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Detecting Coalfires with Remote Sensing: A Comparative Study of Selected Countries

Prasun K Gangopadhyay

International Institute for Geo-Information Science and Earth Observation (ITC), The Netherlands

Kuntala Lahiri-Dutt

Research Fellow, RMAP Program

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Resource Management in Asia-Pacific Program
Research School of Pacific and Asian Studies
The Australian National University
Canberra ACT 0200
Tel: +61 2 6125 9978
Fax: +61 2 6125 4896
Email: rmap@coombs.anu.edu.au

Detecting Coalfires with Remote Sensing: A Comparative Study of Selected Countries

Abstract

Coalfires, both underground and on the surface, are a serious problem in most major coal-producing countries of the Asia-Pacific region including China, India and Indonesia. Australia also experiences similar problems but on a somewhat smaller scale. Combustion can occur either spontaneously or as a result of anthropogenic causes, within the coal seams underground or in piles of stored coal or spoil-dumps on the surface. Once started, they are difficult to extinguish. Coal fires produce large quantities of CO2 along with several other noxious gases such as carbon monoxide, oxides of sulphur and methane. It has been noted that greenhouse gas emissions from coalfires are significant enough to create a global impact. Apart from these large-scale environmental problems coalfires cause many local problems, operational difficulties, lead to consumption of a precious non-renewable energy source, and endanger human security. This paper discusses the significance of satellite remote sensing as a reliable tool to detect and monitor coalfires. In recent years multi-spectral spaceborne thermal remote sensing data have returned very reliable results in identifying coalfires with inputs from local geological maps. This paper elaborates upon examples from selected countries.

Introduction

Coalfire: the problem

Subsurface and surface coal fires are a serious problem in many coal-producing countries (Figure 1). Combustion can occur either within the coal seam, in piles of stored coal or in spoil-dumps on the surface. These fires are widespread in many coal producing places such as China, India, Indonesia and Australia (van Genderen and Guan., 1997, Saraf *et al.*, 1995, Tetuko *et al.*, 2003; Ellyett and Fleming, 1974).

Figure 1. The global spread of coalfires

Considerable environmental and economic problems are directly related to coalfires.

Apart from consuming a valuable resource, it poses enormous operational difficulties by increasing the cost of production or by making existing operations uneconomical. Noxious gases such as SO_x, NO_x and CO often affect the immediate surroundings of an active coalfire.

The emissions from coalfires not only pollute the local atmosphere, but add substantial amounts of the greenhouse gases (CO_2, CH_4) along with the SO_x, NO_x and CO. Large amounts of particulate matter are also emitted into the surrounding areas and increase the aerosol loading in the local atmosphere. This could appear locally as haze. Another associated problem is widespread cracking and subsidence of land surface. As the burned coal turns into ash, voids are created and often the rock overburden can no longer be supported and deep cracks open up. Eventually the surface collapses, which can cause extensive damage to agricultural land, buildings and transport networks. Most of the time these lands are useless for any further (economic) activities.

Impacts of coalfires on climate change, and their contributions to global warming, are increasingly receiving expert attention. Recent coalfire studies of China, one of the major producers of coal, estimate that the country contributes 0.3 (Voigt *et al.*, 2004) to the total world annual output of CO_2 caused by fossil fuels. Other experts put this amount at a much higher level, 3% of the world's total (Cassells, 1998), either of which is not a negligible amount. The greenhouse gases, emitted from all sources have increased the global mean surface air temperature between approximately 0.3 and 0.6ºC since the late 19th century and have led to serious consequences for low-lying coastal areas (NEIC 2005).

