Proceedings of 4th Fire Behavior and Fuels Conference,
February 18 – 22, 2013, Raleigh, North Carolina, USA and July 1-4, 2013, St. Petersburg, Russia.
Published by the International Association of Wildland Fire, Missoula, Montana, USA

A US national fuels database and map for calculating carbon emissions from wildland and prescribed fire

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Abstract:

Biomass burning is an important component of Earth-system models as understanding improves about fire as a global ecosystem process. Smoke emissions are a health hazard to nearby communities, can impair air quality and visibility for hundreds of kilometers downwind, and contribute substantially to the global carbon and aerosol budgets. The Fuel Characteristic Classification System (FCCS) is both a conceptual framework and a software tool for quantifying fuels over spatial domains from a few square meters to many square kilometers. The authors and colleagues developed a spatially continuous classification of fuels, based on the FCCS, for the continental United States and Alaska. The FCCS 1-km fuel map is a core spatial data component of WFEIS, the Wildland Fire Emissions Information System, a web-based tool for computing emissions from wildland fires. The FCCS provides a detailed accounting of the carbon content of fuels, and the proportional consumption of biomass in each fuel category depends on both the fuel type and environmental conditions, such as fuel moisture and wind speed. Applications such as WFEIS can take advantage of the geographic variability of fuels captured by FCCS maps to increase the accuracy of estimates of the contribution of wildfires to the carbon budget.

Additional Keywords: fire emissions, fuels

Introduction

Biomass burning is an increasingly important component of Earth-system models as understanding improves about fire as a global ecosystem process (Bowman *et al.* 2009; Krawchuk *et al.* 2009). Improvements in global fire occurrence databases continue with remote-sensing methods maturing along with more standardized record-keeping and reporting (Giglio *et* *al.* 2010; Raffuse *et al.* 2012). Carbon released from fires during combustion alters the global carbon balance (van der Werf *et al.* 2010). Smoke emissions are also a health hazard to nearby communities (Wegesser *et al.* 2009), can impair air quality and visibility for hundreds of kilometers downwind, and contribute substantially to the global aerosol budget.

A need for improved tools to map and quantify emissions from wildland and prescribed fire is evident. Integral to mapping fire emissions is information on the biomass that burns during fire, also known as fuel. The Fuel Characteristic Classification System (FCCS; http://www.fs.fed.us/pnw/fera/fccs/) is both a conceptual framework and a software tool for quantifying fuels over spatial domains from a few square meters to many square kilometers. Unlike fire-behavior fuel models, whose purpose is to provide parameters useful for predicting fire behavior and fire spread, the FCCS specifies vegetation composition and fuel loading of live and dead fuels, which are easily connected to remotely sensed vegetation types (McKenzie *et al.* 2007). The FCCS fueldbed descriptors provide details on fuel structure and loading (density) by vertical strata (Figure 1), providing data that have relevance for both emissions and basic fire behavior. In this paper we review a spatially continuous classification of fuels, based on the FCCS, for the continental United States (CONUS) and Alaska developed for emissions modeling. The initial versions of the FCCS maps covered forested and shrublands types in CONUS and Alaska leaving large areas of croplands and managed rangelands unmapped. The newly developed map reviewed in this paper includes fuels in forest, rangeland, and croplands across CONUS to allow for modeling of fire in both naturally occurring fires and prescribed burning.

