Improving Fire Emission Estimates in the eastern United States Using Satellite-Based Fuel Loading Factors

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1. Introduction

Wildfires can lead to severe environmental consequences by releasing large amounts of particulate matter (PM) and precursors of ozone (Sandberg et al., 1999; Riebau and Fox, 2001). The Southeast has the most burned area among various U.S. regions (Stanturf et al., 2002) and has regionally some of the highest levels of PM and ozone in the nation. Fires have been found to be an important contributor (Zheng et al. 2002). On the other hand, smoke particles from wildfires are one of the atmospheric anthropogenic aerosol sources. They can affect global and regional radiation and climate (e.g., Penner et al. 1992, Liu 2005a).

Fire emissions can be estimated using fire and fuel properties, including area burned, fuel loading or consumption factor, emission factor, and fuel moisture. These properties have been traditionally obtained by field and laboratory measurements. For fuel loading factor, one of the most important fuel parameters, EPA has formed a table of default values (AP-42 Table) for each of the USDA Forest Service regions (EPA, 1995) on basis of the ground measurements made a few decades ago. A number of fire emission inventories or estimates have been created using the AP-42 Table, including those for nation-wide prescribed fires in 1989 (Peterson and Ward, 1993; Ward et al., 1993), wildfires over 11 western states (Hardy et al., 1998), the National Emissions Inventory for three base years (EPA, 2003), and the historic fire emissions from federal lands (Liu, 2004).

The usage of the AP-42 Table has been a major uncertainty in estimating fire emissions because of the outdated data used and the lack of land cover variability (Liu 1004). In the recent years, satellite remote sensing (RS) has emerged as a useful technique for monitoring wildland fires (Kaufman et al., 1990; Justice et al, 1993; Li et al., 1997) and estimating fuel moisture (Chuvieco et al., 1999; Qu et al., 2003; Riebau and Qu 2004; Qu et al. 2005; Hao et al, 2005) in addition to the regular ground measurements. RS has showed its powerful capacity in regional study because of its high space resolution and extensive coverage. Efforts have also made in mapping the National Fire Danger Rating System (NFDRS) fuel models (Cohen and Deeming, 1985; Burgan et al. 1998) using RS land cover information (WRAP 2002). By integrating all fuel models, each of which comes up with a specified fuel loading factor, a set of representative fuel loading factors has been obtained for each of the contiguous states (EC/R, 2003).

A couple of advantages are expected for the RS based fuel loading factor in comparison with the one specified in the AP-42 Table. First of all, it should be more accurate because of the more detailed land cover information. Furthermore, the RS based, state-integrated fuel loading factors are able to reflect the possibly large variations in land cover from one state to another within a USDA Forest Service region.

This study seeks to improve fire emission estimates in the eastern U.S. by using the RS based fuel loading factors. The results are expected to provide useful information for answers to the two questions: (1) Does the RS technique produce substantial differences in fire emissions in the eastern U.S. in comparison with the AP-42 method? And (2) If the answer to the first question is yes, how do the differences change our understanding of the environmental effects of wildfires?

2. Methodology

The method to calculate wildfire emissions, which was described in detail in Liu (2004), is summarized here: $E_i = F_i A$ *and* $F_i = S_i L$, where E_i is emission (in mass) of the component *i*; *A* land area burned; F_i emission per unit area burned; L effective fuel consumption or fuel loading factor (mass of forest fuel per unit land area burned); and S_i emission factor (mass of pollutant per unit mass of forest fuel consumed). The emission factors, also adopted from the AP-42 Table, are 11.7 ($PM_{2.5}$), 13.0 (PM_{10}), 140 (CO), 0.15 (SO_2), 4 (NO_x), and 19.2 (volatile organic components). The fuel loading factors are listed in Table 1.

Table 1 Fuel loading factor L (ton/acre) (source for RS based values: EC/L, 2003)

State	L (RS)	FS Region	L (AP-42)
MS	9.7	Southeast	9
AL	10.1		
GA	13.2		
FL	19.7		
SC	9.6		
TN	4.3		
NC	9.6		
KY	3.3		
VA	7.7		
IL	3.1	North Central	11
IN	2.4		
OH	3.0		
WI	7.4		
MI	10.1		
WV	4.8	Northeast	11
MA	5.4		
PA	3.2		
DE	7.7		
NJ	11.6		
NY	20.3		
CT	3.1		
RI	3.1		
MA	24.0		
VT	51.3		
NH	33.4		
ME	27.8		

A data set of wildfires developed by the U.S. Bureau of Land management (BLM, 2003) is used. Note that included in the data set are only burnings occurred on the federal lands. The data used for the emission estimates in this study are monthly totals of area burned by wildfires for each of the 48 contiguous states during1980-2002. The statistical features of the fires were described in Liu (2004).

