CHEMICAL ENGINEERING TRANSACTIONS

VOL. 103, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Petar S. Varbanov, Panos Seferlis, Yee Van Fan, Athanasios Papadopoulos

ISBN 979-12-81206-02-1; **ISSN** 2283-9216

DOI: 10.3303/CET23103026

Investigating Methane Emissions from China’s Largest Oil and Gas Storage Base Using TROPOMI Observations

Xinxiang Yang, Yuanming Tao, Bohong Wang*

National & Local Joint Engineering Research Center of Harbor Oil & Gas Storage and Transportation Technology/Zhejiang Key Laboratory of Petrochemical Environmental Pollution Control, Zhejiang Ocean University, No.1, Haida South Road, 316022, Zhoushan, P.R. China
wangbh@zjou.edu.cn

Methane is the second largest greenhouse gas after carbon dioxide. In the midstream storage and transportation system of the oil and gas industry, methane leakage and emissions pose a potential climate threat and environmental problem. This study utilized the Tropospheric Monitoring Instrument (TROPOMI) on the Sentinel-5P satellite to examine the atmospheric methane distribution in Zhoushan during August 2022 and to monitor changes in methane concentration. Furthermore, the effects of cloud coverage and oil storage facilities on the quantity of data obtained by the TROPOMI instrument were assessed. The results show that (1) the larger the cloud cover, the smaller the amount of satellite data acquired; (2) days with data volume higher than 200 were selected for quantitative analysis. The methane concentration of the selected area is between 1,529 ppb and 1,945 ppb; (3) in areas with oil storage bases, atmospheric methane concentrations are generally higher, and transportation and loading and unloading of petroleum products may cause methane leakage and emissions. This study helps to deepen our understanding of methane emissions and proposes corresponding environmental protection measures.

1. Introduction

Methane is the second-largest factor leading to global warming (after carbon dioxide). It has a global warming potential value of over 100 y, which is more than 20 times that of carbon dioxide (Pellegrini et al., 2015). Approximately 56 % of methane in the atmosphere comes from anthropogenic sources directly related to human activities, while 44 % comes from natural sources. The oil and gas (OG) industry is the second-largest anthropogenic methane emission source (Worden et al., 2022). Studying methane emissions in the OG storage and transportation industry is significant for estimating the total methane emissions, planning emission reduction targets, and formulating emission reduction policies.

There are three main ways to detect atmospheric methane: ground-based (Bader et al., 2017), airborne (Kim et al., 2021), and satellite-based detection (Cooper et al., 2022). This paper focuses on satellite-based detection, specifically using the TROPOMI instrument on the Sentinel-5P satellite. Limited research has been conducted on methane emissions from China's OG industry, which could be attributed to the absence of regulations curbing OG emissions. In recent years, China's goal of achieving carbon neutrality has increased awareness and concern about methane emissions from its OG industry. Zang et al. (2020) conducted four ship-based surveys from 2012 to 2017 in the Bohai Sea and concluded that OG platforms are significant sources of atmospheric methane. Chen et al. (2022) used inverse analysis of TROPOMI data to quantify China's methane emissions and sectoral contributions in 2019.

However, few studies have reported on using the TROPOMI instrument to monitor methane emissions from China's OG storage and transportation sector. Zhoushan is an island-type city and has China’s largest OG storage base. Its unique geographic environment has led to a developed OG storage and transportation sector. In 2021, Zhoushan Port had a throughput of 133 Mt of OG, making it the largest port for OG throughput in China. Research on methane emissions from the OG storage industry in Zhoushan can fill the current research gap. This article mainly focuses on the satellite monitoring of atmospheric methane in Zhoushan. The purpose is to

Paper Received: 15 April 2023; Revised: 03 August 2023; Accepted: 06 August 2023
Please cite this article as: Yang X., Tao Y., Wang B., 2023, Investigating Methane Emissions from China’s Largest Oil and Gas Storage Base Using TROPOMI Observations, Chemical Engineering Transactions, 103, 151-156 DOI:10.3303/CET23103026

observe the methane concentration changes in Zhoushan through the Sentinel-5P satellite and explore the impact of clouds and OG storage and transportation bases.

2. Methods

This section describes the methods for collecting and processing the satellite data obtained from TROPOMI.

