ATMOSPHERIC METHANE CONCENTRATION PATTERN OVER INDIA IN RELATION TO VEGETATION DYNAMICS- AN ANALYSIS USING ENVISAT-SCIAMACHY AND SPOT-VEGETATION NDVI DATA

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ABSTRACT:

This paper highlights the spatial and temporal variability of atmospheric columnar methane (CH4) concentration in the Kharif season over India and its correlation with the terrestrial vegetation dynamics. ENVISAT-SCIAMACHY product (0.5o x 0.5o) was used to analyse the atmospheric methane concentration. Weekly data covering the Kharif season (May to October) for two consecutive years (2004 and 2005) were used to compute monthly and seasonal concentration. SPOT-VEGETATION NDVI product for the same period was used to correlate the NDVI with CH4 concentration. Analysis showed that mean monthly methane concentration during the Kharif season varied from 1704 ppbv to 1780 ppbv with the lowest value in May and the highest value in September month. Correspondingly, mean NDVI varied from 0.31 (May) to 0.53 (September). Analysis of correlation between methane concentration and NDVI values at 0.5o x 0.5o grid level over India showed significant positive correlation (r= 0.76). Further analysis using land cover information showed characteristic low correlation in natural vegetation region and high correlation in agricultural area. Grids, particularly falling in the Indo- Gangetic plain contributed significantly to the positive correlation. This was attributed to the rice which is grown as a predominant crop during this period. The CH4 concentration pattern matched well with growth pattern of rice with the highest concentration coinciding with the peak growth of the crop in September. Characteristically low correlation was observed (r < 0.2) in deserts of Rajasthan and forested Himalayan ecosystem. This paper highlights the synergistic use of different satellite based data in understanding the dynamics of atmospheric methane concentration in relation to vegetation as a source of emission.

1. INTRODUCTION

Methane is second most potent greenhouse gas after carbon dioxide. Mixing ratio of methane has increased by a factor of 2.5 compared to pre industrial levels (Etheridge et al., 1992) and reached almost 1,800 parts per billion (ppb) today (Dlugokencky et al. 2003). Our understanding of the spatial distribution and temporal evaluation of atmospheric methane is limited by our current knowledge of their source and sink: their variability being a significant source of uncertaininty (Houweling et al., 1999; Gurney et al., 2002). Regional sources and sinks of atmospheric methane are not well quantified. In particular, in the tropics with no ground based methane measuring stations a large uncertainty in the methane budget exists. The amount of methane emission over a region depends on various sources and sinks as well transport from neighbouring region. Sources can be broadly classified as static as well dynamic, which changes with time. Anthropogenic sources such as fossil fuel burning, livestock based emission can be considered as approximately constant over a period of time (year) while biomass burning, rice cultivation has seasonal distribution. According to current emission inventories, approximately 70 % of global methane emissions are anthropogenic (Lelieveld et al., 1998). The largest contributors are fossil fuel production, ruminants, waste handling, rice ecosystem and wetlands. Studies were carried out at Space Applications Centre (SAC) for assessment of methane emission in India from different sources (ISRO Report 2008). Manjunath et al., 2009 has reported methane emission from the rice ecosystems of India ranged from 1.557 to 5.21 Tg with a mean of 3.383 Tg. Chhabra et al., 2008, 2009 have reported 11.75 Tg of methane emission from enteric fermentation and manure management in India. Garg et al., 2005 have assessed that potential methane emission may vary from 1.27 Tg/ year to 2.31 Tg/ year from wet land in India. Above mentioned information on methane emission were based on inventory on rice, livestock and wetlands generated from remote sensing based land cover (rice, wetlands) as well as field measurements. Measurement of greenhouse gases from space is a new research area and only a few pertinent studies exist in literature. Among the presently available systems SCIAMACHY is unique satellite instrument that measures the vertical columns of methane with high sensitivity down to the Earth's surface (Buchwitz et al., 2005). We have used remote sensing technique to quantify the spatial and temporal variations in methane concentration using SCIAMACHY data over India. Attempt was also made to understand the correlation between CH_4 and vegetation variability at different seasons over Indian sub continent. To carry out this research we used the two consecutive years (2004 and 2005) data of SCIAMACHY atmospheric columnar CH_4 concentration and SPOT NDVI data.

