Detecting the Influence of Gas Seepage on Vegetation, using Hyperspectral Remote Sensing

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ABSTRACT

A high gas concentration in the soil - whether from natural hydrocarbon seepage or from leaking gas pipelines – affects the vegetation reflectance. However, the exact mechanism that is responsible for the changes in reflectance is not known. Besides, it is not known exactly how the reflectance reacts on gas seepage. This paper presents the outline of a study on the influence of gas seepage on vegetation reflectance, in which both natural gas seepage and gas pipeline leakage will be studied.

Keywords: Hydrocarbon seepage, hyperspectral remote sensing, vegetation reflectance

1 INTRODUCTION

The first discoveries of hydrocarbon gas seeps were made in Iran between 6000 and 2000 BC. In the last centuries, hydrocarbon seeps all over the world have been used to locate oil or gas fields. Hydrocarbon seepage directly above oil and gas reservoirs shows that the hydrocarbons seep (nearly) vertical to the surface [1]. In several investigations, hydrocarbon seepage was found to influence the soil and the vegetation around hydrocarbon seeps. The most important changes in the soil exist of microbiological changes, formation of new minerals such as calcite, pyrite and uranium, bleaching of red beds, electrochemical changes and radiation anomalies [1],[2]. In vegetation growing near hydrocarbon seeps, changes in the geobotany, biochemistry and reflectance were observed [3],[4]. Studies on vegetation growing near leaking gas pipelines revealed changes in the geobotany and reflectance as well [5],[6].

It is assumed that hydrocarbon seepage causes changes in the soil air as well as in the soil mineralogy. The gases that seep to the surface partly displace the soil air, including the oxygen that is part of the soil air. In this way, the soil is depleted of oxygen. Moreover, the oxygen that is still present in the soil is used by bacteria that use oxygen to reduce methane into water and carbon dioxide [7],[8]. An oxygen poor environment causes stress in plants [9],[10] and this is visible in the spectra [11].

An anaerobic environment changes the reduction-oxidation potential and the pH in the soil. Directly around the gas leak, the environment is reducing [2],[8]. Because of the reduced environment, the mineralogy of the soil changes. The solubility of macro- and micronutrients changes, which can cause either a nutrient deficiency or nutrient excess for plants [12],[13]. This is a second stress factor for vegetation, which can be visible in the spectra.

Yet another cause for the change in spectra of plants growing near a hydrocarbon seep can be the gas itself. Natural gas is thought not to be toxic to plants, but a trace gas such as carbon dioxide is toxic above a certain threshold. This can cause early senescence or death [14].

The reflectance of stressed plants often shows a higher reflectance in the visible region, lower reflectance in the near infrared, and a shift of the 'red edge' position towards shorter wavelengths. However, the reflectance of plants that are affected by gas does not always follow this pattern. In some investigations, the reflectance in the visible and near infrared regions was higher; in others it was lower [5],[6],[15]. The red edge position often shifted towards shorter wavelengths, but in Yang's research, it shifted towards longer wavelengths [4],[16].

The aim of this research is to find out which changes occur in spectra of plants as a result of gas seepage, both in the visible and in the infrared region, and to find out what caused these changes.

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2 OBJECTIVES AND HYPOTHESES

The objectives of this research are:

1. To understand how gas seepage affects the reflectance of vegetation,
2. To find out how three of the major elements in natural gas (methane, ethane, and carbon dioxide) contribute to the changes in the reflectance,
3. To find out if the location of hydrocarbon seeps can be predicted on hyperspectral images by looking at the vegetation reflectance.

Hypothesis 1:

Different concentrations of gas, as well as different mixes of gas components have the following effects on plant reflectance:

- High concentration of non-toxic gas (as methane) will have the same influence on the spectra as oxygen shortness: higher reflectance in chlorophyll absorption wavelength, shift in the red edge position towards shorter wavelengths, lower reflectance in near infrared.
- A small concentration of CO_2 acts as fertilizer [14],[17] and causes a shift of the red edge towards longer wavelengths and an increase in chlorophyll absorption.
- High concentration of carbon dioxide accelerates senescence [14]: early shift of the red edge towards shorter wavelengths, and a decrease in chlorophyll absorption.

Hypothesis 2:

It will be possible to detect hydrocarbon seeps on hyperspectral images because of a:

- Changed species diversity near the seep due to the changed environment,
- Lower vegetation density near the seep due to the changed environment,
- Changed reflectance of individual plants near the seep.