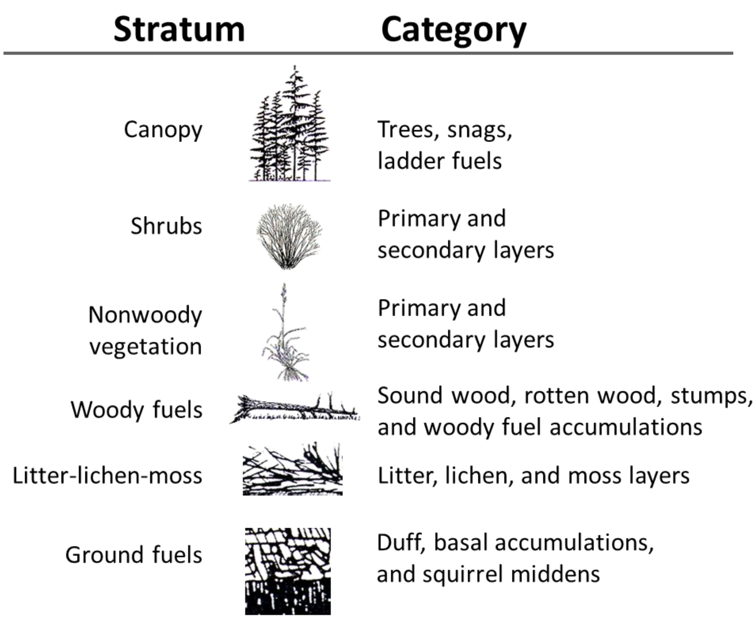

Figure 1: FCCS fuelbed strata used in describing the characteristics of fuels, including fuel structure and loading.

Mapping FCCS forest, rangeland, and cropland fuels

Maps of forest and shrubland fuels across CONUS and Alaska at 30-m resolution were created using a crosswalk to FCCS fuelbeds from the existing vegetation type (EVT) layer of LANDFIRE (www.landfire.gov). Upscaling to a 1-km grid scale was done by aggregating the FCCS fuelbed based on the majority type. Four hierarchical levels were used to decide type majority: fuelbed, species, cover type, and two life-form levels (Table 1). In the upscaling process most fuelbeds were retained with only five fuelbeds across lost due to their rarity.

Assignments for the upscaling were made based on the following decision steps:

- If the majority (>50%) of 30m FCCS fuelbed cells are of a single fuelbed category then the 1km FCCS fuelbed cell will be assigned the majority category.
- If there is no majority fuelbed among the 30m cells in the 1km cell extent, a majority species is sought;
  - if a species holds a majority within the 1km cell extent, the most common fuelbed associated with the species will be used.
- If no majority species exists, the same logic is repeated for the cover type, then life-form1, and finally life-form2 levels.

The final 1-km map (both CONUS and AK) contains 234 FCCS fuelbeds with just five fuelbeds from the original 30-m map lost in the aggregation process due to their rarity. The map of FCCS fuelbed map at the 30-m scale is publicly available from the Landfire webisite (http://www.landfire.gov/NationalProductDescriptions25.php), and the 1-km scale map from the USFS FCCS web site (http://www.fs.fed.us/pnw/fera/fccs/maps.shtml).

The forest and shrubland versions of the FCCS maps were created by the US Forest Service (USFS). They have now been augmented for the CONUS region with data on cropland types for two years, 2009 and 2010. This integrated product is the result of combining the spatially discrete Fuel Characteristic Classification System (FCCS) data of the USFS with the cropland and grassland-specific location information of the US Department of Agriculture's (USDA's) Cropland Data Layer (CDL). Fuel information and loadings on crop types developed by McCarty (2011) were translated into the FCCS format. Based on the CDL type maps, fuelbeds in cropland regions, which were set to zero in the original forest FCCS maps, were mapped. This integrated FCCS fuels map is available at the 30-m scale from the Oak Ridge Distributed Active Archive (ORNL-DAAC; French *et al.* 2013; Figure 2).

Table 1: Excerpted from the full hierarchy table used to downscale the FCCS map from 30-m to 1-km cell size.

