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Decision Support for Public Health and Safety Related to Air Quality

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1.0 Introduction

The Shenandoah Valley Air Quality (SHENAIR) Initiative is a consortium of Virginia universities, local governments, and citizen's groups that is focused on air quality issues in the Shenandoah Valley, Virginia. As part of this effort, researchers at the University of Virginia, James Madison University, and the Office of the State Climatologist for Virginia are working with local community leaders to provide two different decision support tools aimed at improving public health and safety. One tool is the Atmospheric Influences on Respiratory Illness Alert System (AIRIAS) for the Shenandoah Valley. AIRIAS links the spatial synoptic classification system (Sheridan, 2002) with real-time weather data to predict conditions that pose increased health risks to individuals suffering from respiratory ailments.

The other system is the CATS/HPAC decision support system for emergency response. This system (developed by Science Applications International Corporation (SAIC) in the 1990's for the Federal government) uses sophisticated weather and air dispersion models to predict the trajectories and atmospheric concentrations of toxic chemicals released during a hazardous chemical accident or terrorist attack. This paper describes the intended benefits and implications from the deployment of these two systems.

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2.0 Atmospheric Influences on respiratory Illness Alert System (AIRIAS)

The research group at the University of Virginia (led by R. Davis) is charged with examining the atmosphere's influence upon respiratory health through development of the Atmospheric Influences on Respiratory Illness Alert System (AIRIAS) for the Shenandoah Valley. This alert system is based on a suite of atmospheric and environmental variables that may impact respiratory problems. An ultimate goal of AIRIAS is to provide daily forecasts of respiratory distress.

This alert system targets individuals and institutions within the Shenandoah Valley that are directly affected by respiratory illness. Through AIRIAS, we intend to provide a user-friendly alert system that disseminates day-in-advance predictions of respiratory health. Individuals who experience respiratory distress as a result of atmospheric influences comprise the target population for the developed system. We also aim to assist the medical care providers, ranging from school nurses to hospital administrators, by forecasting days with an increased number of patients. The construction of such an alert system not only assists those directly affected by respiratory ailments but also advances scientific understanding surrounding the complex links between respiratory health and environmental factors.

Because of the inherent difficulty in quantifying the environment's impact on human health, many studies take a simpler approach by using only specific atmospheric variables or finite at-risk samples of people. Some research focused only on the daily variability of specific variables (such as ozone, particulates, temperature, and humidity) upon a target population. These investigations have yielded conflicting results. For example, some studies indicate that ozone increases risk of respiratory illness (e.g., Bates and Sizto, 1987; Ponka and Virtanen, 1996; Just et al., 2002; Gent et al., 2003), whereas others claim that ozone is not a significant risk factor (e.g., Hoek and Brunekreef, 1995; Braun-Fahrlander, 1997). These dissimilar findings may be attributed to a variety of factors, such as highly localized influences on respiratory illness, varying target populations, and different methods.

The Shenandoah Valley is approximately 200 miles long, extending from the Virginia-West Virginia border to the vicinity of Roanoke, and is populated by over one million people. Our analysis employs various daily data sets from 2001–2006. One data set includes the number of daily emergency hospital respiratory admissions for Valley residents (as identified by zip code). These data are provided by Solucient, a privately-owned healthcare data company, and represent the number of patients who were admitted to emergency rooms across Virginia. A respiratory specialist identified a list of conditions that could potentially be related to environmental factors. These conditions are designated on the UB-92 form filled out by the patient during the payment process. Although our data set emphasizes severe respiratory cases, we hypothesize that high hospital admissions are also linked to respiratory distress among the entire Valley population (Figure 1).

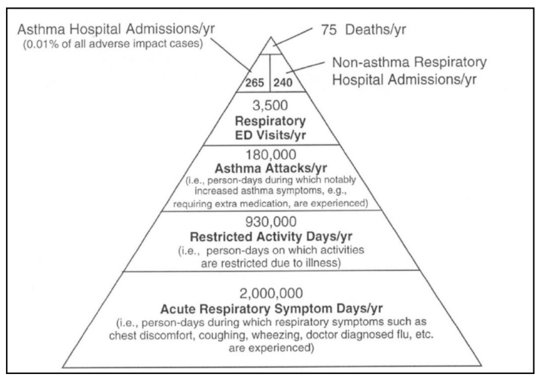


Figure 1. Predicted reductions in adverse asthma response amongst subgroups of the New York City population as a result of improved air quality standards. From Thurston, 1997.

