Remote-sensing GIS based investigations of coal fires in northern China; global monitoring to support the estimation of CO_2 emissions from spontaneous combustion of coal

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Key words: global monitoring, disaster control, coal fires, China

ABSTRACT
The uncontrolled fires burning of coal seams, stock piles and waste dumps pose one of the major threats in the coal mining areas world over. Besides burning of non-renewable energy resources, these fires cause immense environmental pollution. The gaseous emissions from coal fires are a major contributor to the phenomenon of global warming. At a regional scale besides, detecting and mapping the coal fires, our research focuses on a base line inventory of the CO2 emissions from the coal fires, which would reflect the present scenario and the future projected, should the coal fire projects not be undertaken. It will also estimate the actual CO2 reduction, should the existing coal fires be successfully extinguished. Higher resolution multispectral thermal infrared data from new satellite and airborne missions such as ASTER, FOCUS, BIRD, MODIS are used along with field investigations that serve as a tool to detect, map, monitor and model (in 3-D) individual fires. Gaseous emission products are generated based on the integration of high resolution IR imagery and high resolution IR spectrometry, allowing to estimate the burning efficiency and the emission factors from coal fires.

1. INTRODUCTION

In the People's Republic of China (PRC), coal is the most important mineral resource for the national economy. The PRC is also the largest producer of coal in the world.

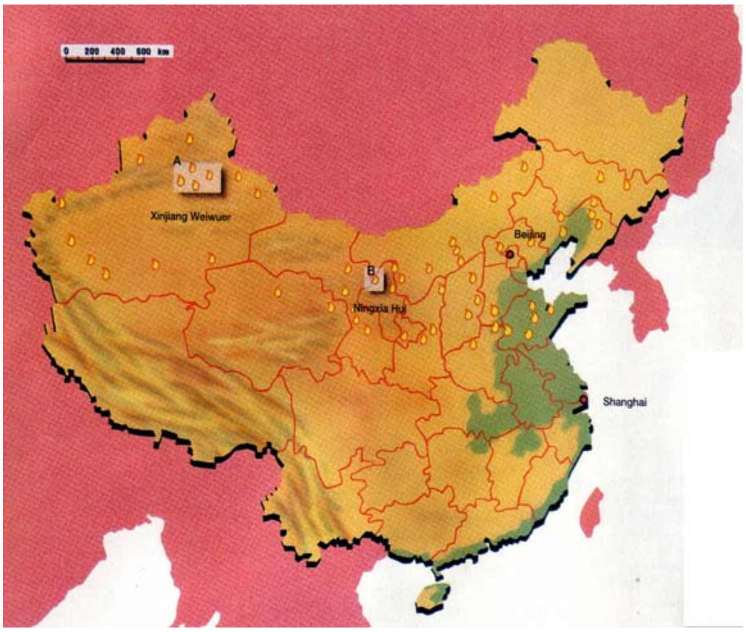

Figure 1. Location of coal fires in China.

The coal basins of China are widely distributed over the country. The estimated total reserves, ranging in quality from lignite to anthracite, amount to 115 Gt (1.15×10^{11} tonnes). China produced 1348 Mt (1.3×10^9 tonnes) of hard coal in 1997 (World Coal Institute, December 1998). Conditions that influence the development of coal fires (Figure 1) are: (1) the type of coal. Its vulnerability to spontaneous combustion decreases with the maturity of the coal, (2) the presence of mining works or faults and fissures in the geological formations, which facilitate the exchange of oxygen and exhaust gasses with the atmosphere, and (3) the burning coal outcrops cover substantial areas. There is geological evidence that coal fires have existed since prehistoric times. Coal fires induce various hazards including loss of coal resources and loss of mining productivity, CO_2 emission, air pollution, degradation of the environment andsafety and health risks for the miners and local population (Zhang et al., 1998).

