Phase 1 Final Report
for NASA-ROSES A.35 Earth Science Applications: Wildland Fires
Feasibility Grant Number: NNX12AQ89G
Performance Period: October 2012 - February 2014

Improving agricultural and wildland fire source emission products and access to information for atmospheric science and smoke modeling applications

Short Title: Fire Emissions Information Support

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Report Date: 15 November 2013

Executive Summary

The fire-related challenge this activity addresses is to provide useful and timely fire emissions estimates with associated uncertainty to end users. Needed are improved spatial and temporal estimates of the magnitude and composition of fire emissions. Our team has developed methods to quantify wildland fire emissions from mapped fires. The Wildland Fire Emissions Information System (WFEIS) can be accessed from any web browser to compute fire emissions for past fire within the US. The decision-making activity we address with WFEIS is to provide users with tools to quantify emissions from fire retrospectively for locations or regions of interest.

NASA's capability in spatial data analysis and systems development can provide important insights for fire emissions modeling. The feasibility project reviewed in this report was formulated to show how WFEIS could be a viable and efficient tool for addressing the decision-making challenge of mapping wildland and agricultural fire emissions across regional scales. For this Applications project we proposed two Focus Areas, Emissions modeling improvements and Transitioning to an operational tool, and we completed a set of tasks in Phase 1 with additional tasks within these Foci proposed for Phase 2.

WFEIS started at an ARL of 4. During Phase 1 we reached the level of ARL 5. We are requesting a budget totaling $697,000 for 3 years of work by the MTRI and USFS team. If funded for Phase 2 we expect to achieve ARL 6 by the end of Year 2. Year 3 we expect to be demonstrating the prototype at the Operational Partner's Institution, achieving ARL 7 by the close of the project. We feel that the goal of ARL 7 can be achieved, and if end users are sufficiently satisfied with output reliability, we feel we are on a solid path to reach an ARL 9 shortly thereafter.

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Part 1: Phase 1 Activities and Outcomes

1.1 Fire-related Challenge and Decision-making Activity

Wildland fire and prescribed burning have become important components of Earth-system models, as understanding improves of their global extent (*Giglio et al.* 2009) and function as ecosystem processes (*Bowman et al.* 2009). Carbon released from wildland fire and agricultural burning during combustion alters the global carbon balance. Smoke emissions have impacts at all spatial scales; they are 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 (*van der Werf et al.* 2006; *Bond et al.* 2013).

The fire-related challenge this activity addresses is to provide useful and timely fire emissions estimates with associated uncertainty to the decision-making, modeling, and policy-making communities. Under this and previous projects we have improved methods for computing spatial maps of fire source emissions by developing superior data inputs than had been available and by improving access to fire-emissions modeling tools. Needed are improved spatial and temporal estimates of the magnitude and composition of fire emissions, which requires attention to the factors that drive emissions variability.

In a previous project funded by NASA and in the one-year activity funded with the feasibility grant, our team has developed methods to quantify wildland fire emissions from mapped fires spatially within the United States (excluding Hawaii and territories). The basic methods used for this tool employ a well-vetted approach that has been used by several research and operational teams for fire emissions estimations (*Seiler and Crutzen* 1980; *French et al.* 2011), including the USFS AirFire Team in the BlueSky Framework (http://www.airfire.org/bluesky/). Complementary to the methodological progress made with this activity we have also created, improved, and maintained a prototype information system to make these data available to users. The Wildland Fire Emissions Information System (WFEIS; Fig 1; http://wfeis.mtri.org) can be accessed from any web browser to compute fire emissions for past fire within the US. While successful as an integrator of available data sets and demonstration of web-enabled access to data and models, the WFEIS prototype needs refinement to meet the critical needs of the user community, but provides an opportunity to move quickly to a solution. We hope to address these shortcomings as our Applications project continues.

The decision-making activity we address with WFEIS is to provide users with tools to quantify emissions from fire retrospectively for locations or regions of interest. The system is currently fully functional for wildland fire in the US and will shortly have the capacity to assess agricultural burning in the Continental US. The end users targeted for the project are atmospheric and smoke modelers and climate-change, wildfire, and smoke policy-makers. These groups include the regional air quality community (e.g. NWCG-SmoC, EPA/CMAQ, CIERA, WRAP) and continental- to global-scale carbon modeling community (e.g. CASA-GFED, NASA-CMS, CarbonTracker, GEIA). Additional potential end users include non-US agencies and institutions that have treaty requirements for reporting emissions, such as requirements set by the IPCC for the international community (e.g. UNFCCC reporting requirements). The focus of the WFEIS approach is on developing methods and tools that users can use to create emissions products that are specific to the user needs, rather than serving out pre-calculated emissions products as GFED does. The products that are possible from WFEIS can be used directly for user-required reporting or decision-making or to be integrated into a system that creates downstream information (e.g. CMAQ for air quality assessment and forecasting).