Coal: properties and burning process

Coal, the most used fossil fuel, is a readily combustible rock containing more than 50 percent by weight of carbonaceous material, formed from compaction and indurations of variously altered plant remains. These remains were initially deposited in a swampy environment in the form of peat. Unpredictable amounts of other chemicals such as sulfur, chlorine, sodium, and various other minerals can be found in coal. The physical properties of coal, such as color, specific gravity, and hardness, vary considerably. This variance depends on the composition and the nature of preservation of the original plant material that formed the coal; the quantity of impurities in the coal derived from soil and silt being co-deposited with the coal; and the amount of time, heat and pressure that has affected the coal since it was first formed. Time, heat and pressure also determine the degree of maturation of the coal, which is classified according to the increasing amount of carbon, as lignite, sub-bituminous coal, bituminous coal, and anthracite. Rank is another index of coal quality. This is a measure of brightness of the coal as measured microscopically, and is a function of the vitrinite content – one of the microlithotypes in coal (D. J. Williams, personal communication).

Oxidization of coal is a chemical process which can be defined in a simplified form as:

$$COAL + O_2 \rightarrow CO_2 + Energy \qquad (1)$$

But practically it is rather more complicated and may consist of different stages, which also depend on the presence of other substances, such as water, pyrite etc. For dry coal, the simplified reaction is described by Schmal (1989), referring to Kok (1981) as:

$$C_{100}H_{74}O_{11} + 113O_2 \rightarrow 100\ CO_2 + 37\ H_2O + 4.2\times10^8\ J/kmol\ O_2 \qquad (2)$$

The first part of the reaction, which consists of chemical absorption of oxygen from the coal surface, can be presented in following equation. However, the heat of absorption is difficult to isolate on CO_2 invariably formed in the process.

$$C_{100}H_{74}O_{11} + 17.5\ O_2 \rightarrow C_{100}H_{74}O_{46} + 2.5\times10^8\ J/kmol\ O_2 \qquad (3)$$

Experiments have found that heat values generally reach between the two above values. A number of factors are responsible for determining the overall rate of the reactions, the main ones being oxygen content of air; exposed surface area of the coal; temperature; and composition of coal.

Spontaneous combustion and coalfire

In the simplest terms, coal fires are caused by oxidation of coal, but the reactions involved in the oxidation process are still not well understood. A broad outline of the reaction is presented below (*after* Banerjee, 1985; Schmal, 1987).

The potential for spontaneous combustion of coal lies in its ability to react with oxygen at ambient temperature. This occurs through the initial *absorption* of oxygen immediately followed by reaction at the surface of the coal and is an exothermic reaction. The temperature of the coal may then start to rise. This is dependent on how easily the heat generated by the oxidation can be carried away, that is the degree of insulation. If the temperature of the coal rises it will continue to do so, as the oxidation rate coefficient also increases with temperature. When it reaches somewhere between 230 and 280^{o}C, the reaction becomes so rapid that the coal reaches 'ignition' or 'flash' point and starts to burn.

It is well known that the most fire-prone coal is often low ranking, probably because low ranking coal has a higher porosity which allows it to easily breathe oxygen from air and start the process. However, the process can stop immediately if the external layer is saturated and internal layer is not sufficiently porous. The low ranking coal often contains large amounts of moisture which fills the pores and blocks the oxygen from getting in. However, when the coal drains on exposure, air can then cause a fire. Coal with very high or very low moisture content tends to exhibit a low oxidation rate (D. J. Williams, personal communication).

A few manmade fires are caused by an external heat source setting fire to the coal. Some examples would be the fires caused by the illegal distillation of alcohol in Indian coalmines (Sinha, 1986).

Surface fires

An open fire is defined as a coalfire that burns in direct contact with the atmosphere, usually with visible flames (Rosema *et al.*, 1999). Open fires can occur in spoil dumps of reactive coal and seams in open cast mines, but generally not at a large scale. The ground in spoil dumps is not heavily compacted and air can get through, especially on a sloping surface. When open or surface fires spread over a large area (as in north China), remote sensing is a useful tool for regular monitoring and for assisting to develop management strategies.

