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Recent Results from PB-Piedmont – a Model to Simulate Smoke on the Ground at Night

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1. INTRODUCTION

The continued supply of our Nation's paper and other wood products increasingly depends on wood fiber produced from Southern forests. Approximately 200 million acres (81 ha) of forestland are within the 13 Southern United States—roughly south of the Ohio River and from Texas east. Although these States represent only 24 percent of America's land area, 40 percent of the Nation's forestland lies within this region. Southern forests are dynamic ecosystems that, under good land stewardship practices, can continue to supply the myriad of goods and services that the American public relies on (SRFRR 1996).

Southern land managers understand that prescribed fire is the most economical way to reduce fuels, remove nutrient-competing species, and lower the wildland fire danger, which can destroy commercial fiber and threaten urban areas. Additionally, threatened and endangered species influence management of some Southern forestlands. For instance, because many threatened plant and animal species are fire-dependent—they rely on fire for reproduction and elimination of competing species—managers consider prescriptions that help to ensure the continued survival of these species.

Land managers use prescribed fire to treat 4 to 6 million acres (2–3 ha) of forest and agricultural lands in the Southern states each year. Although the vast majority of prescribed burns are carried out without incident, there are occasions when meteorological conditions combine with residual smoke to compromise visibility. Multiple-vehicle pileups, numerous physical injuries, extensive property damage, and fatalities have been associated with visibility reductions due to smoke or smoke and fog on roadways. Most serious accidents occur during the night or at sunrise when local fog combines with smoke trapped in stream valleys and basins and drifts across roadways.

Simulating smoke movement at night is a complex, time-dependent problem. Wind shifts transport smoke to different locations at various times during the same night. Land management personnel charged with alerting the appropriate authorities of pending transportation hazards must know where and when smoke will arrive. PB-Piedmont (Achtemeier, 2001) was developed as an operational smoke model to model smoke on the terrain scales that the smoke "sees". Smoke can move through shallow gaps in ridges and down road and stream cuts. Therefore, the mesh size for the model can be as small as 30 m, the minimum resolved grid distance in the digital elevation models (DEM) provided by the U.S. Geological Survey.

Validating PB-Piedmont has been made difficult by the lack of data on smoke movement at night. Achtemeier et al (1998) conducted airborne mapping of near-ground smoke at night using GPS and light-enhancing video imagery. In another instance, smoke movement was compared with an accident location (Achtemeier and Paul, 1994).

2. VALIDATING PB-PIEDMONT

During the 2002 winter/spring burn season in the South, the U. S. Fish and Wildlife Service Piedmont National Wildlife Refuge (PNWR) cooperated with the USDA Forest Service Smoke Management Team (SMT) to provide prescribed burn and smoke data critical for validating PB-Piedmont. The SMT supplied Smoke Observation Forms for recording the dates and times of burns, acres burned, GPS coordinates of the center of the blocks of land burned, and GPS coordinates of the corners of the blocks burned. This information was supplied for each burn by the PNWR along with reports of smoke obtained while driving roads surrounding the burn site during the early hours of the morning. The smoke reports include the date and time of observation, GPS coordinates of the locations of smoke, and brief comments regarding smoke behavior and visibility.

The Smoke Observation Forms were FAXed to the SMT. The SMT gathered weather data for the event and ran PB-Piedmont according to the protocol described in Achtemeier (2001). The resulting smoke plumes were matched with the smoke reports submitted by the PNWR. Each case was written up as a PowerPoint presentation and was posted on the SMT web site at www.srs.fs.usda.gov/smoke/.

