate the plume in the same system.

4. Conclusion and Future Work

This project successfully demonstrated that integration of two traditionally HPC-based multiscale AT&D simulation models with the modest computing hardware-constrained ARES platform created an engaging, interactive training tool for teaching the MDMP/RDSP for CBRN defense scenarios. As a technological achievement, this collaboration demonstrated the ability to utilize ARES' architecture to bring in complex simulation models and create a user-friendly product that trains students and provides them confidence in what they are learning. A quantitative assessment of the efficacy in retention, and understanding provided by time and space resolved, fully dynamic, numerical weather prediction (NWP) and LES-based AT&D simulation capability versus traditional, static, parameterized AT&D models, was not a part of the assessment study performed here. Consequently, no objective conclusion can be drawn as to whether the primary driver of higher mean COA self-efficacy ratings for ARES over traditional methods was due to the ARES system and user environment, the advanced AT&D modeling results provided under VTHREAT, or both.

4.1 Future Work from Study AAR

After discussions between the researchers (from NCAR and the US Army Research Laboratory) and instructors/students at MSCoE, these are some key recommendations for continued research and development.

4.1.1 Tablet Interface Characteristics

- Allow users to edit objects, including lines and polygons even after they have been saved
- Develop functionality to support various overlays on the same scenario that can be turned on/off, similar to layering option in photo processing software
- Improved file sharing between ARES and tablets
- Select and move multiple icons at a time, which provides better visualization during briefs

4.1.2 Map Functionality

- Rotate maps and view them at different orientations on the table
- Users are accustomed to viewing maps from multiple orientations and do not need to be constrained to only "North-up" orientations
- MGRS gridlines need to show the current scale; users prefer 1 km × 1 km grid squares

4.1.3 Chemical Agent Plume Simulation Recommendations

- Ability to pause, rewind, and speed up the plume simulation
- Need feedback to let user know the simulation is working/processing prior to its start
- Be able to enter specific coordinates to precisely define the plume location

4.1.4 Weather

- Include additional weather effects, such as temperature and humidity
- Allow wind direction to be entered precisely with numerical degrees

4.2 Feedback from MSCoE Instructors

4.2.1 Limitations Due to Throughput

The instructors at MSCoE felt they would like to use the ARES/CBRN integrated system as a part of their training, but would have to use it on a limited basis due to the number of students per class that can use a single table at one time. The ARES team has already begun testing a floor-projected version (Fig. 12) that could be a solution for this requirement.

Fig. 12 Floor projected modality in use at Ft Benning (June 2018)

4.2.2 Next Version Evaluation

Instructors wished to evaluate future versions of ARES that integrated some of the feedback recommended in the post-study AAR mentioned in Section 4.1. ARES has been updated to include the 3-D visualization of the plume simulation, which can be seen using AR and VR modalities (Fig. 13). This feature will be demonstrated for MSCoE and evaluated for further feedback.

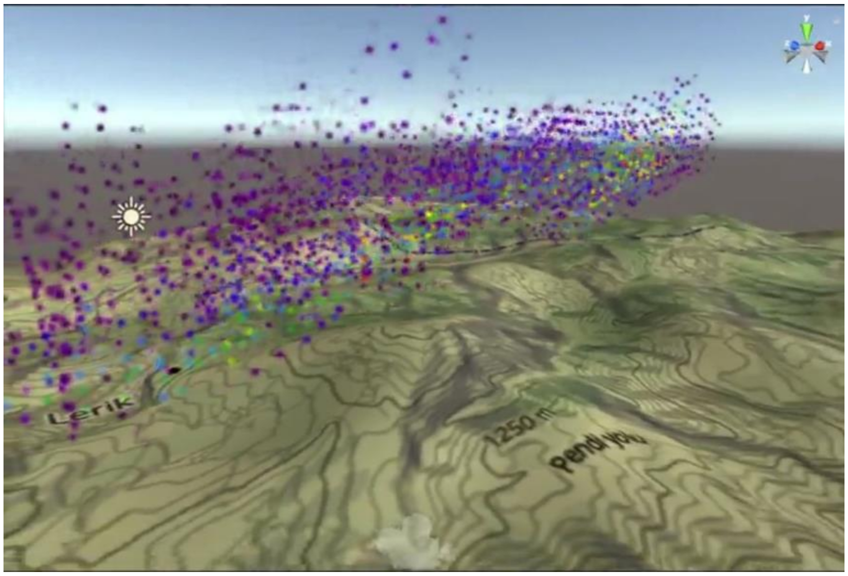

Fig. 13 3-D visualization in AR

ARES version 0.6.1 will be demonstrated for the CBRNC3 instructors, which will include a number of updates that may be of interest. The release notes for this update have been included in the Appendix section.