Subsurface fires

For subsurface combustion, the requisite oxygen enters via cracks or fissures at the surface of old abandoned mine tunnels, or subsided land over the mines which are not stowed properly (generally done with sand or water or both), after mining. It can be said subsurface coalfire and subsidence have a close relation. Figure 2 describes the relations more clearly.

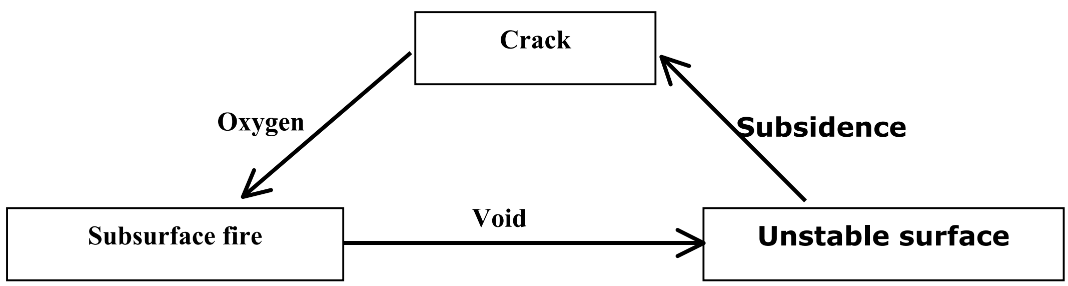

Figure 2. The fire – subsidence nexus

Previous research

Borehole temperature measurements were the main tool to detect subsurface coalfires until the 1960s. The advantage of this method was that temperature measurements were taken close to the fire. However, through this physical verification and measurement approach it remained difficult to gather enough data to produce a large-scale synoptic view. During the early 1960s when airborne thermal scanner data and later, satellite borne thermal scanner data, started to become available, remote sensing based coalfire detection and monitoring became possible. Studies in the United States, Australia, India and China were carried out by concentrating on coalfire detection, monitoring, depth estimation and thermal modelling mostly using Landsat TM and/or airborne thermal data. In these studies, most researchers applied an average emissivity value (0.96) to represent all landcover. As the emissivity values change with the change in landcover, a fixed value can contribute to some error in kinetic surface calculation. For more details see 3.4.

Coalfire in the United States

Coal mining started in Pennsylvania, mainly to make coke for iron smelting. The occurrence of the first coalfire was reported in 1772 and in 1869 it turned into a major disaster and claimed many miners' lives (Glover 1998 cited in Stracher and Taylor 2004). Finally it extinguished itself about a year after an attempt to pour water in the mine failed. The Pennsylvanian fire had so great an impact on the local environment that it nearly destroyed the local flora and fauna, and made it the major acid rain producer in the United States (Glover 1998 cited in Strachar and Taylor 2004). But many underground coalfires have still not been properly verified because they are uneconomic, intangible and unpredictable. The Centralia mine fire (Figure 3), burning since 1962, is one of the worst mine fires in the United States Geissinger 1990 and Memmi 2000 cited in Stacher and Taylor 2004). In 1962, the United States Bureau of Mines reported 223 coalfires all over the United States (Slavecki, 1964). The United States was the first country to apply remote sensing to coalfire detection. Using the 'Reconofax' thermal scanner on an airborne platform, Slavecki (1964), Kunth (1968) and Greene *et al.* (1969) studied fires on waste coal and subsurface coalfires in Pennsylvania, the state where coalfire is still a serious problem. Greene *et al.* also studied the depth of fire and classified fires of three types according to their depth: shallow fire (up to 10m deep), intermediate fires (10 to 30 m deep) and deep fires (more than 30 m deep).

