A SURVEY OF METEOROLOGICALLY-BASED SYSTEMS FOR AIRBORNE-RELEASED HAZARD EMERGENCIES

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1. THE WEATHER ROLE IN EMERGENCY RESPONSE ENVIRONMENTS

On 2009 Aug 4th, the New Bedford, MA fire department responded to an accidental, undefined airborne chemical release that threatened a city transfer station near a public airport. Following standard emergency response procedures, the situation called for an evacuation of the most endangered region and the setting up of a triage area (Buckley, 2009). Just what constituted the threatened or “hot” zone and the safer triage zone were, in part, a function of the atmospheric conditions.

Over the past several decades, the U.S. Army Research Laboratory (ARL) has been investigating atmospheric effects in an urban environment. During the most recent decade, one of the focuses has been on airflow and stability around small urban building complexes. In the course of the progressively more complex field studies, seven wind tunnel urban building flow features were verified, and three urban diurnal stability cycles were defined (Vaucher, 2009; Vaucher and Bustillos, 2008; Vaucher et al, 2008). The last field study, *WSMR 2007 Urban Study* (*W07US*), not only investigated the atmospheric conditions around a small building complex, but included three disaster response drills. The concurrent measurements and simulated emergency drills prompted a Post-*W07US* survey of available weather-related, decision-making tools needed to provide near-real time information regarding insitu atmospheric conditions during potentially life-threatening situations.

This paper briefly describes the emergency type considered in our survey of atmospheric first-responder tools, a typical work scenario for first-responders, a sample of attributes from the contemporary systems surveyed, and some observations to help improve future weather-related tool development.

1.1 Defining the Emergency Type

Emergency first-responders encounter so many different types of emergencies that the survey of weather-related tools began by refining the first-response application. The authors elected to restrict the emergency type to an airborne chemical release in a USA urban or suburban area. The users of the tools surveyed were defined as volunteers; thus, limiting the budget resources and ensuring pointed priority choices.

1.2 Response Environments – The Consequence Management Process

There are four responses associated with Consequence Management procedures (also known as, an emergency response). These stages include Planning, Preparation, Response, and Recovery (see figure 1). Weather interests for the Planning Stage occur as a part of the operational environment and deliberate site assessments. Meteorological tools utilized for these activities include local and regional climatology, as well as atmospheric models to simulate various potentially hazardous scenarios. The Preparation Stage includes monitoring activities, during which permanent meteorological resources linked to atmospheric models can be used to address specific emergency response interests. The Response Stage begins with a “hazardous incident” and concludes when the hazard is considered “contained” or "under control”. Near real-time meteorological information has a significant impact on the Response Stage. The Recovery Stage also has an active need for near real-time weather intelligence. The impact of this weather information is somewhat reduced, due to the imminent return to ‘normal’ conditions associated with this final stage.

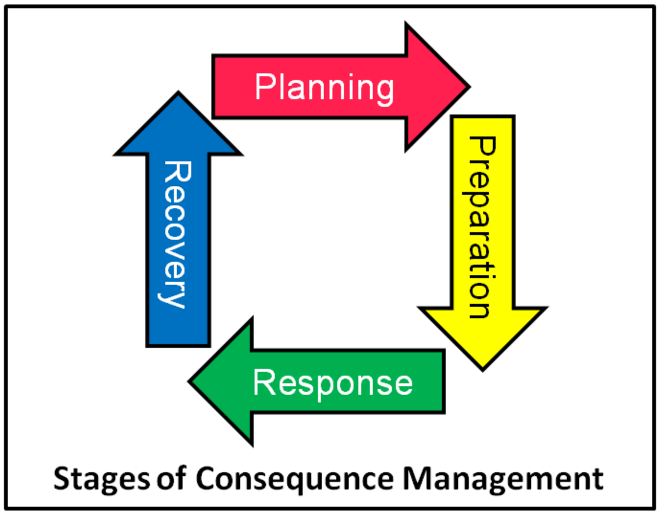

Figure 1. The four stages of Consequence Management.

