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Gas emissions, tars, and secondary minerals at the Ruth Mullins and Tiptop coal mine fires

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ABSTRACT

Both the Tiptop and Ruth Mullins coal fires, Kentucky, were reinvestigated in 2009 and 2010. The Tiptop fire was not as active in 2009 and may have been on the path to burning out at the time of the 2009 visit. The Ruth Mullins coal mine fire, Perry County, Kentucky, has been the subject of several field investigations, including November 2009–February 2010 investigations in which we measured gas emissions, collected minerals and tars, and characterized the nature of the fire. Vents exhibiting the greatest gas flux (> 100,000 mg/s/m^2) are those with the largest amount of condensate minerals and tars. Vents with moderate gas flux (10,000–100,000 mg/s/m^2) are less likely to contain condensate minerals, but are collocated with tars, and vents with the lowest flux (< 10,000 mg/s/m^2) generally lack both minerals and tars. Aliphatic hydrocarbons present in the gases include C1-C9 compounds, and aromatics include BTEX compounds. Diffuse-CO_2 emissions are concentrated along the fracture zones overlying abandoned mine works. The area of peak diffuse flux corresponds to the trend of the collapsed portal that forms vent 5. The greatest vent emissions were also recorded at vent 5. The snow-melt zone mapped in January 2010 overlies the areas of peak diffuse-CO_2 emissions measured in November; together they delineate the zone of active combustion. Comparison of greenhouse gas emissions from the two sources shows that vent emissions exceed diffuse emissions. The highly fractured, quartz-cemented roof rock funnels the majority of emissions toward the vents. Significant decreases are seen in estimates of yearly greenhouse emissions based on data gathered from November 2009 to February 2010, with estimates from November significantly exceeding any previously published estimates. For example, September 2009 estimates from vent 3 alone indicated that 19 ± 7.5 T CO_2/yr were emitted while the November 2009 estimates were 1800 ± 690 T/yr.

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Barometric pressure was lower in November than September. This implies that there are many factors influencing the seasonal variations in fire emissions and that more frequent monitoring will be necessary to derive accurate estimates of coal fires' contribution to the carbon budget.

1. Introduction

Coal fires destroy valuable energy resources and damage ecosystems; they have the potential to damage infrastructure and adversely impact human health. They are a poorly understood source of both greenhouse gases and particulate matter. Coal fires and their environmental implications have gained worldwide attention (Stracher et al., 2010) and steps are being taken to further quantify the extent and potential impact of many of these fires. Ongoing work in India and China (Jiang et al., 2011; Mishra et al., 2011; Prakash et al., 2011; Wu and Liu, 2011; Prakash et al., 2009; Prakash and Berthelote, 2007; Singh et al., 2007; Zhang and Kuenzer, 2007; Chatterjee, 2006; Prakash and Vekerdy, 2004; Gupta and Prakash, 1998) and work in Wyoming (Engle et al., 2011, 2012a) has shown that remote sensing is an extremely valuable tool in monitoring large-scale fires underlying relatively flat strata. Unlike many fires worldwide, the known fires burning in eastern Kentucky do not occur below thin veneers of poorly indurated sediment; they occur in abandoned underground coal mines beneath thick, indurated rocks within a mountainous terrain. The lone exception is the Fishtrap Lake fire, which is visible using MODIS infrared satellite imagery (M. Ruminski, personal communication to Hower et al., 2011). In these settings, ground-based measurements can take the place of remote-sensing in terms of monitoring the extent and migration of the fire. While time consuming, these techniques have the added bonus of providing valuable emissions data necessary for assessing the potential human health and infrastructure impacts. Human health impacts are of especial concern, as many of the fires in Kentucky and worldwide occur near populous areas; indeed, the April 2011 Appalachian Community & Ecosystems Health Summit (http://www.appsciencesummit.eku.edu/) identified coal fires as a point source of concern within the spectrum of cradle-to-grave coal resource contaminants. Before this concern can even be addressed, however, much more information is needed on coal fire emissions and dynamics.

