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8A.5 WES-2 BRIDGE: TRAINING AND SIMULATION CAPABILITIES FOR THE AWIPS-2 PLATFORM

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1. INTRODUCTION

In 2001, The NOAA/NWS' Warning Decision Training Branch (WDTB) in conjunction with the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) at the University of Oklahoma developed and released the first version of the Weather Event Simulator (WES-1; Magsig and Page 2002, 2003). WES-1 provided simulation and training capabilities for the Advanced Weather Interactive Processing System (AWIPS-1). Because of incompatibilities between the WES-1 design and various components of the service oriented architecture of AWIPS Migration (hereafter, AWIPS-2; Tuell 2008), the preservation of training capabilities after deployment of AWIPS-2 requires a complete redesign of the WES. After a brief survey of the history and design of WES-1, this paper documents the provision of initial training capabilities using the AWIPS-2 platform, plans for baseline training capabilities, and future directions.

2. WES-1

2.1 Brief History and Design Considerations

When the WSR-88D was fielded in the mid-1990s, the WSR-88D Operations Course provided initial radar applications training for forecasters. This residence course featured simulations which were implemented using a simple playback of radar data through a Radar Product Generator that fed forecaster workstations. When AWIPS-1 replaced the WSR-88D Principal User Processor as the radar workstation, WES-1 provided training capabilities at each forecast office, using archived AWIPS-1 data. These WES-1 capabilities were basic simulation and case review functions, which could be compared to sequential versus random data access, respectively. Because its initial application was to support training on warning operations during convective weather, only a subset of AWIPS-1 functionality was available in the WES-1. These functions included basic playback of radar and satellite imagery, surface and upper-air observations and model grids as well as the WarnGen application.

WES-1 basically consisted of a single standalone workstation that was based upon the standard AWIPS forecaster display ("LX") workstation augmented with additional disk space to enable local storage of data cases. Software included components from a standard AWIPS-1 build plus custom "data-pump" software. While an operational AWIPS distributed data processing, database, and display functions over multiple machines, the WES consolidated these functions plus the data pump to operate on a single, non-baseline workstation (Fig. 1).

As described by Magsig and Page (2002), the WES-1 data pump systematically renamed weather data files which effectively hid them from the AWIPS-1 D-2D display software. This data-hiding process worked only because D-2D recognized files that were named according to a "YYYYMMDD_HHMM" convention and ignored all others. The weather data files were in standard formats that D-2D could display (e.g., Level III radar data and network Common Data Format (netCDF) files for point, satellite, and gridded data). In other words, these data files were in a *processed* format as opposed to the *raw* data files (WMO bulletins) that arrive to AWIPS via its Satellite Broadcast Network (SBN). The use of processed files by WES-1 eliminated a significant data processing step, enabled random data access required for case review, and allowed for efficient initialization of a simulation. A critically important design consideration pushed as many time-intensive operations as possible to a pre-processing step to ensure the simulation would never fall behind. These time-intensive operations included cataloging and renaming the many thousands of data files which comprise a data case.

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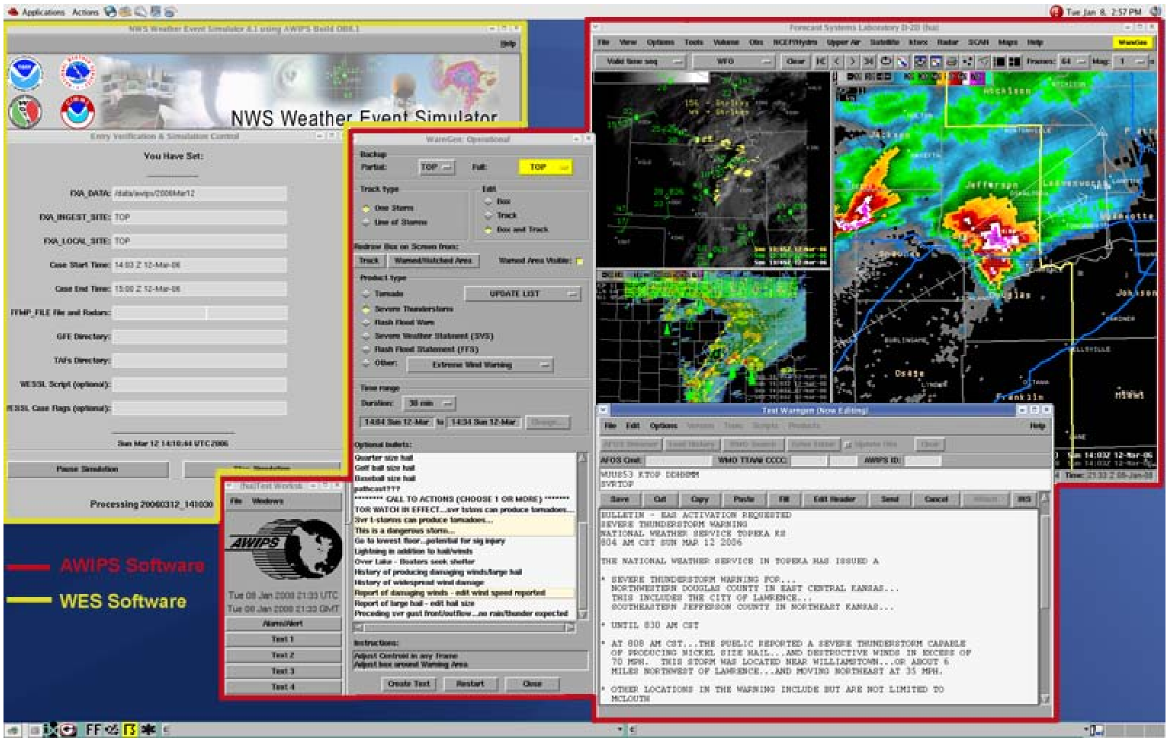

Figure 1. Illustration of AWIPS-1 and WES-1 software operating concurrently on a single simulator. AWIPS-1 components shown include the D-2D display, WarnGen software, and the text workstation. WES-1 components include the data pump and the text window.