The PNWR smoke observations are the first independent data available to validate PB-Piedmont. Each burn was treated as a case study. Each simulation was examined for accuracy. When and where the model failed to simulate smoke correctly

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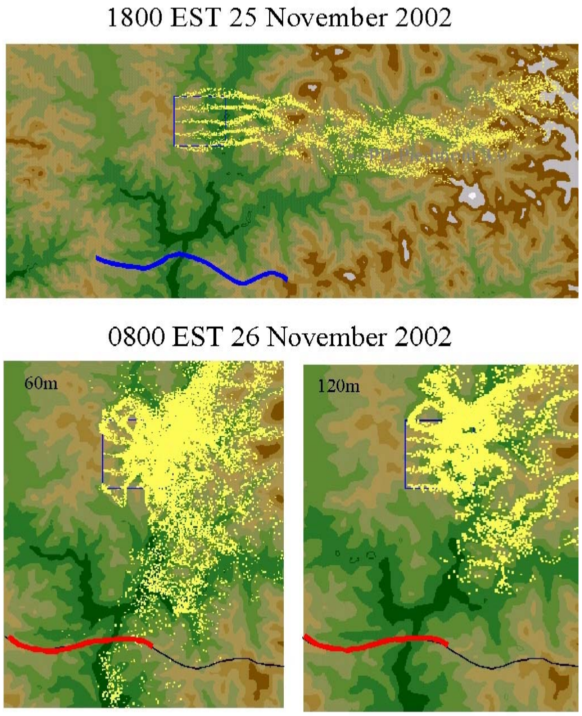
was noted and explanations sought in terms of empirical constants in the model. This approach to validation looks for cases that produce errors that are "systematic". Constants suspected of causing the errors are modified and all cases are reanalyzed.

Four cases from the PNWR have been analyzed thus far. (Results from a fifth case will be available soon.) Salient points from each case are summarized below.

2.a. 25 November 2002

A 345 acre prescribed burn was conducted on 25 November 2002. Weather during the burn and post-burn nighttime period was clear with moderate relative humidity. A high pressure system to the west of the burn site favored winds blowing from the northwest during the day of the 25th. During the evening dry conditions favored rapid cooling and strong drainage forcing. However, cooling to the dewpoint temperature occurred after midnight. Widespread valley fog formed. PB-Piedmont slows cooling rates at locations where the relative humidity reaches 100 percent. Therefore, continued cooling over higher terrain combined with little or no cooling in the valleys combined to weaken drainage flows. Synoptic scale forcing overcame drainage forcing. Northerly winds flowing down valley shifted to blow from the southwest.


1800 EST 25 November 2002

0800 EST 26 November 2002

Figure 1. Graphics for 1800 EST 25 November 2002 and 0800 EST 26 November 2002 showing local terrain, location of the burn site, smoke, and part of a road where smoke observations were taken.

Figure 1 shows sections of graphics produced by PB-Piedmont for 1800 EST 25 November (just after sunset) and 0800 EST 26 November. Features of local terrain are characteristic of the lower Piedmont of the South. Stream bottoms are shaded in green and ridges appear in browns and whites. Maximum elevation difference between ridge top and valley bottom is approximately 100 meters.

The top panel of Figure 1 shows the smoke plume (yellow dots) for 1800 EST. The "threaded" appearance is caused by incipient drainage forcing. At 1800 EST, drainage forcing was still too weak to confine the plume to the valley. However, drainage forcing is sufficient to divert the flow around high points and through gaps in ridges.

Model runs were performed at grid spacings of 60 m and 120 m. The 120 m run failed to locate smoke at the Falling Creek Bridge (intersection of the road (dark blue line) and the dark green Falling Creek Valley) where smoke was observed at 0800 EST 26 November. The 60 m run did place smoke at the bridge however, the run was judged "barely successful". First, smoke was observed from the bridge westward (red line). Second, the observer reported smoke and fog at the bridge with the wind blowing from the northeast. Model winds at the bridge at 0800 EST were blowing lightly from the southwest. The implication of the 25 November case is that the drainage winds simulated by PB-Piedmont were weaker than the observed drainage winds.