2.1 Data sources and processing

Currently, major satellite observation instruments include the Atmospheric Infrared Sounder (AIRS) carried by the Aqua satellite, the Tropospheric Emission Spectrometer (TES) carried by the Aura satellite, the Thermal and Near-infrared Sensor for Carbon Observation-Fourier Transform Spectrometer (TANSO-FTS) carried by the GOSAT satellite, and the TROPOMI carried by the Sentinel series satellites (Magrì et al., 2021). Among them, TROPOMI is currently the most technologically advanced atmospheric monitoring spectrometer in the world. Its imaging swath reaches 2,600 km and covers all parts of the world every day. The imaging resolution is 7 km × 3.5 km (Zhao et al., 2020). The raw atmospheric methane data is in NC format, which needs to be converted to TIF format using MATLAB or other remote sensing tools. In addition, the downloaded raw data covers the entire strip containing the selected area, as shown in Figure 1 below. Therefore, it needs to be processed and clipped to obtain the atmospheric methane distribution map of Zhoushan.

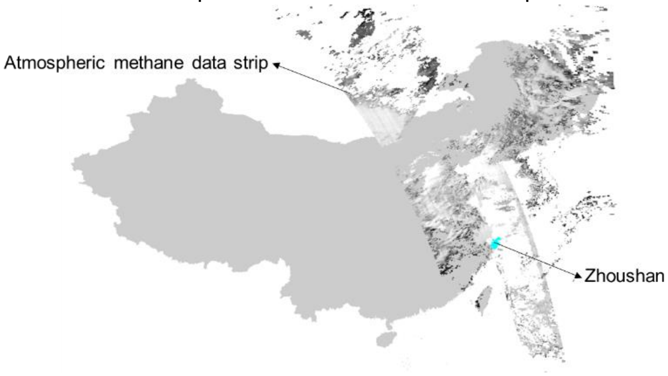

Figure 1: Sentinel-5P data map on August 4-th, 2022

2.2 Quantification of data

Due to the limitations of the TROPOMI instrument itself and the impact of meteorological conditions, the amount of atmospheric methane data in Zhoushan varied greatly from 2019 to 2022. Quantitative processing of the atmospheric methane satellite data was conducted using the ArcMap software. After importing the data into the ArcMap software, the pixel size of the data was set to be the same. The data was then exported, and a mask was applied to the data. The number of pixels was then counted, and the data pixel count was then plotted as a grayscale histogram using MATLAB, as shown in Figure 2 below. The horizontal axis represents the days, and the vertical axis represents the months. The darker the square colour, the larger the number of pixels.

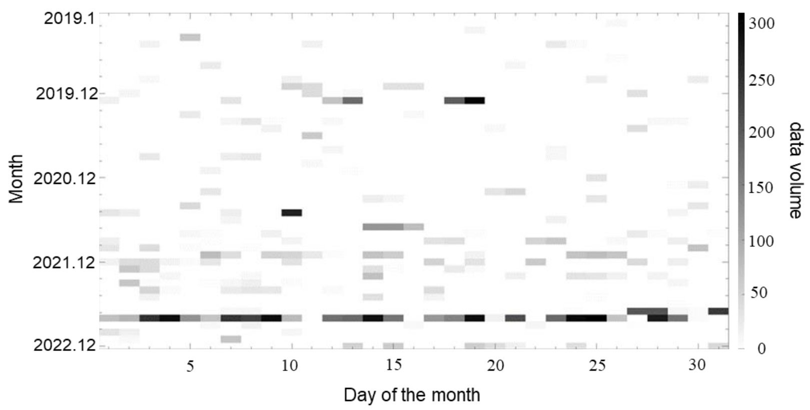

Figure 2: Greyscale histogram of methane data in Zhoushan from 2019 to 2022

According to Figure 2, it can be observed that the amount of atmospheric methane satellite data in Zhoushan is generally limited from 2019 to 2022, and the data in August 2022 is relatively rich compared to other dates. This study focuses on the analysis of August 2022.

3. Result and discussion

Ansyses on the TROPOMI satellite showed that the clouds and the OG storage base affect Zhoushan's methane distribution. This section presents the results and discussion regarding these two influencing factors.