2. STUDY AREA & DATA USED

Study was carried over the Indian region extending from 5^0N to 67.5^0N and 54.5^0E to 147^0E. Study area is represented by two distinct seasons: a *Rabi* season (dry season) from November to April and a *Kharif* season (rainy season) from May to October. There is different agriculture practices associated with various crop rotation systems over the study region. Rice is a staple food crop of India and is grown in most parts of the region during *Kharif* season. Its peak growth period is August through October. Rice is main dynamic anthropogenic methane emission source for causing the seasonality in methane abundances in to the atmosphere. Therefore, understanding the spatial and temporal distribution of columnar methane concentration in the *Kharif* season over India and its relation with the terrestrial vegetation dynamics is indispensable. To know this, the weekly $0.5^0x0.5^0$ resolution data (Buchwitz et al., 2004) of SCIAMACHY atmospheric methane concentration were obtained from University of Bremen (http://www.iup.physik.uni-bremen.de/sciamachy/NIR NADIR WFM DOAS/). The CH_4 data from January 2004 to December 2005 was used in analysis. The CH_4 concentration was retrieved using algorithm called Weighting Function Modified Differential Optical Absorption Spectroscopy (WFM-DOAS) version 0.4 developed at University of Bremen. A detailed description of WFM–DOAS is given in (Buchwitz et al., 2000, 2004; Buchwitz and Burrows, 2004). The ten-day composite NDVI product of SPOT VEGETATION (VGT) was (http://free.vgt.vito.be) used to characterize the vegetation dynamics over study region. The details of the SCIAMACHY and SPOT VEGETATION sensors used in study are given below.

2.1 ENVISAT-SCIAMACHY Spectrometer

The Scanning Imaging Absorption spectrometer for Atmospheric Chartography (SCIAMACHY) instrument (Burrows et al., 1995; Bovensmann et al., 1999, 2004) is a part of the atmospheric chemistry payload of the European Space Agencies (ESA) environmental satellite ENVISAT, launched in March 2002. The primary scientific objective of SCIAMACHY is the global measurement of various trace gases in the troposphere and stratosphere, which are retrieved from the solar irradiance and earth radiance spectra. The SCIAMACHY is a passive remote sensing spectrometer consists of 8 grating spectrometers channels (Bovensmann et al., 1999) that measures spectra of scattered, reflected and transmitted solar radiation up welling from the top of the atmosphere (Burrows and Chance, 1991; Burrows et al., 1995; Bovensmann et al., 1999). The instrument measures between spectral region 214-2386 nm, in which 214 nm to 1773 nm is measured continuous radiances in six channels whereas two additional channels cover the regions 1934-2044 nm and 2259 to 2386 nm (for detection of methane). The SCIAMACHY near infrared (NIR) nadir spectra contain information of many important atmospheric trace gases (e.g., BrO, OCIO, H_2O, SO_2, NO_2, CH_2O, O_3, N_2O, CO, CH_4 and CO_2). The near- infrared spectrometers are used for global measurement of total columns of carbon monoxide and greenhouse gases such as carbon dioxide and methane (Frankenberg et al., 2005). The satellite operates in a near polar, sun-synchronous orbit at an altitude of 800 km and crossing the equator at 10:00 AM local time. The instrument alternates between limb and nadir modes of measurement. In the latter mode, a swath of 960 km gives full global coverage is achieved every six days (14 orbits per day). The typical ground pixel size of SCIAMACHY is 30 km (along track, i.e., approximately North-South) times 60 to 120 km (across-track, i.e., approx. East-West) (Frankenberg et al., 2005).

2.2 SPOT VEGETATION Sensor

SPOT-VEGETATION sensor is a multispectral instrument flown abroad the SPOT satellite platforms. The sensor operates in four spectral bands: blue (0.43-0.47 µm), red (0.61-0.68 µm), near-infrared (0.78-0.89 µm) and shortwave infrared (SWIR, 1.58-1.74 µm) having a spatial resolution of 1 km. The red and near-infrared used to characterize vegetation; the blue wavelength band is used for atmospheric correction of the other bands. The 2250 km swath width allows daily imaging of about 90 % of the equatorial regions, the remaining 10 % being imaged the following day at latitudes above 350 (North and South) all regions are observed daily.

3. METHODOLOGY

Study area comprising of Indian subcontinent was extracted from global data sets by overlaying the India's boundary. In order to facilitate a correlation study between SCIAMACHY CH4 data and with the SPOT NDVI fields, all data have been gridded on a common $0.5^0x0.5^0$ latitude/longitude grid. Normalised Difference Vegetation Index (NDVI) values of all the dates were generated from the Digital Number (DN) values using the formula mentioned in VGT User's guide (1999).

$NDVI= (NDVI_{DN}*0.004)-0.1$

Where $NDVI_{DN}$ = Digital numbers of the original NDVI image dataset. NDVI is defined as

$$NDVI = \frac{\rho_N - \rho_R}{\rho_N + \rho_R}$$

Where & represents the reflectance in Near Infra red (NIR) and Red spectral bands respectively. The values of the NDVI represent the vegetation vigour.

