Comparison analysis of CH_4 estimations from biophysical modeling, satellite measurement and inventory data in Siberian natural wetland

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ABSTRACT: In this study, bio-geophysical models for CH4 emission estimation were derived from Moderate Resolution Imaging Spectroradiometer (MODIS). Atmospheric concentration data from SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) used to be compared with estimation results. One of ground based measurement data named World Data Centre for Greenhouse Gases (WDCGG) was used to validate the methane estimations.

Since global warming, by gradually increasing trend of wetland, the methane emission was increased from 2003 to 2010. The SCIAMACHY measurement indicated similar increasing trends in atmospheric methane concentration, as well as in WDCGG in time series. Moreover, all measurements showed a positive growth rate of methane.

1. INTRODUCTION

Being one of the most important ecosystems, wetlands are presumed to be a source of natural methane emission besides anthropogenic activities. Methane emission always influenced by many factors or environmental conditions and it has complicated variation. In the growing season, climate warmed up and soil organic matter (SOM) is decomposed by a sequence of microbial processes to methane under anaerobic conditions. The methane was emitted to the atmosphere by diffusion and ebullition. Furthermore, vegetation is another crucial factor for methane except temperature. It occupied not only in transport of methane but also in microbial processes. Thus, temperature and vegetation condition are crucial for methane production and emission.

The methane emission is generally estimated from two kinds of measurements: (1) ground based measurement, extrapolation from direct emission measurement or observation sites and process-based modeling; (2) observe atmospheric concentration by satellite, inverse modeling that depends on spatially continuous (aircraft and satellite) observations [1]. Ground based measurement relies on monitoring instrument and measurement techniques such as chamber technique or micrometeorological technique to obtain trace gas emission. This observation is generally affected by ground surface indicators such as temperature, soil moisture, wind speed and so on. Although ground based measurement has high accuracy on time and spatial resolution, it needs various labors and money so that cannot do measurement work all the time. Moreover, it is impossible doing measurement in remote or depopulated area. The satellite observation has its own advantage to fill the weakness of the ground - based measurement. It can cover a wide range, real-time monitoring, cheap even free of charge. But the limitation is the satellite image cannot be exactly ensure the reality of the earth. Thus, connection and comparison of these two measurements are important to understand the reality of methane in the atmosphere. In this study, bio-geophysical models for methane estimation were derived based on in-situ measurement results from Wille et al. [2]. For comparison, SCIAMACHY satellite observation data and WDCGG inventory data were utilized. SCIAMACHY concentration data, which onboard ENVISAT, provided the seasonal variation of methane concentration in the atmosphere from 2003 to 2010. WDCGG provided measurement data and associated metadata of methane and the other related trace gas from various platforms.

The objective of this study is to compare the modeling methane estimations with other numerous estimations. Firstly, using biophysical models estimate methane emissions of wetland in the objective area by MODIS satellite data. Secondly, doing comparison analysis with SCIAMACHY and WDCGG.

2. METHODOLOGY

2.1 Description of Research Site

Figure 2.1 shows study area overlays with MERIS land-cover map. Siberian natural wetland area was selected as the study site (42°N~83°N and 27°E~180°E), include the place such as Tomsk Oblast, Khanty Mansiyskiy avtonomnyy okrug, Vologodskaya obl., RespublikaSakha (Yakutiya) and so on. The north coast of the study area has the arctic climate, and the southernmost part has cold winters and fairly warm summer lasting at least 4 months. The weather in January has average about −15 °C and July about +19 °C. Precipitation is generally low, exceeding 500mm and vegetation have tundra, shrubland and woody grassland.

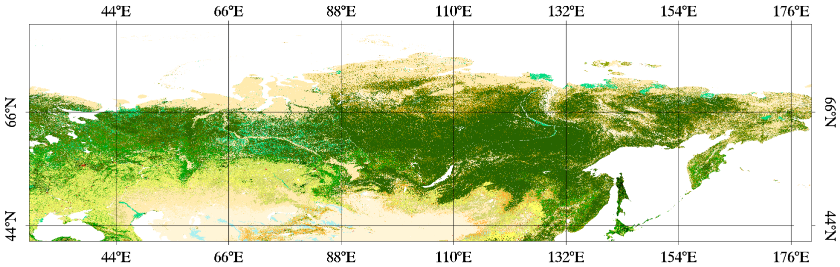


Figure 2.1. Study Area overlay with MERIS land-cover map.

