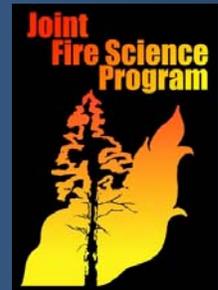


# Uncertainties in the use of Fuel Consumption Models, Fuel Loading Maps, and Fire Reporting Systems



**FINAL REPORT TO THE JOINT FIRE SCIENCE PROGRAM**  
**September 30, 2009**

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**Website:** <http://airfire.org/projects/matrix>

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## Abstract

Fire and fuel managers often need to know how much fuel a fire will consume, and how much smoke the fire will produce. Many factors influence the ultimate smoke impacts, and a variety of fuel models and consumption models have been developed to help provide useful answers. However, recent studies [e.g., Larkin et al., 2009] have shown that the specific choice of which model to use can have an overwhelming effect on the final answer.

This project examined four commonly used fuel consumption models and three different fuel loading maps. Cross comparisons were made for all  $4 \times 3 = 12$  possible combinations across the contiguous United States. Maps were produced of total fuel loadings, component fuel loadings, total consumption, flaming and smoldering consumption components, and more. Additionally, differences in fire information as reported by 3 different reporting systems (ICS-209, HMS, MODIS) were examined to analyze which of these three components introduces the most uncertainty.

Statistical summaries comparing the various fuel loading maps, how well the various consumption models match, and how much the specific combination choice determines consumption estimates were compiled. An interactive website makes the results of these comparisons directly accessible to users. By determining the conditions under which the various models agree and disagree, users can determine which models they trust under which conditions. Additionally, the implications of this work on emissions inventories are discussed.

## Background

Recent studies that have examined different fuel loading and fuel consumption models for specific fires have reported significant inter-model variability (e.g. Larkin et al., 2009). Much of this inter-model variability is unknown to the fire management community.

This project was designed to look at inter-model variability both locally (at a specific point) and more regionally. Is the inter-model variability random or systematic? Are there specific regional differences? How does this variability affect both single-fire calculations and more aggregate statistics like nationwide fire emissions?

To examine these questions, a variety of fuel maps and consumption models, many of which were developed with funding by the Joint Fire Science Program, are examined. This project cross compares several of the most commonly used fuel models and most commonly used consumption models.

Specifically this project utilizes three existing fuel models, including the mostly commonly referenced ones: National Fire Danger Rating System (NFDRS, Deeming et al. 1978) fuels map; the Hardy et al. (1998) update; and the Fuel Characterization and Classification System (FCCS;

McKenzie et al., 2007) fuels map. A fourth, LANDFIRE<sup>1</sup>, will be included in later revisions but is not yet integrated such that it could be used here (see Future Work). The NFDRS fuel map is available on a 1-km grid across the continental United States, with 20 fuelbed types primarily designed to model fire danger. The Hardy et al (1998) fuel map is an update to the NFDRS, done on the same 1-km grid for the western United States with 37 fuelbeds. The FCCS fuel map for the continental USA quantifies live and dead fuel loadings on a 1 km grid (there are currently over 200 individual fuelbed types).

The study considered four consumption models, again including those mostly commonly referenced: the Emissions Production Model (EPM, v1; Sandberg et al., 1984); CONSUME (v3; Ottmar et al., 2002); the Fire Emissions Production Simulator (FEPS, v1)<sup>2</sup>; and the First Order Fire Effects Model (FOFEM, v5; Reinhardt et al., 2003). EPM (v1) utilizes consumption equations based on the first version of the CONSUME model (v1), and is still widely used. CONSUME has since been heavily updated to its current version (v3) through an empirical fit to over 100 pre and post-burn plots. FEPS (v1) utilizes a simple 2-equation algorithm. FOFEM (v5) contains the BURNUP consumption code and was developed independently of the CONSUME lineage, incorporating both theoretical and observed aspects of fire consumption.

The study makes use of new capabilities of the BlueSky Modeling Framework (Larkin et al., 2009). BlueSky is a modular modeling framework that currently connects fire information, fuel loading, fire consumption, fire emissions, plume rise, trajectory, and dispersion models, making the process of combining these models to produce a desired output (e.g. PM<sub>2.5</sub> emissions or smoke trajectories from a fire) easier. BlueSky was recently completely rewritten under a grant from NASA. Since BlueSky can be started and stopped at any point in its modeling chain, it provides a convenient method for connecting fuel loading maps and fire consumption models. Descriptions of each model's implementation can be found on the BlueSky Framework webpage (<http://blueskyframework.org>). While consumption models are affected by many tunable parameters such as wind speed and fuel moistures, these parameters were kept constant across all model runs to eliminate them as a primary factor in the analysis.

Additionally, any calculation of consumption depends on the accuracy of the basic fire information (e.g. location and size) used. Therefore this study also examines three different commonly used fire information reporting systems: the Incident Command System (ICS)-209 reports<sup>3</sup> that record large wildfires nationally, the MODIS hot-spot satellite fire detection reports (Justice et al., 2002), and the SMARTFIRE (Raffuse et al, 2007) system that attempts to reconcile both ground based reports (primarily from the ICS system) with satellite detects. Of particular interest is both how these systems compare both on a national scale as well as more regionally, as different land-use, ownership, and fuel types all affect each system differently.

The entire analysis including databases has been adopted into the Smoke and Emissions Model Intercomparison Project (SEMIP) as the first step (Test Case) in the larger SEMIP intercomparison structure. Details on SEMIP are available at <http://semip.org>.

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<sup>1</sup> <http://www.landfire.gov>

<sup>2</sup> [http://www.fs.fed.us/pnw/fera/feps/FEPS\\_users\\_guide.pdf](http://www.fs.fed.us/pnw/fera/feps/FEPS_users_guide.pdf)

<sup>3</sup> [http://fam.nwcg.gov/fam-web/famweb/index\\$.startup](http://fam.nwcg.gov/fam-web/famweb/index$.startup)

## Description

This project analyses information sources and models at 3 distinct levels: fire size and location reporting systems, fuel loading maps, and fire consumption models.

For fire information all reports over the contiguous U.S. during the period 2003-2006 were analyzed. For the fuel loading maps and fire consumption models over 6 million individual 1km x 1km grid cells were analyzed. Detailed maps showing the fuels and consumption results have been placed online in a specialized website (<http://data.semip.org>) that also allows the user to query the databases for a location of interest. We note that the data and maps produced for this report and available now online contain more information than could possibly be captured in a written summary, and every individual will focus on different elements. This report seeks to convey only the general character and key aspects of the project findings.

Table 1 lists the systems and variables compared here at each level. Note that all model variables were saved and are part of the published database. Model settings were held constant as much as possible between models. See Appendix B for a full list of model settings used.

**Table 1:** Model pathways and output variables used in analysis by output level. See text for exact models used and references.

