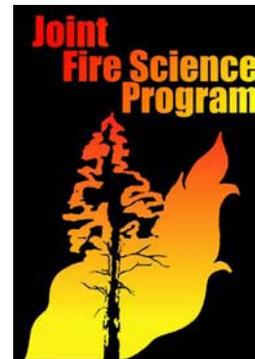


**Wildfire Inputs to Regional Air Quality:  
Remote Spatial-Temporal Measures for Improved  
Inventory Assessments.**

Final Report to the Joint Fire Science Program  
Project Number: 07-2-1-60  
June 30, 2010



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## I. Abstract

Accurate information on regional particulate matter concentrations is essential to burn permitting and airshed management. Such information is essential to efforts to comply with National Ambient Air Quality Standards. The standard approach (as also applied by Malm: # 01-1-5-01 and others) to quantify regional wildfire emissions, while the most widely applied and easily understood, exhibits considerable uncertainty. Specifically, apart from area burned, its parameterization does not account for the high spatial-temporal variability in fuels and fire behavior, nor the associated effects on fuel combustion and emission characteristics. As field measures of these parameters are logistically impossible to collect at scales meaningful for rapid or regional assessments, it is essential to develop and refine remote sensing methods for this purpose. An alternative approach to estimate smoke emissions from wildland fires that has been highlighted in recent years has been to estimate the smoke source strength directly using empirical algorithms based on estimates of the energy radiated by the fire.

In this project we proposed to measure this radiative energy for each fire-affected pixel throughout the entire duration of large-scale candidate fires; and use the corresponding smoke source strength as inputs within regional transport models. Unlike the traditional approach, this method provides data on the rate of smoke emission when the fire is occurring, and so incorporating such measures into regional air quality models (e.g., the BlueSky Smoke Modeling Framework and associated dispersion forecast systems and the AIRPACT-3 regional air quality forecast system) should enable improved real-time spatial-temporal emission assessments.

Specifically, we proposed to: 1) Select several large wildfires and evaluate the spatial-temporal variability of the emission source strengths, 2) Compare the emissions using the traditional methodology and via prior regional assessments 2) Demonstrate the sensitivity of current air quality models to these different emission methods and 4) present findings/method to managers/researchers.

As with all projects it immediately became clear that other research questions and outreach objectives were critical to further advance the science and ultimately inform managers of air quality and smoke management issues. As a result, we conducted considerable additional analysis and expanded our outreach objectives through coordination with companion projects. These additional science and outreach objectives included:

- i. Evaluate the ability of MODIS to actually detect active fires and thus potentially impair the estimation of smoke production,
- ii. Evaluate what factors of MODIS impact the detection of active fires,

- iii. Evaluate the upper limit of smoke production per fire by incorporating vegetation type specific fuels data from FCCS and LANDFIRE,
- iv. Synthesize material relating to air quality and smoke management policies across multiple agencies,
- v. Organize and host two regional workshops aimed at multiple federal and state agency personnel that focus on how to effectively communicate smoke management issues in the face of continually changing policies,
- vi. Develop and offer online trainings in air quality and smoke management based on the presentations and feedback of those workshops,
- vii. Develop trainings materials to accompany the online trainings and workshops, and
- viii. Present feedback and findings of these workshops and online trainings to researchers, in addition to state and agency personnel at meetings and conferences.

These additional tasks were completed partially through additional complementary funding via two other projects funded by NASA (iii.) and by the National Wildfire Coordination Group (NWCG) smoke committee (SMoC, iv-vii).

## II. Background: Emission Calculations

Accurate information on regional particulate matter concentrations is essential to burn permitting and airshed management and also important for quantifying impacts on regional radiative budgets, investigation of regional atmospheric chemistry, and assessment of health risks. Current regulatory restrictions and land management mandates are substantially increasing fire managers' need for accurate emissions information. The 2006 revision of the National Ambient Air Quality Standard for PM<sub>2.5</sub> lowered the 24-hour standard from 65  $\mu\text{g m}^{-3}$  to 35  $\mu\text{g m}^{-3}$ , almost cutting them in half. Healthy Forest Initiative and fuel management targets require land managers to reduce fuels on a scale never before achieved; national discussions of "appropriate suppression response" would blur the current distinction between fire use fires and wildland fires and make these targets even more difficult to attain. The majority of regional wildland fire emission studies rely on the parameterization of a simple equation (Sieler and Cruzten, 1980; Levine 1996; Smith et al 2005):

$$\text{Total Emissions of X} = A * B * b * EF_X \quad (1)$$

Where, A denotes the area burned by the fire (hectares), B denotes the pre-fire fuel loading (kilograms per hectare), b denotes the combustion factor (the proportion of dry biomass actually combusted), and  $EF_X$  denotes the emission factor of a gas X (the amount of gas X emitted in grams per kilogram of dry fuel combusted).

The quantity of fuel combusted is dependent on several factors including the type, arrangement, and moisture of the fuel, in addition to the current seasonal/meteorological conditions (Hardy *et al.*, 2001). This uncertainty has been reported to be as high as  $\pm 23$ -75% in Alaska (French *et al.*, 2004) and is known to vary considerably between flaming and smoldering combustion phases within a single fuel type. For example, in grasslands Ward *et al.*, (1996) reported the percentage of fuel combusted as  $85 \pm 17$  and  $15 \pm 17$  % within flaming and smoldering combustion, respectively.

Emissions from vegetation fires ( $EF_X$ : pounds of gas X per ton of fuel combusted) vary with the stage of combustion and season of fire (Kasischke and Bruhwiler 2003). Specifically, Andreae and Merlet (2001) highlighted that within vegetative fires the emission factors for gases that only contain carbon, oxygen, and hydrogen (i.e. CO, CO<sub>2</sub>, CH<sub>4</sub>, NMHCs) are predominately a function of the fire's combustion characteristics. In an aggregation of emission information from global biomass burning studies, Andreae and Merlet (2001) highlight that the uncertainty of  $EF_X$  for principal carbonaceous species (e.g. CO, CH<sub>4</sub>, etc) is on the order of 20-30%, but that the actual uncertainty is likely higher as this estimate does not include the known differences in emission characteristics present under different combustion phases. In several North American ecosystems (including Douglas fir, ponderosa pine, hardwoods, and mixed conifers), the CO emission factor ( $EF_{CO}$ ) has been shown to vary by up to 500% when considering smoldering over flaming combustion (Hardy et al 2001). Therefore the reliance on measures that do not account for the spatial variation in the fuel load nor the fire behavior, which governs the combustion and emission characteristics, is a considerable limitation.

