MichiganTech Research Institute

Development of the Wildland Fire Emissions Information System for spatial quantification of fire emissions

Nancy French & Tyler Erickson

Funded by NASA Carbon Cycle Science and Applied Science Programs
Project performance period: 4/1/2008 to 3/31/2011

Wildland Fire Emissions Information System (WFEIS)

Project Goal: To improve information products for modeling and estimating fire emissions across North America for users who manage carbon, need emissions information, or model the carbon cycle.

WFEIS Purpose:

- Improve access to emissions modeling data sets and models
- Provide best estimates of total carbon emissions and some emission components to user community
  - Geospatially at 1km resolution
  - At daily to annual temporal resolution
  - For recent fire years (1980's to 2009)

Additional funding allows extension of the project goal to include cropland/rangeland biomass burning and improve emissions factors for use by the EPA

WFEIS Team

Nancy HF French, PI

Tyler Erickson

Michigan Tech Research Institute, Michigan Technological University

Don McKenzie

Roger D. Ottmar

Ernesto Alvarado

Pacific Northwest Research Station, USDA Forest Service

Eric S. Kasischke

Department of Geography, University of Maryland

William de Groot

Great Lakes Forestry Centre, Canadian Forest Service

Research Associates & Interns:

Mike Billmire, Ben Koziol, Eric Keefauver, Liza Jenkins, Ron Kempker, Jef Cieslinski, Marlene Tyner, Reid Sawtell, Christina Nolte, Peter Gamberg, Naomi Hammermesh, Michael Battaglia

Outline of Today's Presentations

1. Overview of NASA project & WFEIS development

2. WFEIS Demo and web system framework
   - Demo of the WFEIS API User Interface ("front end")
   - Details of the WFEIS geospatial framework ("back end")
   - WFEIS output formats – use and data visualization

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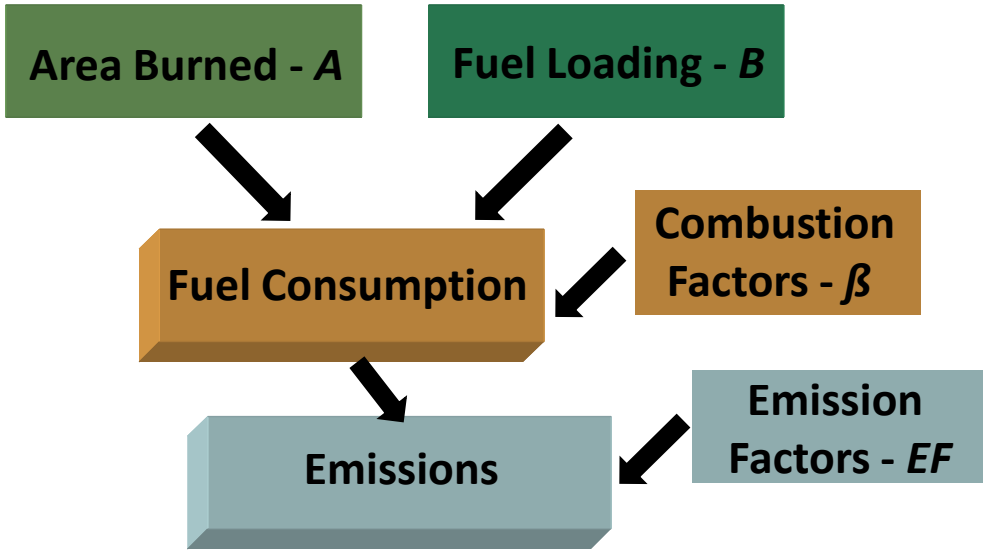
3. Details of WFEIS emissions model (for discussion)

The Wildland Fire Emissions Information System (WFEIS)

http://wfeis.mtri.org/

Photo courtesy NFIC

WFEIS Inputs



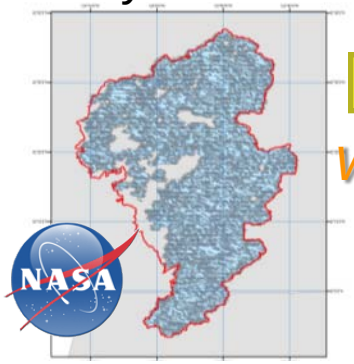
- Burn Area
  - Landsat-derived MTBS perimeters 30 m
  - MODIS-derived burn area (DBBAP) 500 m

- Fuel Loading – FCCS* standard fuelbeds mapped to 1-km
- Combustion factors defined by the CONSUME model; links with FCCS fuelbed by strata; default fuel moisture inputs derived from daily weather data
- Emission Factors – Integrated with COMSUME; applied by FCCS fuel strata for each fuelbed

***Fuel Characteristics Classification System** (http://www.fs.fed.us/pnw/fera/fccs/index.shtml)

WFEIS Estimation of Fire Emissions

Location and day of fire



Where/when?

Daily weather → Fuel moisture

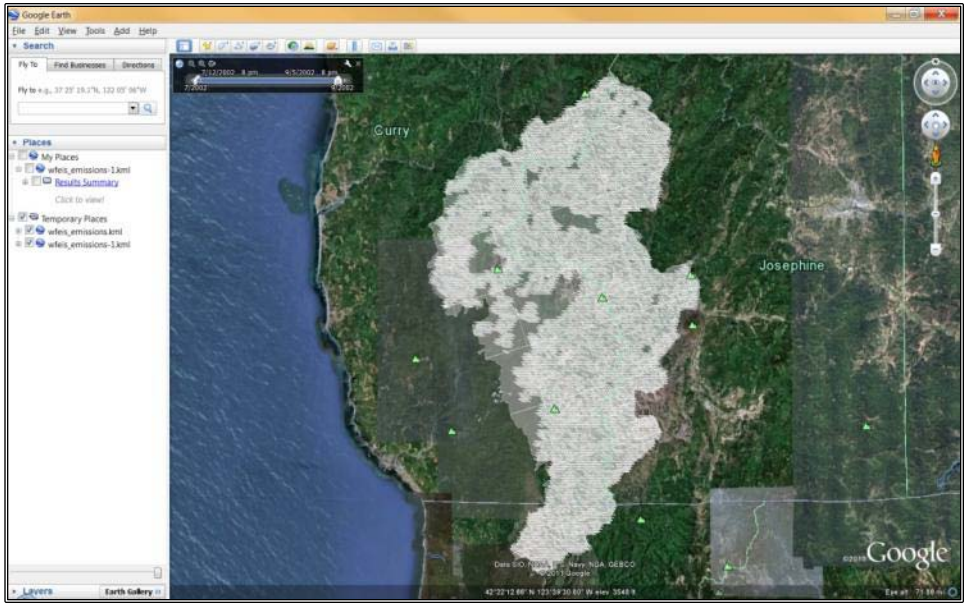
Consumption & Emissions model (Consume - Python)

Output: Spatial representation of emissions

Where?

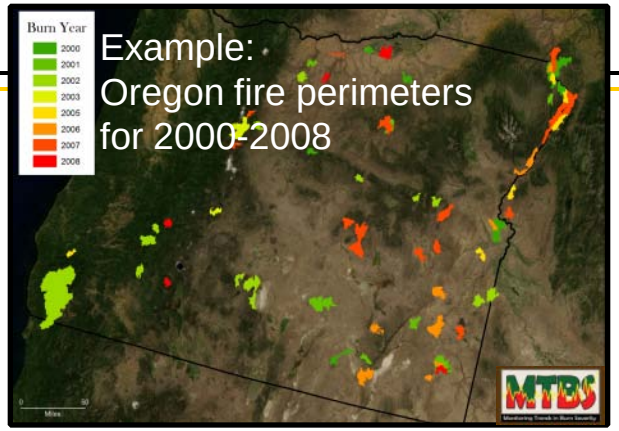
Fuel (vegetation) type (FCCS)

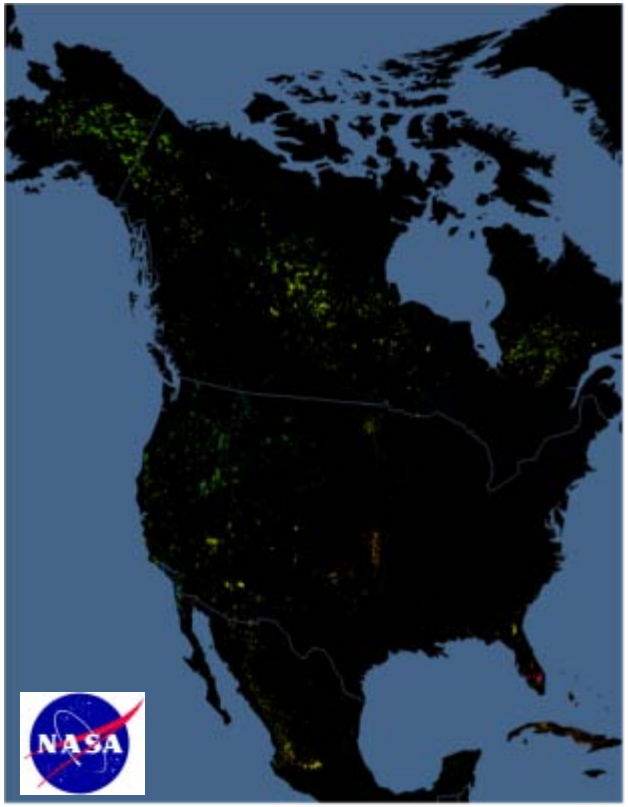
Fuel load (biomass) and fire behavior



Burn Area Datasets

- Perimeters from Monitoring Trends in Burn Severity maps (MTBS) *http://mtbs.gov*
- MODIS-derived Direct Broadcast Burn Area Product (DBBAP)
  - 500 m spatial resolution
  - Algorithm uses MODIS surface reflectance, daily active fire, and land cover products
  - Burn cells tagged by approximate burn date
  - North America-wide for 2001 to present





Fuel Characteristics Classification System (FCCS)

