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Thermal characteristics of coal fires 2: Results of measurements on simulated coal fires

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Abstract

In this paper we present thermal characteristics of coal fires as measured during simulated fires under an experimental setting in Germany in July 2002. It is thus a continuation of the previously published paper "Thermal surface characteristics of coal fire 1: Results of in-situ measurement", in which we presented temperature measurements of real subsurface coal fires in China [Zhang, J., Kuenzer, C., accepted for publication. Thermal Surface Characteristics of Coal Fires 1: Results of in-situ measurements. Accepted for publication at Journal of Applied Geophysics.]. The focus is on simulated coal fires, which are less complex in nature than fires under natural conditions. In the present study we simulated all the influences usually occurring under natural conditions in a controllable manner (uniform background material of known thermal properties, known ventilation pathways, homogeneous coal substrate), creating two artificial outdoor coal fires under simplified settings. One surface coal fire and one subsurface coal fire were observed over the course of 2 days. The set up of the fires allowed for measurements not always feasible under "real" in-situ conditions: thus compared to the in-situ investigations presented in paper one we could retrieve numerous temperature measurements inside of the fires. Single temperature measurements, diurnal profiles and airborne thermal surveying present the typical temperature patterns of a small surface-and a subsurface fire under undisturbed conditions (easily accessible terrain, 24 hour measurements period, homogeneous materials). We found that the outside air temperature does not influence the fire's surface temperature (up to 900 °C), while fire centre temperatures of up to 1200 °C strongly correlate with surface temperatures of the fire. The fires could heat their surrounding up to a distance of 4.5 m. However, thermal anomalies on the background surface only persist as long as the fire is burning and disappear very fast if the heat source is removed. Furthermore, heat outside of the fires is transported mainly by convection and not by radiation. In spatial thermal line scanner data the diurnal thermal patterns of the coal fire are clearly represented. Our experiments during that data collection also visualize the thermal anomaly differences between covered (underground) and uncovered (surface) coal fires. The latter could not be observed in-situ in a real coal fire area. Subsurface coal fires express a much weaker signal than open surface fires and contrast only by few degrees against the background. In airborne thermal imaging scanner data the fires are also well represented. Here we could show that the mid-infrared domain (3.8 μm) is more suitable to pick up very hot anomalies, compared to the common thermal (8.8 μm) domain. Our results help to

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understand coal fires and their thermal patterns as well as the limitations occurring during their analysis. We believe that the results presented here can practicably help for the planning of coal fire thermal mapping campaigns — including remote sensing methods and the thermal data can be included into numerical coal fire modelling as initial or boundary conditions.

Keywords: Coal fire simulation; Simulated heat sources; Thermal analyses; Temperature profiles; Airborne thermal scanners

1. Introduction

Coal fires occur in many countries worldwide (Glover, 1998; Prakash and Gupta, 1999; Pennig, 2003; Kuenzer, 2005). A coal fire is defined as burning volume of coal, which can be a coal seam exposed to the surface, a burning underground seam or a burning coal waste or coal storage pile. The ignition of the fires can occur naturally or through human influence. In most cases coal fire ignition is triggered through mining activities (Kuenzer et al., 2007a). Through the moving and exposure of large coal volumes, reaction surfaces increase and the carbon in the coal reacts with oxygen in the air. This is an exothermal process. If the released heat cannot escape (insufficient ventilation) the coal can ignite at temperatures as low as 80 °C. (Walker 1999; Chaiken et al., 1998; Banerjee, 1982; Banerjee et al., 1972; Bylo, 1960).

Negative influences of such fires are manifold. They include the emission of large amounts of green house relevant as well as toxic and health threatening gasses (Kuenzer et al., 2007b,), the sudden collapse of bedrock due to the volume loss underground (Chen, 1997), the deterioration of vegetation, and the endangering of mining activities (see Fig. 1). Economically, they lead to the loss of the valuable resource coal. We have calculated that the loss of coal due to coal fires in China equals the German annual hard coal production (Kuenzer et al., 2007a). Accordingly, the amount of CO_2 released due to coal fires in e.g. China is estimated to contribute with 0.1% to all human induced CO_2 emissions on a global scale (Kuenzer et al., 2007a,b).

As a consequence of these devastating impacts, numerous authors have addressed the problem of coal fires based on mineralogical, geophysical and remote sensing based research. One research group mainly investigates the formation of new minerals around coal fire induced cracks and vents (Lapham et al., 1980; Coates et al., 2005, Masalehdani et al., 2005; Dai et al., 2002; Livingood et al., 1999). Other scientists employ methods such as gas sample analysis, electromagnetic profile measurements, geophysical modelling, temperature measurements, micro seismic, and geo-electrics to quantitatively analyze, locate and predict the coal fires and their development (Lohrer et al., 2005; Wessling et al., 2005; Litschke et al., 2005; Wessling, 2007. Remote sensing based coal fire research has mainly focused on coal fire related thermal anomaly detection (Ellyett and Fleming, 1974; Fisher and Knuth, 1968; Knuth et al., 1968; Giglio et al., 1999; Mansor et al., 1994; Li, 1985; Moxham and Greene, 1967; Prakash and Gupta, 1999; Prakash et al., 1995; Saraf et al., 1995; Zhang, 2004; Kuenzer et al., accepted for publication; Zhang and Kuenzer, accepted

Fig. 1. Coal fire area in Wuda, Inner Mongolia, China. Note the gas exhaust in the background of the left image. Surface fracturing and land subsidence occurs due to the volume loss underground and is commonplace. Photograph: G. Schaumann, June 2005.