Methane emission modelling from wetlands and waterlogged areas using MODIS data

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In the present study, a Semi-automated Empirical Methane Emission Model (SEMEM) has been developed and used for estimation of methane from wetlands using MODIS (MODerate resolution Imaging Spectroradiometer) data. The model has two key factors, namely temperature and productivity. Area extent of different wetlands has been estimated based on knowledge-based classifier using Normalized Difference Vegetation Index, optical bands (1, 2 and 3) with thermal channel (31 and 32) data. Land Surface Temperature has been generated using Split Window Method of first-order approximation. Based on the analysis of MODIS data, methane emission from wetlands has been estimated for India pertaining to the months of May and October 2005. Results show that emitted methane in May 2005 was 0.329 Tg with 29,308.27 km^2 total methane-emitting area, whereas in October 2005 the total emitted methane was 0.466 Tg with 76,340.92 km^2 methane-emitting area.

Keywords: Emission, land surface temperature, methane, wetlands.

WETLANDS are areas on the landscape where land and water meet and usually lie in depressions or along rivers, lakes and coastal waters. Wetlands are broadly defined as 'a variety of shallow water bodies and high groundwater environments that are characterized by permanent or temporary inundation, soils with hydric properties, and plants and animals that have adapted to life in saturated conditions'. They generally include lakes, ponds, floodplain wetlands, impoundments (tanks, reservoirs), mud/tidal flats and mangroves, besides lowland paddies. Wetland ecosystems in recent years have acquired importance due to their role in biogeochemical cycling, and as source and sink of greenhouse gases (GHG), especially methane.

Wetlands in India are distributed in all ecological regions. Varying estimates of wetland area have been given by different agencies/authors. Wetlands occupy about 4.1 mha area, excluding mangroves in the country[1]. A recent scientific estimate[2] using satellite remote sensing data puts wetland area in the country at 8.27 mha. This excludes paddies and river/canals. Out of this, inland wetlands account for 4.02 mha.

Wetlands are one of the most important sources of atmospheric methane (CH_4), the most significant GHG after CO_2, having 21 times the global warming potential than that of CO_2. Wetlands provide a habitat conductive to methane-producing (methanogenitic) bacteria that produce methane during decomposition of organic material. These bacteria require environments with anoxic and abundant organic matter, both of which are present in wetland conditions.

Emission of methane from wetlands is also dependent on climate/weather conditions, such as temperature and humidity, besides waterspread. Objective global estimates of methane from wetlands are still not available due to lack of temporal data on 'extent and types of wetlands'. Not only methane, but also some other GHGs like N_2O, CO_2, H_2S, etc. are released from the wetlands in small, but varying amounts. There have been several attempts to use measured rates of emission from wetlands for global CH_4 emission[3,4]. A few studies have also used process-based models[5–7] for methane emission. It is estimated that 110 Tg methane is emitted per year from wetlands[3], whereas since 1750 atmospheric concentrations of methane have increased by 150% in 1998, from approximately 700 to 1745 parts per billion by volume (ppbv)[8]. Among the wetlands spread all over world, tropical wetlands contribute 60% of methane emissions, whereas wetlands in the northern latitudes emit about 35% of total global methane emission. High emission from tropical wetlands is primarily due to the higher temperatures in the tropics in comparison to other regions. Tropical wetlands actively produce and emit methane continuously due to flooded conditions.

In the estimation of methane and monitoring the behaviour of wetlands and their waterspread area estimation during the monsoon, pre- and post-monsoon seasons, remote sensing plays an important role because of high temporal resolution. For our study, we chose MODIS (MODerate resolution Imaging Spectroradiometer) data, because they