4.2.3 Certificate of Networthiness (CoN)

ARES is currently being developed and demonstrated in a standalone format disconnected from any Department of Defense (DOD) network. For ARES to be allowed on the Nonclassified Internet Protocol Router Network (NIPRNet) and other DOD networks, a CoN needs to be obtained. Obtaining a CoN would allow instructors to integrate it as a part of their regular training. The ARES team is currently working to obtain a CoN for the system.

4.2.4 Integration with Mission Command (MC) Systems

Instructors and ARES researchers concur that students should learn with tools that soldiers and leaders will have access to when they leave the schools and join their units. As such the ARES team would like to pursue ARES being adopted by an MC system and obtaining a CoN will be a requirement before ARES can be integrated.

There have been cases where ARES has already been used at sites as a command tool. In some scenarios, Live, Virtual and Constructive-Training Environment units are imported via the Distributed Interactive Simulation (DIS) standard adapter (e.g., One Semi-Automated Forces, Virtual Battlespace 3, Close Combat Tactical Trainer) and visualized in ARES. Additionally, units have used ARES itself to track scenario updates based on radio calls in the field.

Furthermore, Program Executive Office Simulation, Training, and Instrumentation PM MC has been in discussions with the ARES team to integrate ARES with the Simulation to Mission Command Interoperability and Mission Command Battle Lab. The Synthetic Training Environment Cross-Functional Team has also expressed interest in ARES for MC systems. The ARES team will continue to pursue these avenues for integration of ARES in MC systems.

4.2.5 Commonality with JEM

MSCoE instructors expressed that possible differences between the ARES CBRN simulation results and the JEM could present challenges to the instructors and students, as there are now two answers to the same problem. The ARES team believes that it is important to emphasize the different potential results based on different models, helping students to demonstrate and document, via technical report or publication and training media, the similarities and differences between the NCAR-developed models and JEM. NCAR has a journal publication in progress that will serve as the FastEddy model overview and technical specification. However, this is not an activity funded under this project, nor will it focus on commonality with JEM. A separate thread of funding resources and milestones efforts from any existing ARES efforts would be required to accomplish this comparison.

4.3 Future Work Recommendations from Researchers

4.3.1 Low/High Fidelity (Meso/Microscale) Coupling

As previously stated, the AT&D integration enabled ARES to use two separate models for different spatial requirements: the LES model is intended for small tactical-oriented AOs with high resolution details and the WRF-based model is intended for large AOs and less detail. As conceptually shown in Fig. 14,[5] coupling these two models together would provide a "telescopic" modeling product that enables one tool to provide both a) strategic and b) tactical perspectives in one application at the same time.

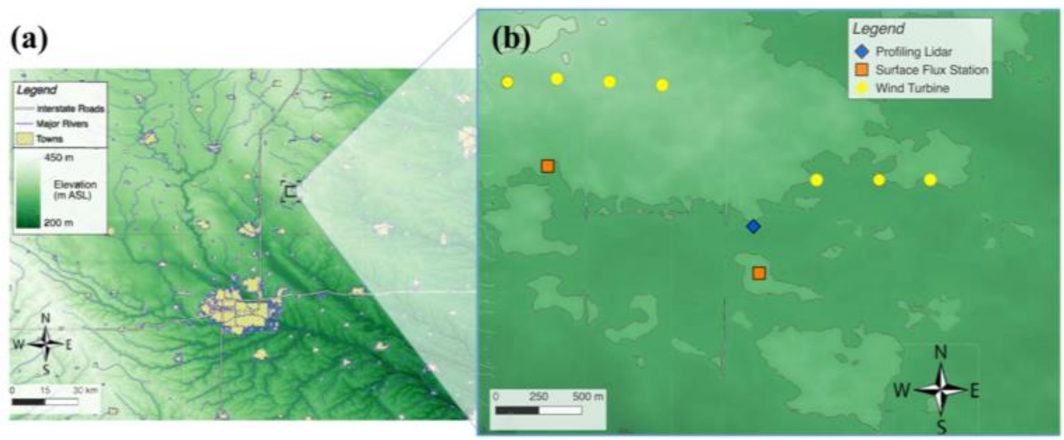

Fig. 14 Visualizing a larger scale map and transitioning to a smaller area for tactical operations

