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Detailed Numerical Simulation of the Graniteville Train Collision

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Abstract—*An unfortunate accident occurred in Graniteville, South Carolina on 6 January, 2005 when a train carrying a variety of hazardous chemicals collided with a stationary train parked on a siding rail (spur). The Savannah River National Laboratory (SRNL) runs prognostic atmospheric simulations of the Central Savannah River Area (CSRA) on an operational basis in the event of such airborne releases. Although forecast information was provided at 2-km horizontal grid spacing during the accident response, a higher-resolution simulation was later performed to examine influences of local topography on plume migration. The Regional Atmospheric Modeling System (RAMS, version 4.3.0) was used to simulate meteorology using multiple grids with an innermost grid spacing of 125 meters. This report discusses comparisons of simulated meteorology with local observations and applications using two separate transport models. Results from the simulations are shown to generally agree with meteorological observations at the time. Use of a dense gas model to simulate localized effects indicates agreement with fatalities in the immediate area and visible damage to vegetation.*

I. INTRODUCTION

The unfortunate accident involving two trains in Graniteville, South Carolina during the early morning of 6 January, 2005 resulted in nine fatalities. A stationary train sitting on a siding rail (spur) was impacted by another train carrying a variety of hazardous chemicals, including liquid chlorine (Cl_2). The switching mechanism was inadvertently set to send trains to the spur, rather than northward and out of town. At 2:40 LST (0740 UTC), the train carrying these chemicals collided with the stationary train resulting in train derailment and compromise to one the cars containing the Cl_2. Upon contact with the atmosphere, the chlorine vaporized and thus became an airborne threat to the immediate vicinity.

The Savannah River National Laboratory (SRNL) runs prognostic atmospheric simulations of the Central Savannah River Area (CSRA) on an operational basis in the event of such airborne releases. Forecast information available at 2-km horizontal grid spacing was available during the time of the incident and used as a supplemental aid to consequence assessment. However, because the accident scene is situated in a valley where topography could strongly influence the movement of a dense gas (Cl_2), it was decided to run more detailed simulations of the wind conditions around the time of the incident. The Regional Atmospheric Modeling System (RAMS, version 4.3.0)[1] was used to simulate meteorology using multiple grids with an innermost grid spacing of 125 meters. This paper discusses the model attributes, comparisons of observed and modeled wind direction and speed during and after the accident, as well as application of this wind information to two separate transport models.

II. DESCRIPTION

A collision involving Norfolk Southern Railroad trains occurred at 02:40 LST (0740 UTC), 6 January 2005 in downtown Graniteville, South Carolina (33.5617ºN, 81.8088ºW). Typical SRNL simulations are run every 3 hours and provide 6-hr forecasts of meteorology in the Central Savannah River Area (CSRA) at an inner grid spacing of 2 km. A prognostic atmospheric model (RAMS) is used to generate three-dimensional atmospheric conditions, with initial conditions provided by the Rapid Update Cycle (RUC). Surface conditions require land-use features such as topography, vegetation type, and soil type. Variable input soil moisture conditions are also used. The lowest atmospheric level above ground is ~20 m. This grid system is designed for emergency response needs at the Savannah River Site (33.256ºN, 81.750ºW), located to the south-southeast of Graniteville by ~30 km (see Fig. 1).

Since the train collision occurred in a valley oriented in the north-south direction and involved dense gas releases to the atmosphere, it was decided to run a much higher resolution RAMS simulation in an attempt to capture the near-surface wind fields very near the crash site. The original two-grid system was modified to incorporate a third and fourth nested grid at 500 and 125-m horizontal grid spacing, respectively. In addition, the vertical grid spacing was reduced such that the lowest vertical level above ground for the two outer grids was ~ 15 m AGL, while for the inner two grids it was ~7 m AGL (resulting in 14 atmospheric levels below 300 m).

