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Tracking Methane Emissions Over South Asia: Insights from Satellite Data With a Focus on Bangladesh

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Abstract

Methane (CH_4) is a potent greenhouse gas, trapping 28 times more heat than carbon dioxide (CO_2). Food and agriculture contribute about one-quarter of global greenhouse gas emissions, with up to 8% originating from South Asia. Bangladesh, with its low-lying topography and 180 million people, produces large amount of CH_4 during food production. Annual flooding during the monsoon season affects 20-65% of the country's land and produces significant amounts of CH_4 countrywide. Agriculture, which accounts for 41% of the labor force and 15% of GDP, plays a vital role in the global GHG budget, yet Bangladesh's total agricultural GHG emissions, especially CH_4's contribution, remain unknown. While recent studies have identified some key CH_4 point sources in Bangladesh using satellite data, emissions from more distributed sources have not been fully quantified. This study explores CH_4 emissions in South Asia, with a particular focus on Bangladesh, using columnar dry-air mole fractions (XCH_4) from the TROPOspheric Monitoring Instrument (TROPOMI) onboard the Sentinel-5 Precursor satellite. Analyzing six years of data from 2019 to 2024 revealed clear seasonal variation and a consistent year-by-year increase in CH_4 levels, with a growth rate of 16.1 ppb, closely matching the 17 ppb observed by GOSAT. TROPOMI's high spatial resolution allowed for the identification of country-specific features. In Bangladesh, XCH_4 levels remained high throughout the year, likely driven by emissions from paddy fields, a significant source of CH_4. High CH_4 concentrations were also detected in Dhaka, the capital city. Since 2014, weekly flask sampling of greenhouse gases has been conducted in Cumilla, Bangladesh. Comparing CH_4 data from 2019 and 2020 between TROPOMI and flask observations showed a low correlation. The high values from flask sampling suggest multiple local CH_4 emission sources around the Cumilla site, which TROPOMI's field of view (7×5.5 km²) could not capture at such small spatial scales. This highlights the difficulty in detecting localized CH_4 increases using satellite data. The significance of our study lies in its ability to provide a deeper understanding of methane emissions in Bangladesh and South Asia, using satellite data to identify key sources and trends, which can inform targeted mitigation strategies for reducing greenhouse gas emissions and addressing climate change.

Background

- Methane (CH_4) concentrations have reached unprecedented levels, with a record of 1921.33 ppb in 2024 (NOAA, 2024). Methane has a short atmospheric lifetime (~10 years) but 34 times the global warming potential of CO_2 over 100 years (Gillett & Matthews, 2010; Myhre et al., 2013), making it a key focus for climate mitigation.
- South Asia contributes ~8% of global CH_4 emissions while covering less than 1% of the global land area (Patra et al., 2013). Anthropogenic sources like rice cultivation, livestock farming, and fossil fuel extraction dominate, yet emission estimates remain uncertain due to limited ground-based data (Dlugokencky et al., 2011; Kirschke et al., 2013).
- Weekly flask sampling in Cumilla, Bangladesh, initiated in 2014, provides a long-term, high-precision dataset of CH_4 concentrations (Patra et al., 2011). This collaboration bridges critical gaps in in-situ greenhouse gas monitoring in the region.
- Space-based sensors like TROPOMI deliver continuous, high-resolution CH_4 observations (Frankenberg et al., 2008). Combining satellite column measurements (XCH_4) with ground-based data enhances the accuracy of spatiotemporal CH_4 distribution assessments (Bovensmann et al., 1999; Kuze et al., 2009).
- With methane's short atmospheric lifetime and high radiative forcing (~0.97 W/m²), reducing emissions can yield quick climate benefits (Myhre et al., 2013). Accurate regional CH_4 data is crucial for developing targeted mitigation strategies (de Gouw et al., 2020).

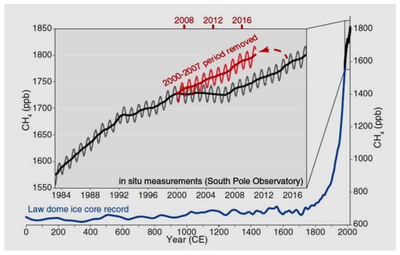


Figure 1: Observations of atmospheric methane over the past 2,000 years. The blue line illustrates the Law Dome ice core record (Etheridge et al., 1998); black represents direct and grey de-seasonalized atmospheric observations from the South Pole (Dlugokencky, 2018); the red line shows the trend if the 7-year stabilization period is removed. (Turner et al., 2019).