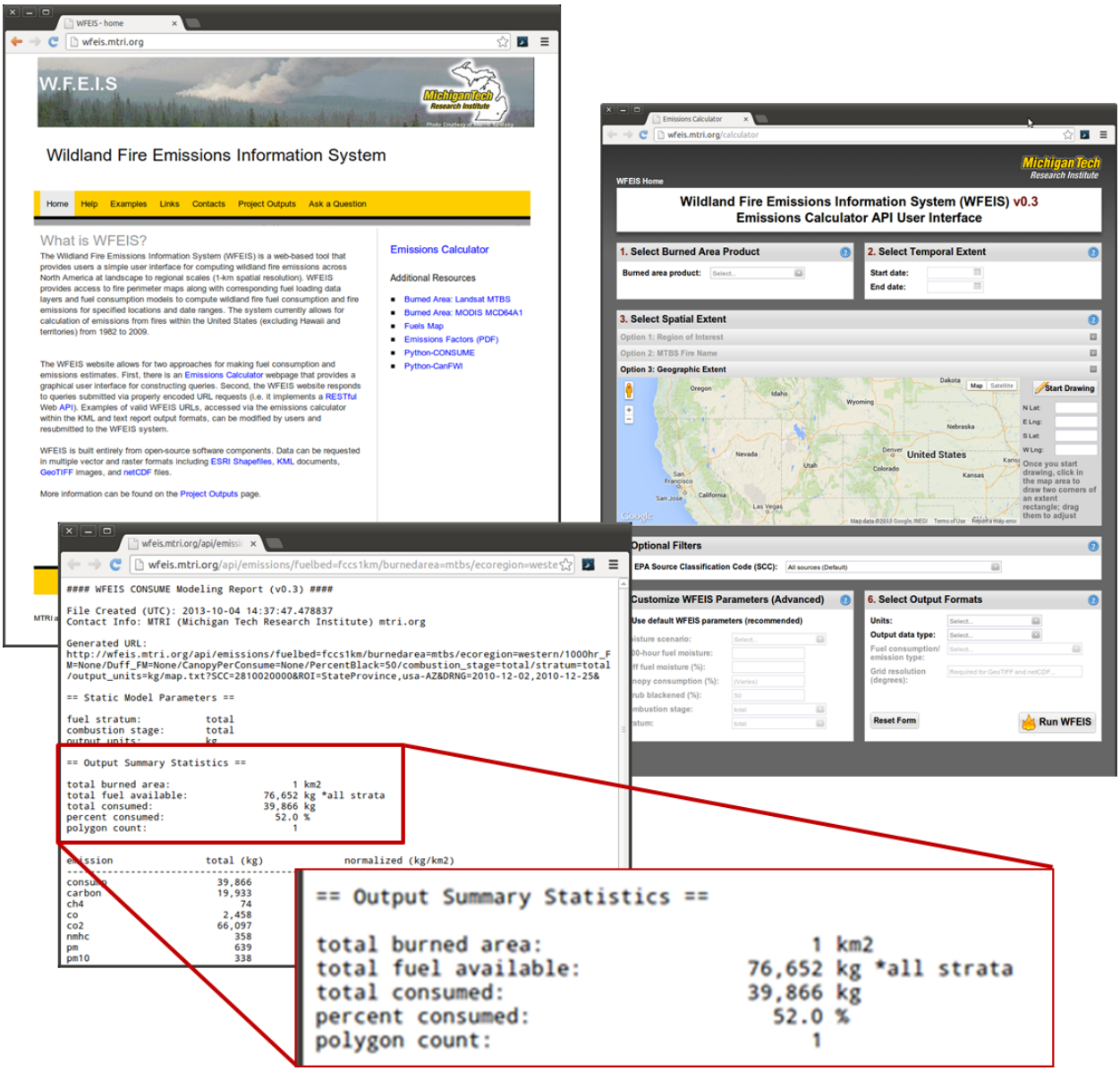

Figure 1. *The WFEIS system can be accessed from any web browser to compute fire emissions for past fire within the US (http://wfeis.mtri.org). The main page (upper left) provides links to base data sets needed for emissions mapping and the WFEIS calculator (right), where users can build a query based on location and timing and designate output format, including a text report (lower left). The text report includes the permalink URL and summary statistics for the output requested and a list of output polygons. GIS (ArcGIS and Google KML) and raster (gridded) outputs are also supported.*

1.2 Feasibility Study Approach

The feasibility project was formulated to show how WFEIS could be a viable and efficient tool for addressing the decision-making challenge of mapping wildland and agricultural fire emissions across regional scales. For this Applications project we proposed two Focus Areas. The Phase 1 tasks planned to show feasibility are listed here.

1.2.1 Focus Area 1: Emissions modeling improvements

Task 1. Consult with fire community to evaluate methods to integrate fire-occurrence data into decision system

Task 2. Explore methods to create dynamic fuels maps

Task 3. Develop improvements in the Consume model, including integration of available emissions factors and development of uncertainty estimation methods

1.2.2 Focus Area 2: Transitioning to an operational tool

Task 1. WFEIS documentation and demonstration to end users; and

Task 2. Explore potential decision system enhancements.

1.3 Earth Observations Used in Phase 1

Earth observation is integral to national-scale emissions mapping and monitoring. Research conducted at NASA by several groups has demonstrated the unique capabilities that NASA science can provide to the problem of spatial fire-emissions modeling. Spatial data sets on fire location and timing and satellite derived land cover dynamics are important information products developed at NASA with remote sensing and geospatial methods. NASA has provided funding to develop fire occurrence monitoring (MCD45, MOD/MYD14, FIRMS), fuels mapping and consumption modeling (WFEIS, BlueSky), vegetation dynamics (CASA-GFED), and web-enabled emissions information portals (BlueSky, WFEIS). Missing from this previous work, but very much the purview of NASA, are methods to quantify the uncertainty in the estimates of both source location and magnitude. NASA's capability in spatial data analysis and systems development can provide important insights for fire emissions modeling needed for fire and smoke management and carbon-budget modeling.

1.3.1 Integration of fire location & timing datasets

WFEIS uses previously developed resources to determine fire location and timing. The emphasis of this project is not on improving remotely sensed fire occurrence data, but we did add a burned-area product into WFEIS in Phase 1: the agricultural burning data developed by Co-I McCarty (*McCarty* 2011). The project plan does not include actively developing new fire occurrence products, but appropriate data sets will be integrated into WFEIS as new satellite-derived products are developed (e.g. VIIRS products).

