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# Local-Rapid Evaluation of Atmospheric Conditions (L-REAC) System: Design and Development – Volume 6 (Original vs LR-x System Comparison)

by Gail Vaucher, Whitney Hicklin, and Marcus Mitchell

## NOTICES

### Disclaimers

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# Local-Rapid Evaluation of Atmospheric Conditions (L-REAC) System: Design and Development – Volume 6 (Original vs LR-x System Comparison)

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**14. ABSTRACT**

Protecting civilian and military personnel caught in airborne hazard scenarios is the underlying purpose of the two systems examined in this report: the Local-Rapid Evaluation of Atmospheric Conditions (L-REAC) System, invented by the US Army Combat Capabilities Development Command Army Research Laboratory, and the LR-x, the evolving Diamond B Technology Solutions (DBTS) equivalent. The systems' provision of timely and relevant wind and plume fields was key to this L-REAC vs LR-x Systems Comparison Study. Calibrating the DBTS product against the original technology was the objective of this study. Two neutral reviewers were introduced to the systems and asked to glean qualitative and quantitative comparison data. System subject matter experts were available for guidance and clarification. The final qualitative comparison showed that the evaluated present-day systems have a slightly higher percentage of features that are the “same” or “equivalent” than “different”. The quantitative comparison focused on the meteorological data used as wind and plume model input, which in turn produces end user displays for first responders. The presumption was that a model is only as good as the data ingested. The quantitative comparison found good agreement between all but two variables. The LR-x pressure variable consistently reported a sea-level magnitude. An analysis suggested that the mismatch may be a function of the test site’s security-required location-identification function blockage. The second irregularity was the diametrically different wind directions acquired by the systems during locally severe weather conditions. After review, it was determined that were the LR-x incident-specific measured weather capabilities included in the test (vs model only), this latter anomaly would not have been observed.

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## Executive Summary

Protecting civilian and military personnel caught in airborne hazard scenarios is the motivating goal of the two systems examined in this report: the Local-Rapid Evaluation of Atmospheric Conditions System, invented by the US Army Combat Capabilities Development Command Army Research Laboratory (ARL), and the LR-x, the evolving Diamond B Technology Solutions (DBTS) equivalent. This study, prompted by a Cooperative Research and Development Agreement, sought to calibrate the current DBTS product against the original ARL technology.

Two neutral reviewers*, having no background in either system, were invited to ARL to learn and extract qualitative and quantitative data from both systems that would be used in a comparison study. While executing the task, subject matter experts from both systems were made available to the reviewers and informed of their findings. Iterative clarifications assisted in this time-constrained assessment.

The qualitative comparison was organized into five general categories common to both systems—namely, Published Purpose, Intended Users, Design-General, Design-Modules, and Documentation. These sections were further subdivided into descriptive attributes. Each subjective feature was evaluated using a four-tiered assessment: Tier 1 represented attributes that were the "same", Tier 2 denoted attributes that were "different", Tier 3 signified "equivalent" attributes, and Tier 4 noted attributes that were "other". The net results of the qualitative comparison showed that the current systems' purposes, intended users, design, and documentation had a slightly higher percentage of features that were the same or equivalent (52%) than different (44%). The only attribute given a Tier 4 "other" rating was the wind model output. The comparison data describing this feature included attributes that were the same (both systems had a 50-m resolution wind model output), different (three model resolution outputs were available on just one system), and equivalent (wind model output displays had similar attributes). Consequently, the wind model output was given a Tier 4 rating.

The quantitative comparison focused on the atmospheric data used as input to both the wind and plume models, which in turn produce an end user display for the emergency first responder. The foundational premise for this approach was that a model is only as good as the data ingested. Thus, assessing the quality of these parameters would reveal any potential systematic strengths and/or weakness between technologies. The quantitative comparison acquired data over four periods of time, labelling the Cases A–D. The results found good agreement between all

* An added benefit of using neutral reviewers was the accumulation of candid observations and lessons learned. This feedback has been included in the Discussion (Section 4). Post-study recommendations from the reviewers have also been noted in Appendix A.

but two meteorological variables. The LR-x pressure variable consistently reported magnitudes one would expect near sea level, though the test sites were over 4000 ft above sea level. The post-test analysis suggested that the test site's security-required blockage of the automated LR-x system-location identifier may have contributed to this mismatch of values. The second irregularity observed was the wind directions acquired during the severe weather event of Case D. The average wind direction difference for Case D was 185°. This disparity implied a need for localized measured weather parameters. While not a part of this comparison study, the LR-x has an automated, incident-specific, measured atmospheric data capability that can be used in their cloud-based product.[1] Post-study review resolved that this latter disparity would not have been observed using the fully-integrated measure and model resourced, LR-x system.

Note: Shortly after the comparison study was completed, DBTS announced the implementation of IBM's The Weather Company data as a standard weather service for their modeled results.[2]

[1] [DBTS] Diamond B Technology Solutions. Diamond B Technology Solutions, LLC (LR-x®) announces strategic reseller agreement with Coastal Environmental Systems [press release]; 2018 Sep 10 [accessed 2019 Sep 20]. http://diamondbts.com/wp-content/uploads/2018/09/DBTS-LR-x-and-Coastal-Environmental-Systems-9.12.18.pdf.

[2] [DBTS] Diamond B Technology Solutions. Diamond B Technology Solutions, LLC (LR-x®) signs agreement with IBM/The Weather Company [press release]; 2019 Sep 6 [accessed 2019 Sep 20]. http://diamondbts.com/wp-content/uploads/2019/09/DBTS-Signs-Agreement-with-IBM_The-Weather-Company.pdf.

## 1. Introduction

Airborne hazards are one of many threats that the military faces. During episodes where such conditions are present, situational awareness is paramount. Critical to the survival of an airborne hazard event is knowing where safe zones are located. In an open atmospheric environment, safe zones can be dynamic. This challenge is remedied only with timely and perpetually current atmospheric intelligence.

The US Army Combat Capabilities Development Command (CCDC) Army Research Laboratory (ARL) invented the Local-Rapid Evaluation of Atmospheric Conditions (or L-REAC*) system to aid Soldiers and civilians facing toxic environments. This system advanced from a technology readiness level (TRL) 1 through TRL 7, and was patented in 2012. As part of a technology transfer program, ARL partnered with Techlink, who presented the system to the civilian market. Diamond B Technology Solutions (DBTS) subsequently requested and was approved for an exclusive patent license agreement.

The ARL design was then communicated to DBTS, who quickly applied their expertise in designing their own version of the L-REAC that would exploit contemporary technologies. Their system is called the LR-x†.

In October 2018, the LR-x had reached a TRL where it could be directly compared with the L-REAC. DBTS was also pursuing a certification status with the Department of Homeland Security under provisions of the Support Anti-Terrorism by Fostering Effective Technologies Act. Calibrating their product against the original L-REAC technology would provide technical feedback to these independent certification evaluators. Thus, the comparison task was initiated.

### 1.1 Long-Term Vision

ARL's vision for the L-REAC is to provide timely and relevant atmospheric intelligence to civilian and/or Soldiers addressing airborne hazards. ARL has also envisioned multiple and diverse civilian and military applications for the technology. As the L-REAC research and operational user's database expanded, the environments and circumstances to which the technology was and could service also increased. This opportunity for growth was transferred and encouraged to those advancing the technology into a format distributable to various "first" responders.

