Atmospheric Environment 71 (2013) 115–121

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

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

Methane emissions from 2000 to 2011 wildfires in Northeast Eurasia estimated with MODIS burned area data

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HIGHLIGHTS

- ► Methane wildfire emissions are estimated and compared to independent results.
- ► Within 48–55°N, wildfires may add 5–20% annually to wetland emissions.
- ► At higher latitudes, the present-day estimates are most variable (uncertain).
- ► Observations of atmospheric methane in 30–60°N are required for further refinement.

ARTICLE INFO

Article history:
Received 21 August 2012
Received in revised form
29 January 2013
Accepted 1 February 2013

Keywords:
Methane emissions
Biomass burning
Satellite observations
Boreal forest

ABSTRACT

Estimates of methane wildfire emissions from Northeast Eurasia for years 2000–2011 are reported on the basis of satellite burned area data from the Moderate Resolution Imaging Spectroradiometer (MODIS MCD45 data product) and ecosystem-dependent fire emission parameters. Average (with standard deviations) emissions are 1.0 ± 0.2 Tg CH_4 year^{-1}, with interannual variations of 0.4–2.3 Tg CH_4 year^{-1}. Most of the emissions are located within 48–55°N, in the southern part of the boreal forest zone, mostly in Siberia and Far East. The largest discrepancies among independent present-day estimates are found in the sub-polar regions of West Siberia and Far East (60–65°N). Compared to the methane wetland emissions reported in literature, the wildfire emissions in the south add about 5–20% to their estimated average annual values and are compared with the magnitudes of their interannual variability. Average seasonal cycle peaks in April–May and July–August, which partially overlaps the summertime peak in wetland emissions. The independent estimates from version 3 of Global Fire Emissions Database (GFED3) are by 50% higher (compared to this study) for average annual emissions over the decade (which is quite good regarding the uncertainties) and showed larger differences for individual years. Possible applications of the results are considered for climate research and inverse modeling studies, as well as for assessment of the uncertainties in the present-day wildfire emission estimates.

1. Introduction

Methane (CH_4) is the second (after the carbon dioxide, CO_2) most important atmospheric greenhouse gas, according to the most recent, fourth assessment report released in 2007 by the Intergovernmental Panel on Climate Change (IPCC AR4) (Forster et al., 2007). Although methane concentrations in the atmosphere (IPCC AR4 reports 1774.62 ± 1.22 ppb as the global average for year 2005) are much lower than those of CO_2, they have more than doubled since pre-industrial times and are currently unprecedented in at least the last 650 kyr according to the ice core measurements (Spahni et al., 2005). The rate of the increase has slowed globally in recent years (Dlugokencky et al., 2003; Lowe et al., 2004), although pronounced increases in methane concentrations were observed at various latitudes in both hemispheres during individual years (Rigby et al., 2008; Terao et al., 2011) that resulted in globally averaged methane growth rates of 3–5 ppb year^{-1} in years 2002, 2003 and 2008 and 9 ppb year^{-1} in 2007 as reported by Dlugokencky et al. (2009). In the middle latitudes (35–50°N) offshore the North Eurasia, Terao et al. (2011) reported increased methane growth rates of 5–10 ppb year^{-1} during 2002–2003 and up to 12–13 ppb year^{-1} in 2007. The reasons of the observed interannual variability are not completely understood, therefore robust and accurate assessments of CH_4 sources and sinks are necessary to explain the current variability and predict future

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http://dx.doi.org/10.1016/j.atmosenv.2013.02.001

trends. The IPCC AR4 reports the strength of the global total CH_4 source to be 500–600 Tg CH_4 year^{-1} according to recent estimates, in which the contribution of each source component and their trends are relatively poorly quantified. Natural CH_4 sources (wetlands, oceans, forest vegetation and fires, termites, wild animals and geological sources) are most uncertain because of impossibility to control the emission processes aggravated by their very high spatial and temporal inhomogeneity complicating direct extrapolation of field flux measurements. An inverse modeling (Enting, 2002; Prinn, 2000) is a promising top–down approach that overcomes these difficulties by employing nature trace gas measurements which tend to become more widespread and frequent year-by-year, and numerical simulations of atmospheric transport and chemistry which have experienced an impressive progress over the recent decades and are still being refined continuously (for example, see Warwick et al. (2002) and Chen and Prinn (2006)). Nevertheless, inverse modeling needs adequately detailed a priori information about the gas fluxes (emissions) as a «first-guess» solution, which makes actual the further development of bottom–up emission inventories.

