Marine and Petroleum Geology 68 (2015) 824–835

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Atmospheric remote sensing constraints on direct sea-air methane flux from the 22/4b North Sea massive blowout bubble plume

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A R T I C L E I N F O

Article history:
Received 23 December 2013
Received in revised form 23 January 2015
Accepted 10 July 2015
Available online 17 July 2015

Keywords:
Remote sensing
Glint
Aircraft
Methane
Blowout
Emission estimate

A B S T R A C T

A new airborne remote sensing approach to estimate an upper limit of the direct sea-air methane emission flux was applied over the 22/4b blowout site located at N57.92°, E1.63° in the North Sea. Passive remote sensing data using sunglint/sunglitter geometry were collected during instrumental tests with the Methane Airborne MAPper – MAMAP – instrument installed aboard the Alfred Wegener Institute (AWI) Polar-5 aircraft on 3. June 2011. MAMAP is a passive short wave infrared (SWIR) remote sensing spectrometer for airborne measurements and retrieval of the atmospheric column-averaged dry air mole fractions of methane (XCH_4) and carbon dioxide (XCO_2). In addition to MAMAP a fast CH_4 in-situ analyzer (Los-Gatos Research Inc. RMT-200), two 5-hole turbulence probes and the Polar-5 basic sensor suite comprising different temperature, pressure, humidity and camera sensors were installed aboard the aircraft. The collected MAMAP remote sensing data acquired in the vicinity of the 22/4b blowout site showed no detectable increase in the derived XCH_4 (with respect to the atmospheric background). Based on the absence of a detectable XCH_4 column increase, an approximate top-down upper-limit for the direct atmospheric 22/4b blowout CH_4 emissions from the main bubble plume of less than 10 ktCH_4/yr has been derived. The constraint has been determined by comparing XCH_4 information derived by the remote sensing measurements with results obtained from a Gaussian plume forward model simulation taking into account the actual flight track, the instrument sensitivity and measurement geometry, as well as the prevailing atmospheric conditions.

1. Introduction

In 1990, Mobil North Sea Ltd. (MNSL) encountered shallow gas at 360 m below seabed, while drilling the exploration well UK22/4b-4, located ~200 km east of the Scottish mainland at N57.92°, E1.63°. The well blew out, creating a massive bubble plume that rapidly decreased after several days. After monitoring of the site by ship and remotely operated vehicle (ROV) surveys from 1990 to 1998, the UK Department of Trade and Industry (DTI) determined that there was no evidence of environmental harm and risk to health and safety in 2000 and thus decided that further monitoring was not required (see also Leifer and Judd, this issue). Nevertheless, a ship survey in 2005 showed strong emissions continuing with a visible bubble plume diameter of approximately 30 m at the sea surface (Schneider von Deimling et al., 2007). In 2010, the UK Department of Environment and Climate Change (DECC) initiated a study to assess the current status of the 22/4b site and to better understand the nature and fate of the gas discharge (Leifer and Judd, this issue).

Up to now there are only a few methods available, which enable the emissions, i.e. surface fluxes to the atmosphere, from localized marine sources (point sources) to be estimated or constrained. These methods typically incorporate ship-based or airborne in-situ measurements in combination with inverse atmospheric modeling. Such an approach was applied for instance to assess the direct atmospheric emissions during the Elgin blowout accident in the North-Sea in 2012 (Mobbs et al., 2012). A drawback of such airborne methods is that they often require low level flight operation e.g. below 500 ft (~150 m) over ground (depending on boundary layer thickness). Regulations such as the minimum safe altitude, or

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http://dx.doi.org/10.1016/j.marpetgeo.2015.07.011
0264-8172/

exclusion zones as established around the Elgin rig in 2012 (Mobbs et al., 2012) could restrict the range of the required flight plans and patterns.

Passive remote sensing technologies offer the potential to overcome these drawbacks, as they sample the atmospheric concentrations around the source remotely from above the boundary layer. However, remote sensing instruments using short wave infrared (SWIR) radiation suffer from the weak reflectivity of water in that spectral region, when measuring in nadir or off nadir directions. To overcome this drawback the use of sunglint has been proposed by Larsen and Stamnes (2006) for methane anomaly detection from space by means of passive remote sensing in the SWIR spectral range. Such approaches have demonstrated the successful detection of methane anomalies over natural marine seepage by using airborne hyper spectral imaging (HSI) instruments operating the SWIR (Roberts et al., 2010; Bradley et al., 2011; Thorpe et al., 2014, and references therein). Recently, successful tests of airborne methane anomaly detection over marine sources have also been demonstrated from retrieved data collected by airborne hyper spectral imaging instruments in the thermal infrared spectral range (Tratt et al., 2014).

Another approach for the retrieval of accurate greenhouse gas (GHG) information is the use of medium and high spectral resolution absorption spectroscopy (i.e. the line shape is such that the FWHM is better than approximately 1 nm) in the SWIR. In contrast to the low spectral resolution spectroscopy, remote sensing with medium and high spectral resolution has the ability to achieve higher accuracy and precision as a result of the much lower sensitivity to potentially spectrally interfering surface spectral reflection features and the lower sensitivity to other gaseous absorbers in the same spectral range. Medium and high spectral resolution spectroscopy has been widely used for accurate retrieval of greenhouse gases in nadir geometry from aircraft (Krings et al., 2011; Gerilowski et al., 2011), and from space (e.g. Schneising et al., 2014, and references therein). Recently, the use of sun glint has been demonstrated for the retrieval of CH_4 with high accuracy and precision from space (Butz et al., 2013).