1.3.2 Data and products for improvements in fuels mapping

In Phase 1 we have investigated a number of Earth Observation data sets for improving the mapped fuels. The following were chosen to for detailed investigation:

- NASA CMS biomass pilot data sets & outputs (http://carbon.nasa.gov/pilot.html)
- MODIS products: Active fire products, Vegetation Continuous Fields (VCF), Leaf Area Index (LAI), Fraction of Photosynthetically Active Radiation (FPAR), Land Cover Type
- Alaska-specific vegetation or cover-type classifications (alternative to Landfire)
- Field vegetation data (Forest Inventory and Analysis [FIA]/Current Vegetation Survey [CVS])
- Forest age and biomass mapping products from USFS-FIA (Blackard et al. 2008; Powell et al. 2010; Pan et al. 2011)
- Landfire "update" datasets of existing vegetation products (EVT/EVC) and FCCS
- USDA-NASS Cropland Data Layer (annual); USDA crop yield data

1.3.3 Data for improving WFEIS-based inputs to Consume

Several Earth Observation data sets for contributing to Consume model improvements were considered. The following were chosen for detailed investigation:

- National Fire Danger Rating System (NFDRS) fire weather and fuel moisture data (http://www.wfas.net/)

- DAYMET daily gridded weather data (http://daymet.ornl.gov/)
- Remote sensing-based fire severity maps for quantifying canopy consumption & shrub blackened levels based on fuel type.

1.4 Progress Report for Feasibility Study

Specific progress is outlined below along with ARL progress and feasibility criteria metrics and results. The project work plan followed in Phase 1 is generally unchanged from the proposal, but it has been combined with tasks for a related project funded through the NASA CMS Program. While related, the two projects have different end goals and foci. Overlapping tasks were merged, and the full MTRI project team is involved with both projects in order to complete the activities of the two projects efficiently.

Project administration and organization has been somewhat modified from the proposal in the Phase 1 activity. As proposed, Dr. Nancy French serves as the PI of the investigation. She is assisted on technical tasks by Co-Is McCarty and Endsley; Co-Is Erickson and Koziol are no longer working at the Institute. Tasks covered by them are being taken on by Endsley and a new research associate at MTRI (Molen). As proposed, Dr. Donald McKenzie of the USFS FERA serves as Co-I to assist the MTRI team and is assisted by Co-Is Ottmar and Prichard. C. Raymond is no longer with FERA so Dr. McKenzie is assisted by a geospatial analyst and a software engineer to complete tasks under Focus Area #1. We have met periodically to review project needs and tasks. Internal MTRI project team meetings are held monthly. Several additional meetings with the FERA project team have been called during this project year, including travel by PI French and a research assistant to Seattle in December.

1.4.1 Focus Area 1: Emissions modeling improvements

Task 1. Evaluate methods to integrate additional fire occurrence data into decision system

- Integrated into WFEIS Co-I McCarty's MODIS-based agricultural burning data set, which includes data from cropland fires that are not available from other sources.
- PI French made connections to other fire mapping activities including consultation with the USFS SmoC committee and JFSP Fire Emissions Inventory Tools Assessment Activity led by S Larkin, USFS.

Task 2. Explore methods to create dynamic fuels maps;

- Made final preparations for integrating croplands into WFEIS. The fuels map product of combined forest, rangeland, and cropland fuelbeds is available through the ORNL-DAAC (*French et al.* 2013a; *French et al.* 2013b).
- Integrated Co-I McCarty's cropland emissions modeling activities into WFEIS. Users will soon be able to query WFEIS to extract agricultural burning data sets developed by Co-I McCarty (*McCarty* 2011) and reported to the EPA for the National Emissions Inventory (NEI).
- USFS investigators developed a method to use MODIS Vegetation Continuous Fields (VCF; http://glcf.umiacs.umd.edu/data/vcf/) products for forest and shrubland canopy load adjustment and completed initial adjusted canopy loading product for integration into WFEIS.
- USFS investigators have obtained a forest biomass layer for the CONUS created by the NASA Carbon Monitoring System Phase 1 activity (http://carbon.nasa.gov/cgi-bin/cms/inv_pgp.pl?pgid=582#datasection). These data will be overlain on the FCCS

map and crosswalked to FCCS fuelbeds differently from the VCF, providing an explicit comparison of methods.

- USFS investigators will be exploring ways to verify or validate the fuel loading maps. Leveraging off of current activities, such as activities under the Biomass Mapping Pilot from CMS, may be the best avenue.
- Before the end of the Phase 1 project period we will demonstrate the use of MTBS fire perimeter maps to tag forest successional stage in order to modify fuel loading at disturbed sites in the FCCS fuels map. We are also considering integrating products from other projects (e.g. Landfire or NASA disturbance products) for this task.

Task 3. Develop improvements in the Consume model, including integration of available emissions factors and development of uncertainty estimation methods

- Proceeded with plans to improve fuel moisture maps used within WFEIS, which provide emissions modeling inputs to system.
- Began uncertainty assessment approach and demonstrated a method of quantifying uncertainty (http://wfeis.mtri.org/media/Docs/WFEIS_UncertaintyAnalysis.pdf).
- USFS team members are modifying (with documentation) the Consume equations in preparation for updating Consume in the near future.