1.3 Survey Application and Key Elements

The survey application focused on the Response Stage, since these activities held the greatest potential gain for the overview of meteorologically-based decision aids. As explained earlier, a Response Stage begins with a trigger, such as an explosion, a chemical release / dissemination, or the appearance of hazardous symptoms (as in the New Bedford case). Local personnel report the incident to a decision maker (911 operator) who must evaluate what type of professionals (volunteers) are needed to address the event. Such trained professionals are tasked to protect life (first-aiders), property (fire fighters) and ensure security (police). In the scenario of an airborne chemical release, the first- and most critical concerns are to identify the hazardous material and the medium of transport (in this case, the atmosphere). BEFORE a response unit can be released, knowledge of where the hazardous or ‘hot’ zone is, and if the situation is dynamic, where the hazardous material is going, is required. As in the New Bedford case, when the initial assessment is too sketchy, the rescue personnel can soon become numbered among those injured by the assailing hazard. Translating this important point into a key survey element, emergency response weather information needs to be both timely and representative of the hazardous environment. Most First-Response Units will react within 5 minutes (+/- some adjustment for the regional size covered and local traffic). This response time means that any weather information needs to be available in less than 5 minutes.

The assessment step of the Response Stage begins with the initial incident report, but then continues throughout the entire stage. Once the incident commander (IC) arrives on site, the next weather-driven action is immediately initiated. That is, the IC must layout the three hazard control zones: “hot”, “warm” and “cold”. The “hot” zone is an area that contains the ‘airborne hazard’. Here, the search and rescue operations, as well as the counter measures, are implemented. Sampling of the hazardous substance occurs within this “hot” region. The “warm” zone functions as the decontamination area, which includes emergency, technical, and equipment decontamination. The “cold” zone is a staging area. Within this cold zone, operations are initiated, support activities are organized, and public relation communications can be safely conducted.

The layout of these three hazard zones is first and foremost a function of atmospheric conditions (see figure 2). Local, steering winds and ambient temperatures are critical inputs for the layout. Practical logistics can usurp this first-preferred layout; however, it generally comes with an acknowledged risk. When the zones are documented, the driving wind direction is clearly annotated! If the wind shifts during the Response Stage, the IC needs to have this wind shift anticipated, or known as soon as possible. The impact of this information not only affects logistics, but more importantly, could be life-threatening to victims, rescuers and on-lookers. Thus, a key element for the survey would be for timely, representative weather information that reflects current and if possible, future local atmospheric conditions.