2. FIELD INDICATIONS OF UNDERGROUND COAL FIRES

The most obvious indicator of the surface and underground coal fires are gaseous emission from the coal fires. These emissions consist of the gases such as CO_2, CO, SO_2, NO_2, water vapor (steam) and aerosol (smokes). One can even smell the sulfur and others (such as paraffin) close to the fires. The gaseous emissions were sampled during this field work and the analysis results will be published elsewhere in the near future. Surface fires and very shallow fires some times show flares. In the most cases the under ground coal fires can only be seen through some cracks especially during nighttime. Surface temperatures around underground coal fires are quite heterogonous. Along the cracks and vents, higher temperatures are generally measured. However, significance of the thermal anomalies in the non-cracked areas above the coal fires depends on the specific part of the coal fires and the depth and ages of the coal fires. Parsed vegetations are an indicator of underground coal fires. The distribution of the parsed vegetation depends on the distance from the cracks, depth of coal fires and the ages of the fires. The newly formed minerals around cracks and vents are another indicator of the underground coal fires. These minerals include tar oils (black), sulfur (yellow), salmiac (white) and decomposition of carbonate rocks (CaO, white). These deposits are related to the stages of the oxidation of the coal and the coal chemistry. The overburden rocks of the burning coal seam can be altered due to the heat released from the fires. These rocks can be baked and change their colours mainly due to the oxidation of iron ions from Fe^{2+} to Fe^{3+}. With the increasing of temperatures the rocks can be partly or totally molten just like lava flow. The spectral characteristics of these thermally altered rocks can be detected by different remote sensing data. After burning out, the several meters thick coal seam becomes ash layers of cent meters. As a result, the overburden rocks will crack or subside due to the lack of support of the coal seams. The cracks, vents developed within the overburden rocks provide ventilation paths for the air for coal fires and hence enhance the coal fire. The development of the collapse, subsidence, cracks and vents depends on the distance from the core of the coal fires.

3. REMOTE SENSING OF COAL FIRES

Remote sensing of coal fires focuses on three aspects namely: (1) monitoring surface temperature anomalies using thermal infrared remote sensing, (2) monitoring subsidence using radar InSAR data and (3) monitoring gaseous emission using near infrared data.

3.1 thermal infrared remote sensing

Field surface temperature measurement showed that the temperatures above the coal fire are quite heterogeneous. The cracks, vents have a high temperature while the intact bulk rock areas have minor thermal anomalies- only several degrees above the background temperature. These minor thermal anomalies in the intact bulk rock areas above the coal fires can only be measured during the predawn time (Prakash et al., 1999).

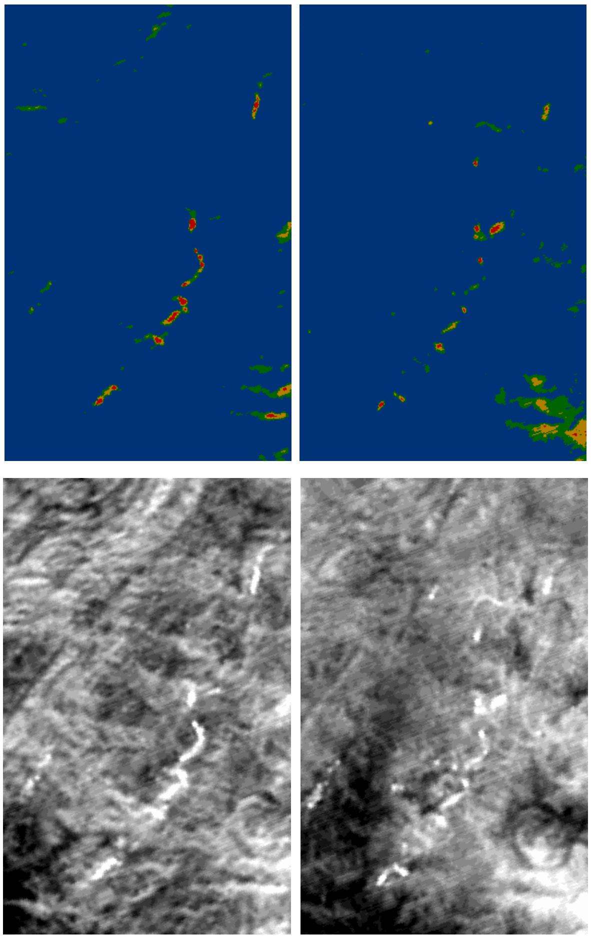

Figure 2. Examples of coal fire related temperature anomalies in Landsat TM band 6 data acquired on 18/12/89(left) and 28/5/95 (right; Zhang et al., 1997).

The heterogeneity above the underground coal fires can be detected by remote sensing data providing the remote sensing data have sufficient high spatial resolution. Data from landsat ETM, ASTER, MODIS and dedicated missions such as BIRD and FOCUS can and have been used for monitoring thermal anomalies resulting from underground coal fires (Figure 2). Heat transfer modeling and model inversion has been used to relate surface temperature anomalies to subsurface heat sources.

3.2 Monitoring subsidence resulting from coal fires

The launch of the ERS-1 satellite by the European Space Agency (ESA) in 1991 opened a new dimension in geology and tectonic research. Deformation of the Earth's surface can be measured over large areas with sub-centimetre accuracy using Synthetic Aperture Radar (SAR) interferometry (InSAR). A demonstration of this technique was given by Massonnet et al. (1993), showing that horizontal and vertical displacements caused by an earthquake could be measured. Comparison of the satellite measurements with numerical models showed remarkable resemblance. Since that time, the application of differential InSAR was extended to many forms of surface deformation including: coseismic deformations, volcano deformation monitoring, land subsidence, glacier monitoring and coal fire induced subsidence monitoring (Figure 3).

