

# Improved parameterization of wildfire $\text{NO}_x$ emissions using MODIS fire radiative power and OMI tropospheric $\text{NO}_2$ columns

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## Introduction

Emissions from vegetation fires are a significant source of  $\text{NO}_x$  to the atmosphere, with consequences ranging from local to global in scale. Currently, emissions are estimated as the product of the total biomass burned in the fire, and an empirically measured emission factor (EF).  $\text{NO}_x$  EFs are based on a limited number of measurements, and emissions vary greatly with individual fire conditions; thus most  $\text{NO}_x$  EFs are highly uncertain ( $\pm 50\%$ ), limiting our ability to quantify the effects of fire emissions on the global atmosphere.

Recent studies have developed “emission coefficients” (ECs) for aerosol fire emissions, in units of mass of pollutant emitted per MJ of energy released by the fire. These coefficients can be advantageous because they eliminate some sources of error in traditional emissions estimates and allow monitoring of fire emissions in near real time, as fire radiative power is measured frequently by satellites.

This work employs the high spatio-temporal resolution of the Aura OMI  $\text{NO}_2$  product, along with measurements of fire radiative energy from the Aqua MODIS instrument, to produce land type-specific radiative energy-based  $\text{NO}_2$  ECs with reduced uncertainties in California and Nevada.

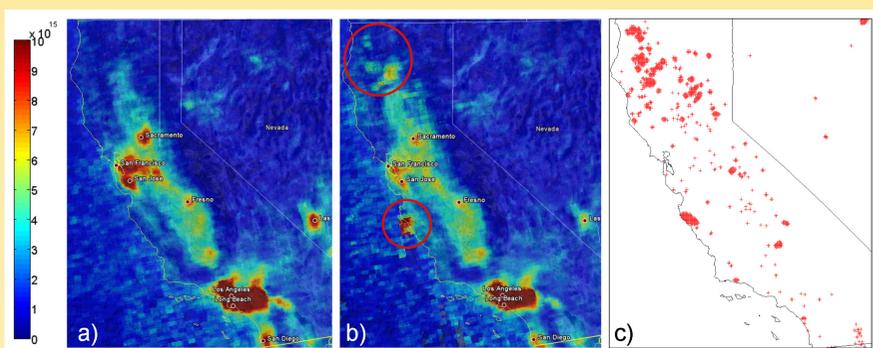


Figure 1. OMI  $\text{NO}_2$  tropospheric column densities (molecules  $\text{cm}^{-2}$ ) over California and Nevada in June-August during 2005 (a) and 2008 (b) [Russell et al., *Environ. Sci. Tech.*, 2010, 44, 9, 3608-3615]. Red circles on (b) indicate locations with elevated  $\text{NO}_2$  due to emissions from the 2008 summer wildfires; panel (c) shows all fires detected by the Aqua MODIS instrument during this same time period (daytime overpass only).