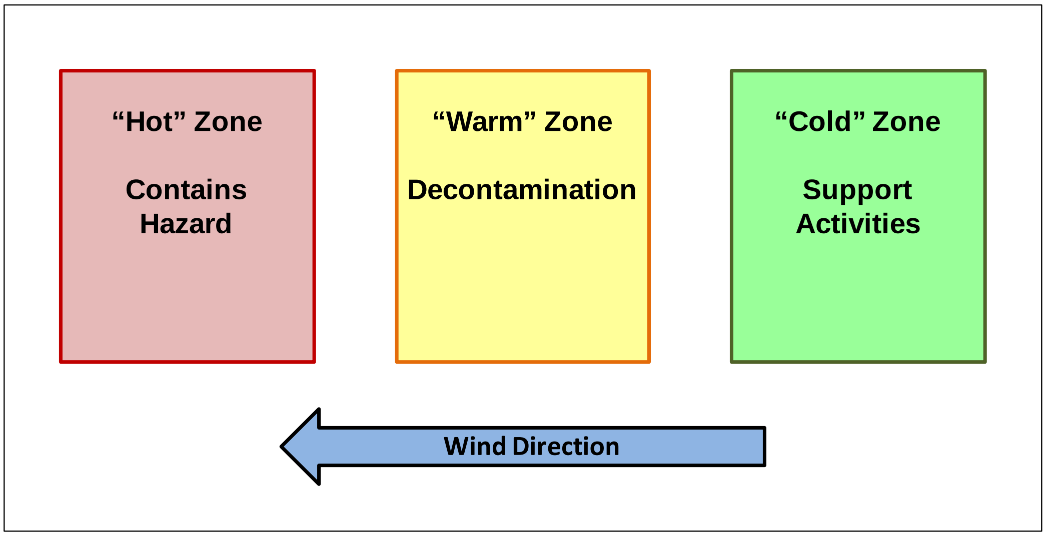

Figure 2. The Response Stage layout requires knowledge of the atmospheric conditions.

During the Response Stage, the given scenario can evolve into another situation entirely. For example, a released chemical could respond to an ambient temperature increase by changing states from liquid to gas. Such a transition could be accompanied by an explosion. This sudden explosion could instantly extend the “hot” zone over the warm and cold zones (see figure 3), endangering all personnel within the new footprint area. The IC needs to know these potential scenario changes, so that those persons most closely impacted by such changes, can be protected. For the survey, the key element is impact. Knowledge of how the current and future weather will impact the ongoing emergency scenario is very important.

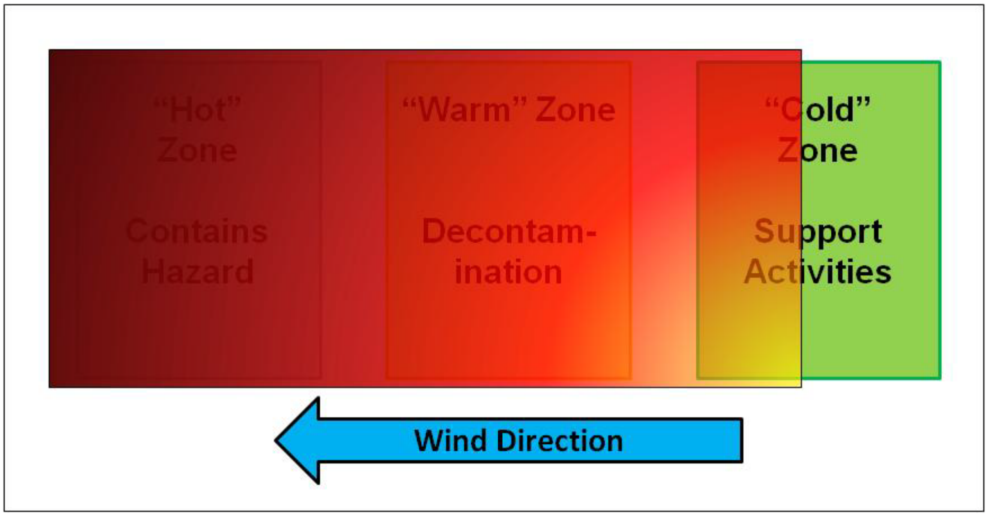

Figure 3. Sudden changes, such as a temperature-driven explosion in the “Hot” zone, impact the Response Stage layout.

In summary, the critical elements for a meteorologically-based emergency response system need to include weather information that is timely, representative of current and future conditions, and flags potential hazardous impacts.

1.4 Survey Content

The initial survey of emergency response tools produced an overwhelming array of useful equipment. Therefore, a refinement was imposed on the targeted products being surveyed. In addition to the pruning qualifications already discussed, additional restrictions included:

(1) Requiring the product to be assembled with minimal training.
(2) Requiring the product to be durable.
(3) Requiring the product input/output to be intuitive (needing minimal training).
(4) Requiring the product to be cost-effective.

System mobility and installation time were also considered very important. Though, systems without these features were not excluded. The final system list was reduced to less than 30 units, and is listed in appendix A.

