Developing an Improved Wildland Fire Emissions Inventory

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ABSTRACT

Smoke from wildland fire is a growing concern as air quality regulations tighten and public acceptance declines. Wildland fire emissions inventories are important not only for understanding air quality impacts from smoke but also in quantifying sources of greenhouse gas emissions. Calculation of wildland fire emissions can be done using a number of models and methods. Under the Smoke and Emissions Model Intercomparison Project, comparisons between different methodologies are being analyzed by examining model-to-model variability. In addition, the relative importance of uncertainties in fire size information, available fuels information, consumption modeling techniques, and emissions factors are being compared. This work highlights the need for accurate fire information that integrates information from multiple datasets. We present a new effort that upgrades the SMARTFIRE-BlueSky Framework, providing constraints on fire information and other errors in the modeling chain, and resulting in an improved wildland fire emissions inventory.

INTRODUCTION

Calculation of accurate wildland fire emissions inventories is increasingly important for understanding wildland fire impact on local and distant airsheds. Tightening of National Ambient Air Quality Standards, implementation of mitigation strategies for visibility impairment under the Regional Haze Rule, and increasing pressure on land management agencies to account for the carbon footprint of land activities (including fire places) have added emphasis on correct determinations of emissions fluxes from wildland fire.

Wildland fire emissions can be determined through any number of satellite- or ground-based modeling systems, but all methods essentially conform to the same basic equation,

Equation (1) $M(x) = A*AFL*\beta*Ef(x)$

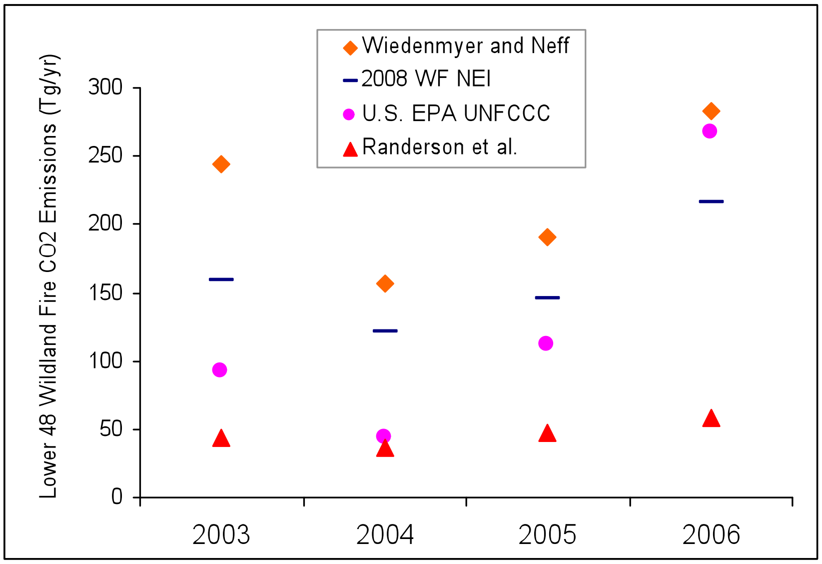
where M(x) = mass emitted of species x
A = area burned
AFL = available fuel loading
B = burning efficiency (fraction of fuels consumed)
Ef(x)= emissions factor of species x

While the bulk formula shows emissions as the product of several components, it is worth noting that in general these components interact, making the above separation less clear cut, as typically each factor is really a sequentially applied modeling step. For example, burning efficiency is typically a function of available fuels and fuel moistures, and emissions factors are often differentiated by burning phase. In addition, not all emissions modeling schemes directly treat each piece of the equation; for example, some satellite based systems use measures of fire intensity or fire radiative power, eliminating area, available fuel loading, and burning efficiency.

Still, the structure of this equation provides a way to examine where uncertainty arises in calculating emissions. Examination of uncertainty in each step of calculating wildland fire emissions can show which sources of uncertainty can most easily be addressed in the short term as we work towards an improved wildland fire emissions inventory. Because many emissions inventories, including the EPA National Emissions Inventory, also allocate emissions vertically, thereby incorporating plume rise information explicitly, we expand the above equation with the addition of plume injection height calculations, which typically occur after the calculation of emissions.