In the following sections, both the ARL-standard (L-REAC) and the DBTS-produced (LR-x) airborne hazard decision aid technologies are described. Note that

* L-REAC is a registered trademark of the US Department of the Army, Washington, DC 20310.
† LR-x is a registered trademark of Diamond B Technology Solutions.

the latter system continues to make advances; consequently, the DBTS system compared was the July 2019 model-only LR-x design.

## 1.2 L-REAC System

The L-REAC system was invented by Ms Gail Vaucher, and co-invented by Mr Robert Brice, Mr Saba A Lucas, and Dr Sean O' Brien. The proof of concept was created in 2009 (Vaucher et al. 2009), followed by a prototype in 2010 (Vaucher et al. 2010), and an operational version in 2011 (Vaucher et al. 2011), which serviced the White Sands Missile Range (WSMR) area from 2011 to 2019. As mentioned earlier, the purpose of the L-REAC system was to improve the Soldier and civilian situational awareness by providing near-real-time measured and modeled atmospheric intelligence that supports the assessment of airborne hazardous environments. The end result would help first responders make more informed decisions regarding 1) whether to Shelter in Place or evacuate, 2) how best to escape the toxins, and 3) the determination of risk mitigation factors.

The L-REAC system has five core modules: the Sensor Module, Model Module, End User Display (EUD) Module, Quality Control Module, and the Archive Module. Each is described below:

- The Sensor Module uses five sensors (barometer, thermometer, hygrometer, anemometer, and pyranometer) to quantitatively characterize real time atmospheric conditions. Using an animated anemometer, such as the Wind Monitor that is installed at ARL/WSMR, enables persons within viewing distance of the L-REAC Sensor Module to visually discern upwind (safe zone) from downwind (hazardous zone), even if the system is denied electricity.

- The Model Module receives raw meteorological data from the Sensor Module and automatically creates a 3-D modeled wind field over a given area of interest. If characterizing information is available regarding an airborne hazard, the sensor input is automatically ingested and processed by a plume model.

  The ARL-developed Three Dimensional Wind Field (3DWF) model is used in the Model Module. Its diagnostic capability coupled with a continuously updated sensor input results in timely and relevant wind field output.

  The Aerial Location of Hazardous Atmospheres Model (ALOHA) plume model that is used in the Model Module was developed by the National Oceanic and Atmospheric Association (NOAA)/ Environmental Protection Agency (EPA). The operator manually enters the known chemical characteristics into the software. This model was selected based on emergency first responder feedback.

- An EUD Module shows the results from both the wind field and plume models in two different formats. The one-plot EUD gives an operator-managed visualization of the wind and plume fields over the area of interest, selected by the system operator. A two-plot EUD separates the wind and plume outputs into higher-resolution graphics.
- The Quality Control Module allows the user to create, view, and evaluate real-time and recent historical data received from the Sensor Module. The displayed graphic is initiated with an icon on the desktop and automatically displays seven meteorological variables from midnight to the current time. The most recent value for each parameter is labelled in green text above its respective time series plot.
- The Archive Module saves the real-time sensor data and upon user request will also preserve the image displays from the EUD. Saving the data and displays allows users to recreate scenarios and also facilitates estimates of post-incident clean-up boundaries.

The system output services authorize users via two access methods: a demilitarized zone (DMZ) shared drive stores the continuously updated output, allowing authorized users to see the wind (and plume, when applicable) results. Viewers who are not system operators are not permitted to control the generation of results. For a wider group of viewers, a government-managed website is also populated by the continual system output. These two resources work concurrently, ensuring a continuous availability of system results.

## 1.3 LR-x System

In late 2017, DBTS obtained an exclusive patent license agreement from ARL. This agreement allowed DBTS to construct an app modeled after the L-REAC system. The system created by DBTS is known as the LR-x. The “LR” is a reference to the original technology’s Local-Rapid Evaluation of Atmospheric Conditions system, or L-REAC title. The “x” is for the “extra” capabilities being added to the application.

The LR-x is a cloud-based system that can be accessed online or via mobile devices. The system requires the user to select the location of the hazard on a map. LR-x then calls upon a service to locate the closest available meteorological data to the user-selected site. If an incident-weather sensor is employed, LR-x will automatically switch to using the closer incident-specific weather data resource.

Wind and plume models are run based on the atmospheric data. The wind model is a contemporary version of the ARL 3DWF model, as is the NOAA/EPA ALOHA plume model. The model output is mapped over the user's area of interest, much like the L-REAC. The LR-x operates on an easy to navigate, single graphical user interface that is responsive to the user managing the model input. The operator can share output with others via an LR-x function.

## 2. System Comparison Method

The objective of the systems comparison task was to assess the similarities and differences between the original ARL- and DBTS-developed systems. To avoid a model validation study, this comparison was subdivided into qualitative and quantitative comparison sections. The qualitative comparison would focus on the general subjective features. The quantitative comparison would define common locations and assess system output information provided to the end user. The following subsections describe each method.

### 2.1 Qualitative Comparison

The qualitative data collection was organized into five categories: Published Purpose, Intended Users, Design-General, Design-Modules, and Documentation. The latter design section was further subdivided into the original five modules. Key attributes for these modules were examined. Each section and multiple subcategories were evaluated using a four-scale comparison rating system:

1 = same
2 = different
3 = equivalent
4 = other

The qualitative data for each system attribute was gathered by a person recently trained on the given system, thus allowing a neutral perspective in each system's descriptive entries. Once the comparison table was completed, ratings were assigned by a non-L-REAC user. The independent data acquisition and review assessments were balanced by having the initial results reviewed by L-REAC- and LR-x-proficient persons. These subject matter experts (SMEs) clarified any potentially confusing or incomplete information. The final scores were tabulated by the analysis team and are summarized in the Results section.

## 2.2 Quantitative Comparison

Descriptions of the quantitative comparison preparation and execution are presented separately, as each provides useful insights for the review. These insights are recaptured in the Discussion section and Appendix A (Recommendations from Independent Reviewers), as potential opportunities for improvements.

### 2.2.1 Quantitative Comparison Preparation

Preparation for the quantitative comparison task began by aligning four common links: time stamps, location, sensor heights, and variables.

**Time Stamps:** Examining the time stamps referenced by both systems revealed that both systems use their respective computer clocks, which are set via an online standard. While this time designation method seemed straightforward, during the trial comparison runs, it was quickly discovered that when both systems were instructed to run their models at the exact same time, the LR-x output consistently reported a few-minute delay in the run start time. After a discussion with DBTS SMEs, it was revealed that a short time interval is required for the LR-x Run Model command to process and initiate its task in the cloud. Consequently, the time stamp strategy was revised from seeking an exact time match to securing one within a 1- to 3-min window.

**Locations:** The exercise of matching locations revealed an opportunity for the LR-x system to add a user interface for manually entering latitude and longitude. This feature would be in addition to their existing street address and "drop a pin on the map" options. All four locations were matched between systems to within about 0.25 m (9.84 inches), using internal LR-x resources to document the locations.