1.5 Defining a Meteorologically-based Emergency Response System

For the survey to evaluate a “system”, a clear definition of what constituted a system was needed. We structured a system around three functions: data input, atmospheric interpretation and user output. “Data input” included any and all measurable quantities logged by the unit. The “atmospheric interpretation” generally consisted of models used by the system. The “user output” included products generated by the unit that the decision maker could employ. Other areas of distinction were the software platform on which the system was constructed, and the power supply options. Power loss is a common occurrence during emergency situations.

1.6 Meteorological Data Impact Emergency Responses

Meteorological data driving decisions made during an emergency is not a new concept. The Environmental Protection Agency (EPA) and National Oceanic and Atmospheric Administration (NOAA) recognized the importance of meteorological data over 25 years ago, which lead to the development of their computer package: Computer-Aided Management of Emergency Operations (CAMEO), Areal Locations of Hazardous Atmospheres (ALOHA) and, Mapping Applications for Response, Planning and Local Operational Tasks (MARPLOT) (Katz, 2006). The EPA/NOAA package has since become a pseudo industry standard, and will be discussed in section 2. In this section, we present a sample of how individual meteorological variables are an integral part in emergency event decisions (see Table 1).

WINDS: The two most critical meteorological measurements for toxic airborne release emergencies are winds and temperatures. Winds provide the primary plume-steering mechanism (advection) in atmospheric transport and diffusion modeling. Chemical plume dispersion is tied to “turbulent mixing”, which is a function of both winds and temperature.

TEMPERATURE: Temperature has additional impacts in that a chemical state can change with a change in temperature. For example, water vaporizes at 100 ^{o}C and freezes at 0 ^{o}C. In contrast, phosphorus hydride vaporizes at -88 ^{o}C. Also, warmer ambient temperatures hold more water vapor. This added vapor could intensify a plume cloud.

Emergency responders are required to wear protective gear. When temperatures are above certain thresholds, this extra material can create a life-threatening condition and cause heat cramps, heat exhaustion or heat stroke. Precautions, such as drinking more fluids, shifting people in and out of activities, can be taken to prevent these life-threatening effects, IF the temperature-driven hazard is known by a decision maker.

RELATIVE HUMIDITY: Relative humidity measurements are a factor in determining the contaminated vapor cloud density, or vapor pressure.

DEW POINT: When an environmental temperature reaches the dew-point temperature, toxic chemicals may become trapped in a low-lying, saturated atmosphere. This situation could result in a hazardous condition on the ground. In an arid desert, this is not generally a factor.

PRESSURE: Barometric pressure impacts the upward and downward vertical air movement in the atmosphere. When the pressure increases, then air aloft will sinks. In this situation, higher pressure could trap air particulates close to the surface. In contrast, if the pressure was falling (air rising upwards), the airborne particulates would rise and disperse into the atmosphere.

RAINFALL: Rainfall can be a favorable or unfavorable contributor to a chemical release. For some chemicals, rain would help wash the potentially contaminating chemical / particulates out of the atmosphere. Unfortunately, the net effect may be to contaminate the ground and/or ground water.

The potential for chemical pooling during a rain storm can create hazardous conditions for first-responders. And finally, water is also an activator for some chemicals, such as phosphine, which is associated with pest control agents (Columbia Weather, 2005).

Winds	**Temperature (T)**	**Relative Humidity**	**Dew-point (T_d)**	**Pressure**	**Rainfall**
Hazard Control Zone Layout.	T& D Modeling Input.	Used to determine contaminated vapor cloud density or vapor pressure.	When $T=T_d$ near the surface, the saturated atmosphere can trap toxic chemicals.	Rising/falling pressure indicates falling and rising air, which can trap or release chemicals in the atmosphere.	Rainfall can help wash contaminating chemicals out of atmosphere.
T& D Modeling Input.	Warmer air holds more water & could intensify a plume.				Rainfall can cause chemical contamination in ground/ground water.
	Chemical state changes at certain temperature thresholds.				
	Heat Index (thresholds)				

Table 1. Examples of how meteorological data impact emergency response decisions.

