Chemical/Biological Plume Analysis Knowledge Source (CPAKS)

Dr. Douglas J. Holzhauer, Dr. George Ramseyer, Capt Robert Duncomb, Mr. David Young
Air Force Research Laboratory
Information Directorate/IFTC
26 Electronics Parkway
Rome, NY 13441-4514

Dr. Digendra Das
SUNY Institute of Technology at Utica/Rome
Utica, NY

Abstract

Rapid determination of a contaminated area's location, size and toxicity is imperative for prompt situational assessment of a chemical/biological incident. The fastest method of predicting a contaminated area's characteristics is by simulating the path of the toxic plume using fluid flow analysis in conjunction with the forecasted weather conditions. The timeliness of this information is critical to the selection of a plan of action to be taken in response to such an incident.

The simulations that solve the partial differential equations describing the fluid flow of the chemical/biological contaminants are a function of the weather, the terrain and the scale of the area of interest. Modeling and simulation software packages, such as Hazard Prediction and Assessment Capability (HPAC), provide very good simulations. However, the results of these stand-alone simulations need to be integrated into a command and control architecture, such as that envisioned by the Air Force Research Laboratory's "Joint Battlespace Infosphere".

This Chemical/biological Plume Analysis Knowledge Source (CPAKS) is a critical step towards total integration of these simulations into a command and control schema based on an agent technology. CPAKS allows for automatic scenario generation and dynamic real time updating of the incident state based on the best available knowledge.

1. Introduction

To move chemical/biological incident information into the command and control information grid, our research has centered on the coupling of symbolic and numeric computing and on the integration of simulation results into dynamic incident planning. The resulting software system uses the Second order Closure Integrated Puff (SCIPUFF)[1] Lagrangian fluid flow simulation, to describe the plume development and subsequent contaminant dispersion. Symbolic reasoning knowledge sources help to develop and control the incident scenario. For better interoperability and control the modeling information is stored on an object-oriented database built on a blackboard architecture. Predicting where the effluents will go after their initial release is largely dependent on the weather conditions at the time of the incident, with the elements of greatest interest being the wind direction and speed. The weather data are obtained from the Air Force's MM5 weather model and are translated into an object format. To ensure the most accurate inputs for the SCIPUFF simulation, a hierarchy of weather objects has been developed. These include incident objects with attributes such as time and type, surface node objects with incident location attributes, and height objects with wind velocity and terrain elevation attributes. Once the incident and weather information is transformed into object form, the scenario knowledge source, a rule-based software package, formulates a series of parametric analyses based on the quality of the information that is available. The first look evaluation, based on limited knowledge, is immediately available to the planner as a worst case analysis.

The goal of this project was to develop a methodology that would allow a stand alone contaminant dispersion software package such as SCIPUFF to be a full participant in a dynamic command and control system such as the Joint Battlespace Infosphere. The Joint Battlespace Infosphere (JBI) is a combat information management system that provides individual users with the specific information required for their functional responsibilities during a crisis or conflict. The JBI integrates data from a wide variety of sources, aggregates this information, and distributes the information in the appropriate form and level of detail to users at all echelons[2]. Stand alone legacy software can provide valuable information to commanders and planners but needs to be more than a wrapper to become a full participant in an agent based system such as JBI. This project has achieved the initial steps toward this goal.

2. Software Architecture

The developed software combines both symbolic and numerical knowledge sources, which are integrated through the use of a blackboard knowledge representation and reasoning paradigm, specifically Generic BlackBoard Builder (GBB) from Knowledge Technologies Inc.[3] Various Knowledge Sources (KS) interact with an object-based representation of the weather forecast. The analysis is also represented as objects on the blackboard. The computational system consists of the following Knowledge Sources:

1) Main-KS
2) Read-prf-file-KS
3) Scenario-generator-KS
4) Read-scipuff-output-KS
5) Evaluate-plume-effects-KS

Although the current system is set up for the sequential implementation of each knowledge source, ideally the control of the analysis should follow a more opportunistic approach, using the full power of the blackboard architecture. This would allow for the activation of a Knowledge Source, as the information becomes available. The prototype used sequential control to allow concentration on the problems associated with integrating numerical and symbolic knowledge sources. Future plans call for the use of an opportunistic approach. During operation, the current software steps through the analysis in the same way an engineer would. The system architecture for the code is shown in Figure 1. The operation of the software is as follows.