2.b. 12 January 2003

On 12 January 2003, the PNWR conducted a 1018 acre prescribed burn. PB-Piedmont was run from 1700 EST 12 January through 0800 EST 13 January. The weather during the burn was clear and dry but became progressively cloudy during the post-burn period. Cloud cover increased from scattered clouds to breaks in a cloud deck at about 3-5,000 m. Synoptic forcing favored winds blowing from the west during the burn.

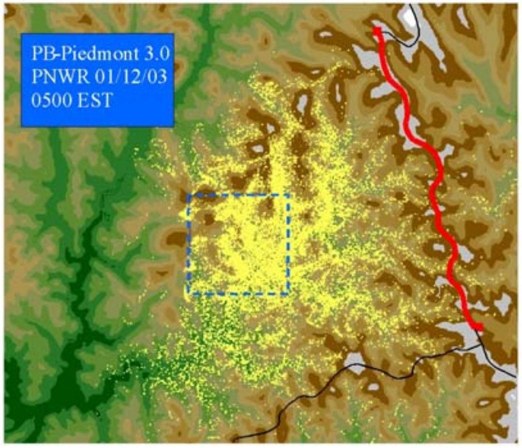


Figure 2. The pattern of smoke modeled by PB-Piedmont for 0500 EST 13 January 2003. The dashed blue line identifies the burn site. The red and black lines identify roads.

During the night, a weak frontal trough developed across the area. Synoptic forcing became weak and at one time favored winds blowing from the north – a reinforcement of drainage forcing. Later in the night, a high pressure system built into the area from the west. This system acted to blow air up valley and over a ridge east of the burn site, much in the same direction as smoke was observed during the daytime burn period.

Figure 2 shows the distribution of residual smoke from the burn as modeled by PB-Piedmont for 0500 EST 13 January. The strong synoptic forcing has pushed smoke up valley and through side valleys and gaps in ridges to cross a road east of the burn site at numerous locations. Smoke was also modeled as flowing across a road to the south of the burn site.

At 0450 EST, a crew from the PNWR found smoke in various concentrations all along the eastern road (red line in Figure 2). No smoke was reported along the road south of the burn site.

2.c. 15 January 2003

The case of 15 January 2003 was the best documented of the smoke observations collected by the PNWR. It is also the best example of movement of smoke trapped in adjacent valleys under rapidly changing weather conditions.

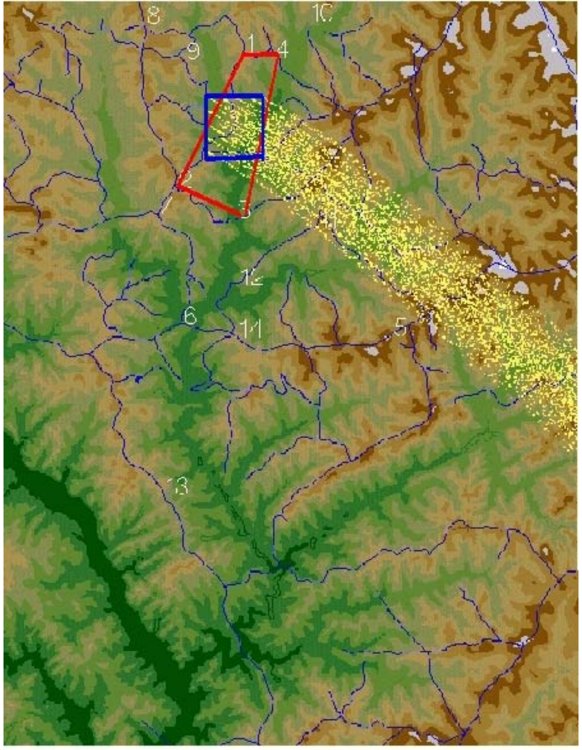


Figure 3. Location of the burn site (blue square) and area of actual burn (red polygon) for a 391 acre prescribed burn on 15 January 2003. Smoke plume is at 1600 EST. White numbers identify smoke observation sites. Blue lines identify roads. The visual domain is 12.6 by 18.9 km.