Canopy Stratum

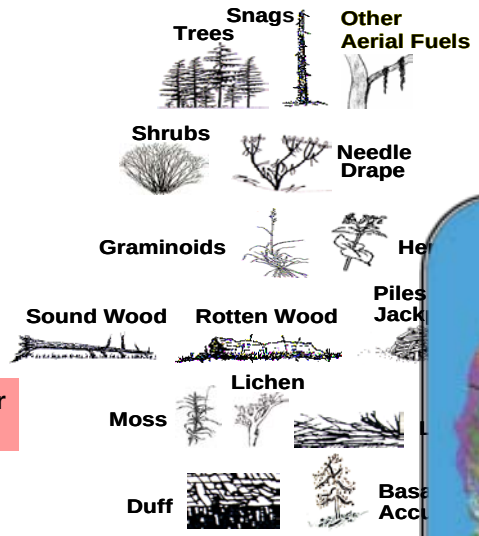
Shrub Stratum

Non-woody Stratum

Woody Fuel Stratum

Moss, Lichen, Litter Stratum

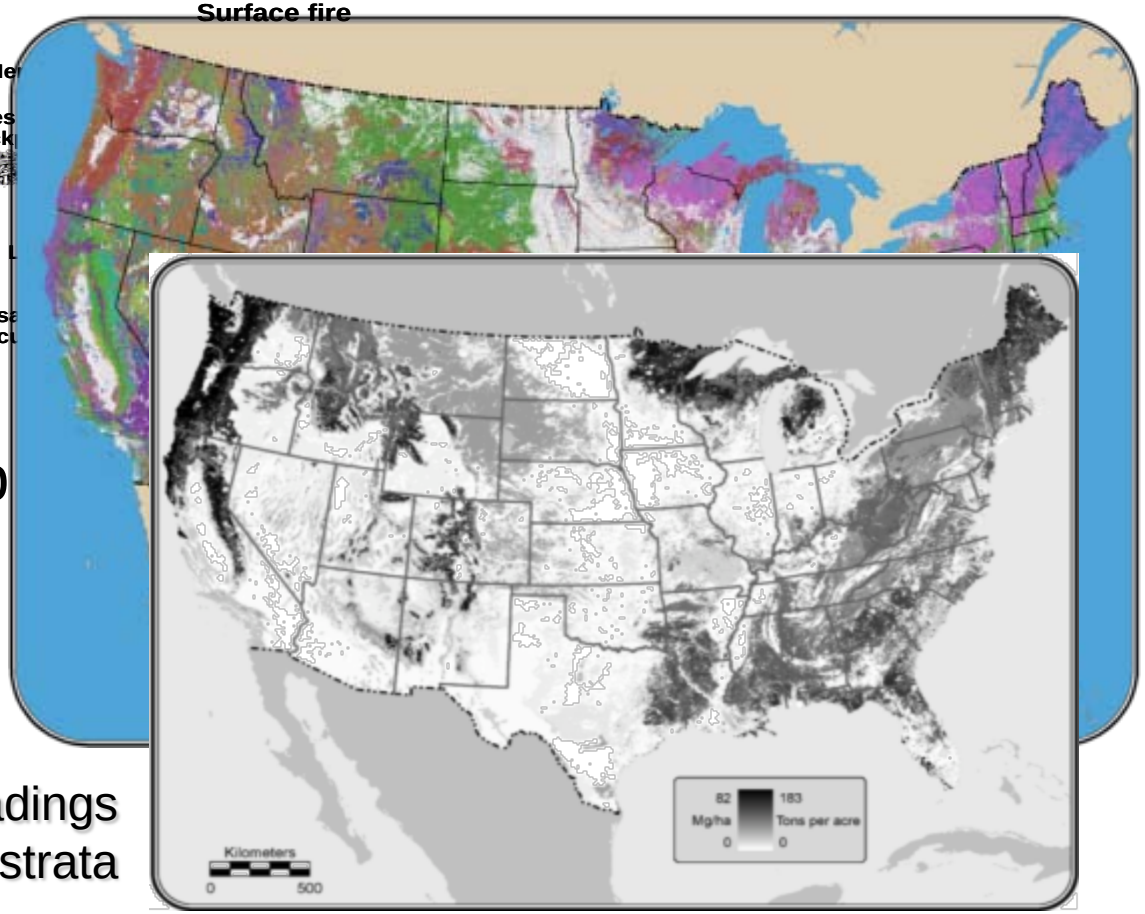
Ground Fuel Stratum



Crown fire

Surface fire

Fuelbed Components



New FCCS 1-km map

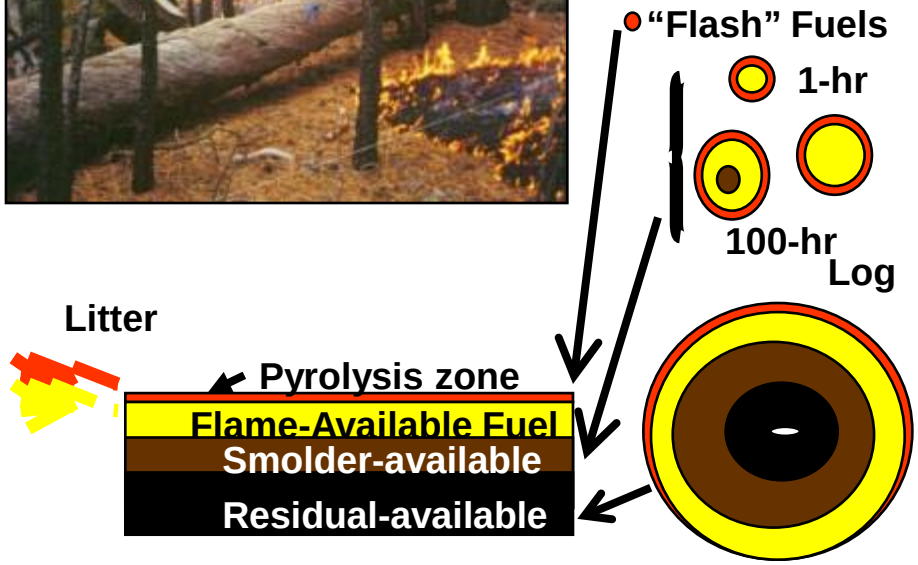
- Aggregated from Landfire 30-m maps
- 97 fuelbeds for CONUS & Alaska

includes fuel loadings by type & strata

http://www.fs.fed.us/pnw/fera/fccs/index.shtml

Fuel Consumption and Emissions: CONSUME

CONSUME estimates fuel consumption and emissions for prescribed and wildland fire. It imports fuelbed data directly from the FCCS, and can be used for all forest, shrub, and grassland types in North America.



- Low-intensity prescribed fire and high-intensity crown fire consume different proportions of each stratum in each combustion phase.
- Estimates combustible biomass of woody fuels in each of the three stages of combustion.
- Predicts fuel consumption, pollutant emissions, and heat release based on:
  - fuel loadings
  - fuel moisture
  - and other environmental factors

http://www.fs.fed.us/pnw/fera/research/smoke/consume/

Ecoregions for Fuel Moisture Mapping

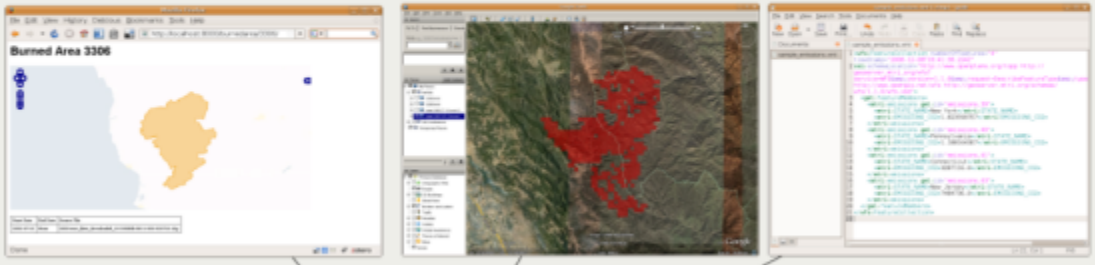
Fuel moisture is mapped daily by ecoregion:

- RAWS station data is used to compute 1000-hr fuel moisture and duff moisture for input to Consume
- Ecoregions are stable regions so are easier to use within the WFEIS system than regions that change over time

Information System Design & Development

Dynamic Browser Web Pages

Data Products
(Fire Perimeter /Fuel Loading / Consumption / Emissions)
provided in standard geospatial data formats
(examples: OGC KML, WMS, NetCDF, SHP)



Client Interface

Application Servers

Geospatial Database

Data Sources

django

python

WFEIS Web Framework

Emissions Model

Consumption Model

PostGIS

Area Burned

Fuel Loading

Regions of Interest

MODIS Burned Area Product

MTBS Fire Perimeters

FCCS fuelbeds

ecoregions, airsheds, user-defined

WFEIS: Open Source Technology

- Benefits
  - Code is highly customizable (great for research)
  - Multiple servers can be setup with no licensing cost

There are <u>many</u> benefits to <u>giving away</u>
your data, source code, and model output!

- Specific Open Source Technologies
  - GeoDjango - web framework
  - GDAL / OGR - raster / vector manipulation libraries
  - Proj4 - projection library
  - PostGIS - geospatial relational client-server database
  - Python - scripting language for integrating components
  - Ubuntu - Linux operating system distribution

Wildland Fire Emissions Information System

Home | Help | Examples | Links | Contacts | Info | Project Outputs

What is W.F.E.I.S.?

The Wildland Fire Emissions Information System (WFEIS) is a web-based tool that provides users a simple user interface for computing wildland fire emissions across North America at landscape to regional scales (1-km spatial resolution). WFEIS provides access to fire perimeter maps along with corresponding fuel loading data layers and fuel consumption models to compute wildland fire fuel consumption and fire emissions for specified locations and date ranges. The system currently allows for calculation of emissions from fires within the United States (excluding Hawaii and territories) from 1982 to 2009.

The WFEIS website allows for two approaches for making fuel consumption and emissions estimates. First, there is an Emissions Calculator webpage that provides a graphical user interface for constructing queries. Second, the WFEIS website responds to queries submitted via properly encoded URL requests (i.e. it implements a RESTful Web API). Examples of valid WFEIS URLs, accessed via the emissions calculator within the KML and text report output formats, can be modified by users and resubmitted to the WFEIS system.

WFEIS is built entirely from open-source software components. Data can be requested in multiple vector and raster formats including ESRI Shapefiles, KML documents, GeoTIFF images, and netCDF files.

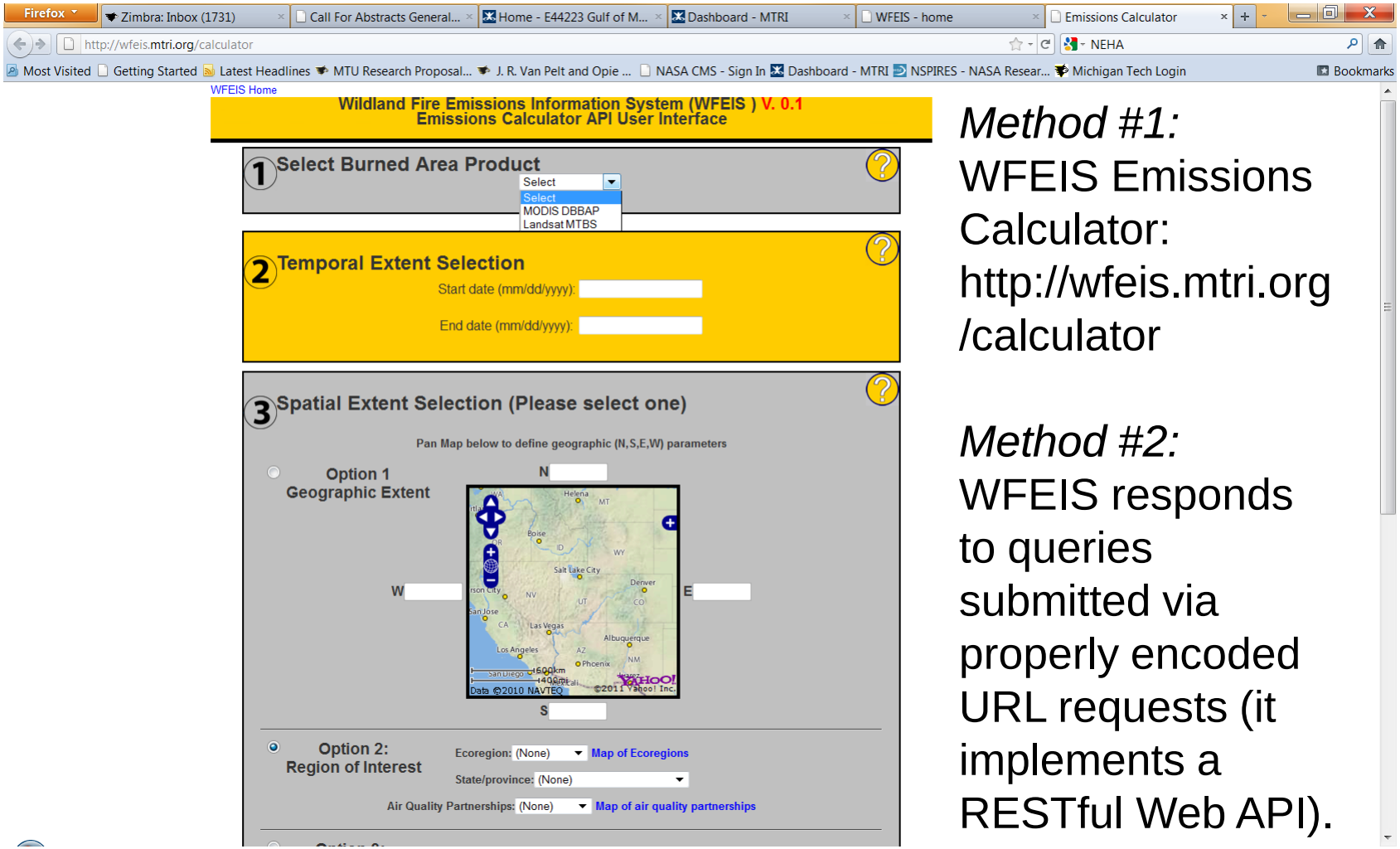
More information can be found on the Project Outputs page.

Fire Data Resources

- Emissions Calculator
- Fuels Map
- MTBS Database
- DBBAP Database
- Emissions Factors (pdf)