The weather data is obtained through the use of the Mesoscale Model 5 (MM5) file transfer program and the MM5 conversion program. These produce the profile.prf file that contains the pertinent information for the plume analysis knowledge source. This file must be created before the activation of the plume analysis knowledge source program.

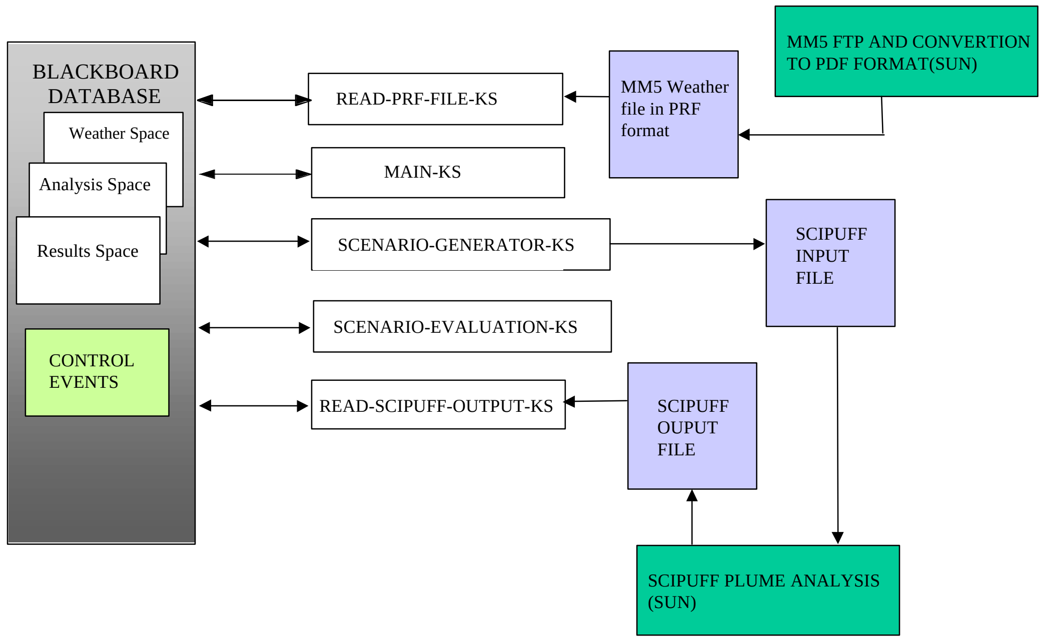

Figure 1 System Architecture

The blackboard system consists of five knowledge sources that are contained in separate files. To activate the system each knowledge source in loaded into the LISP/GBB environment. The first knowledge source is the *Main-KS*, which defines the unit classes, spaces and control structure on the blackboard system. This knowledge source defines the object database that is used to store the weather and plume analysis information.

The *Read-PRF-data-KS* develops the weather analysis objects based upon the unit classes defined by the *Main-KS*. It reads the profile.prf file that results from downloading the MM5 data and its subsequent conversion.

Scenario-Generation-KS is then activated by the instantiation of weather object onto the blackboard database. This knowledge source examines the objects and though a series of evaluations determines what analyses need to be accomplished to determine the effects of the chemical or biological plume on the area. This adds to the blackboard new information that will then be used to write several input files for the SCIPUFF plume analysis code. Several input files are generated using information obtained from the blackboard database. Currently this knowledge source does not directly activate the SCIPUFF analysis code because of difficulties in obtaining a Unix version of the code. Plans are to accomplish this in the very near future.

Once the SCIPUFF analyses have been accomplished, the *Read-output-KS* and *Evaluate-scenario-KS* knowledge sources are fired.