Considered an "initial value problem", a "displaced real-time" simulation begins at its first time step with a full set of data. In other words, the initialized simulation is similar to forecaster sitting down at a workstation at the start of a shift, as the workstation is fully populated with a complete set of current and recent data to facilitate a comprehensive environmental threat assessment. If a simulation starts at 1700 UTC, the forecaster must be able to access loops of at least the past several hours of observational data plus model runs from at least 1200 UTC, if not 0000 UTC, depending upon the objectives of the simulation. To perform a simulation, WES-1 resets the system clock and as the system time advances, WES-1 pumps the data using a 15-second interval to AWIPS-1 by first creating symbolic links to the renamed weather data files and, secondly, by sending notification messages so that the display could refresh. WES-1 also accounts for normal observational and processing delays when revealing some data types, most notably radar data. For example, in real time, AWIPS refreshes its radar displays tilt-by-tilt as the radar sends new radar scans to AWIPS. However, AWIPS time stamps all radar files from one volume scan according to the beginning of the volume scan. To re-create the real-time tilt-by-tilt effect, WES-1 introduces delays which are a function of the radar volume scan pattern. WES-1 calculates these delays as part of its data pre-processing routines.

Because the WES-1 design hides and reveals processed files, a significant limitation results from the time granularity of these files. For example, AWIPS-1 creates most of its data files, with radar and satellite data being the most notable exceptions, using an hourly interval. Hence, surface observations that intrinsically have 5-minute or 15-minute time resolution are stored in hourly files; during a simulation, WES-1 reveals the entire hour's worth of data at once, rather than using the native time frequency of the data. To address this limitation, recent WES-1 builds chop and recombine some of the hourly surface files, but some simulations exhibit inconsistent results.

2.2 Current WES Applications

As additional warning-related AWIPS functionality was developed and as requirements for NWS Training Division courses evolved, so did the capabilities of WES-1 (Magsig 2004, Magsig *et al.* 2005). For example, in 2006, the WDTB developed a winter weather track for their Advanced Warning Operations Course. To support this course, WDTB incorporated the AWIPS Graphical Forecast

Editor (GFE) capability into WES-1 because these functions were necessary for the issuance of winter weather watch, warning and advisory products during a winter weather simulation. Other AWIPS capabilities incorporated into WES-1 after its initial release include the Four-Dimensional Stormcell Investigator (FSI), Flash Flood Monitoring and Prediction (FFMP), the Systems for Convection Analysis and Nowcasting (SCAN), the Aviation Forecast Preparation System (AvnFPS), and the ability to access archived text products with the AWIPS Text Workstation in addition to products *created* during a simulation.

In addition to displaced real-time simulation capabilities, WES-1 could operate in a case review mode. This mode allowed the forecaster to browse through a data case in a non-sequential manner. NWS training officers have regularly used this capability to refresh their staff on science concepts. Quick case reviews after severe weather events have facilitated event debriefings and highlighted areas for storm damage surveys. Case review also enabled forecasters to view AWIPS data for individual research projects long after the data had perished from their real-time AWIPS system. Owing to its operation on standalone workstations, the WES case review has facilitated collaboration of forecast offices with universities on research projects, where forecasters learn new "AWIPS-ready" analysis techniques and students gain operational perspectives. The NWS Training Division and its partners have leveraged both simulation and case review modes of WES as an important element of course development, specifically the application of science, technology, and some situation awareness concepts.

2.3 WES Scripting Language

WDTB also developed the WES Scripting Language (WESSL; Magsig 2004) to add fidelity and context to simulation development. WESSL provided a method whereby non-AWIPS data could be presented to forecasters during a simulation using a time-based script. These types of data have included spotter reports, telephone calls, video clips, and other multimedia content (Fig. 2). WESSL was developed with some sophistication; its ability to designate various events with difficulty flags meant that the same basic simulation script could be used for both novice and expert forecasters. For example, an expert forecaster could be forced to deal with additional distracters.

Additional WESSL functions included the ability to pause and resume the WES simulation, to execute a system command script, and to store student responses in a log. Simulation designers frequently have used the system command function to launch a web browser, which, in turn, presented students with briefing materials at the beginning, end, or midpoints of simulations.

3. WES-2 BRIDGE

One of the consequences of the advent of AWIPS-2 is the obsolescence of the WES-1 design, primarily because the data storage and data access paradigm for AWIPS-2 is much different than that of AWIPS-1. The resulting re-design of WES presents WDTB developers with an opportunity to address various shortcomings of the decade-old design of WES-1. Perhaps the most significant issue of WES-1 is resetting the system time each time a simulation is run and associated difficulties in achieving synchronization of simultaneous simulations. Other usability issues include a lack of case management functions and other user interface designs.