2. SAMPLE OF SURVEYED SYSTEM ATTRIBUTES

The survey's purpose was NOT to rate or endorse any system. Instead, we identified several practical attributes of an emergency response weather system. These attributes constitute only a portion of a complete system. Three of these attributes are described here, to give the reader a sample of how meteorological science and technology is addressing some of the important emergency response concerns. The three attributes that will be discussed include: the networking of samplers to better assess the hazardous situation, the use of various models to diagnose an incident area, and the technical and logistical efficiencies currently available. Before addressing these system characteristics, there was one element that was referenced by the majority of systems surveyed. This apparent 'industry standard' for meteorologically-based emergency response technology was the EPA/NOAA CAMEO / ALOHA / MARPLOT software package.

2.1 An Emergency Response "Standard"

The EPA/NOAA "CAMEO/ALOHA/MARPLOT" software package grew from a need for both insitu meteorological data, as well as a quick-processing dispersion model. Since local data were more representative of the actual incident conditions than a regional airport or fixed site resource, any prediction stemming from a local data resource would, at least theoretically, produce a more accurate picture of conditions and their associated safety options. Consequently, the EPA/NOAA software suite provided, and continues to provide for, both a manual meteorological data entry, as well as an automated meteorological tower data input. The resource for data was left to the user; therefore, the package was considered an element or component, rather than a complete system. Their atmospheric interpretation includes chemical input (CAMEO) and a very basic dispersion model (ALOHA). The system output overlays the calculated chemical plume onto a user selected map (MARPLOT) which can utilize street maps, topography or satellite images. Once the initial data are entered, the efficiency of their system output is most impressive. Automated data-entry-to-mapped-output can occur within a few minutes. (U.S. EPA and NOAA, 2007)

2.2 Networking Samplers

Once a hazardous airborne-release incident occurs, the first step is to assess the situation. As seen in the New Bedford case, knowing the chemical is a critical piece of information, immediately followed by knowing the atmospheric conditions. An example of how a system might conduct the assessment comes from the Advanced Distributed Sensor Systems - SensorPod Network®. Using subsystems, various samplers, such as a ChemPod®, RadPod™, WeatherPod®, CloudPod™, VisPod™, SatPod™ and "C3P" unit were networked together. The ChemPod® sensor was designed as a battery-powered, lightweight, self-contained module for measuring chemical warfare agents, toxic industrial compounds or volatile organic compounds. The module was self-sufficient, wireless, and powered through rechargeable or external batteries, or solar panels. The RadPod™ was similar to the ChemPod®, though its primary function was to identify radioactive materials. The WeatherPod® was a lightweight, miniaturized self-contained unit powered through the same options as the ChemPod®, but served to gather environmental information such as pressure, air temperature, humidity, wind speed, wind direction (ultrasonic), and rain amounts. For remote sampling relevant to assessing current toxic plume conditions, the CloudPod™ provided ceilometer measurements, and the VisPod™ conveyed horizontal visibility. The significant feature of these subsystems was the ability to easily deploy and network all these information-gathering components in a coherent manner; thus, constructively addressing the assessment step(s) of an emergency situation. The SatPod™ and Command, Control and Communications Pod (C3P) assisted in this important effort (French and Tate, 2009; ADSS, 2009).

2.3 Models to Diagnose an Incident

Near real-time insitu data are important to the responder. These data become much more useful when they are interpreted by a model representing the hazardous area. The majority of systems surveyed referenced CAMEO / ALOHA as their primary weather interpretation model. The system described in section 2.2 referenced the *Hazard Prediction and Assessment Capability* (HPAC) for their atmospheric interpretation model (French & Tate, 2009). HPAC is an automated software system that uses integrated source terms, high-resolution weather forecasts and atmospheric transport & dispersion analyses to model hazard areas produced by military or terrorist incidents and industrial accidents. (DTRA, 2009) Verbal communication with Emergency Operations Center personnel and in-field Emergency First-Responders indicate that one of HPAC's greatest strengths seems to be during the Planning and Preparation Stages of the consequence management process.