3.1 Influence of clouds

Although the TROPOMI spectrometer is currently the world's most advanced and highest spatial resolution atmospheric monitoring spectrometer, it also has some drawbacks. Clouds can interfere with TROPOMI observations, especially in conditions of high cloud cover, resulting in reduced accuracy of TROPOMI observations (Trees et al., 2022). Cloud data downloaded from the United States Geological Survey (USGS) is compared with the atmospheric methane satellite data, as shown in the following Figure 3.

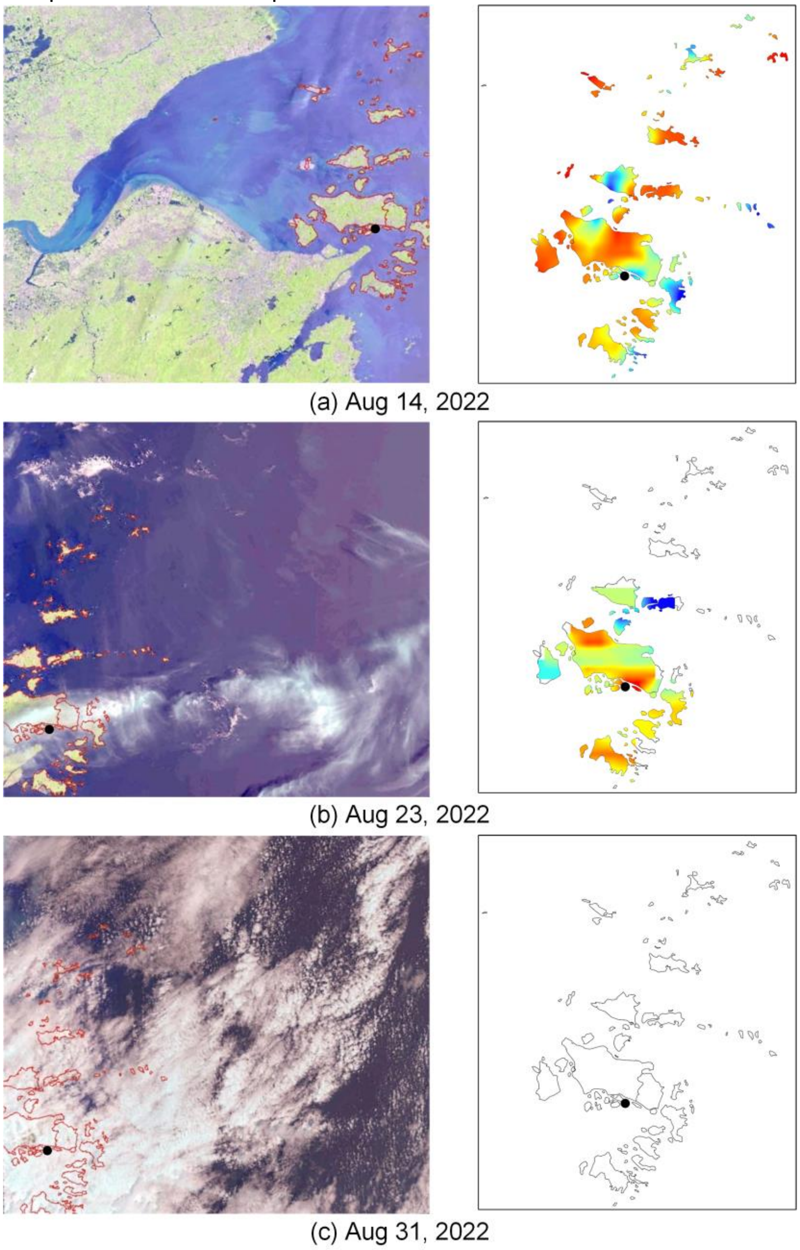

Figure 3: Cloud cover data and atmospheric methane satellite data comparison chart (The black circle represents the reference point)

As an island city located on the east coast of China, the low amount of atmospheric methane satellite data in Zhoushan is closely related to land cloud cover. Land cloud cover is an indicator used to describe the number of clouds and the degree of cloud coverage. Land cloud cover refers to the ratio of the land area covered by clouds to the total land area in a specific area. Based on Figures 3 and 4, it can be observed that cloud cover has a significant impact on TROPOMI observations. There is a negative correlation between cloud cover and the number of pixels in the atmospheric methane satellite data. The larger the cloud cover, the smaller the number of pixels. The reason for the relatively low amount of atmospheric methane satellite data in Zhoushan is closely associated with the cloud cover. Days with data pixel count higher than 200 were selected for subsequent analysis.