**Sensor Heights:** The need for sensor height correlations was based on the typical atmospheric pattern of wind speed increasing with height above ground, due to a decrease in ground friction effects. While the L-REAC sensors were given as 10 m above ground level (AGL), the independent reviewers were unable to locate sensor heights for the LR-x wind sensor values that were ingested from aggregated data sources (e.g., Dark Sky weather service). It was also unclear if the values visually shown from the meteorological service were measured or modeled. Inquiries on these topics to the Dark Sky weather service remained unanswered, as of this publication.

In the course of determining input sensor heights, the wind model options impacting the model output heights and method of displaying results were noted. Both systems use the 3DWF model, but there were several model resolutions used. Each resolution was associated with a specific wind output height. The model output display methods, however, were similar. Examples include the following:

- The L-REAC 3DWF model output for all model resolutions is displayed as blue vectors and yellow streamlines at the 2.5 m AGL height. Measured sensor values are displayed as red vectors and sampled at the 10 m AGL height.
- The LR-x 3DWF model output for the 3DWF model 20-m resolution run is at 7 m AGL. The 3DWF model 50-m resolution output is at 9 m AGL. A color-coded wind speed and arrow orientation wind direction communicate the model results to users.

The display of vectors, streamlines, and colors were similar between the two systems. To visually extract specific values for comparison would have been too subjective for conclusions. Consequently, only values provided in a text format by each system were used in this comparison.

**Variables:** The variables used in the quantitative comparison included the standard meteorological parameters: pressure, temperature, relative humidity, wind speed, and wind direction. When comparing systems, the units of measure were not consistent (Table 1). Consequently, a conversion routine was included in the evaluation table.

**Table 1. Variable units used by each system**

| Variable | L-REAC | LR-x |
|---|---|---|
| Pressure | mb | Inches of Hg |
| Temperature | °C | °F |
| Relative humidity | % | % |
| Wind speed | m/s (mph displayed) | mph |
| Wind direction | ° | ° |
| Solar radiation | $W/m^2$ | N/A |

### 2.2.2 Quantitative Comparison Execution

The quantitative comparison began with three preselected locations, well within the footprint of both systems. Available time for acquiring data was limited; consequently, the atmospheric conditions during the comparison were predominately Fair Weather. When a severe weather event unexpectedly occurred over the test area, a fourth case was quickly added.

The following four locations were chosen:

- Site A: ARL L-REAC Sensor Module location at the time of the study.

- Site B: WSMR Museum Surface Atmosphere Measuring System (SAMS) weather station, maintained by the WSMR Meteorology Branch, and producing data used by the National Weather Service (NWS).
- Site C: A site physically located at the San Augustin Pass, New Mexico, and characterized by another SAMS station, also maintained by the WSMR Meteorology Branch and used by the NWS.
- Site D: Same site as Site C, only the atmospheric conditions were characterized as a "severe weather environment".

Each site was evaluated as a separate case. Thirty chronological data samples were acquired for Sites A, B, and C. Seven samples were taken for the Site D case. The atmospheric data acquired was live or real-time data, extracted and preserved in hard- and/or soft-copy formats from each system's resources. The results were statistically evaluated and assessed for their consistency and contrasts. A summary of the findings is given in the next section.

# 3. System Comparison Results

The following subsections report the net results gleaned from each comparison. The qualitative comparison highlights each design feature, along with its respective assessment. The quantitative comparison captures the operational characteristics that align and distinguish the two systems being matched.

## 3.1 Qualitative Comparison

The qualitative comparison included five major system features. A summary of each system's attributes is described below. For further details on the qualitative results, see Appendix B.

### 3.1.1 System Purpose

The first category in the qualitative comparison was a review of each system's purpose. The paraphrased L-REAC system purpose is to provide a decision aid that will assist Soldiers and civilians encountering airborne-released hazards. The LR-x purpose was an excerpt from the DBTS LR-x website: "LR-x is a cloud based, easy to use, real time technology for heightened situational awareness of chemical spills, CBRN [Chemical Biological Radiation Nuclear] threats, airborne hazard events, and wildfire management" (DBTS 2019a). These guiding principles were assessed as being "equivalent".

### 3.1.2 Intended Users

The next category was an examination of the intended users. Both technologies listed first responders, followed by various subcategories of these professional and layman benefactors. While the detailed users selected for the response were not identical, the net intended patrons were deemed the same.

### 3.1.3 System General Design

The general design category looked at the system design layout and computer platforms. The L-REAC was framed as an integrated system having five core modules (Sensor Module, Model Module, EUD Module, Quality Control Module, and Archive Module) working in a Windows operating system. The LR-x system was initially labeled an integrated design, which utilized a cloud-based operating system. After a discussion with the LR-x SME, this comparison category was expanded to recognize the subtle similarities and differences in modular software construction between the two systems. For this category, the computer platforms were considered “different”, and the design method was “equivalent”.

### 3.1.4 Five Design Modules

Since the two systems utilized an equivalent modular approach, the design comparison section continued by addressing module details. The following sections address the five modules based on the original L-REAC system design.

#### 3.1.4.1 Sensor Module

The first L-REAC system module is the Sensor Module. The L-REAC uses two main data resources: 1) in-situ measurements of pressure, temperature, relative humidity, wind speed/direction are automatically sampled and assimilated by a micro-logger every minute; 2) a local SAMS tower network acquires the same atmospheric data within a given area of interest. The SAMS resource is not required but is used to enhance the relevancy of the model output, when the automated data ingest is populated with measurements.

The LR-x system reports the five key variables—pressure, temperature, relative humidity, wind speed, and wind direction—at the top of their website. Due to limited Dark Sky weather service documentation and unanswered emails, it was difficult to ascertain where these parameter values originated. According to the Dark Sky website section on Data Sources, most data resources are from large-scale models such as NOAA’s Global Forecast System and High-Resolution Rapid Refresh Models. Reference was made to the Integrated Surface Database and the NOAA/Earth System Research Laboratory - Meteorological Assimilation Data

Ingest System (MADIS). The real-time SAMS data that are a part of the MADIS resource were not accessible during the study. Consequently, for the first source input sensor module entry, the *measured* values from L-REAC were assessed as “different” from the implied *modeled* LR-x systems values. The second sensor source input looked at the automated ingest of the L-REAC system vs. the user-initiated data input on the LR-x. These methods of data retrieval were labelled as “different”.

In terms of the atmospheric variables presented to the user from the sensor module, this feature would have been considered the same; however, they used different units of measure, so this attribute was determined to be “equivalent”.

The sensor output was labelled as “different”, since the ARL system uses a micro-logger and the DBTS system uses a service. On both systems, the sensor module output is automated and cannot be altered by the user.

#### 3.1.4.2 Model Module – Wind and Plume Models

The L-REAC Wind Model input comes directly from the measured values of the Sensor Module. In contrast, the LR-x wind model receives its input from the Dark Sky weather service modeled wind speed/direction. The measured versus modeled Wind Model input was assessed as “different”.

The Wind Model output was given the only “4” category assessment in the study. Here, the assessors recognized the three L-REAC system resolutions (5, 50, and 100 m) and that the wind speed markers are color-coded and proportionally sized vectors. Wind direction is demonstrated with a vector’s orientation. The LR-x Wind Model output displays 20- and 50-m resolutions, with the wind field markers being color-coded to coordinate with the miles per hour velocities. While most model resolutions are different between the two systems, there is a 50-m resolution model offered on both systems (same); and, the methods of communicating the wind magnitude results are similar (equivalent). To represent this system feature, the assessment would need to use all three result options. Consequently, a “4” rating was chosen.