The NWS AWIPS Program Office has plans to incorporate training functionality in the AWIPS baseline (Tuell *et al.* 2009) Based on its experience base of building WES-1 outside the AWIPS software baseline, WDTB is currently compiling the technical requirements for the eventual baseline solution. Because this baseline solution (termed WES-2) will not be developed until after the deployment of AWIPS-2, WDTB also is developing an interim solution (termed WES-2 Bridge). In addition, the WES-2 Bridge design informs the requirements for the baseline solution. WDTB intends to synchronize WES-2 Bridge releases with AWIPS-2 builds. While both AWIPS-2 and the WES-2 Bridge are under development at the time of this writing, collaboration between WDTB and the AWIPS-2 developers results in a mature WES-2 Bridge design that is described below.

3.1 Design

As with WES-1, the WES-2 Bridge must encapsulate most of the AWIPS-2 functions on a single machine. These AWIPS-2 functions (shown in a simplified schematic in Fig. 3) require the database, rehosted applications, EDEX (Environmental Data Exchange) Server, CAVE (Common AWIPS Visualization Environment), and some type of storage. The original AWIPS-2 design specified the only data archive to be raw data, written directly by the Local Data Manager (LDM) client and the RadarServer to the raw archive. In addition to preserving AWIPS-1 database functions for hydrological applications and text products, the AWIPS-2 database manages a metadata record for each individual datum (which could be a single surface

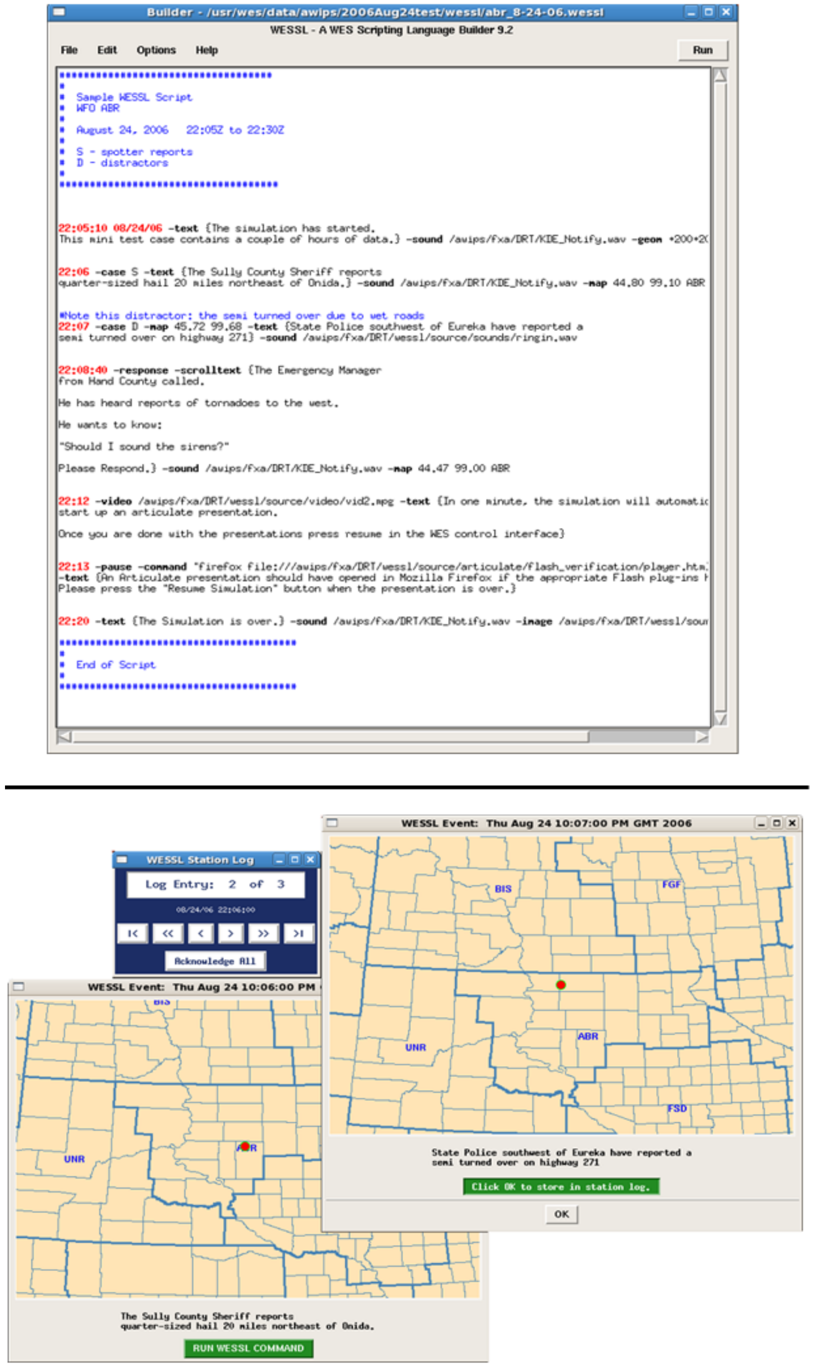

Figure 2. Illustration of the WES Scripting Language including a sample script (top) and the run-time display (bottom).

observation, radar product, satellite image, or model forecast grid). When CAVE attempts to create a data display, it asks the EDEX request server for a "catalog" database query to determine the current inventory of available data.