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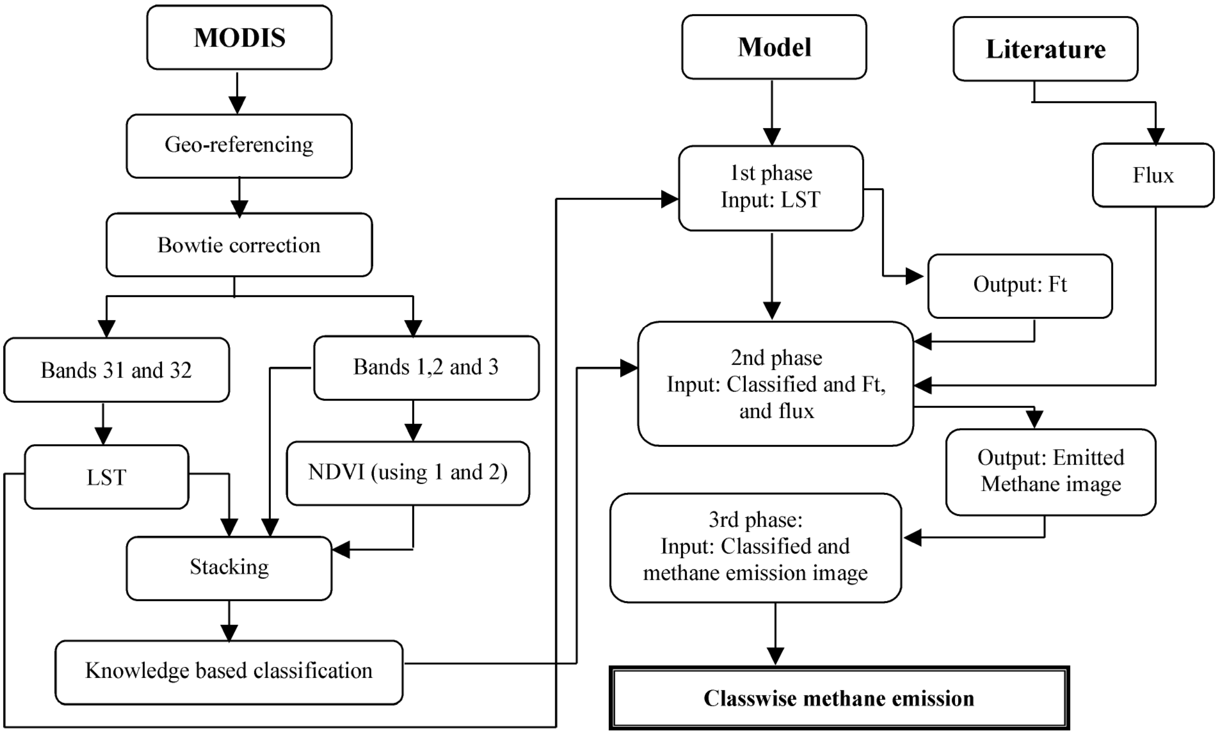

Figure 1. Methodological framework.

have high temporal resolution, and large land cover areas can be scanned in one scene with thermal properties. MODIS is an EOS instrument, which scans the earth ± 55° from nadir, in 36 spectral bands with 250 m (1 and 2 bands), 500 m (3–7 bands) and 1 km (remaining bands) resolution ranging from visible wavelength to thermal infrared (TIR), with 2330 km swath. MODIS provides images of daylight reflection and day/night emission of the earth's surface, repeating global coverage every one or two days. MODIS can monitor the changes in land surface on global/regional scale because of high temporal resolution and wide swath.

In the present work, a Semi-automated Empirical Methane Emission Model (SEMEM) has been developed to estimate methane emission from wetlands and waterlogged areas. This model requires classified wetland areas from satellite data, land surface temperature (LST) from MODIS (or other satellites) and methane emission fluxes from tropical countries. This model has been used for estimating the emitted methane from the entire country, in two different months, i.e. May and October 2005.

Study area

In this study methane emission for the whole of India, including island territories has been estimated. India has a wide physiographical extent and lies between 8°–36°N lat. and 66°–100°E long., having different physical features like the Himalayas, plains, plateaus, alluvial plains like the Gangetic, Brahmaputra, etc.

Data used

MODIS data of May and October 2005 presenting the seasons of pre-monsoon and post-monsoon have been processed for the entire country. Bands 31 (10.28–11.72 μm) and 32 (11.78–12.28 μm) were used for LST estimation, whereas bands 1 (0.62–0.67 μm) and 2 (0.841–0.876 μm) were used for Normalized Difference Vegetation Index (NDVI). LST, NDVI and MODIS 1, 2 and 3 bands have been used for classification.

Methodology

The schematic of the adopted methodology is given in Figure 1.

Preprocessing

MODIS data have been georeferenced using geographic latitude/longitude projection with WGS 84 spheroid. Bowtie correction was applied to rectify overlapping of adjacent scan lines. Subsequently, LST was estimated using thermal bands 31 and 32, and NDVI was calculated using optical bands 1 and 2. LST, NDVI and optical bands 1, 2 and 3 were then stacked together for knowledge-based classification.