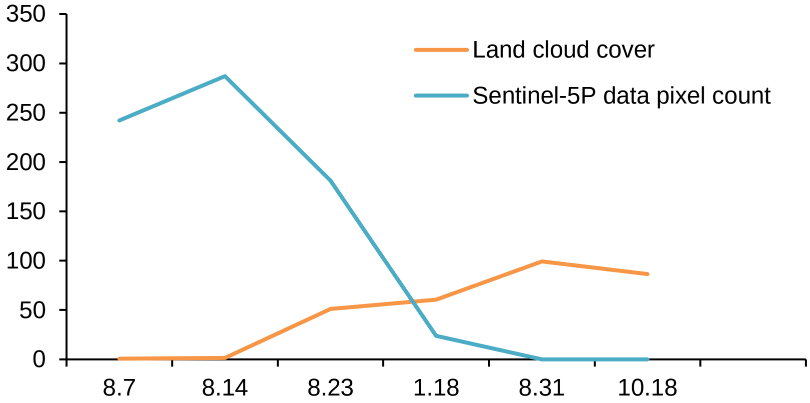

Figure 4: Comparison between land cloud cover and data pixel count

3.2 Influence of oil and gas storage and transportation bases

The OG system is divided into three parts: upstream production and processing, midstream transportation and storage, and downstream distribution systems. The midstream system includes long-distance pipelines, oil depots, and LNG plants, which are transportation and storage facilities. The OG industry in Zhoushan is located in the midstream transportation and storage system. Whether the large-scale storage and transportation of OG will affect the methane content in Zhoushan can be observed by drawing a distribution map of the atmospheric methane satellite in Zhoushan and indicating the location of the oil storage base on the map, as shown in Figure 5. The methane concentration was between 1,529 ppb and 1,945 ppb in Zhoushan in August 2022.

From Figures 5a, 5c, 5e, 5g, and 5h, it can be observed that the storage bases have a certain impact on the methane concentration in Zhoushan. Generally, the regions where the storage bases are located have higher methane concentrations than other areas, and the locations of the oil storage bases are all near the coastline and equipped with transportation terminals. The transportation, loading, and unloading of OG products may cause methane leakage and emissions, which can also contribute to the increase of methane concentration in the surrounding environment. The direct evidence can be seen in Figures 5a, 5c, and 5h because a low-concentration valley existed on the biggest island as the surrounding storage and transportation facilities S1-S9, S11, and S14 all have high concentrations.

At the same time, the atmospheric methane concentrations in some areas of OG storage and transportation bases in Zhoushan are not very high, such as shown in Figures 5b, 5d, 5f, and 5i, but this does not deny the impact of storage bases on methane concentration changes. This is because the TROPOMI observation instrument itself has some limitations, and satellite data acquisition is limited by factors such as clouds, atmospheric turbulence, and surface reflection. Low activity levels at storage bases or loading facilities on a given day may result in lower methane concentrations. The strong winds also affect methane distribution (Cooper et al., 2022). Besides, methane is not only derived from the OG storage and transportation sector but also from human activities such as freshwater or seawater aquaculture, and artificial reservoirs, which can cause significant methane emissions (Yuan et al., 2019). Zhoushan not only has numerous oil storage bases but also has many marine farms and has the title of "China's largest fishery". Even in some areas without storage bases, the atmospheric methane concentration is still relatively high.