Numerous other data were collected to represent the atmospheric and environmental conditions that might potentially impact respiratory admissions rates. For Martinsburg, WV and Roanoke, VA, stations located in the northern and southern parts of the valley, respectively, air flow back-trajectories from the HYbrid Single Particle Lagrangian Integrated Trajectory Model

1997–2006) (HYSPLIT, 2006) were assembled along with daily air mass type using the Spatial Synoptic Classification (SSC, Sheridan 2002) (2001–2006).

Numerous EPA pollution monitoring sites in and around the Shenandoah Valley provided measurements of ozone, sulfur dioxide, nitrogen dioxide, and carbon monoxide (2001–2006) (EPA, 2007). Finally, pollen grain counts from Richmond and Harrisonburg were incorporated to approximate aero-allergen levels for the Valley (2001–2006). The complex interactions (Figure 2) between the environmental variables have likely suppressed advancement of a

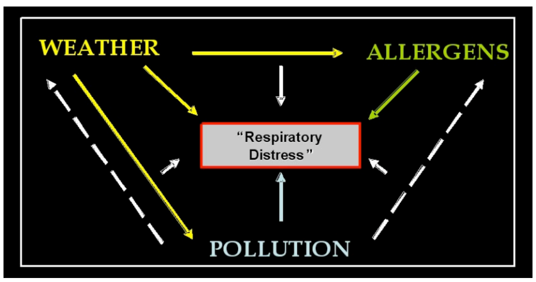


Figure 2. Theorized complex interactions between environmental variables and respiratory distress. Solid lines represent known relationships; dashed lines represent other potential significant feedback mechanisms

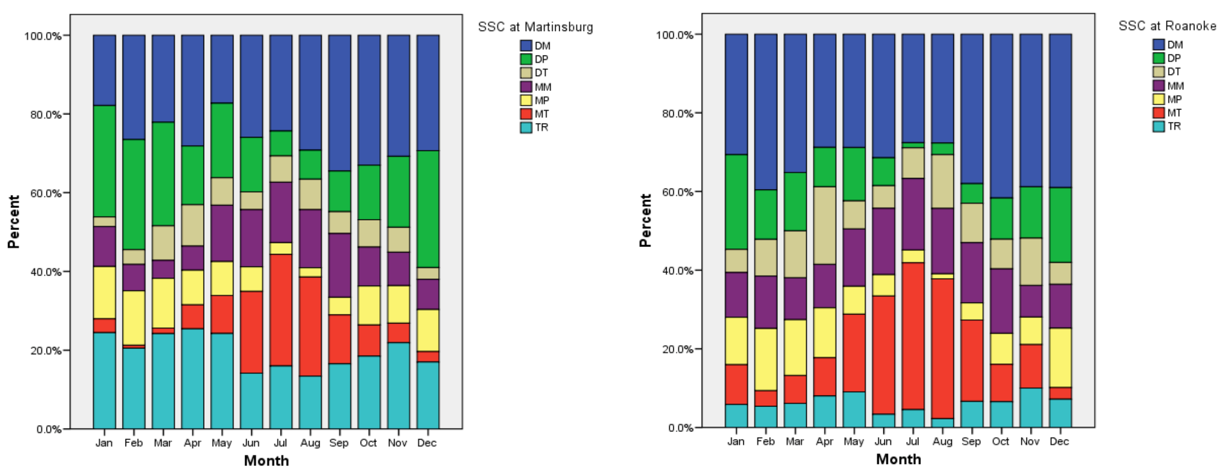
multivariate model linking atmospheric influences to respiratory health. For example, although aeroallergens and pollution are known to have direct influences on respiratory distress, both of these factors are significantly impacted by weather variability, which also influences respiratory conditions. Thus, the interactions between potential predictors must be carefully considered in model development.

As the Shenandoah Valley represents a large geographic area with complex topography, we anticipate that different subgroups of the population experience different exposures to weather, pollutants, and pollens on a daily basis. Accordingly, we first consider the spatial variance between our principal independent variables. To study spatial variance in the weather between Roanoke and Martinsburg, we adopt two approaches: (1) A comparison of the SSC climatologies for the two stations, and (2) A comparison of air flow regimes, captured using back-trajectories generated with HYSPLIT. On fifty percent of days over the past decade the SSC has been the same for both stations. The SSC climatologies of the stations show differences in the seasonality of air mass patterns between the extremes of the Shenandoah Valley (Figures 3a, 3b). This difference in synoptic-scale climate supports our hypothesis on varying exposures to environmental parameters.