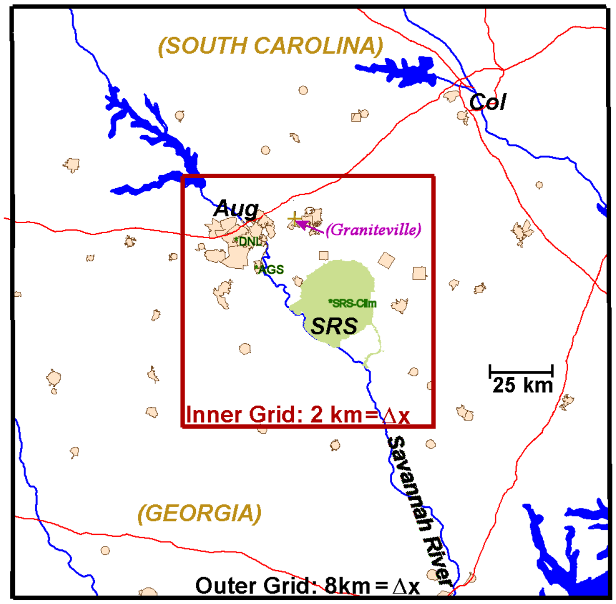

Figure 1: Standard local grid configuration used by the SRNL in generating mesoscale atmospheric conditions. Also shown are regional cities Augusta, Georgia (Aug) and Columbia, South Caroline (Col), along with interstate highways (red lines) and populated places (tan areas).

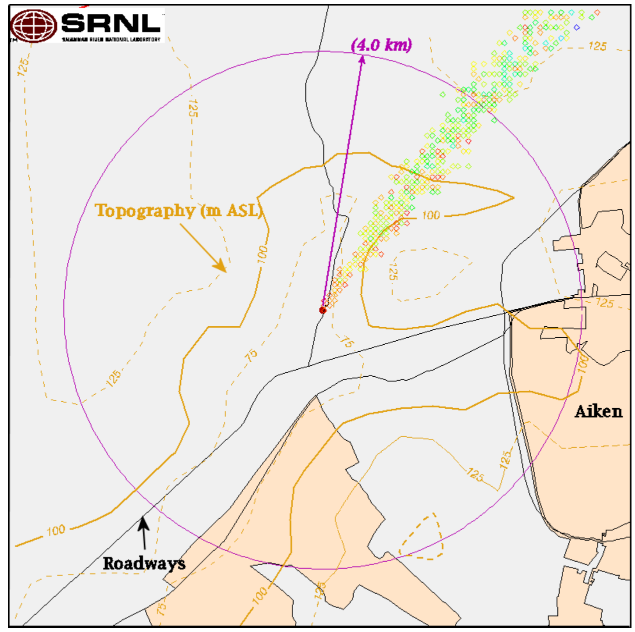

Figure 2: Detailed view of Graniteville crash site (indicated by red dot in center of picture) with topographic contours indicated, as well as nearby roads and population centers. Colored dots indicate a simulated plume transported from the crash site.

Analyzed RUC data at three-hour intervals beginning at 18 UTC, 05 January 2005 was used to create initial and lateral boundary conditions in RAMS. Fine resolution topography (~100 m) from digital elevation maps was used for topography. The orientation of the valley at the crash site is indicated in Fig. 2 showing topographic heights for the 500 and 125-m horizontal grids used in the simulations. The feature of particular interest is the valley oriented from north to south where the accident occurred with steeper terrain located just to the east. The northwestern part of the city of Aiken is located just to the east and southeast of this feature.

There were no meteorological observations taken in the vicinity of the crash site. The closest near-surface measurements were taken at a tower located on the Savannah River Site (SRS) complex, and two National Weather Service (NWS) sites located at Daniel (DNL) and Bush Field (AGS) airports in Augusta, Georgia. Unfortunately, none of these is probably representative of actual wind conditions in the valley at the time of the incident. Pertinent locations are given in Table I and also noted in Fig. 1.

Table I: Observation Information

Observation Location	Latitude (ºN)	Longitude (ºW)	Elevation (m ASL)	Height (m AGL)	$d^{\dagger}$ (km)
AGS	33.37	81.97	40	10	26
DNL	33.47	82.03	134	10	24
SRS-Climatology	33.25	81.65	90	18	40
Graniteville	33.56	81.81	68	10	—

†Approximate distance from crash site to observation location.

