Remote Sensing of Environment 139 (2013) 246–256

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

Methane concentrations over Monsoon Asia as observed by SCIAMACHY: Signals of methane emission from rice cultivation

S. Hayashida [a,*], A. Ono [a], S. Yoshizaki [a,1], C. Frankenberg [b], W. Takeuchi [c], X. Yan [d]

[a] Faculty of Science, Nara Women's University, Kitauoya Nishimachi, Nara 630-8506, Japan
[b] Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA
[c] Institute of Industrial Science, University of Tokyo, 6-1, Komaba 4-chome, Meguro, Tokyo 153-8505, Japan
[d] State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing, China

ARTICLE INFO

Article history:
Received 11 January 2013
Received in revised form 2 August 2013
Accepted 3 August 2013
Available online 4 September 2013

Keywords:
Methane
SCIAMACHY
Monsoon Asia
Rice paddies
Atmosphere

ABSTRACT

We have analyzed the column-averaged CH_4 concentration (xCH_4) using scanning imaging absorption spectrometer for atmospheric chartography (SCIAMACHY) and compared the data with the bottom–up emission inventory data sets and other satellite-derived indices such as the land-surface water coverage (LSWC) and the normalized difference vegetation index (NDVI). The geographical distribution of high CH_4 values corresponds to strong emissions from regions where rice is cultivated, as indicated in the inventory maps. The Pearson's correlation coefficients (r) between xCH_4 and the rice emission inventory data are observed to be greater than ~0.6 over typical rice fields, with outstanding r-values of ~0.8 in the Ganges Basin, Myanmar, and Thailand. This suggests that the emission of CH_4 from rice cultivation mainly controls the seasonality of the CH_4 concentration over such regions. The correlation between xCH_4 and LSWC and NDVI is also as large as 0.6. In Southeast Asia, the r-values of xCH_4 with bottom–up inventory data that includes all categories are not as high as those with the emission, as estimated from the rice category only. This is indicative of the relative importance of rice emissions among all other emission categories in Southeast Asia.

1. Introduction

The concentration of atmospheric methane (CH_4) has more than doubled since pre-industrial times, and its radiative forcing is estimated to be the second largest after carbon dioxide (CO_2) (Forster et al., 2007). However, despite the importance of atmospheric CH_4 in global warming, the significance of individual sources of CH_4 remains highly uncertain (e.g., Dlugokencky, Nisbet, Fisher, & Lowry, 2011).

Many observations were performed to improve our understanding of the various CH_4 sources (e.g., Dlugokencky, Lang, & Masarie, 2009; Dlugokencky, Bruhwiler, et al., 2009). The world meteorological organization's (WMO) global atmosphere watch (GAW) program has taken the initiative of monitoring of atmospheric CH_4 across the world. The data obtained at GAW monitoring stations are made available to the public through The World Data Centre for Greenhouse Gases (WDCGG). Though the current observational network can provide plenty of data to constrain emissions on a global scale, their coverage is insufficient to determine emissions on a regional scale. In addition, most of the current observational sites monitor the background levels of CH_4 concentrations only. Ground-based observation stations are still sparsely distributed in some important source regions, such as the inland areas of Asia and most of Siberia.

Among the various approaches available for measuring the CH_4 concentration, satellite observations have the advantage of providing continuous monitoring of atmospheric species over a wide spatial range, thereby enabling the analysis of spatial and temporal variations with a reasonable resolution. The scanning imaging absorption spectrometer for atmospheric chartography (SCIAMACHY) onboard the ENVISAT satellite allowed the first global measurements of atmospheric CH_4 from space (Frankenberg, Meirink, van Weele, Platt, & Wagner, 2005; Frankenberg et al., 2006), and the derived data have been used in many scientific studies. The global maps of CH_4 generated using the SCIAMACHY reveal that CH_4 emission over Monsoon Asia is noticeably high. Monsoon Asia accommodates about 90% of the world's rice fields and a large number of domestic ruminants (e.g., FAO, 2013).

The SCIAMACHY measures the spectra of the solar reflectance at short-wavelength of the infrared (SWIR), its measurement provides the information of CH_4 distribution at lower altitude down to the surface, while other thermal infrared (TIR) sensors generate information of CH_4 distribution at only mid- or upper-troposphere. As indicated by Randel et al. (2010), convection over the Monsoon Asia is so strong that condensed CH_4 plumes were sometimes observed in the upper troposphere. This was independently inferred from both the TIR satellite sensor (Xiong et al., 2009), as well as from airborne measurements (Baker et al., 2012). Such studies have brought a new aspect of CH_4

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[*] Corresponding author. Tel.: +81 742203440; fax: +81 742203441.
E-mail address: sachiko@ics.nara-wu.ac.jp (S. Hayashida).

[1] Now at: NTT DATA Co. Ltd., Tokyo 135-6033, Japan.