Figure 3

Source: Mr. John Griggs

Coalfire in Australia

The first recorded observation of the famous Burning Mountain coalfire in Australia was in 1828 after its discovery by a local farmer (Ellyett and Fleming by referring Anon, 1972). In 1829 and again in 1831 these fires were mapped with a detailed description by the then surveyor general T.L. Mitchell (Ellyett and Fleming by referring Mitchell, 1839). Later, Abbott recorded detailed information about this phenomenon concerning the movement of the main vent area (Abbott, 1918). Also Bunny (1967) and Rattingan (1967a, b) made detailed and careful contributions on the study of burning mountain coalfire (Ellyett and Fleming by referring Bunny, 1967; Rattingan, 1967a and b). A notable study was produced by Fleming (1972) that suggests the fires could have been burning since the Pleistocene times (Ellyett and Fleming, 1974). Later Ellyett and Fleming (1974) did an extensive study using a Daedalus thermal airborne scanner that operates in 8-14 μm. Today this fire is more than 152 meters underground, and is still slowly burning. Fires also occur spontaneously on open-cut coalmines in many locations such as the Hunter Valley (New South Wales) and the lignite mines in Victoria and South Australia (D. J. Williams, personal communication).

Coalfire in Indonesia

In Kalimantan, formerly the Borneo island of Indonesia, *slash and burn* is a popular and easy method used to claim cultivable land from forests. Often the fires burn out of control and become widespread. Such forest fires sometimes ignite the coal seams that are close to the surface and become very difficult to extinguish because they often ignite in the peat layer (Tetuko *et al.*, 2003). The existence of coalfires in south Sumatra is familiar to the coalfire research community, with some fires several thousand years old. It has been assumed that these ancient coalfires were initially ignited by lighting. In Indonesia, the combination of forest fires, frequent lightning and a warm climate favour spontaneous combustion in exposed layers of coal.

Coalfire in India

Jharia, along with the Raniganj Coalbelt, about 250 km northwest of Calcutta, is producing one third of the coal in India. Many researchers, such as Bhattacharya (1991), Cracknell and Mansoor (1992), Reddy *et al.* (1993), Saraf *et al.* (1995), Prakash *et* al. (1995) have worked on the Jharia coalfire. Using airborne predawn TIR (thermal infrared) and daytime multispectral data Bhattacharya *et al.* (1991) could distinguish the fires from the background. To detect the coalfire another attempt was made by Mukherjee *et al.* (1991) using pre-dawn airborne thermal data. They also attempted to estimate the depth of the fire using a linear heat flow equation. Cracknell and Mansoor (1992) first used Landsat-5 TM and NOAA-9 AVHRR data and found that nighttime NOAA data was quite useful to isolate the warm areas from the background. Reddy *et al.* (1993) used the short-wave infrared (SWIR) region of the EMR, which is covered by Landsat TM band 4,5 and 7. They stated that the hotspots found in the image corresponded well with the field measurements. In the same area, using Landsat TM band 6 and 7, Saraf *et al.* (1995) found that comparatively high temperature zones should correspond with surface fires, while the less warm areas should correspond with subsurface fires. Later Prakash *et al.* (1997) used the Landsat TM TIR and SWIR bands to identify surface and subsurface fires separately. Based on a dual band approach for TM data, Prakash and Gupta (1999) attempted a method for calculating the area of surface fires. The main problem they faced while developing this method was reflected solar energy in the SWIR region.

The Raniganj Coalbelt in the state of West Bengal, adjacent to Jharia coalfield, has been affected by surface and subsurface coalfires since the beginning of mining in the region in the mid-1800s. These fires are endangering the lives of millions of people. This study is based on Landsat5 thermal data with inputs from toposheets and census data (Gangopadhyay, 2000; Gangopadhyay *et al.*, 2005; Lahiri-Dutt *et al.*, 2005).