The two systems both use the 3DWF Wind Model but different versions. The L-REAC uses the original 3DWF model from 2012; LR-x uses the 2015 version of the 3DWF model. The model’s impact was equivalent in both systems.

The Plume Model Chemical inputs for both the L-REAC and the LR-x are entered by the user before any plume model is run. This feature was considered the same.

The Plume Model Weather input for the L-REAC is automatically ingested from the measured Sensor Module data. The LR-x Plume Model weather input is taken from the Dark Sky weather services, after the user requests the task be executed. The request generates original and forecasted plume outputs. These different approaches were labelled as such in the qualitative summary table (see Appendix B).

The Plume Model output for the LR-x matches the user-selected, multi-tiered concentration with the uncertainty curve output of the L-REAC Plume Model. This feature is a standard that was set by the ALOHA software developers. The rescaling and customizing of the plume output was also preserved in both systems, though not identically. Consequently, this latter attribute was labelled equivalent.

#### 3.1.4.3 End User Display (EUD) Module

The L-REAC EUD Wind field continuously updates as new Sensor Module data become available. In contrast (different), the LR-x shows wind field output, once prompted by the user. For this latter system, a series of forecasted wind field displays is automatically generated from the single user prompt.

The plume footprints for the EUD outputs are equivalent in that both EUDs use Keyhole Markup Language (kml) overlays. L-REAC overlays this .kml file in a Google Earth Map used in a "1 Plot" window. The L-REAC 2-plot HTML output separates the wind and plume plots, utilizing the Mapping Application for Response, Planning, and Local Operational Tasks (MARPLOT) output to show a high-resolution picture of the local toxic footprint. The LR-x Plume EUD utilizes the .kml for the original plume field and the subsequent forecasted plume outputs.

EUD-Security Input and Output were assessed as equivalent. For the L-REAC, the system is installed on authorized computers only, and the output utilizes a government-managed DMZ drive and website. DBTS regulates the users by providing each user with individual login accounts to access the application. The LR-x output is managed by approved users through their individual accounts.

The EUD (other) recognized that both systems take the equivalent time (namely, less than 10 min) to process the atmospheric intelligence needed to inform users of the meteorological conditions that are potentially impacting one's future good health. More specifically, the L-REAC system takes about 1–2 min to process a 5-m resolution wind model, 5–8 min to process a 50-m resolution model, and 8–10 min to complete a 100-m resolution wind field. The LR-x processes the original model in roughly 5 min. The subsequent forecast models follow in 4-min intervals from the last model run.

#### 3.1.4.4 Quality Control Module

Specific quality control measures for the LR-x system were unclear at the time of this writing. The LR-x receives atmospheric data from a third-party resource. These data are uploaded to their platform. The presumption is that this third party is responsible for the data quality provided. Instruments used in the L-REAC Sensor Module are monitored by a human-in-the-loop every business day. Quality control issues are addressed and resolved once they are identified. Until additional information becomes available, this attribute was labeled “different”.

Note: Effective September 6, 2019, under an agreement with IBM/The Weather Company, DBTS incorporated IBM’s “Enhanced Current Conditions” and “Enhanced Forecast” services as the standard weather service for the LR-x Technology (DBTS 2019b).

#### 3.1.4.5 Archive Module

The L-REAC Archive Module preserves all sensor data 24/7, as well as any user-selected EUD imagery from incidents. In contrast (different), LR-x utilizes an Amazon database service to store model history in the cloud from the LR-x system. While only the last 10 runs of the LR-x were visible during the quantitative comparison study effort, the LR-x software is designed to access all historical uses of the system.

### 3.1.5 Documentation

The LR-x training method is equivalent to the L-REAC system in that the LR-x method is conducted in a physical classroom or via live conferences.

L-REAC training content is done through a five-tier training program. Tiers 1 and 2 certify the user to interpret the EUD output. Tiers 3–5 content advances the learner to an “Operator” status, where they gain skills toward incorporating model and system strengths and weaknesses. In contrast (different), the LR-x training content emphasizes system features from a user’s application perspective.

Equivalent standard operating procedure (SOP) documentation is provided for both system training methods and programs. The methods for communicating the SOPs reflect their system training environments.

### 3.1.6 Net Qualitative Comparison Results

Table 2 tallies the assessment ranks described previously. While only a small portion was labeled as the same, the sum of same and equivalent rankings is more than half, exceeding the different features by about a third.

**Table 2. Tally of qualitative comparison rankings**

| Qualitative rank | Total percentage |
|---|---|
| Same | 12 |
| Equivalent | 44 |
| Different | 40 |
| Other | 4 |
| Same + Equivalent = 56 | |
| Different + Other = 44 | |

## 3.2 Quantitative Comparison

Three of the four quantitative comparison cases occurred under Fair Weather conditions. The fourth coincided with locally flooding rains and small hail in the area of the sampling site. The following summarizes the case results by their atmospheric conditions. Additional details can be found in Appendix C.

### 3.2.1 Sites A, B, and C

Fair Weather atmospheric conditions prevailed during Cases A, B, and C, which acquired their quantitative data from the locations A, B, and C, respectively. Most variables acquired showed a quantitative difference within about 10% of each other. (See Appendix C for details.) The only exception was the pressure variable. In Cases A and B, the pressure differences between the two systems averaged 143 mb. Case C showed an average pressure difference of 191 mb. Even during the active weather event of Case D, there was a 194-mb difference between the two systems. On closer inspection, the LR-x system pressure values were consistently within a range (+/–2 mb) of magnitudes that one would expect from a sea-level location. In contrast, the L-REAC system values were consistent with the local high plateau elevation.

A suggested explanation for such a large pressure difference might be that when the user logs into the LR-x system, the user is normally given the option of having their location identified by interactive software. Due to security constraints in this study, this option was not available. Perhaps if this inquiry were permitted, the LR-x system would have adjusted for local elevation.

### 3.2.2 Site D

Heavy rains, local flooding, and small hail were observed in the area of interest during the data acquisition for Site D. Consistent with the previous cases, the LR-x pressure at Site D reported values one would expect at sea level. The temperature, relative humidity, and wind speeds were within acceptable limits. The LR-x wind direction, however, averaged 185° different from the L-REAC reported SAMS sensor data at Site D. The minimum wind direction difference was 160°; the maximum difference was 205°. The standard deviation was +/–15°. Wind velocities reported by the SAMS tower data ranged from 3.0 to 7.2 m/s (6.7 to 16.1 mph), indicating a strong enough flow to sustain a definite direction.

Since the primary steering mechanism of a plume model is wind direction, and the product purpose is to discern between safe and hazardous environments, this discrepancy is significant. For example, if the winds were coming from the north transporting a plume to the south, the safe zone would be to the north. Projecting Case D results into this example, the airborne hazard data of the model-only resourced LR-x was indicating that the safe zone was to the south, directly into the existing plume.