III. RESULTS

III. A. Simulated Meteorology

The detailed simulation indicates relatively light (< 2 m/s) surface winds near the crash site and channeling through the valleys of Graniteville at the time of the accident. Wind speeds increase to ~2.5 m/s by sunrise (7:00 AM), and to ~4 m/s by mid-afternoon (15:00 AM). The direction is generally from the SSW or SW during the entire period.

Vertical cross-sections of various meteorological variables (vertical velocity [m s^{-1}], turbulent kinetic energy [m^2 s^{-2}], potential temperature [K], and relative humidity [%]) over the lowest 600-m of the atmosphere along a west-to-east orientation intersecting the train collision location are shown in Fig. 3 for a time of 0800 UTC. The location of the train wreck is indicated by the arrow. Vertical velocities are very light near the crash site with low turbulence levels. Potential temperature profiles indicate a stratified atmosphere and humidity levels are very high (near 100%). For a dense gas such as chlorine, light wind conditions coupled with slightly downward air motion near the surface would support gravity driven flow.

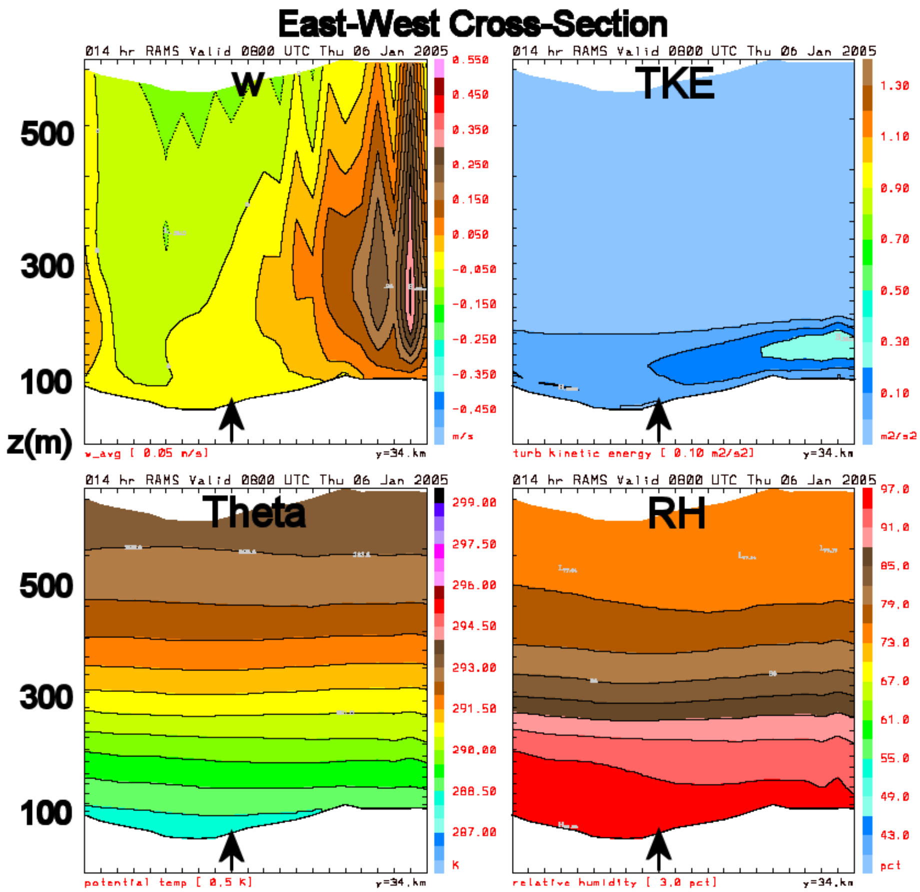

Figure 3: Vertical cross-section along the inner grid along the latitude of the crash site (indicated by the vertical arrow). Plots of meteorological variables (vertical velocity [w], turbulent kinetic energy (TKE), potential temperature (Theta), and relative humidity (RH) are for a time of 0800 UTC (04:00 LST).

Surface wind speeds increased by sunrise, and the depth of the boundary layer began to grow (not shown). By 1600 UTC (11:00 LST), vertical velocity is seen to be upward at the crash site, and the boundary layer depth has grown to between 300 and 400 m. The atmospheric moisture content had also begun to drop. This would also support assertions that the cloud had dispersed by this time.