Land surface temperature estimation

LST is one of the important parameters for studying land surface. In the present study LST has been used as one of

Table 1. Methane emission fluxes for different classes

Class	Flux	
	Yearly flux/seasonal flux	Monthly flux
Water	50,487.40 kg/km^2/yr	42,07.28 kg/km^2/m
Aquatic vegetation/marshes	Summer (February–May)	48,758.4 kg/km^2/m
	Rainy (June–September)	20,757.6 kg/km^2/m
	Winter (October–January)	10,772.4 kg/km^2/m
Flood plain high moisture	62,474.31 kg/km^2/yr	5206.19 kg/km^2/m
Mud flats	67,941 kg/km^2/yr	5661.7 kg/km^2/m
Salt flats	64,562 kg/km^2/yr	5380.1 kg/km^2/m

the major parameters for estimation of methane emission from wetlands. Various methods of LST determination such as spectral ratio method[9], reference channel method, emissivity normalization method, alpha residue method[10], split window method (SWM)[11,12] and constant emissivity method[13] have been evaluated. However, one of the major problems encountered in estimating kinetic temperature of various land-cover types is emissivity. SWM corrects for the effects of the atmosphere based on the differential absorption in adjacent infrared bands. In the present study SPW of first-order using bands (31 and 32) MODIS data have been used for LST estimation. Assuming constant emissivity of 0.93, according to different land uses in the 31st band (10.28–11.77 μm), temperature was calculated for each pixel using Planck's law:

$$T = \frac{C_2}{\lambda\left(\log\left\{\frac{\varepsilon \cdot C_1}{R \cdot \lambda^5} + 1\right\}\right)}, \quad (1)$$

where $C_1 = 2\pi hc^2 = 3.74183 \times 10^{-16}$ wm^2, $C_2 = 1.4388 \times 10^{-2}$, ε is the emissivity, λ the wavelength and R the radiance.

From these temperatures, pixel-wise emissivities have been calculated in the 32nd band (11.77–12.28 μm) using the relation

$$\varepsilon = \frac{R\lambda^5}{c_1}\left(e^{\frac{c_2}{\lambda \cdot T}} - 1\right), \quad (2)$$

Emissivities thus obtained have been used to rectify the temperature in the 31st band by using eq. (1) and T_{31} has been estimated. Similarly, constant emissivity ~0.99 has been used to estimate temperature T_{32} in band 32.

Using first-order approximation, a linear (eq. (2)) has been solved for estimating the coefficients a and b. Again using equations (3) and (4) LST has been estimated.

$$(T_s - T_{32}) = a \times (T_s - T_{31}) + b, \quad (3)$$

$$T_s = T_{31} + [(b + \Delta T)/(1 - a)], \quad (4)$$

where T_s is the surface temperature and ΔT the temperature difference between bands 31 and 32.

Classification

Knowledge-based classification has been used to classify wetland classes and waterlogged areas using LST, NDVI and optical bands 1, 2 and 3. Supervised classification was not found suitable to classify the various methane-emitting classes due at national/regional level. Knowledge-based classification is like decision tree classification, where decisions have to be made by researchers on the basis of different constraints. In the present study, ranges of values are decided for various classes for each layer like LST, NDVI, and optical bands 1, 2 and 3. Then, a multiple decision tree has been developed for satisfying all the ranges and constraints for each layer and for each class.

Estimation of methane emission

Methane emission has been estimated using an empirical model (SEMEM). T-factor (temperature-related factor) was used to model the change in methanogenic activity as a function of temperature. Experiments have shown[14] that the optimal temperature for the majority of methanogens ranges from 30°C to 40°C. Methane emission from wetlands is described by the following equation[14]:

$$E_{CH_4} = E_{obs} F_t A, \quad (5)$$

where E_{obs} is the observed methane flux from different classes, F_t is the T-factor and A the area. Observed methane fluxes (Table 1) for all the classes have been used based on recent literature[5,15–21].