The dynamic weather of Site D was purposefully chosen to challenge the alignment of the two systems. While weather models have advanced, their limitations are often linked with data resources and model resolutions. The presence of locally heavy rain and hail in this case indicate a thunderstorm event, which normally includes strongly inhomogeneous spatial distribution of wind and precipitation fields. These local effects are due to the convective cell structure and highly variable (in time and space) outflow wind fields of thunderstorms. Perhaps the Dark Sky weather data sites and grid resources were not distributed to fully characterize such a highly localized phenomena. This scenario strengthens the wisdom in combining incident-onsite measured atmospheric parameters with the regional-modeled weather resources, as found in the full LR-x system (DBTS 2018).

## 4. Discussion

In this section, Case D is reexamined to assess the atmospheric conditions reported by both systems. These observations are followed by independent comments from the two neutral system comparison reviewers, who were given an opportunity to independently document their observations and lessons learned.

### 4.1 Case D Revisited

To test the believability of the Case D data, the observed severe weather scenario was weighed against the data acquired. The quantitative differences between the systems were calculated using the "LR-x minus L-REAC" equation. For Case D (see Appendix C), the consistently positive pressure differences indicate that LR-x is overestimating the value. As with the other three cases, the LR-x pressure discrepancy likely stems from a sea-level pressure reference.

The consistently positive temperature and negative relative humidity differences indicate that the LR-x data source was showing warmer and drier conditions than what was measured by the L-REAC data source. Knowing that an active storm was in the area of interest, winds were examined more closely. Here, the wind speed bias transitioned from negative differences (stronger L-REAC winds) to positive (weaker L-REAC winds) differences in a period of minutes, which is consistent with the observed passage of the thunderstorm's outflow boundary around 1550 local time. Thus, the believability of the L-REAC standard and difference results remains intact.

## 4.2 General Observations

Independently generated general observations by the system reviewers follow.*

**Reviewer 1:** The L-REAC and LR-x systems have the same objective and targeted audience. Looking at the qualitative data, the L-REAC is defined and thorough in its atmospheric collection of data from top to bottom. The five core modules work together seamlessly, and with the addition of the quality control module, the operator is able to detect any unusual patterns. The use of an animated anemometer ("Model–Wind" feature) is advantageous and demonstrates a forward-thinking concept when dealing with crisis situations. The L-REAC is a working concept that, if developed to be more accessible to the public, could be an effective tool. The cloud-based concept of the LR-x is genius and relevant to the current digital era. The model output should display latitude/longitude and additional resolutions. The length of the wind vector should also have significance in the application. When looking at the quantitative data, the L-REAC had the most dependable data in the sense that the sensors were on-site. The LR-x in comparison measured within 10% of the sampled variable under Fair Weather conditions. However, after conducting a fourth data acquisition, the wind direction demonstrated a skewed reading of approximately 180°. The pressure constantly read that the model was at sea level (30 inches of Hg). With purposeful effort, the latitude and longitude of the selected sample sites were able to be within 0.25 m (< 1 arc s) between both systems.

**Reviewer 2:** The concept and overall prototype of the LR-x system was appealing, but when using the system to run a model more than 10 times, opportunities for improvement were noticed. First, after executing 30 model runs (data samples), the LR-x system history could only recall the last 10 models that were run. Fortunately, each model output was preserved in a hardcopy printout, ensuring continued access to the quantitative results. . . .

* Reviewer response excerpts are presented verbatim but lightly edited for clarity.

Finally, before we could acquire quantitative data, we had to get the latitude and longitude referenced by both systems to be as close as possible. This task required countless times of having to drop a pin on the LR-x map and manually inspecting the element within the source code. Having the option to manually enter latitude and longitude, so the product can place the pin, would be helpful.

## 4.3 Lessons Learned

The two independent system reviewers were given an opportunity to identify lessons learned during their L-REAC and LR-x system comparison. A sample of their suggestions are documented below.*

**Reviewer 1:** This project required a special attention to details. Understanding the atmosphere and how it operates has a direct effect on the population, especially in an airborne hazardous incident. The analysis conducted revealed that even in the technology industry, atmospheric conditions play an important role. Interpreting weather processes and concepts was foundational in the understanding of the comparison results. Atmospheric comprehension is also key for revealing actions needed to ensure that there can be solid technological improvements.

**Reviewer 2:** Lessons learned from this assessment (from a future Soldier's perspective): I prefer accuracy and consistency over newer technology that's lightweight. The L-REAC system uses actual sensors that can be a negative because that means added weight that must be accounted for, if you want to be mobile. But, you will never have to question the accuracy (of the results) if your sensors are calibrated. The LR-x system has solved the weight issue by building a system that receives weather data from other sources, but the [Model-only LR-x] accuracy is not to par with the L-REAC system.

In an infantry platoon, one squad carries heavy equipment and supplies to support the mission. I'd rather have a squad from my platoon carry the weight of a system with a laptop if that system is going to give me accurate readings when I'm out in the field. . . . I'd rather carry more weight . . . [to] have the reassurance that I have accurate data whenever it's time to make decisions regarding leading my platoon in an airborne hazardous situation.

(Author note: The fully integrated measurement- and model-resourced LR-x system was not available for this comparison study.)

* Reviewer suggestion excerpts are presented verbatim but lightly edited for clarity.

## 5. Summary and Conclusion

This comparison study was purposefully designed to include two neutral reviewers having no background in either system. The reviewers, however, were required to have a vested interest in the technology's long-term application of saving lives, thus enabling them to better envision its implementation during their career as protectors of our nation's population.

The system comparison reviewed the technology through both qualitative and quantitative perspectives. The qualitative comparison showed that the current systems have a slightly higher percentage of features that are the "same" or "equivalent" (52%) than "different" (44%). Only one feature, wind model output, was reported as "other", since it had attributes that were the same (50-m model resolution), different (three model resolutions were available on just one system), and equivalent (output display had similar features).

The quantitative comparison focused on the meteorological data used as input to both the wind and plume models, which in turn produce an end user display for the first responder. The foundational presumption was that a model is only as good as the data ingested. Thus, calibrating off these parameters, the quantitative comparison found good agreement between all but two meteorological variables. The pressure variable reported by the LR-x consistently implied a sea-level value. The analysis suggested that the test site security-required denial of LR-x's automatic location-identifying software may have contributed to this mismatch of values. The second irregularity was the diametrically different wind directions acquired by the systems during locally severe weather conditions. This disparity implied a need for localized measured weather parameters. While not a part of this comparison study, the LR-x has an automated, incident-specific, measured atmospheric data capability that can be used in their cloud-based product. Post-study review has determined that both observations would have resolved if the fully integrated measurement- and model-resourced LR-x system were used in the comparison study.

A sample of the recommendations suggested by the two neutral system comparison reviewers is provided in Appendix A.

## 6. References


[DBTS] Diamond B Technology Solutions. Diamond B Technology Solutions, LLC (LR-x®) announces strategic reseller agreement with Coastal Environmental Systems [press release]; 2018 Sep 10 [accessed 2019 Sep 20]. http://diamondbts.com/wp-content/uploads/2018/09/DBTS-LR-x-and-Coastal-Environmental-Systems-9.12.18.pdf.