As new data are received by the either the LDM Client or RadarServer and are processed by AWIPS-2, a complex chain of events occurs. A detailed description of these events is beyond the scope of this paper. However, one of the final events in the chain is a message sent by EDEX over an Advanced Messaging Queuing Protocol (AMQP) topic. The CAVE display client listens to this topic and

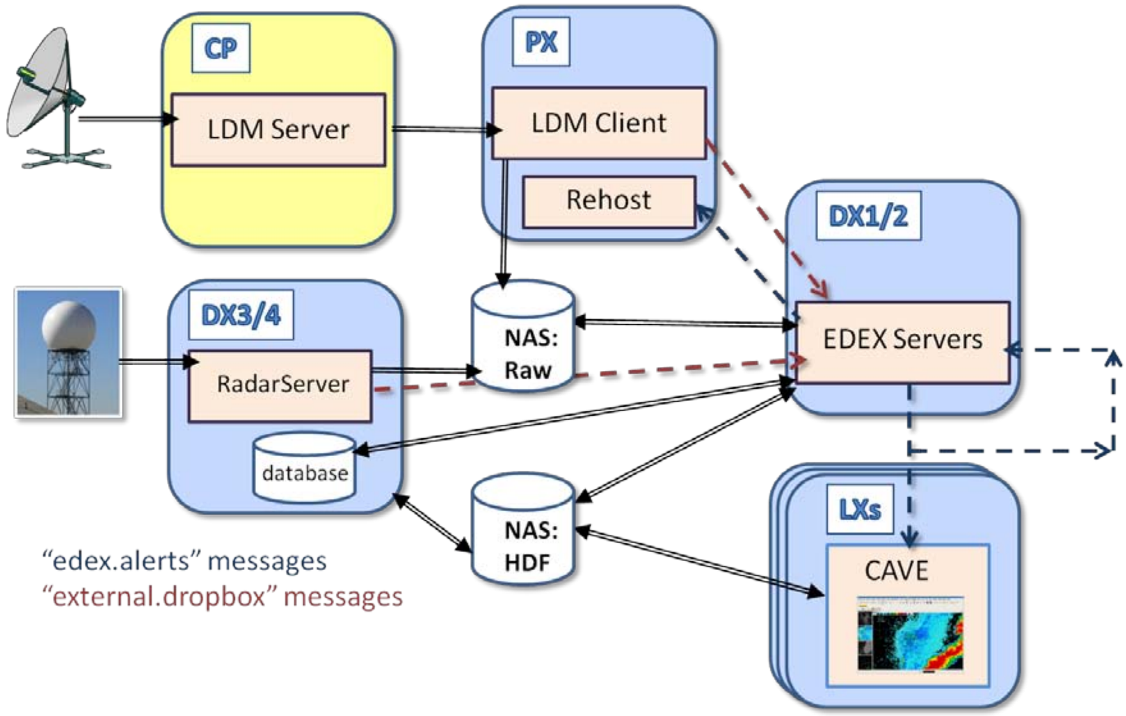

Figure 3. Simplified schematic of proposed organization of AWIPS-2 important for the development of training functionality. Double arrows indicate data flow; dashed lines indicate AMQP message paths.

refreshes its display with the new data when it sees a message that matches a product it has previously loaded. In addition, other downstream processes monitor this topic and execute when their required data arrives. For instance, the main SCAN processes run when certain radar products (*e.g.,* Storm Track Information, Composite Reflectivity, etc.) are received and processed by the system.

As stated earlier, a pragmatic requirement for efficient simulation and case review functions is to build a case with processed data. For its data repository, AWIPS-2 uses the Hierarchical Data Format (HDF) rather than the netCDF and native storage formats of radar data and "redbook" graphics used in AWIPS-1. In AWIPS-2, while all data have metadata records, the majority of data types also have corresponding storage locations in an HDF file; the few remaining types are stored completely within the database. Consequently, a correctly functioning AWIPS-2 system must maintain synchronization between its metadata database and its HDF data repository. However, data can be effectively "hidden" from the AWIPS-2 system if its metadata record is removed from the database, even though its processed data remains in the HDF repository. Alternatively, "future" data in a simulation can be hidden from AWIPS-2 if the catalog database queries incorporate the simulation time as a constraint. Thanks to collaboration between the WES-2 Bridge design team and the AWIPS-2 developers, this latter mechanism is leveraged to hide and reveal data at the appropriate times, while simultaneously streamlining WES-2 Bridge processing. The flip-side consequence of this design is that either metadata records that were inadvertently lost or somehow corrupted, or future design changes in the database structure, could render otherwise perfectly-decoded data unusable or irretrievable by the system. Hence, to ensure the integrity of the data case, the WES-2 Bridge design specifies archiving both raw and processed data so that the processed archive can be rebuilt if necessary.

The WES-2 Bridge design imposes additional constraints to define a "data case" that didn't exist in the WES-1 era. A WES-2 Bridge case must contain the following elements: hourly dumps of the AWIPS-2 metadata database records, corresponding hourly HDF files, localization/configuration files, and "case metadata" files to tie these elements together. The case metadata also forms the basis of the data management functions of WES-2 Bridge. To enable a case review, the WES-2 Bridge simply loads the database records into the database, and places the processed data repository and configuration files in the proper locations. To initialize a simulation, WES-2 Bridge performs these same functions, except that it manages the simulation time which hides the future data. As the simulation progresses, WES-2 Bridge simply sends a message at the appropriate time that the data are ready to be displayed. This message is identical to the message that EDEX normally sends when data have just been processed in a real AWIPS-2 system. Hence, the WES-2 Bridge essentially performs a detour around the ingest, decoding, and storage functions of AWIPS-2 and allows all other AWIPS-2 functions to progress normally. Posting individual database records also has the advantage of revealing a portion of a processed data file, rather than the entire file as did WES-1. The AWIPS-2 metadata records also contain a database insert time which accounts for observational and processing delays of each datum. If raw data have to be reprocessed at a later time, then WES-2 Bridge modifies the insert time with an appropriate value.