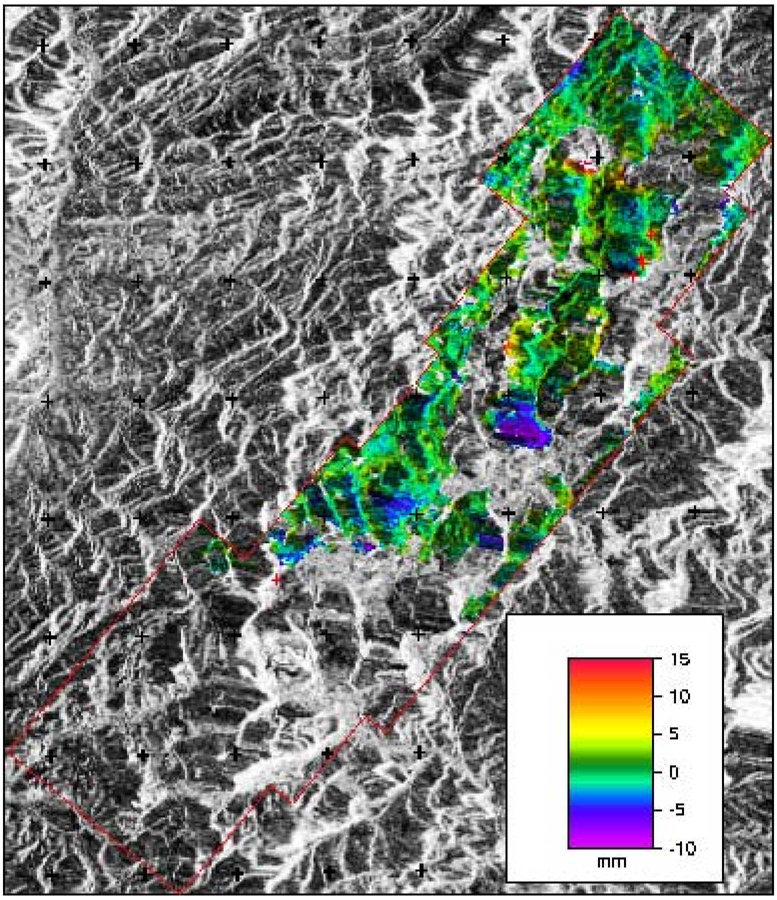

Figure 3. Example from mining-induced subsidences in Northwest China. Colours show range changes due to subsidences in areas whith sufficient coherence with the SAR amplitude image in the background.

3.3 Monitoring gaseous emission from coal fires

Raw calibrated spectrometer data have the general appearance of the solar irradiance curve, with radiance decreasing towards longer wavelengths, and exhibit several absorption bands due to scattering and absorption by gasses in the atmosphere. (Figure 6). Only the wavelength regions outside the main absorption bands of the atmospheric gases can be used for remote sensing.
Radiation reaching the sensor can be split into four components: path radiance, reflected diffuse radiance, reflected direct radiance, and reflected radiance from neighbourhood. Radiative transfer RT codes model the atmosphere's optical behaviour given user defined boundary conditions. The inverse problem of atmospheric correction of imaging spectrometer data with the aim of obtaining radiance and/or reflectance at the ground surface can be achieved in various ways. Radiance-type spectrometer data shows absorption features that can be attributed to atmospheric gasses. Vice versa, these absorption features can be used to map quantities and differences in these gasses in the atmospheric column. Using ratios of absorption band depth estimates of water bands at 0.95 μm and 1.15 μm, it has been demonstrated that water vapour total column abundance can be mapped from imaging spectrometer data. Measuring CO_2 emission has not yet been demonstrated mainly because there are few places in the world where substantially anomalous emission of CO_2 can be observed. Over active coal fires a unique opportunity exists to attempt to use imaging spectrometer data to map CO_2 emission using a absorption band ratioing technique that could be identical to those used for water vapour and SO_4. In the optical window there are abundant CO_2 absorption lines that could be deployed for

such a band depth deconvolution. To establish a functional environmental model, it is important to know the amount of Green House Gas (GHG) emissions on local scale. Radiative transfer codes, such as FASCOD (Fast Atmospheric Signature Code) with HITRAN2K (High Resolution Transmission) spectral database can simulate atmospheric transmission and path radiance with customized gas composition and concentration to understand the phenomena in a specific wavelength region. The present study aims to identify those particular CO2 absorption bands which are not influenced by other atmospheric gases, to use in estimating CO2 concentration (ppmv) with the help of hyperspectral remote sensing data. Partial Least Square (PLS) Regression was used to identify the CO2 absorption bands with different concentration on CO2 in a defined atmosphere (Figure 4).