In contrast, the methodology presented in this project will provide direct measures of the total biomass combusted and importantly, apart from low combustion rates ( $<0.001 \text{ kgs}^{-1}/0.132 \text{ bsm}^{-1}$ ), this method provides very accurate (i.e.  $\pm 15\%$ ) estimates of the rate of fuel combusted (Wooster et al 2005) and smoke emitted. As outlined by Lentile et al (2006) and Kremens et al. (2010), following early research at the Missoula Fire Lab by Wilson et al (1971), remote sensing in the middle infrared (MIR:  $3.9 \mu\text{m}$ ) and thermal infrared (TIR:  $11 \mu\text{m}$ ) has allowed physical measures of the energy radiated by the combustion of fuels within each fire-affected pixel to be measured by aerial and satellite sensor systems (Kaufman et al. 1998; Butler et al 2004; Ichoku and Kaufman 2005). This quantity is called the fire radiative power (FRP) and is directly proportional to the rate of fuel combusted (Kaufman et al 1998; Wooster et al 2005). The total energy radiated within a pixel is called the fire radiative energy (FRE) and is calculated by summing-up the power within each pixel over the entire duration of the fire. If the heat yield of the fuels is known then the biomass combusted per pixel can be simply calculated by dividing the FRE by the heat yield (Andrews and Rothermel 1982) or by applying experimental regressions.

The fire's energy can be measured using field, aerial, and satellite sensors (Butler et al 2004; Riggan et al 2004; Smith and Wooster 2005). Importantly, this allows for near real-time fire behavior monitoring, and also enables accurate fire location and intensity information to be obtained. Although numerous satellite sensors have been used to measure FRP, including a geostationary satellite capable of measurements every 10 minutes (Wooster et al 2005), the most appropriate satellite sensor for real-time monitoring in North American wildfires remains the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor, which acquires data 3 to 4 times within a 24-hour day. Ideally, we would want near-continuous measures as could be obtained with in-situ or some aerial systems, however MODIS data is free and always available, while aerial systems can be both costly and require flying permissions. More importantly if such remote systems can be used in the future, this would limit future risk to field crews that are currently monitoring fire behavior and emissions.

### III. Data and Methods

#### 1. Calculating Smoke Emissions from MODIS

In this project, we used the FRP heat flux methodology to infer smoke emission rates in six large (>10,000 ha) Pacific Northwest (PNW) region wildfires that have occurred since 2004. These six fires were chosen with advice of our Forest Service collaborators and included the Columbia Complex Fire, the Boundary Complex Fire, the Rattlesnake Complex Fire, the Red Mountain fire, the South Fork Complex fire, and the Tripod fire. For each fire, we collected the daily fire progression maps that were generated by RSAC/EROS and obtained via NIFC. These progression maps were generated using Landsat data. Figure 1 illustrates the progression maps on the Gash Creek fire. This example additionally highlights that each day the LANDFIRE vegetation type from which fuel loading can be evaluated via the FCCS system.

Figure 2 illustrates the density of MODIS active fire product points within the Columbia Complex Fire.

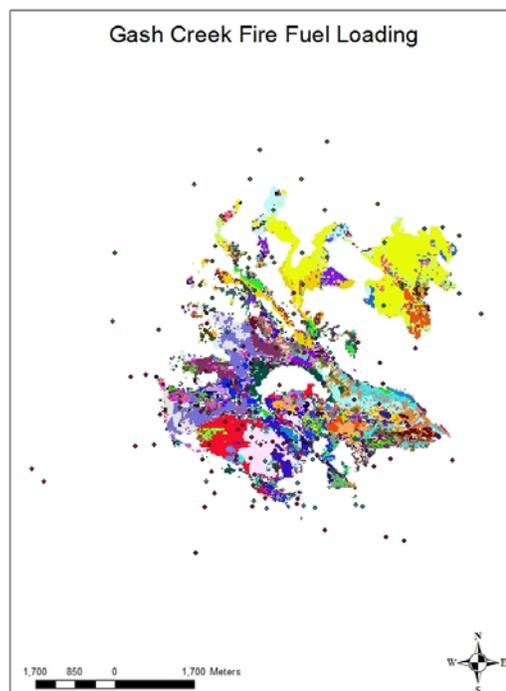
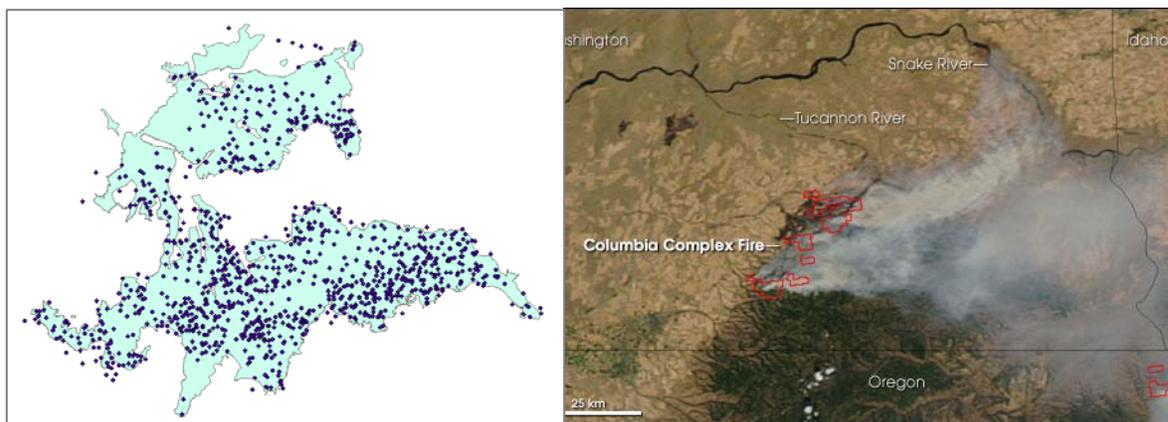


Figure 1. Example Progression map from the Gash Creek fire. Blue dots represent MODIS FRP points.