Natural wetlands in middle and high latitudes (north of 30°N and south of 30°S) contribute about 8% (or 43 ± 17 Tg CH_4 year^{-1} on average, with published estimates of 24–72 Tg CH_4 year^{-1}) to the global total methane source, according to the recent estimates published by EPA (Environmental Protection Agency, 2010). The predicted climate change may substantially increase these emissions (see, for example, estimates for West Siberian wetlands of Denisov et al. (2010)). A substantial part of Northern Hemisphere middle and high latitude wetlands are located in Northeast Eurasia within 50–70°N, where a peak of wildfire activity was detected on the basis of satellite observations (Vivchar, 2011). Till the recent decades, these wildfire emissions were poorly quantified because of their strong spatial and temporal variability and physical inability to continuously detect and control wildfires in vast and remote boreal areas. This complicated interpretation of inverse modeling solutions, as most of the measurement stations are located just downwind of the continent (see Fig. 1 of Chen and Prinn (2006)) and accumulate traces from all the continental methane emissions. Nowadays, a number of global and regional inventories provide estimates of wildfire emissions from boreal Northeast Eurasia, using different emission models and input data, but only few of them report methane emissions (Hoelzemann et al., 2004; Soja et al., 2004; van der Werf et al., 2010). This study employs an emission model of Seiler and Crutzen (1980) and new satellite data on fire-affected areas for years 2000–2011 to calculate atmospheric methane emissions from wildfires in Northeast Eurasia (42–75°N, 10–180°E). The approach is based on a spatially semi-explicit method when biomass density, combustion completeness and emission rates are dependent on a bioclimatic zone. This allows to reproduce many important features of spatial, interannual and seasonal variations in large-scale emissions. The method allows estimating biomass burning emissions of many trace gases (including CO, CO_2, NO_x and non-methane hydrocarbons) and aerosol at $30 \times 30''$ latitude–longitude grid and with daily time step (using MODIS Active Fire observations). Any coarser spatio-temporal resolution of the resulting data may serve as a compromise between detailed representation of the emissions and associated commission, omission, timing and geolocation errors.

2. Data and methods

Net mass M (g) of CH_4 gas emissions from biomass burning was estimated with the original model of Seiler and Crutzen (1980):

$$M = A \cdot B \cdot \mathrm{CC} \cdot \mathrm{EF}, \qquad (1)$$

where A (ha) is the area burned by fire, B (kg ha^{-1}) is the density of dry biomass in the area, CC (%) is the fraction of biomass consumed by fire (combustion completeness), and EF (g kg^{-1}) is the mass of CH_4 gas released per kilogram of the biomass burned (emission factor).

The burned area was estimated on the basis of the satellite MODIS MCD45 Burned Area Level3 product, which provides the most comprehensive data on fire-affected areas in remote boreal regions today. The MCD45 algorithm maps the approximate day and extent of burning by locating the occurrence of rapid changes in multi-spectral daily surface reflectance time series data. This makes the MCD45 data product less insensitive (compared to the products that are based on thermal hot spot detection algorithms and do not use multi-temporal observations) to the errors associated with time of satellite overpass and cloud or smoke obscuration (depending on the relative persistence of cloud or smoke and the post-fire change in reflectance) (Roy et al., 2005). The MODIS Level3 data products are available on global regular data grids in sinusoidal projection with 500 m spatial and monthly temporal resolution. The date of burning in grid cells is defined with an uncertainty of ±8 days. The original MCD45 data was reprojected on a 15″ latitude–longitude grid with the special MODIS tool, and the area of each cell of the new grid was calculated on a geographical sphere.

Other emission model parameters used in formula (1) are summarized in Table 1 as averages for bioclimatic zones according to the UMD–GLC University of Maryland's Global Land Cover map (taken at $30 \times 30''$ lat–lon resolution) (Hansen et al., 2000). The values for B and EF are taken from Wiedinmyer et al. (2006), which used a slightly different land cover classification scheme. Namely, for «woodlands» (UMD-GLC class 6) no data was reported, so in Table 1 emission parameters of «temperate or sub-polar broadleaf deciduous forest» are used instead. The «wooded grassland» (UMD-GLC class 7) is most likely to be the forest steppe, where predominantly herbaceous vegetation burn, so the emission parameters of «temperate or sub-polar grassland with a sparse tree layer» are used. The combustion completeness (CC) is calculated as a weighted sum of CCs for woody and herbaceous vegetation in a bioclimatic zone according to the empirical formulas used by Wiedinmyer et al. (2006) and subsequently averaged over several bioclimatic zones.

The results of this study were compared with estimates from the GFED3 inventory which reports monthly wildfire emissions since 1997 on a $0.5 \times 0.5°$ latitude–longitude grid based on the Carnegie-Ames-Stanford-Approach (CASA) biogeochemical model and satellite-derived estimates of fire activity and plant productivity (Giglio et al., 2010; van der Werf et al., 2010). Burned areas in GFED3 are estimated on the basis of MODIS data, but an alternative (not the MCD45) algorithm is used. The GFED3 model employed an advanced version Seiler and Crutzen's (1980) formula, with

Table 1
Emission model parameters for each bioclimatic zone (according to UMD-GLC classification) in Northeast Eurasia (Wiedinmyer et al., 2006). See details in the text.

NN	Description	B (kg ha^{-1})	CC (%)	EF (g kg^{-1})
1, 3	Evergreen and deciduous needleaf forest	14	0.4	4.8
4	Deciduous broadleef forest	9.5	0.4	4.5
5	Mixed forest	12	0.4	4.5
6	Woodland	9.5	0.4	4.5
7	Wooded grassland	1.1	0.9	3.1
8, 9	Shrubland	4.3	0.5	3.1
10	Grassland	1.1	0.9	3.1
11	Cropland	0.5	0.9	2.2
0, 12–14	Water bodies, barren, built-up, undefined	0.0	0.0	0.0