3. Weather Information and Read-prf-data Knowledge Source

Access to high-resolution numerical weather prediction model data is available from many sources including; the Air Force Weather Agency (AFWA), the Fleet Numerical Meteorology and Oceanography Center (FNMOC), and the National Centers for Environmental Prediction (NCEP). An important consideration in choosing our source is whether that same data will be available in a contingency location. This rules out our use of NCEP data which isn't available at high-resolution globally. The Air Force Weather Agency was chosen as the best source both because of the accuracy of their Mesoscale Model 5 (MM5) and their numerous 36km and 12km resolution windows available over contingency theaters worldwide. AFWA's weather data is available in many forms including raster images, textual observations and forecasts, and gridded binary (GRIB). We chose to work with gridded data because it offers us the ability to create a virtual observation post and virtual vertical profile for the point of release.

Currently, SCIPUFF accesses the required weather elements it needs by remote access to a server either at DTRA, AFWA, FNMOC, or at the Sembach Operational Weather Squadron in Germany. These servers have taken the raw GRIB data and run them through some conversion code to convert the raw data into SCIPUFF-formatted surface observations, gridded data, or vertical profiles. This data is retrieved from the server and then used to run SCIPUFF locally on a PC. There are some problems with this method including; the time delay with the remote access, the dependency on available communications and bandwidth, and the fact that this only returns one result at a time versus having the capability to do an ensemble of model runs. We have chosen to take a different route in the handling of weather inputs to SCIPUFF; a route that we think has advantages over the traditional method and is worth considering in the future operational architecture. This method is now described.

We utilize an automated file transfer pull script to bring the latest GRIB MM5 36km data to a local database. This GRIB data is then post-processed to index each forecast element in the database by time and height. A script defining the location of the incident is then used to extract a virtual vertical profile for the point of interest or a set of profiles for some user defined area of interest around the release site. This profile data is then read directly into an object database for use by the SCIPUFF program to produce the plume forecast. This method increases the timeliness of response by hosting the GRIB data locally which decreases communications and bandwidth dependencies and allows multiple runs of the same scenario with varying inputs to factor in uncertainty.

The blackboard database is used to store the weather information in an object format. This is accomplished by *Read-prf-data-ks*. This weather information is then available to any software agents that are a part of the JBI combat information system. The object nature of the information makes it more easily assimilated into an agent-based system. The development of an independent weather information base in a form that will be able to interact with many JBI client applications is planned. This knowledge source also creates additional wind objects that take into account the variability of the predicted wind speed. These can be used to develop a minimum wind condition for full characterization of the contaminated area. With winds, for example, this variance can be as much as 6 knots (Figure 2).

