Acquisition and Display of Real-Time Atmospheric Data on Terrain

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Abstract. This paper investigates the integrated acquisition, organization, and display of data from disparate sources, including the display of data acquired in real-time. In this case real-time acquisition and display refers to the capture and visualization of data as they are being produced. The particular application investigated is 3D dynamic atmospheric data on terrain, but key elements presented here are applicable more generally to other types of real-time data. 3D Doppler radar data are acquired and visualized with global, high resolution terrain. This is the first time such data have been displayed together in a real-time environment and provides the potential for new vistas in forecasting and analysis. Associated data such as buildings and maps are displayed along with the weather data and the terrain. A global hierarchical structure makes these disparate data available for integrated visualization in real-time. Requirements for effective 3D visualization for decision-making are identified, and it is shown that the applications presented meet most of these requirements.

Keywords: weather, visualization, atmosphere, decision-support, terrain, large scale data, real-time

1 Introduction

The advent of nationwide meteorological networks such as 3D Doppler radar, high resolution weather satellites, and automated surface sensors has lately given weather forecasters and researchers who develop improved analysis and predictive tools access to much more observational data for making decisions in severe weather situations than ever before. These data sources provide higher spatial and temporal resolution than was previously available, but processing this vast amount of information in order to extract and display what is useful to the forecaster or analyst presents a formidable challenge. For the weather forecaster the challenges and benefits are especially acute. Even as the forecasting community struggles to take advantage of abundant observational data, the general public is expecting data that are both more precise and more highly customized to their particular geography and lifestyle. To meet this expectation, it is necessary to integrate very detailed thematic data (e.g., terrain, roadways, rivers/streams, political boundaries, landmarks) with the weather data. There are significant advantages to combining these data into a new type of universal dataset with significant limits on times of access, display, and analysis.

In this paper we present initial results that concentrate on the integrated acquisition, organization, and visualization of atmospheric data with high resolution terrain. Among the atmospheric results that can be included are 3D Doppler radar, satellite imagery, chemical plumes, weather simulations, and other data. With respect to the Doppler radar measurements, this is the first time such data have been acquired and displayed together in a real-time environment. Heretofore the Doppler radar features have only been displayed, after analysis, as moving 2D icons on 2D maps with no terrain elevation information and with no direct display of radar feature heights or volumes (though that information is available). The real-time environment is crucial for decision-making in severe storm situations where, for example, weather forecasters may have only a few minutes to issue warnings to affected areas [Eil95]. The integrated data permits observation of geospatial features that may affect weather patterns and the combining, for example, of flood and terrain models for accurate flood prediction. In addition the results present an extension of current real-time terrain data organizations and visualization systems since these are not designed to handle the 4D (time + space or dynamical) aspects of the integrated data sets.

2 Related Work

Weather visualization has been a fairly popular topic over the years. We will not give here an exhaustive review of this work but will rather concentrate on representative work related to interactive visualization of weather data or simulations. In many cases these visualizations are intended for analysis of weather patterns and in a few cases for decision-making.

There are visualization/analysis tools developed on top of toolkits. For example, the Vis5D display and analysis tool [Hib96] and Display 3D (D3D94) developed by the National Oceanic and Atmospheric Administration (NOAA) Forecast Systems Laboratory have 3D display capability. However, these tools have been designed not as general 3D visualization interfaces, but rather to focus on numerical model output. In addition, these tools do not have an operational decision support focus (attained by supplying the most pertinent information for decision-makers). Finally they do not address the issues of scalably large data and integration of geospatial data. There are also tools developed on platforms such as AVS Express [Che96]. These tend to be for analysis of fixed data rather than real-time visualization of potentially large and constantly updated datasets.

There is also research that has combined visualization with the value-added of storm tracking analysis. Cheng et. al. [Che98] use fuzzy logic to develop a storm tracking algorithm that presents results that closely match an expert meteorologist's perception. This work is relevant to our approach of displaying results of automatic analysis to aid in decision-making. However, it does not address the issues of real-time 3D visualization and does not present weather along with other relevant data, such as terrain. So far, the major real-time acquisition and display system [NWS98] is the Advanced Weather Interactive Processing System (AWIPS). However, it only provides 2D visualization. The present paper provides the first example of real-time acquisition and interactive visualization of 3D weather data from multiple sources.