FCCS hierarchy

fccsID	fuelbed.name	species	covertype	lifeform1	lifeform2
0	Agriculture – Urban – Barren	barren	barren	barren	barren
1	Black cottonwood - Douglas-fir - Quaking aspen	cottonwood	poplar	broadleaf	tree
2	Western hemlock - Western redcedar - Douglas-fir forest	whemlock	hemlock	conifer	tree
4	Douglas-fir / Ceanothus forest	Douglas-fir	Douglas-fir	conifer	tree
5	Douglas-fir - White fir forest	Douglas-fir	Douglas-fir	conifer	tree
6	Oregon white oak - Douglas-fir forest	owhite-oak	oak	broadleaf	tree
7	Douglas-fir - Sugar pine - Tanoak forest	Douglas-fir	Douglas-fir	conifer	tree
8	Western hemlock - Douglas-fir - Western redcedar / Vine maple forest	whemlock	hemlock	conifer	tree
9	Douglas-fir - Western Hemlock - Western redcedar / Vine maple forest	Douglas-fir	Douglas-fir	conifer	tree
10	Western hemlock - Douglas-fir - Sitka spruce forest	whemlock	hemlock	conifer	tree
11	Douglas-fir / Western hemlock - Sitka spruce forest	Douglas-fir	Douglas-fir	conifer	tree
12	Mountain hemlock - Red fir - Lodgepole pine - White pine forest	mhemlock	hemlock	conifer	tree
14	Black oak woodland	black-oak	oak	broadleaf	tree
15	Jeffrey pine - Red fir - White fir / Greenleaf manzanita - Snowbrush forest	Jeffrey-pine	pine	conifer	tree
16	Jeffrey pine - Ponderosa pine - Douglas-fir - Black oak forest	Jeffrey-pine	pine	conifer	tree
17	Red fir forest	red-fir	fir	conifer	tree
18	Douglas-fir / Oceanspray forest	Douglas-fir	Douglas-fir	conifer	tree
19	White fir – Giant sequoia – Sugar pine forest	white-fir	fir	conifer	tree
20	Western juniper / Huckleberry oak forest	wjuniper	juniper	conifer	tree
21	Lodgepole pine early seral forest	lodgepole	pine	conifer	tree
22	Lodgepole pine forest	lodgepole	pine	conifer	tree
24	Pacific ponderosa pine - Douglas-fir forest	ponderosa	pine	conifer	tree
25	Pinyon - Juniper forest	wjuniper	juniper	conifer	tree
27	Ponderosa pine - Two-needle pine - Juniper forest	ponderosa	pine	conifer	tree
900	Water	barren	barren	barren	barren