3 METHODS

The research consists of four steps:

1. Laboratory research at Wageningen University, The Netherlands
2. Field set-up at Nottingham University, UK
3. Field research at Ventura, USA
4. Image processing

3.1 Laboratory research

The first part of the research involves an experiment in which Zea mays (maize) and Triticum aestivum (wheat) will be exposed to gas. Maize has a C3-photosynthesis method (most plants of the temperate regions have C3-photosynthesis); wheat has a C4-photosynthesis method (like many tropical plants). C4-species have a much higher assimilation rate than species that use C3 photosynthesis, due to a different biochemical pathway [18]. They are tested both to see if there is any difference between their reactions on hydrocarbon seepage. The plants will be growing in pots, to which gas is delivered through pipelines at the bottom of the pot. The soil will be covered by plastic, so that gases cannot escape into the air. Four different gases will be delivered: one test will be done with methane, one test with ethane, one test with carbon dioxide, and one test with natural gas. For each gas, two different concentrations will be tested (a high and a low gas concentration). With this set-up, it will be possible to test 1) the influence of different concentrations of one specific gas, 2) the influence of different gases, and 3) the difference between the reactions of the two species.

After the plants have been sowed, spectral measurements will be done at regular time intervals. This will be done by using a GER3700 spectrometer (which covers a wavelength range from 300 to 2500 nm). The pots will be brought to a dark room, where spectra will be taken of the whole plot and from single leafs.

The concentration of chlorophyll a and b, and water in the leaves will be measured chemically. This will be done to correlate the chlorophyll and water content with the reflectance. Besides the spectral and chemical properties, the size of the plants will be measured.

3.2 Field set-up Nottingham

On a field next to Nottingham University, natural gas is delivered to twelve plots of 2.5 by 2.5 m, on which different crops are growing. Six additional control plots are gas-free. The gas is delivered by pipelines that end in the centre of each plot 1 meter under the surface. The pipelines have small holes at 3 cm intervals around the bottom 20 cm of the pipe, so that the gas is evenly distributed through the plot. The same two species (maize and wheat) will be sown here. The field site offers the opportunity to upscale the natural gas experiment from the lab to a semi-controlled field experiment. Spectra will be taken again every week of single leaves, and canopy spectra will also be taken. This will be done by using an ASD field-spec spectrometer.

3.3 Field research Ventura

In the third part of the research, a fieldwork will be conducted at a natural hydrocarbon seep (Figure 1). Two seeps in Ventura County will be used to analyse the reflectance of the vegetation growing near them. Spectra will be taken with ASD field-spec spectrometer. Both spectra of individual leaves and of the canopy will be taken. The cover density will be estimated by looking at a fixed sample size along the transect. Species diversity will be measured by counting the number of different species growing on sample plots along the transect.

Figure 1. Ventura seep

3.4 Image processing

There are Probe-1 images available from the fieldwork area in Ventura (Figure 2). Their spatial resolution is 5 m, and the spectral resolution is 15 to 20 nm, with 128 bands covering the wavelength region of 0.45 to 2.5 µm. The images have been atmospherically and geometrically corrected. Besides Probe-1 data, spaceborne data like ASTER can be used. These images are of medium resolution (15 m to 30 m spatial resolution and 30 to 100 nm spectral resolution for the visible and (near) infrared, and 350 - 700 nm resolution in the thermal infrared). The patterns around the seeps will be studied and correlated with the field data.

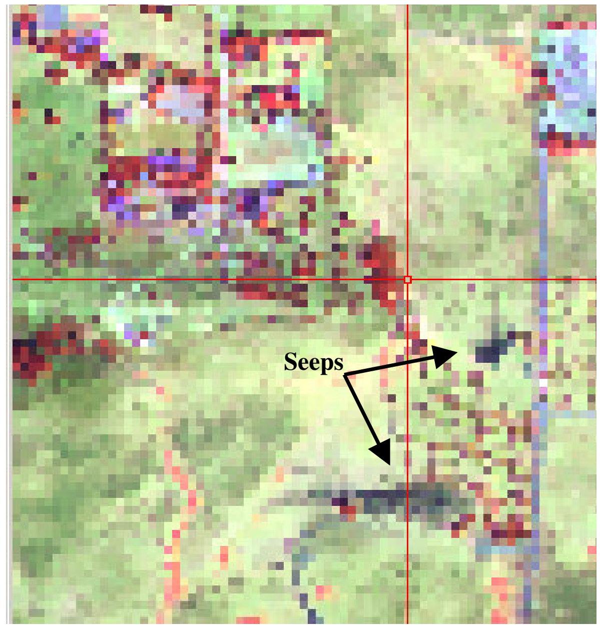

Figure 2. Probe-1 image of seepage area

The combination of the three experiments and the images will give a clue about how the reflectance of the individual plants changes, how the vegetation cover is affected and how vegetation diversity is affected by gas in the soil. Eventually, these characteristics can be a key to predict hydrocarbon seeps from hyperspectral images.

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