Atmospheric Environment 138 (2016) 152–161

Contents lists available at ScienceDirect

Atmospheric Environment

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

High-resolution historical emission inventories of crop residue burning in fields in China for the period 1990–2013

Jing Li, Yaqi Li, Yu Bo, Shaodong Xie*

College of Environmental Science and Engineering, State Key Joint Laboratory of Environmental Simulation and Pollution Control, Peking University, Beijing, People's Republic of China

HIGHLIGHTS

- Multi-year emission inventories of crop residue open burning were established.
- Agriculture mechanization ratios and locally observed emission factors were introduced.
- MODIS satellite data were used to allocate the annual provincial emissions into high resolutions.
- Emissions form crop residues burning have strong temporal pattern.

ARTICLE INFO

Article history:
Received 17 October 2015
Received in revised form
26 April 2016
Accepted 2 May 2016
Available online 13 May 2016

Keywords:
High-resolution
Emission inventory
Interannual variations
Crop residue burning
MODIS

ABSTRACT

High-resolution historical emission inventories of crop residue burning in fields in China were developed for the period 1990–2013. More accurate time-varying statistical data and locally observed emission factors were utilized to estimate crop residue open burning emissions at provincial level. Then pollutants emissions were allocated to a high spatial resolution of 10 km × 10 km and a high temporal resolution of 1 day based on the Moderate Resolution Imaging Spectroradiometer (MODIS) Fire Product (MOD/MYD14A1). Results show that China's CO emissions have increased by 5.67 times at an annual average rate of 24% from 1.06 Tg in 1990 to 7.06 Tg in 2013; the emissions of CO_2, CH_4, NMVOCs, N_2O, NOx, NH_3, SO_2, $PM_{2.5}$, OC, and BC have increased by 595%, 500%, 608%, 584%, 600%, 600%, 543%, 571%, 775%, and 500%, respectively, over the past 24 years. Spatially, the regions with high emissions had been notable expanding over the years, especially in the central eastern districts, the Northeastern of China, and the Sichuan Basin. Strong temporal pattern were observed with the highest emissions in June, followed by March to May and October. This work provides a better understanding of the spatiotemporal representation of agricultural fire emissions in China and can benefit both air quality modeling and management with improved accuracy.

1. Introduction

Since the pioneering study by (Crutzen et al., 1979), biomass burning, which contains forest fires, savanna and grassland fires, crop residues burning, and peat combustion (van der Werf et al., 2010), has been considered an important source of atmospheric trace species and primary fine particles that has a significant impact on regional air quality, global climate change, as well as human health (Crutzen and Andreae, 1990; Akagi et al., 2012; Permadi and Oanh, 2013; Johnson et al., 2005; Li et al., 2016a).

In China and other agriculture-based-economy countries, crop residue burning in fields is one important kind of biomass burning and poses a serious threat to human health and air quality (Streets et al., 2003; Marlier et al., 2013; Li et al., 2015), which began to receive governmental and scientific attention within China as early as the 1990s. Streets (2003) estimated that 730 Tg of biomass was burned in Asia in 2000, 250 Tg of which was the open burning of crop residues; China and India accounted for 110 Tg and 84 Tg, respectively of the residues burning. Quantifying the magnitude and trend of pollutants and greenhouse gas emissions from crop residue burning in fields is of great important for air quality modeling and management in China. However, emissions caused by crop residue burning in fields in China has not been studied in great detail and is not well characterized. It is essential to establish

* Corresponding author.
E-mail address: sdxie@pku.edu.cn (S. Xie).

http://dx.doi.org/10.1016/j.atmosenv.2016.05.002

an accurate and high resolution emission inventory of crop residue burning in fields.

One approach to estimate biomass burning emissions is based on the burned area detected by satellites and calculated as the product of burned area, fuel loads, and combustion completeness. GBA2000 (Gregoire et al., 2003), GLOBSCAR (Simon et al., 2004), GLOBCARBON initiatives (Plummer, 2006) and Global Fire Emissions Database (GFED) (Randerson et al., 2012) have yielded burned area estimates for global biomass burning. However, this method has limitations, when used to quantify small fires, particularly under continued hazy sky conditions (Roy et al., 2008; Barret et al., 2010). In China, the average farming area of a farming household is only two acres (0.001334 km^2) (China statistical yearbook, 2013). Moreover, beginning in 1997, Chinese government has enacted a series of regulations and laws to prohibit field burning (Yan et al., 2006); thus, it occurs on a small scale in dispersed locations, making it difficult to assess well via satellite (Streets et al., 2003).

Another approach to estimate fire emissions is the use of the Seiler and Crutzen (1980) style equation to estimate emissions by multiply statistical data and the corresponding emission factors (EFs). The reliabilities of EFs, grain-to-straw ratios, dry matter content, proportion of crop residues burned in the field, and burning efficiency are the major challenges in producing an accurate emission inventory based on this method (Klimont and Streets, 2007). The spatial and temporal distribution of such burning can be presented in grids by combining fire counts product and land cover map.