On 15 January the PNWR conducted a 391 acre prescribed burn located as shown in Figure 3. Weather during the burn and post-burn period was clear and dry. A high pressure system located to the west of the burn site favored winds blowing from the northwest during the day of the 15th. The high moved over during the night setting up conditions for the dominance of drainage forcing. The very dry conditions favored rapid cooling and strong drainage flows. The high passed to the east during the night setting up conditions favorable for brisk winds from the southeast by sunrise. PB-Piedmont was run from 1600 EST 15 January through 0900 16 January. The plume at 1600 EST is shown blowing to the southeast in Figure 3.

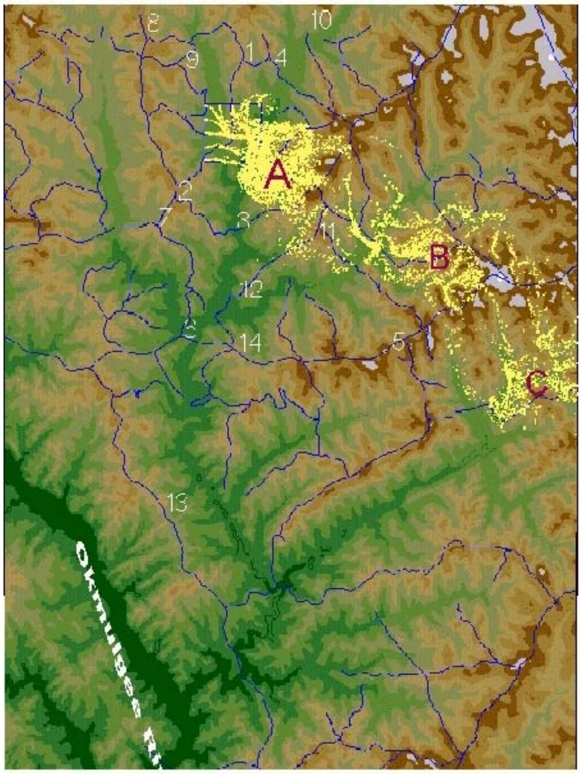


Figure 4. Smoke near the ground simulated by PB-Piedmont for 1900 EST 15 January 2003.

Figure 4 shows the modeled smoke plume for 1900 EST 15 January. Drainage forcing has broken the plume into three patches (identified by the letters A, B, C) which will be confined to the three adjacent valleys. During the course of the night, the patch at C will move down valley to the southwest eventually reaching the Okmulgee River valley. Patches A and B will merge to flow down the Falling Creek valley between points 12 and 13.

Figure 5 shows smoke at 0800 EST 16 January 2003. Smoke from location C has filled the Okmulgee River valley. Smoke from A and B has merged to fill the Falling Creek valley. Increased synoptic forcing favoring winds from the southeast has pushed smoke to the northwest of the burn site (blue square). The result is a ground-level smoke pattern totally unlike the smoke plume observed on January 15 (Figure 3). The visual domain was 12.6 by 18.9 km. Thus smoke from the burn site was predicted to be located approximately 10 km southeast of the burn site, 15 km south of the burn site, and moving off the grid at least 5 km to the northwest of the burn site.