Models of fire area, fuel loadings, consumption rates, emissions speciation, and plume rise vary. Unfortunately, reliable observations of each component (e.g., fuel loadings, fire consumption, or plume injection height) are available for only certain locations and times. Many models extrapolate localized observations using dynamical equations or remote sensing measurements. The result is that different modeling efforts can vary considerably, even in national annual wildland fire emissions totals (Figure 1).

Figure 1. Comparison of CONUS annual total wildfire CO_2 emissions from four different studies. Each study has different methodologies for how the emissions are computed. The 2008 Wildfire (WF) NEI method is described in the text. Wiedinmyer and Neff (2007) is based on satellite data primarily. Randerson et al. (2005) uses a biogeochemical model for aspects of the calculation. The method used by the EPA report to the United Nations Framework Convention on Climate Change (U.S. EPA UNFCCC) uses wildfire statistics for area burned. Note that the 2008 NEI WF inventory excludes agricultural burns and the EPA UNFCCC method excludes both agricultural and rangeland burns.



A new project, the Smoke and Emissions Model Intercomparison Project (SEMIP, http://semip.org) is quantifying the differences between various models at each step using a number of test cases spanning individual fires (e.g., the 2006 Tripod Fire in northern Washington State), regional fire events (e.g., the California fires of 2007 and 2008), and the equivalent of the EPA's National Emissions Inventory of 2008. At each step in the modeling chain, SEMIP is directly comparing various models to examine the model-to-model variability, and where possible, evaluating models against direct observations. While this work is still in progress and results are being refined, the analysis so far has pointed to several avenues for potential improvements in the process of calculating wildland fire emissions. These include improved plume rise algorithms, modified fuel moistures, and the inclusion of additional fire information reporting systems. Many of these improvements are now being addressed through various projects with results expected soon.

BODY

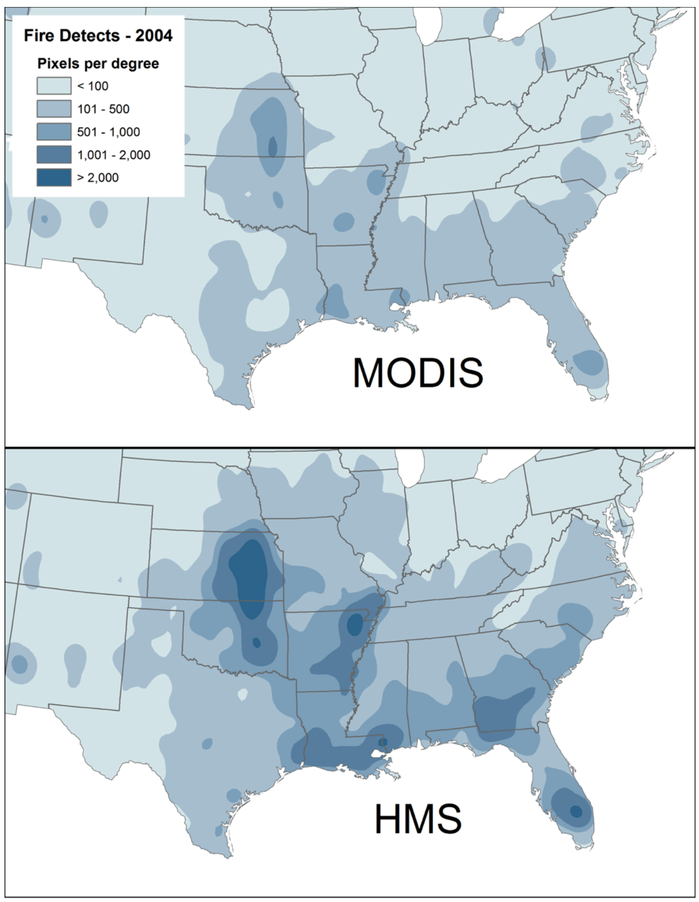
The preliminary 2008 wildland fire emissions inventory developed by the EPA utilizes fire location and size information from ICS-209 wildfire reports and the NOAA Hazard Mapping System satellite fire detects (via the current SMARTFIRE system), and then models fuel loadings, fire consumption, and speciated emissions primarily through the Fuel Characteristic Classification System (FCCS) fuel loading map (McKenzie et al., 2007), the CONSUME 3.0 fire consumption model (Ottmar et al., 2006; Pritchard et al 2008), and the Fire Emissions Production System (FEPS) emissions factors and plume rise scheme (Anderson et al., 2004) as implemented in the BlueSky Framework version 3.1 (Larkin et al. 2009). Emissions factors are supplemented from scientific literature to incorporate additional species.