Treinish [Tre98] has considered the general issues of visualization design for weather forecasting, including 2D and 3D visualizations. The latter are classified as either 3D browsing or analysis tools. The perceptual issues in using color and the representations for quantities such as wind vectors are also considered. Our approach combines browsing and analysis in a coherent 3D setting. We also build on some of the design issues presented in [Tre98].

Djurcilov and Pang [Dju99] address the issue of missing data in Doppler radar and other gridded data. Because of the curvilinear nature of the radar scan (Fig. 1), the data are rather sparse when usual visualization techniques (i.e., isosurfaces and volumetric rendering), which use regular grids, are applied. To the extent that the pre-analysis tools in our approach take into account the data non-uniformity (and the possibility of false readings), some of this uncertainty is accounted for. However, it is still useful to show the locations and scan patterns (and location-dependent uncertainties) for the radars, especially since in the future overlapping radars will be used. In the future we also expect to apply more direct and detailed rendering of data; here the considerations in [Dju99] will be important.

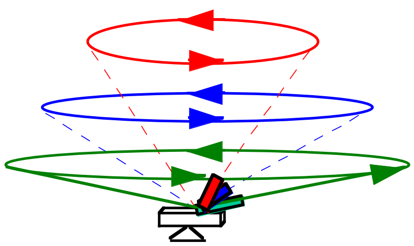

Fig. 1 Sparse scanning geometry for 3D Doppler radar.

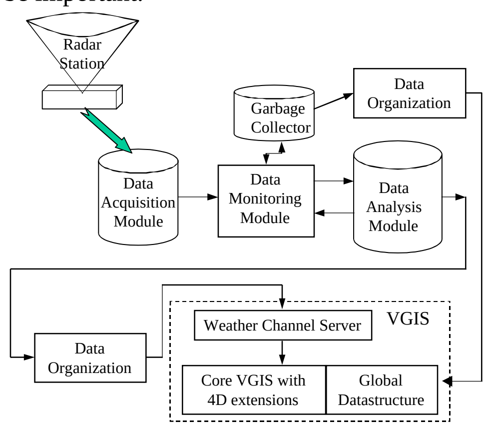

Fig. 2 Flow chart of acquisition and display of Real-time weather data on terrain.

In this work we present time-dependent weather and other atmospheric patterns in a global terrain visualization environment [Fau00]. We have built a highly interactive exploratory visual interface [War99a, War99b] for this environment that will be useful for decision-makers. The global environment is effective for out-of-core visualization, which is necessary for the large-scale data considered here. A principle reason for the effectiveness of our approach is that it uses application-controlled demand-paging [Cox97, Dav98], where the system knows something about what data are needed and when. We have shown that the same concept can be extended beyond terrain to other geospatial data, such as buildings and other static objects [Dav99]. We are confident that the global hierarchy can be extended to moving objects and other geo-located features.

3 Data Acquisition and Visualization

Requirements for Decision-Makers. We list first some requirements for real-time acquisition and effective visualization for decision-making (including weather and chemical/biological situation forecasting).

- Real-time data acquisition and data communication. This requires that real-time acquired data should be organized and inserted in data structures, then transferred to data analysis modules for analysis, and finally displayed in an interactive environment.

- End-to-end real-time capability. This means not only real-time acquisition but also visualization and on-the-spot analysis in appropriate time budgets.
- Capabilities for both browsing (or exploring) and analyzing time-dependent 3D data, including historical data.
- Easy-to-use 3D navigation and manipulation.
- Details on demand, to eliminate clutter presenting the important details initially.
- Integration of relevant data in a combined scene (e.g., weather and terrain).
- Easy-to-use quantitative tools and information-retrieval tools to augment the qualitative visualizations.

Schneiderman and co-workers [Tan97] have shown that the details on demand strategy can be very effective when coupled with fast display updates and easy-to-use controls for adjusting the detail. Since the atmospheric visualization application presented here is coupled to our terrain navigation system, it naturally has a browsing capability.