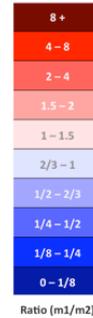
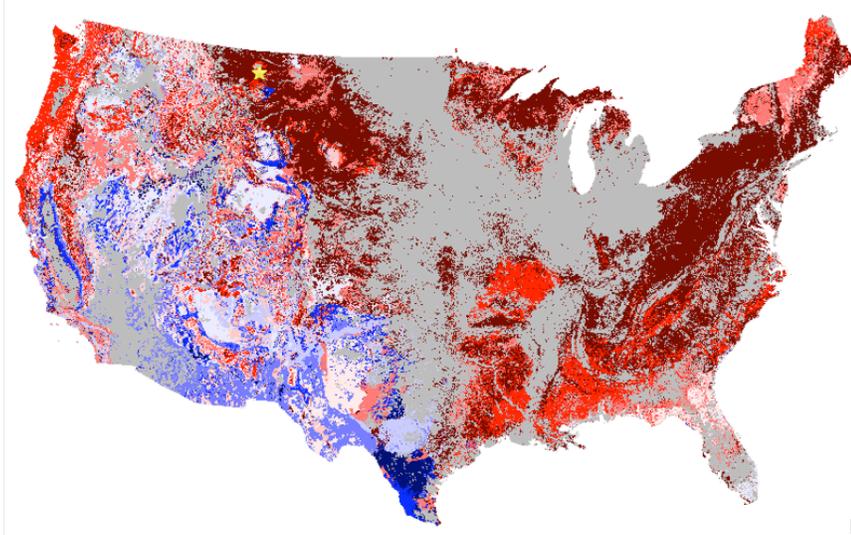
	Output Level		
	Fire Reporting	Fuel Loadings	Consumption
<b>Pathways</b>	3	3	12
<b>Systems compared</b>	SMARTFIRE ICS-209 MODIS	NFDRS Hardy FCCS	NFDRS -> FOFEM EPM FEPS CONSUME3  Hardy -> FOFEM EPM FEPS CONSUME3  FCCS -> FOFEM EPM FEPS CONSUME3
<b>Variables saved</b>	All	All	All
<b>Variables focused on</b>	Fire size Aggregate area	1 HR 10 HR 100 HR 1000 HR 10000 HR 10000 <sup>+</sup> HR DownedWoody <sup>1</sup>	Total Consumption Flaming Consumption Smoldering Consumption
<b>Analysis region</b>	CONUS 4 years	CONUS 6,166,618 1km x 1km cells	

<sup>1</sup> Total downed woody fuels = 10HR + 100HR + 1000HR + 10000HR + 10000<sup>+</sup>HR as used here

### Map Viewer

View:  Statistic:  Model 1:  Model 2:    State Overlay

Currently viewing: FCCS->Consume / NFDRS->EPM Total Consumption Ratio



■ = no data

### Point Location Information

Lat:  °N  Lon:  °E

i:  j:

**Fuels Consumption**

Showing consumption information for grid cell (1390,2515) at Lat:47.86, Lon:-109.40

**Model combinations found (total 12):**

- FCCS->Consume3, FCCS->Burnup, FCCS->EPM, FCCS->FEPS
- NFDRS->Consume3, NFDRS->Burnup, NFDRS->EPM, NFDRS->FEPS
- Hardy->Consume3, Hardy->Burnup, Hardy->EPM, Hardy->FEPS

Consumption (tons/acre)	Total*	Flaming	Smoldering
<b>Min-Max (all locations)</b>	<b>0 - 583.25</b>	<b>0 - 33.71</b>	<b>0 - 580.02</b>
FCCS->Consume3	21.54	1.08	4.72
FCCS->Burnup	3.19	1.87	1.32
FCCS->EPM	3.8497866	1.6309617	2.218825
FCCS->FEPS	2.63644	0.201202	0.991218
NFDRS->Consume3	0.96	0.92	0.05
NFDRS->Burnup	1	0.5	0.5
NFDRS->EPM	0.5	0.5	0
NFDRS->FEPS	0.057376	0.028688	0.028688
Hardy->Consume3	0.59	0.43	0.13
Hardy->Burnup	0.35	0.3	0.05
Hardy->EPM	1.4100001	1.4100001	0
Hardy->FEPS	0.150279	0.00865	0.055675

\*Total ≠ Flaming + Smoldering due to duff, canopy, and other consumption

**Figure 1:** Data viewer website showing fuels and consumption model output data and analyses from this project. The upper map is selectable from over 900 analysis maps; the point location information table can be queried from over 6M 1km x 1km grid cells. <http://data.semip.org>.

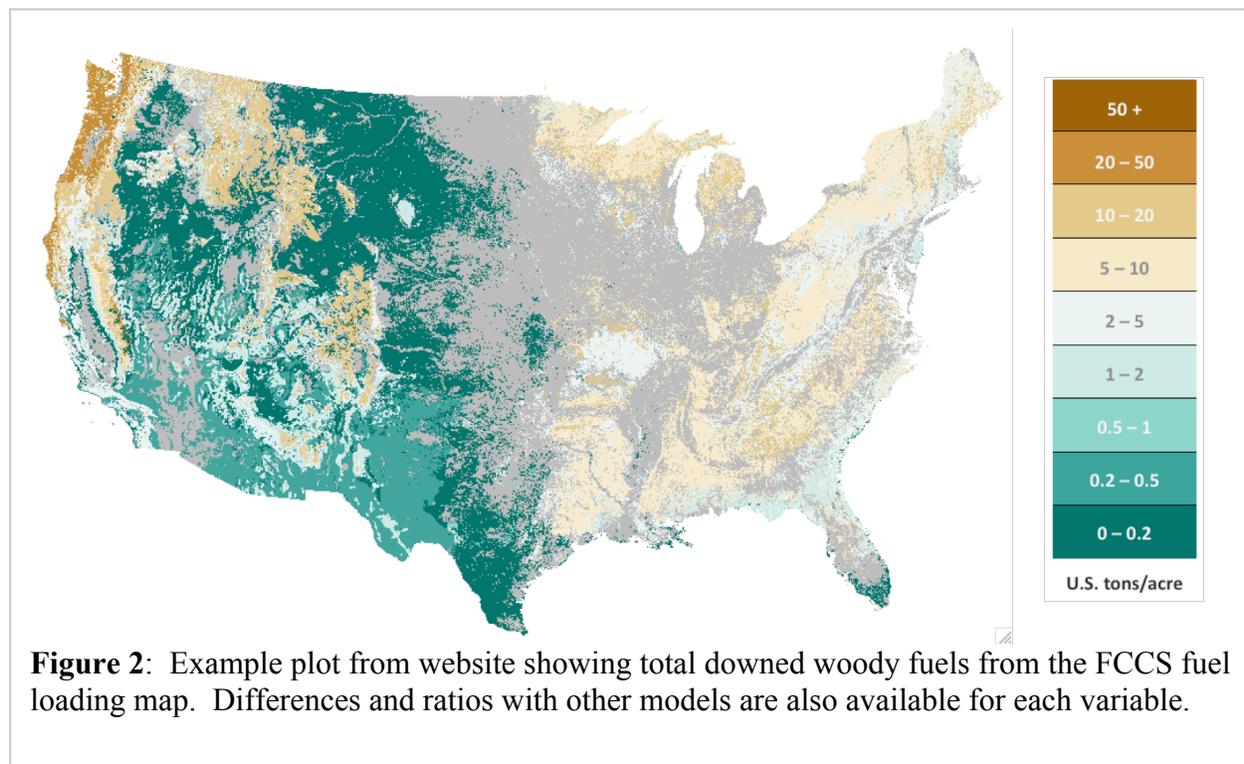
## Fire information

Comparisons of area burned over CONUS for the years 2003-2006 were done using three fire information sources: SMARTFIRE, ICS-209 ground reports, and MODIS active fire detections (hot-spots). These 3 systems are not independent. SMARTFIRE utilizes the ICS-209 data, and through use of NOAA's Hazard Mapping System (HMS) for fire, indirectly uses the MODIS hot spot data as well. However each system uses data in subtly different ways and represent real world choices on fire information pathways, therefore such a comparison is warranted and needed.