Studies of coal fires in Kentucky have concentrated on the six mine fires that are most easily accessible: Laura Campbell (Stracher et al., 2008), Ruth Mullins (Hower et al., 2011; Silva et al., 2011a, 2011b; O'Keefe et al., 2010), Truman Shepherd (O'Keefe et al., 2010; Hower et al., 2013; Dindarloo et al., 2015), Old Smokey (O'Keefe et al., 2011), Tiptop (Hower et al., 2009), and Lotts Creek (Hower et al., 2012; Garrison et al., 2017).[6] The Ruth Mullins coal mine fire (Fig. 1) is the most studied coal fire in eastern Kentucky. The fire was first visited by Hower, Stracher, and others in March 2007. Following remediation in the spring of 2007, it was thought to be extinguished until smoke was noted on the opposite side of the ridge in September 2007. Hower, O'Keefe, and others visited the site shortly after reports of smoke were received and they were able to see flames and glowing embers on the floor of one abandoned mine shaft and smoke exiting several others. At that time, all abandoned mine portals on the exposed ridge face were intact and no slumping had occurred. Since 2007, the Ruth Mullins site has changed significantly. Large blocks have slumped away from the cliff face and all mine portals have collapsed. Trees have fallen as the roots were burned from the bottom up. In the space of the 10 months of this study, more slumping was apparent, and since the completion of this study, progressive failure of the highwall has continued. This fire has not been extinguished and poses eventual risk to Kentucky Highway (KY) 80, a major four-lane divided regional highway, and possibly the reclaimed mine on the far side of KY 80. A service station is located near the fire, and while not in any danger from the fire, per se, continued exposure to emissions could impact the employees' health.

The Tiptop coal mine fire (Fig. 1) has been examined on multiple occasions since 2008. Fire flare-ups ignited forest fires on the overlying slopes in fall 2008 and summer 2009. Following both forest fires, remediation of the active burn zone was attempted. This consisted of pushing loose dirt over the exposed mine shafts and auger holes. These efforts were largely unsuccessful in extinguishing the fire, although the later efforts resulted in significantly decreased emissions. This fire is located in a single isolated ridge surrounded by active underground and surface mining operations, directly across a valley from a coal preparation plant. The mining operations are in no danger from the fire, although the health of mine employees and preparation plant workers could potentially be impacted by the emissions.

1.1. Prior work

The Ruth Mullins and Tiptop coal mine fires have been under investigation since the spring of 2007 (Stracher et al., 2008; O'Keefe et al., 2010) and the spring of 2008 (Hower et al., 2009), respectively. These investigations made first-order quantifications of CO_2, CO, and Hg vent gas concentrations using Dräger tubes and an Arizona Instruments Jerome 431-X Mercury Vapor Analyzer. The S-type pitot tube in conjunction with a Flow Kinetics FKT 1 1DP1A-SV flow meter, as was used for the Wyoming studies (Engle et al., 2011, 2012a), was first employed at the Ruth Mullins fire in the spring of 2009, allowing vent emission estimates to be calculated (O'Keefe et al., 2010).

Results from these basic surveys indicate that vent temperatures in both cases range between ambient and extreme (291 - > 300 °C) temperatures, with greatest concentrations of greenhouse gases recorded from the hottest vents. In all cases, Dräger tube-indicated CO concentrations exceeded OSHA 8-h limits (> 50 ppm). In many cases, Dräger tube-indicated CO_2 concentrations also exceeded OSHA 8-h limits of 0.5 vol%, ranging from 0.25–6.0 vol%. The Jerome instrument provided very low elemental Hg vapor concentrations at the Ruth Mullins fire, between 0.009 and 0.560 μg/m^3, although still above typical background concentrations of about 1.5 ng/m^3. The Jerome instrument provided significantly higher concentrations at the Tiptop fire, ranging from < 9–580 μg/m^3. High benzene and other volatile organic compounds (VOCs) were measured at both sites. Initial vent velocity measurements at Ruth Mullins ranged from 0.25–0.95 m/s. Prior to the current work, vent velocity measurements had not been made at the Tiptop mine fire.

These initial analyses allowed us to estimate that Ruth Mullins is emitting roughly 734 T of CO_2, 21 T of CO, and 0.84 T of Hg per year. We expect that overall greenhouse gas emission estimates from the initial survey of Tiptop will be similar, given similar conditions, although Hg emissions are likely higher. When compared to coal-fired power plants and larger fires in the United States (Engle et al., 2011, 2012a; Ide and Orr, 2011), emission estimates from both Ruth Mullins and Tiptop are small. However, when multiplied by the number of fires of this size estimated to be burning in Kentucky alone, a number certainly in the 'tens', these numbers become significant. It is, therefore, necessary to arrive at a better estimate of coal fires' contribution to the North American carbon budget.

[6] In Kentucky, where possible, coal fires are named for the person who reports them. This is the case for the first three fires noted.