Acquisition and Display Structure. Fig. 2 shows the flowchart for the particular case of 3D Doppler radar. Different acquisition points would be used for satellite imagery and other types of data. As shown in Fig. 2, remote radar stations (operating as shown in Fig. 1) collect sets of volumetric data. Each set of volumetric data is composed of multiple sweeps. Once a sweep is done, data are passed to a data acquisition module via a set of T-1 lines. The data acquisition module organizes the raw volumetric data into a form appropriate for the hierarchical global data structure [Fau00]. The data analysis module then applies a set of pre-analysis and modeling tools, using methods developed by the National Severe Storms Lab (NSSL) [Eil95, Joh98, Mit98]. The tools are embedded in the Warning Decision Support System (WDSS), used by weather forecasters to make severe storm and tornado warning decisions. The pre-analysis is described further in the results section below. Since it is made for operational weather forecasting, the WDSS can analyze 3D Doppler radar on-the-fly. An extension of the structure of our terrain visualization system permits immediate insertion of these data and the accompanying raw volumetric data as a time-stamped stream of objects for real-time display.

Typically it takes about 5-7 minutes to collect a set of volumetric data. In order to prevent the constant stream of networked data from backing up, there is an incoming data monitoring module (Fig. 2). If the data analysis module can not analyze the incoming data faster than the data acquisition module delivers it, the data monitoring module will dump obsolete data to a collector for later organization and recording. After volumetric data is analyzed, the organized data (both raw and analyzed data) is sent in an efficient, compact form to the real-time server channel of VGIS. VGIS, which supports the interactive display part of our visual interface, then provides an updated visualization.

Visual Interface. Any interface for extended 3D data presents challenges for the development of effective and intuitive tools for navigation and selection, especially when using a mouse. There are two navigation modes, orbital and fly in our interface

(C.P. 1 and C.P. 3—see the color plates). Since we use a variety of interaction tools, including the mouse, joystick, and devices with 6DOF trackers, we must consider how to best operate these modes for each tool. The orbital mode presents a god's eye view and has navigation characteristics similar to those for a 2D interface (including panning, zooming, and rotation). This mode is straightforward to operate with all interaction tools. For the fly mode (similar to flying along the Earth in an airplane) using the mouse and to some extent the joystick, we have found after significant testing and evaluation of alternatives that it is best to constrain degrees of freedom. In the present work we map pitch to vertical mouse movement and yaw to horizontal mouse movement. The attitude of the viewpoint is fixed on a platform parallel to the Earth's surface, so there is no roll. One navigates forward by pushing the left mouse button and backward by pushing the middle mouse button. One changes speed through a menu option. This interface is reasonably straightforward to use and makes operations such as taking a 360° look about a location easy to do.

We have implemented a more intuitive 3D interface for the 6DOF device on the virtual workbench (C.P. 4). Here one switches from orbital to fly mode simply by turning a tracked button stick (shown in C.P. 4) to vertical position. The interface automatically switches to a mode where the stick acts like an airplane joystick. Turning it to left or right causes yaw to left or right; pushing forward or backwards causes flight in that direction; lowering or raising the stick causes descending or ascending flight. This interface is reasonably intuitive to use. In the following discussion we will concentrate on the mouse-based interface, though the capabilities described can also be applied to the workbench interface.

For the remainder of this section, we will discuss the visual interface in terms of the weather application. However, applications using other types of atmospheric data can be invoked, as discussed in the next section. One can individually turn on or off the time-flows of raw and analyzed weather data, or view them simultaneously, as in C.Ps. 1 and 2. This permits forecasters to quickly isolate details or view correlated phenomena. The latter can be useful since the detailed development of the raw data may reveal behavior not shown in the analyzed data. The forecaster can fly in for closer inspection, including correlation with terrain or map features, or back out for an overview. The bright cylinders in C.Ps. 1 and 2) reveal analyzed mesocyclone cells with possible tornadic action. These correlate with the underlying patterns in the raw data.

In addition to on-the-fly results, the forecaster must often analyze previously archived histories. For efficient use of this mode, we have provided a control panel. This control shows where the displayed frame is in a given time series and permits the frame rate of weather steps to be slowed down or speeded up. The user can also specify a time range or a time step and immediately see it. Thus the forecaster can look more carefully and more slowly at particular sequences of steps.

