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Comparison of global inventories of CO_2 emissions from biomass burning during 2002–2011 derived from multiple satellite products

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ABSTRACT

This study compared five widely used globally gridded biomass burning emissions inventories for the 2002–2011 period (Global Fire Emissions Database 3 (GFED3), Global Fire Emissions Database 4 (GFED4), Global Fire Assimilation System 1.0 (GFAS1.0), Fire INventory from NCAR 1.0 (FINN1.0) and Global Inventory for Chemistry-Climate studies-GFED4 (G-G)). Average annual CO_2 emissions range from 6521.3 to 9661.5 Tg year^{-1} for five inventories, with extensive amounts in Africa, South America and Southeast Asia. Coefficient of Variation for Southern America, Northern and Southern Africa are 30%, 39% and 48%. Globally, the majority of CO_2 emissions are released from savanna burnings, followed by forest and cropland burnings. The largest differences among the five inventories are mainly attributable to the overestimation of CO_2 emissions by FINN1.0 in Southeast Asia savanna and cropland burning, and underestimation in Southern Africa savanna and Amazon forest burning. The overestimation in Africa by G-G also contributes to the differences.

1. Introduction

Biomass burning emissions from forest fires, savanna fires, agricultural waste burning and peatland fires have been recognized as a significant source of greenhouse gases (e.g., CO_2, CH_4 and N_2O), which significantly impact ecosystem productivity, global atmospheric chemistry and climate change (Andreae and Merlet, 2001; Vadrevu et al., 2014). Moreover, biomass burning emissions contribute significantly to the budgets of several trace gases and aerosols (Qin and Xie, 2011) and are one of the primary causes of interannual variability in the growth rate of several trace gases, including the greenhouse gases CO_2 and CH_4 (Langenfelds et al., 2002; Duncan et al., 2003). Furthermore, biomass burning emissions have become an important source of uncertainty in atmospheric transport simulations of trace gases (Bian et al., 2007; Marlier et al., 2013). Therefore, accurate estimates of CO_2 emissions from biomass burning at both global and continental levels is urgently needed to better understand the interactions between fire and climate.

Studies focusing on the estimates of fire emissions at both global and regional scales are mostly based on the product of the burned area, fuel loads, combustion factors and emission factors over the time and space of interest (van der Werf et al., 2010; Wiedinmyer et al., 2011). Another approach that has been developed over the past decade is the measurement of fire radiative power (FRP) (Kaiser et al., 2012). FRP relates directly to the rate of fuel consumption, which is proportional to the fire emissions.

Currently, several biomass burning emissions inventories derived from multiple satellite datasets (e.g., Global Fire Emissions Database (GFED) (van der Werf et al., 2010), The Global Fire Assimilation System (GFAS) (Kaiser et al., 2012), the Fire INventory from NCAR (FINN) (Wiedinmyer et al., 2011), the Global Inventory for Chemistry-Climate studies (GICC) (Mieville et al., 2010)) have been developed and applied in atmospheric circulation simulations. The emission inventories of GFED, FINN and GICC are based on the burned area method but with different input data, whereas GFAS uses the FRP method to provide near real-time biomass burning emissions. In general, the use of different inventories and various methods usually leads to large variations in emissions estimations, which are subject to different inputs as a result of spatial

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and temporal variations in fire activity, fuel load and seasonality (Shi et al., 2014). Moreover, uncertainties in the input data regarding burned area and fuel loads in either the modeling or inversion technique amplify large differences in both the geographical distribution and temporal dynamics of global and regional CO_2 emissions estimates (Shi and Yamaguchi, 2014). However, these available emission inventories are still widely used in atmospheric simulations. For example, GFED3 is used as an a priori flux dataset to optimize surface CO_2 flux in inverse modeling by Greenhouse gases Observing SATellite (GOSAT) L4A products (Maksyutov et al., 2013). GFAS, as a priori emission, is used to optimize CO emissions using observations from the Infrared Atmospheric Sounding Interferometer (Krol et al., 2013). FINN is employed to predict surface ozone and CO production (Amnuaylojaroen et al., 2014).

At present, little is known about similarities and differences among inventories, and spatial characteristics and variability at continental and global levels, which all have a large impact on the uncertainties of the climate change simulation and atmospheric chemical transport model. In this study, the currently existing four globally gridded inventories of CO_2 emissions from biomass burning and a new inventory developed in this study are investigated at both global and continental levels. The objective of this paper is to present a comparison of five globally gridded datasets of monthly CO_2 emissions from fire-induced biomass burning for the years 2002–2011. In particular, we aim to highlight similarities and differences in the geographical distribution and variation of emissions at global and continental levels across the three broad land cover types: forest, savanna and cropland.