WFEIS Web-accessible Framework

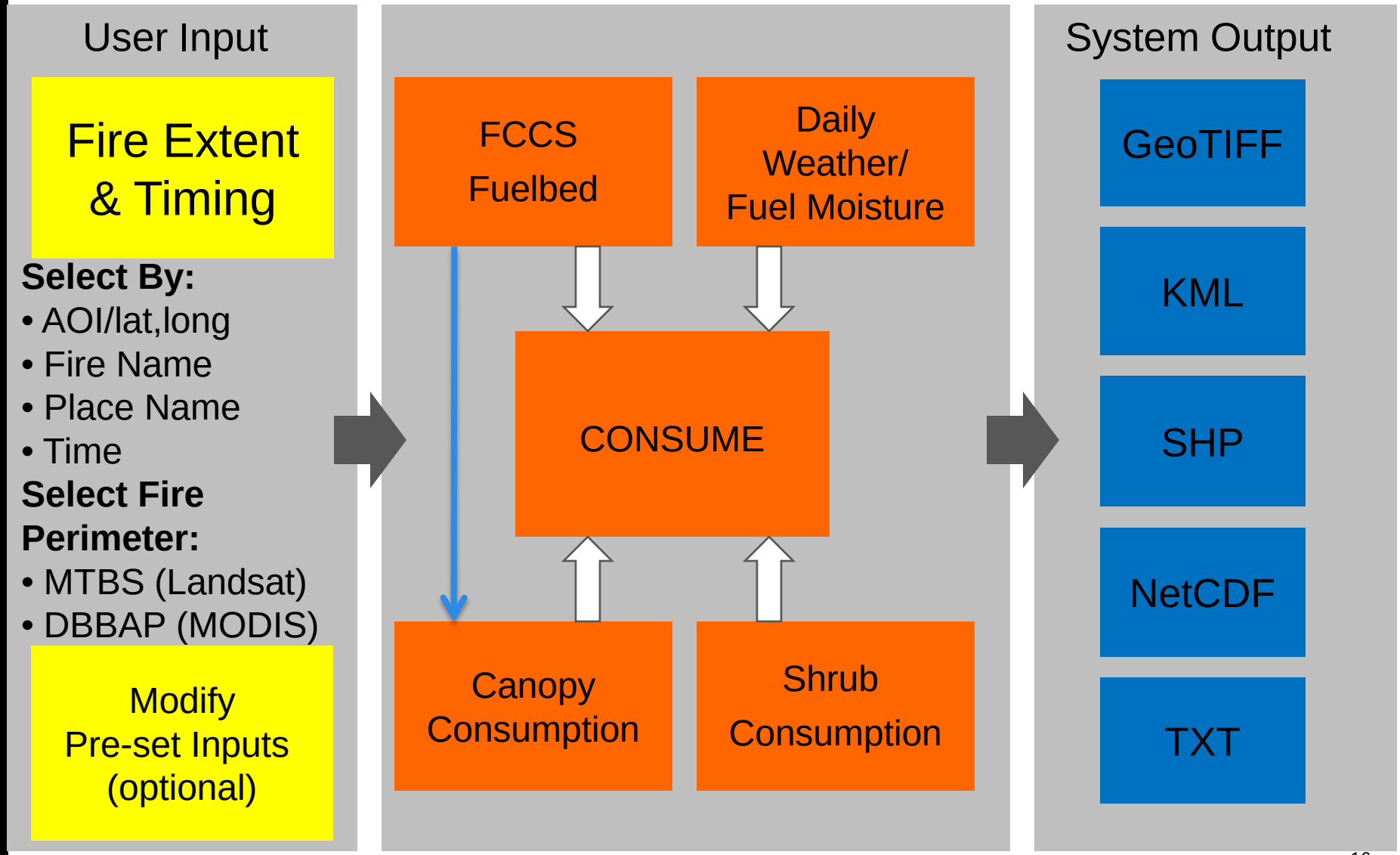
The WFEIS website allows for two approaches for making fuel consumption and emissions estimates



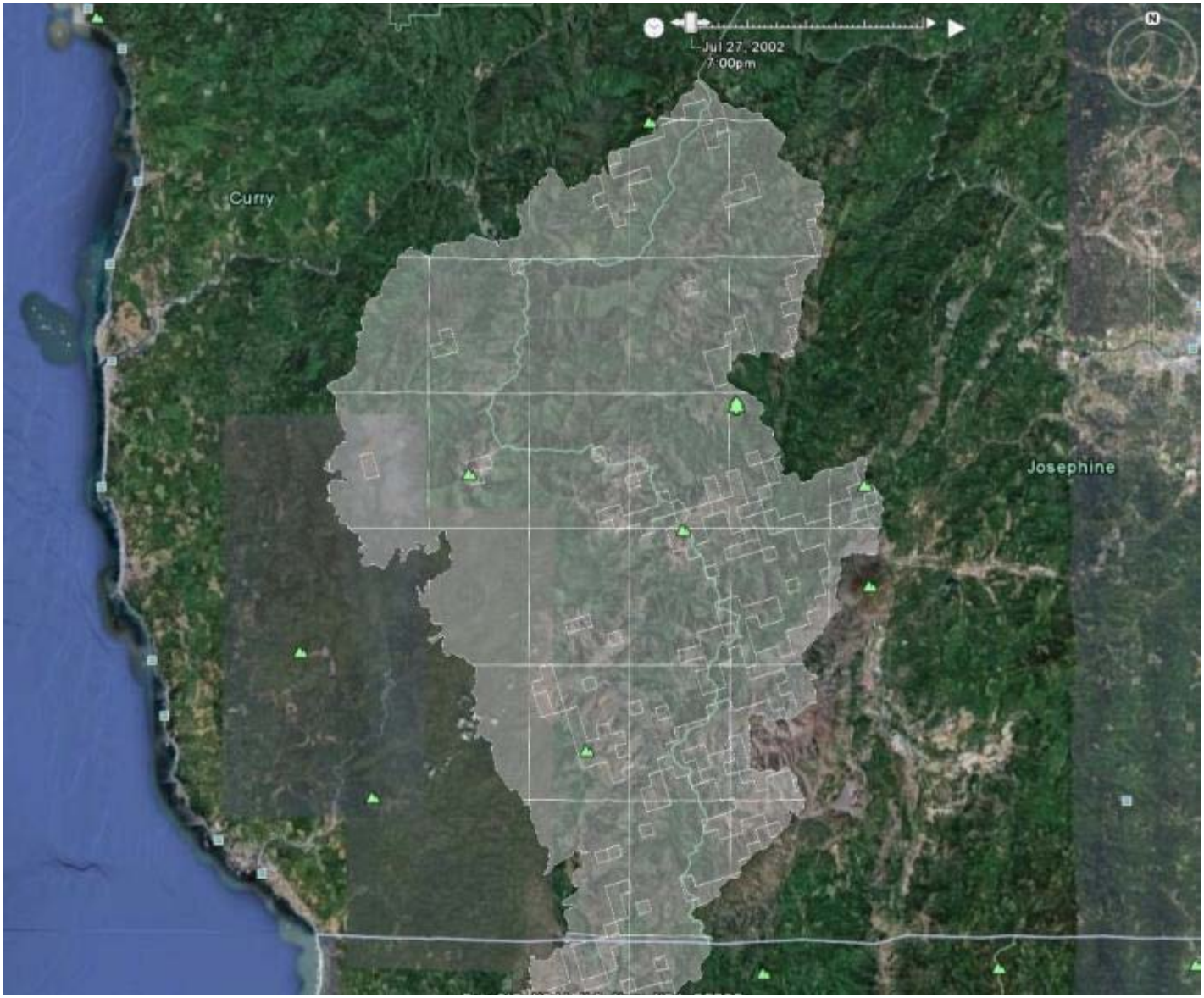
Method #1:
WFEIS Emissions Calculator: http://wfeis.mtri.org/calculator

Method #2:
WFEIS responds to queries submitted via properly encoded URL requests (it implements a RESTful Web API).

WFEIS Components



KML Output in Google Earth



Intercomparison Study

The six models:

-- CONSUME 3.0

-- FOFEM 5.7

-- WFEIS

-- CanFIRE

-- Canadian FBP system approach

-- GFED

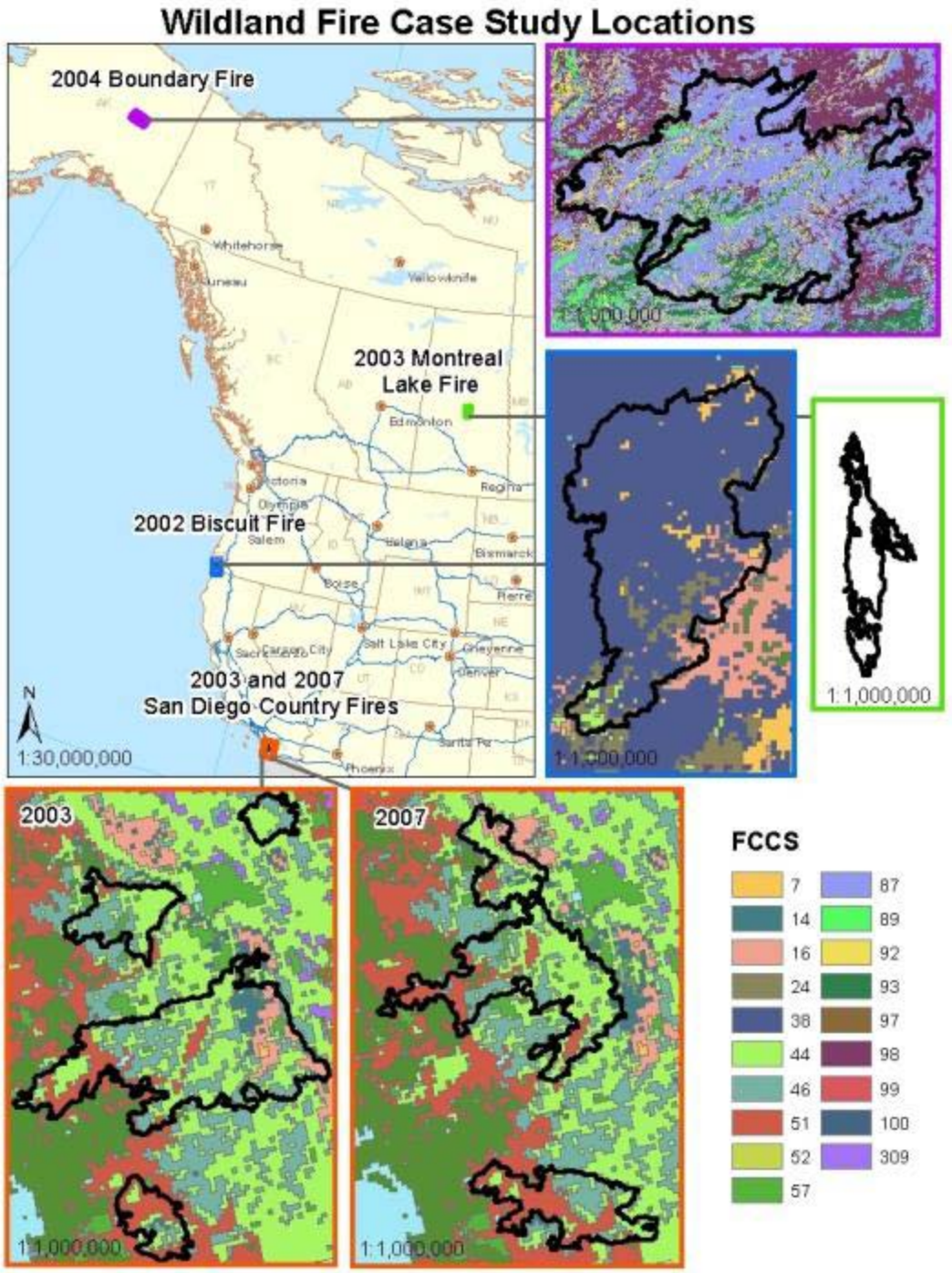
Five fire events:

-- 2002 Biscuit fire in southern Oregon

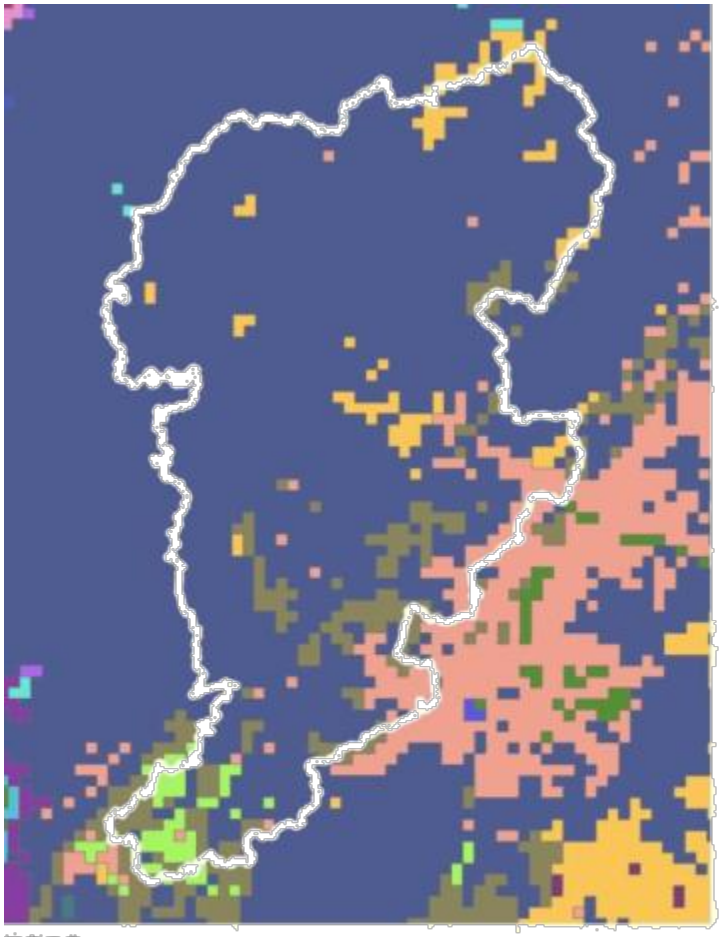
-- 2003 Montreal Lake fire in central Saskatchewan

-- 2004 Boundary fire in interior Alaska

-- San Diego County, California Oct. 2003 and Oct. 2007

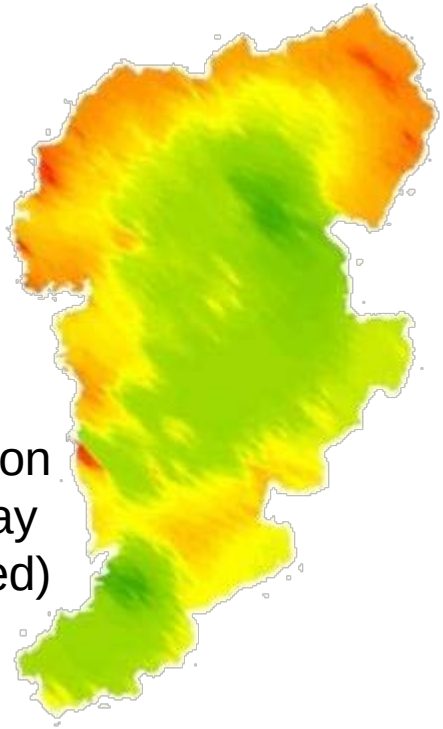


WFEIS Example: Biscuit Fire



FCCS
- 7 Douglas-fir, sugar pine, tanoak forest
- 16 Jeffrey pine, ponderosa pine, Douglas-fir, California black oak forest
- 24 Pacific ponderosa pine–Douglas-fir forest
- 38 Douglas-fir, madrone–tanoak forest
- 44 Scrub oak chaparral shrubland

