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# Evaluation of thermal infrared hyperspectral imagery for the detection of onshore methane plumes: Significance for hydrocarbon exploration and monitoring

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ABSTRACT

Methane ($CH_4$) is the main constituent of natural gas. Fugitive $CH_4$ emissions partially stem from geological reservoirs (seepages) and leaks in pipelines and petroleum production plants. Airborne hyperspectral sensors with enough spectral and spatial resolution and high signal-to-noise ratio can potentially detect these emissions. Here, a field experiment performed with controlled release $CH_4$ sources was conducted in the Rocky Mountain Oilfield Testing Center (RMOTC), Casper, WY (USA). These sources were configured to deliver diverse emission types (surface and subsurface) and rates (20–1450 scf/hr), simulating natural (seepages) and anthropogenic (pipeline) $CH_4$ leaks. The Aerospace Corporation's SEBASS (Spatially-Enhanced Broadband Array Spectrograph System) sensor acquired hyperspectral thermal infrared data over the experimental site with 128 bands spanning the 7.6 µm–13.5 µm range. The data was acquired with a spatial resolution of 0.5 m at 1500 ft and 0.84 m at 2500 ft above ground level. Radiance images were pre-processed with an adaptation of the In-Scene Atmospheric Compensation algorithm and converted to emissivity through the Emissivity Normalization algorithm. The data was processed with a Matched Filter. Results allowed the separation between endmembers related to the spectral signature of $CH_4$ from the background. Pixels containing $CH_4$ signatures (absorption bands at 7.69 µm and 7.88 µm) were highlighted and the gas plumes mapped with high definition in the imagery. The dispersion of the mapped plumes is consistent with the wind direction measured independently during the experiment. Variations in the dimension of mapped gas plumes were proportional to the emission rate of each $CH_4$ source. Spectral analysis of the signatures within the plumes shows that $CH_4$ spectral absorption features are sharper and deeper in pixels located near the emitting source, revealing regions with higher gas density and assisting in locating $CH_4$ sources in the field accurately. These results indicate that thermal infrared hyperspectral imaging can support the oil industry profusely, by revealing new petroleum plays through direct detection of gaseous hydrocarbon seepages, serving as tools to monitor leaks along pipelines and oil processing plants, while simultaneously refining estimates of $CH_4$ emissions.

## 1. Introduction

Methane ($CH_4$) is the main component of natural gas. It originates from oil/gas reservoirs and anthropogenic sources, which were estimated to be 202 ± 35 $Tg(CH_4)\ yr^{-1}$ and 354 ± 45 $Tg(CH_4)\ yr^{-1}$, respectively, in 2011 (IPCC, 2013). Concentrations of $CH_4$ in the environment are increasing steadily. Emissions from fossil fuels are considered the second largest source of $CH_4$ released to the atmosphere, contributing to 20%- 30% of the global budget (EPA, 2013, 2016).

The detection of fugitive emissions that escape naturally from geological reservoirs (seepages) or through leaks along oil and gas networks (pipelines and refineries) (Fig. 1) remains an ill-explored subject. Emission rates from geological reservoirs are uncertain, with estimated values totaling 40–60 $Tg(CH_4)\ yr^{-1}$, shared between onshore (10–25 $Tg(CH_4)yr^{-1}$) and offshore (20 $Tg(CH_4)yr^{-1}$) settings (Etiope et al., 2008; Kvenvolden and Rogers, 2005). From 2000–2009, oil