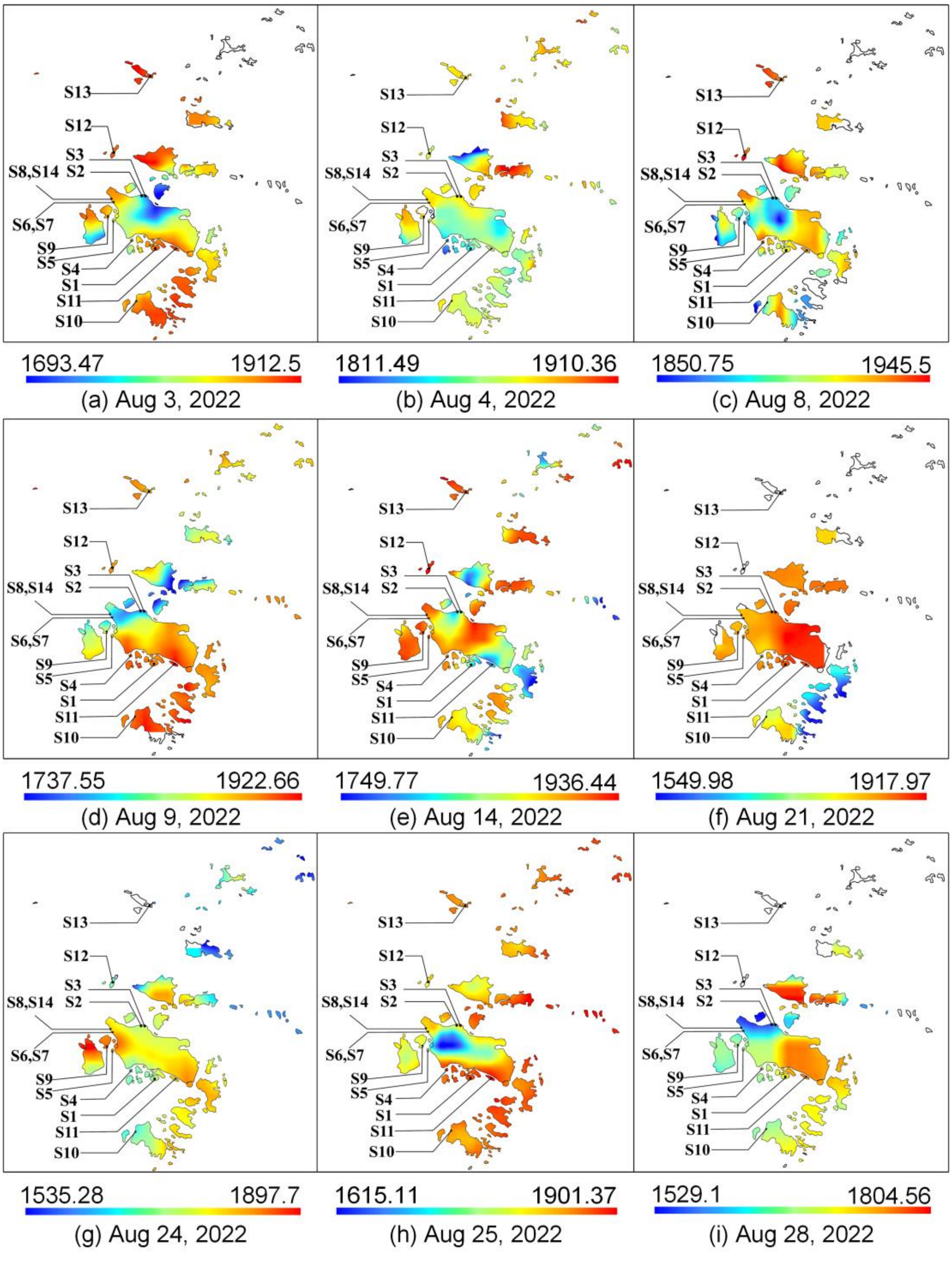

Figure 5: Distribution map of atmospheric methane satellite in Zhoushan in August 2022 (Unit: ppb. S1: National Oil Storage Base; S2: CNOOC Zhoushan Petrochemical; S3: Zhoushan Century Pacific Chemicals Co., Ltd.; S4: Jianqiao Energy Xixiazhi Oil Depot; S5: Guanghai Petroleum Zhoushan Storage and Transportation Base; S6: Zhejiang Ocean Petroleum Chemical Co., Ltd.; S7: Zhoushan Jintai Petrochemical Co., Ltd.; S8: Zhejiang Petrochemical Industry Park Co., Ltd.; S9: Sinopec Cezhoudao Oil Depot; S10: Jinrun Petroleum Storage and Transportation Co., Ltd.; S11: Zhejiang Zhongyou Dongshun Petrochemical Co., Ltd.; S12: Zhejiang Petrochemical Industry Co., Ltd. Control Center; S13: Yangshan Shengang International Petroleum Storage and Transportation Company; S14: Zhejiang Tianluo Chemical Co., Ltd.S)

4.Conclusion

Using the TROPOMI satellite instrument is a vital means of monitoring atmospheric methane concentration, compensating for low ground-based and aerial coverage. Through studying atmospheric methane satellite data in Zhoushan, it was found that OG storage and transportation activities significantly impact atmospheric methane concentration, with higher concentrations (up to 1,945 ppb) in areas with oil storage bases. The results implicate that the oil and gas storage base and facilities are highly likely to emit methane into the atmosphere. Cloud data is a crucial aspect of using TROPOMI to monitor methane concentrations, with cloud cover negatively correlated with the amount of methane satellite data. The larger the cloud cover, the smaller the amount of satellite data obtained.