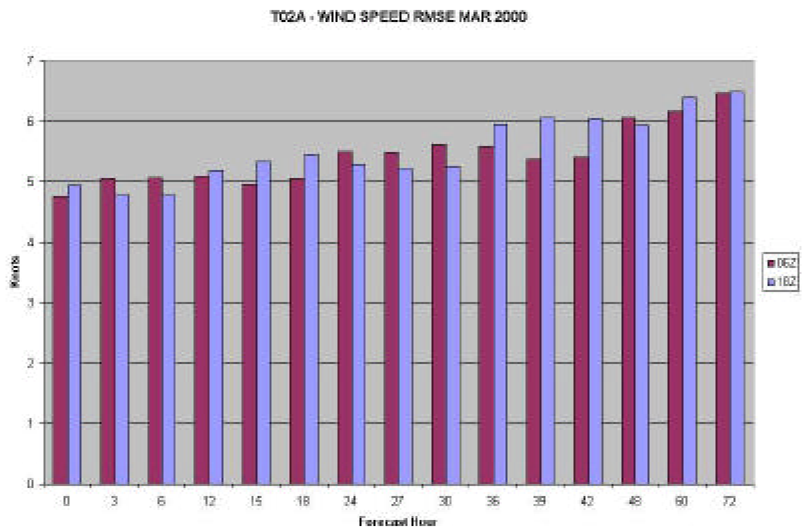

Figure 2 - Wind Speed Forecast Variation

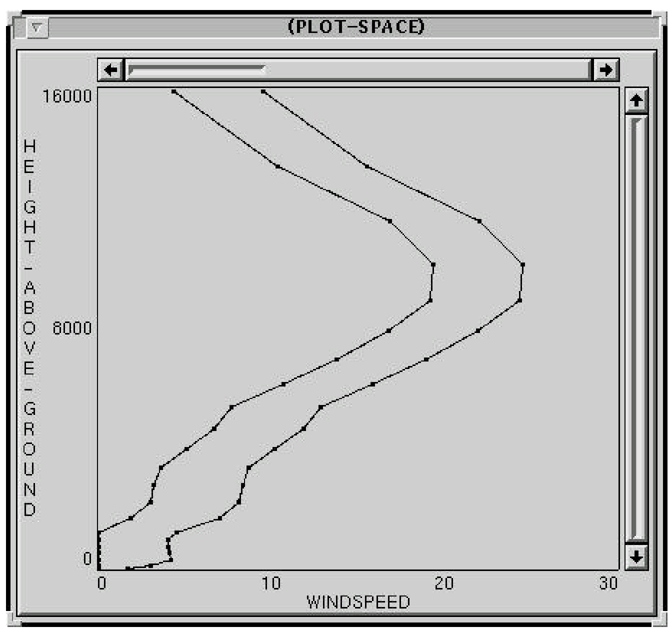

Figure 3 - Minimum and maximum predicted wind speed (m/s)
as function of height above ground (m)

4. Scenario Generator Knowledge Source

Given time, sensors can be placed in the areas of interest which are most likely effected by an incident, and parameters such as the type and extent of the effluent can be accurately determined. This information can then be entered into the combat information system, and very accurate incident information can then be obtained for the areas surrounding the sensor locations. However, the most critical time for responses from battlefield decision-makers are immediately after an incident occurs, when there is the greatest uncertainty as to the details of the event, and least probability that a sufficient number of sensors have been concentrated in the areas of interest. Chemical plume simulations can add to the incident information at this early stage where there are few sensors at the incident location. Because of the many uncertainties associated with the incident at the early stage of development, it is necessary that the limits of the variability be determined to preclude any false safety from being implied. In order for detailed simulations to provide decision-makers with their initial information on the scope of the incident, a knowledge source *Scenario-generator-ks* has been developed to determine the most probable initial incident parameters and write the corresponding input files for the chemical plume simulations. The project goal is to integrate CPAKS into a combat information system where *Scenario-generator-ks* will check with other agents within the command and control structure to obtain attack information such as launch locations, target location, rocket type and payload size. From that information *Scenario-generator-ks* will determine the likely candidates from possible aggressor countries and agents which then can then be used to determine the most probable contaminants from those countries.

In its present stage of development *Scenario-generator-ks* determines the probable aggressor and effluents for the incident, and generates SCIPUFF input files based on the effluents and on the wind forecast variation. This knowledge source uses the longitude and latitude of the attack location to determine the aggressor. If there were no known specific adversaries, then *scenario-generator-ks* defaults to using the weapons most characteristic for a terrorist group. Information from AFWA has shown that the root mean square differences in wind speeds vs. forecast hours can vary significantly. Data is presented in Figure 2 for the month of March 2000 for the example incident area. The 6Z and 18Z forecasts are both graphically presented. The differences in winds speeds were calculated by subtracting the predicted wind speeds from the actual measured wind speeds. The MM5 wind speeds are forecast as maximum values, and measured wind speeds were on the average 5-6 knots less that forecast. In Figure 3 is a plot of the wind speeds (knots) vs. the height above ground (meters) for this same time period. This data is taken from the blackboard database and was used to generate the input files for the SCIPUFF analyses. The maximum wind speed is the speed that is predicted by the MM5 model, while the minimum is the average measured wind speed.