2.2 Flowchart of the study

The flowchart of this study demonstrates in Figure 2.2. First step is mapping wetland area in the study site. The study is done by Schneider et al. [3] shows, more than 85% of CH4 emission released from the place where growing sedge, moss and tundra in Siberian natural wetland. So that corresponding the vegetation type in the study area, 7 of 22 classes: 110, 120, 130, 140, 160, 170 and 180 were extracted to represent permafrost wetland, noted as Wetland Fraction Coverage (WFC) map hereafter. Secondly masked CH4 estimation results by wetland land cover map to obtain the CH4 emission in wetland area. Finally, do comparison analysis between estimated CH4 emission and SCIAMACHY measurement data and WDCGG inventory data. The WFC map was used for represents the distribution of wetlands and measurement indices such as NDVI, Land Surface Temperature (LST). Then, regression analysis was utilized to simulate the seasonal-changing rule of NDVI and LST, which inference model was implemented to estimate the methane emission. In this part there are three aspects to emission estimation, and all of them follow the theory that is, there was no emission when the ground was frozen.

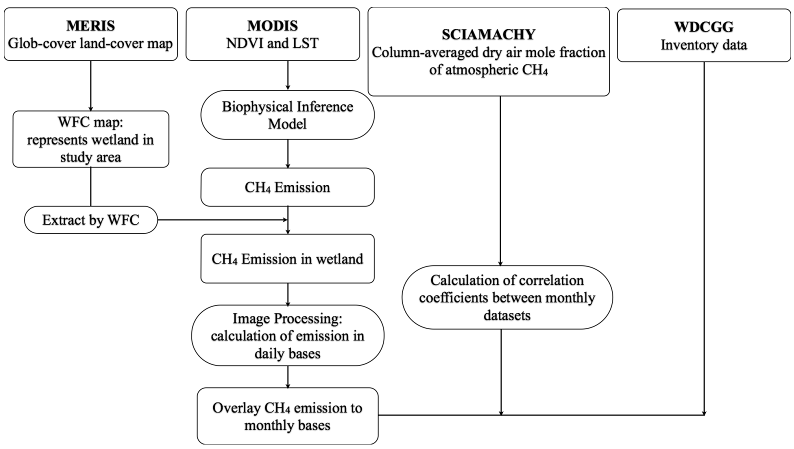


Figure 2.2. Flowchart of the study. There are three parts included: mapping the wetland area, methane estimation and comparison analysis with SCIAMACHY and WDCGG.

3. RESULTS AND DISCUSSIONS

3.1 Methane emission estimation model

Through regression analysis which based on published literatures [2, 4], methane estimation models were derived. Then according to the natural phenomenon, vegetation and land surface temperature, we modify the threshold and obtained more realistic models, CH4_lst, CH4_ndvi and CH4_Ndl (Eq. (1), (2) and (3)).

$$\mathbf{YCH4_{lst}} = \begin{cases} 0.4181 * \mathbf{LST} + 37.102, & \mathbf{LST} > 0 \\ 0, & \mathbf{LST} \leq 0 \end{cases} \qquad (1)$$

$$YCH4_{ndvi} = \begin{cases} 0.1505 * NDVI + 33.371, & NDVI \geq 40 \\ 0, & NDVI < 40 \end{cases} \quad (2)$$

$$YCH4_{Ndl} = \begin{cases} 0.1505 * NDVI + 33.371, & LST > 0 \\ 0, & LST \leq 0 \end{cases} \quad (3)$$

Where YCH4lst= CH4 emission in LST function (mg $m^{-2}day^{-1}$); YCH4ndvi = CH4 emission in NDVI function (mg $m^{-2}day^{-1}$); YCH4Ndl = CH4 emission, combine LST and NDVI function (mg $m^{-2}day^{-1}$), NDVI = original NDVI * 100.