To demonstrate the ability of accurate sun glint retrieval with medium resolution spectroscopy from aircraft, a team from IUP, GFZ, and AWI equipped the AWI Polar-5 BT-57 aircraft (a Basler modified DC-3T) with a medium spectral resolution spectrometer, to perform a test measurement over the 22/4b blowout site within the framework of a joint campaign called AIRMETH. The AIRMETH payload for that flight consisted primarily of the Methane Airborne MAPper - MAMAP, a passive near infrared (NIR) and SWIR remote sensing instrument (Gerilowski et al., 2011) to determine column-averaged dry air mole fractions of the greenhouse gases methane, CH_4 (denoted as XCH_4) and carbon dioxide, CO_2 (denoted as XCO_2) (Krings et al., 2011, 2013), a fast CH_4 in-situ analyzer (Los-Gatos Research Inc. RMT-200), two turbulence probes (an AIMMS-20 and the custom developed AWI- nose-boom turbulence probe, Cremer, 2008), the Polar-5 basic sensor suite comprising different temperature, pressure, humidity and camera sensors, as well as a data acquisition and assimilation system (Optimare MEDUSA-P).

On 3. June 2011 several flights over the 22/4b blowout site were performed and remote sensing and in-situ data were collected. Based on the MAMAP remote sensing data, acquired using sunglint/sunglitter geometry, an approximate top-down constraint for the direct atmospheric 22/4b blowout CH_4 emissions from the main bubble plume area has been derived. The constraint has been determined by the comparison of XCH_4 predicted differences calculated by an Observation System Simulation Experiment (OSSE) incorporating different Gaussian plume forward model simulations, and taking into account the instrument noise and sensitivity, the actual flight track and the prevailing atmospheric conditions. Results from the OSSE have been compared to the XCH_4 retrieved from the MAMAP measured spectra, and an upper limit of the direct 22/4b blowout surface flux caused by ebullition could be derived. OSSE simulations for measurements with the same instrument configuration performed one day later (4. June, 2011), but in nadir geometry, over a terrestrial point source with known emission strength, are presented for comparison and justification of the used approach.

This manuscript is organized as follows: Section 2 describes the used instrumentation and briefly explains the remote sensing retrieval algorithm as well as the methodology applied for emission simulation. Section 3 presents the successfully accomplished measurements and summarizes the results. Section 4 describes the simulations used to determine the upper limit or constraint for the direct surface flux form the 22/4b blowout site. Section 5 summarizes the results and presents the conclusions.

2. Instrumentation and methodology

2.1. Instrumentation

2.1.1. Remote sensing instrumentation for atmospheric greenhouse gas measurements

The remote sensing instrument for GHG measurements installed on the Polar-5 aircraft in addition to its basic sensor suite, is MAMAP, a passive nadir looking spectrometer system for retrieval of methane (CH_4) and carbon dioxide (CO_2) vertical columns and column-averaged mole fractions, XCH_4 and XCO_2 (Gerilowski et al., 2011). This instrument was developed by the Institute of Environmental Physics (IUP), University of Bremen, Germany in cooperation with the Helmholtz Centre, Potsdam German Research Centre for Geosciences (GFZ). MAMAP measures back-scattered and surface-reflected solar radiation (see Fig. 1) in the Short Wave Infrared (SWIR) and Near-Infrared (NIR) spectral range at moderate spectral resolution. The NIR channel at around 0.76 μm measures the atmospheric O_2-A-band absorption with a resolution of ~0.46 nm full width at half maximum (FWHM). The SWIR channel yields measurements of absorption bands of CH_4 and CO_2 in the spectral range from ~1.59 to 1.69 μm at a spectral resolution of ~0.86 nm FWHM. Information from these bands is used for the retrieval of the column-averaged dry air mole fractions of CH_4 and CO_2 (denoted as XCH_4 and XCO_2, see also Gerilowski et al., 2011; Krings et al., 2011). These data can be used for top-down estimates of atmospheric surface fluxes of local sources via inverse modeling (Krings et al., 2011, 2013). In addition to the MAMAP instrument, also a push-broom imaging DOAS spectrometer instrument for remote sensing measurements of nitrogen dioxide (NO_2) was installed on the aircraft, as described in Schönhardt et al. (2014).

As a result of the weak reflectivity of water in the relevant SWIR spectral range, signal to noise ratios (SNR) over water are small and typically not sufficient for accurate retrieval of XCH_4 or XCO_2. To improve the SNR over water, the MAMAP instrument was modified for sunglint/sunglitter operation in 2011 by introducing a fiber coupled gimbal telescope mounted on a ZEISS SM-2000 gyro-stabilized platform. This gimbal can be manually pre-adjusted on demand to a fixed position for nadir or sunglint operation. After the pre-adjustment, the position is stabilized and tracked automatically by a SM2000 gyro-stabilized platform. Inclination and heading of the optical head was recorded by a Microstrain 3DM-GX1 and a 3DM-GX3 attitude heading reference system (AHRS). The described modification has been used to collect data in sunglint geometry over the 22/4b blowout site.