The AWIPS-2 architecture features a plug-in concept that allows the system to be easily extended. In fact, most of the data decoder and display functions in AWIPS-2 are implemented using plug-ins. Along with a custom "wes.time" AMQP topic to provide a 15-second heartbeat, WDTB has developed a WES plug-in to enable communications between the external WES-2 Bridge routines and CAVE (Figs. 4 and 5). This plug-in sets various configuration parameters in CAVE and manages the CAVE clock without having to re-set the system time. This design also makes multiple synchronized clients possible (described below).

Besides the obsolescence of the WES-1 design, the move to AWIPS-2 also renders the existing archives of AWIPS-1 data useless. WDTB alone has produced upwards of 50 nationally-distributed simulations for existing training courses; hundreds, if not thousands, of other cases are used for local WFO training and research. Hence, as part of the WES-2 Bridge software, a case converter has been developed to re-process as much AWIPS-1 data into AWIPS-2 processed data formats as possible. Because the AWIPS-1 storage processes have discarded some of the information that forms the basis of AWIPS-2 metadata, a complete 100% conversion may not be possible. Nevertheless, allowing all past data to pass into obscurity is undesirable and requiring all current simulations to be redeveloped with new cases is not practical.

3.2 WESSL-2

Because of the complete re-design of WES-2 Bridge, WESSL also required substantive improvements. WESSL-1 was written in Tcl/Tk and required simulation developers to know a set of commands and syntax to create a simulation script. Developed in Python, WESSL-2 uses a tabular graphical interface to construct the script (Fig. 6a) and diminishes the possibility of errors generated by typographical mistakes. Events to occur at prescribed times are chosen from pull-down menus. These events include reports, sounds, videos, presentations, and system commands. The script itself is stored in a database table.

To operate, WESSL-2 listens to the same AMQP "wes.time" topic that WES-2 Bridge implemented for its heartbeat. WESSL-2 queries its database for events that match the current time as broadcast over the wes.time topic, and simply executes those events. To pause or resume a simulation, WESSL-2 also broadcasts a message on an AMQP topic; WES-2 Bridge listens for the message and reacts accordingly. For display of spotter reports, WESSL-2 queries the GIS-enabled AWIPS-2 maps database for the exact same geographical overlays that CAVE uses to render its maps. Thus, WESSL-2 draws maps of the reports (Fig. 6b) on-the-fly that match a similar geographical context already familiar to the user. For future releases of WESSL-2, WDTB plans to exploit other GIS functions including automated evaluation of user-generated warning polygons.

3.3 Implementation

As was the case with WES-1, the WES-2 Bridge will be implemented in NWS forecast offices using a non-baseline machine that is based on a standard forecaster display workstation. This workstation was procured in late 2010 to support AWIPS-2 display requirements. The existing WES-1 workstation will be retained until each forecast office migrates to WES-2 Bridge. After the migration, the WES-1 workstation may be converted to a "WES-2 Bridge Lite" workstation which can be used to offload time-consuming re-processing of raw data. The WES-2 Bridge Lite may also be utilized for future collaborative simulations (described in Section 5).

Experience with AWIPS-2 pre-release builds has indicated a typical AWIPS-2 data case may require significantly more disk space than a corresponding AWIPS-1 case. Thus far, AWIPS-2 has not uniformly applied optional compression across all data types for real-time performance reasons. Even so, larger AWIPS-2 data cases coupled with ever-increasing data volumes (e.g., GOES-R and dual-polarization upgrades to the WSR-88D) requires significantly larger data storage capabilities for WES-2 Bridge than WES-1. Accordingly, the WES-2 Bridge workstation includes two 1.5 TB internal hard drives for

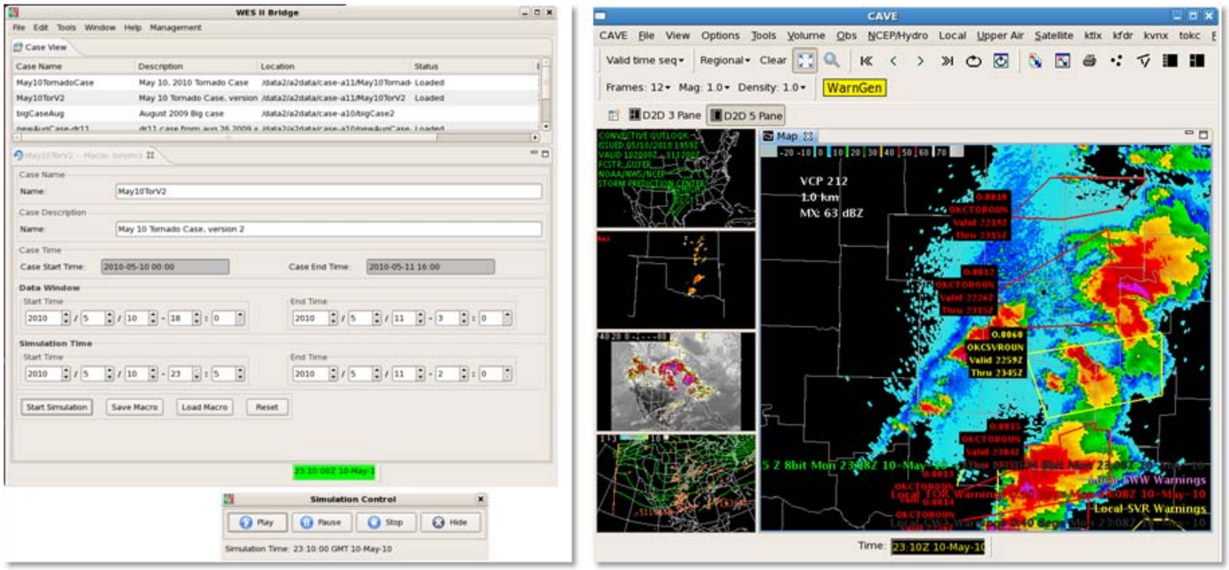

Figure 4. Example of a prototype WES-2 Bridge simulation with a data management window and simulation control (left) and corresponding CAVE display (right).