SMARTFIRE output includes daily estimates of area burned per fire, but ICS-209 and MODIS do not. Estimates of daily area burned for the ICS-209 data and MODIS data had to be calculated before proceeding to the comparison step. To obtain daily area burned from cumulative area burned from the ICS-209 reports, we subtracted the previous day's reported area from the current day. Fires were modeled as a single point source located at the reported ignition point of the fire. To develop a nominal area burned per MODIS hot-spot we compared MODIS total hot-spot counts with final helicopter-flown burn perimeters using 30 fires. Results indicated that nominal area burned per hot spot is equal to 100 acres.

## Fuel loading maps

We compared three fuel loading maps: the FCCS map, the NFDRS map, and the Hardy et al map (hereafter referred to as Hardy).



FCCS, NFDRS, and Hardy were intercompared at the total downed woody and timelag woody (1 hr to 10,000<sup>+</sup> hr<sup>+</sup>) levels. These fuel loading maps were also used at the fuel-consumption modeling intercomparison level. The fuel loading maps report fuel loadings on a 1 km x 1 km

grid across the contiguous US and they are all available as choices through the BlueSky Framework. Each map covers different regions, but at least one of the three is available in over 6.6M 1km x 1km cells, and all 3 are available in nearly 2.3M cells (see Table A1).

### **Fuel-Consumption model combinations**

Four consumption models were selected to calculate consumption: the consumption calculation model embedded in FOFEM (BURNUP), CONSUME 3, EPM, and FEPS. Each was run with every fuel loading resulting in 12 model pathway combinations. It is expected that not all model pathways are created equal – model A might be designed to work best with model B and not model C. For example, the FCCS fuel loadings and the CONSUME 3 model have been designed to pair together. However, many different combinations of models have been used for various calculations in the past, and this project is partially designed to identify good combinations, so no model pathways were excluded *a priori*.

Total, flaming and smoldering consumption values were compared where data existed for all three fuel loadings. Maps were generated for the SEMIP viewer where they can be examined along with the differences between and ratios of the model combinations. In general the FCCS→CONSUME 3 combination is higher than others in part due to the additional information in the FCCS fuelbed (canopy fuels, etc...) that can be best utilized by CONSUME.

### **Initial statistics for fuel loading and consumption values**

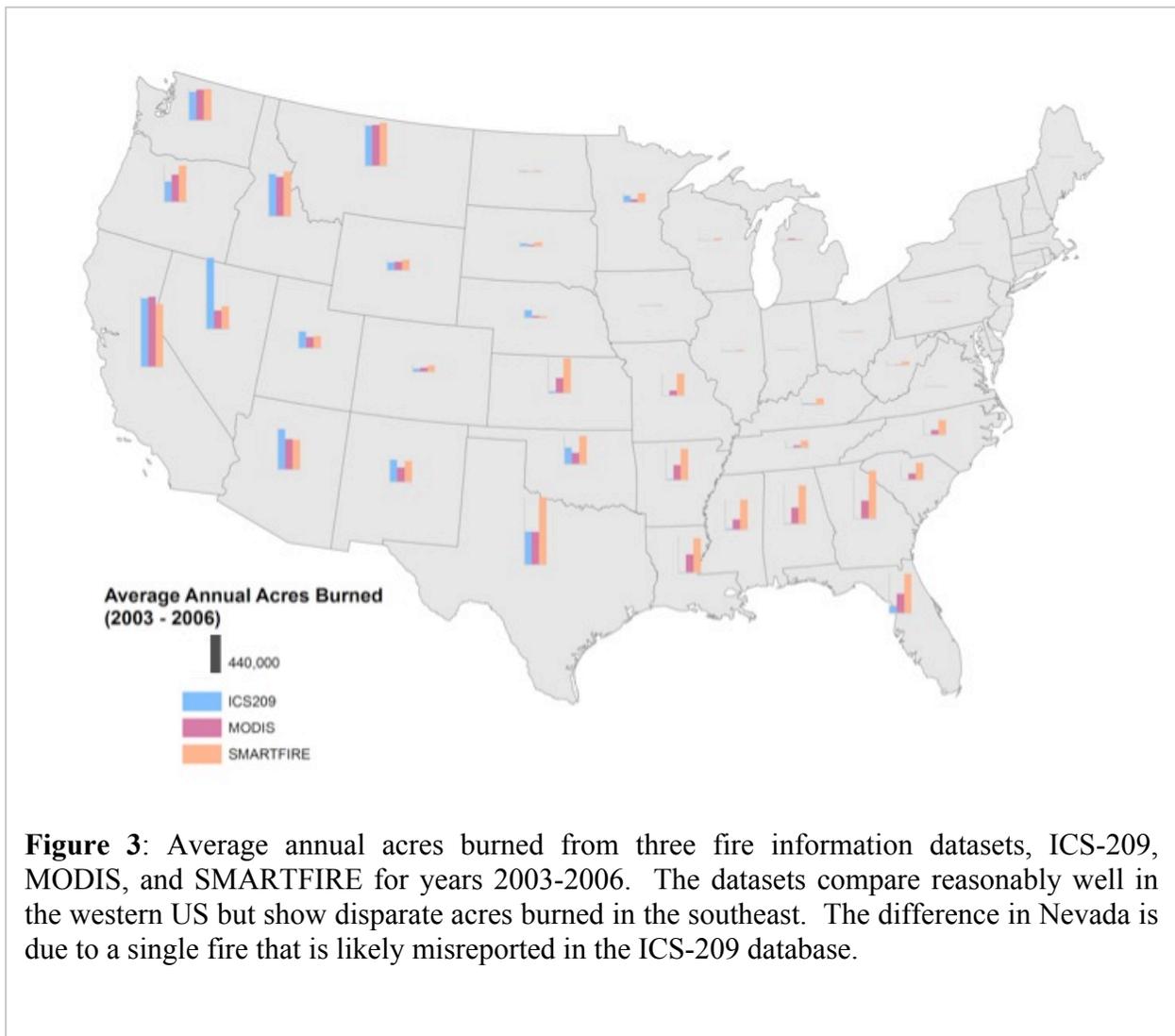
To further investigate the data initial statistics average, maximum, minimum, mean fractional bias (MFB), mean fractional error (MFE), and factor-of-two (FA<sub>2</sub>) were examined (see <http://semip.org/stats> for definitions). Error and bias imply a known “truth” – in the context of model intercomparison generally a single model or the aggregation of all the models is chosen as a surrogate for “truth”. Both have been done; in the Appendix we present the simpler case where each modeling pathway is compared to one chosen pathway – in this case FCCS→CONSUME3 – as this is generally easier to interpret.

Statistics were calculated only where all modeling pathways had results, which limited the region to the 2.3 M cells where all three fuel loading maps had values – all in the western U.S. Water, agriculture, urban, and barren fuel loadings of zero were taken out of the datasets. Grasslands with some non-zero fuel loading, but potentially zero woody fuels were not removed. There are times where one fuel loading map considers the grid cell to be grassland while others consider woody material to be present. The fuel loading statistics were only done for woody fuel loadings. Consumption statistics include all consumption including woody and grasses.