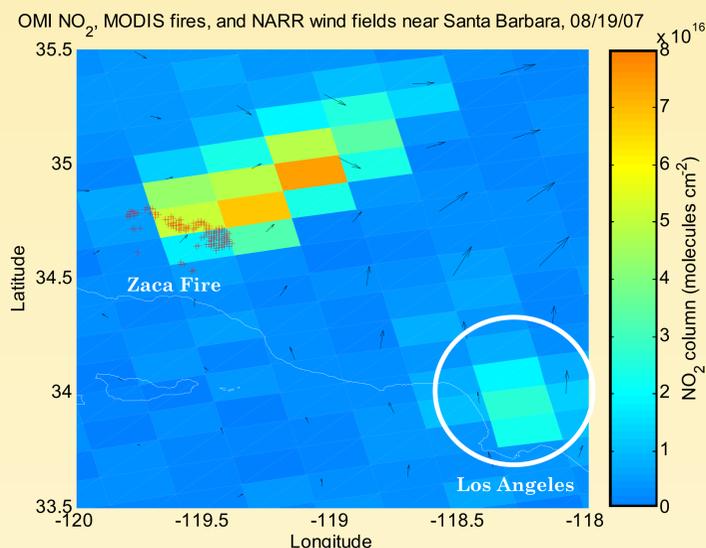


Figure 2. In 2007, the Zaca fire burned 240,207 acres near Santa Barbara, CA. This image, from August 19, 2007, shows MODIS fire pixels, NARR 900mb wind vectors, and OMI  $\text{NO}_2$  tropospheric columns (molecules  $\text{cm}^{-2}$ ). Elevated  $\text{NO}_2$  in the fire plume is clearly visible, and dwarfs the signal coming from Los Angeles (white circle).

## Methods

- Adapted from Ichoku and Kaufman [*IEEE Trans. Geosci. Remote Sens.*, 2005, 43, 11, 2636-2649], quantifying aerosol emissions from fires
- Identify land type of each fire pixel; group fire pixels and OMI pixels into rectangular regions within the OMI coordinate system
- Using OMI  $\text{NO}_2$  standard product, calculate mass of  $\text{NO}_2$  contained in this region; subtract background  $\text{NO}_2$  to obtain mass of  $\text{NO}_2$  emitted by fire
- Use wind vectors at 900mb (1km) from NARR to determine time for transport out of the region; gives the time over which the measured smoke was emitted
- Divide mass by time, obtain mass emission rate (MER, kg/s) for each fire; obtain fire radiative power (FRP, MJ/s) for each land type by summing pixel FRP
- Filter out points with high MER uncertainty, or very aged plumes (>3 hours)
- Apply multiple regression over land type FRP to yield emission factors; use nonparametric bootstrap resampling to calculate uncertainties

Biased as a result of significant deposition or formation of  $\text{NO}_x$  reaction products (e.g. PAN) within the first few hours after emission (mix of fresh and aged smoke) – limitation due to the length scales of an OMI pixel

- 1D model to describe the relationship between the total  $\text{NO}_2$  emitted and the fraction present on spatial scales of an OMI pixel
- Use to estimate a correction factor (CF) for our ECs due to low resolution (compared to plume dimension) sampling:

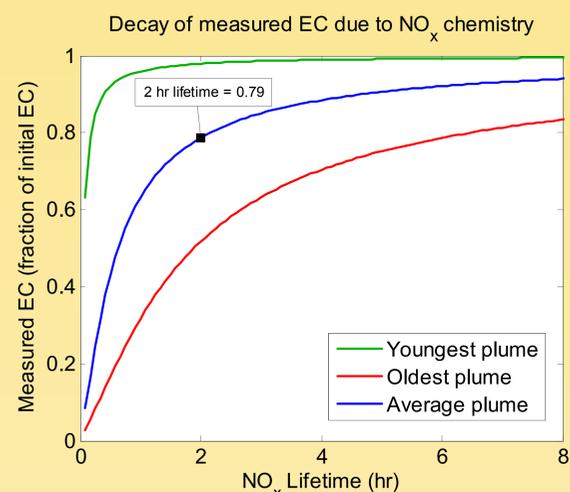


Figure 4. Measured EC (as a fraction of the initial EC) for a single fire, using a simple 1D model of our technique and assuming exponential decay of  $\text{NO}_x$  with time. The red and green lines represent the oldest and youngest plumes in our analysis, respectively; the blue line represents a plume of average age. We estimate a  $\text{NO}_x$  lifetime of  $\sim 2$ hrs based on data shown in Alvarado et al [*Atmos. Chem. Phys. Discuss.*, 2010, 10, 15325-15377]; the corresponding CF is 0.79. Unless the lifetime is shorter than  $\sim 1$ hr, this correction is likely good to within  $\sim 20\%$ .