case storage, a Blu-Ray read/write DVD drive for offline case storage and sharing, and a port for a 1 TB eSATA external hard drive for transferring data between the AWIPS archiver and the WES-2 Bridge.

In the past, WDTB distributed WES-1 to non-NWS university users on a per-request basis. WDTB intends to follow a similar practice for WES-2 Bridge until the baseline WES-2 solution is complete. Details regarding any redistribution of AWIPS-2 software still need to be worked out. However, the AWIPS Program Office has stated the desire to engage research partners such as universities by allowing the distribution of AWIPS-2 via organizations like Unidata (Unidata 2010a,b).

4. BASELINE WES-2

As mentioned previously, the NWS AWIPS Program Office is planning on funding the development of WES-like functionality in the AWIPS baseline as part of their AWIPS-2 Extended project (the baseline WES-2). While WDTB is currently compiling detailed technical requirements, the baseline WES-2 will provide robust training capabilities inherent in the AWIPS-2 software. Moreover, the training functionality will become part of the design of new applications from their inception rather than the current situation of trying to design training capabilities after the applications were essentially already developed. The current approach sometimes results in inefficient designs when attempting to incorporate the applications in case review and simulations.

Though the baseline WES-2 will provide intrinsic training functions with standard AWIPS software and hardware, NWS forecast offices likely will still install the WES-2 on one or more workstations external to their live AWIPS. This configuration allows maximum flexibility and essentially prevents accidental dissemination of forecast

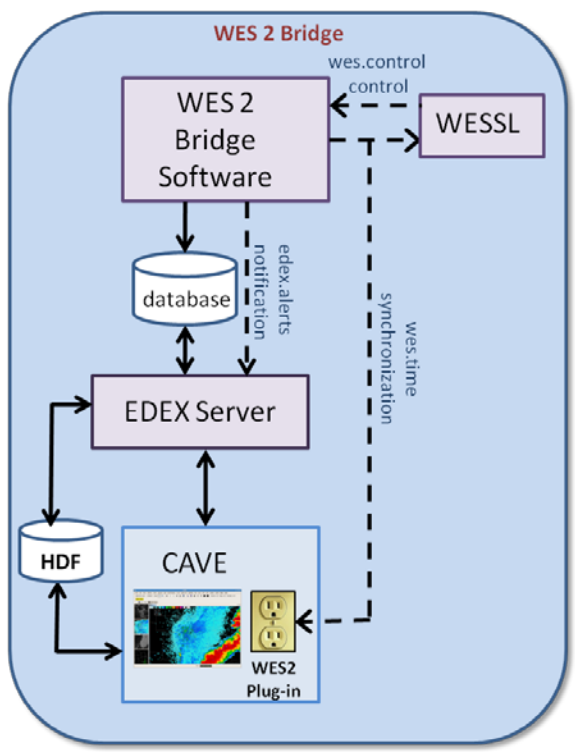

Figure 5. Schematic of WES-2 Bridge interactions with AWIPS-2 components.

and warning products generated during simulations. The technical requirements for the baseline WES-2 may also include the ability to reconfigure regular forecaster workstations as offline simulation clients on benign weather days.

An additional benefit of a baseline WES-2 solution is that it allows WDTB to focus on developing more robust and integrated training, evaluation and assessment tools in WESSL-2. These tools could include methods to measure forecaster situation awareness, short training vignettes or job-aids available on-demand from within AWIPS applications, and the ability to compare forecaster solutions of a simulation with one or more "expert" solutions. In addition, WDTB and its partners may be able to develop and facilitate more robust multi-player simulations, described below.

Another advantage of baseline WES-2 functionality accrues to the NWS AWIPS Program itself. Much more sophisticated and context-specific testing of future AWIPS software components can be achieved prior to field deployment than is currently possible. The final beneficiary would be individual forecast offices which should receive a better software product.

5. FUTURE DIRECTIONS

One of the advantages of the WES was that it allowed forecasters to "train as they fight" (that is, they train in an operationally representative environment). However, the vast majority of simulations are *isolated*, meaning that only one forecaster at a time participates in a simulation,