**Figure 2.** Spatial extent and location of MODIS FRP points within the Columbia Complex fire.

The MODIS 14 active fire product already calculates the radiant heat flux for all detected fire-affected pixels. The product is free and is acquired 3 to 4 times per day. The product contains the lat/long, time of day, and heat flux of each pixel detected as containing an active fire. Following Smith and Wooster (2005), we corrected the radiant heat flux value of the fire's radiated energy for the true area of the pixel (as MODIS pixels become warped at the edge of the swath). The product is easily downloaded from the NASA Distributed Active Archive Centers (DAACs), of which one is hosted by USGS-EROS. For each of our selected fires, we summed the FRP for each fire-affected pixel over the lifetime of the fires. This integral enabled generation of the Fire Radiative Energy (FRE). We then applied existing published relationships between FRE and smoke source strength as presented by Ichoku and Kaufman (2005) and others (e.g., Freeborn et al 2009) to evaluate the  $PM_{2.5}$  emission rates for each point for each day of the fire's progression. A conversion factor between FRE and  $PM_{2.5}$  has been determined for several different fuel types. The conversion factor for evergreens in the Northwest are in the range of 0.018 and 0.066 kg/MJ; for this project, we take 0.04 kg/MJ as an average. As such, multiplying the FRE each day by this factor will produce daily  $PM_{2.5}$  emissions in kg/day.

## 2. Calculating Smoke Emissions from SMARTFIRE

The BlueSky Modeling Framework (Larkin *et al*, 2009; <http://blueskyframework.org>) was developed by the U.S. Forest Service AirFire Team to facilitate the connections between fire information, fuel loading, fire consumption, fire emissions, plume rise, and dispersion and transport models. Originally intended to help model prescribed burning, BlueSky has also been used for general (all fire) wildland fire smoke modeling, as well as to facilitate emissions inventory calculations such as the US EPA National Emissions Inventory (NEI).

Under a grant from NASA, and in conjunction with Sonoma Technology, Inc., BlueSky has recently been updated and paired with the new SMARTFIRE fire information system (<http://blueskyframework.org/smartfire>) that reconciles ground based and satellite fire information systems into a single data stream. SMARTFIRE uses fire detects from NOAA's Hazard Mapping System (HMS) in conjunction with the wildfire ICS-209 ground reports, and combines the results into fire perimeters and fire areas. This reconciliation is done on a daily basis.

The NOAA HMS fire detect product used by SMARTFIRE utilizes a large number of satellite sensors, including the MODIS active fire product, as well as GOES fire detects via WF-ABBA. All fire detects are quality controlled/quality assured by a combination of automated systems and human expert opinion. Known false detect hotspots are removed and probable fire locations not detected but that have a clear visible smoke signature are added. The resulting product contains a mix of satellite-derived fire detects from various sensors.

Fire emissions were computed by running SMARTFIRE reconciled (HMS + ICS-209) fire areas through fuel loading and consumption calculations enabled by BlueSky. Because BlueSky is a modular framework that implements many different models for each modeling step, it is important to note the specific modeling pathway used for any purpose as different pathways can yield different answers. For purposes here, emissions were calculated using SMARTFIRE v1.0 area estimations in conjunction with the fuel loadings from the FCCS 1-km map, the CONSUME3 consumption calculation, and FEPS emissions speciation as implement in modules in BlueSky version 3.0.1. For purposes here we shorthand this process as "SMARTFIRE."

### **3. MODIS Active Fire Product Detections**

A stated limitation of the proposed approach was that the MODIS sensor acquires 3-4 scenes a day and thus does not provide a continuous assessment of the fire's heat flux, as could be achieved via aerial or in-situ systems. In the proposal we highlighted that although this data might not provide a representative distribution of the wildfire source strengths, we anticipated that the time integrated heat flux measure (per pixel) over the lifetime of the fire will provide sufficient information to characterize the spatial variability. Further, we noted that even 3-4 measures of the spatial-temporal variation in source strength provides more physically based information than the traditional approach, which only provides a singular spatial estimate.

Although beyond the scope of this project, a question that was raised was whether the MODIS active fire product could provide reasonable assessments of actual fire observations. To achieve this H. Heward (University of Idaho) got Fire Use Modules (FUMs) and Interagency Hotshot

Crews (IHCs) to take active-fire observations that could be compared to the MODIS active fire data. In total, 22 FUMs and 78 IHCs agreed to make fire observations for her study.

Each participating group was sent observation packets and asked to record fire behavior and location information that they would otherwise normally record as part of normal operations. In addition to the standard observations they were asked to record whether other fires were present within 1km of their observation such that we could determine whether other energy sources from the same fire were contributing to the MODIS active fire detection. In total, 265 crew observations were collected from wildland fires, with data covering 23 different ecoregions.

#### **4. Synthesis and Development of Smoke Management Trainings**

Increasing knowledge of air quality impacts on human health is leading to the tightening of more stringent air quality standards. These standards affect natural resource managers tasked with meeting ecological and management objectives while simultaneously adhering to the latest air quality standards. This creates a need for management professionals who are familiar with the latest air quality regulations, knowledgeable of the air quality effects of their actions and how to mitigate them, and are capable of interacting with multiple stakeholders to collaboratively address smoke management and air quality issues.

To help meet these needs we, alongside a complimentary project funded by the National Wildfire Coordinating Group's (NWCG) Smoke Committee (Smoc), have and are continuing to develop a suite of educational materials to help further the knowledge of air quality and smoke management:

- **Workshops and Online training modules** are directed at agency fire personnel responsible for coordinating and collaborating with air quality regulatory agencies at the state level.
- **Online tutorials** are designed for members of the fire community who are seeking an overview of air quality impacts and their effects on prescribed and wild fire management.
- **Smokepedia** is an online interactive glossary of smoke management terms and acronyms.
- **AQ Library** contains links to several air quality guides and web sites.

##### **i. Workshops and Online Trainings**

To date, two regional 3-day workshops were organized in 2008 and 2009 (Figure 3).

**Figure 3.** Workshops arranged in coordination with funding from the NWCG that focused on inter-agency collaboration issues that occur due to changes in smoke policies.