Figure 3.1 and Figure 3.2 shows the comparison map of methane emission in April and October in 2003 and 2010 by the three modeling. Figure 3.1 indicates methane emitting area in April extends in 2010 ((a′), (b′) and (c′)) than in 2003 ((a), (b) and (c)). It means during several years methane emission starts earlier in 2010 than in 2003. In summer, growing season continuous CH4 emissions have been increased till temperature goes minus. Figure 3.2 displays the methane emission area of October in 2003 and 2010. It shows an area extension phenomenon as well as in April, implies the methane ends later and summer time last longer in the past several years.

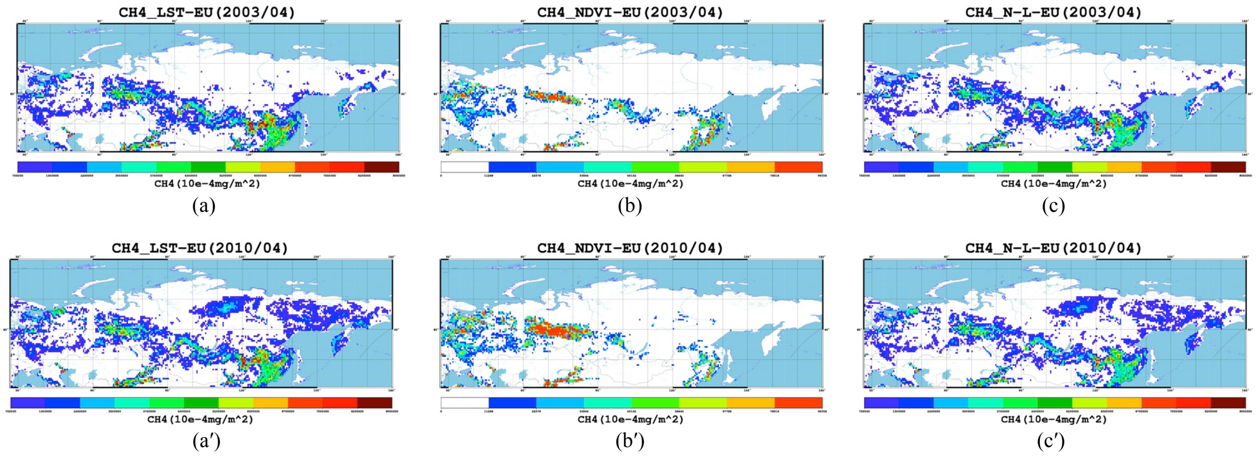


Figure 3.1: Monthly methane emission map of April in 2003 and 2010 by CH4_lst ((a) and (a′)), CH4_ndvi ((b) and (b′)) and CH4_Ndl ((c) and (c′) modeling respectively. There are obvious area extension in 2010 compare with it in 2003, imply the methane starts more and more early in past several years.