Back-trajectory analysis also supports our hypothesis, as comparisons of normalized trajectories into the stations reveal significant differences during certain air masses and seasons (Table 1). Complete details of the trajectory comparison procedure may be found in Hondula et al.

	DM	DP	DT	MM	MP	MT
Winter	+			+	+	
Spring	+		+	+	+	
Summer	+			+	+	+
Fall				+		+

Table 1. Summary of statistical comparison between trajectory groups into Martinsburg and Roanoke. + sign indicates a significant difference between trajectory groups based on station at α = 0.05.



Figures 3a and 3b. Spatial Synoptic Classification Climatology for air mass frequency, by month (a) Martinsburg, WV, and (b) Roanoke, VA, 1997–2006. The air mass classifications are: Dry Moderate (DM), Dry Polar (DP), Dry Tropical (DT), Moist Moderate (MM), Moist Polar (MP), Moist Tropical (MT), and Transition (TR).

Pollution and aeroallegern measurements also reveal spatial variability across our study area. While inter-station correlations between pollutant time series are relatively high, these correlations decrease with increasing distance. For example, the ozone time series between Arlington, VA and Fairfax, VA, two stations separated by approximately 25 km, have a Pearson correlation of 0.89, whereas the correlation between Arlington and Wythe, VA (≈430km) is 0.57. This pattern is mirrored for other pollutants.

Pollen data are available for two measuring sites, Harrisonburg, VA and Richmond, VA, but only the first is located within the confines of the Shenandoah Valley. However, the correlation between the two stations reveals high regional variability in aeroallergen concentrations. The correlation for mold spores is statistically significant but is only 0.72. The correlations for tree, grass, and ragweed pollens between the two sites are not statistically significant and are less than 0.50.

The combination of spatially varying climate, air flow regimes, and pollutant and aeroallergen concentrations support a division of the study area into Northern Valley and Southern Valley subregions. While this still leaves relatively large subregions, it should reduce the variance in exposures to environmental parameters.

As the goal is to predict day-to-day deviations in the hospital admission pattern that result from atmospheric influences, we apply a LOWESS smoother on the 6-year mean hospital admissions to remove long-term patterns that are likely unrelated to the short-term changes in weather, pollution, and aeroallergens. We then standardize our residuals assuming a Poisson-like distribution to remove temporal heterogeneity in the admissions variance. Figure 4 shows the LOWESS smoother for the entire valley population. Thus, our model will predict the deviation of daily hospital admissions from the smoothed value that effectively removes a fairly complex seasonal signal in our dependent variable.

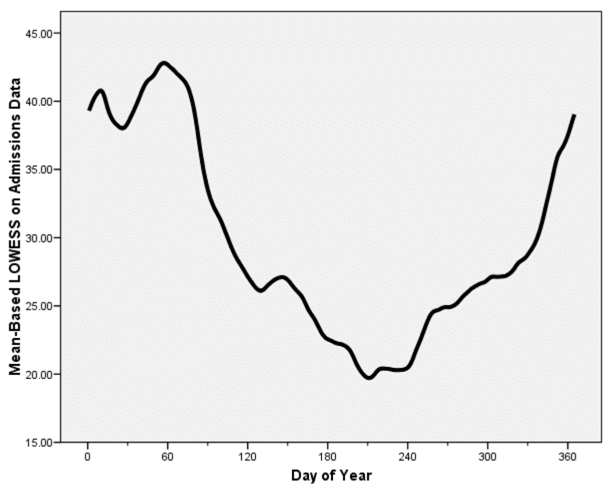


Figure 4. LOWESS smoothed six-year mean respiratory admissions in the Shenandoah Valley.

Present research at UVA and the State Climatologist is focused on determining the suite of interactions between the independent variables and the associated response of the dependent variable. We have found significant relationships between air masses and both pollutant levels and back-trajectories but no significant relationship between pollen concentrations and either air masses or individual weather variables. Time-series analysis reveals high autocorrelation in pollution and pollen data. Preliminary results suggest elevated risk during Dry Moderate, Dry Tropical, and Moist Tropical air masses and when mid-morning temperatures fall below -5°C, although this research is ongoing.

In the near future, UVA will develop a multivariate predictive model that will run for one year in a pilot study. This study will have four major goals: (1) Determine the predictive accuracy of the model, (2) Evaluate behavioral impact on target audiences, (3) Evaluate the functional utility of the alert system technology, and (4) Determine the suitability of the overall model design. The target audiences will be comprised of stakeholders who live or work in the Shenandoah Valley, including chronic respiratory sufferers, hospital administrators, physicians, and school nurses.