A user will want to quickly obtain detailed 3D views from any location and angle. To do this we have provided a selection and jump mode. Selection is straightforward in orbital mode but more challenging in fly mode. For the latter the system casts a ray from the eyepoint through the selected point and finds the terrain intersection point. If the ray misses the terrain, no selection is made. This ray and the intersection point are displayed, which helps the user perceive the location of the intersection point and also select an altitude value. The latter is done by moving the mouse up or down, with the ray end following the moving cursor. The altitude value is displayed at the top of the window (Fig. 3). Upon completion of the selection, the ray is replaced by a ray perpendicular to the Earth ellipsoid [War9a] at the intersection point and of length equal to the chosen altitude (Fig. 3). Upon selection the user's view now jumps to the selected 3D location and switches to fly mode. The user is then free to look or move around. A jump-back option on the menu permits the user to return to the original viewpoint position and navigation mode. Not only does the jump mode permit the user to quickly move in for detailed views, it reduces the possibility of getting lost during navigation. Selected positions remain displayed for future use but can be turned off via a menu option.

4 Results

Real-Time Weather Volumes. We have used our system on sequences of analyzed data from a Doppler radar located at the National Weather Service (NWS) facility in Peachtree City, GA. We visualize both raw data and analyzed results, using simple shapes for the latter. Our display meets the real-time requirement. The process of data acquisition, analysis, preparation for display, and display takes about 1 minute (Fig. 2). Most of this time is spent in the analysis step, which could be speeded up. This should be compared with the 5-7 minutes it takes to collect the 3D Doppler radar volume, which involves a series of 2D scans at progressively larger angle with respect to the ground (Fig. 1). For a series of time steps, display is typically in the range of 5-15 updates per second in a stereoscopic environment and about double that in a monoscopic environment. (The update rate depends on the amount of data displayed. It is 15 fps if only the analyzed shapes are shown.)

To show the capabilities of our methods in detail, we use some previously captured severe storm data. Forecasters will often look at histories as well as at current data. The data presented are from a series of severe storms that occurred over Georgia from 2 am till 10 pm on March 19, 1996. There are 72 time steps in these results, but the system could handle a much larger group of time steps. The analyzed data were in the form of mesocyclones and tornadic vorticity signatures. The mesocyclones are areas of large coherent rotation and are possible precursors to tornadoes. The tornadic signatures are obtained by looking for compactness, intensity, and shear in adjacent radar bins. At least some of these signatures were actual tornadoes. The heights and elevations off the ground (which can be seen clearly in fly mode) of the mesocyclones are indicators of their power and potential for damage. Both types of signatures were built from the stacked 2D scans using simple spatial correlation. The 3D view of the arrangement and time evolution of these structures can provide the forecaster with useful additional information.

We used semi-transparent cylinders and cones to represent the mesocyclones and tornadic signatures respectively. The rotation intensity was mapped to the color with the range of color chosen to be similar to the range employed in 2D visualizations used by forecasters. Icons similar to the ones used in the 2D visualizations were attached to the tops of the mesocyclones so that in orbital mode the 3D scene looks similar to the 2D scene. However, these features are also shown in correlation with the raw 3D radar scans (C.Ps. 1 and 2). In addition, a lot more information is displayed showing correlation with terrain features, urban areas, roads, and rivers. (C.Ps. 2 and 3, and Fig. 4). Details from the full time-dependent Doppler radar set, retrieved on-the-fly from the hierarchical data structure, are shown in C.P. 3. Here we have mapped the 3D data onto cones representing the Doppler scans. We can even display weather features over maps (Fig. 4), which can be interactively blended in or removed. All this additional information has never been visualized in detail simultaneously with time-dependent 3D weather data. Although the correlation between analyzed storm cell features and underlying Doppler radar features is good in C.P. 2, these features can diverge over time—some of the divergence may be due to terrain features or even human activity. In addition, the integrated visualizations give ample, immediate information about what the storm cells are hitting or about to hit. We have added a grid that can be turned on and off through a menu option (C.P. 3) to show the coverage of the radar.

In overview, one can easily see the sweep of the storms as they progress from the Alabama border across North Georgia. (See, for example, C.P. 1.) Since the weather visualization is embedded in a global terrain framework, one does not have discontinuous or truncated views but can move smoothly to any view with higher resolution terrain and feature data coming in wherever they are available. For example, the visualization does not stop abruptly at the Georgia border. In the next generation of weather forecasting tools, data will be collected from overlapping Doppler radars and other sensors over a much larger area. The global terrain capability will be even more useful when this occurs.

The orbital and fly modes permit a continuous movement between browsing and more detailed analysis. For example, Fig. 4 shows an overview of storm cells as they increase in size and intensity over Atlanta. The forecaster can use the jump mode (and then can fly around) to see the relation of these features to urban areas and can also see the heights of these features and their relation to each other and to the ground. The jump mode also permits one to quickly get to the tornadic signatures, which show clearly as bright blue objects with crosses on top (Fig. 3).