Coalfire in China

With an enormous reserve of coal stored under its landmass, coalfires are an immense environmental problem in northern China (Figure 4). An interesting study by Huang *et al.* (1991) using Daedalus data, presented a frightening picture of the extent of coalfires. In Xinjinag and Ningxia Hui regions several ITC based researchers have worked on coalfires since 1986. By using pre-dawn airborne thermal scanner data, Yang (1995) identified several coalfires in these areas, which correlated well with field observations. Later Wan and Zhang (1996), and Zhang *et al.* (1997a, b, c, and d) carried out a detailed study in the same area. They used daytime Landsat TM band 6 data to estimate the relative amount of solar illumination during the overpass time, which was used to correct for the effect of terrain. Because the spatial resolution of Landsat 5 thermal band is quite poor (120m) and cannot detect small fires, Zhang *et al.* (1997b) tried a sub-pixel temperature estimation method and found if a pixel had a considerably higher temperature than that of the surrounding background, is was easy to detect. They also highlighted how a fire can be identified if the background temperature is known. Cassels (1996) attempted to model underground coalfires in the Kelazha area of northern China with the inputs from a 3D geological model that has returned quite significant results. By analyzing SWIR spectra of rocks, Zhang Jianzhong (1996) identified the burnt rocks, which are also an indication of coalfire. In 1997, Peng *et al.* attempted some fire depth estimation in the Kelazha area. In Xinxiang province, Wang (2002) identified coalfire-affected areas with ASTER and Landsat TM data.

Figure 4. Coal fires an immense environmental problem in northern China

In the Wuda mining region, situated in Inner Mongolia, an extensive study has been undertaken on coalfires using satellite derived emissivity that provides a more reliable surface temperature (Gangopadhyay, 2003; Gangopadhyay *et al.*, 2004). As emissivity values vary somewhat with the change of landcover, one of the outcomes of this research was that satellite derived emissivity values can increase the accuracy of kinetic surface calculations.

Coalfire and Surface Temperatures

Surface temperature depends on several factors. Those factors are not only inherent properties of a surface, but are also affected by the conditions of the surrounding area. In the case of a subsurface coalfire, the surface temperature also depends on rock and soil type; topography; local atmosphere; emissivity; crack or fissures on the surface; and depth of fire.

Effects of the local atmosphere on surface temperature

Atmospheric factors that influence and decrease the surface temperature are evaporation and strong wind, for example evaporation from a wet surface causes a strong decrease in surface temperature amplitude as the water collects latent heat during the evaporation process. It has been observed that if the surface is wet the overall heat transfer coefficient is larger than in the case of a dry surface (Rosema et al., 1999). Strong winds have a reasonable impact on surface temperature and decrease the temperature amplitude.

Effect of ground material on surface temperature

Most ground material is composed of sediments and rocks and these materials are related to the thermal conductivity and volumetric heat capacity. Together with these thermal properties, radiative properties also play a significant role in the temperature response of the surface to solar radiation, which is directly related to surface albedo or reflectivity (ρ) and emissivity (ε). Table 1. describes the thermal properties of some materials that are common in mining areas.

Table 1: Thermal properties of some materials (CGS units for 20°C)

Material	Thermal conductivity K	Density ρ	Thermal capacity C	Thermal diffusivity κ	Thermal inertia P
Sandstone	0.0120	2.5	0.19	0.013	0.054
Shale	0.0042	2.3	0.17	0.008	0.034
Sandy soil	0.0014	1.8	0.24	0.003	0.024
Limestone	0.0048	2.5	0.17	0.011	0.045
Coal	-	-	-	-	2.5
Coal dust	-	-	-	-	0.5

Source: Kahle A.B., 1979

Effect of terrain on surface temperature

Topography, earth cover-type, slope and aspect also have a significant effect on surface temperature, and this is particularly noticeable during daytime, due to effect of solar heating. A typical 24 hr diurnal temperature curve of the earth's surface is shown in Figure 5. This curve displays a minimum 2-3 hrs before sunrise as the optimum time for remote sensing image acquisition.