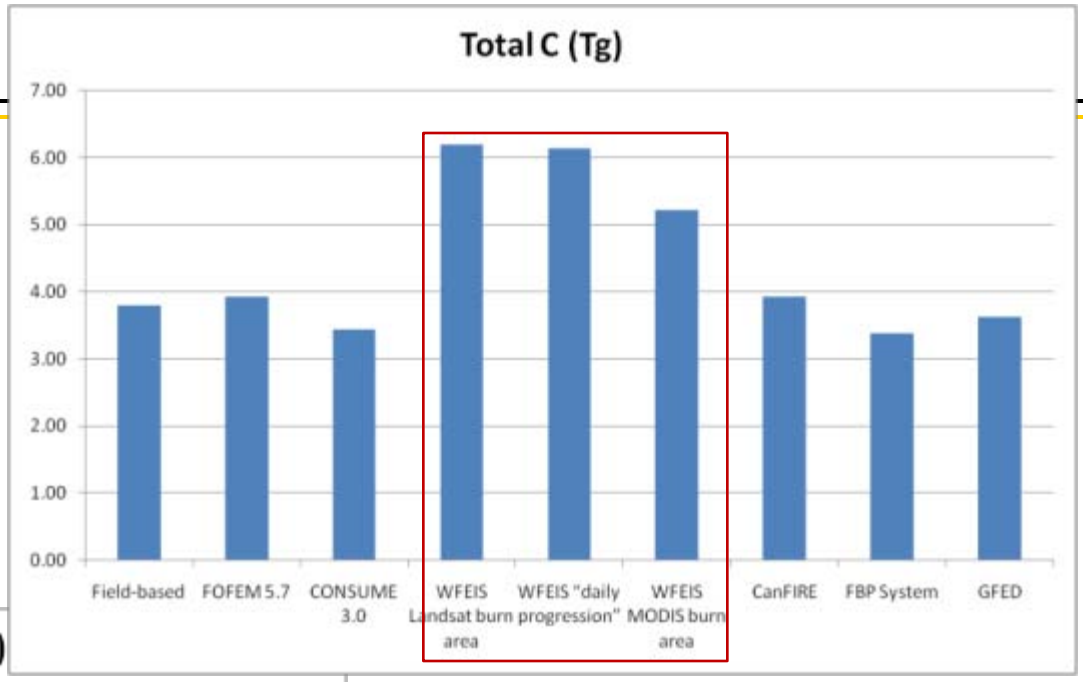
- The Biscuit Fire burned in 2002 approximately 200,000 ha of conifer forestland in southeastern Oregon (US Pacific Northwest)
- Site is dominated by Douglas-fir forest communities with a ponderosa pine component

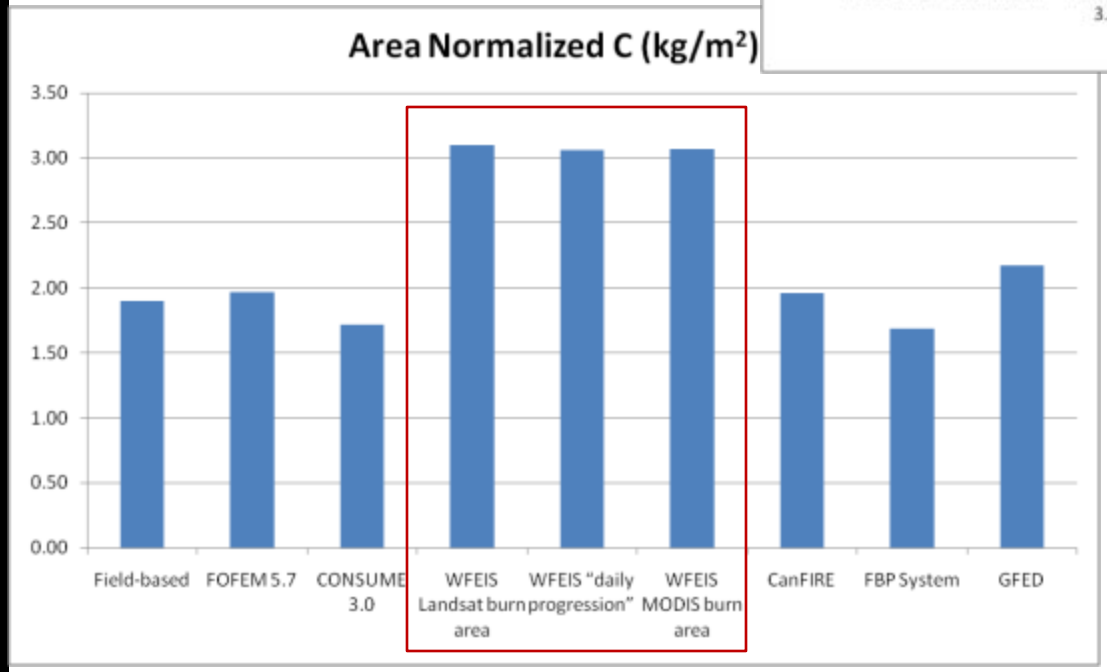


Fire Progression
Julian Day
195 (green) – 244 (red)

WFEIS Results: Biscuit Fire

Comparison to other emissions methods



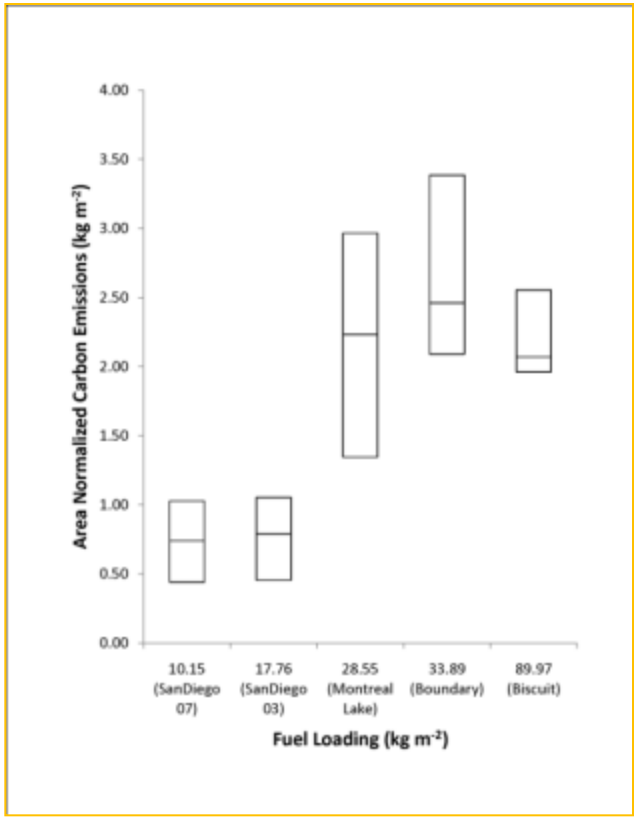


WFEIS is consistent with other model results for this and five additional cases

*French, de Groot, et al. 2011 (*in press) *for Journal of Geophysical Research special issue on disturbance and carbon*

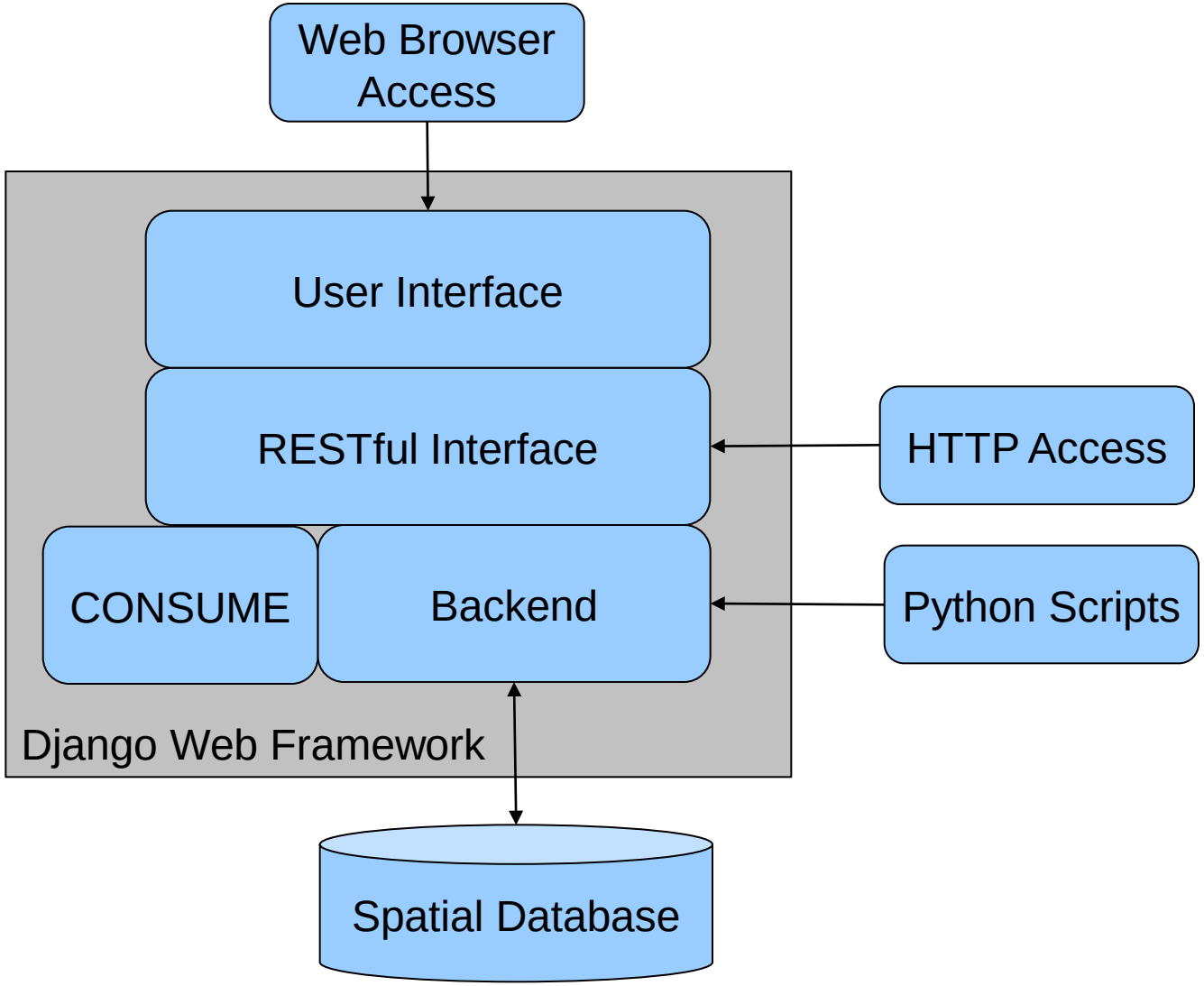
Study Discussion and Conclusions

- Models generally agree (within 25% of each other)
- Vegetation fuel density, structure, and condition (fuel moisture) are important drivers of emissions
- Global-scale GFED modeled emissions are consistent with landscape/regional-scale estimates
- Variability in model assumptions creates various emissions results
- The models reviewed are sufficiently structured to include the variables that drive carbon emissions