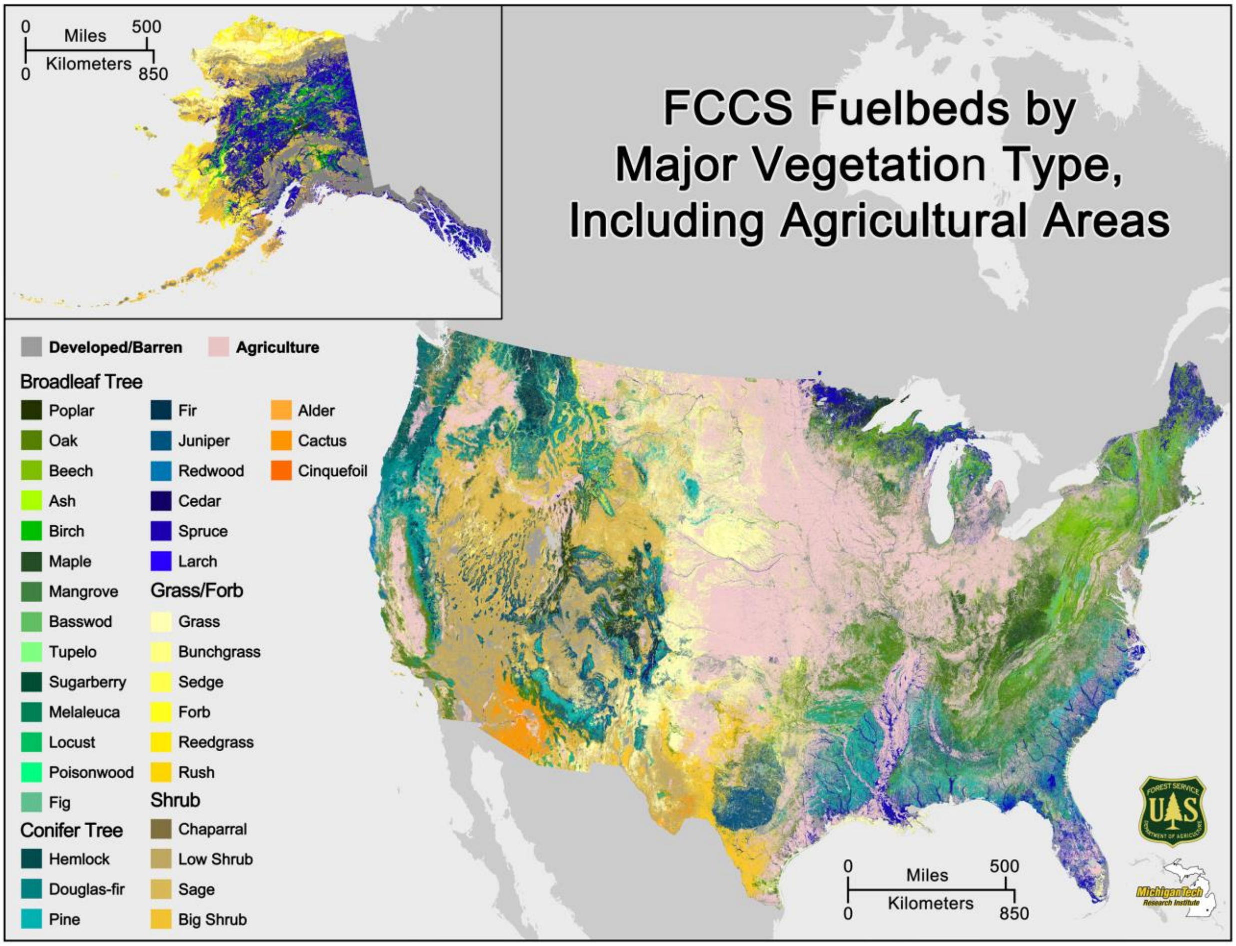

Figure 2. Final map of combined fuelbeds for the US.

Uses of the FCCS map databases

The FCCS map databases are used in diverse modeling efforts from real-time carbon-emission calculations for individual fires to continental-scale simulations of air quality. The FCCS provides a detailed accounting of the fuels available for burning in each stratum. Fire affects each fuel stratum in specific ways that influence the emissions produced. Specifically, fuels in the various strata have specific structures and are composed of many combustible materials. Also, fire can burn in flaming or smoldering combustion in any of these strata, which produces different emissions composition, and this can vary between strata. Therefore, characterizing fuels and combustion by stratum aids in more accurate accounting of emissions and the proportion of CO_2 versus other gaseous emissions released. Here we review a few of the applications where the spatial fuels maps we have developed have been of value.

Carbon emissions mapping: The FCCS 1-km fuels map is a core spatial data component of WFEIS, the Wildland Fire Emissions Information System (http://wfeis.mtri.org/), a publicly available web-based tool for computing emissions from fire in the CONUS or Alaska at landscape to regional scales (1-km spatial resolution). WFEIS was initially developed with funding from the NASA Carbon Cycle Science Program for the North American Carbon Program (http://www.nacarbon.org/nacp/). A principal use of WFEIS outputs is regional-scale spatially explicit estimates of carbon emissions from fire (French *et al.* 2011). The proportional consumption of biomass in each fuel category is modeled in WFEIS based on the fuel type, fuelbed structure, and the environmental conditions such as fuel moisture and wind speed. Applications such as WFEIS that take advantage of the geographic variability of fuel characteristics captured by the FCCS maps can increase the accuracy of estimates of the contribution of wildfires to the carbon budget. With the FCCS fuel maps as a core spatial data layer, the WFEIS provides access to fire-perimeter maps from one of two sources, MODIS-derived burn area (Giglio *et al.* 2009) and the Monitoring Trends in Burn Severity products from the USGS (http://www.mtbs.gov/), overlays them on the fuel maps, and calculates fuel consumption and emissions with an open-source version of the Consume model, also publicly available (http://code.google.com/p/python-consume/). Besides tabular results, WFEIS produces multiple vector and raster output formats, including ArcGIS shapefiles, KML, GeoTIFF, and netCDF. The system is built entirely from open-source software that follows international standards developed by the Open Geospatial Consortium (http://www.opengeospatial.org/).

<u>Emissions monitoring of greenhouse gases and pollutants</u>: In addition to carbon cycle science, the FCCS maps are a valuable data source for mapping emissions of several important pollutants. The US National Emissions Inventory (NEI; http://www.epa.gov/ttn/chief/), the Regional Haze Rule (http://www.epa.gov/visibility/factsheet.html), and the US-EPA climate-change program (http://epa.gov/climatechange/emissions/usinventoryreport.html) require monitoring of pollutants from a variety of sources, including fires. National fire databases provide fire location information that can be overlain on the FCCS maps to estimate total fuel loadings within a fire perimeter. Consumption estimates and emission factors are then applied to calculate amounts of pollutant species, both aerosols and particulates, lofted into the atmosphere. This methodology was used in calculation of emissions from cropland burning for the 2005 and 2008 NEIs (Pouliot *et al.* 2008; Soja *et al.* 2008). Until the 2005 NEI, burning in agricultural regions was not fully accounted for due to a lack of information on where and how much burning was occurring in US agricultural operations. Using new information on fire occurrence, overlain with fuels information, these emissions are now more reliably included in the NEI. The 2011 NEI will include cropland burned area and emissions from the approach developed by McCarty (2011), which was used to inform the development of the improved FCCS data.