## Key Findings

### In the west: US fire information datasets produce similar average annual acreage burned estimates

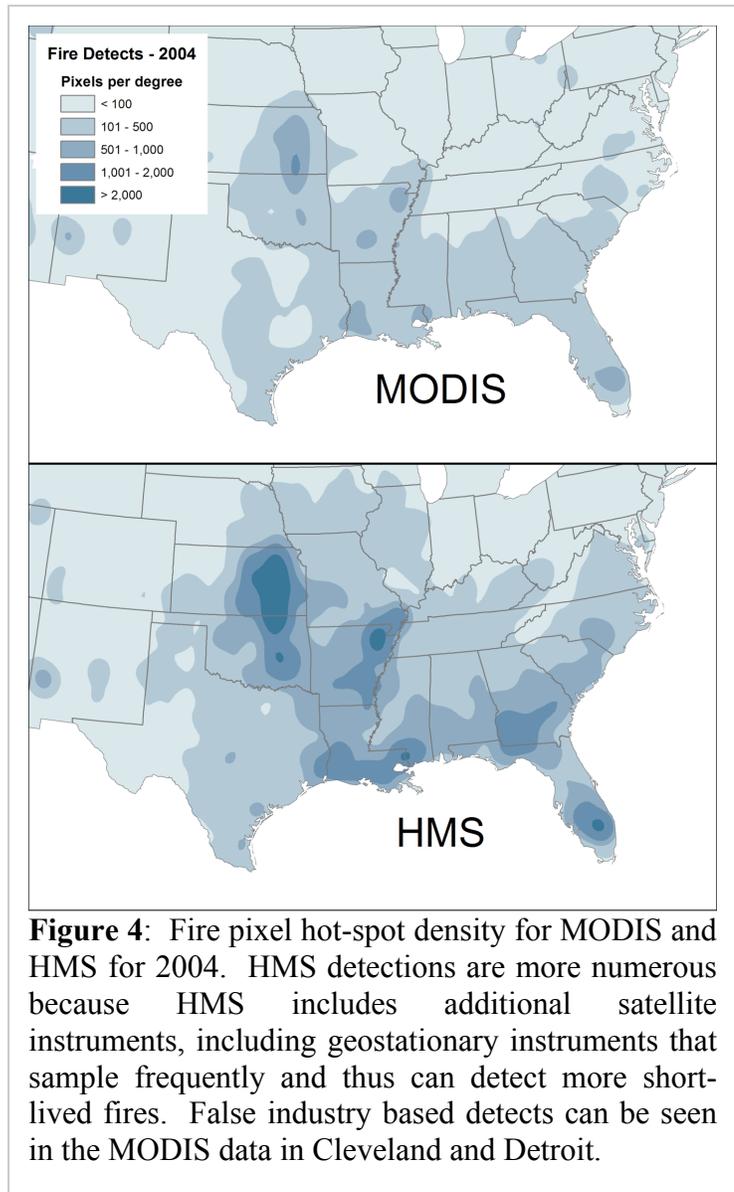
Average annual area burned in the West is dominated by wildfires, which is captured well both by ground reports (ICS-209s) and satellite (MODIS). The annual averages are similar for all three data sources (Fig. 3), with the exception of Nevada, where the ICS-209 value is much larger than the others. The large ICS-209 value is caused by what is believed to be a typographical error in a single fire. The error highlights the type of errors that can occur in the ICS-209 data.



**Figure 3:** Average annual acres burned from three fire information datasets, ICS-209, MODIS, and SMARTFIRE for years 2003-2006. The datasets compare reasonably well in the western US but show disparate acres burned in the southeast. The difference in Nevada is due to a single fire that is likely misreported in the ICS-209 database.

## In the southeast: US fire information datasets produce disparate total annual area burned

The data for the southeast show little area burned from the ICS-209 dataset and SMARTFIRE estimates over twice the area burned in the region compared to MODIS (Fig. 4). The fires in the southeastern United States are largely due to prescribed burning. ICS-209 reports are not created for the vast majority of prescribed burns, so this dataset has little to no reported acreage burned. SMARTFIRE uses NOAA HMS as its source of satellite-derived fire detects. HMS gathers fire detects from several instruments, including MODIS. Although MODIS is the most sensitive and sophisticated instrument that HMS relies on for fire information, MODIS data are typically only available twice per day over the lower 48 states. Thus, small, short-lived fires, burning during cloudy conditions (such as many prescribed fires in the southeastern US) are easily missed by the MODIS instrument (Figure 4). HMS incorporates fire detects from GOES and AVHRR in addition to MODIS. GOES in particular is useful for detecting these short-lived fires because, as a geostationary instrument, it detects fire every 30 minutes. This additional satellite information explains the additional activity reported by SMARTFIRE in the Southeast.



**Figure 4:** Fire pixel hot-spot density for MODIS and HMS for 2004. HMS detections are more numerous because HMS includes additional satellite instruments, including geostationary instruments that sample frequently and thus can detect more short-lived fires. False industry based detects can be seen in the MODIS data in Cleveland and Detroit.

## MODIS data contain significant false detects

Industrial heat sources often result in false positives in the fire detection algorithms, such as those used by MODIS. These false positives are less common in the SMARTFIRE data because the HMS data set undergoes a human quality control process that removes most of them (Figure 4).

## **Spatial resolution of satellite detected fire data provides benefits over ICS-209 data**

ICS-209 reports describe the location of a fire of any size by a single latitude/longitude pair that represents the ignition point of the fire and remains fixed for the fire's duration. For modeling emissions, this means that any fuel loading derived from that location, and subsequently any consumption and emissions calculations that rely on the fuel loading, do not vary throughout the life of the fire (except by area per day). By contrast, satellite instrumentation can detect large fires as a large number of satellite pixels, which can provide better location of the active fire core and the ability to track a fire across fuel loadings.

## **Direct comparisons are more difficult due to differential model availability.**

Of the nearly 6.2 M grid cells where one of the FCCS, Hardy, and NFDRS models exist, only 37% (2.2M) grid cells have fuel loadings from all 3 models. Even for FCCS and NFDRS which both nominally cover all of CONUS, only 76% of the possible grid cells have data from both. Table A1 describes the number of grid cells where each map has data.

## **Overall average total downed woody fuels vary little; maximum values differ**

Where all three fuel loading maps contained values, the average total downed woody fuel loadings ranged from 4.5 tons/acre (FCCS) to 6.9 tons/acre (Hardy). Maximum values ranged from 29.3 tons/acre (NFDRS) to 48.3 tons/acre (FCCS) (Table A2). However, mapping the fuel loadings revealed that any of the fuel loadings could be higher or lower depending on the specific point of interest. The average values tend to mask these sometimes significant (factor 10+) regional differences.