To demonstrate the CPAKS code an example incident of an unexpected attack in a rural area of CONUS is presented. *Scenario-generator-ks* evaluates two variables in determining what analyses should be performed, the location of the incident and the variation of the forecasted wind. There are currently three locations evaluated in the code to determine the effluent: CONUS, Korea, and Middle East. Our example location is in the continental United States. CPAKS proposed a terrorist incident and listed anthrax and sarin gas as the two most likely materials that would be used. Without sensors, it was initially impossible to know which material is being used, so to accurately evacuate the incident, two analyses would have to be accomplished. These two materials transport through the atmosphere very differently as will be seen in the outputs. Additionally, the variation of the weather elements impacts the quality of the simulation results. We can account for this by varying the elements within their expected accuracy range. Simulations were done at both the forecasted and 6 knots below the actual forecast wind speeds. The resulting outputs, which are discussed below, are a more accurate representation of the possible solution space meaning a much greater risk reduction of exposed troops to harmful effluents.

5. SCIPUFF Plume Analysis

The Software SCIPUFF (Second Order Closure Integrated Puff**)** developed by the Titan Corporation is used for the chemical/biological plume analysis. SCIPUFF is a Lagrangian puff dispersion model that uses a collection of Gaussian puffs to simulate a three-dimensional time-dependent concentration. The turbulent diffusion parameterization is based upon modern turbulence closure theory, providing a direct relationship between the predicted dispersion rate and turbulent velocity statistics of the wind field. The model has unique features in that it applies second order turbulence closure techniques, provides a prediction of the statistical variance in the concentration field, and performs accurate treatment of wind shear and merges puffs in addition to splitting them and uses an efficient adaptive multi-grid scheme.

In our example incident *Scenario-generator-ks* produces the four SCIPUFF input files that were then are currently run manually. Our plans are to have SCIPUFF activated by script language on a Sun computer. This will occur when we get a Unix version of the code. The basis of the selection of these scenarios was described in the previous section. The effluents used in the models are anthrax (biological agent) and serin (chemical/nerve agent). Additionally the two levels of wind speeds were used to develop two input files identified as maximum (profile-max.prf) and minimum (profile-min.prf), for each effluent. This resulted in four input files being written and subsequently four analyses being accomplished to describe the incident. As described in the section on the weather information section, we have used the MM5 36km data that has been stored on the blackboard database. The weather data used in the models was limited to a maximum elevation of 1500m. The simulation results for the biological agent tests are shown in Figure 4a (maximum wind speed) and Figure 4b (minimum wind speed). The chemical agent simulation results are presented in Figure 5a (maximum wind speed) and Figure 5b (minimum wind speed). These results indicate that the system developed performs reasonably well and produces meaningful simulation results.

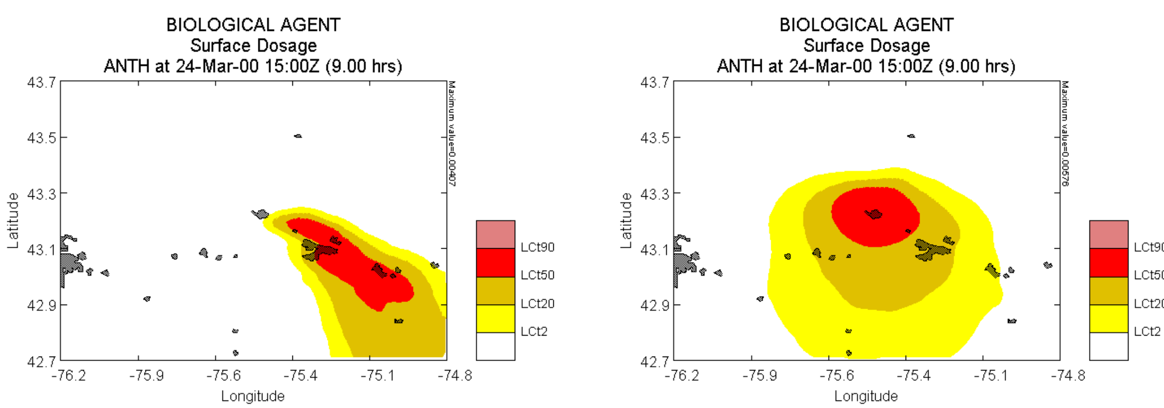

Figure 4a,b - Dispersion of a biological agent in maximum and minimum wind forecast conditions.