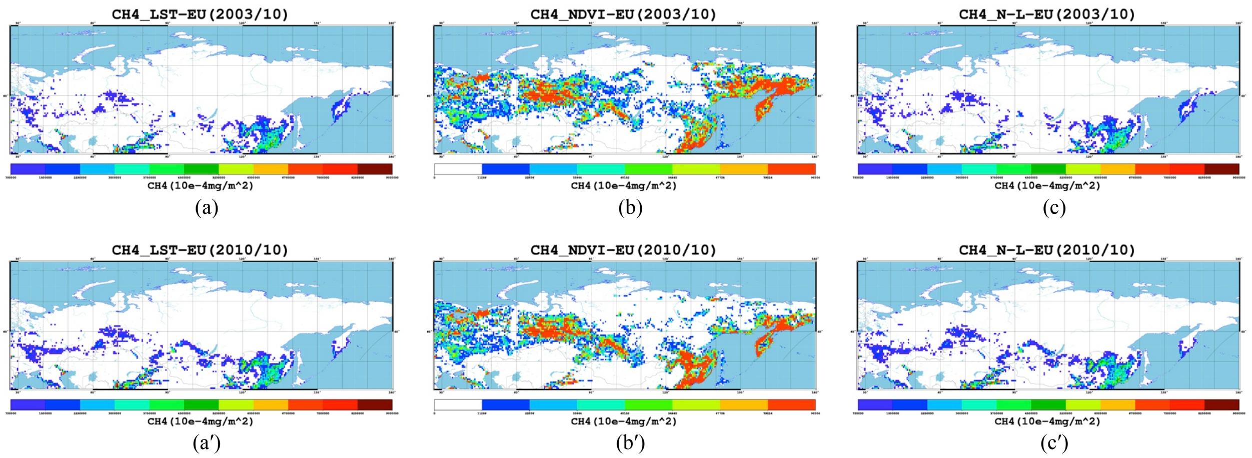


Figure 3.2: Monthly methane emission map of October in 2003 and 2010 by CH4_lst ((a) and (a′)), CH4_ndvi ((b) and (b′)) and CH4_Ndl ((c) and (c′)) modeling respectively. There are obvious area extension in 2010 compare with it in 2003, imply the methane ends more and more late in past several years.

3.2 Comparison analysis with SCIAMACHY and WDCGG

1. The SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) sensor on board on ENVISAT provides the information of methane distribution at lower altitude down to the surface. It is an eight-channel grating spectrometer that takes measurements in the ultraviolet, visible, and near-infrared wavelengths, its objective is the global measurement of various trace gases in the troposphere and stratosphere

including CH_4, CO_2, NO_2, H_2O, SO_2 and O_3.

CH4 data used in this study are retrieved from the nadir spectra in a micro-window of Channel 6 ranging from 1640 to 1670nm [5]. Figure 3.3 illustrate the monthly averaged SCIAMACHY maps of April and October in 2003 and 2010. When we compare these figures, it is evident that in 2010 the average concentration value is much higher than that in 2003 in the same month of the year, which means methane concentration reached higher value earlier and earlier in early summer during the past 8 years.

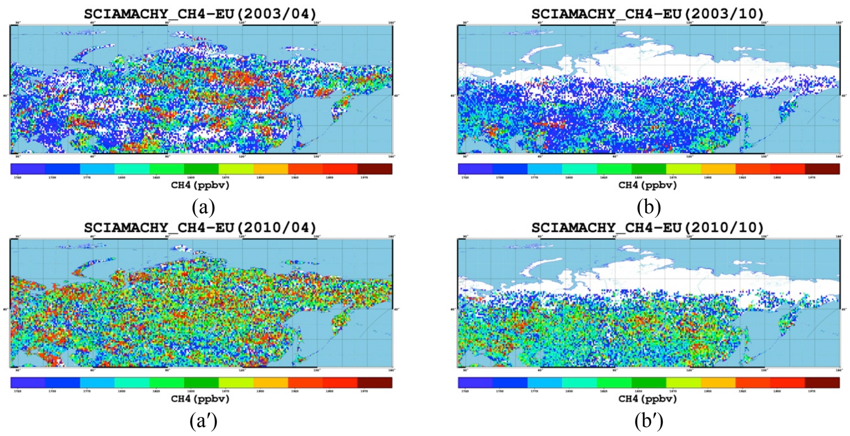


Figure 3.3: Monthly methane emission map of April ((a) and (a′))and October ((b) and (b′)) in 2003 and 2010 from SCIAMACHY observation. It appeared obvious increasing of methane concentration in 2010 compare with it in 2003.

Table 3.1 shows a proximity matrix of the Pearson's correlation coefficients (r). From this table we could understand SCIAMACHY data has a significant correlation with CH4_lst model estimation, r=0.854 and secondly with CH4_Ndl model estimation, r=0.845. Table 3.2 shows the growth rate and annual growth rate of SCIAMACHY and methane emissions by model estimations. In this table, calculation period of methane estimation is from 2003 to 2012 and of SCIAMACHY is from 2003 to 2010 because of data shortage. The methane growth rates appear positive values no matter for SCIAMACHY measurement or model estimation. It is clear that along with the temperature rising, the methane emission gradually increasing in time series.