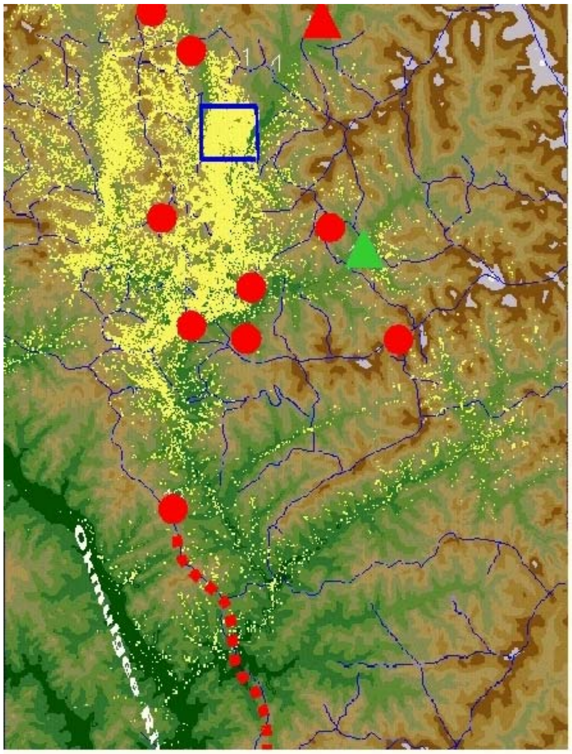


Figure 5. Pattern of smoke predicted by Pb-Piedmont for 0800 EST 16 January 2003. The blue square identifies the burn site. Circles and triangles locate smoke observations.

The circles and triangles in Figure 5 identify locations where smoke observations were taken. Red circles identify locations where PB-Piedmont predicted smoke where smoke was observed. The dashed red line identifies smoke having been observed continuously along a road. The red triangle at the top of Figure 5 identifies a site where smoke was reported but not predicted by the model. Had the northern boundary of the model burn site been located at the northern boundary of the PNWR burn site (Figure 3), it is likely PB-Piedmont would have placed smoke correctly. The green triangle identifies a site where PB-Piedmont predicted smoke but smoke was not observed.

2.d. 25 March 2003

On 25 March 2003, the PNWR conducted a 1085 acre prescribed burn at the location shown in Figure 6. The road identified by the red line was the south boundary for the burn site.

The weather during the burn and the post-burn period was clear and dry. Strong synoptic forcing favored winds blowing from the southwest during the day and from the south at night. The surface geostrophic wind, a measure of the strength of the synoptic forcing, ranged from 8-14 m/sec. Winds at the Macon, GA, weather station, located in a river valley approximately 50 km south of the burn site, ranged from 2-4 m/sec from the south during the night.

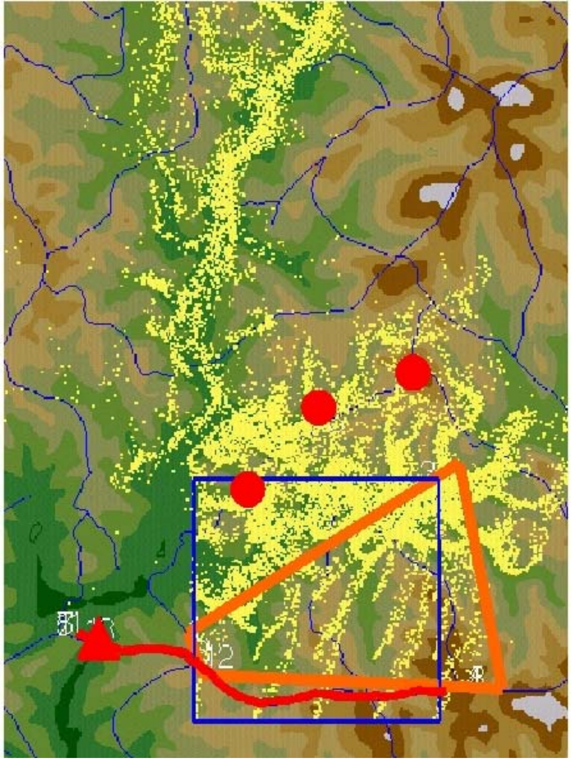


Figure 6. PB-Piedmont smoke plume at 0800 EST 26 March 2003 for a 1085 acre prescribed burn on 25 March 2003. Blue square identifies the model burn site. Orange polygon identifies the PNWR burn site. Blue lines identify roads.