These inter-agency training workshops were aimed at personnel who need to work with the public and other agencies to develop smoke management/air quality approaches. Each was entitled, “*Effective Communication for Smoke Management in a Changing Air Quality Environment*”. The first workshop was aimed at the Eastern United States and was located at the Great Smoky Mountains National Park (September 16 - 18, 2008), while the second workshop was aimed at the mid-western United States and was located at the Carl T. Curtis National Park Service Midwest Regional Headquarters (February 24 - 26, 2009). These workshops qualified for 17 continuing education credits through the Society of American Foresters.

Subject matter experts from the BLM, EPA, state agencies, The Keystone Center, and USFS presented current air quality regulation and policies, their implications to fire management, how to address these changing policies, and communicate in a group of multiple stakeholders to address these issues. Topics included (not an exhaustive list):

- Air quality regulations
- How fire managements fits into the EPA’s regulatory structure
- Fire emissions: composition and human health effects
- Visibility and smoke
- Prescribed Fire Councils: Their Role and Importance in Addressing Smoke Management and Air Quality Issues
- Fire Activity and Emissions Inventories: Their Use in Smoke Management Decision Making and State Implementation Plans
- A Look at the Arizona Smoke Management Program

Additionally, the workshop included a day long “*Negotiating Smoke Management Rules in a Changing Air Quality Environment*” exercise that was developed by the Keystone Center. All the presentations were recorded with the MediaSite Suite, which enables video and presentations to be seamlessly recorded and re-presented on a slide-by-slide basis.

The screenshot shows the Blackboard interface for a discussion titled "EPA perspectives" under the course "Effective Communication for St...". The discussion description asks: "To the best of your knowledge what is the information required to demonstrate that a prescribed burn or wild fire qualifies as an Exceptional Event? If you have been involved in submitting information for an Exceptional Event designation, what information did you include, and was it successful? Note: Please include which EPA region to which you are referring in your post." A highlighted message box contains the same text. Below the message is a "Create Message" form and a list of discussion topics including "EPA perspectives (New)", "interim policy (New)", "EPA perspectives (New)", "Re:EPA perspectives (New)", "Rx as an Exceptional Event (New)", and "EPA Perspectives".

**Figure 4.** Example of an online discussion in the Blackboard software package.

The online training is a two month program based upon material from these regional workshops, with the addition of interactive components such as online discussion groups (Figure 4). Participants view presentations from smoke management and air quality experts in multiple agencies. As they advance through material, participants engage each other in online discussions where they examine air quality and smoke management issues they are dealing with, how they address these issues, and how the material viewed relates back to their work. Four main topic areas of this training are:

- Basic air quality regulations and impacts
- Multiple perspectives on smoke and air quality
- Negotiating and networking
- Smoke management plans and approaches

## ii. **Online tutorials**

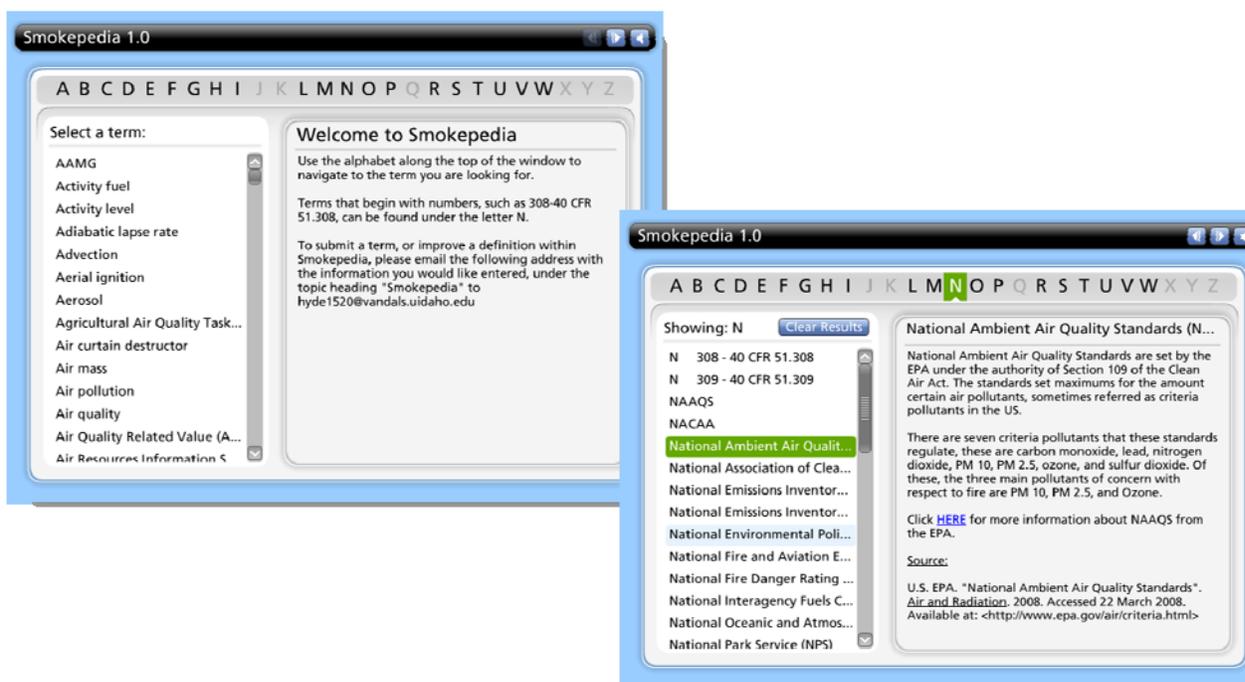
The tutorials provide a web-based overview of material on air quality and smoke management, and examples of instances where air quality concerns and management affected each other. These tutorials are open to all and available at:

[http://www.cnr.uidaho.edu/smoc/online\\_refresher.htm](http://www.cnr.uidaho.edu/smoc/online_refresher.htm)

## iii. **Smokepedia and AQ Library**

Smokepedia makes common smoke management and air quality terms and acronyms quickly accessible by alphabetically organizing them in an online glossary through which users can search for specific terms. This feature is also available in the online trainings and tutorials and is continually updated based on user input.

The AQ Library, or Air Quality Library, is a list of links to documents, guides, and websites used in the development of the online tutorials and Smokepedia. This list of materials makes it easy for users to further pursue documents and materials to broaden their knowledge on a range of smoke management and air quality subjects.