1.4.2 Focus Area 2: Transitioning to an operational tool

Task 1. WFEIS documentation and demonstration to end users; and

- WFEIS system documentation is underway (Figure 2) and will be completed under the Phase 1 activity (by February 2014).
- Enhancements of the GUI emissions calculator have been implemented to make the system more helpful to users and include the creation of a user information and feedback form for users to contact us.
- Identified operational partners to approach to develop transition plans (see next section).
    - US-EPA Air Quality modeling group to help serve GHG and NEI needs
    - USFS Remote Sensing Applications Center (RSAC)
    - Identified possible avenues to discuss transitioning WFEIS to non-US countries for international reporting needs.
- Created products and demonstration materials to review with potential operational partners and cooperators:
    - Discussed WFEIS utility and possible avenues for system migration to and use by EPA greenhouse gas team members (Jim Szykman).
    - Reviewed WFEIS with Brad Quayle of the USFS Remote Sensing Applcations Center (RSAC) and provided transition plan report for his consideration. RSAC may be the best choice for operational partner for WFEIS.
    - Reviewed WFEIS with Mexican (D Perez-Salicrup) and Russian (D Ershov) potential partners for use internationally while at St Petersburg fire conference in July.
    - Connected with GOFC-GOLD lead Dr. Chris Justice who has invited PI French to present WFEIS to an international audience at an upcoming GOFC-GOLD Fire Team meeting focused on emissions.

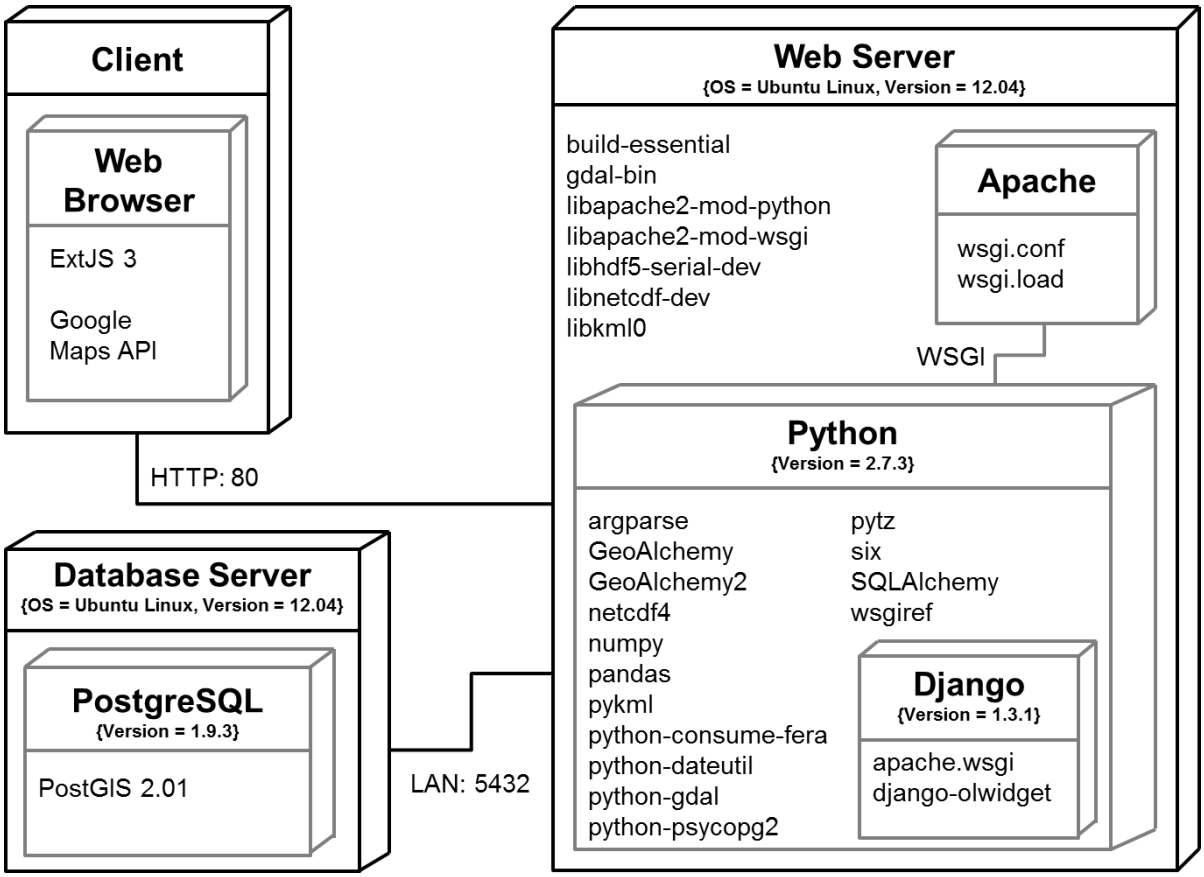

Figure 2. *Schematic of the WFEIS front end (upper left), database (lower left) and backend (right). Full documentation of the system is in process. WFEIS is built entirely from open-source software components, facilitating development of the web-accessible data and modeling framework. WFEIS uses RESTful software architecture to implement its Application Programming Interface (API) for producing emissions estimates.*

Task 2. Explore potential decision system enhancements.

- Created an automated WFEIS installation and deployment tool for Linux, which will allow adopters to set up their own WFEIS server and database with relative ease.
- Improved load-balancing by incorporating redundancy and query replication into the database system architecture; specifically, WFEIS is now served by a PostgreSQL database cluster of two separate PostgreSQL servers, each running PostGIS and with its own replication of the WFEIS datasets, which allows the current system to support twice as many users at the same level of performance.
- Added in-database support for the storage and manipulation of raster data, which will enable an expansion of services and faster data migration.
- Upgraded server environment for the current WFEIS instance from Ubuntu 10.04 to Ubuntu 12.04, taking advantage of improved security, performance, and continued long-term support (LTS) updates.
- Removing any obsolete, deprecated or irrelevant code is an ongoing task that seeks to improve overall code quality and therefore comprehension by potential adopters.