Table 3.1: Proximity Matrix of SCIAMACHY and methane estimations.

	Correlation between the value of the vector			
	SCIAMACHY	CH4_lst estimation	CH4_ndvi estimation	CH4_Ndl estimation
SCIAMACHY	**1.000**	**.854**	**.673**	**.845**
CH4_lst estimation	**.854**	**1.000**	**.868**	**.996**
CH4_ndvi estimation	**.673**	**.868**	**1.000**	**.904**
CH4_Ndl estimation	**.845**	**.996**	**.904**	**1.000**

Table 3.2: Growth rate and annual growth rate of SCIAMACHY and methane estimations. In this table, calculation period of methane estimation is from 2003 to 2012 and of SCIAMACHY is from 2003 to 2010 because of data shortage.

	Growth rate (%)	Annual growth rate (%)
SCIAMACHY	**12.68**	**1.72**
CH4_lst estimation	**0.24**	**0.03**
CH4_ndvi estimation	**4.74**	**0.52**
CH4_Ndl estimation	**0.36**	**0.04**

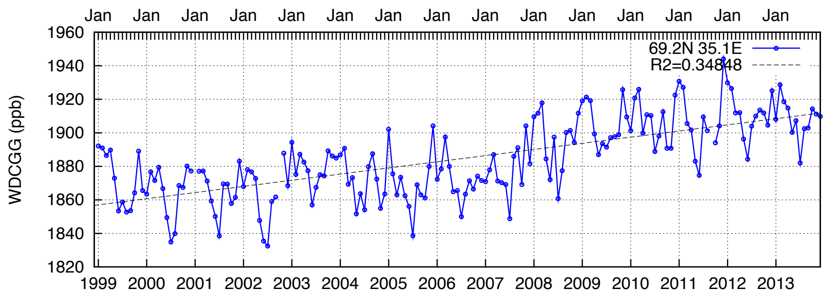
2. The World Data Centre for Greenhouse Gases (WDCGG), which provided by NOAA is one of the WDCs under the Global Atmosphere Watch (GAW) programme. GAW focuses on six measurement groups: Greenhouse gases, UV radiation, aerosols, ozone, major reactive gases (CO, VOCs, NOy and SO2), and precipitation chemistry [6]. The contributor of the data from WDCGG used in this study is Main Geophysical Observatory (MGO), Russian Federation.

Among all stations in WDCGG, there are seven stations available corresponding to the area of interest of this study. After checking those points on Google Earth, it was found that only one point could be used for comparison in long-term analysis. There are differences between SCIAMACHY and WDCGG. One is WDCGG belong to ground based measurement, can be accurately on small region or area, but SCIAMACHY overlay huge area; another is satellite sensor sometimes cannot detect the earth because of climate reason. Therefore, the different measurement technique will create a different result at the same point.

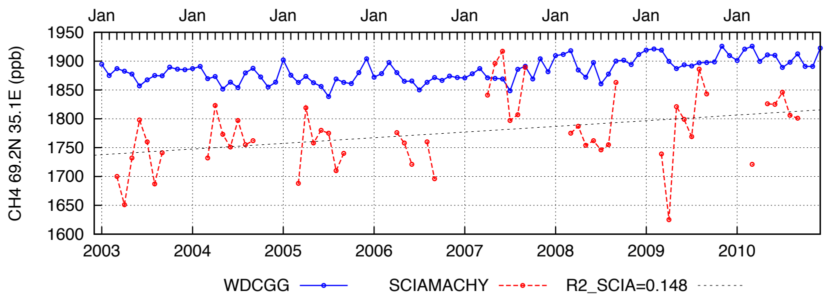
The data used here from WDCGG located in Teriberka, Russia (69.20N 35.10E). In convenience to compare, the data were archived monthly basis and the methane concentration was measured by Gas Chromatography (FID) technique. Atmospheric concentration data cannot directly compare to ground based measurement result. Ground based estimation measured the methane emission while atmospheric concentration data represented the density of methane. Therefore the point concentration data only used to compare the changing tendency in this study.