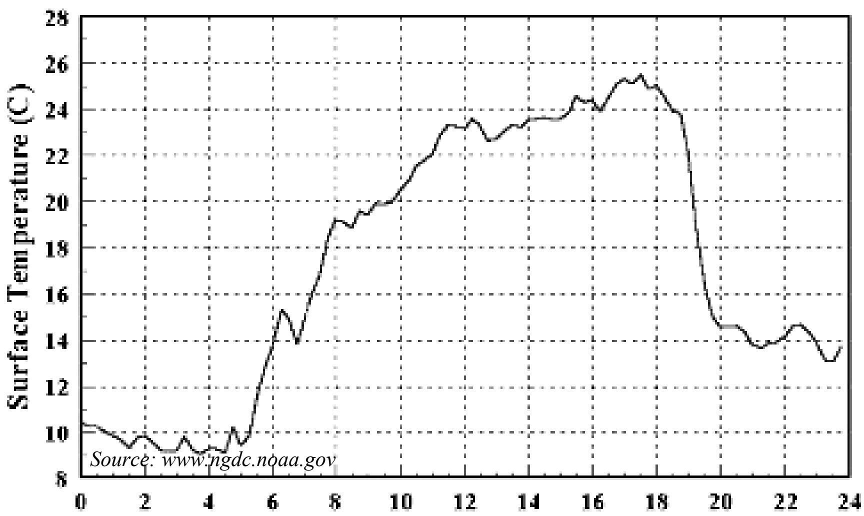

Figure 5. A typical diurnal surface temperature variation

Effect of emissivity on surface temperature

Emissivity or emitting capability of a surface compared to a blackbody (perfect radiator) depends on the intrinsic properties of the surface. Emissivity depends on:

- the phase of the matter (solid, liquid, or gaseous);
- the temperature of the body;
- the condition of the surface (polished, dull, rough, porous) for opaque solid bodies, and absorption within the material for semitransparent bodies;
- wavelength;
- the kind of radiation as specified by the spectral composition and the state of polarization; and
- the direction of the radiation

As emissivity decides the amount of energy that will be released from a hot body it makes a significant contribution to the radiant temperature of a surface. Most of the earth's surfaces falls within the emissivity range of 0.85-0.99 (Rees, 1990).

Remote Sensing, Surface Temperature and Coalfire

The whole process of remote sensing can be described as follows:

- energy source - illuminates or provides electromagnetic energy to the target of interest;
- radiation - energy travels from its source to the target;
- interaction with the target - depending on the properties of both the target and the radiation;
- interaction with atmosphere – reflected and radiated energy from target interacts with atmosphere and transmitted through atmosphere;
- recording of energy at the sensor - a sensor collects and records the transmitted electromagnetic radiation;
- transmission, reception, and processing - the energy recorded by the sensor is transmitted to a receiving and processing station where the data are processed into an image;
- interpretation and analysis - the processed image is interpreted, visually and/or digitally, to extract information about the target, which was illuminated;
- application - the final element of the remote sensing process is achieved when it reveals new information or assists in solving a particular problem

In the electromagnetic spectrum the 3-60μm region is referred to as the thermal infrared region (NPL 2005). Practically, beyond 15μm the energy radiation from the earth's surface is insignificant and complicated to acquire data. Within 15μm, 3-5μm and 8-14μm regions are used in thermal remote sensing as energy is greatly absorbed by atmospheric gases in the other part of the wavelength.

Thermal-infrared sensing exploits the fact that everything above absolute zero (-273^{o}C) emits radiation in the thermal infrared range of the electromagnetic spectrum. Thermal infrared radiation of an object is controlled mainly by the emissivity; geometry of the object; and its temperature. Thermal infrared sensors record differences in the received infrared radiation from various objects. Since these differences are often considerable, an infrared image can exhibit a wide range of contrasts. The sensors carried by aircraft or spacecraft sensitive to this (infrared) region provide a possible means of making synoptic measurements of land surface temperatures. The relation between radiated energy recorded by the sensor and the temperature of the surface can be drawn by Planck's distribution function. The equation in fact describes the energy emitted by a surface which has an emissivity of 1. In the case of a perfect radiator (blackbodies) the calculated surface temperature from recorded radiance coincides with the original surface temperature, ignoring atmospheric conditions. The emissivity of most land surface types has a value between 0.85-0.99 (Rees, 1990). If the emissivity of a particular surface is known then it can be applied to calculate the surface temperature of the body. Estimation of land surface temperature is more difficult than estimation of sea surface temperature because the land's surface is less uniform.