Atmospheric CH4 concentration was retrieved from SCIAMACHY data using WFM-DOAS version 0.4 algorithm developed at University of Bremen. DOAS technique primarily uses the concept of differential detection of radiances in gaseous absorption channels with respect to neighbouring atmospheric transparent spectral channels (not influenced by gas) to estimate the concentration of desired gas. Fitting a linearized radiative transfer model plus a low–order polynomial to the logarithm of the ratio of a measured nadir radiance and solar irradiance spectrum is used in implementation of WFM-DOAS approach. Present analysis consists of extraction of study region from global data, analysis of seasonal fluctuation in methane as well as NDVI data, validation of methane product using NOAA-CMDL Global view field measurement data and correlation analysis between CH4 and NDVI during Kharif season in India. The flow diagram of the different components of the study is shown in Fig 1. weekly composite data of CH4 was averaged at monthly interval for compatibility with monthly NDVI derived from 10 day composite data. Due to unavailability of systematic calibrated field measured data during the study period, NOAA-CMDL, GLOBAL VIEW data at Assekrem, Algeria (23.180N, 5.420E) available at weekly interval was used to validate the CH4 concentration over the corresponding region. Correlation coefficient was calculated to determine the relationship between the averaged CH4 and NDVI during Kharif season by pooling the data of two years (2004 -05). The correlation coefficient r_{xy} is defined as

$$r_{xy} = \frac{COV(X,Y)}{\sigma_x \cdot \sigma_y}$$

Where: $r =$ Correlation coefficient, X refers to monthly mean CH_4 concentration (ppbv), Y refers to monthly mean NDVI, σ_x and σ_y are standard deviations of X and Y respectively and $COV(X,Y)$ is

$$COV(X,Y) = \frac{1}{n}\sum_{j-1}^{n}\left(x_j - \mu_x\right)\left(y_j - \mu_y\right)$$

Where x_j & y_j are monthly means of CH_4 and NDVI, μ_x and μ_y represents the seasonal mean CH_4 and NDVI whereas n is number of observations.

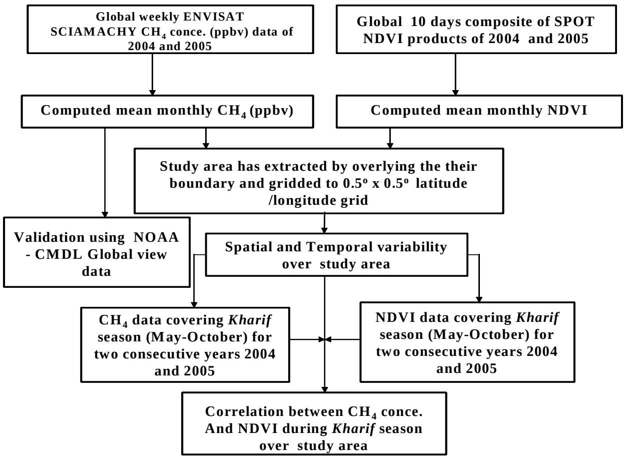

Figure 1. Flow Diagram Showing Different Components of Study on Correlation Between Columnar Methane Concentration with Vegetation Phenology During *Kharif* Season

4. RESULTS AND DISCUSSION

4.1 Variation of Methane Over India

The seasonal distribution of CH_4 concentration over India was analyzed using SCIAMACHY sensor data and it was correlated with vegetation growth characteristics. Fig. 2 shows the spatial variation of average CH_4 conc. during *Kharif* season over Indian subcontinent. It can be seen from the figure that rice dominated regions of parts of Indo- Gangetic plain (UP, Bihar, WB) is associated with higher CH_4 concentration as compared to arid and semi aid regions of western India (Rajasthan, Gujarat). Fig. 3 shows seasonal pattern of CH_4 conc. from representative regions of India. The reported IPCC global mean value of CH_4 concentration is 1774 ppb in 2005 (IPCC report 2007). India's average CH_4 concentration (2004-05) estimated from present study is also shown in Fig. 3 which ranged from 1693 ppbv to 1780 ppbv with a mean of 1726 ppbv. Considerable increase in CH_4 concentration was observed in the *Kharif* season which ranged between 1704 ppbv to 1780 with an average of 1750 ppbv. Methane conc. was found minimum in May with peak value in September. It can be seen from the Fig. 3 that West Bengal and Punjab is associated with higher CH_4 concentration as compare to Tamilnadu and Himalayan forested region (Jammu and Kashmir) in *Kharif* season. The above observations can be attributed to as an effect of rice cultivation. It can also be seen that Tamilnadu shows more than above Indian average concentration during winter season due to rice cultivation in Northeast monsoon. High altitude and low population density is the major reason behind lower concentration of CH_4 during all the months in Himalayan forested regions.