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Vaucher GT, Brice R, Luces SA, O'Brien S. Local-rapid evaluation of atmospheric conditions (L-REAC™) system, design and development, Volume 3 ("Operational L-REAC™"). White Sands Missile Range (NM): Army Research Laboratory (US); 2011 Sep. Report No.: ARL-TR-5727.

## Appendix A. Recommendations from Independent Reviewers

The following two sections present a sample of the various recommendations suggested by the two neutral participants co-executing the systems comparison study.* Their fresh perspectives enable an open-minded look at the technologies. Their careers protecting our nation's population is the context of their comments.

## A.1 Reviewer 1 Recommendations

Looking at this research from a Soldier's perspective and as a future leader, being able to communicate accurate data is of the upmost importance. When conducting a mission, even the weather plays a pivotal role in a Soldier's gear and approach. The source of measured and modeled data must be properly authenticated from all angles. Improvements to the LR-x system should include stabilization regarding the model run times, archive, and data quality control.

## A.2 Reviewer 2 Recommendations

The L-REAC system provided better accuracy of atmospheric conditions due to the system having calibrated sensors. Alternatively, the LR-x system offered a lightweight system with newer technology that used forecasted data from an outsourced platform—in this instance, Dark Sky.

The following list outlines my recommendations for the next iteration of the LR-x system:

- Allow the user to recall a history of all model runs during the current session.
- Before the user logs out, ask them if they would like to save their previous models to their local hard drive.
- Allow the user to manually enter latitude and longitude. Every location on this earth has a longitude and latitude, but not every location has a street name.
- "Model running…" displayed at the top of the LR-x window is too vague. Knowing which model is running would be helpful.
- Add a "stop model run" button.

The last two suggestions are small details, but they would allow the user to know that the correct model is running; and if it's not the correct model, the user can quickly end that model rather than having to wait until it has finished computing.

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* Reviewer recommendation excerpts are presented verbatim but lightly edited for clarity.

# Appendix B. Local-Rapid Evaluation of Atmospheric Conditions (L-REAC) and LR-x System Qualitative Comparison Results

A qualitative comparison of the Local-Rapid Evaluation of Atmospheric Conditions (L-REAC) system and its Diamond B Technology Solutions–equivalent LR-x (2019 July model-only version) was conducted in July 2019. Five major system attributes framed the subjective comparison. Subcategories were added to the main features to better align the elements. Data describing each element were generated by independent investigators and reviewed by system subject matter experts (SMEs). Each element listed was evaluated individually. The results were further assessed by system SMEs who recognized the ratings as representative of the L-REAC and LR-x subjective attributes. Table B-1 details the results of the qualitative assessment.

# Table B-1 Qualitative comparison study details

| Reference # | FEATURES | QUALITATIVE ASSESSMENT RATING | | | | L-REAC® | LR-x® |
|---|---|---|---|---|---|---|---|
| | | 1 = Same | 2 = Different | 3 = Equivalent | 4 = Other | | |
| 1 | SYSTEM PURPOSE | | | 3 | | To provide a decision aid that will assist soldiers and civilians encountering airborne released hazards. | LR-x® is a cloud based, easy to use, real time technology for heightened situational awareness of chemical spills, CBRN threat, airborne hazard events, and wildfire management.(https:// diamondbts.com, "First Line-Homepage" last viewed 20190730, WH) |
| 2 | INTENDED USERS | 1 | | | | First Responders (Firefighters, Law Enforcement, Soldiers) | First Responders (Firefighters, Law Enforcement, Soldiers) |
| | | | | | | | |
| 3 | DESIGN - GENERAL | | | | | | |
| 3.1 | Modular vs Other | | | 3 | | Five Integrated modules | Intergated Design with Modular software |
| 3.2 | Computer Platforms | | 2 | | | Windows OS | Cloud OS |
| 4 | DESIGN - 5 MODULES | | | | | | |
| 4.1 | SENSOR MODULE | | | | | | |
| 4.11 | Sensor Module - Source Input (1) | | 2 | | | Measured Values | Values from Dark Sky Weather Models |
| 4.12 | Sensor Module - Source Input (2) | | 2 | | | 5 sensors: barometer, thermometer, hygrometer, anemometer, pyranometer. | Automated Data Input |
| 4.13 | Sensor Module - Sensor, Variable and Default Units | | | 3 | | Barometer: pressure (mb), thermometer: temperature (C & F), Temperature Gradient (C/m), hygrometer: relative humidity (%), anemometer: wind speed (m/s & mph)/direction(deg), pyranometer: solar radiance(W/m^2). | Pressure (Inches of Hg), Temperature (F), Relative Humidity (%), Wind Speed (mph), Wind Direction(deg). |
| 4.14 | Sensor Module - Output | | 2 | | | Micro Logger | Dark Sky Weather |
| 4.2 | MODEL MODULE | | | | | | |
| 4.21 | Model - Wind (input) | | 2 | | | Anemometer provides measured WS/WD input values / SAMS data used in an object analysis supplimenting dedicated sensor values. | Modelled Wind Speed/Direction from Dark Sky Wx data. |
| 4.22 | Model - Wind (Output) | | | | 4 | Three resolution (5m, 50m, 100m) 3DWF wind model outputs. WS color coded & proportionally-sized vector; WD is shown with vector. | Two Resolution (20m, 50m) Wind Field with color-coded mph velocities; WD shown as vector. |
| 4.23 | Model - Wind (Other) | | | 3 | | Orginial 3DWF Model (~2012) | 2015 3DWF Model |
| 4.24 | Plume Model - User Input (weather) | | 2 | | | Measured meteo data automatically ingested from sensor module. | Dark Sky Wx Model Data input after user prompt run. |
| 4.25 | Plume Model - User Input (chemical) | 1 | | | | Operator inputs chemical data(hazard type, amount, release method) | User input chem data(hazard type, amt, release method) |
| 4.26 | Model - Plume (Output) | 1 | | | | Multi-tiered concentration with uncertainty curve. Static view overlaid with ALOHA hazard footprint | Multi-tiered concentration with uncertainty curve. Plume forecast developed from weather conditions provided by Dark Sky and user-inserted chemical field descriptions. |
| 4.27 | Model - Plume (Other) | | | 3 | | Automated with HTML | Can be altered via Customize & Control button |
| 4.3 | END USER DISPLAY [EUD] MODULE | | | | | | |
| 4.31 | EUD - Wind Field | | 2 | | | Continuously updated wind fields displayed. | Original* and forecasted wind field models are displayed. |
| 4.32 | EUD - Plume Field | | | 3 | | Plume overlay using KML on Google Earth map(1 Plot); using MARLOT plume display (2 Plot) | Original and forecasted plumes are displayed. |
| 4.33 | EUD - Security Input | | | 3 | | L-REAC® System installed on authorized computers. | Login is provided by DBTS; User then has access to application. |
| 4.34 | EUD - Security Output | | | 3 | | Authorized users have access thru DMZ and/Webdrive. | Operator manages EUD distribution. |
| 4.35 | EUD - Other | | | 3 | | 1-2 min update(5m), 5-8 min update(50m), 8-10 min update(100m). | First Model (current conditions): 5 min from clicking 'Run New Model'. Forecasts 1-4 populate 4 min after previous model generated. |
| 4.4 | QUALITY CONTROL MODULE | | 2 | | | Real time data displayed from sensors. | Unkown |
| 4.5 | ARCHIVE | | 2 | | | Archive saves all L-REAC® sensor data, & user-selected EUD imagery from incidents. | Amazon database service stores Model History in cloud. |
| 5 | DOCUMENTATION | | | | | | |
| 5.1 | Training Method | | | 3 | | 5-Tier Training (Tier 1 -2: Certifies "user"; T3-5: Certifies "operator") | Classroom session or Live Conference |
| 5.2 | Training Content/Documentation | | 2 | | | Documentation exercises interpretation of System Features & Models | Documentation explains use of System Features |
| 5.3 | SOP Documentation | | | 3 | | 5-Tier training program includes SOPs | User Manual (available on application under Settings) |