MichiganTech
Research Institute
WFEIS Demo
NASA
Photo courtesy NFIC

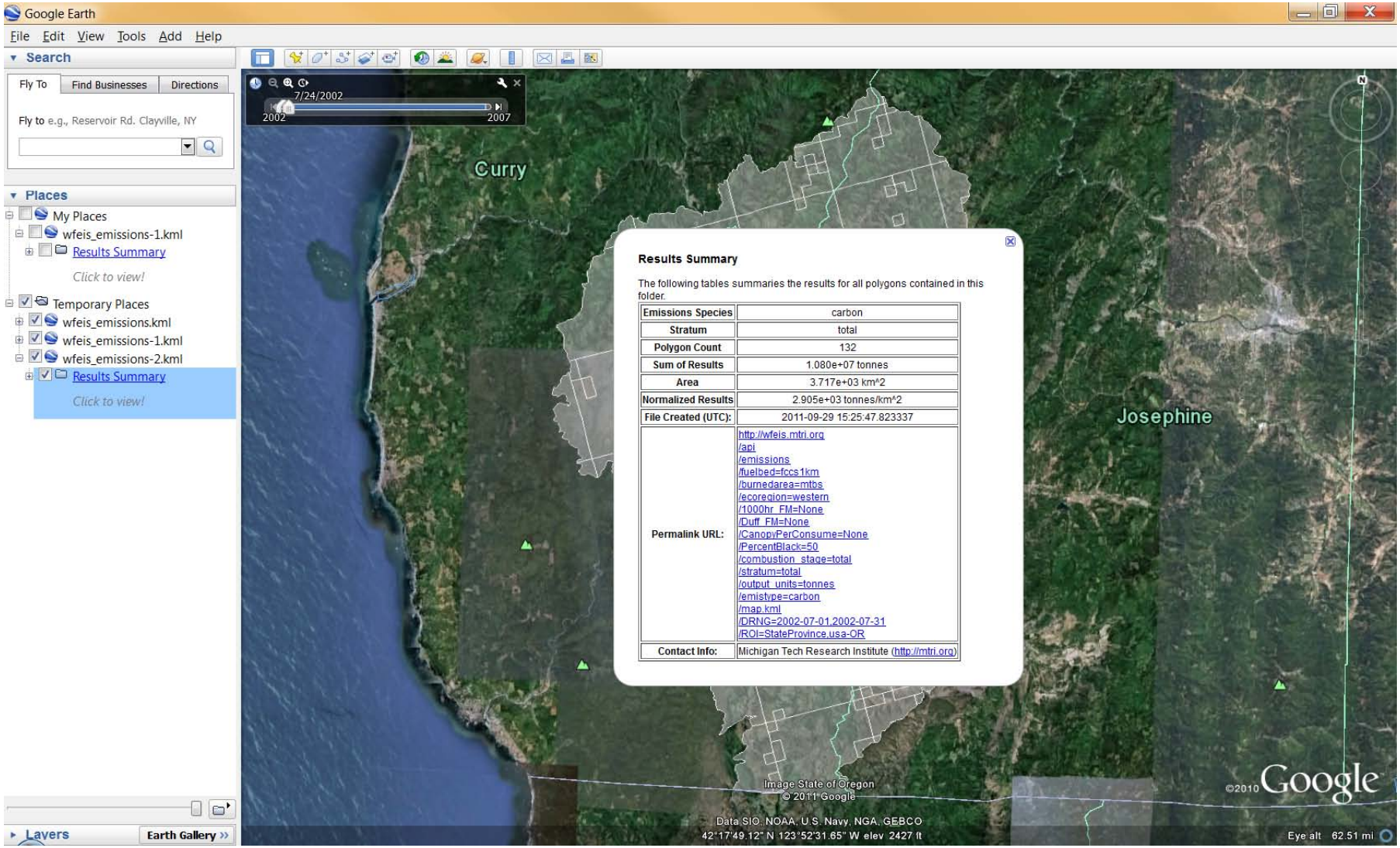
WFEIS Framework



WFEIS Output Formats

- KML – suitable Google Earth
- ESRI Shapefile – suitable for desktop GIS
- NetCDF – suitable for atmospheric scientists
- GeoTIFF – a georeferenced image
- Text Report – a summary report that can be imported to spreadsheet or word processor

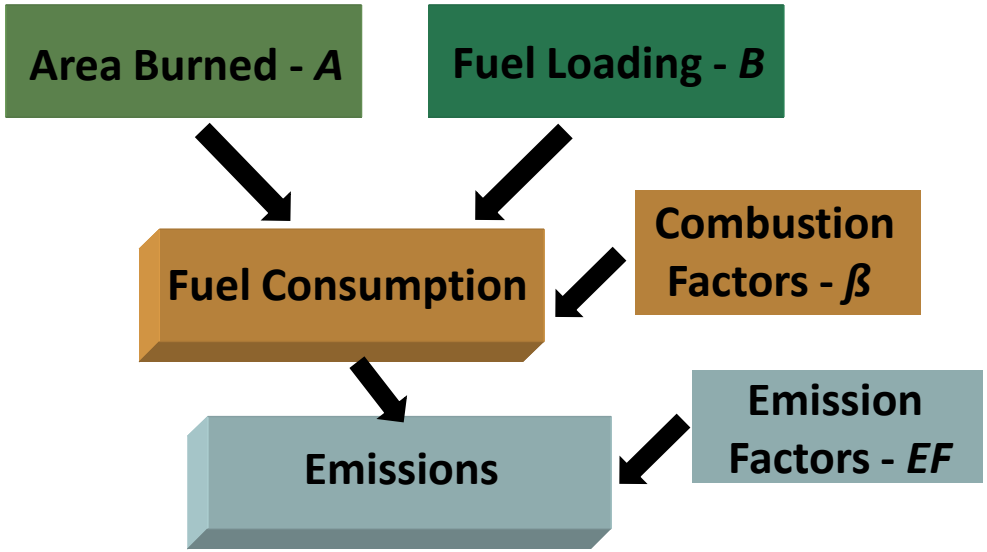
WFEIS Output




MichiganTech
Research Institute
Discussion & Questions
NASA
Photo courtesy NFIC


MichiganTech
Research Institute
Data Inputs for WFEIS
NASA
Photo courtesy NFIC

WFEIS Inputs



- Burn Area
  - Landsat-derived MTBS perimeters 30 m
  - MODIS-derived burn area (DBBAP) 500 m

- Fuel Loading – FCCS* standard fuelbeds mapped to 1-km
- Combustion factors defined by the CONSUME model; links with FCCS fuelbed by strata; default fuel moisture inputs derived from daily weather data
- Emission Factors – Integrated with COMSUME; applied by FCCS fuel strata for each fuelbed

***Fuel Characteristics Classification System** (http://www.fs.fed.us/pnw/fera/fccs/index.shtml)

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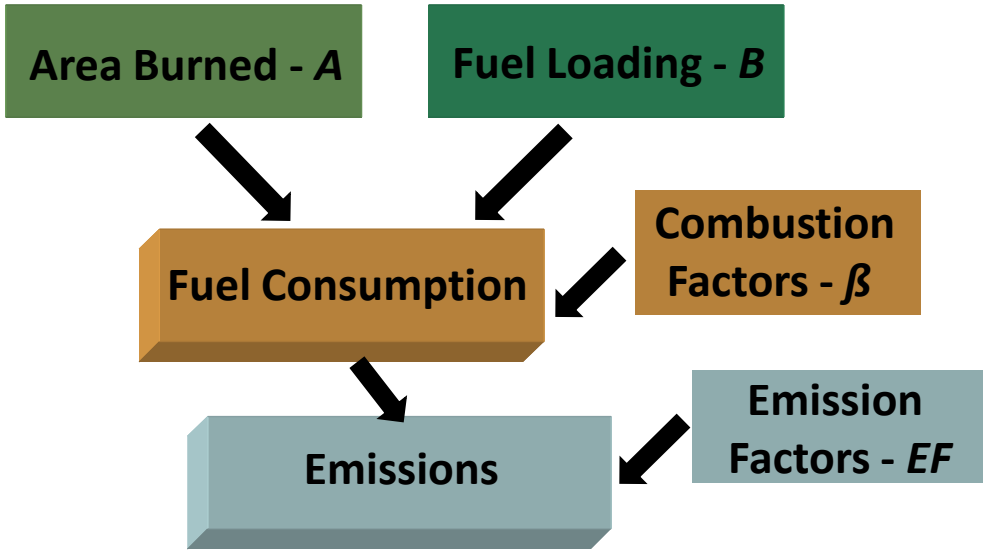

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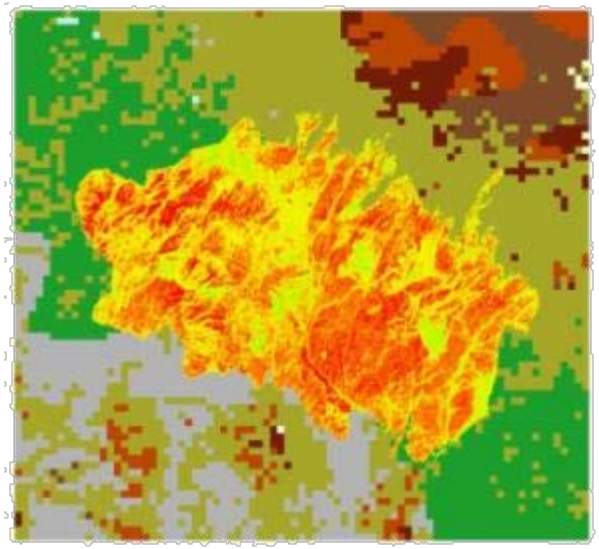
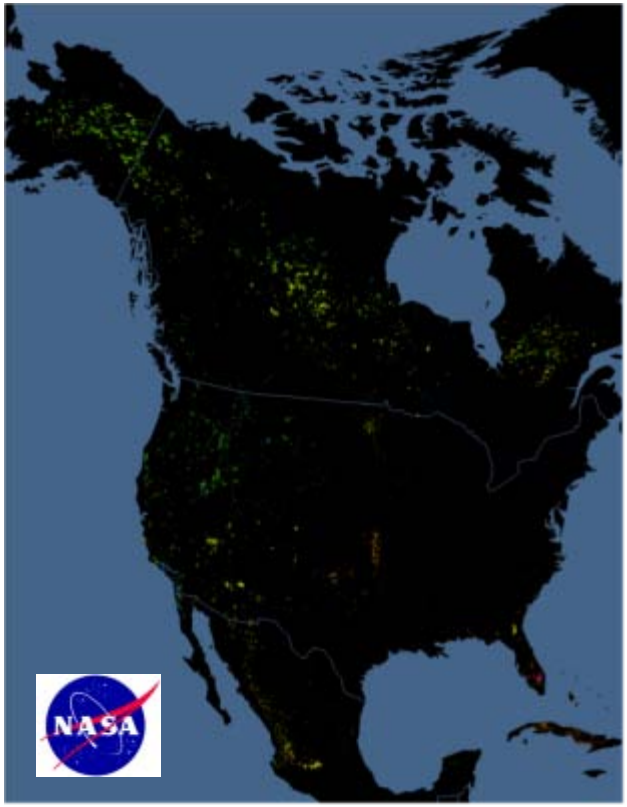
Burn Area

Two Choices for the User:

- Landsat-derived perimeters from USGS (MTBS) *http://mtbs.gov*
- MODIS-derived burn area from NASA (DBBAP)





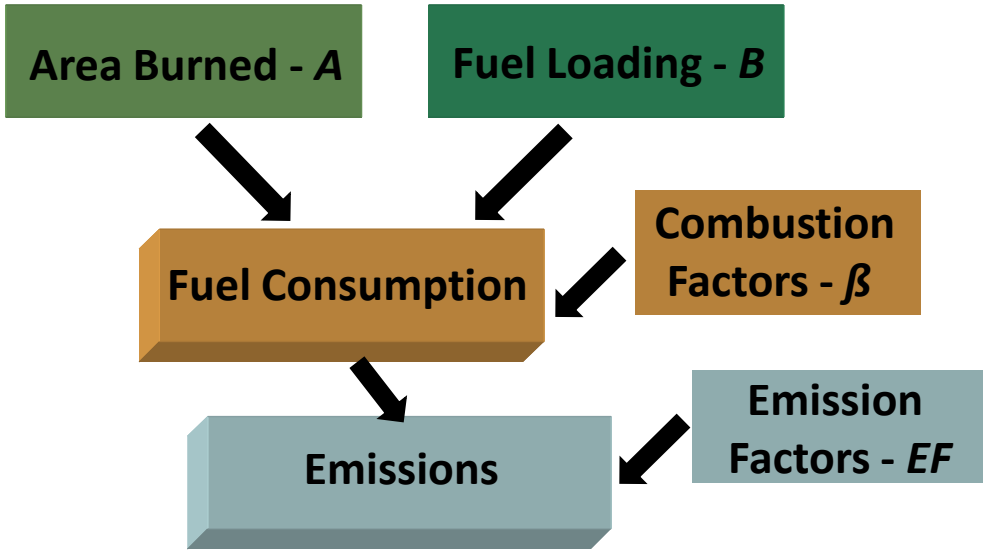
Burn Area - Landsat

- Landsat-derived perimeters from USGS (MTBS) *http://mtbs.gov*
- WFEIS interface includes query choice by MTBS fire name (or multiple fire names; no need to populate lat/long or date)
- These data include a perimeter shapefile that we have ported to WFEIS
  - Perimeter gives location info
  - Fire date (for defining fuel moisture) defined initial as start date (supplied by MTBS), but will be revised to represent the peak day of buring
  - Peak day of burning define with MODIS active fire prodct (T Loboda at UMd)
- MTBS data are not directly served out on WFEIS web site – we re-direct to the MTBS web site

Burn Area – MODIS

- MODIS-derived Direct Broadcast Burn Area Product (DBBAP) – see *Giglio et. al 2009*
  - Algorithm uses MODIS surface reflectance, daily active fire, and land cover products
  - 500 m spatial resolution
- North America-wide for 2001 to present
- Burn cells tagged by approximate burn date
  - Used in WFEIS for fuel moisture
  - Daily information creates a more complex product
- DBBAP burn area product served out through the WFEIS web site (nowhere else right now)