Investigating the methane emission in the OG storage and transportation sector is crucial to achieving China's "dual carbon" goals and addressing climate change, making it of great significance. However, due to the impact of observation methods, operational trajectories, and self-limitations, the spatial coverage of satellite-detected methane data is limited. Future work will focus on the causes of temporal changes in methane distribution and differentiating natural methane and methane emitted from oil and gas storage bases. The addition of direct measurements, such as handheld equipment and wheeled vehicle-based surveys, would help to locate the methane emission sources in Zhoushan.

Acknowledgments

This work was supported by the Science Foundation of Zhejiang Ocean University (11025092122, 11025092222, JX6311020523), and the Scientific Research Fund of Zhejiang Provincial Education Department (Y202250605).

Reference

Bader W., Bovy B., Conway S., Strong K., Smale D., Turner A.J., Blumenstock T., Boone C., Collaud Coen M., Coulon A., Garcia O., 2017, The recent increase of atmospheric methane from 10 years of ground-based NDACC FTIR observations since 2005. Atmospheric Chemistry and Physics, 17(3), 2255-2277.

Chen Z., Jacob D.J., Nesser H., Sulprizio M.P., Lorente A., Varon D.J., Lu X., Shen L., Qu Z., Penn E., Yu X., 2022, Methane emissions from China: a high-resolution inversion of TROPOMI satellite observations. Atmospheric Chemistry and Physics, 22(16), 10809-10826.

Cooper J., Dubey L., Hawkes A., 2022, Methane detection and quantification in the upstream oil and gas sector: the role of satellites in emissions detection, reconciling and reporting. Environmental Science: Atmospheres, 2(1), 9-23.

Kim Y.M., Park M.H., Jeong S., Lee K.H., Kim J.Y., 2021, Evaluation of error inducing factors in unmanned aerial vehicle mounted detector to measure fugitive methane from solid waste landfill. Waste Management, 124, 368-376.

Magrì S., Vairo T., Reverberi A., Fabiano B. 2021, Oil Spill Identification and Monitoring from Sentinel-1 SAR satellite earth observations: A machine learning approach. Chemical Engineering Transactions, 86, 379-384.

Pellegrini L.A., De Guido G., Consonni S., Bortoluzzib G., Gatti M. 2015, From biogas to biomethane: How the biogas source influences the purification costs. Chemical Engineering Transactions, 43, 409-414.

Trees V.J., Wang P., Stammes P., Tilstra L.G., Donovan D.P., Siebesma A.P., 2022, DARCLOS: a cloud shadow detection algorithm for TROPOMI. Atmospheric Measurement Techniques, 15(10), 3121-3140.

Worden J.R., Cusworth D.H., Qu Z., Yin Y., Zhang Y., Bloom A.A., Ma S., Byrne B.K., Scarpelli T., Maasakkers J.D., Crisp D., 2022, The 2019 methane budget and uncertainties at 1° resolution and each country through Bayesian integration Of GOSAT total column methane data and a priori inventory estimates. Atmospheric Chemistry and Physics, 22(10), 6811-6841.

Yuan J., Xiang J., Liu D., Kang H., He T., Kim S., Lin Y., Freeman C., Ding W., 2019, Rapid growth in greenhouse gas emissions from the adoption of industrial-scale aquaculture. Nature Climate Change, 9(4), 318-322.

Zang K., Zhang G., Wang J., 2020, Methane emissions from oil and gas platforms in the Bohai Sea, China. Environmental Pollution, 263, 114486.

Zhao X., Griffin D., Fioletov V., McLinden C., Cede A., Tiefengraber M., Müller M., Bognar K., Strong K., Boersma F., Eskes H., 2020, Assessment of the quality of TROPOMI high-spatial-resolution NO_2 data products in the Greater Toronto Area. Atmospheric Measurement Techniques, 13(4), 2131-2159.