1.5 Operational Partners

In Phase 1 we identified potential operational partners to transition WFEIS out of the development environment at MTRI into an agency or institute that can house and maintain the system for the range of end users that WFEIS serves. Two are US Government partners, the USFS Remote Sensing Applications Center (RSAC) and the US EPA, who would be interested primarily in taking on the existing system that operates for CONUS and Alaska. Also under consideration is one or a group of international partners that would take on a more ambitious development activity in order to make the system relevant in an international setting. The US-based system, while operational now, has development needs that are different from needs required to roll out a system that operates in a non-US setting. If transitioned to an international setting, development would be fairly straightforward, since the system architecture is established, but new data sets would need to be integrated. While no confirmed Operational Partners are currently identified, we expect to have progress on this before the end of our Phase 1 activity in February. Discussions with US-EPA and the USFS RSAC group have occurred. Ideas for international partners will be developed based on contacts we have made, including discussions with Chris Justice, lead of the GOFC-GOLD-Fire activity (http://gofc-fire.umd.edu/index.php), who has invited us to an upcoming GOFC-GOLD meeting to present WFEIS. We have also had the suggestion to contact AMESD SADC, an African Institution that works on spatial data analysis and solutions, including fire management (http://www.amesdsadc.org/fire-products).

1.6 Phase 1 Outputs and Outcomes

1.6.1 Outputs

Published from this and previous work on the WFEIS:

- McKenzie, D., N. H. F. French, and R. D. Ottmar. 2012, *National database for calculating fuel available to wildfires*, EOS, 93(6), 57-58.
- French, N.H.F., D. McKenzie, N. Hamermesh, and J. McCarty. 2013. *NACP Integrated Wildland and Cropland 30-m Fuel Characteristics Map, U.S.A., 2010.* Data set. Available on-line [http://daac.ornl.gov] from ORNL DAAC, Oak Ridge, Tennessee, U.S.A. http://dx.doi.org/10.3334/ORNLDAAC/1163.

Conference presentations & proceedings:

- *AGU Fall'12, 7 Dec 2012, San Francisco, CA, USA:* "Estimating Biomass Burning Emissions for Carbon Cycle Science and Resource Monitoring & Management" Poster Presentation. French, NHF, D McKenzie, T Erickson, J McCarty, RD Ottmar, ES Kasischke, S Prichard, E Hoy, KA Endsley, N Hamermesh. Poster Presentation #NH53A-1807.
- *ForestSAT 2012, 14 Sept 2012, Corvallis, OR, USA:* "Remote sensing and geospatial data and tools for estimating pyrogenic carbon emissions" French, NHF, D McKenzie, J McCarty, T Erickson, B Koziol, M Billmire,. Oral Presenation
- *IAWF 4th Fire Behavior & Fuels Conference, 3 July 2013, St Petersburg, Russia:* "A US national fuels database and map for calculating carbon emissions from wildland and prescribed fire" French, NHF, D McKenzie, RD Ottmar, J McCarty, RA Norheim, N Hamermesh, Poster Presentation.

Internal reports and documents created or are in process for Phase 1:

- *WFEIS Installer* by N. Molen. Allows WFEIS to be passed to operational partners with relative ease.

- *WFEIS Uncertainty* by N. Hamermesh, A. Howes, and A. Grimm is a report documenting the approach planned for developing a complete uncertainty assessment of WFEIS. Available at: http://wfeis.mtri.org/media/Docs/WFEIS_UncertaintyAnalysis.pdf

- *WFEIS System Documentation* by N. Molen, K.A. Endsley, M. Billmire is in preparation.

1.6.2 ARL progress in Phase 1

The WFEIS has been developed through several funding vehicles with the explicit intent of making fire emissions information and tools fully accessible to the user community. The system is created from unrestricted data products, using a non-proprietary emissions model developed by the USFS, and a system software architecture that is made up exclusively from open-source resources. While fully operational, the WFEIS prototype requires further attention if it is to become a valuable resource to end users. Before the start of Phase 1, WFEIS was at an ARL of 4. The system worked with few glitches and was accessible via web browsers within and outside of the development lab, but full validation of the information supplied was not complete. Additional development has made WFEIS more reliable, there will be a full set of documentation completed by the end of Phase 1, and outputs have been compared to other emissions estimates and found to be within a reasonable range, although a full validation activity has not been conducted. Just before and during Phase 1 our team was involved in a project that used WFEIS output to estimate source emissions to compare to human health data, therefore the system was "tested in a simulated decision-making environment" which transitions it to a current level of ARL 5.

Table 1. *Required data sets needed for operation of WFEIS for within and outside of the US. "Current" are data used in WFEIS; "Desired" are data available but not yet integrated into WFEIS.*

Resource type	***Status***	***Resource***	***US-only***	***Global***
Burned area data	Current	Landsat MTBS	x	
		Landsat Daily	x	
		MODIS MCD64A1		x
	Desired	SmartFire for US	x	
		Country-specific		x
Fuel map	Current	1-km MODIS(VCF)-enhanced FCCS	x	
	Desired	Global 1-km FCCS (under development by M.L. Pettinari) or country-specific		x
Fuel loadings	Current	FCCS-derived loadings file for CONSUME	x	
	Desired	Loadings associated w/ Global1-km FCCS		x
Fuel moisture	Current	RAWS interpolated to Bailey's Ecoregions Level II	x	
	Desired	RAWS interpolated to 40-km grid	x	
		Country-specific		x
Consumption equations	Current	CONSUME	x	
	Desired	Country-specific and/or Global		x
Emissions factors	Current	CONSUME internal	x	
	Desired	Country-specific		x
		User-defined		x
Database backend	Current	PostgreSQL 9.1.9	NA	
	Desired	PostgreSQL 9.3+		
Database server	Current	Multi-master PostgreSQL cluster (pgpool II)		
JavaScript framework for emissions GUI	Current	Sencha Ext JS 3.3.1		
	Desired	Sencha Ext JS 4.2+		
Web framework	Current	Apache 2; Django 1.3.1		
Web server	Current	Virtual system: Linux Ubuntu 12.04 32-bit		
	Desired	Virtual system: Linux Ubuntu 12.04 64-bit		