III. B. Comparisons with Observations

Time-series plots of wind speed and direction have been generated for the period 0730 UTC, 06 January to 0000 UTC, 07 January and interpolated to the observation locations discussed previously. In addition, simulated wind speed and direction as interpolated to the surface level (10 m AGL) in Graniteville at the crash site are also plotted. All simulated values (except Graniteville) were taken from meteorology generated on Grid 2. Comparisons of wind direction are given in Fig. 4.

At the time of the crash, all three observation sites indicate winds from the SSW to SW, although DNL was closer to 225º, while the other stations were closer to 200º. Directions were generally uniform throughout the period, with veering to 240º by late day (~22 UTC). Simulated values were generally within 20º to 40º, although early morning values at SRS indicate a southerly component. As expected, simulated values at Graniteville lie within values obtained from all of the measurement sites.

Observed wind speeds (not shown) are all ~ 3 m s^{-1} at the time of the accident, before peaking at ~8 m s^{-1} by late afternoon. The simulated trends follow along these lines, although values between 0730 and 1200 UTC at the airports are < 2 m s^{-1}. Simulated wind speeds at Graniteville steadily rise from 1 m s^{-1} at the time of the crash, to a maximum of 4.5 m s^{-1} by 1900 UTC, before tailing off later in the afternoon.

