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Modeling of Thunderstorm Induced Wind Shifts

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Introduction

Shifting winds present hazardous conditions to fire crews as slow-spreading lower intensity flanking fires can quickly transform into raging high-intensity head fires. Thunderstorms are one driver of potential wind shifts. During the life cycle of a thunderstorm surface winds shift from inflows feeding the updraft of developing thunderstorms to outflows as downdrafts develop in the later stages of the storm's evolution. Thunderstorm outflows are capable of traveling long distances across the landscape, resulting in strong wind shifts in areas with minimal signs of changing weather.

Thunderstorm induced wind shifts have had a role in a number of firefighter fatalities. Haines (1988) described the role of a thunderstorm on the 1981 Ransom Road Fire in Florida that resulted in a ninety-degree wind shift and an increase in wind speeds from an average of 7 to 25 miles per hour (11 to 41 kilometers per hour) with gusts reaching 52 mph (84 kph). Goens and Andrews (1998) suggest that a thunderstorm downdraft played a role in the 1990 Dude Fire fatalities in Arizona. Channeling of the outflow winds through the rugged terrain led to the rapid down- and cross-slope fire spread that entrapped the firefighters.

In this paper, we describe results from a thunderstorm-induced wind model capable of describing the evolution of outflow winds. The model is designed to allow fire personnel to assess the risk of changes in wind speed and direction, and take action to move fire crews to safety up to 30-60 minutes before wind shifts arrive at a fire site. The model links real-time operational radar precipitation data with ambient temperature and relative humidity to map locations and fields of outflow wind velocities as they evolve relative to local terrain during the course of the day. The 2013 Yarnell Hill Fire is used as a case study.

Model Description

The outflow model combines a simple density current model developed for simulating nocturnal smoke movement (Achtemeier, 2005) with a simplified description of the thunderstorm life cycle. Thunderstorms are envisioned as "black boxes" whose intensity is determined by the intensity of radar precipitation measurements. The strength of the downdraft is determined from the combination of precipitation intensity, ambient temperature and potential for evaporation as precipitation falls through dry sub-cloud air. The downdraft strength relates to the outflow temperature thus producing the cold air mass that pushes beyond the parent storm, displacing nearby warmer air masses. The boundary of the cold air mass (gust front) is a near-discontinuity in temperature, wind direction, and wind speed.

Results

On June 30,2013 nineteen members of the Granite Mountain Interagency Hotshot Crew died on the Yarnell Hill Fire in central Arizona. While much is unknown concerning this tragic event, changes in fire behavior induced by changing weather conditions had a role as winds shifted throughout the afternoon. At 1630 local standard time, thunderstorm outflows reached the southern perimeter of the fire. Winds increased substantially; the fire turned south and overran the Granite Mountain IHC at about 1642 LST (Yarnell Hill Serious Accident Investigation Report, 2013). The following is our attempt to recreate the wind shifts of this event with a tool that can eventually be used on fire incidents to better convey the threat of potential wind shifts.

Figure 1 shows the relationship between Yarnell, the radar site in Flagstaff AZ and various topographic features. Yarnell is approximately 92 miles (142 km) west-southwest of the radar site. Important topographic features include the Mogollon Rim near Flagstaff with elevation approximately 7600 ft (2320 m) and two mountain ranges between the Mogollon Rim and Yarnell. Prevailing thunderstorm movement was from the northeast at about 10 mph which caused most thunderstorm outflows to be concentrated along the southwest-facing slopes of the Mogollon Rim.