3. Results

Fig.1 shows geographic distribution of annual fire emissions of $PM_{2.5}$ averaged over 1980-2002. An interpolation technique was used to convert the values from states to a grid with the horizontal resolution of 60 km. This technique applies a weight factor, which is inversely proportional to the distance between a grid point and a state. A primary feature with the fire emissions in the eastern U.S. is the dominant amount in Florida with a magnitude of about 20 kg km^{-2}. The emissions decrease rapidly to about 0.5 kg km^{-2} in the nearby states, and are blow 0.2 kg km^{-2} in other states. This feature is also clearly shown in the area-integrated wildfire emissions of $PM_{2.5}$ averaged over 1980-2002 for each state (Fig.2). The total Florida emissions are over 6000 ton. In comparison, those of Mississippi, Georgia, or North Carolina are less than 500 ton.

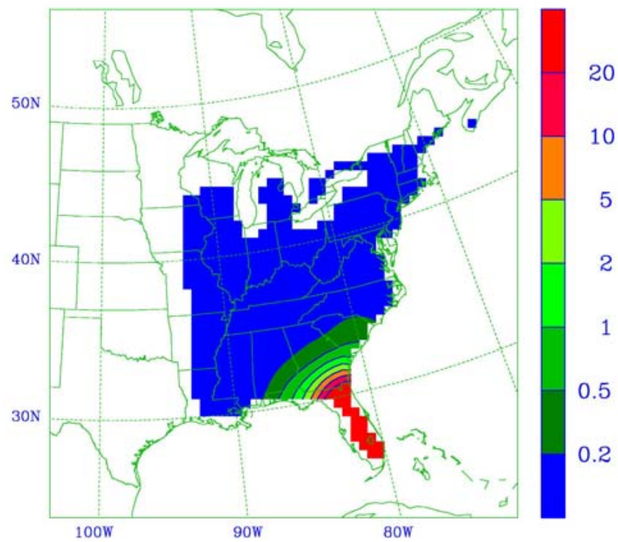

Fig.1 Spatial distribution of annual wildfire emissions of $PM_{2.5}$ (kg km^{-2}) estimated using the remote sensing based fuel loading factors.

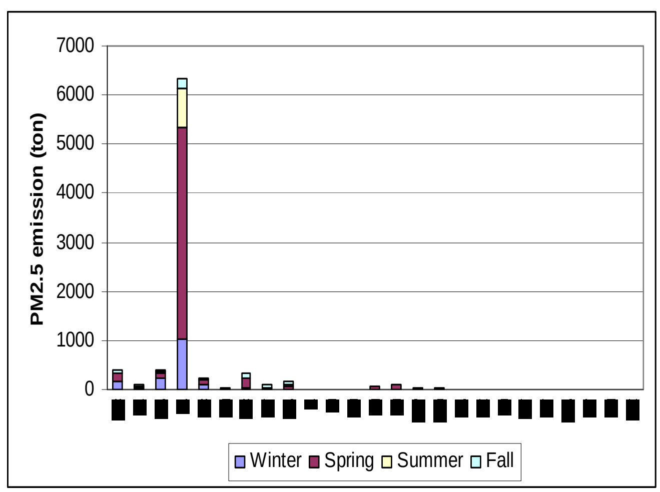

Fig.2 Wildfire emissions of $PM_{2.5}$ by state and season.

The emissions of PM_{10}, VOC and NO_x are roughly comparable to those of $PM_{2.5}$, while the emissions of other components are significantly different. CO and CO_2 are about 10 and 100 times larger, respectively, while SO_2 is about 100 times smaller. They reflect the differences in the AP-42 emission factors.

A substantial part of wildfire emissions in Florida and many other Southeast states occurs in Spring, when the weather is warming up but not very moist yet. This is different from the western U.S., where Summer has the largest number of wildfires in most states. Standard deviation of annual emission series has the same magnitude as the average, indicating large inter-annual variability.

Substantial differences in fire emissions are found between the RS technique and the AP-42 Table. The fire emissions from the AP-42 Table (Fig.3) are less than 10 kg km^{-2}. Fig.4 shows the ratio of the difference in emissions between the RS technique and AP-42 Table to the emission from the AP-42 Table. Application of the RS technique leads to much larger emissions in the Gulf coastal states. The emission in Florida, for example, increases by 1.5 times. Likewise, the technique leads to larger emissions in most New England states. The change is even bigger. The emission in Vermont, for example, increases by 4.5 times. The technique, however, leads to decrease s by 50~80% in most states between the two regions.