#### IV. Further Directions

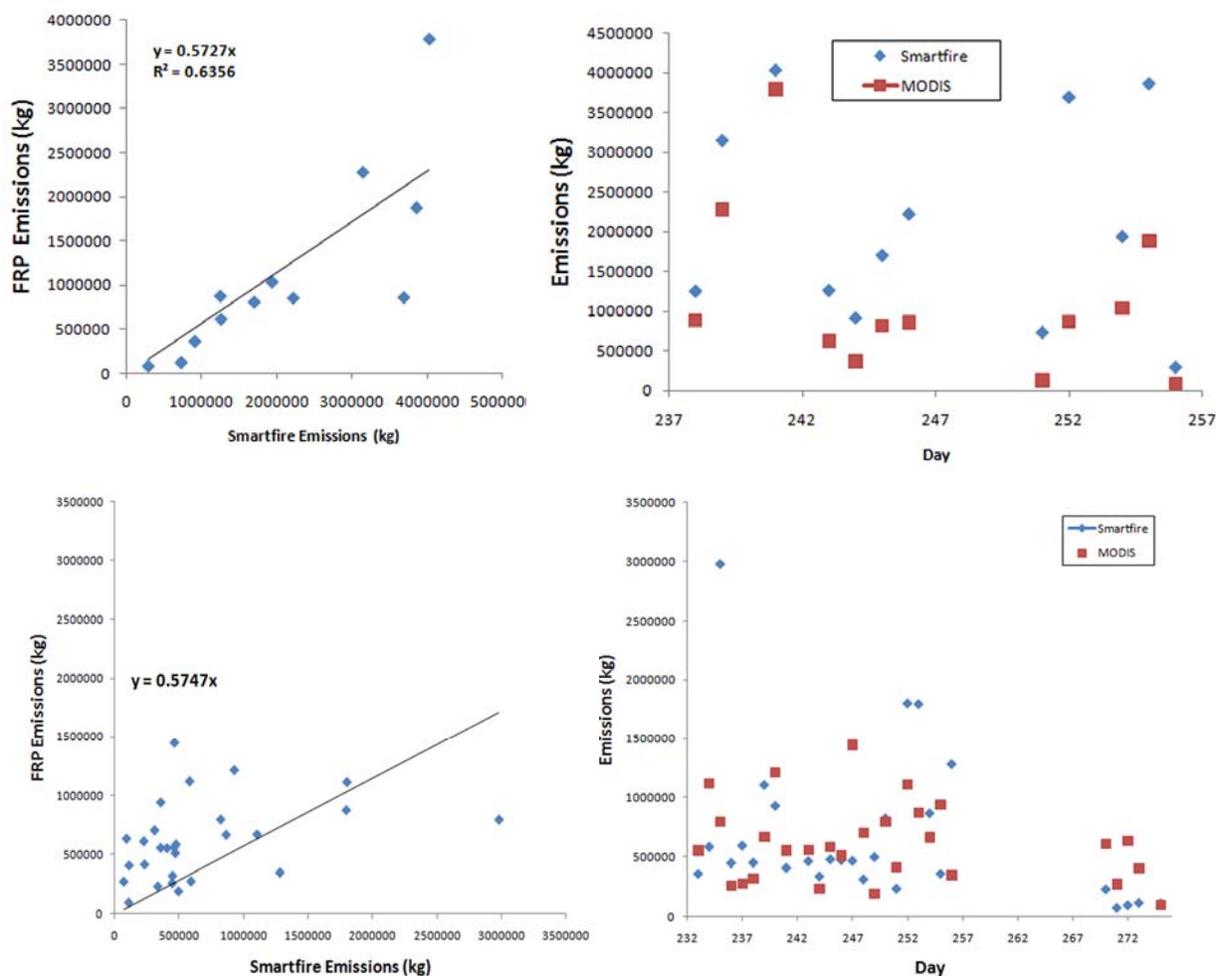
Via continued coordination with NWCG SMOc we are continuing to advance outreach in air quality and smoke management beyond the lifetime of the current proposal. An ongoing area of advancement includes a review of air quality and smoke management content in position task books and federal training courses. This review of current courses and multi-agency positions is being undertaken to assess their smoke management and air quality content requirements; the goal being to provide potential recommendations on content, requirements, and delivery formats of those materials. We are also coordinating with NWCG SMOc to potentially help update the Smoke Management Guide and the associated Rx-410 training materials.

#### V. Key Findings

##### a) Comparing Smoke Source Strength Using MODIS and SMARTFIRE

The comparison across all six fires highlighted that in general MODIS estimated 53% of the smoke emissions estimated by SMARTFIRE (Figure 8). Figures 5 and 6 illustrate that for 4 of

the 6 investigated fires MODIS estimates were between 27 and 48% less than emissions obtained from SMARTFIRE. However, these results were not globally consistent, as Figure 7 shows that in two fires, the MODIS estimates were larger than those from SMARTFIRE by up to 200%.



**Figure 5.** Comparison of MODIS FRP and Smartfire PM<sub>2.5</sub> emissions from the Boundary Complex (Top) and Rattlesnake Complex (Bottom) fires.

The day by day comparison of the MODIS FRP and SMARTFIRE estimates of PM<sub>2.5</sub> yield an interesting result. Although Figures 5-6 differ in estimation magnitude the temporal trends of these six datasets do appear to show similar trends. i.e. peaks and troughs generally appear at the same time intervals (albeit the differences may be generally higher or lower depending on the fires). Although more research is clearly warranted to evaluate this comparison across a much wider range of fires, especially in a broader set of fire prone ecosystems, the results do suggest that both approaches offer high degree of agreement of the emission estimates.