Since the emissions from crop residues burning in fields tend to be largely underestimated if they are based on global burned area products, and the burning of crop residues is strongly correlated with agricultural practices, we chose the second approach to build the historical emission inventory. Emissions from crop residue burning in fields in China have been estimated in several publications using this approach (Streets et al., 2003; Yan et al., 2006; Wang and Zhang, 2008; Zhang et al., 2008; Huang et al., 2012; Jain et al., 2014; Wu et al., 2016). However, the parameters used to calculate emissions inventories were imprecise, which can result in errors in simulations and mislead policy-making. For example, most early studies used EFs determined by foreign researches or applied the same factor to the burning of different crops; most previous studies assumed the proportion of crop residue burned in fields by using statistical reports or values based on experience; the grain-to-straw ratios used in previous studies were derived from outdated data based on the results of studies conducted from 1980 to 1984. Moreover, those inventories all focused on residues open burning emissions for a single year with a low temporal and spatial resolution. For most air quality simulations, a more detailed inventory with high temporal and spatial resolution is preferred. Understanding the interannual variations of residues burning in fields emissions and their spatial and temporal distribution is essential to support the analysis and modeling of air quality and climate change issues.

In this study, we used the statistical data approach to develop China's historical emission inventories of CO_2, CO, CH_4, NMVOCs, N_2O, NOx, NH_3, SO_2, $PM_{2.5}$, OC, and BC from crop residues burning in fields at a spatial resolution of 10 km × 10 km for the period of 1990–2013. In the process of estimating China's crop residues burning emissions, crop-specific local measured EFs and most detailed and accurate activity data were used. For the period 2001–2013, the annual provincial results were allocated to one day intervals and 10 km grid emissions by combining daily MODIS Thermal Anomalies/Fire products and Climate Change Initiative Land Cover Maps (CCI-LC Maps). For the year prior to the MODIS period (1990–2001), the annual emissions were allocated to county-level by county-specific sow area, and the county-level inventories were converted to grids at a resolution of 10 km ×().

2. Methodology

2.1. Emissions estimation

Burning emissions of crop residues were initially calculated at the provincial level using the product of the mass of each crop type residues burned and the corresponding EF, as shown in equation (1):

$$E_{m,i} = \sum^{j} EF_{i,j} \times M_{m,j} \quad (1)$$

where E is the emission from crop residues burning in fields, EF is the corresponding emission factor, $M_{m,j}$ is the mass of crop residues burned in fields, m stands for each province (including 31 provinces, autonomous regions and municipalities in China mainland excluding Hong Kong and Macau Special Administrative Regions and Taiwan province), i for different emission species (including CO_2, CO, CH_4, NMVOCs, N_2O, NOx, NH_3, SO_2, $PM_{2.5}$, OC, and BC); j for different crop types (including rice, wheat, corn, legumes, tubers, cotton, peanut, and rapeseed).

2.1.1. Mass of residues burning in fields

The provincial mass of crop residues burned of each crop type (M) was calculated on the basis of crop production using equation (2):

$$M_{m,j} = C_{m,j} \times R_{m,j} \times \varphi_{\mathrm{m}} \times \sigma \times \delta_j \quad (2)$$

where C is crop production (China Statistical Yearbook, 1991–2014); R is the grain-to-straw ratio, which refers to recent data shown in Table S1 (Wang et al., 2012); φ is the proportion of crop residues burned in the field, σ is the proportion of dry matter in the crop residue, and δ is the burning efficiency.

The parameter σ is assumed as 80% according to the field measurements by Zhang et al. (2013), Jain et al. (2014). Burning efficiencies (δ) specific to various crops were compiled from (Turn et al., 1997) and (de Zarate et al., 2005), with values obtained for rice (0.89), wheat (0.86), corn (0.92), beans (0.68), tubers (0.8), cotton (0.8), peanuts (0.8), and rapeseed (0.82).

The proportion of crop residues burned in the field (φ) was an important factor to be determined. Field surveys have shown that when a crop is harvested by a combine harvester, the proportion of residues burned is much greater than that when crops are harvested manually (Yang et al., 2008; Erenstein, 2011; Mishra and Shibata, 2012). In this study, φ for crops harvested mechanically and for those harvested manually are given respectively. Eq. (2) can be transformed into Eq. (3):

$$M_{m,j} = \left(A_j \times \alpha_{m,j} + B_m \times \left(1 - a_{m,j}\right)\right) \times C_{m,j} \times R_{m,j} \times \sigma \times \delta_j \quad (3)$$

where $\alpha_{m,j}$ is the proportion of the crop harvested mechanically for crop type j in province m, $1-\alpha_{m,j}$ is the proportion of the crop harvested manually, A and B are ϕ for crops harvested by combine harvester and by hand, respectively (the rest of the variables have already been defined).

$\alpha_{m,j}$ was taken from the China Agricultural Machinery Industry Yearbook (Table S2). The coefficient A was determined from field investigations. About 82% of mechanically harvested wheat was burned in the field, whereas that of other straw crops was about 37% (Yang et al., 2008). The value of B was determined with the same method as Li et al., 2016b. In this study China's provinces were categorized into six groups, according to the proportion of