Another weather and chemical interpretation "model" cited in the survey was ADASHI® (Automated Decision Aid System for Hazardous Incidents). This software package was integrated into a portable, wireless weather station called WEATHERPAK®. Thirty-second updates of their chemical plume modeling recognized the need for timeliness and representative measurements. Further investigation showed that the ADASHI® software was certified as "Qualified Anti-Terrorism Technology" by the U.S. Department of Homeland Security (ADASHI, 2009). ADASHI® was designed for managing, communicating, responding to, and reporting critical incidents. Comments from first-response users reinforced the timely conveyance of information, the improved logistics and coordination activities experienced during an event, and the assistance gained by the visualization software. The chemical dispersion model used by ADASHI®/WEATHERPAK® was the EPA/NOAA CAMEO / ALOHA.

This pattern of finding significant improvements to sensors and application software, but an absence of “new and improved” meteorological modeling software was not novel. A potential “lesson learned” from this subtle pattern will be expounded further in section 3.

2.4 Quick System Implementation

When an airborne hazard is released, the First-Response Team’s highest priority is to minimize human casualties. Time spent preparing their equipment for use is important; however, their professional priorities dictate that the value added from this setup time investment must be balanced against the time lost in attending to human casualties. For meteorological equipment that is intended to be an insitu measurement, this means that the physical setup of hardware must be extremely efficient. Two examples of systems addressing this issue were the Rainwise HM-1 HAZMAT Weather Station, and the Coastal Environmental WEATHERPAK®. The HM-1 HAZMAT contained an internal electronic compass to ensure that the wind direction was accurate regardless of the assembly’s orientation. The sensor measurements consisted of the standard meteorological variables (pressure, temperature, dewpoint, relative humidity, wind speed/direction), as well as heat index and nuclear radiation values. Their weather interpretation model was CAMEO/ALOHA. The time reported for setup and being operational was less than 2 minutes (Rainwise, 2009).

The WEATHERPAK® System also recognized the need for an efficient setup. The self-contained weather station included a self-aligning compass, interlocking connections and setup procedures that required no fine hand movements. The system utilized CAMEO/ALOHA as one of their chemical plume modeling software options. With no cables or connectors to contend with, the company reported that one person wearing protective gear could set up the system in less than one minute without tools (WEATHERPAK®, 2009).

3. DISCUSSIONS: WHAT’S MISSING?

The technology reviewed during the survey was truly impressive with the many improved technological efficiencies, attention to hardware details and the networking capabilities. What seemed to be lacking, though, was the same revolutionary advancements in the area of operational atmospheric models.

Numerous transport and diffusion models were identified by both individual software packages, as well as three detailed model-summary directories published since the 1990s. From these resources, it was clear that each model brought rich, helpful insights into the atmospheric transport and diffusion (and atmospheric dispersion) efforts. However, when these tools were matched with Response Stage requirements, the list of applicable software programs was reduced significantly. For example, in a document prepared for the Department of Energy, 94 atmospheric dispersion models were summarized using 23 attributes (Mazzola et al, 1995). Since the Response Stage involves life-saving decisions, the attribute selected as most-relevant was model “validation (/verification)”. Mazzola et al distinguished verification from validation as follows, “An atmospheric transport model can be verified by comparing field data gathered in an environmental monitoring program, to predicted model results. …A model can be validated by comparing its results to hard calculations which only assures that the computer is following the appropriate algorithms and logic. Most models undergo extensive validation, but suffer from lack of environmental monitoring data to meet strict verification criteria.” (Mazzola et al, 1995). For our system survey, only those software packages that referenced a data verification of their model were included. Out of the 94 potential candidates, only 44% of them qualified. To determine which of these qualified models might be appropriate in an operational Response Stage weather system, the time required to produce a decision-worthy output was investigated.