The model output will be a daily categorized risk level of elevated respiratory distress admissions, sent via e-mail and text message. Each target group will be asked to keep a daily health log, recording respiratory response/observations and actions taken.

Other daily system measures will be recorded by the SHENAIR team, including the asthma alert level generated by the model, the number of alerts sent out, and the number of hits on the model's webpage. The complete set of performance measures will be used for model tuning and system design adjustments prior to final model implementation for the general public in 2009.

3.0 CATS/HPAC Decision Support for Emergency Responders

The James Madison University team (led by M. Deaton) has the responsibility for developing the Decision Support System for Emergency Responders. The objectives of this effort are to: (1) generate a prototype decision support system based on the combined capabilities of CATS/HPAC, (2) test through a pilot study the utility of the decision support system for emergency responders, and (3) generate a practicable tool.

In the late 1980s, the National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA) jointly developed a system for emergency responders termed Computer Aided Management of Emergency Operations (CAMEO). CAMEO relies on a modified Gaussian dispersion model termed ALOHA. A series of "puffs" are modeled that follow a Gaussian dispersion. There are limitations to ALOHA including (1) it provides only rough estimates of the concentrations in the affected areas, (2) it has a limited range away from the source (<10 km), and (3) there are restrictive assumptions about the terrain, buildings, constant wind, and neutral buoyancy. CATS/HPAC aims to ameliorate or remove some of these constraints

The Consequence Assessment Tool Set (CATS) was developed by the Federal Emergency Management Agency (FEMA) and the Defense Threat Reduction Agency. The Hazard Prediction and Assessment Capability (HPAC) also was developed for the Defense Threat Reduction Agency and has been used in diverse applications such as for military support in Iraq and Afghanistan, Presidential Inaugurations, and the US-hosted Olympics. SAIC developed the combined CATS/HPAC system for the federal government in the 1990s. It uses sophisticated weather and air dispersion models to predict the trajectories and atmospheric

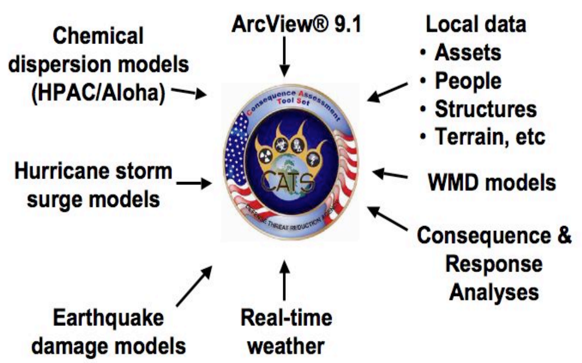


Figure 5. Elements incorporated into the CATS/HPAC.

concentrations of toxic chemicals released during a hazardous chemical accident or terrorist attack (figure 5).

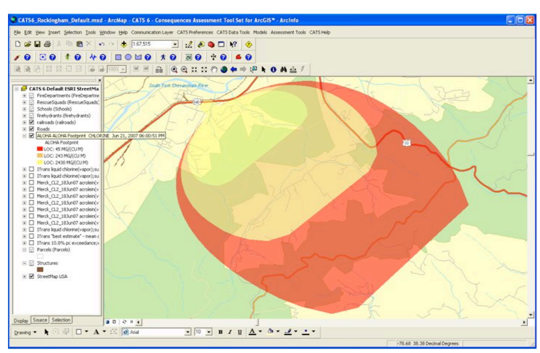
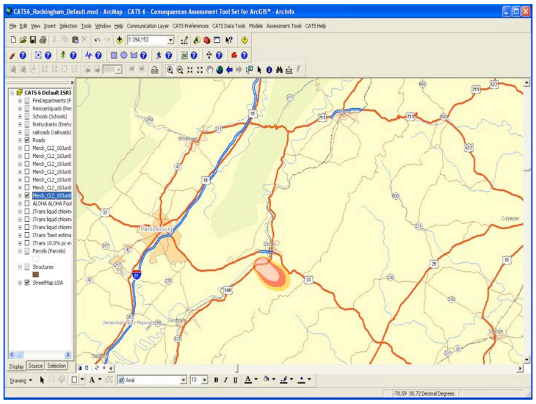


Figure 6. ALOHA model results of hypothetical release in downtown Harrisonburg

A comparison of the ALOHA and CATS/HPAC dispersions for a hypothetical release in downtown

Harrisonburg, VA can be seen in figures 6-9.