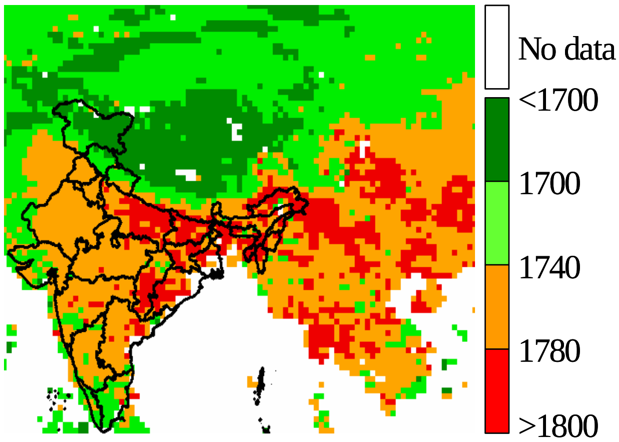

Figure 2. Two year *Kharif* season average of columnar atmospheric concentration (ppbv) of CH_4 retrieved from SCIAMACHY from May-October of 2004 and 2005. The measurements have been gridded with a spatial resolution of 0.5° longitude time's 0.5° latitude

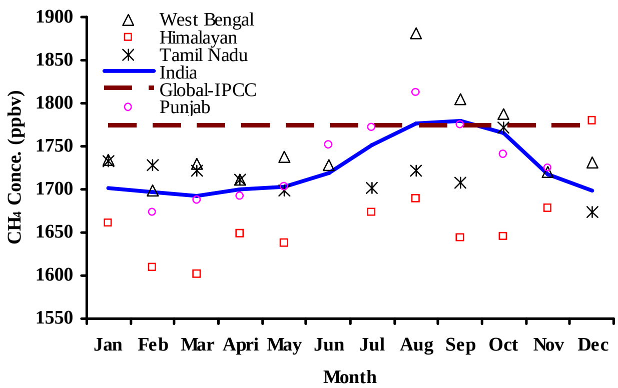

Figure 3. Temporal and Spatial Variation of Atmospheric CH_4 Concentration Over India During 2004 – 05

4.2 Validation of Methane Product

SCIAMACHY based measurements were compared with the surface methane concentration data, which are available from the

NOAA ESRL Global monitoring division (NOAA-ESRL) (Carbon Cycle Greenhouse Gases Group, NOAA Climate Monitoring and Diagnostics Laboratory, Boulder, Colorado. A comparison of the averaged columnar CH_4 derived from SCIAMACHY was made with measurements from NOAA-CMDL, GLOBAL VIEW data at Assekrem, Algeria (Lat 23.18^{0}N Long 5.42^{0}E). The seasonal variability of columnar CH4 derived from the SCIAMACHY measurements and the NOAA-CMDL data was found to have a good agreement. SCIAMACHY retrievals were found underestimated by 6.5 % from measured NOAA-CMDL data.

4.3 Variation of NDVI Over India

Spatial and temporal variability of NDVI was analysed over Indian subcontinent during 2004-05. Fig. 4 shows the average distribution of NDVI during *Kharif* season (May-October) in 2004 - 05. Evergreen Himalayan ecosystem from Kashmir to North East and forest regions of Western Ghats (Kerala) are associated with higher NDVI (>0.4) as compared to arid regions of India (<0.2). Parts of rice ecosystems in Indo Gangetic Plains including Andhra Pradesh, Karnataka, Chattisgharh, and Orissa are associated with NDVI ranging from 0.2 to 0.4. Fig. 5 shows the India average temporal distribution of vegetation growth (NDVI). Distinct two peak system comprising of trough in May (NDVI= 0.31 in summer) and peak I, peak II in February (NDVI= 0.44) and September (NDVI= 0.53) respectively can be seen in the Fig. 5.