WFEIS Inputs



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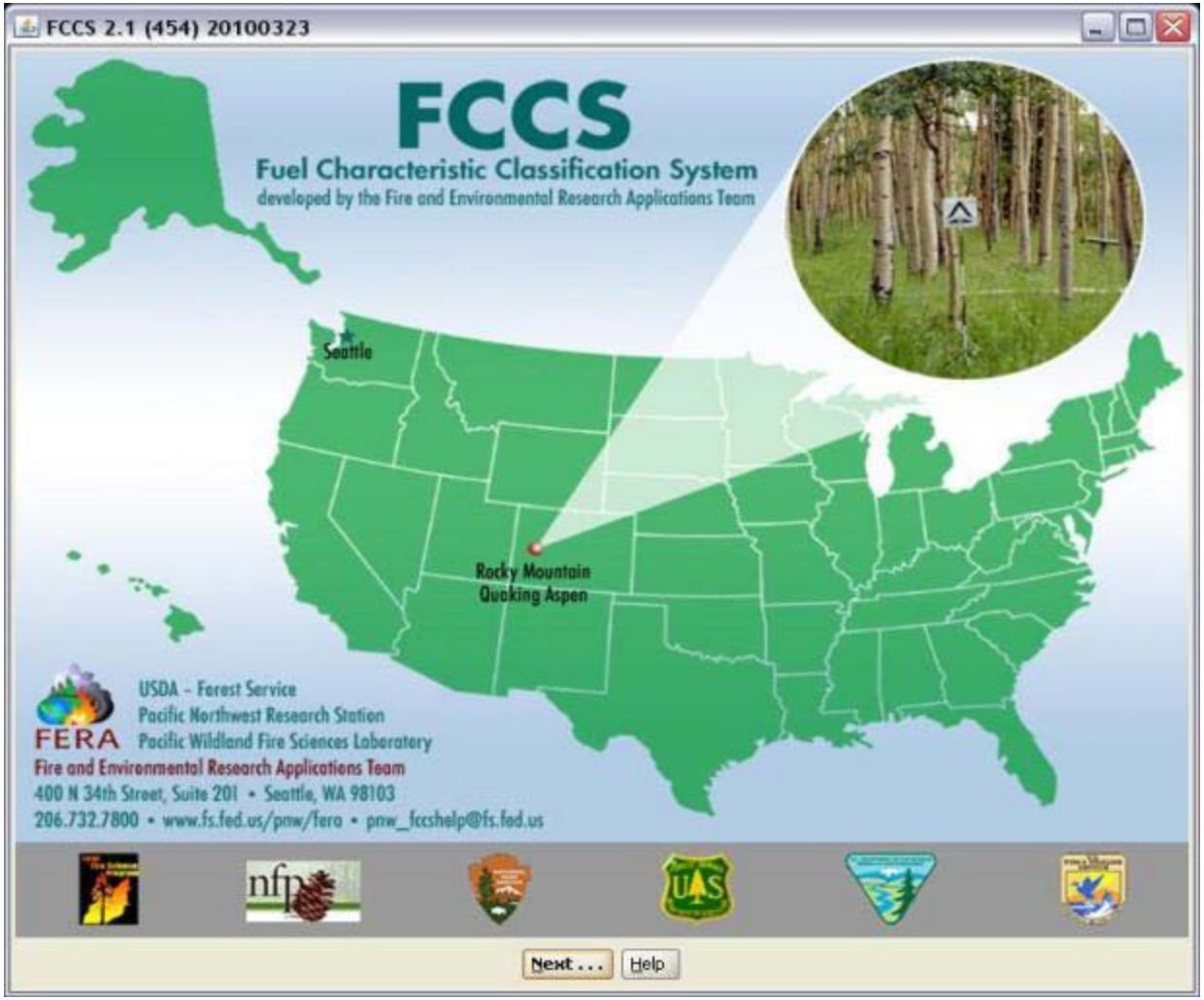
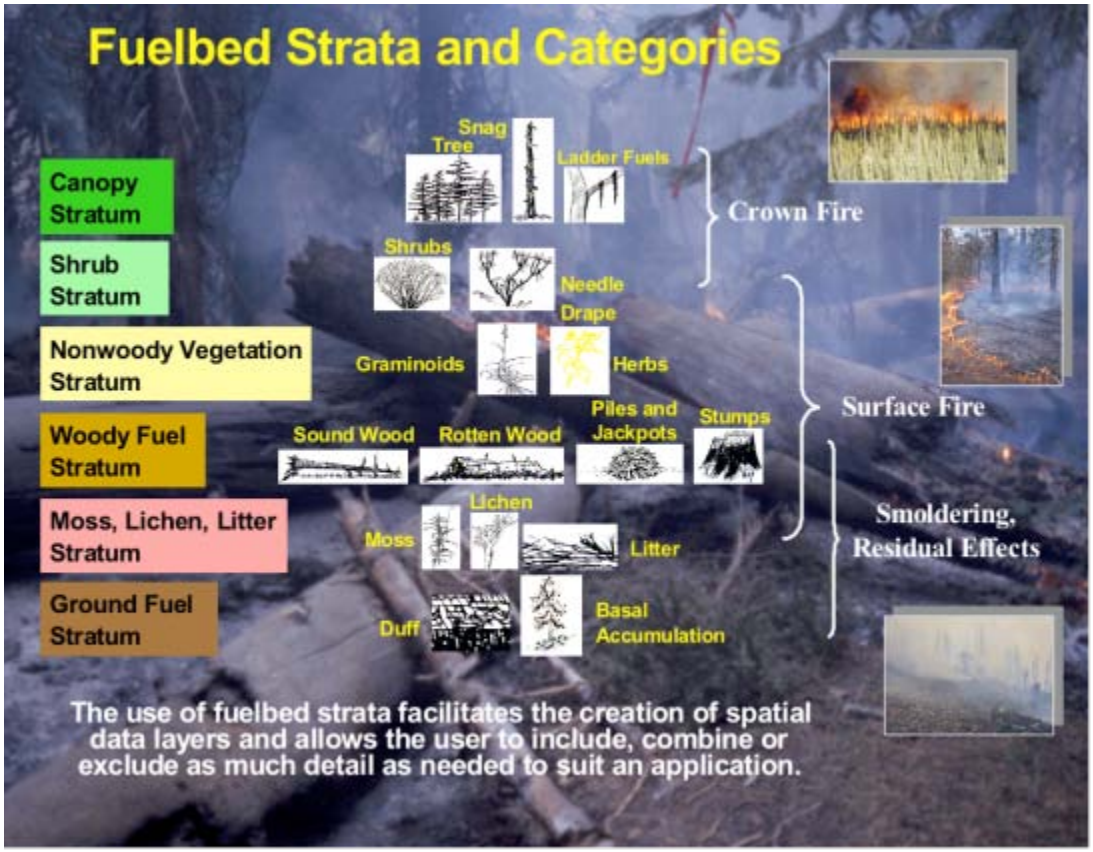
Fuel Characteristics Classification System



http://www.fs.fed.us/pnw/fera/fccs/

Fuel Loading: Fuel Characterization Classification System (FCCS)

- **FCCS** provides an comprehensive description of fuel layers.
- Compiled from scientific literature, fuels photo series, fuels inventories, and expert opinion, and represent fuel conditions at multiple scales, from single plots to 1-km cells or larger.
- Fuelbeds are mapped via crosswalks to satellite-derived vegetation and land cover, at scales from < 25 m (landscape applications) to >36 km (continental and global applications).

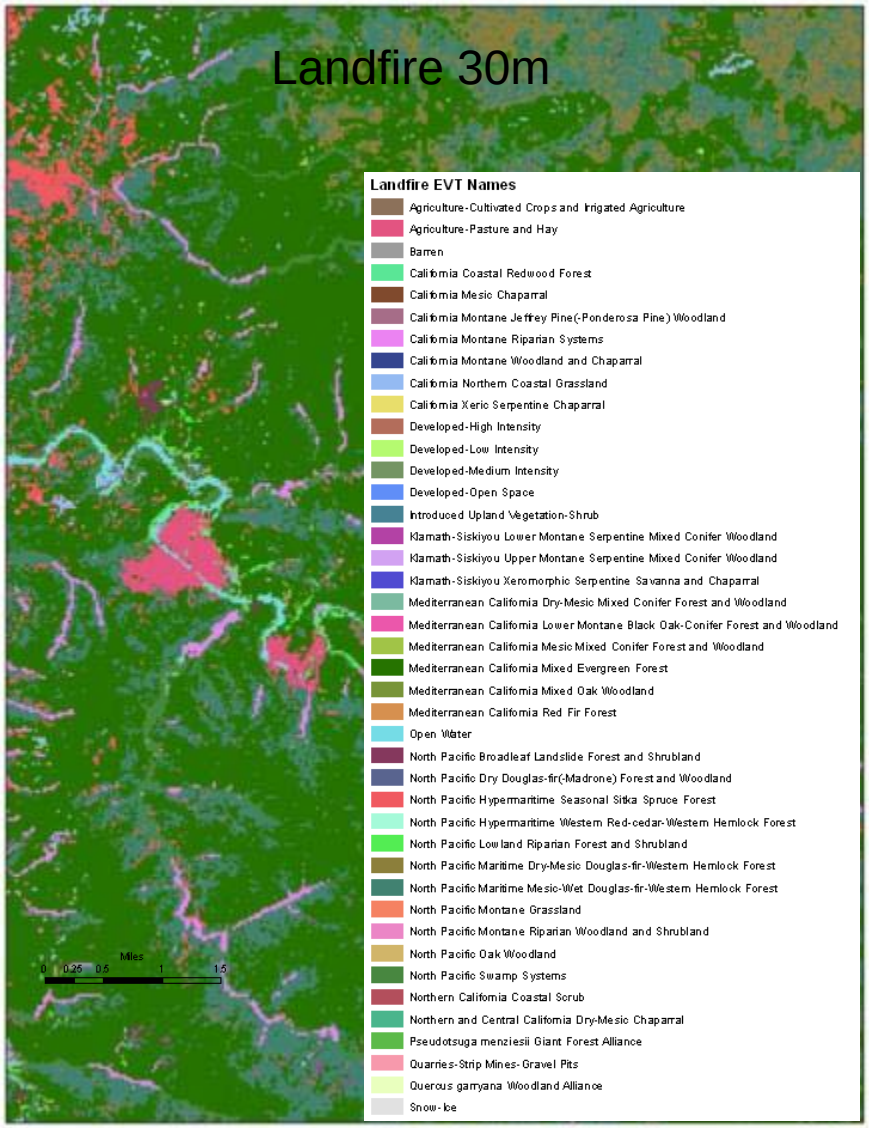


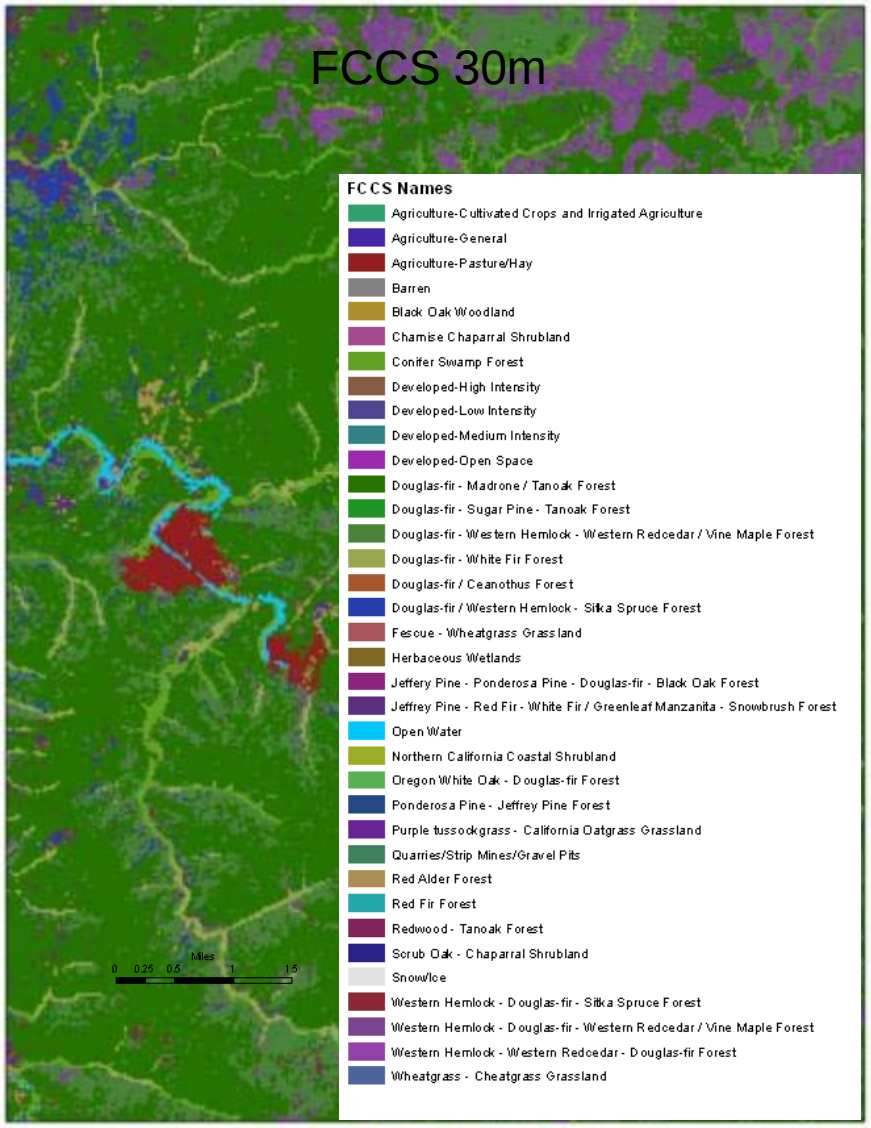
There are two current FCCS GIS raster layers, one at 1 km resolution, and one at 30 m.