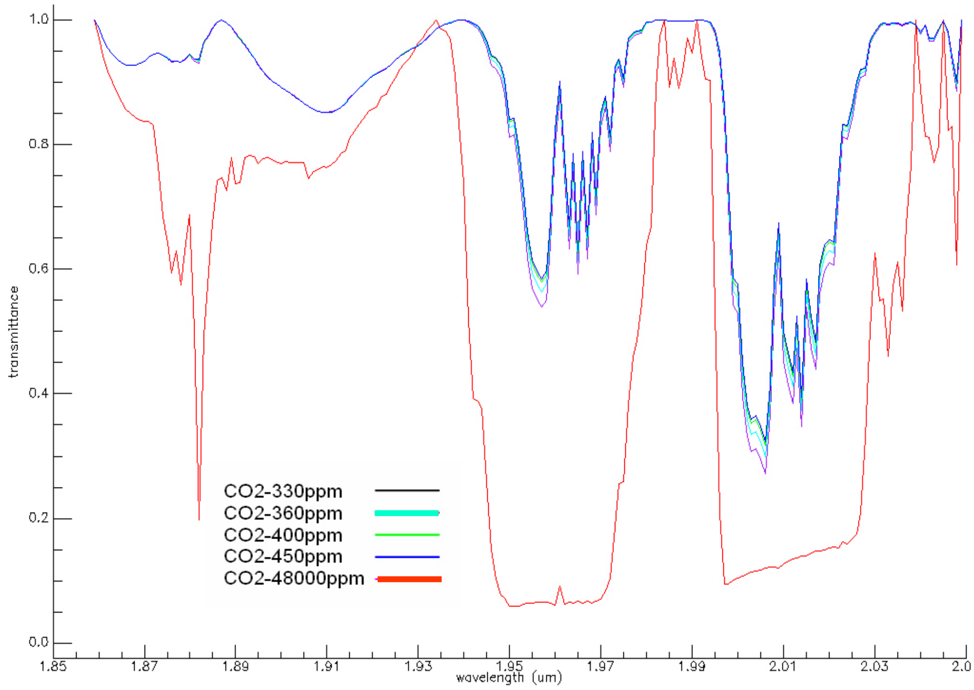

Figure 4. Model runs of radiative transfer through atmosphere profiles with variable CO2 concentrations. Note the increase of CO2 related absorption features with increasing concentration.

4. CONTRIBUTION TO GLOBAL MONITORING

The recently launched initiative of the European Space Agency on the Global Monitoring of the Environment and Security (GMES) illustrates this. GMES reconciles the political needs associated with environment and safety issues with the scientific and technological capacities offered by information society technologies and Earth observation technologies, e.g. observation satellites. The system should be able to rapidly respond to issues related to Land cover change, environmental stress, global ocean, atmosphere and vegetation monitoring, risk management and in specific cases to issues related to crisis management. In the earth observation segment we have seen a trend towards high spatial as well as higher spectral resolving power, to near-real time data access, to long-term monitoring achieved by data standardization and a shift from data to products. Earth observation has been developing alongside the geo-information sciences, however we can foresee that in the near future, Earth Observation systems will be fully integrated in the Geo-information chain. Geospatial data infrastructures will become increasingly more important and will develop into global spatial data infrastructures. The Earth Observation segment itself will be more and more integrated and directed not only toward delivering true user-defined end-products, but also to monitoring of global earth processes. In terms of data visualization, there is a trend from 2D surface representation (maps) to 3D object representation (on the surface) complementing the 3D subsurface representation of information that we have seen in earlier years. There is also a clear trend from 2D static representation of information to 2-D-t multi-temporal representation of information in line with a development toward a process-centered analysis. It should also be acknowledged that maps, may they be analog or digital, are the end-product of a mapping and interpretation cycle and hence represent a model of the reality highly biased toward the ideas of the interpreter. In our field, with the advancement of mobile computing, we see opportunities arising in dynamic map objects and location-based geologic services.

5. CONCLUSIONS

Spontaneous combustion of coal and associated underground coal fires are a treat to the environment and contribute to the emission of gaseous such as CO and CO2 to the atmosphere hence contributing to the global change. At various scales these coal fires are studied and the challenge lies in connecting these scales of observation so we can go from local scale emission to global scale contributions. Remote sensing observations of coal fires allow to monitor temperature anomalies, land subsidence and gaseous emission products. These are important land parameters in the framework of large-scale monitoring systems such as the EU –ESA GMES initiative. We are still a long way from a operational monitoring system for coal fires and probably further away from implementing counter measures as a result of this. These are the challenges for the future.

6. REFERENCES

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