## **Overall average consumption values vary little, with the exception of FCCS→CONSUME**

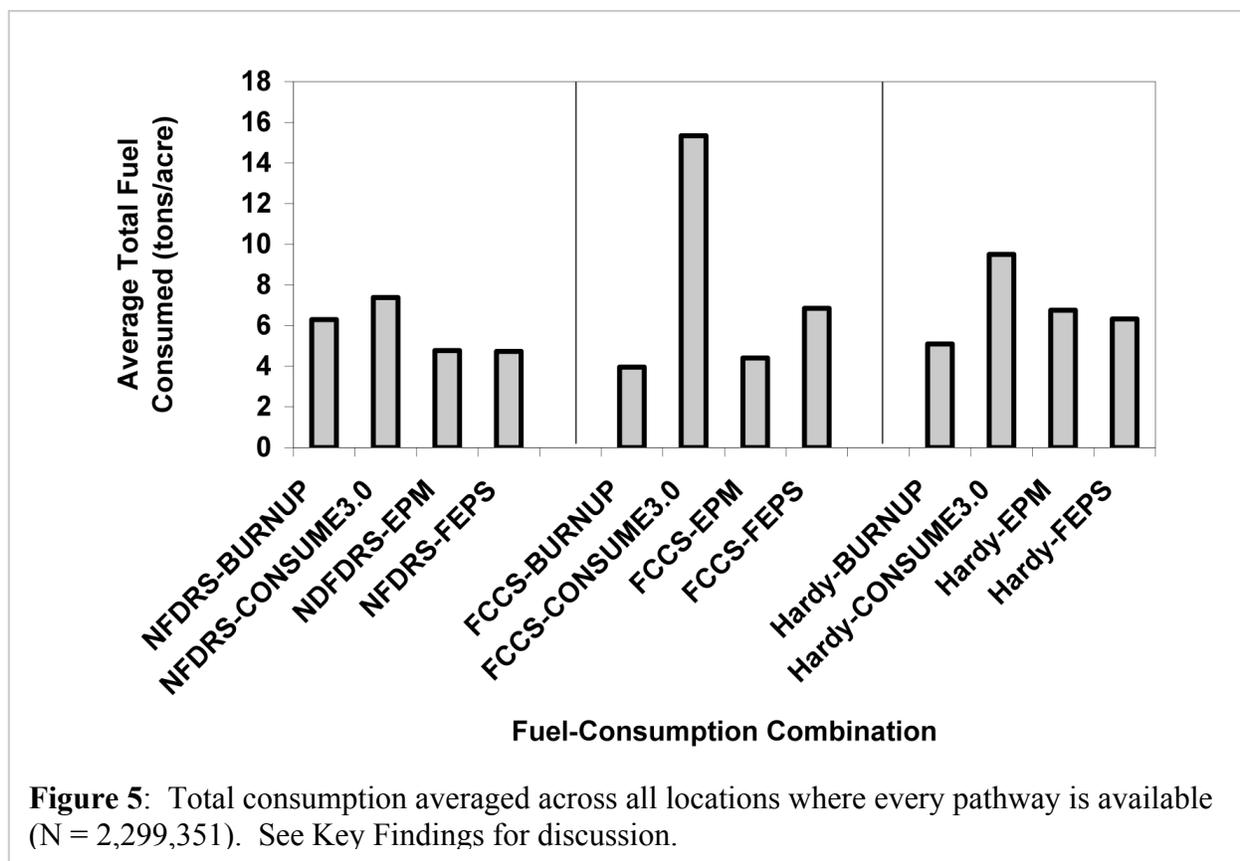
The aggregate average consumption values vary little across the 12 fuel-consumption model combinations. The exception is FCCS→CONSUME, which has a high smoldering component (Table A4) resulting in significantly higher total consumption. It is likely that inclusion of a duff layer in the FCCS fuel bed and CONSUME's ability to use that layer accounts for the difference. However, mapping the consumption values shows that significant differences in both directions occur for all models depending on the location of interest. Again the average values mask the significant regional differences.

## **There are systematic errors that cross multiple variables**

Because aggregate variables of fuel loadings do not show better agreement than component variables, at least in fuel loadings, there must be systematic errors among the various fuel loading maps. Random errors would result in an increase in agreement (e.g. FA2 statistics) for aggregate variables but this is not seen (see Table A3).

## **Fuel consumption average statistics show that consumption models may compensate for differences in fuel loadings**

MFB and MFE statistics for fuels are generally higher than MFB and MFE for consumption. This indicates less agreement in the fuels than in the resulting consumption output. Hence the consumption models are reducing the variability found in the fuels models. This is a fortunate result for those concerned primarily with consumption.



## Management Implications

### Choosing the right model is critical and is likely to be location dependent

Significant variability exists over large regions of the country. Each model or modeling pathway has regions where it is the highest and regions where it is the lowest. For applications where fuels maps or consumption models are being applied to a few or a single fire, this choice can greatly affect the resulting numbers.

### Implementing the model combination that allows for duff smoldering is critical for certain regions of the country

FCCS has a duff fuel loading and CONSUME3.0 uses duff loading if it is provided. The FCCS→CONSUME3.0 combination provides the largest maximum and average smoldering consumption totals (Table A4). Using this fuel-consumption model combination may be important in regions where duff fuelbeds are likely to be present.

### The SEMIP viewer can be used by managers to explore fuels and consumption

The SEMIP viewer ([data.semip.org](http://data.semip.org)) provides a quick and easy way for land managers either planning a prescribed burn or working on a wildfire to view potential fuel loadings and their

range of modeled consumption. Although not customizable, its instant access allows for “back-of-the-envelope” style calculations and comparisons. By visualizing the range of possible fuel loadings (at least as mapped) and their potential consumption (as modeled), managers can begin to have a better understanding of the function of these models.

### **A qualitative understanding of uncertainty can be easily gained through simple web browsing**

If the actual fuel loadings are known, the user can compare these to the fuel loading maps. The difference in magnitude and the sign of the difference between the known loadings and the fuel map loadings can be inferred and intelligent assumptions and adjustments can then be applied to the predicted total consumption values, emissions, and smoke concentration predictions for the area. Using the data in this manner builds a qualitative understanding of uncertainty in the predictions.

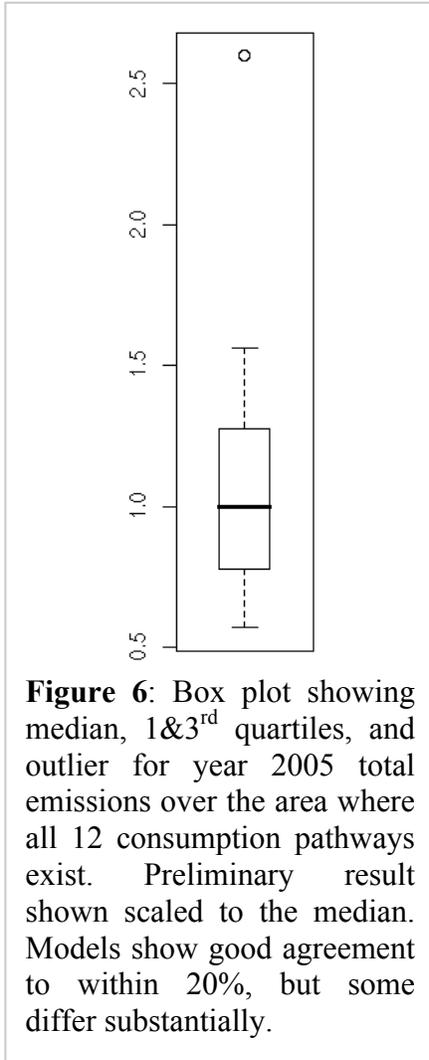
## **Related Work**

This project serves as the first component of the larger Smoke and Emissions Model Intercomparison Project (SEMIP) funded by the Joint Fire Science Program. As such it forms only the first piece of a larger analysis chain that is designed to intercompare models at a variety of output levels all the way through smoke dispersion.

Additionally, this project has benefited from improvements and work to the BlueSky Framework (<http://blueskyframework.org>) that allow these models to be more easily used in combination and compared. This relationship is reciprocal – lessons learned from this comparison have already been incorporated both into revised modules within BlueSky version 3.1 and into plans for future versions of BlueSky, including a newly funded NASA ROSES project that address some of the shortcomings found by this analysis and will also allow for comparison with radiative fire power emissions estimates.

Mostly, however, this project has greatly benefited from all of the previous projects (many funded by the JFSP) that created the fuel loading maps and consumption models being compared. Several of the model creators also helped significantly and allowed access to model code and improvements.

Over the past 2 years, the EPA has generated its National Emissions Inventory fire component through a pathway utilized here: SMARTFIRE→FCCS→CONSUME. Hence this work bears directly on the EPA’s NEI calculations. (See Figure 6 and Future Work).



## Future Work Needed

### Addition of LANDFIRE-FCCS fuels map

As this final report comes due, a new fuel loading map is available that links LANDFIRE vegetation with FCCS fuelbeds. This map will be incorporated in the analysis shortly but was not available in time to be included in this report.