2. Data and methods

2.1. Global CO_2 emissions

We employ four widely used global inventories of CO_2 emissions from open biomass burning based on remotely sensed burned area/active fire products (GFED3, GFED4, GFAS1.0, FINN1.0) and a new dataset developed in this study (G-G) (Table 1).

2.1.1. GFED3

The Global Fire Emissions Database version 3 (GFED3) estimates the spatiotemporal distributions in global fire-induced biomass burning emissions at monthly intervals from July 1996 to February 2012 with 0.5° × 0.5° spatial resolution (van der Werf et al., 2010). The emissions of trace gases and aerosols can be expressed as follows:

$$Emissions = \sum_{i=1}^{n} BA \times F \times CF \times EF \quad (1)$$

where BA denotes an important parameter of burned area (m^2); F is the available fuel loads (kg dry matter m^{-2}); CF is the combustion factor, representing the fraction of available fuels exposed to fires that are actually burned during combustion (−); EF is the emission factor (g kg^{-1}), defined as the amount of trace gases emitted per unit of fuel combusted, and i is types of land cover. Burned area estimates were derived from a combination of active fires depicted by MODerate resolution Imaging Spectroradiometer (MODIS), fire observations, and burned area (MODIS) for selected regions. The improved Carnegie-Ames-Stanford-Approach biogeochemical model with the fire process included predicts biomass densities (fuel loads), which are based on satellite-derived information on vegetation characteristics and productivity to estimate carbon outputs through heterotrophic respiration, herbivory and fires. The combustion factor is calculated within the model based on moisture conditions for each fuel type. Finally, emission factors from Andreae and Merlet (2001) are employed to convert the burned biomass into emissions of trace gases and aerosols.

2.1.2. GFED4

The Global Fire Emissions Database version 4 (GFED4) combines satellite information on fire activity and vegetation productivity to estimate globally gridded monthly burned area and fire emissions. Each data file has a 0.25° × 0.25° spatial resolution, and data from 1995 to the present are available. The most important difference between GFED3 and GFED4 is that GFED4 data are based on burned area with small fires included (Randerson et al., 2012; Giglio et al., 2013). According to Randerson et al. (2012) and Giglio et al. (2013), the key differences between the two versions are: (1) the burned area increased substantially due to the addition of "small fire burned area" (pixels that the active fire algorithm indicated as fire occurrence but the burned area algorithm showed as no response), especially in regions dominated by small fires (less than 500 m) based on active fire detections, such as agricultural areas; (2) validation against consumed fuel loads measured in the field resulted in fewer grassland and savanna fuel loads in GFED4.

2.1.3. GFAS1.0

The Global Fire Assimilation System version 1.0 (GFAS1.0) emissions inventory provides daily near real-time fire emission estimates at 0.5° × 0.5° resolution from 2001 to the present (Kaiser et al., 2012). GFAS1.0 is based on the assumption that there is a linear relationship between fuel consumption and total emitted fire radiative energy. Wooster et al. (2005) demonstrated a linear relationship between fuel consumption and total emitted fire radiative energy as follows:

$$Emissions = FRE \times \beta \times k = \sum_{i=1}^{n} \int_{t_1}^{t_2} FRPdt \times \beta \times k_i \quad (2)$$

where FRE is the fire radiative energy (MJ), FRP is the fire radiative power (MW), t_1 and t_2 are the beginning and ending times of biomass burning, respectively, and β is the associated conversion factor (kg (dry matter) MJ^{-1}), and k (g kg^{-1}) is the emission factors for each land cover class i. The global FRPs are derived from the MODIS instruments aboard the Terra and Aqua satellite, and corrected for partial cloud-cover and observation gaps. GFAS1.0 emission estimates are calculated using biome-specific conversion factors to link FRP in the GFAS1.0 and dry matter combustion rate in GFED3. The combustion rate of dry matter burned is then linearly

Table 1
List of remotely sensed global CO_2 emissions datasets on biomass burning considered in this study.

Inventory	Method	Spatial resolution	Temporal resolution	Period	Reference
GFED3	Burned area	0.5° × 0.5°	Month	1997–2011	van der Werf et al. (2010)
GFED4	Burned area	0.25° × 0.25°	Month	1995–now	Giglio et al. (2013)
GFAS1.0	Active fire	0.5° × 0.5°	Day	2001–now	Kaiser et al. (2012)
FINN1.0	Active fire	1 km × 1 km	Day	2002–2014	Wiedinmyer et al. (2011)
G-G	Burned area	0.25° × 0.25°	Month	1996–2013	Mieville et al. (2010)