Figure 6 shows that drainage forcing was restricted to channeling the smoke as it blew north from the burn site. Beginning at 0500 EST, crews from the PNWR observed smoke at the Falling Creek Bridge (red triangle). Between 0500 EST and 0800 EST (Figure 6), smoke was observed from the bridge along the road south of the burn site. Given the strength of the synoptic forcing, the presence of smoke at these locations was unexpected. Smoke was also observed north of the burn site at 0800 EST (red circles).

With strong synoptic forcing, the case of 25 March 2003 should have been one of smoke blowing to the north with some channeling by local terrain. Yet smoke was observed all along the ridge top road south of the burn site (red line in Figure 6). This suggests that smoke movement and dispersal along the upwind side of the burn site was influenced by factors other than a combination of synoptic and drainage forcings.

Strong winds blowing over the crests of

ridges can set up lee side horizontal roll vortices that can suck smoke back toward the upwind boundary of a burn site. Lateral air currents within these vortices can move smoke along the ridgeline to either side of the burn area. This mechanism, if it occurred on 26 March, might be able to explain the presence of smoke from the burn site west to the Falling Creek Bridge. PB-Piedmont does not support simulation of roll vortices.

3. PB-PIEDMONT REANALYSIS

The findings from the case of 25 November 2002, 25 March 2003, and an additional case not reported in this paper showed that drainage flows generated by PB-Piedmont were too weak and were overcome by opposing synoptic pressure forces too easily. In the model equations, the pressure that drives drainage flows is the mean pressure for the drainage layer – a seemingly logical choice as the drainage layer is an “integrated layer” and is moved by the mean wind for the layer. However, the model validation studies call this choice into question.

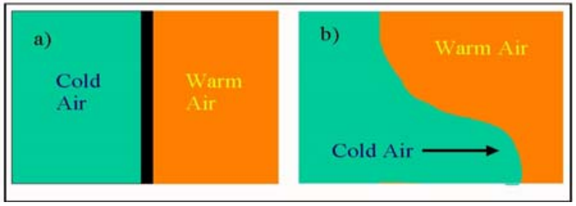


Figure 7. Schematic showing a) cold and warm air separated by a partition and b) after partition has been removed.

Figure 7 shows a schematic of the formation of a pressure-driven flow when a partition separating cold air from warm air is removed. The surface is where pressure anomaly within the cold air is greatest and is where the cold air displaces the warm air most rapidly.

The PNWR prescribed burn case studies are being reanalyzed with the mean pressure for the drainage layer replaced with the surface pressure. The first reanalysis was for 25 November 2002 with grid spacing of 120 m. Refer to the 120 m panel of Figure 1 for comparison.

Figure 8 shows a close-up of the drainage flow near the Falling Creek Bridge (thick red line segment) for 0800 EST 25 November 2002. Isotherms (white lines) are in degrees F. For wind symbols, each long barb equals 1.0 m/sec and a short barb equals 0.5 m/sec. Replacing the mean drainage layer pressure with the surface pressure created drainage flows that pushed smoke down Falling Creek Valley past the bridge. The drainage flows had weakened after 0300 EST as fog formed in the valley and PB-Piedmont reduced cooling rates there. Yet by 0800 EST, winds remained from the north within the narrow valley from Falling Creek Bridge southward. Winds were blowing from the southwest over higher ground.

Figure 8. PB-Piedmont reanalysis for 0800 EST 25 November 2002. The road where smoke/fog was observed is marked with red line.

The red line identifies the location along the road where PNWR crews observed smoke/fog. A weak eddy placed smoke in a side drainage just west of the bridge and north of the road. The model did not place smoke over the road except near the bridge. Fog is possible where the temperature is less than 32F (0C).

4. ACKNOWLEDGMENTS

The ongoing work of Ken Forbus and Tim Giddens in preparing data sets for the PB models and in acquiring validation data is appreciated.

5. REFERENCES

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