## Results & Conclusions

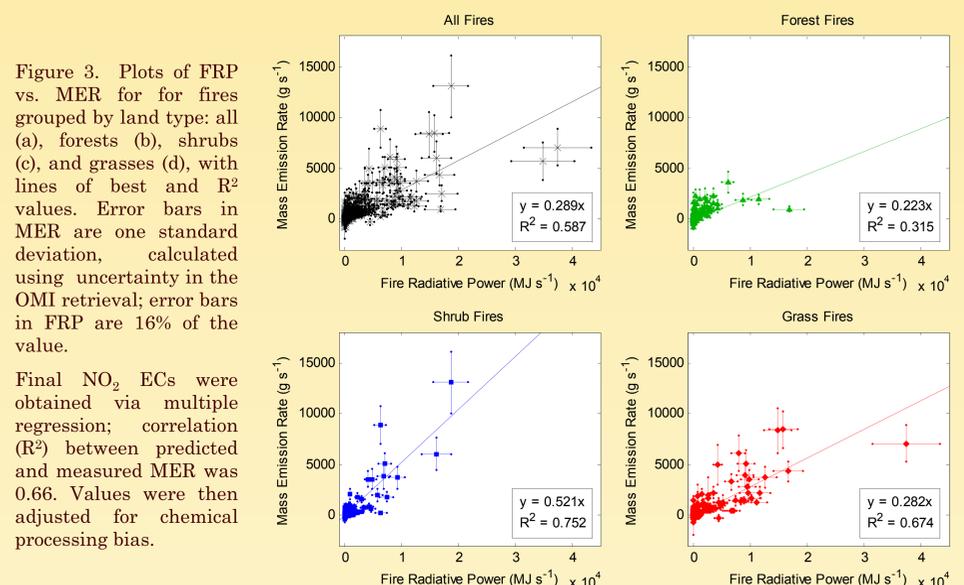


Figure 3. Plots of FRP vs. MER for fires grouped by land type: all (a), forests (b), shrubs (c), and grasses (d), with lines of best and  $R^2$  values. Error bars in MER are one standard deviation, calculated using uncertainty in the OMI retrieval; error bars in FRP are 16% of the value.

Final  $\text{NO}_2$  ECs were obtained via multiple regression; correlation ( $R^2$ ) between predicted and measured MER was 0.66. Values were then adjusted for chemical processing bias.

Land Type	$\text{NO}_2$ ECs ( $\text{g MJ}^{-1}$ ) This Study	$\text{NO}_2$ ECs ( $\text{g MJ}^{-1}$ ) Battye and Battye*
Forest	$0.282 \pm 0.083$	$0.85 \pm 0.41$
Shrub	$0.65 \pm 0.10$	$2.21 \pm 0.92$
Grass	$0.336 \pm 0.051$	$1.12 \pm 0.31$
S:G:F ratio	<b>2.3 : 1.2 : 1</b>	<b>2.6 : 1.4 : 1</b>

Table 1. ECs ( $\text{g NO}_2 \text{ MJ}^{-1}$ ) from this study, obtained via multiple regression, and from Battye and Battye [EPA, North Carolina, 2002]. Uncertainties are one standard deviation. Values from Battye and Battye were originally presented as EFs ( $\text{g NO}_x \text{ kg}^{-1}$ ); conversion required assuming  $[\text{NO}_2]/[\text{NO}_x] = 0.75$  and  $\text{kg burned MJ}^{-1} = 0.453$ , measured by Freeborn et al. [*J. Geophys. Res.*, 2008, 113, D01301].

- Follow general pattern in relative magnitude of S:G:F
- Represent a roughly 3x smaller mass of  $\text{NO}_x$  than previously reported EFs; this may indicate:
  - Systematic biases in OMI retrieval for all fire plume conditions
  - Currently accepted EFs overestimate fire  $\text{NO}_x$  emission
- Reduced statistical uncertainties when compared to previously measured emission factors

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