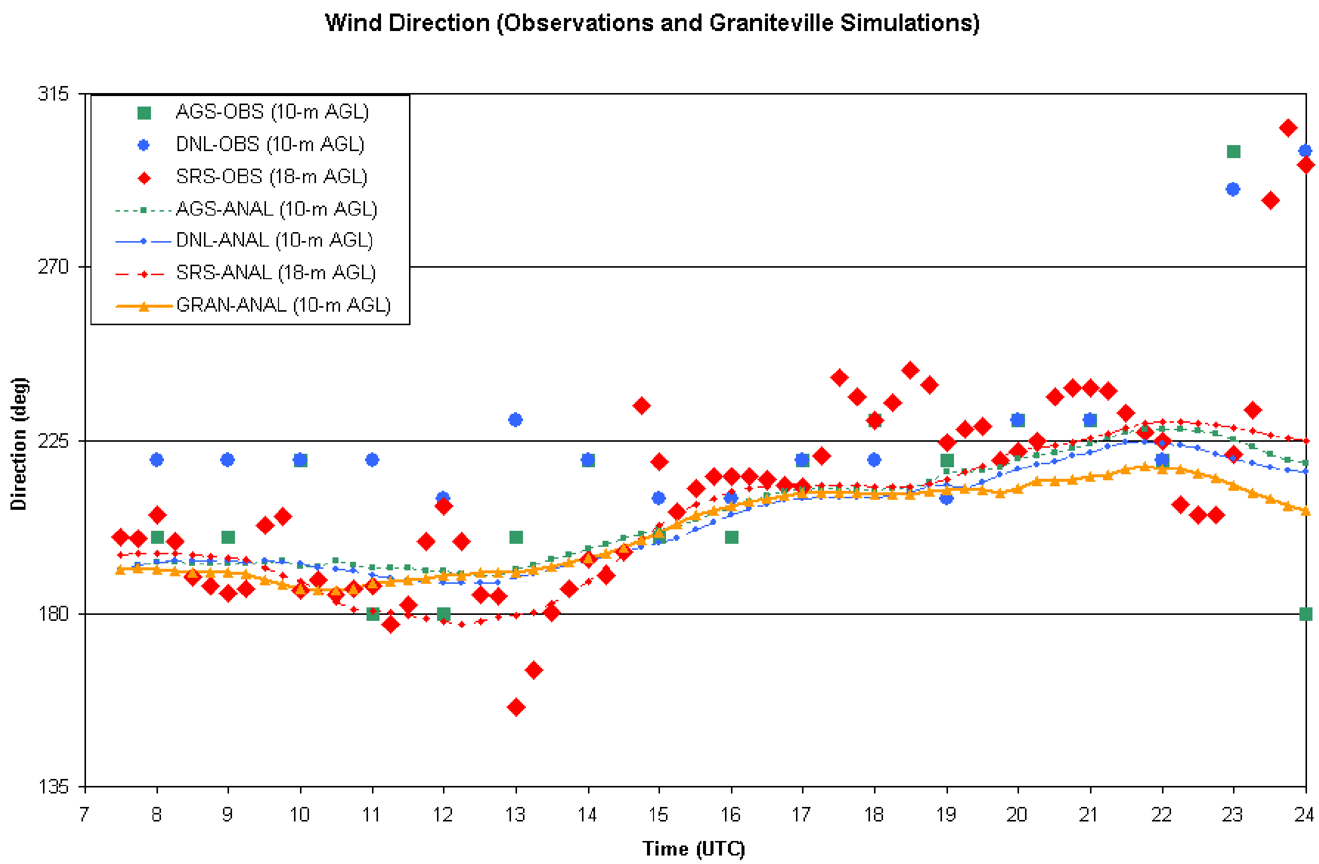

Figure 4: Comparison of observed wind direction from various locations (isolated markers) and simulated values using RAMS (lines) as a function of time from the beginning of the incident on 06 January, 2005. The orange line indicates results from Graniteville, where no observations of wind direction were taken.

III. C. Transport

A Lagrangian Particle Dispersion Model (LPDM)[2] was used to simulate transport of effluent from the crash site. LPDM assumes a passive tracer, so it is not strictly proper for chlorine gas modeling. Nonetheless, it is used here as a means of examining general transport directions. LPDM uses the wind and turbulence fields generated by RAMS to transport the pollutant through the atmosphere. An example of particle locations at 2000 UTC is given in Fig. 2 under the assumption of a continuous release. Particles are color-coded by height (where red particles are nearest the surface, and green/blue particles are at the highest altitudes).

The Hazard Prediction and Assessment Capability (HPAC, v 4.0.4)[3] was used to simulate the effects of the dense gas very near the release location. An industrial transport accident was assumed for a tanker containing ~20000 gallons of liquid chlorine. A major leakage was assumed to occur expelling over 62000 kg of chlorine gas in both vapor and aerosol phase. Dense gas calculations are made within HPAC, and appropriate median lethal (LCt) and incapacitating (ICt) concentration levels as well as temporary emergency exposure limits (TEEL) were then determined. Figure 3 illustrates the plume footprint one hour after the crash using the 500 meter resolution RAMS winds, with detailed road overlays and the approximate location of deaths that occurred as a result of the accident. Since terrain near the site is actually lower to the southwest of the crash site, the relatively light winds coupled with the dense gas explains why several deaths occurred southwest of the wreck, even though winds were simulated to be blowing from the southwest toward the northeast at the time of the crash.

The simulations appear to be reasonable in one other way. Visual evidence of damage to vegetation in the Graniteville area was inspected in mid-February. Most of the plant damage could be seen by examination of pine trees and juniper bushes. Also shown in Fig. 5 (in blue) is an approximate outline of visible damage to vegetation in the area. The resulting footprint compares favorably with both vegetation damage and the locations of deaths that occurred as a result of the incident.

IV. CONCLUSIONS

Detailed numerical simulations of meteorology during the Graniteville train collision were generated using the mesoscale RAMS model nested with 4 grids of horizontal spacing 8, 2, 0.5, and 0.125 km. The lowest vertical level above ground was 7 m. Simulated fields compare well with nearby observations, with transport for the first day indicating a plume directed between north and northeast.

Since chlorine was so dense, and the winds were relatively light at the time of the accident (~3AM LST), the cloud appears to have been driven initially by gravity towards the southwest (lower elevations); later, as the boundary layer grew and mixing occurred, the plume was dispersed toward the north and northeast. Use of a dense gas model to simulate localized effects indicates agreement with fatalities in the immediate area and visible damage to vegetation.

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3. DTRA (Defense Threat Reduction Agency), *The HPAC User's Guide. Hazard Prediction and Assessment Capability, Version 4.0*, 605 pp. (2001).