Research Objective

This study aims to measure and analyze methane (CH_4) emissions in South Asia, with a specific focus on Bangladesh, utilizing satellite data and ground-based observations to facilitate actionable insights for reducing methane emissions in Bangladesh, contributing to regional and global climate change mitigation efforts.

Data and Methodology

This study analyzed TROPOspheric Monitoring Instrument (TROPOMI) on Sentinel-5P data from 2019 to 2024 to understand the methane emission concentration in the South Asia region. The study examined weekly atmospheric flask sampling measurements in Cumilla since 2015-2020.

Resolution	Product	Band Name (Units)
1113.2meter	GEE Sentinel-5P OFFL CH_4	Band Name: CH_4_column_volume_mixing_ratio_dry_air (ppb)

Seasonal Variation of TROPOMI XCH_4 over South Asia

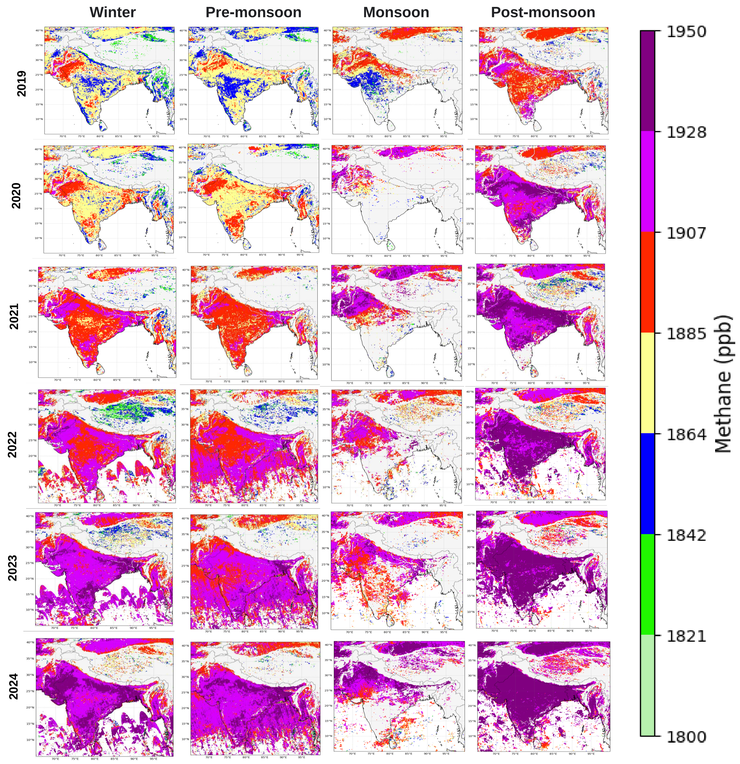
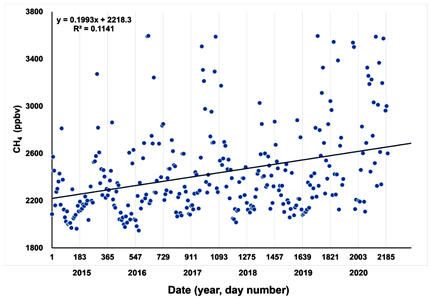


Figure 2: Seasonal Variation of TROPOMI XCH_4 over South Asia.

- **Spatial and temporal variations are clearly observed for XCH_4.**
- **XCH_4 is the lowest in pre-monsoon season and highest in winter season.**
- **Number of data are still limited in Monsoon season.**

Season	Winter			Pre-monsoon/ Summer			Monsoon			Post-monsoon/ Autumn		
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Time series of CH_4 mole fractions observed by flask sampling in Cumilla



- High CH_4 mole fractions are detected over this area (sometimes exceeding 4000 ppb).
- Surface CH_4 in August-October shows the highest peak.
- The rice-paddy field, biomass burning, enteric fermentation, wastewater handling all contribute to this phenomenon.

Figure 6: Time series of the CH_4 mole fractions at Cumilla in 2015-2020.

Interannual Variation of XCH_4

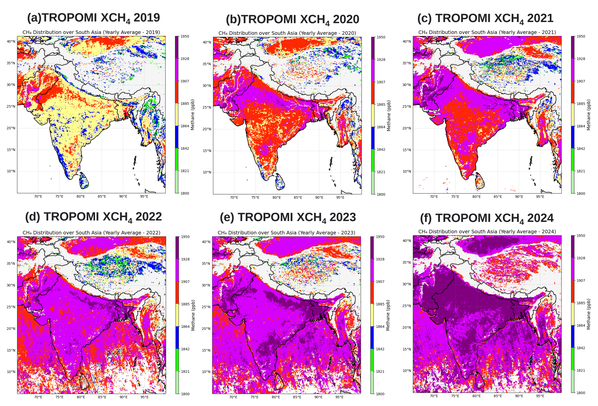
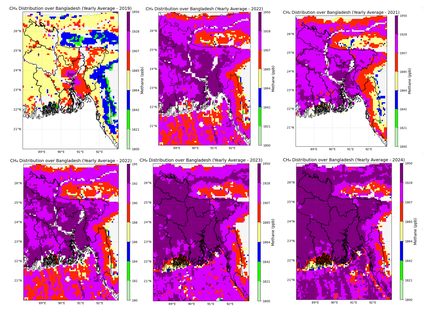