SEMIP has examined this emissions inventory pathway and computed the same results by means of alternate methods and models. In this way, the effect of replacing one or more of the models used can be explicitly examined (for example, what is the effect of replacing the FCCS fuel loadings with those from LANDFIRE? or the CONSUME consumption rates with those from FOFEM?). Additionally, SEMIP has examined sensitivity to externally specified parameters such as wind speed and fuel moisture. The results allow us to begin to place the sources of uncertainty in context, identifying both the largest sources and those most easily addressed through alternate methodologies. In general, those modeling steps determined to have the largest sources of uncertainty were found to change depending on whether only national annual totals are considered, or whether more spatially and temporally resolved (e.g. daily) inventories are used.

For national annual totals, preliminary results indicate that each step—fire area, available fuels, consumption, emissions factors, and plume rise—has similar model-to-model uncertainties when examining $PM_{2.5}$. Fire area becomes a much larger issue at more localized scales that are important for regional totals or air quality modeling. For example, the presence or absence of a small fire can have important air quality implications for the town just downstream that day, while not affecting the annual total emissions substantially. Fuel loading values are found to vary considerably, even among recent high-resolution mapped datasets, resulting in differing available fuels, consumption amounts, and burning intensities. Even with the same fuel loadings, consumption calculations can vary, although the most recent models have begun to show greater agreement. Consumption models also are found to be differentially sensitive fuel moisture levels. Emissions factors are limited and have the most poorly characterized uncertainties; while published factors may be close to each other, it is unclear how representative they are of all of the fires to which they are applied. While not needed for emissions totals, commonly used plume rise schemes are poor when compared with satellite observations, and the resulting error in injection height can directly translate into misplaced smoke impacts downstream.

Perhaps the largest challenge relates to fire activity information (i.e., the existence, location, and size of fires). Fire information exists at a number of conceptual levels depending on the source, and wildland fire emissions similarly need to be tracked at a variety of geopolitical levels depending on the use envisioned for the emissions calculations. Soja et al. (2009) have shown that state-by-state annual totals of fire area in the western U.S. can vary substantially depending on the system used, and satellite detects themselves can vary substantially even over large regions, especially in areas with predominantly smaller fires like the southeastern U.S. (Figure 2). Hyer et al (2009) have also shown that satellite overpass timing, coupled with fire's diurnal cycle, is an important factor in fire detection efficiency and therefore should be considered when computing emissions inventories.

Figure 2. Comparison of annual total fire detect density from the MODIS active fire detect product (top) and the NOAA Hazard Mapping System (HMS) fire detect product (bottom), which utilizes not only MODIS but also fire detects from other satellite systems including geostationary detects from GOES. HMS also utilizes quality control from algorithms and human analysts to remove false detects and to add in detects where visible smoke or other signs of fire exist. Even over regional scales, these two systems are found to have considerable differences in the amount of fire activity. From Larkin et al. (2009b).