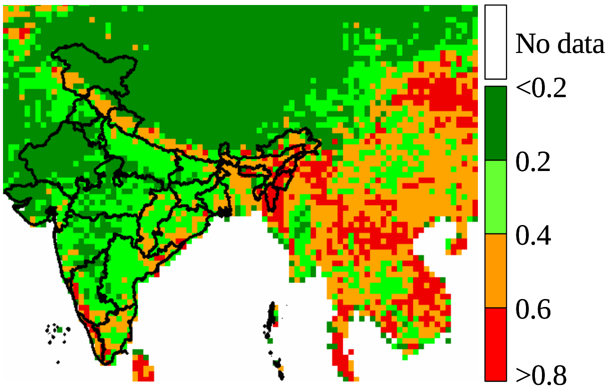

Figure 4. Distribution of NDVI (Vegetation) over India During *Kharif* Season (May-October) in 2004-05

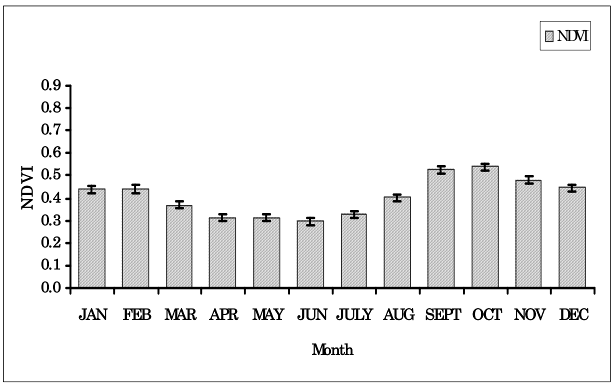

Figure 5. Temporal Variation of Vegetation Over India During 2004–05

4.4 Relationship Between Methane and Vegetation Phenology

Correlation coefficient (r) was calculated between the averaged CH_4 concentration and NDVI during *Kharif* season. Gridded values of correlation coefficient are given in Fig.6. A significant positive correlation was found in rice growing areas of Indo Gangetic plain (r= >0.7) Hilly terrain of Jammu and Kashmir, desert of Rajasthan and other natural ecosystem showed the significantly low correlation (<0.1 to 0.1). It was observed that parts of North East India which was found to have high CH_4 concentration and vegetation vigour showed lower correlation coefficient (r). This indicates that high CH_4 concentration in North East region of India could be due to other sources of emission including transport instead of vegetation.

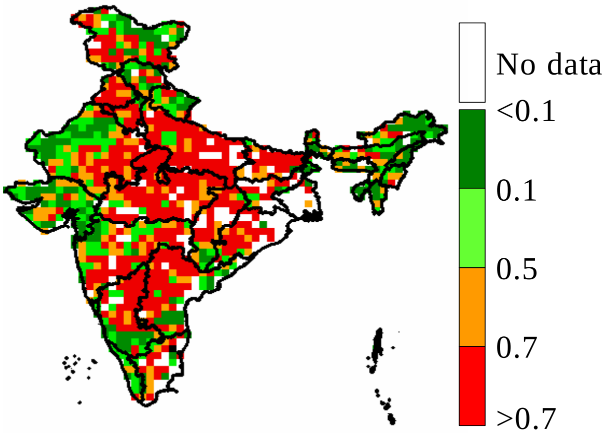

Figure 6. Correlation Between Columnar Methane Concentration and Vegetation During *Kharif* Season in 2004-05

5. CONCLUSIONS AND FUTURE DIRECTION

Atmospheric methane concentration over India was analysed in relation to vegetation dynamics using ENVISAT-SCIAMACHY and SPOT-VEGETATION NDVI data. It was observed that rice dominated regions of parts of Indo- Gangetic plain (UP, Bihar, WB) was associated with higher CH_4 concentration (> 1780 ppbv) as compared to arid regions of western India (Rajasthan, Gujarat) and Jammu and Kashmir (<1700 ppbv). Parts of forest ecosystem of North Eastern India also showed very high concentration of methane during *Kharif* season. The CH_4 concentration temporal profile was found to be in agreement with growth pattern of rice with occurrence peak in September. A validation of the columnar CH_4 derived from SCIAMACHY measurements showed 6.5% underestimation in comparison to NOAA-CMDL, GLOBAL VIEW data at Assekrem, Algeria (23.18^{0}N, 5.42^{0}E).A very significant high correlation (r= 0.76) coefficient was observed between CH_4 concentration and vegetation growth during *Kharif* season. The rice growing areas of Indo Gangetic plain showed the significantly high positive (r=>0.7) correlation. Characteristically low correlation was observed (r=0.1) in deserts of Rajasthan and forested Himalayan ecosystem. The results obtained in seasonal fluctuations of methane in rice ecosystem were in accordance with field observation of Manjunath *et al.* 2009 data. Improved methane estimation for more number of year from presently available data from GOSAT mission as well as future Indian satellite on greenhouse gases would add further understanding over the variability of methane concentration *vis* a *vis* different sources of emission.

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