Next to changing emissivity, another factor which plays a key role when trying to determine the surface temperature is the atmospheric condition at the time of data acquisition. The energy used to record in a space borne sensor that is the unity of energy radiated by an object and the energy absorbed and reemitted by the atmosphere (Figure 6). These days many commercial and research satellites are acquiring data in the thermal infrared region all over the world. Most of these satellites are operating in 8-14µm that is relatively transparent to atmospheric absorption. Among them Landsat7 ETM+ band 6 thermal data has 60m spatial resolution which is the highest in commercially available thermal satellites. Landsat 7 produces two thermal images, one acquired using a low gain setting (refers as band 6L) and the other using a high gain setting (refers as band 6H). Presently Landsat is non-operational due to some scanner failure. Another useful thermal scanner on the TERRA satellite is ASTER. This has five channels in the thermal infrared region (8.125-8.475µm, 8.475-8.825µm, 8.925-9.275µm, 10.25-10.95µm, 10.95-11.65µm) and provides an opportunity for researchers to estimate emissivity values directly from the satellite data. Different methods have been developed by researchers to extract emissivity from ASTER data that can provide a better surface temperature anomaly in the area under consideration. With a spatial resolution of 1.1.km, AVHRR scanners on the NOAA satellite are also useful for a larger study area.

Coalfires on the surface, as a high temperature event, emit significant thermal energy that is easy to detect by any remote sensing scanner. However, in the case of a subsurface coalfire the surface heating is comparatively less and may be masked by the solar heating. In this case it is necessary to use nighttime remote sensing data to reveal and measure the extent of heating. Coalfire detection using remote sensing basically has three steps:

1. Acquiring a thermal image (preferably night) of the area under investigation using remote sensing and processing digitally to create a surface temperature map to reveal the temperature anomalies;

2. Acquiring information about the local geological setting, temperatures of coalfire vents and different landcovers through field survey;

3. Using the geological field data to eliminate anomalies other than coalfires and produce a final temperature map calibrated with field-collected temperatures to reveal the coalfires.

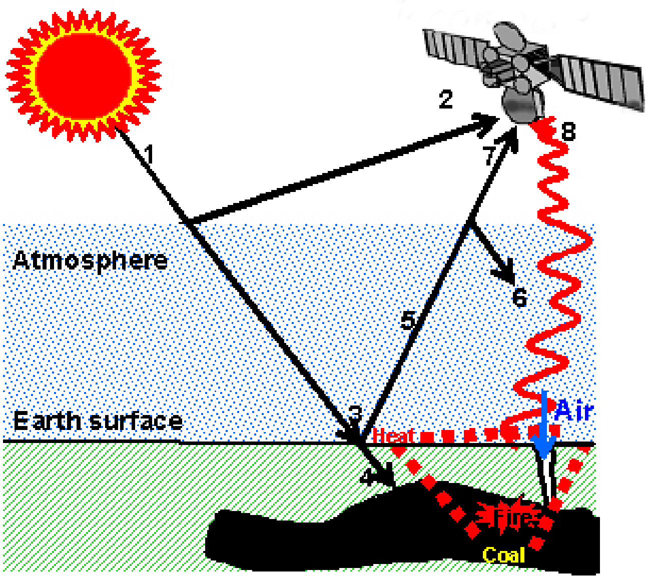

Figure 6. The energy used to record in a space borne sensor.