4.3.2 Urban Area Effects

Data from Geographic Information System (GIS) sources could be incorporated into the simulations, enabling far more detailed results. GIS data could add building height and footprint morphology as well as surface information (park/foliage, road/highway) to create detailed simulations that account for urban effects on CBRN transport. This extends the scenarios in which ARES could be used and provides intuitive visual representations of complex urban effects.

4.3.3 Chemical Downwind Message (CDM) Integration

The ARES interface could be enhanced to integrate CDMs (Fig. 15) as input, which could automatically be utilized as weather input parameters for the CBRN simulation. With CDMs, an existing meteorology reporting standard is incorporated and it is a format that users will be familiar with using.

Standard Format	USMTF Format
CDM	CDM
110500Z 110600Z I Corps WM 120010418742 XM 125019416742 YM 130005518642	MSGID/CDM// OBSTIME/110500Z// FCSTIME/110600ZMAR83// IIXAREA/I CORPS// FVALUE/WM/120/010/4/18/7/4/2// FVALUE/XM/125/019/4/16/7/4/2// FVALUE/YM/130/005/5/18/6/4/2//

Fig. 15 Example of chemical downwind message

4.3.4 Cloud-Based Simulation Service

Currently the simulation runs on a specially designed computer (SimBox), which costs about $10,000 per installation. If the simulation were instead deployed in the cloud, this cost would no longer be required. Instead, ARES would be able to connect to the CBRN simulation service through the ARES server. This could be deployed on existing DOD HPC, where NCAR is currently pursuing an official port of FastEddy to multiple GPU-accelerator devices for dramatically enhanced performance and simulation capacity. Additionally, all updates could be automatically deployed rather than requiring a locally administered update on each existing SimBox.

4.3.5 Complex Constituents (Agent-Specific Effects)

The current capability utilizes passive scalar tracers for plume constituent, which does not capture important effects of some agents. The simulation could be extended to account for dense gas (e.g., sarin or chlorine), for humidity effects on biological agent lifetimes, and for other non-passive constituent effects. This would increase the accuracy of the models for mission-specific scenario depictions and enhance training topics for agent-specific effects.

4.3.6 NATO CBRN Model Implementation and Comparison

To provide a standard operating procedure reference, the NATO standard formulations could be depicted alongside the model result (Fig. 16). This reduces the potential for human error in NATO-defined hot/warm/cold zone map calculations. Comparing the two models will demonstrate real-case considerations or departures from standard predictions.

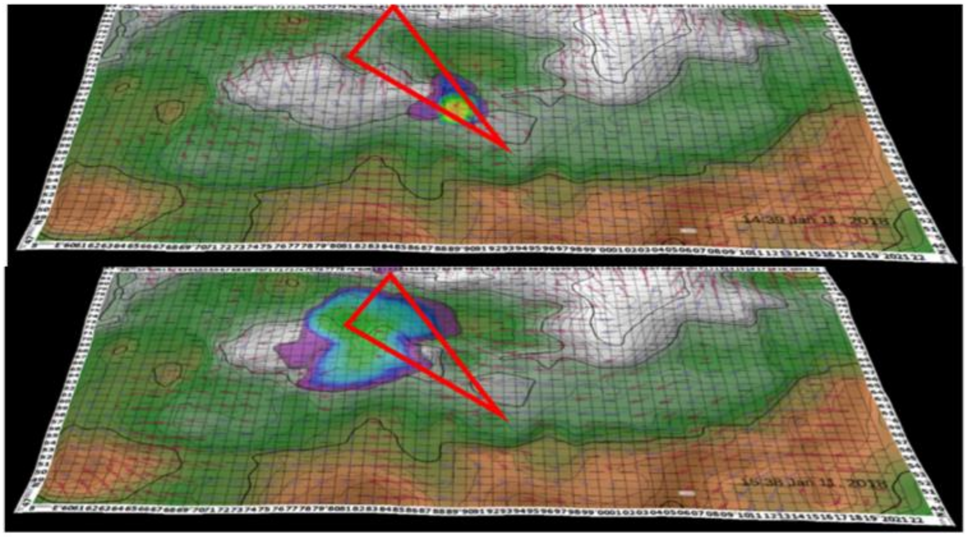

Fig. 16 NATO standard CBRN model depicted alongside model result

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Appendix. ARES Release Notes