We have found that terrain features, such as mountains or buildings, plus the 3D shapes of the storm signatures are especially prominent on the virtual workbench (C.P. 4). Here the stereoscopic display makes the 3D structure “stand out” automatically, even without changes of view by the user. Further, the workbench provides a large work surface for analysis and collaboration among users. The navigation modes are also fast and intuitive.

Chemical/Biological Clouds. Aside from real-time weather data on terrain, our techniques and data modules can also be applied to acquisition and display of chemical/biological clouds in real-time. Through the Center for Emergency Response Technology, Instrumentation, and Policy (CERTIP), we recently worked on urban emergency response to a terrorist attack. This culminated in an exercise on the Georgia Tech campus. The visual interface and global data structure described here were used for situation assessment. The exercise began with the Atlanta Fire Department arriving on the scene. As soon as it was determined that a toxic chemical (Sarin gas) was being released from the roof of a campus building (C.Ps. 5, 6 in orbital and fly modes, respectively), a special team was called in and set up an Emergency Operations Center (EOC). The EOC team used a set of simulation codes to generate time series plumes every 5 minutes. The large colored area emanating from the top of the building in C.Ps. 5, 6 is one of those simulated plumes displayed in real-time. Large red human icons (C.P. 6) are EOC first responders with GPS units and wireless LAN transceivers. Their positions are also updated in real-time. Letters “A, B, C”, and “D” (C.P. 5) are labels for operations areas at different locations around the attacked building.

The first responders, wearing level A suits (special garb to protect again toxic chemicals), entered the building, using a chemical sensor to detect Sarin and a radar flashlight to detect whether people were behind closed doors. They used high resolution imagery and 3D buildings for the Georgia Tech campus (C.Ps. 5, 6) to plan their movements. Query capability was installed in a web-server version of the visual interface and the personnel could click on the building where the attack took place and retrieve floor plans for each floor. They could also retrieve overview maps for the nearby downtown Atlanta area. The visualizations were dynamically updated with simulation and other movement information every 40 seconds. The mobile, wireless LAN sent the products from the EOC (maps and plumes) and retrieved medical info from the first responders (blood pressure, pulse, heart rate, and EKG along with a web-cam pictures of the victims after removal from the building). This “Reachback” was intended to allow doctors at a nearby medical evacuation location to advise the first responders on diagnosis and treatment. In the future, we will augment the urban database employed here and use it with entirely mobile computers (e.g., laptops and wearables) with wireless communication. We will also develop new interfaces for the mobile applications.

5 Conclusions and Future Work

We have presented methods and results for real-time acquisition, organization, and visualization of atmospheric data in a geospatial environment, emphasizing capabilities that will be of use to forecasters and other decision-makers. We expect these capabilities will also be useful to others concerned with the analysis of weather or other atmospheric data, such as researchers or planners. Our atmospheric visualization application meets most of the requirements listed at the beginning of Sec. 3. In particular the application provides real-time acquisition, end-to-end real-time capability, integrated browsing and analysis, details on demand, and integration of relevant data in one visualization. This last capability can help researchers develop better models of storm development, which will yield rules for how storms behave in the presence of hills or mountains and other features.

The results show how time-dependent atmospheric data in a geospatial environment can be effectively explored visually using appropriate interactive tools. These include direct manipulation tools for navigation and manipulation, and interface elements for controlling animation and scale. With these tools and with multiresolution global visualization the user is able to quickly get to features of interest and to gather more information than was available before for decision-making.

We have several avenues of future work. We expect to redesign our prototype application and bring more elements from the menus into an always visible control panel for faster access. We will also produce a finder window that will give a simultaneous wide area orbital view. As the user moves around the main window, an icon showing current position and direction will be updated in the finder window. The moving storm cells will also be displayed in the finder window, and the user can execute jumps from either window. Once these features are in place, we will give the application to colleagues at the NSSL and to NWS forecasters for evaluation. In the longer term we will develop new methods for detailed rendering of the 3D radar data. These data will be in the form of "hierarchical geospatial volumes" so that they have levels of detail that fit into our overall global data structure [Fau00, Dav99]. This will be a major step towards fully implementing the most detailed and accurate views of the evolving 3D weather patterns.