Unfortunately, most model documentation did not report the data-to-results efficiency. This calibration void may be due to the constantly evolving computer technology. Or, perhaps it was due to the significant challenge in defining a consistent, inter-model stopwatch start, required content and stopwatch end. With the diversity of model types and content, creating benchmark standards are not trivial.

Perhaps a better approach to calibrating time efficiency might be to consider the entire weather system and simulate the challenge faced by the first-responder. That is, begin a timed sequence with the installation of the first hardware piece and end the calibration time with the first decision-making output of the system. A form of this approach was conducted by the System Assessment and Validation for Emergency Responders (SAVER) Program. In 2006, the results of a six-system inter-comparison were summarized. Using a scale of 100, each system was evaluated on affordability, capability, deploy-ability, maintainability, and usability. Results ranged between 58-80%, indicating room for improvement.

4. SUMMARY AND RECOMMENDATIONS

When a toxic chemical is released into the atmosphere, emergency personnel need to make critical decisions based on the atmospheric conditions that could save or lose lives. A survey of meteorologically-based tools was conducted. A refinement of survey requirements focused the decision applications on the third stage of a Consequence Management Process, called the Response Stage. This stage begins with a hazardous incident and ends when the hazard is ‘contained’ or ‘under control’. The type of emergency was defined as an airborne, chemical release hazard. The meteorological data involved in responding to airborne chemical hazards included standard meteorological variables. An explanation of each variable’s significance to the emergency decision maker was provided.

Systems surveyed showed several important features for the first-responder, such as the networking of various samplers, the use of various models to diagnose an incident and, the efficiency of hardware installation. With all the hard- and software technological advancements, the one piece that didn’t seem to keep pace with the other system improvements was the integration of an advanced operational atmospheric transport and dispersion models. The models themselves have advanced; however, their operational readiness for emergency first-responder, decision-making implementation, had not yet come together.

Recommendations for future actions included the integration of advanced ‘certified’ models into the current, progressive operational weather systems, and the establishment of a system efficiency standard. The latter observation was based on the need to balance time taken to install systems during an emergency against the time needed for ‘search and rescue’ operations. One suggested approach for determining a system’s efficiency was to measure the time interval between starting to install the system hardware and reaching the first decision-making output. Variations of this time efficiency calibration were conducted on six weather systems by SAVER. The results indicated room for improvement. Simulating the first -responders environment would not only assist in resolving the question of system efficiency, but may also prompt additional system improvements. As emergency response weather systems improve, better decisions can be made, and the potential for saving lives from hazardous environments will also be increased.

5. ACKNOWLEDGEMENTS

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APPENDIX A: List of units included in the emergency response weather systems survey.

Manufacturer	Unit Name
Advanced Distributed Sensor Systems	WeatherPod
AFC International, Inc./Casella USA	Nomad/187115D
Alluviam, LLC	HazMasterG3
Campbell Scientific	Air Port Get Weather Station
Campbell Scientific	ET107 weather station
Campbell Scientific	Fire Weather
Campbell Scientific	Visual Weather Station
Climatronics	TACMET II HazMat Station
Coastal Environmental	C-5 Standard
Coastal Environmental	Urban WeatherPak
Coastal Environmental	WEATHERPAK
Columbia Weather System	Orion Nomad
Columbia Weather System	Pegusus EX FlyAway Kit
Davis Instruments	6163 wireless Vantage Pro 2 Plus
Defense Group Inc.	CoBra
Mesotech	HazMat Stationsame as micro weather pro
New Mountain Innovations Inc.	NM100 Ultrsonic Weather
NovaLynx Corp.	110-ws-18/Portable weather station
Onset	HOBO U30-NRC weather station starter kit
RAE Systems INC.	HazMet Detection Technology
RainWise	HM-1 HAZMAT
RainWise	Rainwise MK-III RTN-LR Long Range Wireless Weather Station
WeatherHawk	240 wireless Weather Station
WeatherHawk	511 wired Weather Station
Yankee Enviromental Systems	TMS 7200 Total Metorological Sensor

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