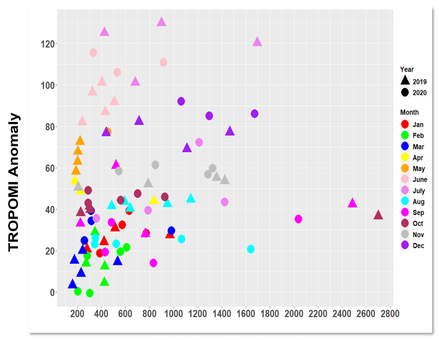
Figure 3 : Average yearly distributions of XCH_4 obtained from TROPOMI observations over the South Asia region for (a) 2019, (b) 2020, (c) 2021, (d) 2022, (e) 2023, and (f) 2024. Methane levels have significantly increased over time, particularly in northern India, Bangladesh, and parts of Pakistan, regions with the most prominent hotspots. By 2024, there is widespread coverage of high methane concentrations (>1920 ppb) across the region, indicating a significant rise in methane emissions compared to 2019.



- A general increase in High CH_4 concentration over time is evident, with 2024 showing the highest values and a predominant purple shade, indicating widespread elevated CH_4 levels.
- The central and southern regions of Bangladesh exhibit consistently high methane levels.
- Coastal areas and regions near the Sundarbans show slightly lower concentrations compared to central regions.

Figure 4: Yearly Average XCH_4 Distribution over Bangladesh (2019–2024)

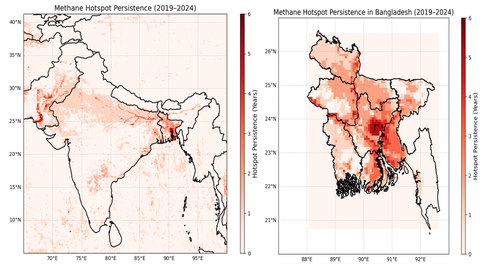
Correlation between flask sampling and TROPOMI data



- Location: Cumilla (23.43° N, 91.18° E), Bangladesh, Time Period: December 2018 to November 2020.
- Correlation was almost insignificant.
- When CH_4 is emitted from the surface, it is rapidly mixed in the planetary boundary layer (PBL) and the CH_4 concentration observed on the surface would increase.
- However, it takes time for the CH_4-rich air masses to rise to the free troposphere.
- If high concentrations of CH_4 are confined in the PBL, the rate of increase in XCH_4 will be small.

Figure 7: Correlation between the anomaly in the flask sampling data and the anomaly in the TROPOMI data

Hotspot Analysis for Methane Emissions



The image depicts the persistence of methane (CH_4) hotspots across South Asia (left) and Bangladesh (right) over the period 2019–2024, derived from satellite observations. The color gradient represents the number of years a hotspot has been detected in the same location, with darker red areas indicating more persistent hotspots.

Figure 5: Spatial Persistence of Methane Hotspots in South Asia and Bangladesh (2019–2024). Significant hotspots are observed in regions such as the Indo-Gangetic Plain, eastern India, and Bangladesh. The distribution aligns with areas of intensive agricultural activity, livestock farming, and other anthropogenic methane sources. A zoomed-in view focused on Bangladesh highlights localized methane emissions. Persistent hotspots are concentrated in central and southern Bangladesh.

Conclusion

- The growth rate in XCH_4 obtained by TROPOMI was about 16.1 ppb, which is consistent with 17 ppb reported from GOSAT observations.
- Six-years datasets of TROPOMI from 2019 through 2024 showed clear seasonal variation; an increasing trend year by year was also clearly observed.
- The correlation between the Cumilla flask sampling and TROPOMI dataset showed only a negligible correlation coefficient.
- High values of the flask sampling data suggest that the Cumilla site is surrounded by various emission sources of CH_4 .
- TROPOMI could not detect such a rapid increase in CH_4 concentration due to small spatial scales below the field of view.
- As TROPOMI observed only column-averaged amount, investigations using meteorological data on the PBL height will allow a detailed analysis of the sensitivity of XCH_4 to the changes in the surface CH_4 concentrations.

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