Release Notes for ARES v 0.6.1

The Augmented REality Sandtable (ARES) version 0.6.1 will be demonstrated to instructors. While this version is still being tested for performance, most changes have been documented in the 0.6.1 release notes. These release notes may be subject to change depending on performance testing of the updates listed here.

- Export current sand configuration to a terrain format that can be used by other simulation systems
  - Supported export formats (GeoTIFF, OTF 8.6, LTF)
- Hololens table
  - Connect to a table and visualize ARES scenario using the HoloLens
  - Display terrain based on current sand configuration
  - Display 2525C symbology
    - ✓ Tactical symbols and graphics
  - Multipoint symbols
- Tactical planner updates
  - Enhanced UI for selecting 2525C tactical graphics
    - ✓ Symbol type filtering
    - ✓ Searching
    - ✓ Thumbnail selection
- Support for exporting scenarios created in ARES to Military Scenario Definition Language (MSDL)
- Support for creating hypsometric color profiles
- Distributed interactive simulation (DIS) performance improvements
- Beta features
  - First-person point of view (POV)
    - ✓ Use Vive controller for showing controlling first-person POV of the battlefield
  - ASCEND integration

- ✓ Using ASCEND to build terrains (LTF, OpenFlight, Unity, Cesium) for ARES to be utilized for LTF-based features and visualizations

- o Naval AR demo
  - ✓ Visualize mines and ships (2525C) on the table with water
- o Importing GeoPDFs as a source for ARES terrain creation tool
- o HoloLens table
  - ✓ Visualize terrain databases
  - ✓ Pipeline for generating Unity Asset Bundles from OpenFlight
- o Tactical planner updates
  - ✓ Offline mode
    - Create scenarios/terrains on the mobile tactical planner not connected to ARES table
- o ARES voice recognition prototype
  - ✓ Add/remove unit
  - ✓ Enable/disable functionality
    - Line of sight
    - Grid lines
    - Height labels
    - Contour lines
- o Server
  - ✓ Support for collaborating with remote tables via the ARES server
  - ✓ Video teleconferencing support for relaying video fees through the ARES server

- Avatar prototype without audio
- Mortar visualization
- Tactical planner updates (set location of tactical symbol, set altitude of symbol)
- Chemical, Biological, Radiological, and Nuclear
- Performance/stability fixes

List of Symbols, Abbreviations, and Acronyms

2-D	2-dimensional
3-D	3-dimensional
AAR	after-action review
AO	area of operations
API	application programming interface
AR	augmented reality
ARES	Augmented REality Sandtable
ARL	US Army Research Laboratory
AT&D	atmospheric transport and dispersion
CBRN	Chemical, Biological, Radiological, and Nuclear
CBRNC3	CBRN Captain's Career Course
CDM	chemical downwind message
CoN	certificate of networthiness
COP	common operating picture
COTS	commercial off-the-shelf
CPU	central processing unit
DIS	distributed interactive simulation
DOD	Department of Defense
DTRA	Defense Threat Reduction Agency
GIS	geographic information system
GPU	graphics processing unit
HMD	head-mounted display
HPC	high-performance computer
JEM	joint effects model
JWARN	Joint Warning and Reporting Network

LES	large eddy simulation
MC	mission command
MDMP	military decision-making process
MSCoE	Maneuver Support Center of Excellence
MVC	model-view-controller
NATO	North Atlantic Treaty Organization
NCAR	National Center for Atmospheric Research
NIPRNet	Nonclassified Internet Protocol Router Network
NWP	numerical weather prediction
POV	point of view
RDSP	rapid decision-making and synchronization process
SOA	service-oriented architecture
TAM	technology acceptance measure
TDS	team diagnostic survey
TTX	tabletop exercises
UI	user interface
VR	virtual reality
VTHREAT	virtual threat response emulation and analysis testbed
WRF	Weather Research and Forecasting

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