1.6.3 Feasibility criteria results

The following criteria metrics were proposed in the Phase 1 plan to assess the feasibility of the project to progress to Phase 2. Here we review the status of these metrics:

1. ***Are users interested/engaged?***
   YES. Based on conversations and informal inquiries users find a spatial emissions mapping is of value to end users. US-EPA contacts have expressed interest in having this information available is an easy to use format that is repeatable. A WFEIS-like system was enthusiastically welcomed by potential international end users. One of the tasks left to complete before the close of the project is to poll potential end users to quantify interest. A web use counter has recently been installed to assess web activity.
2. ***Are data sets available for quantification of emissions and uncertainty?***
   YES. Improvements in several spatial data sets from existing WFEIS data are available. Table 1 lists required data sets for emissions mapping and validation/uncertainty assessment resources, including resources for development of a system outside of the US.
3. ***Are methods to disseminate products in place or easily developed?***
   YES. In Phase 1 we developed an installer script to buddle and automatically set up the WFEIS environment and dependencies. WFEIS will be distributed as an archive hosted on MTRI's FTP server once the need is defined. Because WFEIS uses open source software and unrestricted data inputs, and the Consume model is a non-proprietary model, dissemination of the system will have no restrictions. The system is "development friendly", meaning system components are accessible so future development outside of MTRI is possible.
4. ***Cost reality for operational partners and end user– do they have a mandate/need for the products they will eventually produce; are the costs of product creation within the limits of the user?***
   YES/UNKNOWN. There is a need for fire emissions information that is spatially explicit. Currently, many users do not have access to the level of information needed for emissions mapping that WFEIS provides for CONUS. For CONUS users, data from WFEIS needs to be vetted and validated to be valuable; for non-CONUS users, data needs to be compiled and WFEIS-like systems created for the country/region of interest. What is unknown is the cost reality of running WFEIS in comparison with users' resources. Table 2 provides an assessment of the resources required for maintaining WFEIS, assuming no data enhancements, once transitioned to an operational partner. Cost of end users (not operational partners) to run WFEIS queries would be minimal, so is not evaluated here.

Table 2. *Resources required for maintaining and servicing WFEIS.*

Resource	***Estimated resources/cost***
Physical or virtual web server	System w/ at least 4 GB RAM, 2 dual-core processors, Linux Ubuntu OS
Physical or virtual database server	System w/ at least 4 GB RAM, 2 dual-core processors, Linux Ubuntu OS
Maintenance labor	5% FTE
Data Updates (as needed)	5-10% FTE
Software/OS licenses	None (all FOSS)

Part 2: Phase 2 Plan

As explained above, **the decision-making activity** we address with WFEIS is to provide users with the ability to quantify emissions from fire using only their web browser. **The fire-related challenge** is to provide useful and timely fire emissions estimates to users with limited resources or expertise. In phase 1 we have demonstrated the operational capability of WFEIS and worked on identifying end users with needs this system can address. We also developed a specific method of transferring WFEIS to an operational partner. As stated in our Phase 1 Feasibility proposal, we propose two general thrusts (Focus Areas) for Phase 2 activities that build from the successes of Phase 1 and which if funded, will bring WFEIS from the current ARL 5 to a minimum of ARL 7:

1. Complete a set of system improvements to WFEIS input data, methods, and output data features and reliability to provide information that is useful to the end users;
2. Develop, demonstrate, and implement the transition of WFEIS to partner organizations that can house the system and service the end users.

We first review the work plan, and next review potential risks for success in Phase 2.

2.1 Work Plan for Addressing the Challenge of Quantifying Fire Emissions

The proposed work plan reviews our concepts on how to proceed to support end users' needs successfully. As partnerships with end users and operational partners mature this plan will be modified to fit with their goals and expectations.

2.1.1 Focus Area 1: System improvements for providing useful fire emissions estimates

The thrust of this focus is to continue to identify and implement improvements for WFEIS. The Focus includes improvements in data resources and system functionality. Many activities for WFEIS improvements have been or will be completed under the Phase 1. More advanced tasks have been identified for Phase 2. Specifically:

1. **Continue to integrate new remote sensing data products into WFEIS**—As new products for burn area and fuels mapping are developed, these data will be integrated into WFEIS. Specifically:
   a. Fire products from the VIIRS satellite could be valuable for fire location and timing for emissions, so we will assess new products as they are released;
   b. The USFS project team members will continue efforts to create improved FCCS loadings with MODIS and other remote sensing data sets;
   c. Efforts to create dynamic fuels maps (annually changing fuels) will continue and will tap into on-going projects at USFS, NASA, or USGS.
   d. Integration of moderate-scale (30m) fuels maps, which are available for the US, will be considered for specific end users for local/landscape-scale applications (e.g. operation within a specific National Park, National Forest, or small country).
2. **Integrate new Consume equations into WFEIS**—USFS team members are in the process of revising and evaluating the Consume model equations. WFEIS will be updated as necessary to stay current with the newest model features, which will include improved assessment of model uncertainty.
3. **Improve uncertainty assessment and output validation**—An important aspect of providing useful information for decision-making is providing some level of confidence in the estimates reported. Phase 2 will include efforts to assess the error introduced from the various system components and to develop metrics to be reported out with emissions estimates on the reliability of the results.