### Data mining and exploration

With over 900 maps (fuel loading and fuel consumption model combinations) and over 6,000,000 data points covering the contiguous US there are many ways to explore the data. The datasets are now in a form that makes analyses and comparisons easier and the data are available for use through JFSP's SEMIP. To date, basic comparisons of the fuel loading and consumption totals have been done on a national scale. Analyses on a regional scale or at a fuel type level may prove insightful.

### Examining the influence of these calculations on the National Emissions Inventory fire emissions

The total consumption variability relates directly to variability in emissions, and emissions are generally calculated as little more than a fixed proportion of total consumption. Therefore the statistics in the Appendix directly relate to error estimations and uncertainty in the NEI. Preliminary work that will be continued through SEMIP is shown in Figure 6 where the total annual

emissions were calculated for 1 sample year (2005) using all 12 modeling pathways over the area where they exist. Since the data is only preliminary the plot only shows the normalized (by the median of all the model pathways) values, but still reflects the relative range. Many of the modeling pathways are found to be in relatively (20%) close agreement, but some differ substantially more. The FCCS→CONSUME pathway is the maximum value, but this may be because it accounts for types of consumption the other pathways do not. Future work will check these results and expand them to multiple years.

### Examining the influence the range in consumption values has on surface smoke concentrations and smoke plume footprints

The consumption data can be used as input into the BlueSky Framework to explore the subsequent range of predictions made by a smoke transport model (i.e. CALPUFF). This will result in a cumulative concentration footprint that will provide a 'best-prediction' based on the modeled range of consumption values. These concentration data can then be analyzed against observed data using the MFB, MFE and FA<sub>2</sub> metrics. The multiple smoke plume footprints can be plotted and a probabilistic smoke plume location calculated based on the 12 consumption values.

## Deliverables Crosswalk Table

**Table 2: Deliverables crosswalk**

<b>DELIVERABLES LISTED IN PROPOSAL</b>			
<b>Deliverable</b>	<b>Description</b>	<b>Promised Timeline</b>	<b>Status</b>
Data information	Relational data base containing all model and fuelbed inter-comparisons/web access to this information,	upon project completion	COMPLETE AVAIL ONLINE
Publications - Reviewed papers	Two papers to refereed journals, <i>e.g.</i> , IJWF and J of Env. Qual.	near end/shortly after project completion	IN PROGRESS 3 PUBLICATIONS see below
Presentations/ Conference(s)	<i>e.g.</i> Annual Fire Behavior & Fuels Conf, IWF and Core Fire Science Caucus	various times throughout project	16 COMPLETE MORE UPCOMING see below
Publication/ Final report	project post-mortem	JFSP/FS and interested parties	COMPLETE

### Publications List

The project team is currently working on 3 papers based on this project. The first is focused on what this project can say about uncertainties in the fire component of the National Emissions Inventory (NEI), and is slated for submission to Science magazine in October 2009. A more detailed paper that presents the full scope of this project has been drafted and is slated for submission to the International Journal of Wildland Fire in November/December 2009. This paper will be accompanied by a peer-reviewed GTR that can contain additional figures and statistics not publishable in the paper due to space limitations.

Additionally, a short whitepaper has been written for distribution to land managers to allow them to understand the ramifications of this work for their documentation and decision support workflows, and to introduce the data visualization and access interactive website. This will be distributed to users beginning at the November 2009 4<sup>th</sup> Fire International Fire Ecology and Management Conference in Savannah, Georgia.

### Website Tools List

This project's website is located at:

- <http://airfire.org/projects/matrix>

This page details the project and provides links to access visualizations of the data including maps and plots as well as downloadable dataset files.

The visualization component of this project, which was originally intended to be a stand-alone application, has instead been adapted to become the first step in the larger Smoke and Emissions Model Intercomparison Project (SEMIP) data viewer. Doing so places the results of this project into the larger context of the SEMIP project and provides a seamless user experience across all

levels of the SEMIP output. More details on SEMIP are available at <http://semip.org>. The data viewer is available at:

- <http://data.semip.org>

A tutorial on how to use the data viewer is included as Appendix C.

## Presentations List

All presentations that discussed aspects of this work are listed. Additional presentations are planned at 2009 fall and winter meetings.

Strand T.M., Larkin N.K., Solomon R., Raffuse S., Sullivan D., Craig K., Pryden D., Wheeler N., Chinkin L., Brown T. 2009. The BlueSky Framework. Biomass Co-oP Meeting, Monterey, California, June 25-26.

Raffuse S.M., Reid S.B., Pollard E.K., Wheeler N.J. 2009. A daily fire greenhouse gas emission inventory for the United States and comparison with other inventories. First International Greenhouse Gas Measurement Symposium, Burlingame, California, March 22-25.

Larkin N.K., Raffuse S., Strand T.M., Solomon R., Sullivan D., Wheeler N. 2008. Smoke and emissions model intercomparison project (SEMIP): an invitation. Fall Meeting, San Francisco, California, December 15-19.

Strand T.M., Larkin N.K., Solomon R., Raffuse S., Sullivan D., Craig K., Pryden D., Wheeler N., Chinkin L., Brown T., Procter T. 2008. New tools for fire and smoke and their application to the 2008 California wildfires. Pacific Coast Fire Conference: Changing Fire Regimes, Goals and Ecosystems, San Diego, California, December 15-19.

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## Appendix A: Selected Analysis Summary Tables

**Table A1:** Number of grid cells with fuel loading map coverage. Note that even for the more expansive (full CONUS) fuels maps (NFDRS and FCCS), only 76% of the possible grid cells match.

Model(s)	Number of 1km x 1km cells			
	with data (ratio of possible)	when no NFDRS data	when no FCCS data	when no Hardy data
<b>Possible</b>	6,166,618 (=1.00)	426,584	1,145,141	3,550,353
<b>NFDRS</b>	5,740,034 (0.93)	-	1,079,230	3,285,041
<b>FCCS</b>	5,021,477 (0.81)	360,673	-	2,626,765
<b>Hardy</b>	2,616,265 (0.42)	161,272	221,553	-
<b>All 3 simultaneous</b>	2,299,351 (0.37)	-	-	-
<b>NFDRS &amp; FCCS simul.</b>	4,660,804 (0.76)	-	-	2,361,453

Mean Bias (MB), Mean Error (ME), Mean Fractional Bias (MFB), Mean Fractional Error (MFE), and Factor of 2 (FA<sub>2</sub>) statistics were calculated on fuel loading and consumption data using the standard equations which can be found at <http://www.semip.org/statistics>.

To calculate MFB, MFE and FA<sub>2</sub> one of the datasets must be considered a base case. The current default model and pathway through the BlueSky Framework was selected as the base case dataset. For the fuel loading level FCCS is the base case and for the fuel-consumption level the FCCS-CONSUME3.0 combination is the base case. The MFB, ranges  $\pm 200\%$ , describes the overall bias or trend of the datasets and the MFE, ranges 0-200%, describes the difference between the two datasets. FA<sub>2</sub> is the fraction of the time the data are within  $\frac{1}{2}$  to 2 times the base case. The following tables present the results calculated only over the region where data exist for all 3 fuel loading maps.