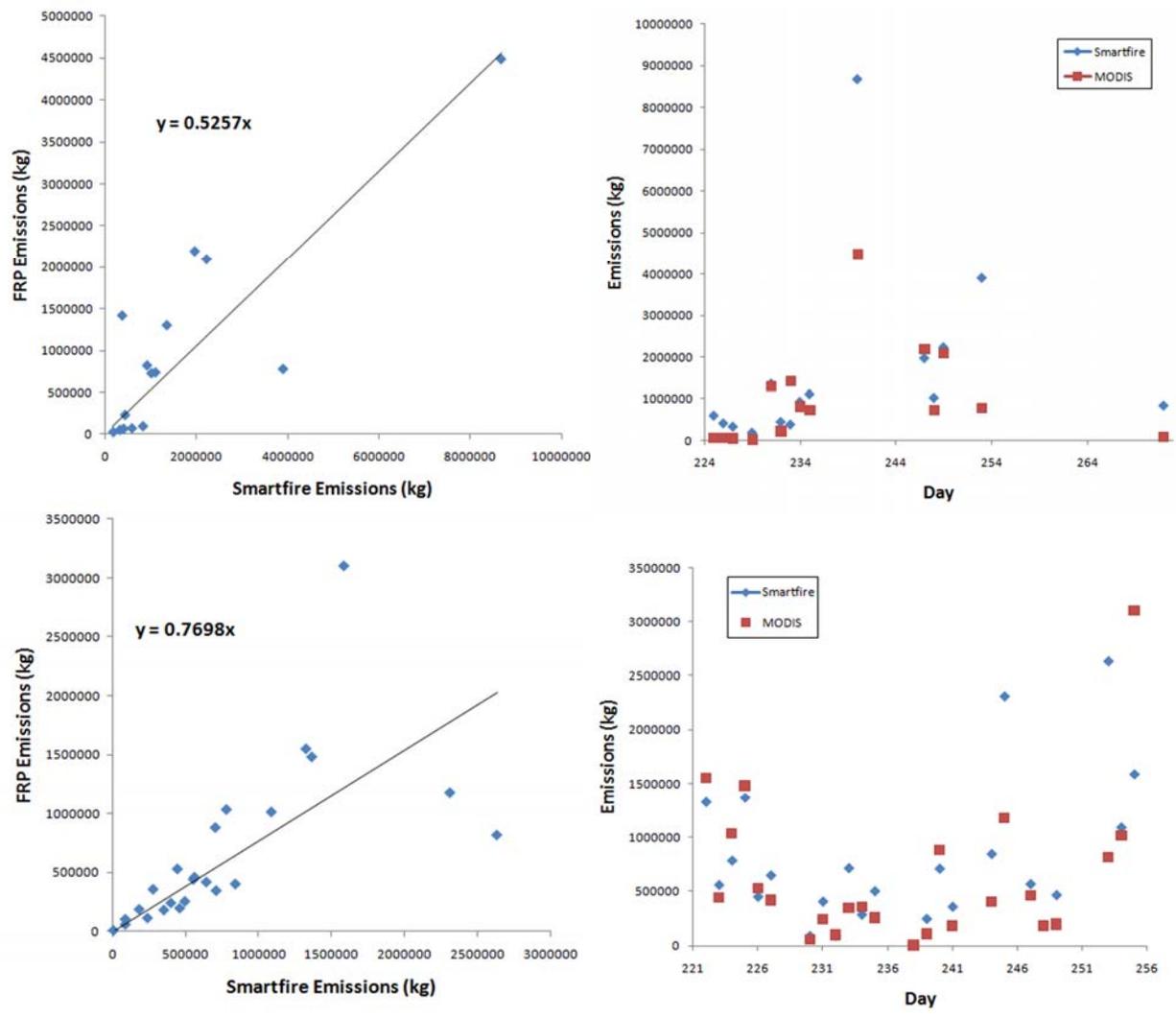
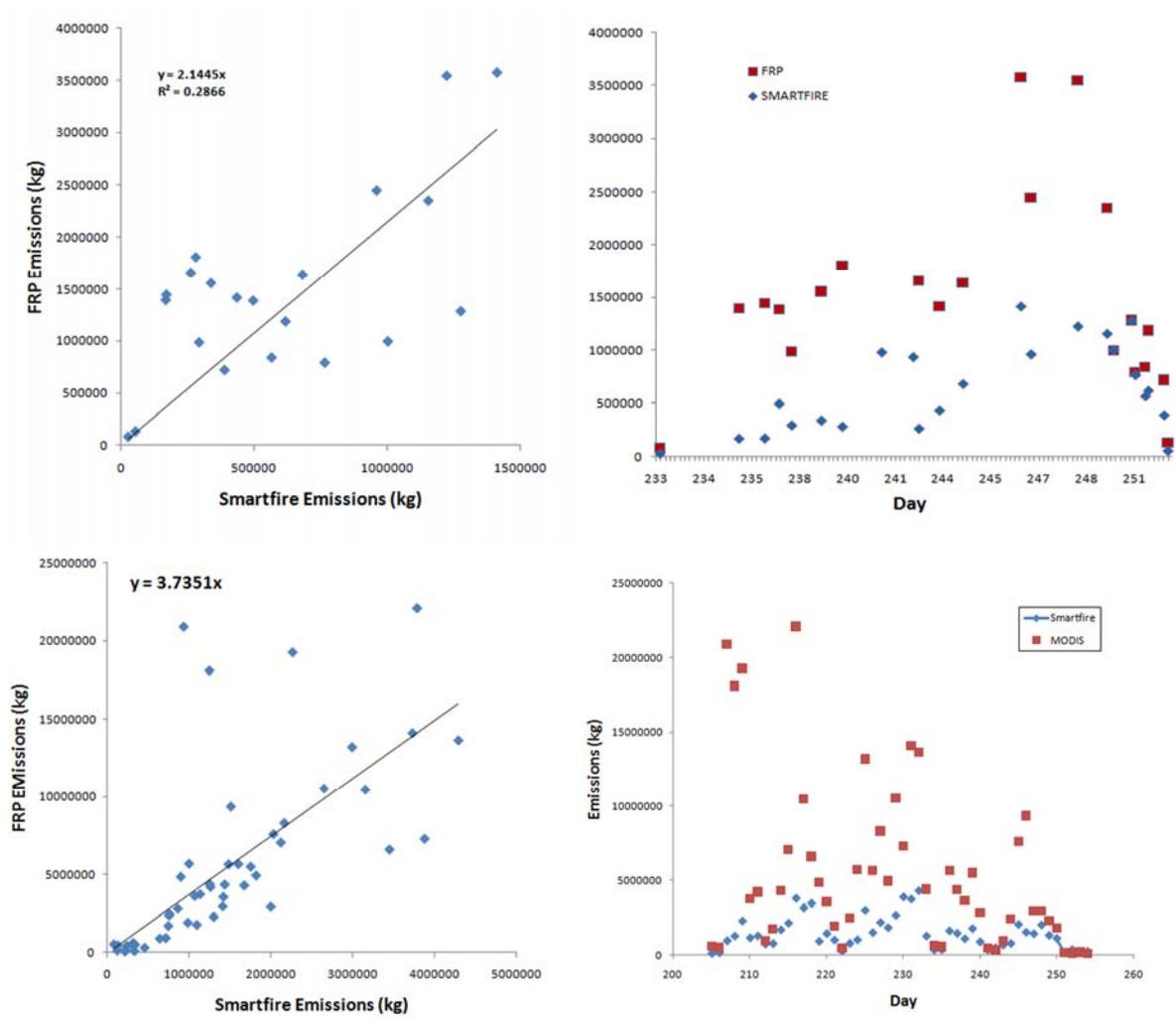
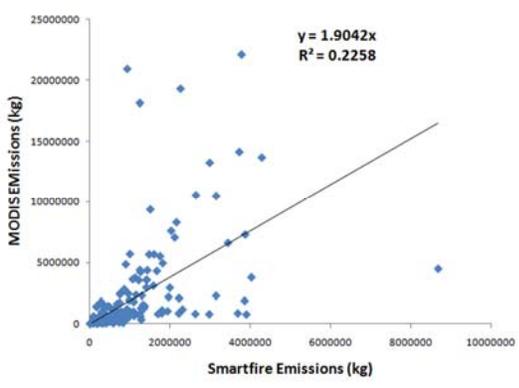