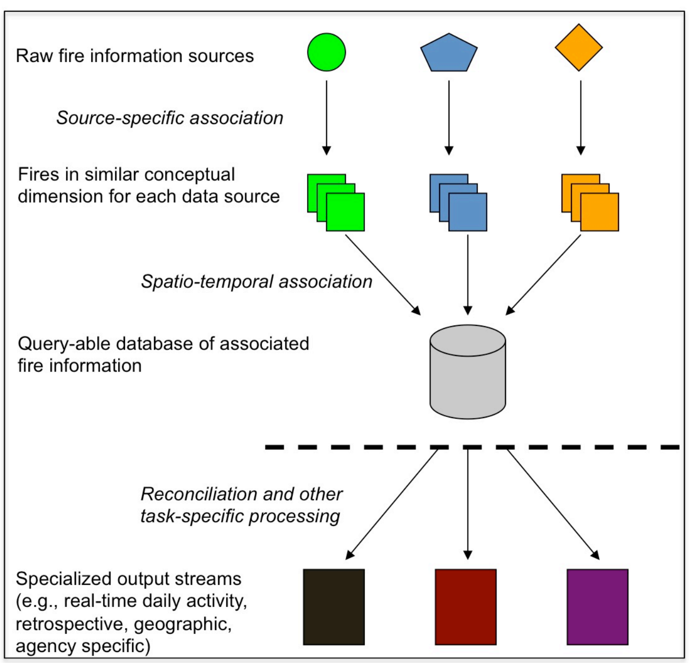


Other modeling steps present their own challenges. Emissions factors are the hardest to obtain and validate because they require extensive field and laboratory observations. Plume rise is another difficult problem, and commonly used schemes need to be updated to reflect the complex buoyancy common in wildland fire, including the idea of multiple convective "cores." Doing so will likely require work to make complex fire behavior/plume models more computationally available and interactive with each other.

Still, a number of improvements are possible in the short term, and work is under way to improve the existing smoke emissions model pathway. The treatment of fuel moisture is being redone within the BlueSky framework to incorporate satellite-derived fuel moisture observations. Plume rise constraints are being derived from satellite observations and will be included in the framework. The differences found in fire area and in fuel loadings, however, point to the need to be able to incorporate and integrate more localized databases in which greater accuracy is available because local managers have validated the data. An effort to perform such integration is now under way in a revamped SMARTFIRE 2 system.

Currently the SMARTFIRE system (v1) uses one ground-based reporting system (the Incident Command System-209 wildfire management reports) and the NOAA HMS system satellite fire detects. Both systems are available in near-real time, allowing SMARTFIRE to function similarly. A redesign of SMARTFIRE is now under way, with the goal of being able to utilize many different types of fire information, including retrospective reports. Additionally, SMARTFIRE 2 is designed to be able to use area-summed annual totals (available from some reporting systems) and other non-time-resolved data, and to be able to integrate this data with more time-resolved information. Figure 3 shows a schematic of the SMARTFIRE 2 system. At its core, SMARTFIRE 2 is an association engine that links reports covering the same fire in any number of multiple databases. In this process, all input information is preserved, and no attempt is made to reconcile conflicting or potentially contradictory information (for example, the existence of a fire in one database but not another).

Figure 3. Schematic of the conceptual architecture for the SMARTFIRE 2 fire information system currently in development.



SMARTFIRE 2 is designed to be able to utilize any number of input datasets including highly localized databases. Specific datasets being included in SMARTFIRE 2 include the USFS Monitoring Trends in Burn Severity (MTBS), which is derived from LANDSAT change detection analysis and the Western Regional Air Partnership's Fire Emissions Tracking System. Some locally developed forest fuel loading databases are also being included as a proof of concept. Additional datasets to be included are being determined.

After the associations are created, various processing streams will be performed to create a reconciled, unified fire information stream. SMARTFIRE 2 allows for the ability to apply a processing stream using a customized set of weights on a subset of the available databases. In this way, different analysis weights and algorithms can be directly tested against each other. Additionally, real-time processing streams can be trained against the output from processing streams that use all available data, including datasets not available in real time. This will allow adjustments to be made to real-time output algorithms to bring them more in line with the end results expected after additional, retrospective data is brought to bear.

CONCLUSIONS

Accurate wildland fire emissions inventories are becoming increasingly important for regulatory and accounting requirements. Considerable uncertainties currently exist in methods for calculating such emissions. Recent analysis has begun to place these uncertainties in context, and has pointed the way for an improved methodology. Considerable work is under way on all components of the modeling process. This work includes a more integrative fire information system and better treatment of fuel moistures and plume rise, all of which will start being available in the next year, with additional changes over the next few years. These modifications are expected to help improve not only national annual totals for emissions but also more spatially and temporally resolved emissions needed for air quality modeling.

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