**Table A2.** Average, maximum, minimum fuel loadings by woody fuel loading type and total woody. These data are calculated over the region where all 3 fuel loading models exist (N=2,299,351).

tons = short		Average (tons/acre)			Maximum (tons/acre)			Minimum (tons/acre)		
	Fuel Map	FCCS	Hardy	NFDRS	FCCS	Hardy	NFDRS	FCCS	Hardy	NFDRS
<b>Fuel Loading Type</b>	1 hr	0.17	0.18	1.67	1.30	0.70	5.00	0.00	0.00	0.40
	10 hr	0.45	0.86	1.19	3.20	1.80	5.50	0.00	0.20	0.00
	100 hr	0.68	1.25	1.13	4.90	4.20	5.60	0.00	0.00	0.00
	1000 hr	1.38	2.50	2.14	12.00	13.90	13.20	0.00	0.00	0.00
	10,000 hr	1.24	1.51	NA	35.00	13.70	NA	0.00	0.00	NA
	10,000 <sup>+</sup> hr	0.53	0.63	NA	10.00	5.60	NA	0.00	0.00	NA
	Total Downed Woody	4.45	6.93	6.12	48.30	31.80	24.00	0.00	0.20	0.40

Note that Total Downed Woody = 1 hr + 10 hr + 100 hr + 1000 hr + 10000 hr + 10000 hr<sup>+</sup> as used here

**Table A3.** The percentage of grid cells fuel loadings from Hardy and NFDRS that are within a factor of two of FCCS (FA<sub>2</sub>) and the mean fractional bias (MFB) and mean fractional error (MFE) of Hardy and NFDRS fuel loadings relative to FCCS for all woody fuel types. These metrics were calculated over the number of grid cells only where all three fuel loadings exist (N = 2,299,351)

		FA <sub>2</sub> (%)		Mean Fractional Bias (%)		Mean Fractional Error (%)	
	Fuel Map	Hardy	NFDRS	Hardy	NFDRS	Hardy	NFDRS
<b>Fuel Loading Type</b>	1 hr	47.70	2.80	17.88	169.00	121.90	169.00
	10 hr	33.50	43.00	105.30	96.84	125.90	124.30
	100 hr	49.90	64.90	79.58	-30.57	131.00	137.60
	1000 hr	71.30	68.40	2.62	-49.06	128.20	147.90
	10,000 hr	73.90	NA	44.49	NA	128.00	NA
	10,000 <sup>+</sup> hr	75.60	NA	-12.18	NA	183.80	NA
	Total Downed Woody	22.10	26.50	100.80	111.40	139.20	137.30

**Table A4.** Average, maximum, and minimum values for total, flaming and smoldering consumption produced by the 12 different fuel-consumption model combinations (N = 2,299,351).

in U.S. tons/acre	Total Consumption			Flaming Consumption			Smoldering Consumption		
Combination (Fuel-Consumption)	Average	Max	Min	Average	Max	Min	Average	Max	Min
NFDRS-BURNUP	6.29	17.81	0.70	3.91	17.39	0.30	2.38	11.42	0.35
NFDRS- CONSUME3.0	7.38	22.26	0.68	6.18	19.20	0.64	1.20	5.90	0.03
NDFDRS-EPM	4.77	15.80	0.40	4.20	13.58	0.40	0.57	2.48	0.00
NFDRS-FEPS	4.73	20.96	0.03	2.36	10.48	0.01	2.36	10.48	0.01
FCCS-BURNUP	3.96	32.10	1.05	1.76	5.69	1.05	2.20	28.89	0.00
FCCS-CONSUME3.0	15.34	125.00	0.08	5.38	33.71	0.07	9.95	93.64	0.00
FCCS-EPM	4.41	24.40	0.00	2.26	13.16	0.00	2.16	16.96	0.00
FCCS-FEPS	6.85	64.30	0.11	2.90	28.89	0.05	3.27	31.21	0.05
Hardy-BURNUP	5.10	19.19	0.35	1.27	5.40	0.00	3.83	18.22	0.05
Hardy-CONSUME3.0	9.50	35.88	0.59	5.23	15.90	0.43	4.28	19.98	0.16
Hardy-EPM	6.76	21.68	1.41	4.12	10.11	1.41	2.64	15.19	0.00
Hardy-FEPS	6.33	30.14	0.15	2.75	13.68	0.01	3.04	14.66	0.06

**Table A5.** The percentage of grid cells fuel loadings from the fuel-consumption model combinations that are within a factor of two of the FCCS-CONSUME3.0 combination (FA<sub>2</sub>) and the mean fractional bias (MFB) mean and fractional error (MFE) relative to FCCS-CONSUME3.0. These metrics were calculated over the number of grid cells where all three fuel loadings exist (N = 2,299,351)

Combination (Fuel-Consumption)	Total Consumption			Flaming Consumption			Smoldering Consumption		
	FA <sub>2</sub> (%)	Mean Fractional Bias (%)	Mean Fractional Error (%)	FA <sub>2</sub> (%)	Mean Fractional Bias (%)	Mean Fractional Error (%)	FA <sub>2</sub> (%)	Mean Fractional Bias (%)	Mean Fractional Error (%)
NFDRS-BURNUP	28.58	-9.56	100.60	23.02	-2.25	88.70	18.45	18.10	131.70
NFDRS-CONSUME3.0	29.20	-3.00	101.90	49.70	32.82	76.30	20.79	-31.60	119.80
NDFDRS-EPM	38.74	-38.24	99.20	43.28	-6.19	76.00	6.61	-166.00	179.60
NFDRS-FEPS	31.61	-76.23	109.40	23.81	-95.90	112.50	13.37	-4.10	136.30
FCCS-BURNUP	40.50	-56.20	86.70	54.20	-37.90	80.40	26.30	-95.70	130.90
FCCS-CONSUME3.0	.	.	.	.	.	.	.	.	.
FCCS-EPM	28.80	-115.00	115.40	35.60	-94.70	105.10	21.20	-121.80	136.80
FCCS-FEPS	28.60	-103.80	104.40	26.20	-120.70	120.70	59.40	-22.10	71.60
Hardy-BURNUP	28.06	-40.77	109.50	23.32	-74.84	117.40	24.02	13.61	132.90
Hardy-CONSUME3.0	23.56	-6.82	107.40	29.34	0.85	89.90	25.97	26.03	124.30
Hardy-EPM	29.86	-7.12	94.20	50.89	16.80	67.00	12.48	-33.23	152.80
Hardy-FEPS	37.92	-56.63	103.90	34.36	-95.15	110.50	24.34	6.16	130.20

## Appendix B: Model Settings

This appendix lists the various model settings used here (e.g. in Appendix A). Additional runs were done and continue to be done using variants to check sensitivities.

EPM:

```
1000-hr fuel moisture: 12%
10-hour fuel moisture: 9%
  surface wind speed: 9 mph
  burn-site slope: 10%
    Region: EO
  Vegetation Type: H
  days since last rain: 9
  fuel moisture method: A
```

FEPS (consumption):

```
  duff moisture: 12%
  fire type: WF (wildfire)
  fire severity: Severe
                    (allows for canopy consumption)
  piles: 0
  scatter: 0
```

CONSUME3:

```
1000-hr fuel moisture: 12%
  Fire Adjustment: 0.6
                    (60% of canopy available for burning)
  Duff Moisture: 40%
                    (note: much higher than for other
                    models)
```

when used with NFDRS & HARDY only:

```
-----
  ecoregion: 210
  midstory: 0
  understory: 0
  snags_C1woFoliage: 0
    snags_C2: 0
    snags_C3: 0
    snags: 0
  shrubs_Primary_perc_live: 95.0
  shrubs_Secondary: 0
  shrubs_Secondary_perc_live: -3.00
  nw_Primary_perc_live: 95.0
    nw_Secondary: 0
  nw_Secondary_perc_live: -3.00
    w_Stump_Sound: 0
    w_Stump_Rotten: 0
  w_Stump_Lightered: 0
  litterDep_perc: 85.0
```

```

        litterArrange: 1
          lichenDep: 0
        lichenDep_perc: 5
          mossDep: 0
        mossDep_perc: 40.0
          mossType: 1
        litterShortNeedle_perc: 20.0
        litterLongNeedle_perc: 20.0
        litterOtherConf_perc: 20.0
        litterBroadleafDecid_perc: 20.0
        litterBroadleafEver_perc: 20.0
          litterPalmFrond_perc: -1
          litterGrass_perc: -1
        g_DuffLoad_Total: 0
        g_DuffDep_Upper_perc: 100.0
        g_DuffDerivation_Upper: 2
          g_DuffDep_Lower: 0
        g_DuffDep_Lower_perc: 100.0
        g_DuffDerivation_Lower: 4
          g_BasDerivation: -3
            g_BasDep: -3.00
          g_BasPercent: -3.00
          g_BasRadius: -3.0
          g_SMDepth: -2.00