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http://dx.doi.org/10.1016/j.rse.2013.08.008

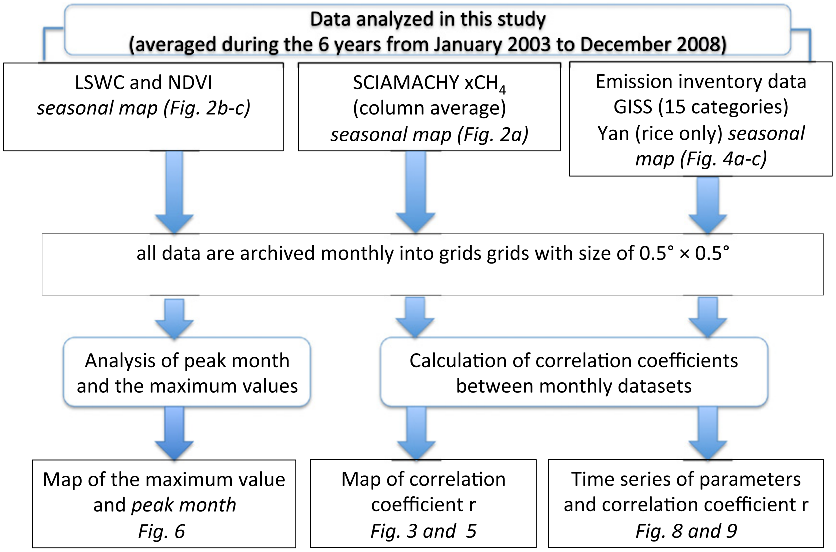

Fig. 1. A flow chart of the data processing technique applied in this study.

emission estimation coupled with the atmospheric transport model. However, the CH_4 concentration in the lower troposphere should be more influenced by the CH_4 emission from the ground; and thus, the data obtained from SWIR sensors are more indicative of the emissions from the ground. Sheshakumar, Singh, Panigrahy, and Parihar (2011) indicated that the CH_4 concentration patterns match very closely with the growth patterns of rice in North India. In this study, we have also observed a similar relationship of high CH_4 concentration in rice cultivation areas over Monsoon Asia.

According to the research on bottom–up inventory databases such as NASA's Goddard institute for space studies (GISS) (Matthews, Fung, & Lerner, 1991), Asia contributes about 155 Tg of CH_4 emissions annually, which represents more than one-fourth of the total global emission (Denman et al., 2007). As per the GISS estimates, among all individual source categories, rice cultivation contributes the maximum amount of CH_4 emission in Monsoon Asia. However, significant uncertainty remains in the quantitative estimation of CH_4 emissions from rice cultivation. The intergovernmental panel on climate change (IPCC, 1994) summarized the scattered values in their early studies, estimating a mean of 60 Tg CH_4 yr^{-1} with a range of 20–100 Tg CH_4 yr^{-1}. The most recent bottom–up study by Yan, Akiyama, Yagi, and Akimoto (2009) (referred to as YAN2009 hereafter), who applied the Tier 1 model recommended by the IPCC (IPCC, 2007), estimated global CH_4 emission from rice fields in 2000 to be 25.6 Tg yr^{-1}. Their estimate is at the lower end of the range estimated by IPCC (see Fig. 1 of YAN2009).

To reduce the uncertainty in CH_4 emission on a regional scale, we need to examine the changes in the geographical distribution of CH_4 in more detail, including seasonal and year-to-year variability, and to compare these findings with factors that control CH_4 emission. As suggested by Sass and Cicerone (2002), methane emission from rice fields is the result of complex processes including anaerobic fermentation of carbon sources such as straw and additional fertilizers. Water flooding of rice fields creates an anaerobic environment that promotes such processes. Rice plants play a crucial role in methane emission from rice paddies as well. First, rice roots are a source of carbon and oxygen that affect the production and oxidation of methane. Second, the majority of methane emission from rice paddies is transported through rice plants (Cicerone & Shetter, 1981; Seiler, Holzapfel-Pschorn, Conrad, & Scharffe, 1984). Therefore, factors such as water surface coverage and vegetation enhancement that corresponds to growth of rice should be closely related to CH_4 emission from rice paddy fields.

In this study, we have focused our attention only on Monsoon Asia and have shown the characteristics of the CH_4 distribution in this region. We have also determined the relationship between the atmospheric CH_4 concentration and other related factors; we have also compared the distribution of CH_4 using the SCIAMACHY CH_4 products with some satellite-derived indices to characterize surface conditions such as land-surface water coverage (LWSC) and normalized difference vegetation index (NDVI). Fig. 1 summarizes the data processing procedure applied in this study. The details of the data used in this study will be described in the following sections; SCIAMACHY CH_4 data will be described in Section 2, the LSWC and the NDVI in Section 3. For comparison, we will also use the emission inventory data, which will be described in Section 4. Distribution and correlation among those parameters mentioned above will be shown and discussed in Section 5.

2. Scanning imaging absorption spectrometer for atmospheric chartography (SCIAMACHY)

The SCIAMACHY instrument onboard the European space agency's environmental research satellite, ENVISAT, is an eight-channel grating spectrometer that takes measurements in the ultraviolet, visible, and near-infrared wavelengths (240–2380 nm) (Bovensmann et al., 1999). The satellite operates in a near-polar, sun-synchronous orbit at an altitude

Table 1
List of methane data and satellite-derived indices shown in Fig. 2.

	Satellite	Sensor	Grid size archived in this study	Reference
xCH_4	ENVISAT	SCIAMACHY	0.5° × 0.5°	Algorithm Version 5.5 Frankenberg et al. (2006)
Land Surface Water Coverage (LSWC)	Terra/Aqua Aqua	MODIS AMSER-E	0.5° × 0.5°[a]	Takeuchi and Gonzalez (2009)
Normalized Difference Vegetation Index (NDVI)	Terra/Aqua	MODIS	1° × 1°	Huete et al. (2002)

[a] 1/12° × 1/12° in the original data set.