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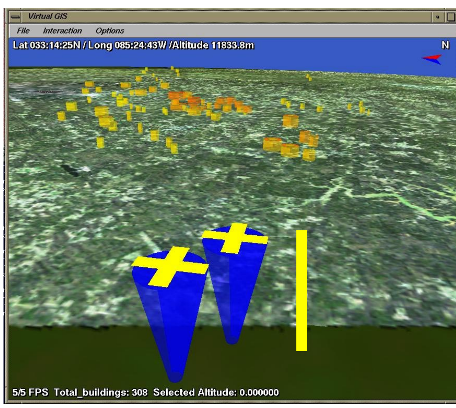


Fig. 3 Tornadic signatures with altitude measure (right line).

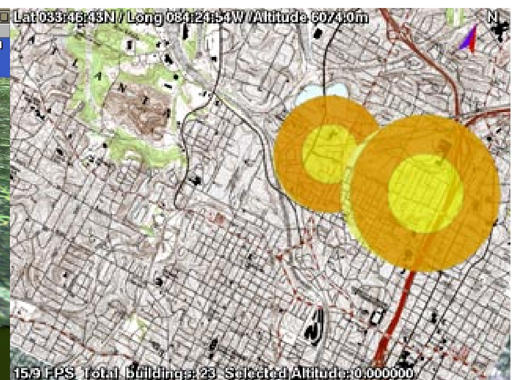
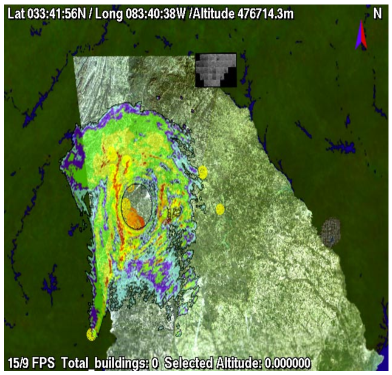
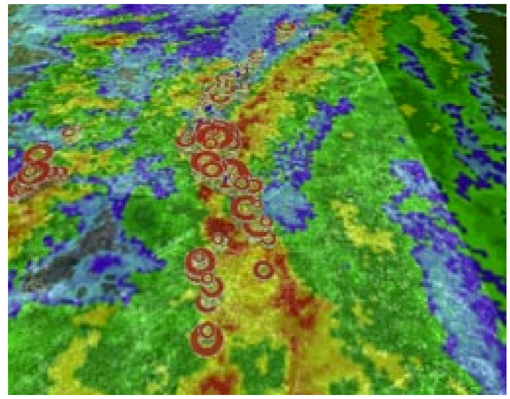


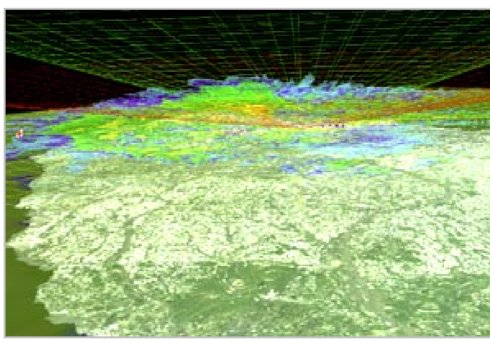
Fig 4. Detailed Atlanta map turned on interactively to correlate with mesocyclone features.





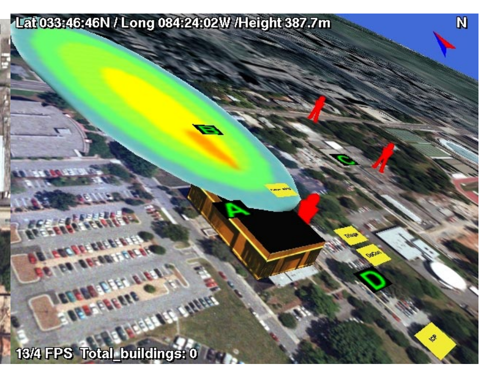
CP. 1 Overview of combined raw and analyzed data for a given time step.

CP. 2 Close-up of combined data at same timestep. Reddish icons are analyzed mesocyclones.



C.P. 3 View of raw 3D data in fly mode.

C.P. 4 Weather visualization using the virtual workbench interface.



C.P. 5 Overhead view of emergency response area and simulated toxic gas plume.

C.P. 6 Fly mode view of simulated toxic gas plume. Positions of first responders are 1indicated by the red icons.