4. **User-defined spatial aggregation within the Emissions Calculator**—Currently, estimates of fire emissions are returned for every burned-area polygon within the area of interest (AOI). We propose to extend the WFEIS response system so that (a) it can provide aggregate estimates for user-defined AOIs and (b) it allows users to upload complex AOIs with many sub-units (e.g. watersheds) and will aggregate emissions.
5. **Accepting user-submitted burned area data**—In addition to the Monitoring Trends in Burn Severity (MTBS) and MODIS MCD64A1 catalogs, we would like to allow end users of WFEIS to upload their own burned area datasets for use in emissions calculations. A possible feature related to this would be to enable mobile fire mapping so emissions can be calculated "on the fly".
6. **Support for bulk emissions queries**—One outstanding feature request from the user community has been for support for bulk queries (or running WFEIS in "batch mode"). Currently, users are forced to use the WFEIS REST API, either directly by formatting request URLs or indirectly through the Emissions Calculator, for running only one query at a time. Where server resources are available, we will allow users to submit multiple queries at once, have the multiple outputs processed in a stream, and sent directly to users.
7. **New streamlined user interface for the Emissions Calculator**—The design of the current version of the Emissions Calculator user interface (UI) has been updated from the original. The change allows faster development, a build process for decreasing framework overhead, new and native features, and other general improvements. Most notably, the UI framework added support for (apparent) asynchronous file uploads, which is required in order to support user-submitted burned-area datasets.
8. **Additional improvements to support user integration of WFEIS outputs**—We will work with end users to determine what new export file formats or web services would be useful. Some may be possible to implement within the current grant period.
9. **Determine and optimize for user needs**—To support the previous item and other technical improvements, we will survey our stakeholders and the fire science community about what improvements can be made to the WFEIS system.
10. **Complete documentation of the WFEIS software architecture**—The effort to completely document the WFEIS code base has already begun. The end goal is to have documents and figures that completely describe the software architecture at a level appropriate for software developers to enable future enhancements and modifications. Higher-level documentation will also be developed for non-developers.

2.1.2 Focus Area 2: End-user transition

Before and during Phase 1 we developed and refined a fully functional system to map wildland and agricultural fire emissions across CONUS and Alaska, as well as a software script to transfer the system into the hands of an operational partner. The transition of the WFEIS system to RSAC or another potential partner is straightforward. No hardware will need to be transferred – the WFEIS system currently runs on a virtual Ubuntu Linux server, which could be installed on existing hardware at most organizations, including RSAC. The database server is hosted by a separate virtual server but could be run on the same virtual server as the WFEIS web server. In Phase 1 we created an installer script (see section 1.4.2). An important part of the effort planned in Phase 2 will be to have MTRI experts – the people who developed and designed the WFEIS – implement the transition of the system out of MTRI and into the institutional setting of the operational partner. This will involve hands-on coordination with the operational partner personnel.

The USFS Remote Sensing Applications Center (RSAC) is a logical choice for a partner to adopt WFEIS and transition it to an operational setting. If transitioned to RSAC the main emphasis for development will be in improving FCCS maps of fuels and Consume modeling of emissions within the US along with a concentrated effort to assess the validity of the data inputs, model, and output products (emissions estimates). Housing the WFEIS at RSAC would allow users from across the US government, including the US-EPA GHG and NEI teams, to access reliable data on fire emissions that is consistent between government agencies and consistent in space and time (see letter from L. Tarnay). We would work directly with these US-based end users to be sure the system complemented other tools and data systems and used standard, vetted data inputs (see letter from N. Larkin, head of USFS AirFire Team, regarding coordinating standardized data inputs and models).

An additional US Government operational partner is the US-EPA, which requires emissions data for GHG and emissions inventories as well as air quality modeling. EPA has been involved in aspects of WFEIS development (under a previous NASA Applications project lead by A. Soja). The agricultural emissions data developed by Co-I McCarty and available from WFEIS was delivered to EPA for the 2011 NEI, and the products are accessible through the WFEIS UI. We are planning to discuss specifics on how US-EPA may access WFEIS with Tom Pierce, Deputy Director of US-EPA Atmospheric Modeling and Analysis Division. One pathway would be to have USFS RSAC house WFEIS and have USEPA partners access via RSAC.

Development of WFEIS for use outside of the US has great potential (see Table 1 and letter from G. Frost, co-Chair of GEIA). International operational partners have not been identified, but the ability and the need are there. For example, Mexico is moving to improving their fire emissions accounting with an emphasis on improving fuels maps and fire detection capabilities (D. Perez-Salicrup pers. comm.), and many efforts are in place to develop country specific datasets required to model at better than IPCC Tier 1 for wildland and prescribed fires. Before Phase 1 is complete we will have completed a scoping of possibilities for including international partners (see section 1.5).

We will provide specific metrics for assessing the benefits and impacts to operational partners in adopting WFEIS for emissions modeling. Such metrics include measuring the level of effort or length of time used for obtaining emissions estimates through current methods versus WFEIS. In all cases, we will set a benchmark metric before implementing transition steps. Specifically, we will measure and quantify the process currently used to assess fire emissions for the user's application (e.g. the effort for EPA NEI to compile data on wildland and prescribed fire, or the current assessment tier used by a country for international fire emissions reporting). We will then assess the expected level of effort once WFEIS is integrated into the process. While full integration (ARL 9) is not expected to be accomplished by the close of the Phase 2 activity, we will be in a position to assess the impact of the system on the decision-making process realistically, and may be very close to full operation as the project closes. Expectations are that WFEIS will be very cost effective for providing data on wildland and prescribed fire because the system provides a very fast processing environment, is data-ready (the best data sets for assessment are pre-loaded), and the system needs little operator involvement.