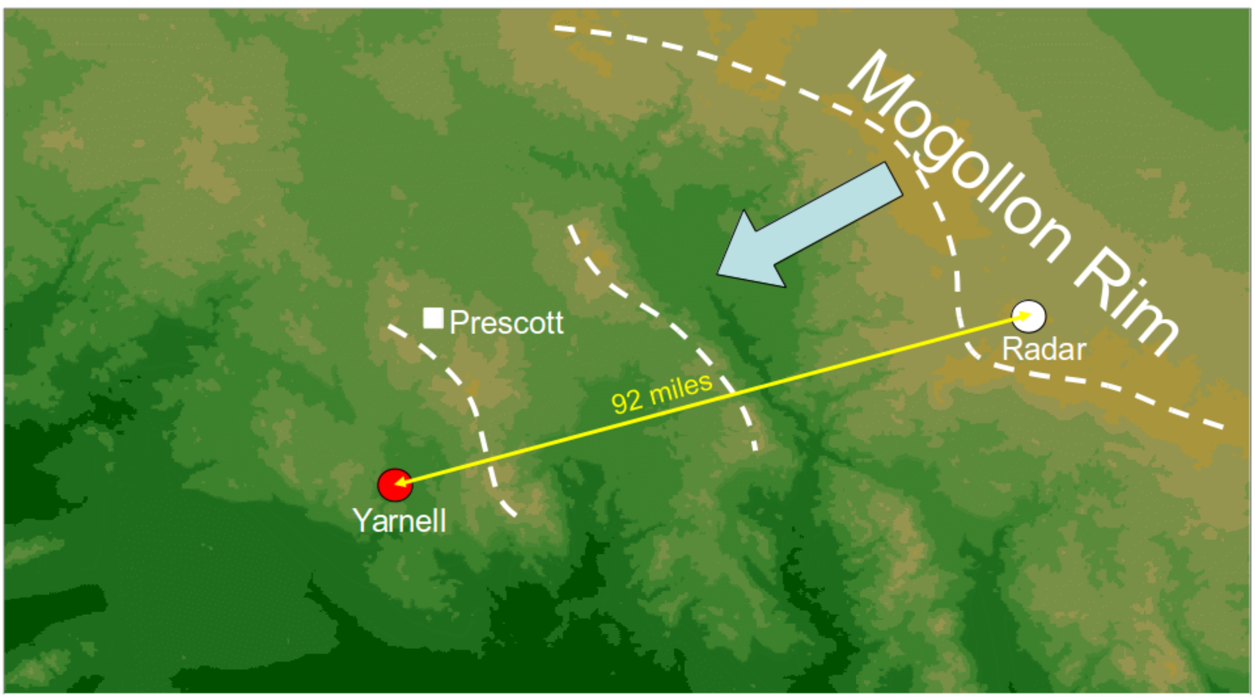

Figure 1:Topographic features in study area. Darker greens are lower elevations while tans show higher elevations. Dashed lines indicate edge of Mogollon Rim and select mountain ranges.

Convection began late morning along the Mogollon Rim and by 1200 LST the outflow boundaries from several strong storms had begun to merge along a northwest to southeast axis along the Rim (Figure 2a). By 1335 LST, outflows from storms pushing off the Mogollon Rim had merged into a single boundary advancing toward the southwest (arrows in Figure 2b). Meanwhile, outflows from the storms over high ground northwest of Yarnell were pushing toward lower elevations toward the southeast. By 1430 LST, outflows had merged into a single boundary and new storms were forming over the first mountain range southwest of the Mogollon Rim (Figure 2c). At 1500 LST, The southwest-moving outflow boundary had stalled along the mountain range just east of Yarnell (Figure 2d).

