



Proceeding Paper On the Methane Emissions of the Greater Thessaloniki Area⁺

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Abstract: We examine the atmospheric concentrations of methane (CH_4) over the Greater Thessaloniki Area using data from the periods 2003–2004 and 2018–2022. Earlier data are from SCIAMACHY on ENVISAT, while the later years are from TROPOMI on Sentinel 5P. Large increases are observed over this period, as expected from the overall global trend. The data show increased concentrations over the rice fields of Chalastra, biological waste treatment units and biogas plants, and garbage burial sites. The highest concentrations are observed during autumn, while the lower ones are observed during spring. The 2022 levels are around 1900 ppb. Annual increases in the examined period up to 16 ppbv (2019–2020) have been observed. During December 2021, very high CH_4 was observed over an area when no high CH_4 concentrations had been observed prior to or after this episode.

Keywords: methane; satellite; rice fields

1. Introduction

In Greece, according to the Ministry of Environment and Energy (MEEN, 2021), waste management is the largest anthropogenic methane source, accounting for 47% of the total (without land use, land-use change and forestry—LULUCF) 2020 emissions. Solid waste disposal on land and wastewater treatment are responsible for these emissions. Agriculture (mainly animal husbandry) accounts for another 45% of the total emissions. Methane emissions from the Energy sector (mainly fugitive emissions from coal mining and production, processing, and distribution of liquid fuels and natural gas) account for another 10.5% of the total emissions [1]. The reported decrease of total emissions by around 12% in the period 2008–2020 (Figure 1a) is reported to come from the Energy and Agricultural sectors.



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Figure 1. (a) Emissions of CH_4 from Greece 2003–2020 (data from [1]); (b) Probability density function of TROPOMI XCH4 over the area of interest for the different years. Note that for 2018 and 2022, data were not available for the whole year.

2. Materials and Methods

The area of interest (AOI) extends from 40.4° N to 41° N and 22.3° E to 23.5° E. Within the AOI lies the metropolitan area of Thessaloniki at the center, some small cities in the periphery, industrial areas, rice fields and the National Park of the Deltas of Axios–Loudias–Aliakmonas. Due to the diversity of the AOI, and because within the AOI, there are some areas with uses that are potential methane sources, four (4) areas of special interest (AOSI) have been defined within the AOI (see below).

With a population of nearly 1 million, the metropolitan area of Thessaloniki is the second largest in Greece. The city is built around Thermaikos Gulf. The main industrial area is to the W-NW of the city. The most extensive rice fields in Greece, with around 50,000 acres, are located in Chalastra, around 20 km to the W of the city center. Chalastra produces around 70% of Greek rice in the river basin of the Axios, Loudias and Gallikos rivers and primarily in the areas near the river deltas, with irrigation carried out through canals.

In the present work, Level-2 TROPOMI [2] XCH4 methane_mixing_ratio_bias_corrected albedo corrected data from the period 30 April 2018 to 10 October 2022 from the Copernicus Sentinel-5P Pre-Operations Data Hub were used. The data have a resolution of 5.5 km \times 5.5 km. From the total of 1625 days of the period, 630 days had available data over the area of interest. Python was used for the data analysis.

3. Results and Discussion

Ref. [3] presented two years (2019–2020) of methane measurements over Thessaloniki with an EM27/SUN ground-based, direct solar-viewing low-resolution Fourier Transform Infrared (FTIR) spectrometer measuring direct solar radiation in the NIR spectral range [4]. They report low XCH₄ concentrations in spring, which rise in the middle of summer to reach their maximum (around 0.04 ppm above the spring values) in November–December. Methane showed a slight annual increase of 20 ppb from 2019 to 2020. The collocated XCH4

TROPOMI observations over Thessaloniki had a mean value of 1.871 ± 0.017 ppm, while FTIR mean values were 1.872 ± 0.014 ppm [3].