F_t is defined as follows[14]:

$$F_t = \frac{F(T_s)}{\overline{F(T_s)}}, \quad (6)$$

where

$$F(T_s) = \frac{e^{0.334(T_s - 23)}}{1 + e^{0.334(T_s - 23)}}. \quad (7)$$

T_s(°C) has been calculated for each pixel using the SWM. $\overline{F(T_s)}$ is the mean of $F(T_s)$ over land. Coefficients of

Table 2. Methane emitting areas and methane estimates in India

	May 2005		October 2005	
Class	Area (km^2)	Methane (Tg)	Area (km^2)	Methane (Tg)
Water	10,587.93	0.040	37,772.43	0.127
Aquatic vegetation/marshes	5071.96	0.241	20,081.66	0.239
Flood plain high moisture	1636.72	0.008	4551.74	0.05
Mud flats	5952.79	0.038	9096.24	0.055
Salt flats	6058.85	0.002	4838.83	0.030
Total	29,308.27	0.329	76,340.92	0.466

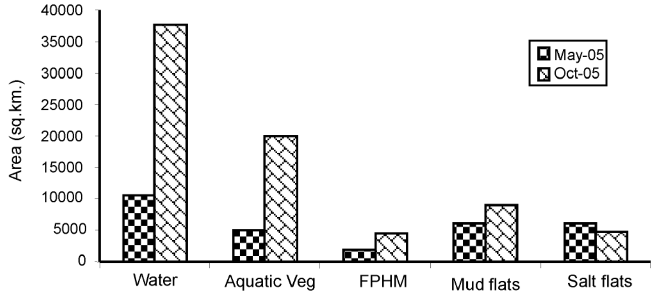

Figure 2. Variation in methane-emitting areas in May and October 2005.

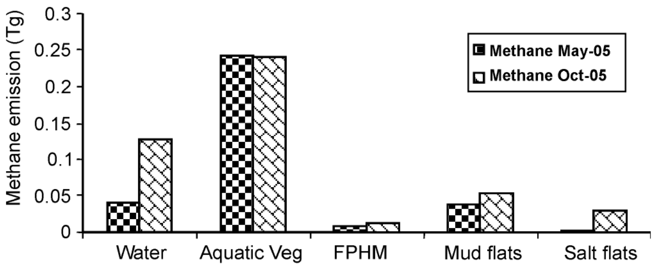

Figure 3. Comparison of estimation of emitted methane in May 2005 and in October 2005.

this exponential equation have been taken from the literature[14]. Subsequently, classified image and F_t image have been used for obtaining the class statistics for all classes. A semi-automated procedure incorporating all steps required for data analysis and methane estimation has been developed and used for the processing of MODIS data for India.

Results and discussion

An attempt has been made to model the emission of methane from different methane-emitting classes for India. A semi-automated empirical methane emission model has been developed incorporating LST, productivity, methane-emission flux and area of methane-emitting classes. Methane emission flux have been taken from the literature[5,15–21]. MODIS data for two months, i.e. May and October 2005, representing pre- and post-monsoon seasons respectively, have been processed using the developed model and estimates of emitted methane have been obtained for five methane-emitting classes, viz. water, mud flats, aquatic vegetation/marshes, salt flats and flood plain high moisture.

Thermal bands, band 31 (10.78–11.28 μm) and 32 (11.77–12.27 μm) of MODIS data, have been analysed for estimation of LST using SWM of first order approximation, while optical bands 1 (0.62–0.67 μm), 2 (0.841–0.876 μm) and 3 (0.459–0.479 μm) along with LST have been used for NDVI calculation and knowledge-based classification. A comparative study has been carried out using MODIS data of May and October 2005 to investigate the variation in the amount of the emitted methane from wetlands and waterlogged areas. Results are summarized in Table 2.

Results show that emitted methane in May 2005 was 0.329 Tg with 29,308.27 km^2 total methane-emitting area, whereas in October 2005 total emitted methane was 0.466 Tg with 76,340.92 km^2 methane-emitting area. Comparison of the methane-emitting area and estimated total methane from wetlands for both the months are shown in Figures 2 and 3.

Conclusion

SEMEM has been developed using temperature, productivity, area and observed methane fluxes for estimation of methane emissions. This model is sensitive to changing temperature, which is the most critical factor in methane emission. Based on this approach an assessment of methane emission from Indian wetlands and waterlogged areas has been made.

Monthly emission is required for assessment of annual global/regional methane emission budget from wetlands and other methane-emitting sources. This work is a step towards attaining knowledge about monthly emitted methane from wetlands of India for two months (May and October 2005). In this regard, MODIS data have been utilized to study land surface parameters like LST and NDVI. These data have also been used for extraction of different methane-emitting classes with LST and NDVI.

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