2.2 Expected Timeline and ARL Achievement

Year 1 and 2 will require significant hands-on work by MTRI and USFS FERA, but by year 3 we expect to have the system in the hands of operational users and be only troubleshooting and maintaining the system, while writing final documentation and assessing system performance. Metrics for assessing ARL level will be formulated with the help of the NASA Applications and

Operational Partner(s), and we expect to achieve ARL 6 by the end of Year 2. Year 3 we expect to be demonstrating the prototype at the Operational Partner's Institution, achieving ARL 7 by the close of the project.

2.3 Key Challenges and Risks

One challenge that could limit the success of making WFEIS an operational tool is the lack of financial or personnel resources of operational partners, who may have financial challenges that are difficult to foresee. First, US Government agencies, including the USFS RSAC, are operating in a very uncertain financial climate. On the positive side, however, adoption of WFEIS as a tool for mapping emissions sources across the US could be one of the more cost-effective approaches for delivering emissions maps. WFEIS has a fairly low level of operational maintenance (Table 2) and uses open resources, making upgrades easier and less costly than with proprietary systems. Second, the integration of WFEIS into international settings is difficult to gauge, since dissemination could take several possible routes. Exploration of mechanisms to move WFEIS into non-US settings is just starting. Although the WFEIS team has confidence that the system can operate outside of the US, and that data sets and models are available (see Table 1), the mechanisms to fund the transition and operation of such a system are not yet clear.

A possible risk we may encounter is that the WFEIS modeling system will not be accepted by operational end users as a viable method for fire emissions accounting. We have little concern regarding available data sets to run WFEIS inside or outside of the US (see Table 1). Efforts to create global maps of the components used for emissions modeling are underway, including a global FCCS fuels map (*Pettinari et al.* 2013). The robustness of WFEIS outputs is still being evaluated and improved, and we expect that they can be vetted in collaboration with end users to alleviate concerns about output validity. If this concern is alleviated the goal of ARL 7 is achieved, and we feel we are on a solid path to system development to rapidly reach an ARL 9.

2.4 Phase 2 Team and Estimated Cost

The project team will be essentially unchanged from our current effort. Dr. French will lead the effort as PI. Funding to include the USFS partners, with Dr. McKenzie as Institutional PI, is requested as they provide critical expertise and capability in fuels mapping and connection to the emissions model used within WFEIS. USFS funds will support a post-doctoral research associate and a geospatial analyst, with Co-I McKenzie and Co-I Ottmar's salaries contributed. An estimate of annual costs with break-down is given in Table 3[1].

Table 3. *Estimated cost for 3-year POP.*

		Year 1	***Year 2***	***Year 3***	***Total***
Labor	~36 mos FTE*	$120,000	$110,000	$70,000	$300,000
Travel	Project mtgs**	8,000	3,000	6,000	$17,000
Misc M&S		1,000	1,000	1,000	$3,000
F&A	50.75%*	66,000	56,000	40,000	$162,000
USFS costs***	~30 mos FTE	100,000	80,000	35,000	$215,000
Total		295,000	250,000	152,000	$697,000

*Estimates are based on current salaries, fringe and F&A rates and are likely to change. Labor FTE is for all team members and years combined. Fewer hours are budgeted in Y3 due to diminishing project scope.
**Travel includes trips to visit NASA program office, operational partners, and project team members
***USFS costs include salaries, fringe, and indirect costs for spatial data analysis and technical (software) support and travel for the PI to NASA meetings. USFS senior scientists' salaries are contributed (not included in estimate).

[1] *The information provided in this document is for discussion purposes only. It does not represent a firm quote and it does not commit University personnel, facilities or funds. Final terms and conditions of this sponsored activity are subject to University review and authorization of a formal proposal or agreement.*

3.0 Partner Endorsements

For the Phase 1 proposal we included two endorsement letters, one from Sim Larkin who leads the AirFire team and development of the BlueSky Framework, and one from Greg Frost, of UCAR/NOAA and co-chair of GEIA. These two cooperators have recently endorsed further development of WFEIS (see attached letters). Both of these cooperators are working on the same issues of finding solutions for providing data and information on emissions to managers, regulators, and policy makers, with Dr. Larkin serving the US land management community and Dr. Frost involved with international emissions inventories and policy. Additionally, an interested end user, Dr. Leland Tarnay, who works as Smoke Information Officer for Yosemite National Park, has agreed to provide a letter. We are expecting to have a letter of endorsement from RSAC and may have more information on potential international cooperators before the briefing in December.

UNITED STATES DEPARTMENT OF COMMERCE
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November 7, 2013

Dr. Nancy French
Senior Scientist
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Ann Arbor, MI 48105

Dear Nancy:

I am pleased to continue to be involved in the study "Improving agricultural and wildland fire source emission products and access to information for atmospheric science and smoke modeling applications". I look forward to connecting your efforts to the work of the Global Emissions InitiAtive (GEIA, www.geiacenter.org), which strives to enhance access to emissions information and facilitate analysis that improves the scientific basis of emissions data. As the co-chair of GEIA, I welcome the opportunity to bring attention to the problem of fire emissions estimation and mapping. The work of MTRI and FERA to improve US fire emissions information is quite useful to the atmospheric science community. The WFEIS represents a nice example of interoperability in earth science datasets, a goal shared by GEIA and other earth science community efforts.

From my short introduction to the WFEIS, I have seen that MTRI and FERA have developed a useful prototype approach and system for helping the community to coordinate fire emissions modeling. During Phase 2 of this study, I am happy to use my knowledge and experience with GEIA, as well as engaging the help of the GEIA leadership team, to facilitate connections to the emissions and atmospheric modeling communities, to provide advice on possible end users of a US system for emission mapping, and to advise MTRI and FERA in a possible extension of WFEIS to a global scale.

Sincerely,

Dr. Gregory J. Frost
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