In Figure 1b, the probability density function of the TROPOMI CH₄ volume mixing ratio (vmr) for the different years (2018–2022) is shown. It was calculated by applying kernel density estimation (KDE) to the daily averages of methane over the AOI. The spatial distribution over the AOI of yearly averages of XCH₄ is presented in Figure 2. Georgoulias et al. [5] reported SCIAMACHY XCH₄ during 2003 and 2004 over the area of the Eastern Mediterranean. For the same AOI, XCH₄ values, as measured by SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Cartography) on ENVISAT and reported by [5], were 1757 ppb and 1755 ppb during 2003 and 2004, respectively (Figure not shown). Hence, CH4 values seem to have increased by around 8% from 2003 to 2022. It should be noted that the pixel size of SCIAMACHY (1 × 1 deg) used in the [5] study is larger than the TROPOMI one ($5.5 \times 7 \text{ km}^2$) used in the present study. For 2019 and 2020, the methane values in the present study are in good agreement with the study of Mermigkas et al. [3].



Figure 2. Averaged XCH₄ for (**A**) 2018, (**B**) 2019, (**C**) 2020, (**D**) 2021 and (**E**) 2022 over the AOI. Note that for 2018 and 2022, data were not available for the whole year.

It should be mentioned that for 2018 and 2022, data were not available for the whole year. Two features are evident in Figures 1b and 2: firstly, methane vmr is increasing from year to year during 2018–2022, and secondly, there are some areas within the AOI that have higher CH_4 vmr than their surroundings. These areas are the areas near the small towns of Trilofos, Mavrorrachi, Chalastra and Langadas. The potential sources of these elevated

 CH_4 vmr are listed in Table 1. They include biogas units, municipal waste disposal and treatment, rice fields, etc. Due to these features, we had a more careful look at the methane vmr over these four areas, which we term thereon areas of special interest (AOSI).

Table 1. Difference (in ppb) of yearly mean XCH4 in the four areas of special interest (AOSI) from the yearly mean XCH4 over the whole AOI. The yearly mean XCH4 (in ppb) over the whole AOI is in the last line of the table.

AOSI Year:	2018	2019	2020	2021	2022
Trilofos (agriculture, farms, biogas unit, municipal waste treatment units)	20.9	-5.9	4.5	-1.9	-3.1
Mavrorrachi (Thessaloniki solid waste disposal (400,000 tn/yr))	1.7	4.4	-6.2	-6.1	-2.9
Chalastra (rice fields, river deltas National Park)	2.7	3.8	7	2.6	0.1
Langadas (municipal wastewater treatment unit, animal husbandry units, slaughterhouse)	-2.6	-1.3	3.2	2.8	3
AOI	1866.2	1867.2	1883.6	1893.8	1900.2

As seen in Table 1, after 2020, Trilofos and Mavrorrachi no longer have higher values than the mean CH_4 over the AOI, and Langadas, which had lower values than the AOI mean until 2019, had higher values than the AOI mean after 2020.

With regard to the seasonal variation of methane over the AOI (Figure 3), overall, higher values are observed during autumn. There is one exception, notably, due to very high CH_4 concentrations observed during December 2021 over an area E-NE of Marathousa, when no high CH_4 concentrations have been observed prior to or after this episode; this area appears in Figure 3 as having higher concentrations during winter. We do not know the reason for the elevated methane vmr during December 2021, as the area does not have any apparent methane sources other than the nearby wetlands of Koroneia Lake.



Figure 3. Averaged XCH₄ for the different seasons over the AOI, (**A**) winter, (**B**) spring, (**C**) summer and (**D**) winter. Only 2019–2021 data were used since the 2018 and 2022 data were not available for the whole year.

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Data Availability Statement: The XCH₄ data used in this study are available at the Copernicus Sentinel-5P Pre-Operations Data Hub, https://s5phub.copernicus.eu/dhus/#/home (accessed on 15 September 2022). No new data were created in this study, and hence data sharing is not applicable.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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