LANDFIRE Vegetation Map

- LANDFIRE vegetation map units are derived from NatureServe's Ecological Systems classification, which is a nationally consistent set of mid-scale ecological units.
- Using NatureServe's Ecological Systems search tool, FCCS fuelbeds and Landfire data can be linked spatially on a species level.
  - http://www.natureserve.org/explorer/servlet/NatureServe

Reassignment of classes LANDFIRE EVT to FCCS





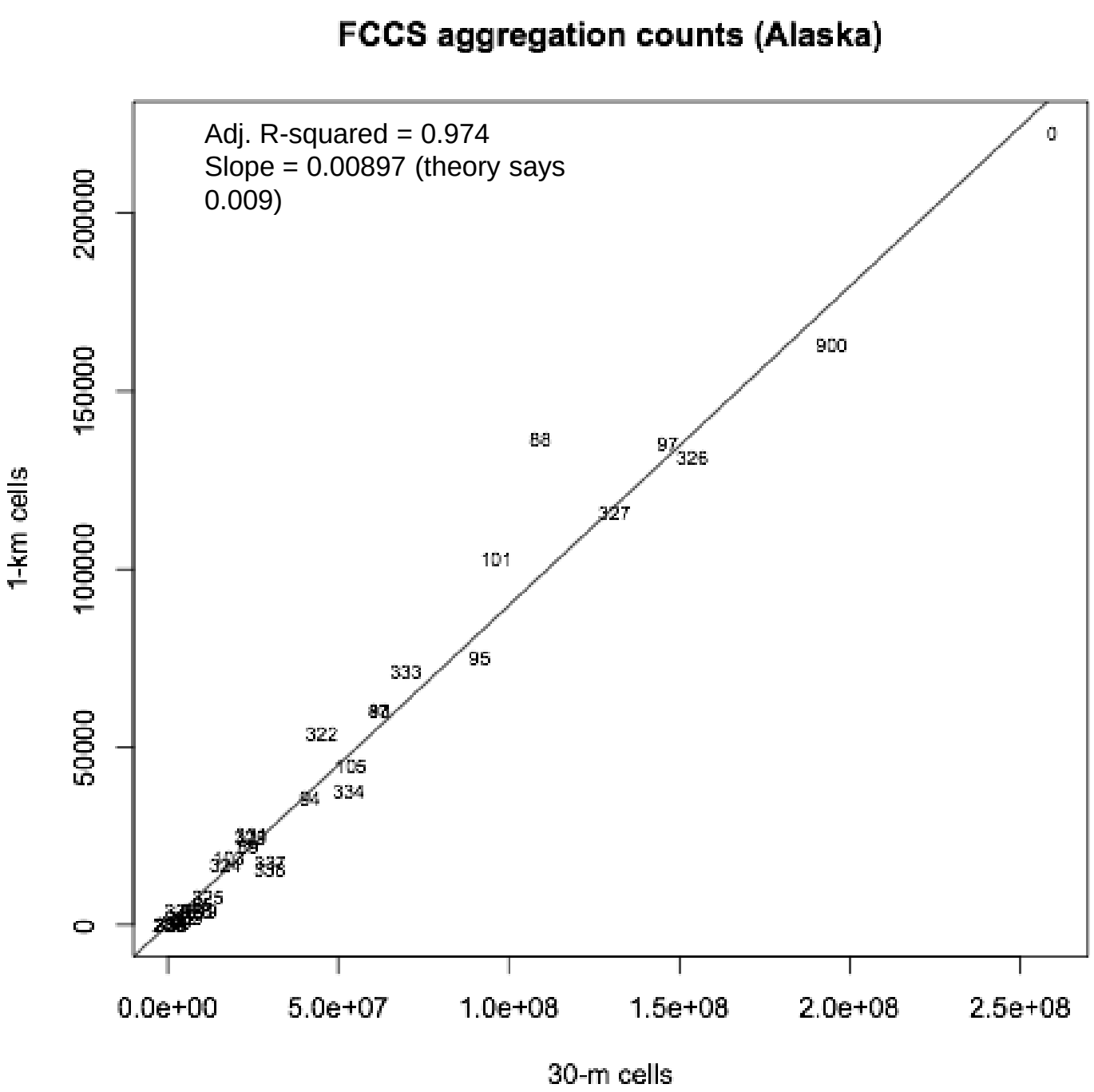
The FCCS fuelbed hierarchy

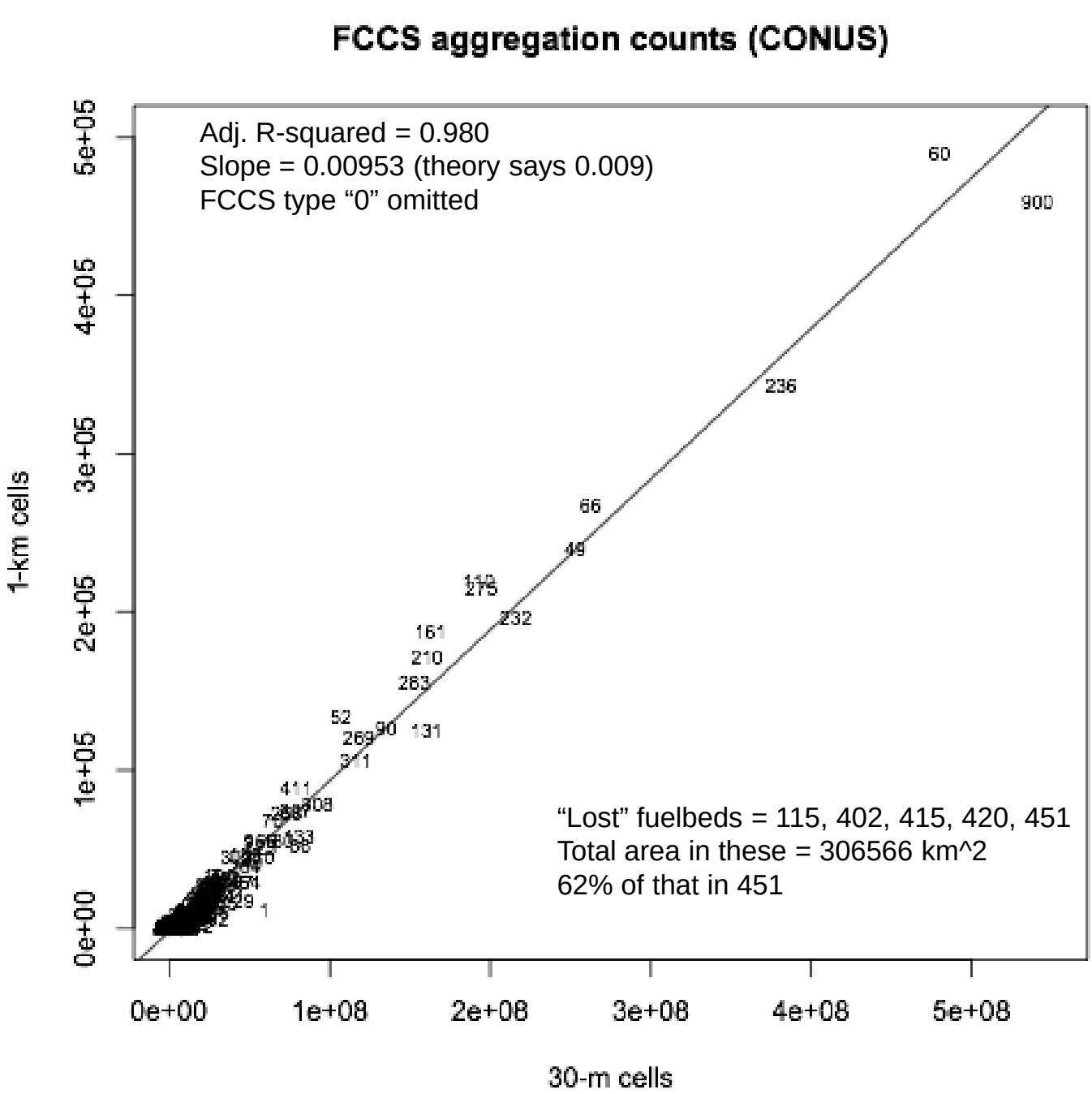
- There are 10,000 30-m cells for every 9 1-km cells.
- The most common fuelbed in a cell may not be representative of the vegetation.
- How can we maximize the representativeness?

There are 4 levels in which we seek a majority

FCCS hierarchy

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

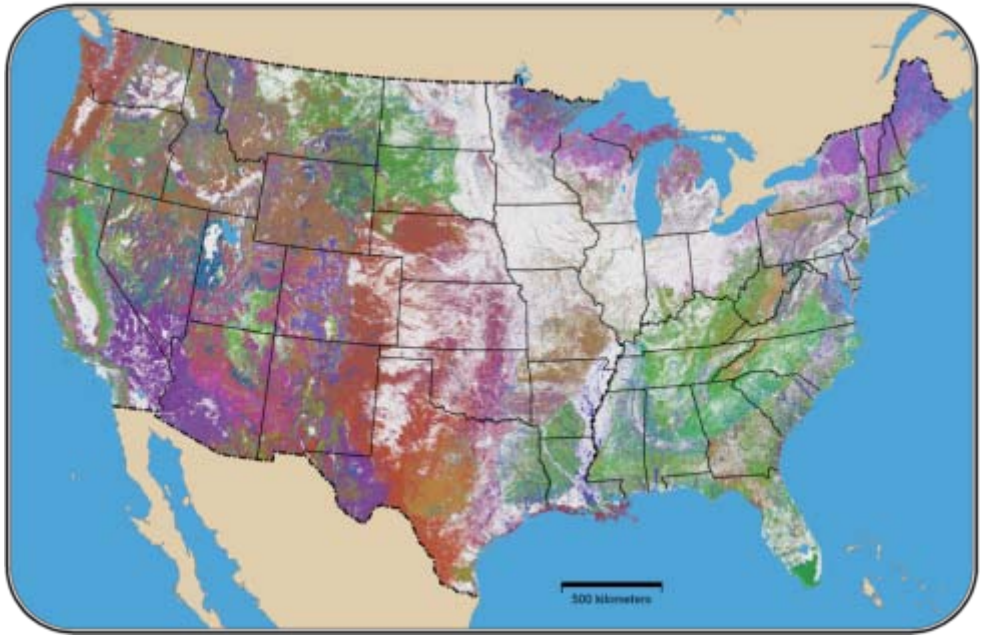

FCCS aggregation counts (Alaska)
Adj. R-squared = 0.974
Slope = 0.00897 (theory says 0.009)
1-km cells
30-m cells
0
50000
100000
150000
200000
0.0e+00
5.0e+07
1.0e+08
1.5e+08
2.0e+08
2.5e+08
900
326
327
101
95
333
322
105
334


FCCS aggregation counts (CONUS)
Adj. R-squared = 0.980
Slope = 0.00953 (theory says 0.009)
FCCS type “0” omitted
“Lost” fuelbeds = 115, 402, 415, 420, 451
Total area in these = 306566 km^2
62% of that in 451
1-km cells
30-m cells
0e+00
1e+05
2e+05
3e+05
4e+05
5e+05
0e+00
1e+08
2e+08
3e+08
4e+08
5e+08