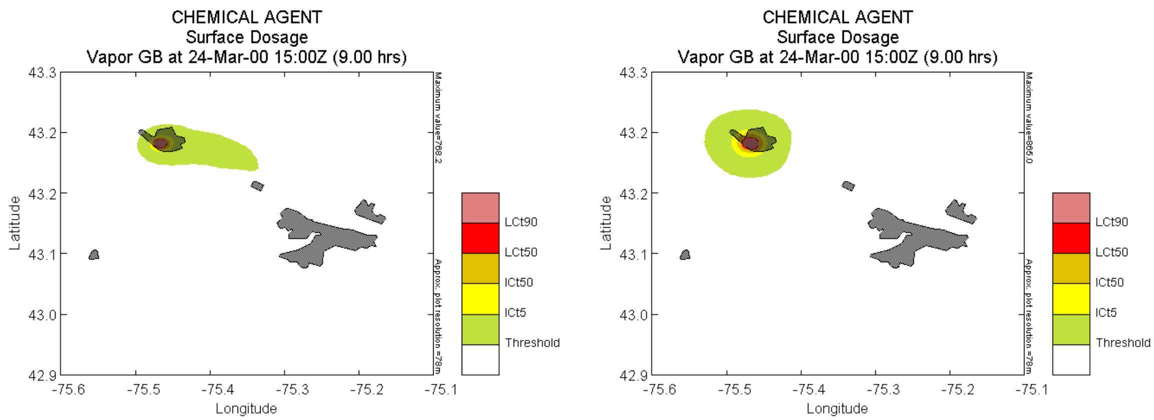

Figure 5a,b - Dispersion of a chemical agent in maximum and minimum wind forecast conditions.

6. Conclusion

The results indicate that the effects of the uncertainty and the variability of the information are important to the definition of the contaminated area. A single run of the SCIPUFF analysis would not have shown this. The purpose of this project was to demonstrate the concept of integrating knowledge based analysis and numerical analysis software in order to automate the chemical plume analysis. Throughout the project, the goal has been to produce software that can be integrated into the JBI concept. Currently the project has produced software consisting of an object database for weather information, and knowledge sources that evaluate this information determining which situations need to be analyzed, and then creates the appropriate input files for running SCIPUFF. Future work includes the development of a Java-based system that will allow for integration across multiple processors and allow for distributed processing of the plume analyses.

7. Acknowledgements:

We thank the following individuals for their assistance in this project. Ron Meris (DTRA), Terry Jarrett (SAIC), Steve Lowe (SAIC), and Joanna Wensell (SAIC), Ed Killian (Gemini Team) provided technical assistance with the ftp pull script and GRIB to SCIPUFF conversion code. Kelly Monovan (Logicon) provided PC-SCIPUFF. Stephen Parker and R. Ian Sykes (Titan ARAP) provided technical assistance and batch mode instructions for HPAC/SCIPUFF. Jonathan Carruthers (Defense Group Incorporated) and R. Pisares (FNMOC) obtained our HPAC accounts for access to the HPAC servers. Air Force Weather Agency provided the GRIB MM5 data needed to make this all work.

8. References

[1] Sykes, R.I., Parker, S. F., Henn, D. S., Cerasoli, C.P., Santos, L.P., 1998 PC-SCIPUFF version 1.1 PD.1 Technical Documentation, ARAP Report No 718, Titan Corporation, P.O. Box 2229, Princeton, NJ 08543

[2] Report on Building the Joint Battlespace Infosphere, SAB-TR-99-02

[3] Knowledge Technologies Inc., 401 Main Street, Amherst MA 01002