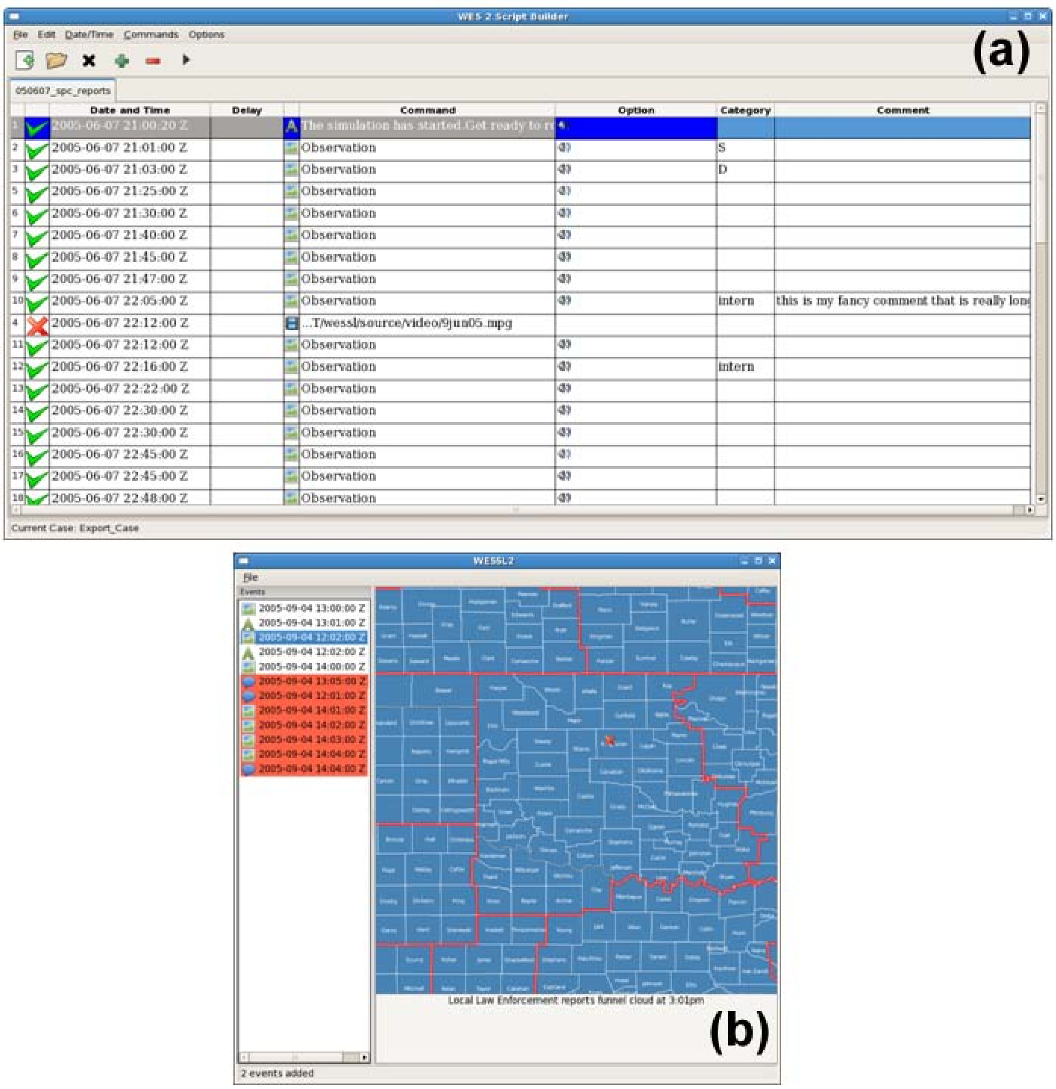

Figure 6. A sample WESSL-2 script (a) and associated map display for a storm report (b).

partly due to difficulties in easily synchronizing multiple WES-1 workstations. Nevertheless, the forecast and warning problem in the U.S. is inherently a distributed and collaborative decision-making process with multiple forecasters and integrated warning team partners like broadcasters and emergency managers contributing to the final warning products and associated public response (Mileti and Sorenson 1990, Doswell *et al.* 1999).

Recent analysis by WDTB of NWS service assessments as well as root cause analyses submitted by every NWS forecaster has revealed that most shortcomings in the warning process are related to human factors as opposed to scientific deficiencies (for example, incomplete understanding of natural processes) and technological failures (hardware or software; Liz Quoetone, pers. comm.). Many of these human factors relate to various teamwork and leadership issues such as communication, collaboration, and coordination. These issues can occur both internal to a forecast office as well as with external partners. While numerous training programs can and should be developed to address these shortcomings, the only way to practice new skills and refine existing skills *in context* of the actual problem is to work through exercises and drills using a distributed and collaborative simulation system. Experience with adult learning has shown that it is highly contextual (Knowles *et al.* 1998). Therefore, WDTB has developed a strategic vision for a distributed simulation system (Fig. 7).

This distributed system would leverage the baseline training functionality. Because AWIPS-2 Extended also includes the integration of N-AWIPS and CHPS for national centers and river forecast centers, respectively (Tuell *et al.* 2009) a distributed simulation concept would also include end-to-end exercises for the first time. Through eventual Thin Client and Collaboration capabilities that arise through the AWIPS-2 Extended project, it may be possible to include some customers and partners in these exercises as well. These distributed exercises could be classified as intraoffice (multiple forecasters in a single office), interoffice (neighboring forecast offices with national and regional centers), and interagency (a forecast office with its core partners). Routine exercises of these types will help forecasters to maintain expertise, improve communications skills, and refine proficiency in decision support. In addition, these drills can also serve to expose any problems that can be corrected prior to actual events, similar to preparedness exercises that emergency managers regularly conduct.