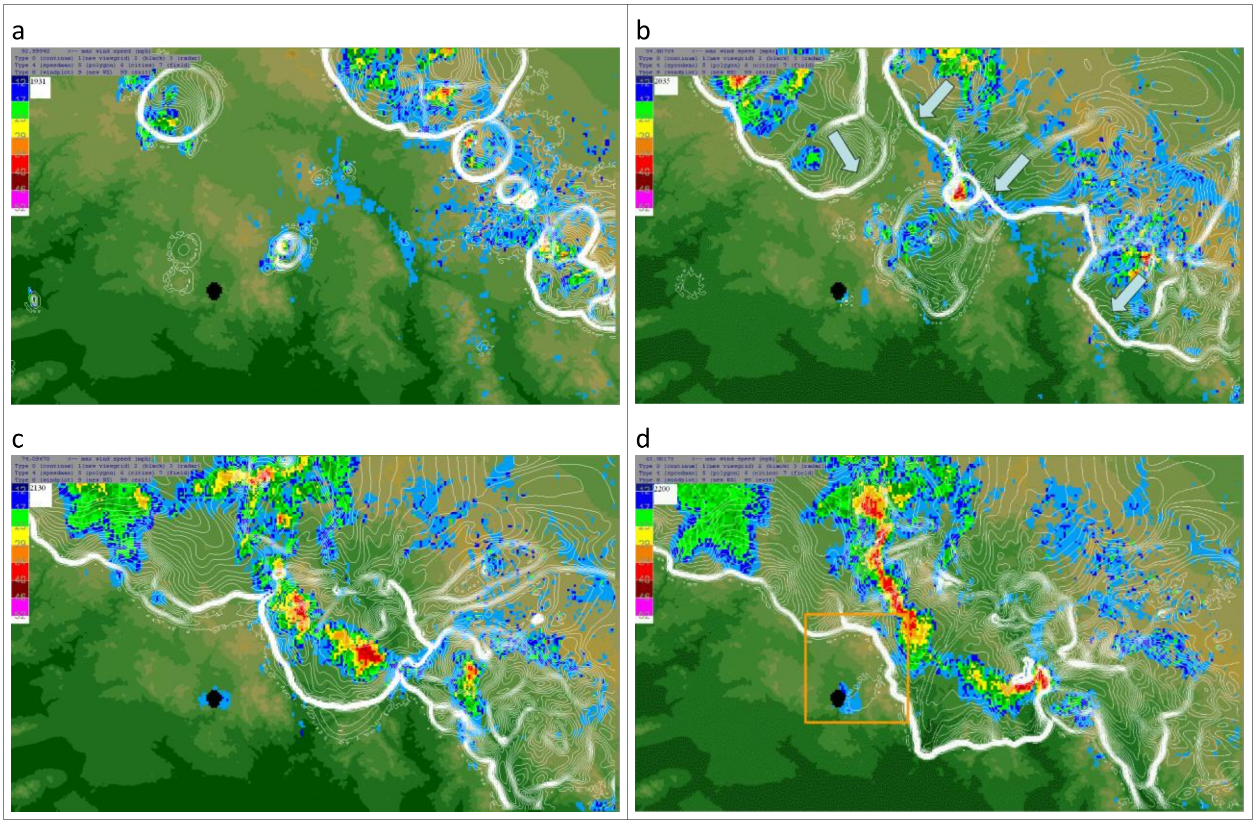

Figure 2: Radar precipitation echoes overlain on the elevation map and thunderstorm outflows identified by white contours for a) 1231 LST, b) 1335 LST c) 1430 LST and d) 1500 LST. The blackened area identifies the location of the Yarnell fire smoke plume as observed by radar at an elevation of 8,000 feet. The orange box in (d) represents the area of focus in Figure 3.

By 1500 LST the outflow boundary reached the closer of the two ridges northeast of Yarnell (Figure 3). New storms began to form as air was forced upward by the ridge. The ridge presented a barrier to the southwestward advance of the outflow boundary until the newly developing storms contributed additional cool dense air to fuel the gravity currents. By 1515 LST the outflows surged through a gap in the ridge and began southwestward at 40-46 mph (64-74 kph). At 1615 LST the outflow boundary reached the northern boundary of the radar-observed Yarnell smoke plume. Meanwhile, a second outflow surge has breached a second gap in the ridge to the east-northeast and is racing toward Yarnell from the east. By 1645 LST the outflows have merged and shifted the winds to blow from the northeast over the Yarnell fire.