1. energy from source
2. energy reaching sensor, reflected from atmosphere
3. energy reaching earth surface
4. energy transmitted through earth surface
5. energy reflected from earth surface (lower wavelength)
6. energy re-reflected towards earth by atmosphere
7. energy transmitted through atmosphere (to sensor)
8. energy emitted from (hot) surface (higher wavelength)

The process discussed above is complicated by several parameters that require attention. For example, the atmosphere that stays between phenomenon (coalfire) and receiver (remote sensing sensor) plays a very significant role in determining the surface temperature from remote sensing. While many methods are available to reduce the atmospheric effect, none are totally able to compensate for this effect.

Other Methods for Coalfire Detection

The conventional method is borehole temperature measurement in coal seams to identify anomalies. This method is useful to validate the processed remote sensing data and to identify deep subsurface fires. Some geophysical methods are also being used to measure the subsurface temperature anomalies from remotely sensed data. Two of them are described below:

Radioactive method

Sedimentary rocks contain radioactive elements such as Uranium ($^{92}U_{235}$, $^{92}U_{238}$), Thorium ($^{90}Th_{232}$). These radioactive elements emit α particles during decay. During this process they are transformed into Radon ($^{86}Rn_{222}$, $^{86}Rn_{220}$, $^{86}Rn_{219}$) having a half-life of 3.96 sec to 3.825 days. The concentration of α particles measured depends on temperature, that is if temperature is higher the transportation of α particles is higher. Factors other than temperature influencing the transportation include pressure, porosity and water content (WMA, personal communication).

Resistivity method

The resistance of rock is calculated using a few electric poles by measuring resistance in ohms (Ω) per meter and comparing these with the standard value. Under normal conditions the resistance of sedimentary rock is 600-800 Ω/m, but in burnt rock it increases to 1200-3000 Ω/m, because of high porosity, cracks and low water content (WMA, personal communication).

Impact of Coalfire in the Environment

Coal is one of the non-renewable energy sources used widely in developing countries when available locally. With time, the use of coal has increased in the power generation industries as well as in other sectors. Coal mining and its related activities not only provide the energy resource but also causes environmental hazards. Underground or opencast coal mining operations have significant negative impacts on the environment. Mining operations directly impact upon deforestation; subsidence; lowering of the groundwater table; air and noise pollution; destruction of microbes in the soil which recycle the biodegradable matters; degradation of land; and coalfires contribute to greenhouse gases and lead to local and global warming. Noxious gases such as sulfur dioxide, nitrogen oxides, carbon monoxide and carbon dioxide often affect the immediate surroundings of an active coalfire. Smoke and wind blown ash can also plague the surrounding areas. Another associated problem is widespread cracking and subsidence of land surface. As the burned coal turns into ash, often the rock overburden can no longer be supported and deep cracks open up. Eventually the surface collapses causing extensive damage to agricultural land, buildings, transport network etc. It is, therefore, of utmost importance that these coalfire affected areas should be identified and regularly monitored.

Over the past two centuries anthropogenic emissions of greenhouse gases (GHG) have increased alarmingly. This steady increment of GHGs in the atmosphere acts as a blanket that retains solar radiation leads to global warming. Among all the GHG, CO2 has a significant status in this phenomenon. Since the pre-industrial era the concentration of CO2 has increased from 280 ppm to 380 ppm. The extent of this increment is not only influenced by human activity such as rapid industrialization and deforestation but also some geo-natural events such as coalfire. Coalfires are widespread in most of the coal producing countries that emit a significant amount of CO2.

Conclusions

Coalfire is a widespread problem in most coal producing countries. Remote sensing can play a significant role in detecting and monitoring coalfires, and perhaps in preventing huge economic loss and environmental disasters. Though most of the researchers have concentrated their studies primarily on coalfire detection and monitoring, the green house gases emitted from coalfires need to be considered more seriously. Coalfire-related green house gases make a significant adverse contribution to the global climate.

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