Figures 7-9 Progression of CATS/HPAC model results over time due to hypothetical release in downtown Harrisonburg

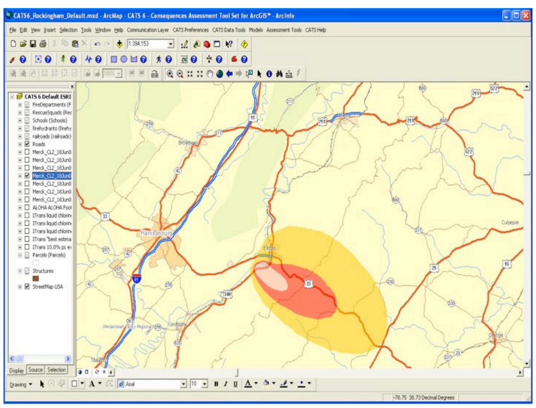


Figure 8

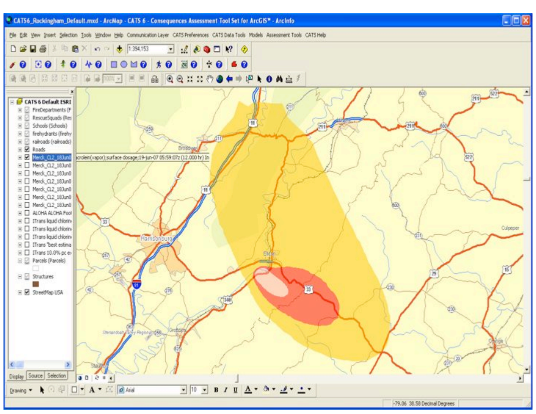


Figure 9 Note wind shift between figures 8 and 9 that blows the plume northward.

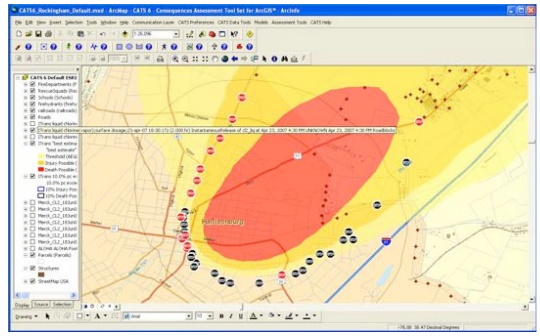


Figure 10 shows how the "assets" (emergency squads, fire vehicles, police vehicles, etc.) can be arranged to deal with the affected area of a release.

Limited experience with the CATS/HPAC model shows that it is far too complex for emergency responders to use on a routine basis. Some effort will be needed to extract the essence of the model so that the administrative features are transparent to the emergency operators. This effort is essential if the CATS/HPAC is to be used in emergencies.

The first step (in early December 2007) is to conduct a series of simulated "tabletop" exercises with emergency responders in the local area of JMU to determine what they like and do not like about the model, and what needs to be added. In early discussions, the comment was made that toxic events (either actual or potential) are rare, but still occur at least once a month on the I-81 corridor in Virginia. (I-81 cuts through the eastern half of Winchester, VA, and splits the JMU campus in half. So, toxic spills have great potential for casualties.) Flash floods and forest fires, however, are regular occurrences. (For example, the Shenandoah Valley is bounded by extensive National and State Parks, and National Forests.) An early effort, therefore, will be to incorporate the capability to deal with flash floods and forest fires.

Development of the CATS/HPAC decision support tool for emergency responders is in the early stages. Once the tabletop exercises have been completed and the results analyzed, full-scale simulations will be carried out in conjunction with other exercises required of the emergency responders. Those simulations are expected to be conducted during the first half of 2008.

4.0 Summary and conclusions

One of the objectives of the SHENAIR initiative is to put science to work for local users, and decision support tools are one of the most effective ways to do so. The AIRIAS support tool is aimed at the health provider community and those in the Valley who are susceptible to aeroallergens. The objective is to predict conditions that pose increased health risks to individuals suffering from respiratory ailments. If successful, the AIRIAS will give advance notice to health providers of when to expect patients to arrive at their doors.

The CATS/HPAC tool is aimed at a different clientele – emergency responders. The objective here is to provide the responders with the capability to manage their resources under stressful conditions when critical, life-threatening situations arise. One of the most daunting tasks is to extract that portion of the CATS/HPAC capability most useful to the emergency responders for not only toxic releases, but for the more common flash foods and forest fires as well.

For both AIRIAS and CATS/HPAC knowledge of environmental conditions and predictive values are critical to the success of each tool. Air quality is a common theme throughout.

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