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Evaluating the effects of surface properties on methane retrievals using a synthetic airborne visible/infrared imaging spectrometer next generation (AVIRIS-NG) image

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ABSTRACT

Atmospheric methane has been increasing since the beginning of the industrial era due to anthropogenic emissions. Methane has many sources, both natural and anthropogenic, and there continues to be considerable uncertainty regarding the contribution of each source to the total methane budget. Thus, remote sensing techniques for monitoring and measuring methane emissions are of increasing interest. Recently, the Airborne Visible-Infrared Imaging Spectrometer - Next Generation (AVIRIS-NG) has proven to be a valuable instrument for quantitative mapping of methane plumes. Despite this success, uncertainties remain regarding the sensitivity of the retrieval algorithms, including the influence of albedo and the impact of surfaces that may cause spurious signals. To explore these sensitivities, we applied the Iterative Maximum a Posterior Differential Optical Absorption Spectroscopy (IMAP-DOAS) methane retrieval algorithm to synthetic reflected radiances with variable methane concentrations, albedo, surface cover, and aerosols. This allowed for characterizing retrieval performance, including potential sensitivity to variable surfaces, low albedo surfaces, and surfaces known to cause spurious signals. We found that dark surfaces (below 0.10 $\mu Wcm^{-2}nm^{-1}sr^{-1}$ at 2139 nm), such as water and green vegetation, and materials with absorption features in the 2200–2400 nm range caused higher errors in retrieval results. We also found that aerosols have little influence on retrievals in the SWIR. Results from the synthetic scene are consistent with those observed in IMAP-DOAS retrievals for real AVIRIS-NG scenes containing methane plumes from a waste dairy lagoon and coal mine ventilation shafts. Understanding the effect of surface properties on methane retrievals is important given the increased use of AVIRIS-NG to map gas plumes from a diversity of sources over variable landscapes.

1. Introduction

Methane (CH_4) is a potent greenhouse gas that contributes significantly to global climate change. Methane is estimated to be responsible for about 20% of the total global warming induced by anthropogenic greenhouse gases (Kirschke et al., 2013) and abundances have been increasing since the industrial revolution (Ciais et al., 2013). However, from 1999 to 2006 the growth rate stagnated only to rise again starting in 2007 (IPCC, 2016; Nisbet et al., 2014). The cause of this stagnation and subsequent rise is still debated. Some argue that the increase in methane is due to the natural gas industry while others argue it is due to increased emissions from wetlands (Nisbet et al., 2016; Schaefer et al., 2016; Schwietzke et al., 2016). Other studies point to changes in the methane lifetime (Rigby et al., 2017; Turner et al., 2017). Regardless of cause, the recent unexpected rise in methane reflects our uncertainty regarding the contribution of various sources to the total methane budget. In addition, recent increases in atmospheric methane have revived concern about its relative contribution to global warming, which has resulted in some states, such as California, enacting new regulations to curb emissions (SB-1383, Lara, 2016; AB-

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1496, Thurmond, 2015). These policy measures underscore the importance of unraveling sectoral contributions through deployment of effective techniques for monitoring and quantifying methane emissions.

Using remote sensing to study greenhouse gases, such as methane, has gained prominence over the last decade (Jacob et al., 2016). There have been a variety of instruments launched into space with the goal of observing methane and other greenhouse gases. The Atmospheric Infrared Sounder (AIRS), the SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY), and the Greenhouse gases Observing SATellite (GOSAT) are three such examples (Frankenberg et al., 2011; Strow et al., 2003; Yokota et al., 2009). These sensors generate global maps of gas concentrations with coarse spatial resolutions on the order of kilometers. AIRS, SCIAMACHY, and GOSAT have greatly increased our understanding of global methane distribution and quantity, but lack the spatial resolution to directly attribute observed emissions to individual sources. Finer spatial resolution sensors are necessary to improve sensitivity to local emissions sources. For example, the 30 m pixel resolution of the Hyperion imaging spectrometer enabled the space-based detection of a methane plume from Aliso Canyon (Thompson et al., 2016). However, the Aliso Canyon plume was anomalously large and Hyperion was not well suited for methane detection given an aged focal plane at the time of detection and low signal-to-noise ratio in wavelength regions capturing methane absorption (Green et al., 2003).

In addition to space-based observations, airborne observations have also been used to detect and measure methane. Airborne remote sensing has fine spatial resolution and is well suited to resolving individual sources, although these retrievals are limited in time. Current airborne sensors used to measure methane emissions include the Methane Airborne MAPper (MAMAP), a non-imaging spectrometer specifically designed to map methane and carbon dioxide (Gerilowski et al., 2011). This sensor was able to obtain flux estimates from point sources such as landfills and coal mine ventilation shafts (Krautwurst et al., 2017; Krings et al., 2013). MAMAP and other similar sensors are able to make very accurate column concentration estimates but must fly many downwind transects in order to map a full plume. This makes detection of emissions from unknown sources difficult, and these sensors are best suited for studying known methane sources. More recently, imaging spectrometers have been used to map methane. Thermal imaging spectrometers such as Mako and the Hyperspectral Thermal Emission Spectrometer (HyTES) have successfully mapped methane plumes from multiple sources (Hulley et al., 2016; Tratt et al., 2014). However, the sensitivity of these sensors to emissions near the ground depends on the thermal contrast between the ground and atmosphere and decreases as flight altitude increase, which in turn limits ground coverage.

The Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) and the Next Generation instrument (AVIRIS-NG) are imaging spectrometers that measure reflected solar radiation in the visible and shortwave infrared (VSWIR) and have also been used to map methane emissions (Frankenberg et al., 2016; Roberts et al., 2010; Thompson et al., 2015; Thorpe et al., 2013, 2017). AVIRIS measures a spectral range between 400 and 2500 nm and has a 10 nm spectral sampling (Green et al., 1998) while AVIRIS-NG measures the same spectral range with 5 nm spectral sampling and improved signal to noise ratio (SNR) (Hamlin et al., 2011). AVIRIS-NG has a 34° field of view with a 1 mrad instantaneous field of view that results in spatial resolutions that typically range between 1 and 8 m depending on the flight altitude. These sensors were not originally designed to map greenhouse gases but their sensitivity to gas absorption features between 900 nm and 2500 nm has allowed for detection and quantitative mapping of methane, carbon dioxide, and water vapor (Bradley et al., 2011; Dennison et al., 2013; Gao and Goetz, 1990; Roberts et al., 2010; Thorpe et al., 2017). Recently, quantitative retrievals have been developed to estimate column concentrations of methane from AVIRIS-NG data (Thompson et al., 2015; Thorpe et al., 2014; Thorpe et al., 2017). For example, the Iterative Maximum a Posterior Differential Optical Absorption Spectroscopy algorithm (IMAP-DOAS; Frankenberg et al., 2004) was adapted for AVIRIS-NG (Thorpe et al., 2017). Success using AVIRIS-NG for methane mapping has prompted multiple flight campaigns in the Western United States focused on mapping methane emissions from the energy sector (Thompson et al., 2015; Frankenberg et al., 2016; Thorpe et al., 2017).

Although AVIRIS-NG has been used successfully to map methane plumes, there are still uncertainties regarding the sensitivity of the retrieval algorithms, including the influence of albedo on results and the impact of surfaces that can cause spurious signals. Low albedo surfaces reduce the observable difference in reflected radiance between a background methane concentrations and enhanced concentrations. At the 5 nm spectral sampling of AVIRIS-NG, surfaces with absorption features in the shortwave infrared can mimic the absorptions caused by methane. In this study, we apply the IMAP-DOAS algorithm to a synthetic image with variable methane concentrations, surfaces, and albedo. In an observed AVIRIS-NG scene we cannot control the exact column concentration of a gas, but synthetic radiances based on accurate radiative transfer modeling allows us to control these values and therefore test the accuracy of the algorithms used to estimate the gas concentrations (Dennison et al., 2013; Guanter et al., 2009; M. Zhang et al., 2017). In addition, the land cover properties, such as albedo and surface type, can be controlled, allowing us to test the sensitivity of the algorithms to these factors. The ability to manipulate these parameters allows us to quantify how the retrieval algorithm is impacted by variations in albedo, surface type, and specific surfaces known to cause spurious signals in order to improve our understanding of retrieval results. In this study, we will first create a synthetic image, run the IMAP-DOAS retrievals algorithm on the synthetic image, and then compare the retrieved CH_4 values to the known values.

2. Methods

The general method for this study is to create a synthetic image and to run the IMAP-DOAS algorithm on the synthetic image. Fig. 1 summarizes the workflow for creating the synthetic image and the steps to achieve the results discussed subsequently. Details on the synthetic image and IMAP-DOAS algorithm are discussed below.

2.1. Synthetic image

The synthetic image used in this study consists of three main

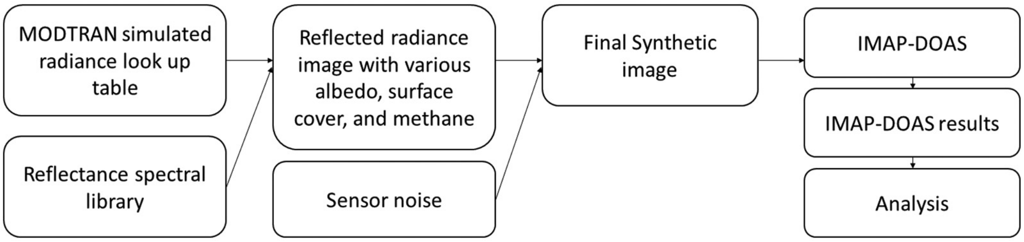

Fig. 1. Workflow framework for the study.