3.2 Time series of methane trend comparison

Figure 3.4 represents the WDCGG and SCIAMACHY curve at Teriberka (ppb). Figure 3.4 (a) shows methane flask in whole covering period (1999 to 2013) of the point Teriberka by WDCGG platform. The data appear phenomenal increasing tendency (R^2 = 0.34848). Because of the changing range of the point was not so big (around 140 pipe), so that overlay with SCIAMACHY observation data to check the changing tendency. Figure 3.4 (b) overlay the methane curves by WDCGG and SCIAMACHY. The SCIAMACHY curves also appear increasing trends (R^2=0.148) from 2003 to 2010.



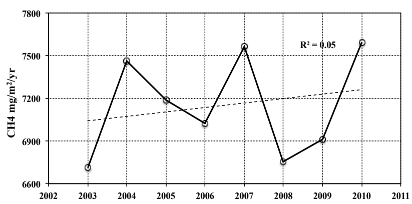
(a)



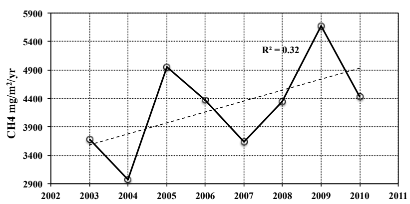
(b)

Figure 3.4: The methane concentration at Teriberka from WDCGG and corresponding grid of SCIAMACHY. (a) represents from WDCGG in time series 1999 to 2013. (b) is from WDCGG overlay with SCIAMACHY from 2003 to 2010.

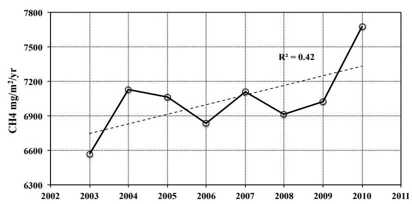
Figure 3.5 represents annual methane emission from modeling estimations. (a), (b) and (c) on behalf of CH4_lst, CH4_ndvi and CH4_Ndl three modeling results separately (mg/m^2/yr). All three curves show increasing tendency same as what was indicated in Figure 3.4.



(a)



(b)



(c)

Figure 3.5: Estimations of annual methane emission from 2003 to 2010. (a), (b) and (c) represent CH4_lst, CH4_ndvi and CH4_Ndl modeling result respectively.

4. CONCLUSION REMARKS

In this study, the methane estimation results were represented in northern permafrost wetland. The modeling results had good correlation with SCIAMACHY observation data as well as with WDCGG. Although they were not in the same scale measurement, show the proximity trends and seasonal changes in time series. An 8-year (2003-2010) simulation (Table 3.2), the yearly growth rate of methane emission and concentration were increased in the time series and showed positive year growth rate.

Determine the source of atmospheric methane is extremely difficult and it related with numerous influence factors. Even in the same measurement point, the different source and measurement mechanism will lead a different result.
From correlation analysis, high Pearson's correlation coefficients appeared between SCIAMACHY and model estimations. Therefore, on the one hand the estimation models made a satisfactory simulation of methane emissions; on the other hand, estimation results and SCIAMACHY can check the methane fluctuation each other in permafrost wetland area.

Many limitations and uncertainties are present in methane estimation. In high latitude area (> N60), the SCIAMACHY measurement value will be less than in low latitudes because of low tropopause height. Also, the land-sea distribution, atmospheric circulation and other atmospheric motion will effect on methane concentration. For ground base measurement, the methane emission will influence by land cover type, soil moisture, wind speed etc. Therefore, collaboration relative indices are the appropriate way to improve the estimation model. However, it is sometimes difficult to gather every element. In order to let emission and concentration value comparable, the atmospheric transport model should be considered .

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