```

FOFEM (BURNUP):

```

        10-hr moisture: 9%
        1000-hr moisture: 12%
          duff moisture: 12%
          soil moisture: 12%
        foilage/branch split: 50-50
                                (if only total canopy is provided)
        3-6 to 6-9inch split: 30-70
                                (if only 3-9, ie 1000hr)provided
                                (roughly equiv to the 'right'bias for
                                this category in fofem gui)
        percent crown burn: 60%
        percent rotten 3+: 10%
          region: PW (avail list: PW,IW,NE,SE)
          soil: FS (avail list: FS,F,CS,CL,LS)
          season: Summer
        moisture condition: Dry (avail list: VD,D,M,W)
        Fuel Category: Na (avail list: Na,Pi,Sl)
        Moist Method: AN (avail list: E,L,N,AN)
        fire severity: H (avail list: L,M,H,V)

```

# Appendix C: Data Viewer Tutorial

The data viewer for this project is available at <http://data.semip.org>. The following slides describe how to use it.

The SEMIP Data Viewer allows the user to drill down into model results in three stages:



1) Select Model Level

Home Analysis Results

You are here: **Fuels**

Model levels: [Overview](#) → [Fuels](#) → [Consumption](#) → [Emissions](#) → [Plume Rise](#) → [Smoke Dispersion](#)

2) Select data and view map

### Map Viewer

View: Total Sound Fuels    Statistic: Ratio    Model 1: FCCS    Model 2: NFDRS    View Map     State Overlay

Currently viewing: FCCS / NFDRS Total Sound Fuels Ratio

Ratio (m1/m2)

- 8+
- 4-8
- 2-4
- 1.5-2
- 1-1.5
- 2/3-1
- 1/3-2/3
- 1/4-1/2
- 1/8-1/4
- 0-1/8

■ = no data

2) Refine location and view detailed data

### Point Location Information

Lat: 44.18 °N    Lon: -114.71 °E    i: 927    j: 2163    Get Data

Fuels Consumption

Showing fuels information for grid cell (927,2163) at Lat:44.18, Lon:-114.71

**Fuelbeds found:**

- FCCS: Lodgepole pine forest (#22)
- NFDRS: Open pine perennial grass understory (#3)
- Hardy: Ponderosa Pine - Medium Load (#4.2)

Fuel Loadings (tons/acre)	FCCS	NFDRS	Hardy	Min/Max all locations
TOTAL WOODY*	14.9	3.2	15.6	0 - 48.3
1 HR	0.4	1	0.1	0 - 5
10 HR	2.2	2.2	1.6	0 - 5.5
100 HR	2.8	0	4.2	0 - 6.2
1000 HR	8.3	0	2.1	0 - 15
10000 HR	0.7	0	2.9	0 - 35
10000 HR PLUS	0.5	0	4.7	0 - 10
DUFF	1.92	0	1.3	0 - 45.48
GRASS	0.14	0.8	0	0 - 3
SHRUB	0	0.8	0	0 - 11.5
CANOPY	4.16	0	0	0 - 36.15

\*TOTAL WOODY = 1-HR + 10-HR + 100-HR + 1000-HR + 10000-HR + 10000-HR-PLUS as used here

Results in the SEMIP Data Viewer are organized by modeling step. In the screen below, the user has selected the Fuels step. In addition to the fuels and consumption modeling steps, the user can select Overview, which provides a terrain base map, to get their bearings.



To view results in the Map Viewer, the user selects the parameter to view (in this case Total Sound Fuels), the statistic (Ratio), Model 1 (FCCS), and Model 2 (NFDRS). Clicking the View Map button will load the chosen results. Here the viewer is examining the ratio of total sound fuels in FCCS to that of NFDRS.

Map Viewer

View:  Statistic:  Model 1:  Model 2:    State Overlay

Currently viewing: FCCS / NFDRS Total Sound Fuels Ratio

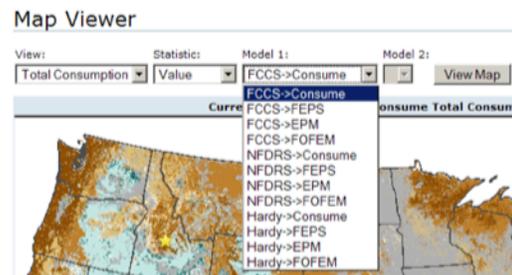
8+  
4-8  
2-4  
1.5-2  
1-1.5  
2/3-1  
1/2-2/3  
1/4-1/2  
1/8-1/4  
0-1/8  
Ratio (m1/m2)  
no data

This button toggles a state outline overlay on the map.

While the map is useful for examining overall patterns, the user can also look at detailed results for specific points. Clicking on the map will change the active data location, shown by the yellow star.

Parameter-specific legend

For later model steps, the full pathway must be chosen. For example, in the Consumption step, the user must select combinations of Fuel Load and Consumption models, such as FCCS->Consume or NFDRS->FOFEM.



The location selected in the Map Viewer is shown as latitude and longitude, as well as the i and j values of the SEMIP data grid cell for the corresponding location. A Google Map shows the local surroundings. The location can be changed by entering new latitude and longitude values, or by clicking on the map. Clicking on the Get Data button, will retrieve values for the current location.

Data tabs are available for the Fuels and Consumption model steps.

**Point Location Information**

Lat: 44.18 °N

Lon: -114.71 °E

i: 927

j: 2163



<http://data.semip.org/index.php?comparisonLevel=fuels&selectedView=woody&selectedStat=ratios>

**Fuels** **Consumption**

Showing fuels information for grid cell (927,2163) at Lat:44.18, Lon:-114.71

**Fuelbeds found:**

FCCS: Lodgepole pine forest (#22)  
 NFDRS: Open pine perennial grass understory (#3)  
 Hardy: Ponderosa Pine - Medium Load (#4.2)

Fuel Loadings (tons/acre)	FCCS	NFDRS	Hardy	Min/Max all locations
TOTAL WOODY*	14.9	3.2	15.6	0 - 48.3
1 HR	0.4	1	0.1	0 - 5
10 HR	2.2	2.2	1.6	0 - 5.5
100 HR	2.8	0	4.2	0 - 6.2
1000 HR	8.3	0	2.1	0 - 15
10000 HR	0.7	0	2.9	0 - 35
10000 HR PLUS	0.5	0	4.7	0 - 10
DUFF	1.92	0	1.3	0 - 45.48
GRASS	0.14	0.8	0	0 - 3
SHRUB	0	0.8	0	0 - 11.5
CANOPY	4.16	0	0	0 - 36.15

\*TOTAL WOODY = 1-HR + 10-HR + 100-HR + 1000-HR + 10000-HR + 10000-HR-PLUS as used here

Clicking on the Bookmark button provides a unique URL to the exact parameter and location the user is currently browsing. This URL can be copied and shared with collaborators.

Results for all models in the currently selected step are shown at once in a combined tabular/graphical view. The bars show the ratio of the value at the selected location to the maximum value at all locations for all models.