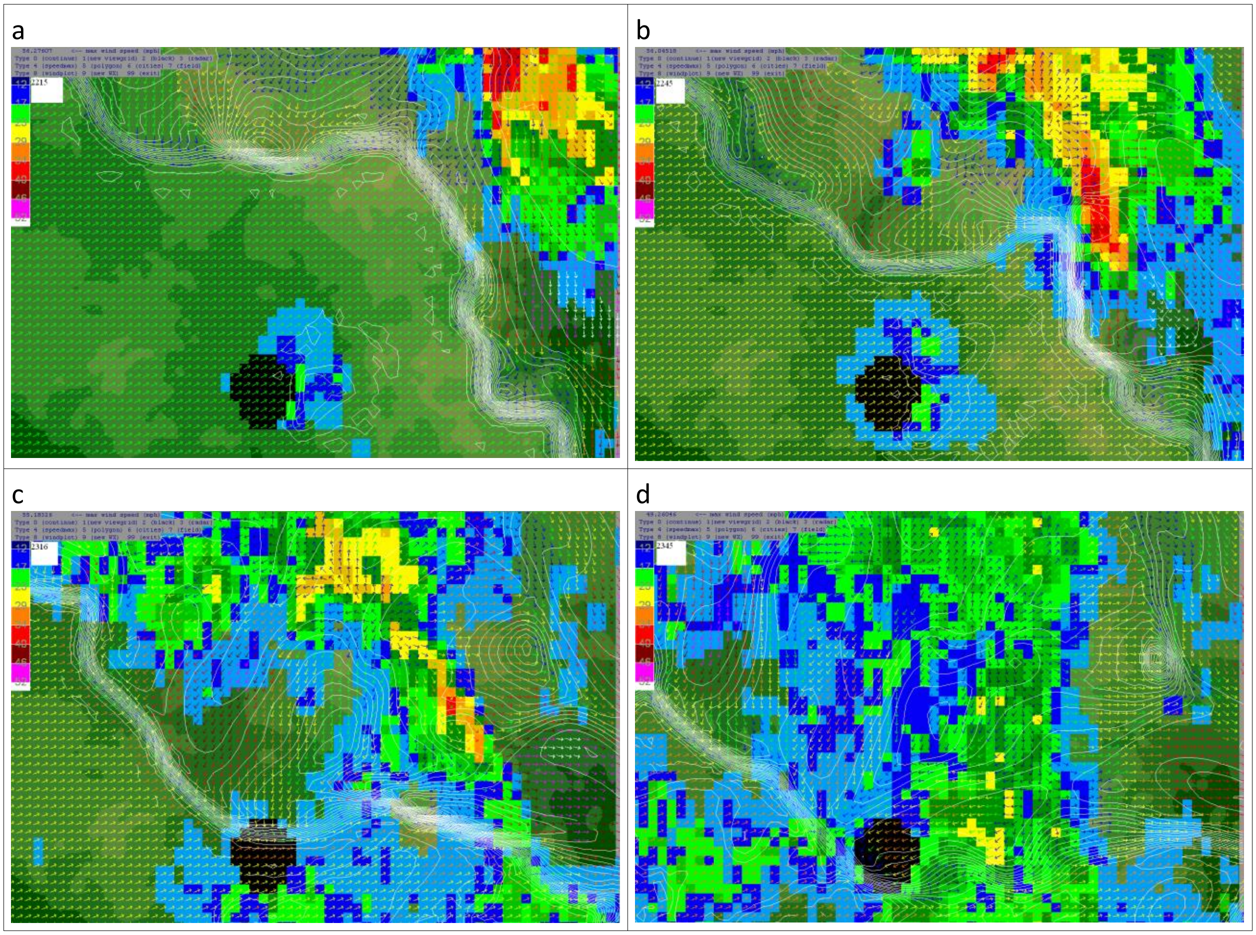

Figure 3: Closeup of radar echoes overlaid on terrain with modeled evolution of the outflow boundary (white line) as it progresses toward the Yarnell Hill Fire at a) 1515 LST, b) 1545 LST, c) 1615 LST and d) 1645 LST.

Summary

Overall the model did a reasonable job of capturing the complexities of the outflows as they evolved over the course of an afternoon and traveled roughly 90 miles from the initial area of convection. Topographic channeling of the outflows was effectively captured by the model which contributed to the model doing a good job of conveying the complexity of the evolving wind field far beyond what is currently conveyed in weather forecasts.

The model captured the major wind shifts associated with the thunderstorm outflows. However, there were other weaker wind shifts that occurred mid-afternoon that were not captured in this simulation. As the model is solely focused on simulating the evolution of the outflows there are other aspects of the flow that are neglected. Slope flows induced by solar heating of the terrain would influence the evolution of the outflows to some degree but are currently neglected. The simple, single layer formulation of a density current is an additional limiting factor as three dimensional effects may also play a role. Despite these limitations the model did supply a useful description of the evolution of surface wind field for this event as the model captured the most dominant features of the flow and the simplifying assumptions allows the model computations to be performed fast enough for this tool to be useful in an operational environment.

References

Achtemeier GL (2005) Planned Burn-Piedmont. A local operational numerical meteorological model for tracking smoke on the ground at night: Model development and sensitivity tests. *International Journal of Wildland Fire* 14, 85-98.

Goens DW and Andrews PL (1998) Weather and fire behavior factors related to the 1990 Dude Fire near Payson, Arizona. In *Proceedings, 2nd Symposium on fire and forest meteorology*. Boston MA, American Meteorological Society, 153-158.

Haines DA (1988) Downbursts and wildland fires: a dangerous combination. *Fire Management Today* **49**(3) 8-10.