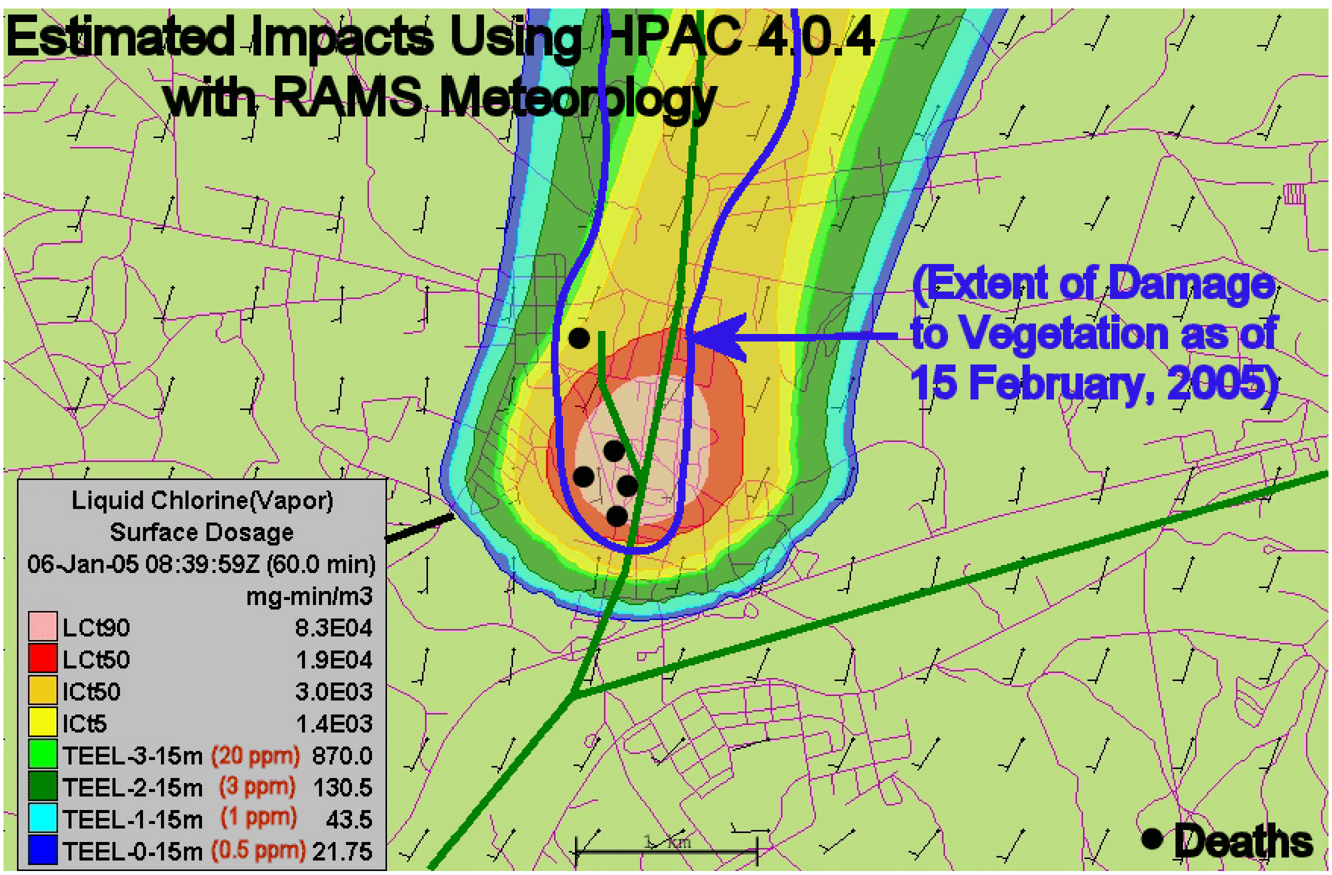

Figure 5: Plume showing transport of liquid chlorine vapor as simulated by HPAC using RAMS meteorology (shown as wind barbs) at ~03:50 LST. Different isopleths indicate varying median lethal (LCt) and incapacitating (ICt) concentration levels, as well as temporary emergency exposure limits (TEEL). The thick green lines indicate railroad tracks, the thin purple lines indicate roads, and the large dots show the location of deaths that occurred from the accident. In addition, the solid blue line denotes the visible extent of vegetation damage roughly one month after the incident.