# Appendix C. Local-Rapid Evaluation of Atmospheric Conditions (L-REAC) and LR-x System Quantitative Comparison Results

Four cases comparing the Local-Rapid Evaluation of Atmospheric Conditions (L-REAC) and LR-x systems quantitatively were conducted between July and August 2019. Each comparison was at a unique site and time. Data from Sites A, B, and C were collected under Fair Weather conditions. Site D acquired data while severe weather was in the area. All data were extracted in a real-time mode, being preserved in hardcopy as well as electronically. Inconsistent variable units were converted before the "LR-x system value minus the L-REAC value" differences were calculated. Using this differential ensured that when LR-x overestimated the parameter, the values were positive; underestimations were negative. The results were used to evaluate the systems in terms of output product as well as operational attributes.

As stated earlier, the quantitative differences were calculated using the "LR-x minus L-REAC" equation. The consistently positive pressure differences indicate that LR-x is overestimating the value, providing a sea-level magnitude. In Case D, the consistently positive temperature and negative relative humidity differences indicate that the LR-x data source was showing warmer and drier conditions than what was actually measured by the L-REAC data source. Wind speed bias went from negative (stronger L-REAC winds) to positive (weaker L-REAC winds) over a short time period. This observation is consistent with the passage of a thunderstorm's outflow boundary around 1550 local time.

Tables C-1 through C-4 provide the quantitative comparison study data from Sites A–D.

**Table C-1 Case A/Site A (quantitative comparison data): Aug 1, 2019. Southwest Tularosa Basin, New Mexico. Fair Weather sky.**

| | | Table of Differences | | 190801 - Comparison Site A | | |
|---|---|---|---|---|---|---|
| | | Pressure | Temperature | Relative Humidity | Wind Speed | Wind Direction |
| | | (mb) | (deg C) | (%) | (m/s) | Deg |
| | | | | | | |
| | | 141.1 | -2.9 | 9.7 | 1.24 | 141 |
| | | 141.4 | -2.3 | 5.4 | -1.72 | 110 |
| | | 141.5 | -2.7 | 5.0 | -3.34 | 107 |
| | | 141.6 | -1.9 | 2.8 | 0.06 | -100 |
| | | 141.7 | -1.5 | 0.8 | -1.26 | 62 |
| | | 141.7 | -1.7 | 1.3 | -0.92 | 83 |
| | | 141.9 | -1.7 | 2.5 | 0.23 | 178 |
| | | 142.1 | -1.6 | 3.0 | -2.15 | 120 |
| | | 142.2 | -1.8 | 3.4 | 1.75 | -145 |
| | | 142.1 | -1.7 | 1.3 | 0.46 | 103 |
| | | 142.5 | 1.1 | -0.7 | -4.44 | -51 |
| | | 142.6 | 1.7 | -4.5 | -2.70 | -76 |
| | | 142.7 | 0.8 | -4.0 | -3.08 | -76 |
| | | 143.0 | 1.2 | -4.8 | -4.13 | -98 |
| | | 142.9 | 1.2 | -5.7 | -3.83 | -86 |
| | | 142.9 | 1.8 | -6.0 | -3.26 | -109 |
| | | 143.4 | 0.6 | -1.9 | -2.56 | -78 |
| | | 143.4 | 1.0 | -1.8 | -2.98 | -112 |
| | | 143.3 | 0.7 | -2.4 | -1.27 | -50 |
| | | 143.3 | 0.0 | -2.1 | -1.32 | -42 |
| | | 143.3 | 0.8 | -0.9 | -2.03 | 1 |
| | | 143.3 | 0.8 | 0.0 | 1.24 | 21 |
| | | 143.5 | -1.7 | 2.9 | 0.87 | 114 |
| | | 143.6 | -1.8 | 0.1 | -0.08 | -138 |
| | | 140.7 | 0.3 | -0.8 | -1.34 | -97 |
| | | 143.8 | -1.1 | -0.5 | 0.27 | -121 |
| | | 143.8 | -0.7 | -0.6 | 0.60 | 175 |
| | | 143.9 | -1.2 | -0.2 | 1.50 | 135 |
| | | 144.1 | -7.0 | 0.7 | 0.61 | -93 |
| | | 144.1 | -1.3 | 0.8 | -1.37 | -47 |
| | | 144.1 | -1.0 | 1.0 | -0.55 | -69 |
| Site A | AVG: | **142.77** | **-0.77** | **0.13** | **-1.15** | **-7.69** |
| | MAX: | **144.14** | **1.82** | **9.67** | **1.75** | **178.18** |
| | min: | **140.67** | **-6.97** | **-5.98** | **-4.44** | **-144.99** |
| | STDEV: | **0.97** | **1.80** | **3.38** | **1.79** | **104.33** |

**Table C-2 Case B/Site B (quantitative comparison data): Aug 2, 2019. West Tularosa Basin, New Mexico. Fair Weather sky.**

| | | Table of Differences | | 190802 - Comparison Site B | | |
|---|---|---|---|---|---|---|
| | | Pressure | Temperature | Relative Humidity | Wind Speed | Wind Direction |
| | | (mb) | (deg C) | (%) | (m/s) | Deg |
| | | | | | | |
| | | 142.0 | 0.8 | -1.4 | 0.74 | 99 |
| | | 142.5 | -0.3 | -0.7 | -0.16 | -61 |
| | | 142.7 | -0.2 | -0.8 | -0.67 | -18 |
| | | 142.8 | -0.4 | -1.7 | -1.44 | -27 |
| | | 142.8 | 0.3 | -1.6 | -0.84 | -18 |
| | | 142.9 | 0.5 | -1.6 | 0.10 | -34 |
| | | 143.0 | 0.4 | -0.4 | -0.02 | -8 |
| | | 143.0 | 0.0 | -1.1 | -0.15 | -168 |
| | | 143.1 | -1.1 | -0.8 | -0.45 | -94 |
| | | 143.1 | -1.1 | -1.5 | 0.15 | 92 |
| | | 143.2 | -0.5 | -1.0 | -1.58 | 90 |
| | | 143.2 | -0.6 | -0.9 | -0.47 | 86 |
| | | 143.3 | -1.0 | -0.3 | -0.05 | 72 |
| | | 143.4 | -0.3 | -0.6 | -0.09 | 141 |
| | | 143.5 | -0.1 | -1.2 | -0.41 | 228 |
| | | 143.5 | -0.3 | -1.0 | -0.94 | 33 |
| | | 143.5 | 0.1 | -1.1 | 0.54 | 158 |
| | | 143.5 | 0.6 | -2.8 | 0.12 | 36 |
| | | 143.5 | 0.8 | -2.8 | 0.37 | -7 |
| | | 143.7 | -0.1 | -3.9 | 1.03 | 145 |
| | | 143.7 | 0.4 | -4.6 | 0.53 | -132 |
| | | 143.8 | 0.9 | -4.2 | 0.90 | -82 |
| | | 144.0 | 0.5 | -4.0 | 0.96 | -36 |
| | | 144.1 | 0.4 | -3.4 | -1.60 | -160 |
| | | 144.2 | 0.9 | -3.8 | -0.53 | -165 |
| | | 144.3 | -0.3 | -2.7 | -0.59 | -111 |
| | | 144.4 | 0.1 | -2.9 | 0.79 | -41 |
| | | 144.3 | -0.1 | -3.2 | 0.41 | -124 |
| | | 144.5 | -0.6 | -2.8 | -2.30 | -10 |
| | | 144.5 | 0.0 | -3.2 | -2.48 | -24 |
| Site B | AVG: | **143.48** | **0.00** | **-2.07** | **-0.27** | **-4.69** |
| | MAX: | **144.52** | **0.93** | **-0.30** | **1.03** | **227.60** |
| | min: | **142.02** | **-1.08** | **-4.60** | **-2.48** | **-167.60** |
| | STDEV: | **0.63** | **0.56** | **1.30** | **0.92** | **103.38** |