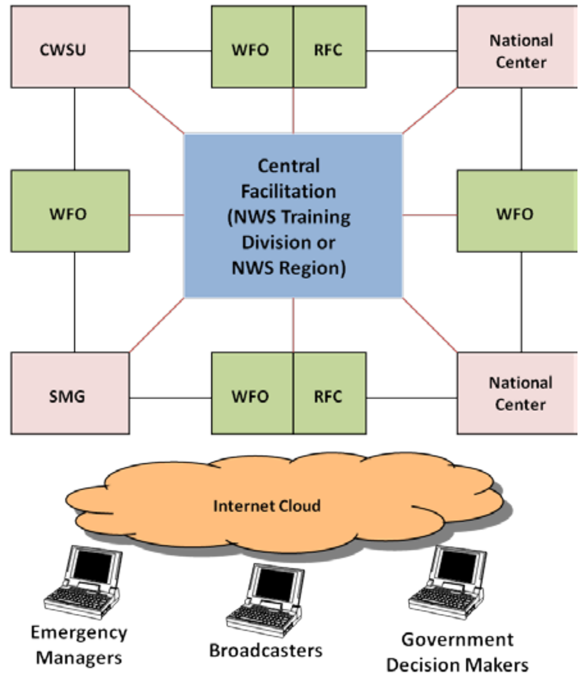

Figure 4. Illustration of distributed and collaborative simulation concept**.**

While details of the distributed simulation system still require some definition, preliminary testing based on an early design (Fig. 8) of synchronized WES-2 Bridge clients was successful. This testing leveraged the heartbeat broadcast by WES-2 Bridge by clients on separate machines; all CAVE displays simultaneously refreshed when new data was made available by the simulator.

6. SUMMARY

Along with a history of simulation capabilities in the NWS, a number of design considerations for simulation and case review functions are presented. Important design factors include a standalone workstation with significant storage capacity, clock management, use of processed data files, sequential and random data access for simulation and case browsing, simulations fully initialized with recent data, revealing of data according to its native time frequency after accounting for normal observational and processing delays, and presenting non-AWIPS data using a time-based script. The concept of an eventual baseline WES-2 and interim WES-2 Bridge solutions are discussed. WDTB is addressing these design constraints in the WES-2 Bridge as a prototype for the eventual baseline WES-2. In particular, the WES-2 Bridge exploits several key features of the AWIPS-2 architecture including its metadata database and AMQP communications systems. Several benefits arise from a baseline WES-2 including better testing of AWIPS-2 itself,

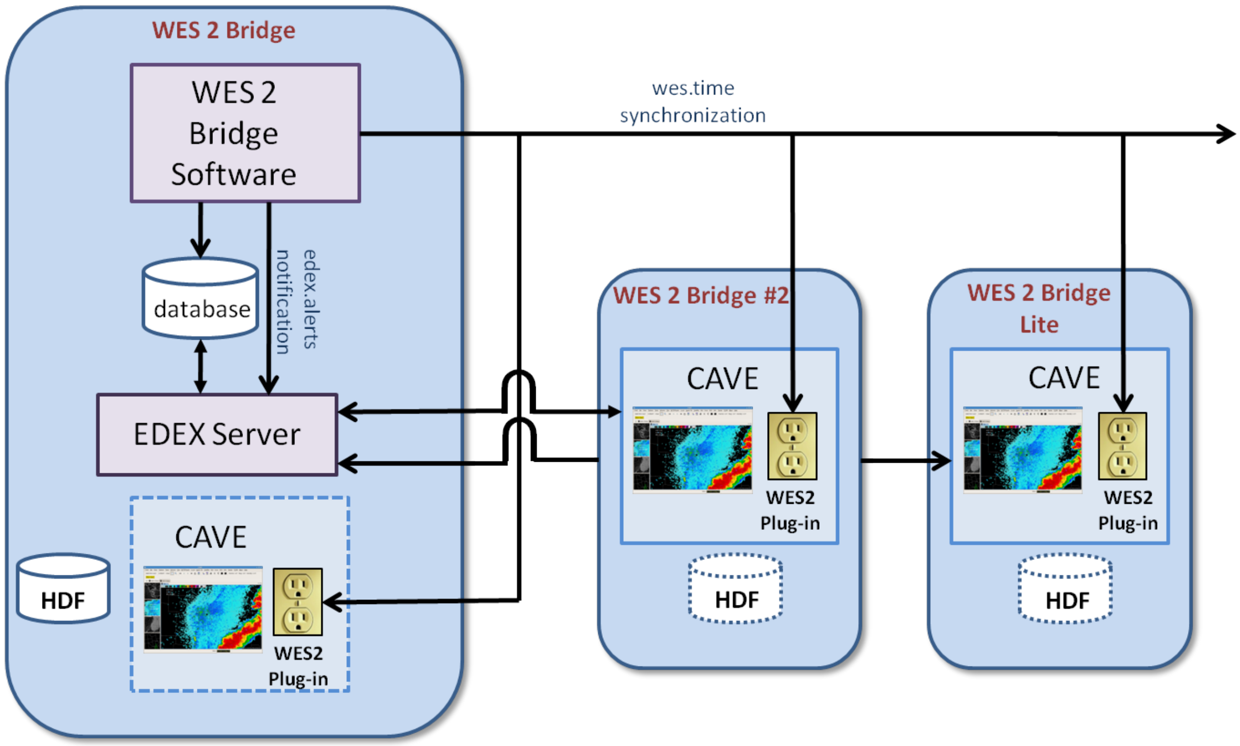

Figure 8. Preliminary design of synchronization of distributed WES-2 Bridge simulation clients.

training functionality across the software enterprise, and development of advanced training and assessment tools. Finally, a brief rationale and vision for a future distributed and collaborative simulation system is presented; the system would help reveal, address, and correct deficiencies in communication, collaboration and coordination. This collaborative simulation system would engage local forecast offices with their stakeholders, including their local partners and decision makers, as well as their colleagues in regional and national centers.

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