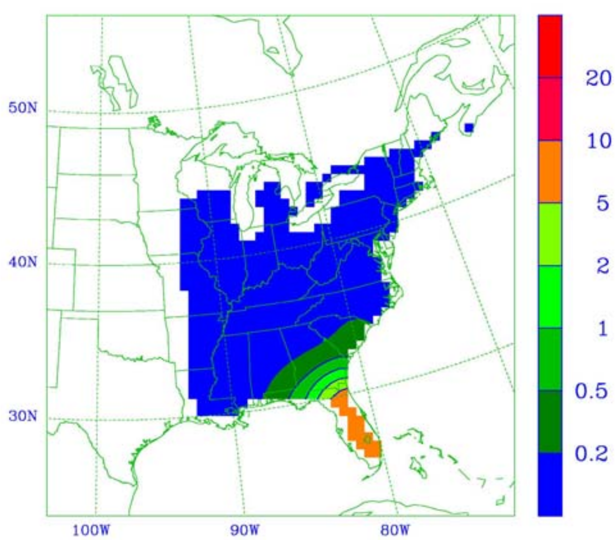

Fig.3 Spatial distribution of annual $PM_{2.5}$ emissions from wildfires (kg km^{-2}) estimated using fuel loading factors in the AP-42 Table.

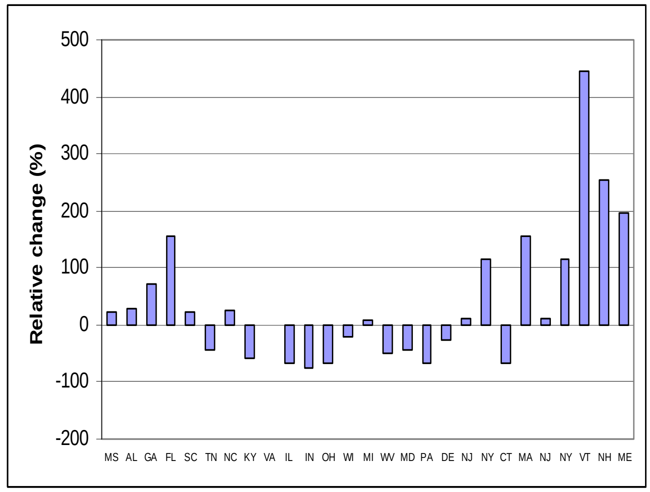

Fig.4 Ratio of the difference in fire emissions between RS technique and AP-42 Table to the emission estimated using AP-42 Table..

Regionally, by using the RS technique instead of the AP-42 Table, fire emissions increase 102% in the USDA Forest Service Southeast region and 18% in the North Central. They change little in the Northeast. While this study focuses on the eastern U.S., fire emissions in the western U.S. are also analyzed for comparison. Fire emissions decrease in all western regions except Southwest, where they increase by 34%. The emissions decrease by 40 (South), 10 (Pacific South), 8 (Inter-Mountains), 78 (Rocky Mountains), 80 (Pacific North), and 9% (North), respectively.

4. Concluding Remarks

It is concluded that the application of satellite remote sensed fuel loading factors has significantly changed the estimates of fire emissions in the eastern as well as the western U.S. This should have some important implications for the environmental effects of wildfires. A simulation with CMAQ (Byun, and J. Ching, 1999) and using the estimated fire emissions from the AP-42 Table indicated significant impacts from fires in Florida, which accounts for a dominant portion of total emission in the eastern U.S., on regional air quality (Liu et al., 2004). The adverse air quality effect of wildfires should be much more serious because the new emission amount estimated using the RS technique is about 1.5 times larger than the previous value. In addition, a simulation with a regional climate model indicated the role of wildland fires in enhancing drought (Liu 2005b). The understanding of the role could be different if applying the RS technique to estimating fire emissions.

It appears that application of the RS technique can improve estimates of fire emissions. This would have a significant impact on fire-environment interaction research. The EPA Regional Planning Organizations, for example, has recently decided to re-calculate the 2002 national emission inventory of wildfires using this technique (WRAP 2005).

Acknowledgements This study was supported by the USDA Forest Service National Fire Plan through the Southern High-Resolution Modeling Consortium (SHRMC) and by the USDA Forest Services / Southern Research Station Award (No. SRS 04-CA-11330136-170).

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