Figure 6. Comparison of MODIS FRP and Smartfire PM2.5 emissions from the Red Mountain (Top) and South Fork Complex (Bottom) fires.



**Figure 7.** Comparison of MODIS FRP and Smartfire PM2.5 emissions from the Columbia Complex (Top) and Tripod (Bottom) fires.



**Figure 8.** A comparison of PM2.5 emissions by day as calculated with MODIS FRP and SMARTFIRE across all days of 6 investigated fires

### **b) MODIS Active Fire Product Detections**

The ground-truth fire observations compiled by Heward demonstrated that of the 265 observations, MODIS only detected 1/3<sup>rd</sup> of the active fire points. Clearly, if we transfer these results to the assessment of smoke and emissions then this could lead to a serious source of underestimation in the event that insufficient spatial coverage of FRP points was available. Further work is required to confirm these results and develop methods for improving the satellite detection techniques.

### **c) Ongoing and Future Collaboration with the NWCG Smoke Committee:**

Alongside the NWCG Smoke Committee we are continuing to review, synthesize, and provide recommendations to update smoke management and air quality trainings and materials. As part of this effort, we are currently conducting a comprehensive review of all NWCG course materials and position task books, in addition to internal agency requirements (e.g. FSH 5109.17) to evaluate their smoke management and air quality content. Although an ongoing effort, initial findings have indicated that per the PMS-310 framework of NWCG positions only eleven currently require formal course material in air quality and smoke management. However, the review highlighted that of these eleven only two require trainings in Rx-410 Smoke Management Techniques; i.e. RXB1 and LTAN positions. Additionally, it is feasible to attain a position via multiple career paths that may / or may not require trainings with formal smoke management and air quality trainings. Via this coordinated effort, we are envisioning that research findings from the current project (and from other JFSP projects) will be recommended as revisions to the smoke management and air quality training materials.

### **Summary and Potential Further Research**

In closing, this project would have to conclude that at present using MODIS FRP to get emissions is not needed as the SMARTFIRE approach sufficiently appears to capture the temporal emission trends and the magnitude to a comparable order of magnitude to what MODIS also estimates. However the jury is still out on which approach is actually more accurate. Answering this would require probably combustion lab/emission experiments that tackle the emissions from the two standpoints. i.e. (1.) where the radiative power is measured and (2.) using custom fuel beds in FCCS / Consume and then input those values into SMARTFIRE. The key is that the radiative power approach is mechanistic so should be more accurate - but we probably need data from airborne sensors (like RIT's WASP) or the FIREMAPPER that can capture radiative power emissions every few minutes during the fire. MODIS fails in this regard given it only gets 3-4 images a day.

## References

- USDA FS. 2006. Wildland Fire and Fuels Research and Development Strategic Plan; Wash, DC: U.S. 50
- Andreae, M.O. and Merlet, P., (2001), Emission of trace gases and aerosols from biomass burning, *Global Biochem. Cy.*, 15, 4, 955-966
- Andrews, P.L., and R.C. Rothermel. 1982. Charts for interpreting wildland fire behavior characteristics. USDA For. Serv. Gen. Tech. Rep. INT-121
- Butler, B.W., Cohen, J., Latham, D.J., Schuette, R.D., et al., (2004), Measurements of radiant emissive power and temperatures in crown fires, *Can. J. For. Res.*, 34, 1577-1587.
- French, N.H.F., Goovaerts, P. and Kasischke, E.S., (2004), Uncertainty in estimating carbon estimates from boreal forest fires, *J. Geophys. Res.*, 109, D14S08, doi:10.1029/2003JD003635.
- Hardy, C.C., Ottmar, R.D., Peterson, J.L., Core, J.E. and Seamon, P (2001) Smoke management guide for prescribed and wildland fire, National Wildfire Coordination Group Publication PMS 420-2, USDA
- Ichoku, C. and Kaufman, Y.J. (2005) A method to derive smoke emission rates from MODIS fire radiative energy measurements, *IEEE Geosci. Remote*, 43,11, 2636-2649.
- Kasischke, E.S. and Bruhwiler, L.P. (2003) Emissions of carbon dioxide, carbon monoxide, and methane from boreal forest fires in 1998, *J. Geophys. Res.*, 108, 8146, doi:10.1029/2001JD000461
- Kaufman, Y.J., Kleidman, R.G. and King, M.D. (1998) SCAR-B fires in the tropics: Properties and remote sensing from EOS-MODIS, *J. Geophys. Res.*, 103, 31,955-31,968
- Larkin N.K., O'Neill S.M., Solomon R., Raffuse S., Strand T., Sullivan D., Krull C., Rorig M., Peterson J., Ferguson S.A. 2009: The BlueSky smoke modeling framework. *Inter. J. Wildland Fire*, 18, 906-920.
- Lentile, L.B, Holden, Z., Smith A.M.S, Falkowski M.J., Hudak, A.T., Morgan, P., Gessler, P.E. and Benson, N.C., 2006 Remote sensing techniques to assess active fire and post-fire effects, *International Journal of Wildland Fire*, 15, 3, 319-345
- Riggan PJ, Tissell RG, Lockwood RN, Brass JA, Pereira JAR, Miranda HS, Miranda AC, Campos T, Higgins R (2004) Remote measurement of energy and carbon flux from wildfires in Brazil. *Ecol. Apps* 14, 3, 885-872.
- Smith AMS, Wooster MJ (2005) Remote classification of head and backfire types from Modis fire radiative power observations. *International Journal of Wildland Fire* 14, 249-254
- Strauss, D., Bednar, L., and Mees, R. (1989). Do one percent of the forest fires cause ninety-nine percent of the damage? *Forest Science* 35: 319-328
- Ward, D.E., Hao, W.M., Susott, R.A., Babbitt, R.E., et al., (1996) Effect of fuel composition on combustion efficiency and emission factors for African savanna ecosystems, *J. Geophys. Res.*, 101, D19, 23569,23576.
- Wooster, M.J., Roberts, G., Perry, G.L.W. and Kaufman, Y.J., (2005) Retrieval of biomass combustion rates and totals from fire radiative power observations: Part 1 - Calibration relationships between biomass consumption and fire radiative energy release, *J. Geophys. Res.*, 110, D21111: doi: 10.1029/2005JD006318.