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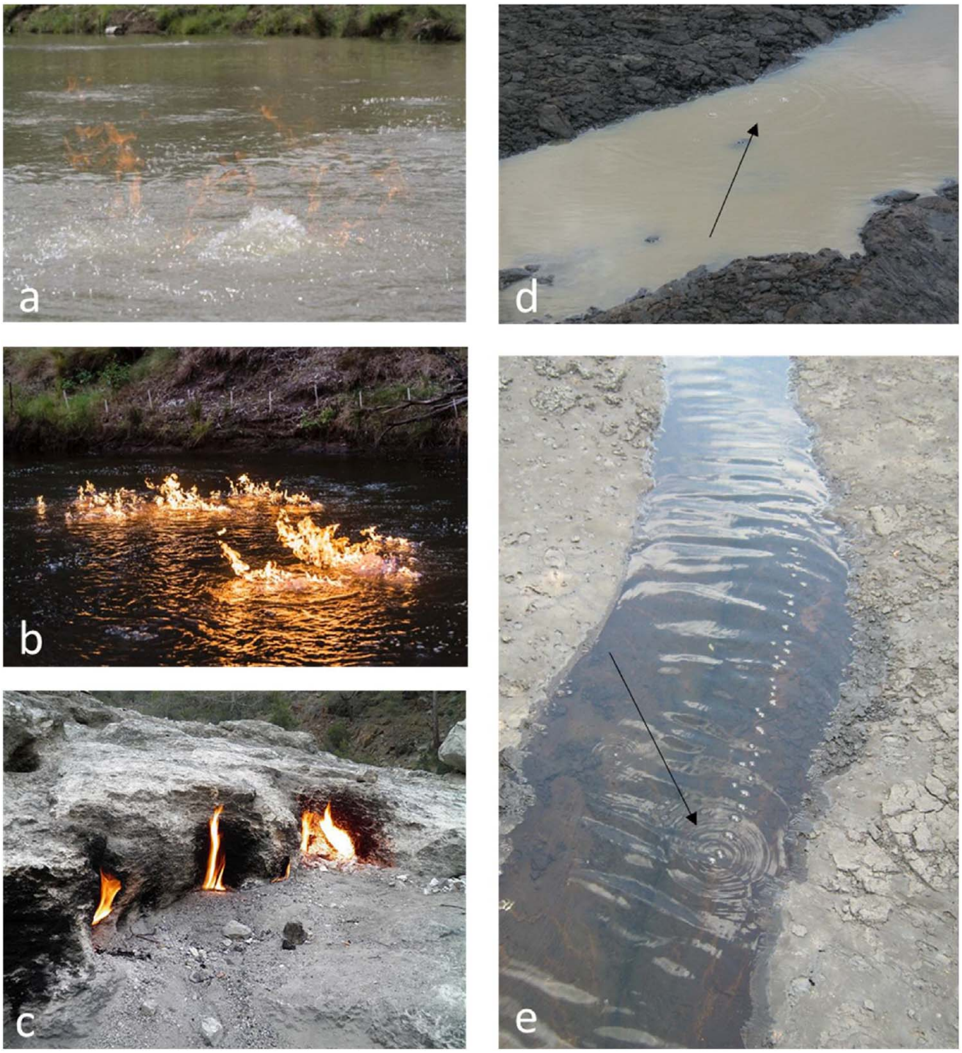


**Fig. 1.** Natural gas seeps around the world: (a) and (b) Australia (photo credits: Jeremy Buckingham and Max Phillips); (c) Turkey, (d) and (e) Trinidad (photo credits: Dave Bodecot – http://bodecott.com).

industry-related fugitive emissions were estimated at 77–123 Tg($CH_4$) $yr^{-1}$ (IPCC, 2013). Although substantial, such emissions are commonly neglected in the global budget of methane concentrations.

Gas seeps indicate the occurrence of hydrocarbon accumulation at subsurface and can guide exploration efforts (Abrams, 2005; Etiope, 2015). Early detection of pipeline leakages can assist maintaining the network distribution, avoiding significant production losses (Hausamann et al., 2002; Thompson et al., 2016). Monitoring of local emissions is usually based on terrestrial in situ measurements (Farrell et al., 2013; Leifer et al., 2013), however, despite effective and accurate for measuring the concentrations of gas point sources, these methods do not provide information about plume dimension and dispersion. Furthermore, equipment mobility depends on the access to target areas, implying limited spatial coverage.

Airborne hyperspectral sensors have the potential to detect $CH_4$ sources and map gas plumes, improving emission estimates (Barnhouse, 2005; Thorpe et al., 2012). Available sensors offer versatility and various detection scales, supplying additional data to in situ measurements and coverage over large areas and difficult to access terrains. Gaseous hydrocarbons have distinct spectral signatures that can be used as vectors to petroleum plays, allowing abundance estimates in both local and regional scales.

Bradley et al. (2011), Kastek et al. (2012), Roberts et al. (2010), Thorpe et al. (2012) and Thorpe et al. (2014) showed the applications of NASA JPL's AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) shortwave infrared (SWIR: 1.1–3 μm) hyperspectral data for the detection of $CH_4$ occurrences using several approaches. Tratt et al. (2014) (Spatially-Enhanced Broadband Array Spectrograph System (SEBASS) and MAKO sensors), Hall et al. (2015) (Mineral and Gas Identifier (MAGI) sensor), and Hulley et al. (2016) (Hyperspectral Thermal Emission Spectrometer (HyTES) sensor) explored $CH_4$ detection using the thermal infrared range (TIR: 3–15 μm), demonstrating that data acquired from airborne thermal hyperspectral sensors can realistically detect $CH_4$ emissions and characterize the transience and variability of gas plumes. The authors showed results with applications for the detection of plumes with high emission fluxes ($>$ 250 scf/hr), as well as for the differentiation between different gasses (e.g. $H_2S$, $NH_3$, $NO_2$, $SO_2$). Despite advances achieved previously, the applicability of airborne TIR hyperspectral sensors for the detection of small fugitive emissions ($<$ 50 scf/hr) requires further analysis.