**Table C-3 Case C/Site C (quantitative comparison data): Aug 5, 2019. San Augustine Pass, New Mexico. Fair Weather sky.**

| | | Table of Differences | | 190805 - Comparison Site C | | |
|---|---|---|---|---|---|---|
| | | Pressure | Temperature | Relative Humidity | Wind Speed | Wind Direction |
| | | (mb) | (deg C) | (%) | (m/s) | Deg |
| | | | | | | |
| | | 189.8 | 0.3 | -4.1 | -1.94 | 70 |
| | | 189.8 | 5.0 | -11.6 | -2.88 | 91 |
| | | 189.8 | 1.0 | -5.3 | -1.51 | 96 |
| | | 189.8 | 0.8 | -4.0 | -0.38 | 96 |
| | | 189.9 | 0.6 | -3.8 | -0.17 | 92 |
| | | 189.9 | 0.6 | -3.8 | -0.90 | 73 |
| | | 190.0 | 0.9 | -4.1 | -1.21 | 120 |
| | | 190.1 | 0.2 | -1.5 | -1.78 | 85 |
| | | 190.0 | -0.4 | -0.3 | -0.67 | 89 |
| | | 190.1 | 0.0 | -1.8 | -0.78 | 57 |
| | | 190.1 | 6.0 | -12.9 | -0.76 | 65 |
| | | 190.2 | 0.6 | -2.4 | -1.01 | 81 |
| | | 190.2 | 0.1 | -2.1 | -1.30 | 44 |
| | | 190.3 | 0.8 | -1.5 | -1.34 | 63 |
| | | 190.4 | 1.1 | -2.6 | -1.75 | 65 |
| | | 190.7 | -0.1 | -2.3 | -0.23 | 1 |
| | | 190.7 | 4.8 | -9.2 | -0.20 | -7 |
| | | 190.8 | 3.7 | -7.9 | -1.87 | -168 |
| | | 190.8 | 4.9 | -9.3 | -0.55 | -137 |
| | | 190.8 | 0.7 | -3.0 | -0.28 | -84 |
| | | 190.8 | 0.3 | -2.5 | -0.09 | -92 |
| | | 190.8 | 0.0 | -0.2 | -0.42 | -130 |
| | | 190.9 | 4.4 | -8.2 | 0.78 | 66 |
| | | 190.9 | -0.6 | 1.5 | 1.11 | 99 |
| | | 191.5 | 2.0 | -2.5 | -1.46 | -117 |
| | | 191.5 | 2.1 | -2.9 | 0.07 | -122 |
| | | 191.5 | 1.5 | -2.4 | -0.14 | -74 |
| | | 191.6 | 0.6 | -0.9 | 0.19 | -127 |
| | | 191.6 | 4.3 | -7.3 | 1.23 | -81 |
| | | 191.8 | 0.1 | -0.2 | 0.62 | -200 |
| Site C | AVG: | 190.59 | 1.55 | -3.97 | -0.66 | 0.51 |
| | MAX: | 191.82 | 6.02 | 1.50 | 1.23 | 120.10 |
| | min: | 189.82 | -0.58 | -12.90 | -2.88 | -200.00 |
| | STDEV: | 0.64 | 1.91 | 3.51 | 0.95 | 99.79 |

**Table C-4 Case D/Site D (quantitative comparison data): Aug 7, 2019. San Augustine Pass, New Mexico. Severe weather in area.**

| | | Table of Differences | | 190807 - Comparison Site D | | |
|---|---|---|---|---|---|---|
| | | Pressure | Temperature | Relative Humidity | Wind Speed | Wind Direction |
| Time | Time | (mb) | (deg C) | (%) | (m/s) | Deg |
| HH | MM | | | | | |
| 15 | 36 | 193.3 | 5.2 | -11.4 | -4.07 | 205 |
| 15 | 46 | 193.4 | 8.1 | -16.6 | -3.13 | 160 |
| 15 | 50 | 193.4 | 4.4 | -13.1 | -0.75 | 196 |
| 15 | 54 | 193.5 | 4.2 | -13.3 | 1.16 | 195 |
| 15 | 58 | 193.6 | 3.8 | -12.6 | 2.08 | 175 |
| 16 | 13 | 193.7 | 4.4 | -14.1 | 2.63 | 180 |
| 16 | 17 | 193.8 | 4.0 | -13.2 | 2.83 | 188 |
| Site D | AVG: | 193.55 | 4.84 | -13.47 | 0.11 | 185.36 |
| | MAX: | 193.82 | 8.07 | -11.40 | 2.83 | 205.20 |
| | min: | 193.32 | 3.75 | -16.60 | -4.07 | 159.60 |
| | STDEV: | 0.18 | 1.49 | 1.61 | 2.81 | 15.33 |

## List of Symbols, Abbreviations, and Acronyms

| | |
|---|---|
| 3DWF | Three Dimensional Wind Field |
| AGL | above ground level |
| ALOHA | Aerial Location of Hazardous Atmospheres |
| ARL | Army Research Laboratory |
| CBRN | Chemical Biological Radiation Nuclear |
| CCDC | US Army Combat Capabilities Development Command |
| DBTS | Diamond B Technology Solutions |
| DMZ | demilitarized zone |
| EPA | Environmental Protection Agency |
| EUD | End User Display |
| inHg | inches of mercury |
| kml | Keyhole Markup Language |
| L-REAC | Local-Rapid Evaluation of Atmospheric Conditions |
| MADIS | Meteorological Assimilation Data Ingest System |
| MARPLOT | Mapping Application for Response, Planning, and Local Operational Tasks |
| NOAA | National Oceanic and Atmospheric Association |
| NWS | National Weather Service |
| SAMS | Surface Atmosphere Measuring System |
| SME | subject matter expert |
| SOP | standard operating procedure |
| TRL | technology readiness level |
| WSMR | White Sands Missile Range |

| | |
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