### Summary of Deliverables

<b>Proposed</b>	<b>Status</b>
Website, Annual, and Final Report	Completed:
Peer reviewed paper	<p>Expanded:</p> <p>Main research paper (that these results highlight) is currently in internal reviews and will be uploaded on JFSP page once in formal peer review</p> <p>A review paper focusing on smoke production and the combustion of coarse woody debris was published by Joshua C. Hyde:</p> <p>Hyde, J.C., Smith, A.M.S., Ottmar, R.D, Alvarado E.C., and Morgan P., [exp 2011] The Combustion of Sound and Rotten Coarse Woody Debris: A Review, <i>International Journal of Wildland Fire</i>, in press</p> <p>2 additional research papers will be shortly submitted for review as a result of the extra MODIS fire detection research. These will be uploaded on JFSP page once in formal peer review</p>
<p>Contribute to a brochure &amp; Synthesis</p> <p>Update Online GTR</p>	<p>Modified and Partially Completed.</p> <p>The findings have been included as part of the broader effort with the NWCG SMOc. This synthesis has been incorporated into the development of online trainings (currently via SMOc) in addition to the two formal workshops. Via this NCWG SMOc connection we are also working towards including the methods highlighted in this proposal in a forthcoming revision of the Smoke Management Guide and related training materials.</p>
Presentations:	<p>Completed:</p> <p>Start, R., Lamb, B., Smith. A.M.S., and Potter, B., 2008, Using MODIS FRP values to estimate forest fire PM2.5 emissions, <i>EOS Trans</i>, 89 (53), Fall Meet. Suppl., Abstract B31C-0306</p> <p>Start, R., Lamb, B., Smith, A.M.S. Potter, B., Hyde, J., Wildfire Inputs to Regional Air Quality Remote Spatial-Temporal Measures for Improved Inventory Assessments, International Fire Congress, Savannah, GA, December 2009.</p>
Develop GS-0401 course syllabus and lectures	<p>Modified and Completed.</p> <p>Material was included within the online training course developed alongside the NWCG SMOc committee. The online course is a 2 month training that includes presentations from the regional workshops and discussion forums.</p>

Update other GS-0401 (e.g., UI: 435-remote sensing of active fire and post fire effects)	Completed.  The 435 course will be next offered for both online and on campus participants in Spring 2011.
Host Handbook on FRAMES	Not Completed - However, goal is to incorporate the findings (and methods) highlighted in this proposal within a pending effort with NWCG SMOc to revise the Smoke Management Guide and related training materials. This update will include an online version of the smoke management guide to be hosted on FRAMES.
<b>Additional Deliverables:</b>	Completed in conjunction with NWCG SMOc
<b>Synthesis</b>	Synthesis of air quality and smoke management terms and related policies was completed. An online glossary of the air quality and smoke management terms, called Smokepedia, was developed. Accessible via:  <a href="http://www.cnr.uidaho.edu/wildlandfire/smoc.htm">http://www.cnr.uidaho.edu/wildlandfire/smoc.htm</a>
<b>Workshop</b>	Effective Communication for Smoke Management in a Changing Air Quality Environment I  This first regional workshop was aimed at the Eastern United States and was located at both the Great Smoky Mountains National Park (September 16 - 18, 2008).
<b>Workshop</b>	Effective Communication for Smoke Management in a Changing Air Quality Environment II  This second regional workshop was aimed at the mid-western United States and was located at the Carl T. Curtis National Park Service Midwest Regional Headquarters (February 24 - 26, 2009).
<b>Training Session (online course)</b>	Completed - currently 500 persons have taken this online training in " <i>Effective Communication for Smoke Management in a Changing Air Quality Environment</i> " - the goal is to continually offer this training course via a University of Idaho's online course.
<b>Website</b>  (including online trainings materials)	The University of Idaho and the National Wildfire Coordinating Group's (NWCG) Smoke Committee (SmoC) have developed a range of educational materials to further your knowledge of air quality and smoke management. These resources can be found at:  <a href="http://www.cnr.uidaho.edu/wildlandfire/smoc.htm">http://www.cnr.uidaho.edu/wildlandfire/smoc.htm</a>
<b>Poster</b>	The effect of decomposition on coarse woody debris combustion: a preliminary investigation, Hyde, J., Smith, A.M.S., Ottmar, R., Morgan P., Robberecht, R. International Fire Congress, Savannah, GA, December 2009

<b>Poster</b>	Hyde, J., Smith, A.M.S., Lahm, P., O'Neill, S.O., Fitch, M., George, M., Sherron, R. and Curcio, G., Furthering air quality and smoke management trainings, poster prepared for USDA FS DC Office.
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