<u>Air-quality simulations</u>: Projections of future air quality rely on meteorologically-based simulations of transport and on inventories of pollutants that can be measured or otherwise estimated consistently over large spatial domains (regions to continents). The FCCS maps have become a key component of integrated modeling frameworks such as BlueSky (http://airfire.org/bluesky), which links independent models of fire information, fuel loading, fire consumption, fire emissions, and smoke dispersion (Larkin *et al.* 2009). BlueSky is used daily by air-quality and fire managers in the Pacific Northwest, USA, for smoke forecasts from ongoing fires, but also is used for future projections at both regional (McKenzie *et al.* 2006) and national (Chen *et al.* 2009) scales.

Watershed-scale fire management: Local applications of fuels databases, such as planning fuel treatments to reduce fire hazard, especially around the wildland-urban interface, would ideally use local fuel inventories. These are time-consuming and expensive to assemble, however, and are lacking in many critical fire-prone areas, such as the chaparral ecosystems of Southern California. The high-resolution (30-m) FCCS map layer provides surrogates for local databases when they are either lacking or of questionable accuracy, out of date, or incomplete. For example, the 30-m resolution FCCS was used to estimate emissions from the 2007 southern California wildfires to inform respiratory health research in San Diego (Koziol et al. 2010).

Updating and refining the map layers

In croplands, the spatial location of crops varies annually, meaning that the fuels burning at a particular place can be different from year to year. In cropland areas, FCCS can be mapped annually from the CDL so accurate loadings are used in assessments. In some forested ecosystems, such as arid mountain forests with frequent wildfires, fire affects up to 10% of the total area in one year. Like many broad-scale geospatial databases, the FCCS maps within these forested landscapes will gradually become obsolete because they reflect a static vegetation layer (based on LANDSAT imagery) that involved substantial computation and cannot feasibly be updated annually. To improve on this, updates of the FCCS can be made using information on disturbance. For example, in the US fire perimeters are mapped annually from Landsat imagery under the Monitoring Trends in Burn Severity (MTBS) project lead by the USGS (http://www.mtbs.gov/). The LANDFIRE project updates vegetation products every five years using this and other disturbance information. From these products and using simple forest succession models the FCCS maps could be updated annually, ensuring that they remain reasonably current. For both agricultural and forested sites, therefore, information is available for creating more temporally dynamic fuels that would improve emissions assessments.

Another fuels mapping improvement under development is a method to refine fuel loadings in the dominant vegetation layer at each location by informing the FCCS map layer with MODIS-derived data. First is the Vegetation Continuous Fields (http://glcf.umiacs.umd.edu/data/vcf/) product, which gives proportional estimates for vegetative cover, and second is a map of estimated total biomass in forested ecosystems developed by the NASA Carbon Monitoring System Phase 1 activity (http://carbon.nasa.gov/cgi-bin/cms/inv_pgp.pl?pgid=582#datasection). These overlays will provide improved canopy fuel loadings for each cell, which can be updated as the MODIS products are refreshed and give more precise estimates of: 1) fuel loadings within a cell; and 2) their variability at spatial scales from watersheds to the continent.

Conclusion

Mapping fuels is important in developing improved assessment of fire emissions across local to global scales. We have developed maps of fuels appropriate for regional to continental-scale fire emissions assessments that use ecological principles to describe fuel characteristics relevant for emissions calculation. The maps are based on USGS, USDA and USFS data on vegetation distribution. The maps have application for a variety of emissions mapping needs, including use within the WFEIS model for carbon cycle accounting.

Acknowledgements

The research presented was supported through grants from the NASA Carbon Cycle Science Program (Grant # NNX08AK69G to MTRI and USFS), the NASA Applications Air Quality program (Grants #NNX09AP53G to the National Institute of Aerospace, A. Soja, PI), the NASA Applications Wildland Fire program (#NNX12AQ90G to MTRI and USFS), and the NASA Carbon Monitoring Program (Grant #NNX12AM91G to MTRI and USFS).

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