FCCS: the WFEIS fuels map

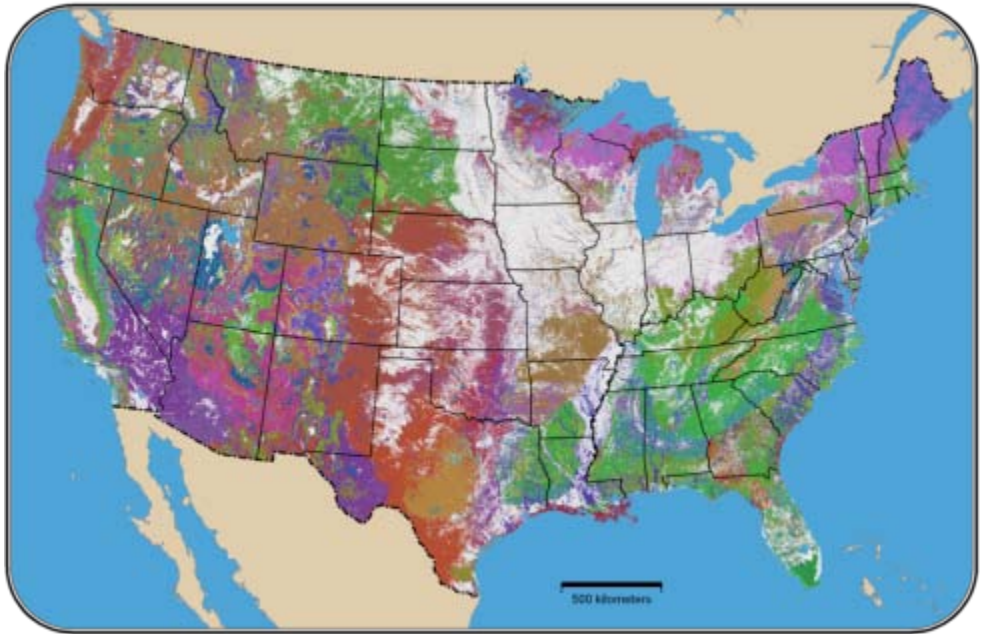
- Scaling to meet the needs of regional-scale models from 30-m LANDFIRE product to 1-km
- Decisions for aggregating 30m FCCS Landcover data to 1km data
  - If the majority (>50%) of 30m FCCS fuelbed cells are of a single category then the 1km FCCS fuelbed cell will be assigned the majority category.
  - If there is no majority fuelbed exists among the 30m cells in the 1km cell extent, a majority species is sought.
    - If a species holds a majority within the 1km cell extent, the most common fuelbed associated with the species will be used.
  - If no majority species exists, the same logic is followed looking to the covertype, then lifeform2, and finally lifeform 1 attributes.
- Revised, LANDFIRE-based 1-km FCCS map available for US (CONUS and Alaska) and soon for Mexico

30-m resolution

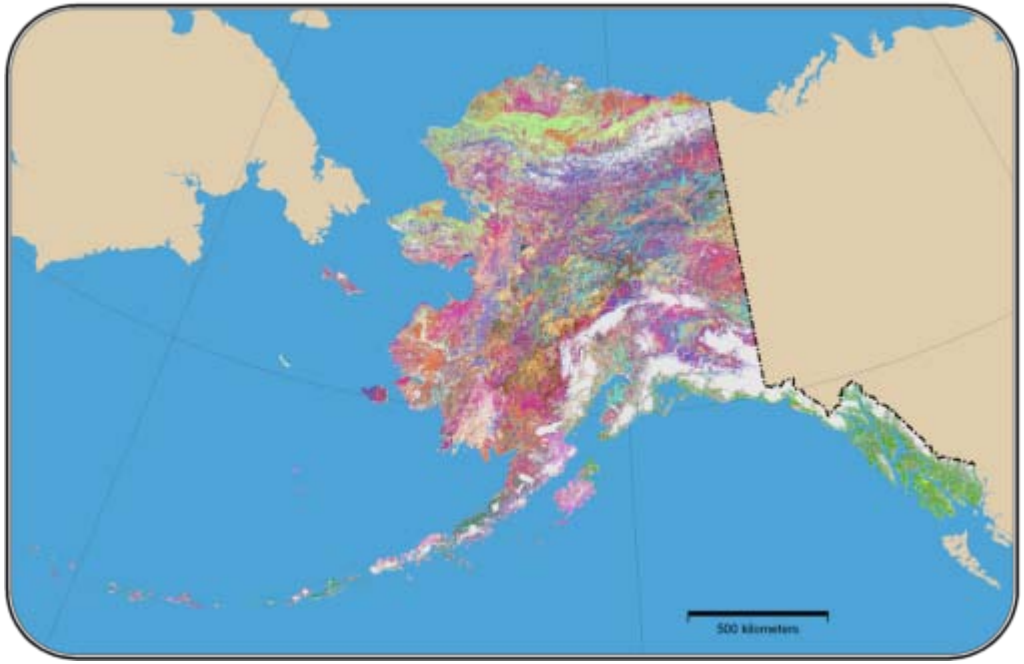


197 fuelbeds: 5 lost in aggregation

1-km resolution

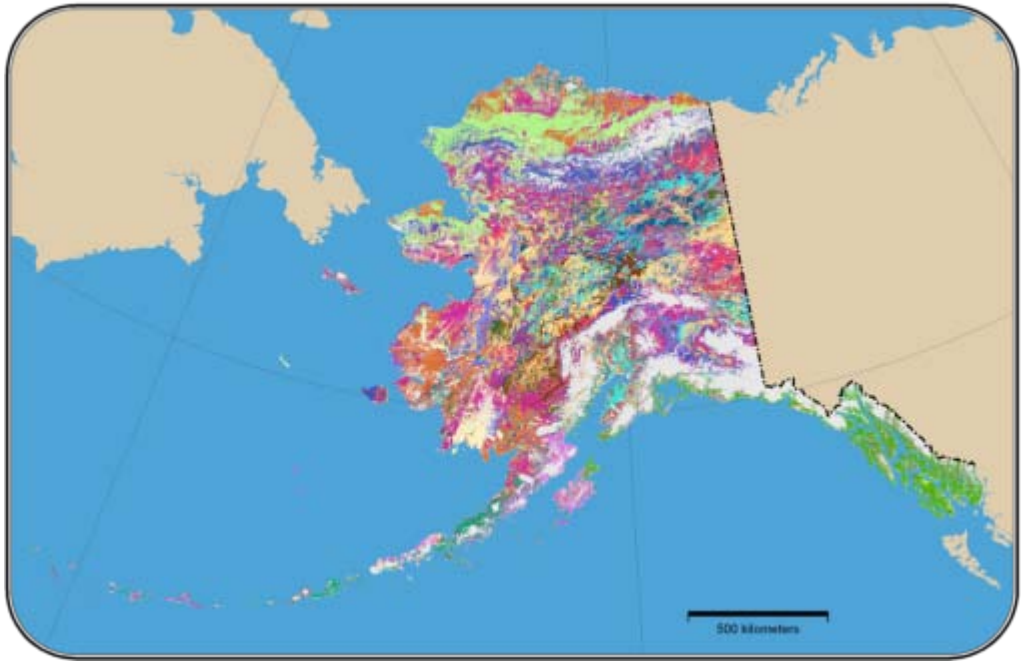


30-m resolution

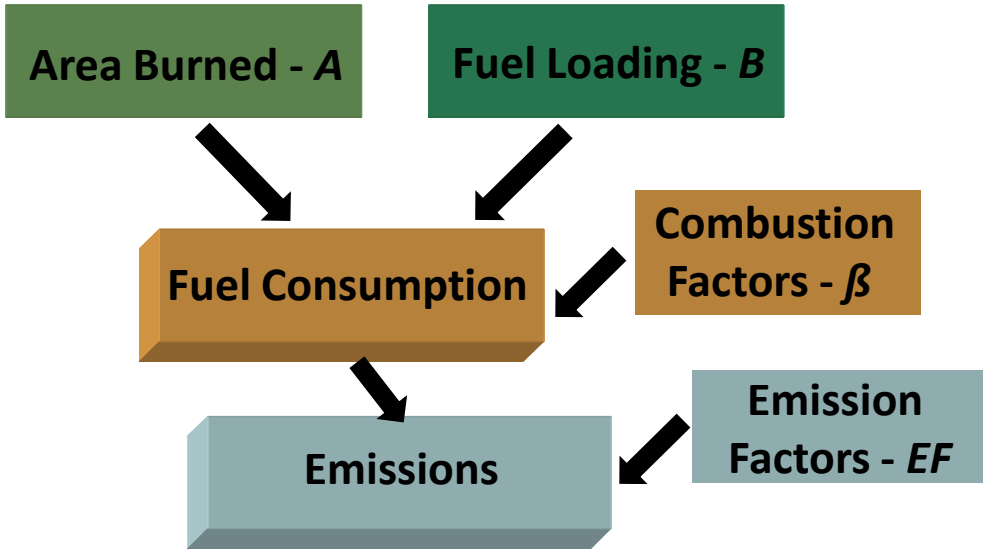


37 fuelbeds: 0 lost in aggregation

1-km resolution



WFEIS Inputs



- Burn Area
  - Landsat-derived MTBS perimeters 30 m
  - MODIS-derived burn area (DBBAP) 500 m

- Fuel Loading – FCCS* standard fuelbeds mapped to 1-km
- Combustion factors defined by the CONSUME model; links with FCCS fuelbed by strata; default fuel moisture inputs derived from daily weather data
- Emission Factors – Integrated with COMSUME; applied by FCCS fuel strata for each fuelbed

*Fuel Characteristics Classification System (http://www.fs.fed.us/pnw/fera/fccs/index.shtml)

Modeling Fuel Consumption
CONSUME 3.0

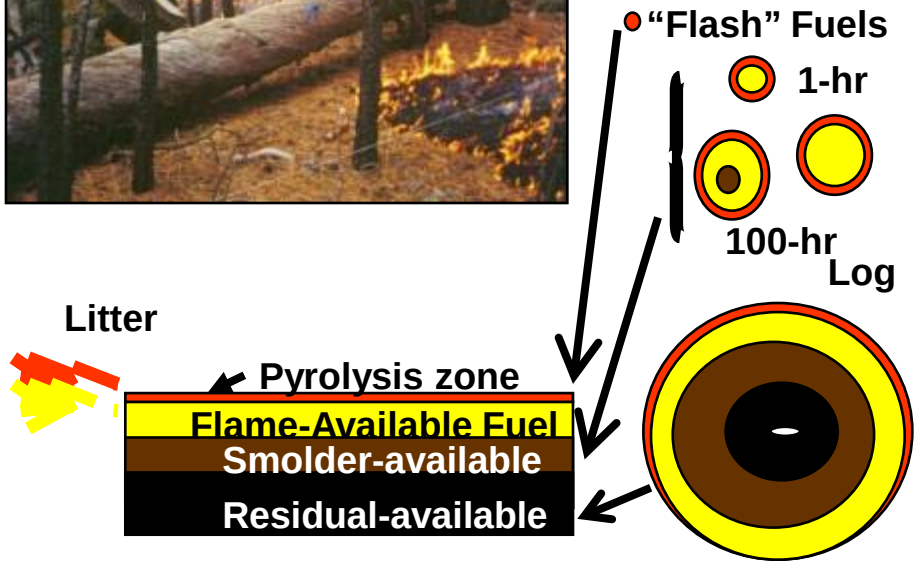
- Decision-making tool to assist resource managers in planning for prescribed fire and wildfire
- Predicts fuel consumption, pollutant emissions, and heat release based on
  - fuel loadings
  - fuel moisture
  - and other environmental factors

- Uses information collected on fuel consumption and emissions through field collections

Pre-fire
Site Inventory
Post-fire

Fuel Consumption and Emissions: CONSUME

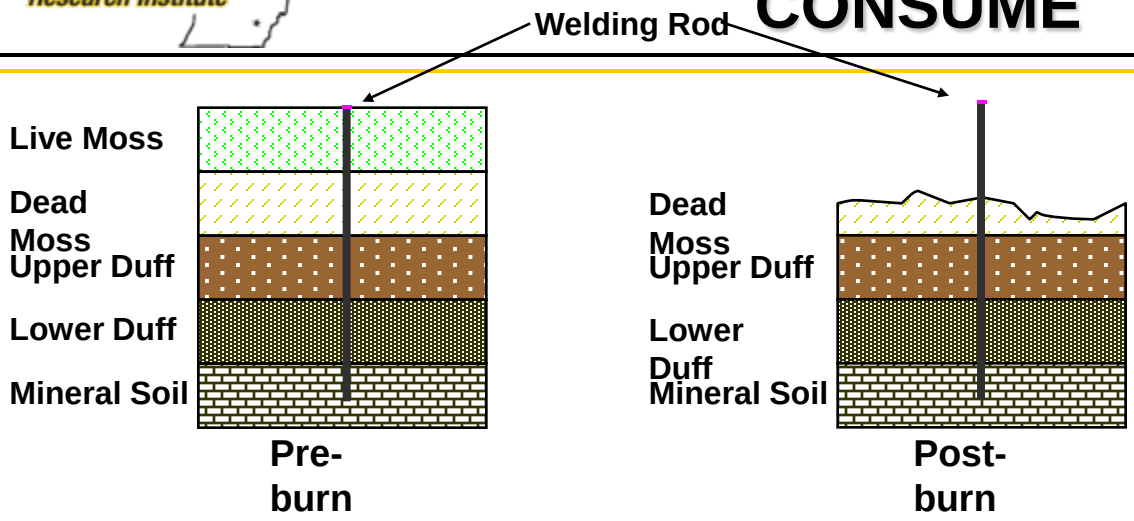
CONSUME estimates fuel consumption and emissions for prescribed and wildland fire. It imports fuelbed data directly from the FCCS, and can be used for all forest, shrub, and grassland types in North America.



- Low-intensity prescribed fire and high-intensity crown fire consume different proportions of each stratum in each combustion phase.
- Estimates combustible biomass of woody fuels in each of the three stages of combustion.
- Predicts fuel consumption, pollutant emissions, and heat release based on:
  - fuel loadings
  - fuel moisture
  - and other environmental factors

http://www.fs.fed.us/pnw/fera/research/smoke/consume/

Fuel Consumption and Emissions: CONSUME



CONSUME uses information collected on fuel consumption and emissions through field collections

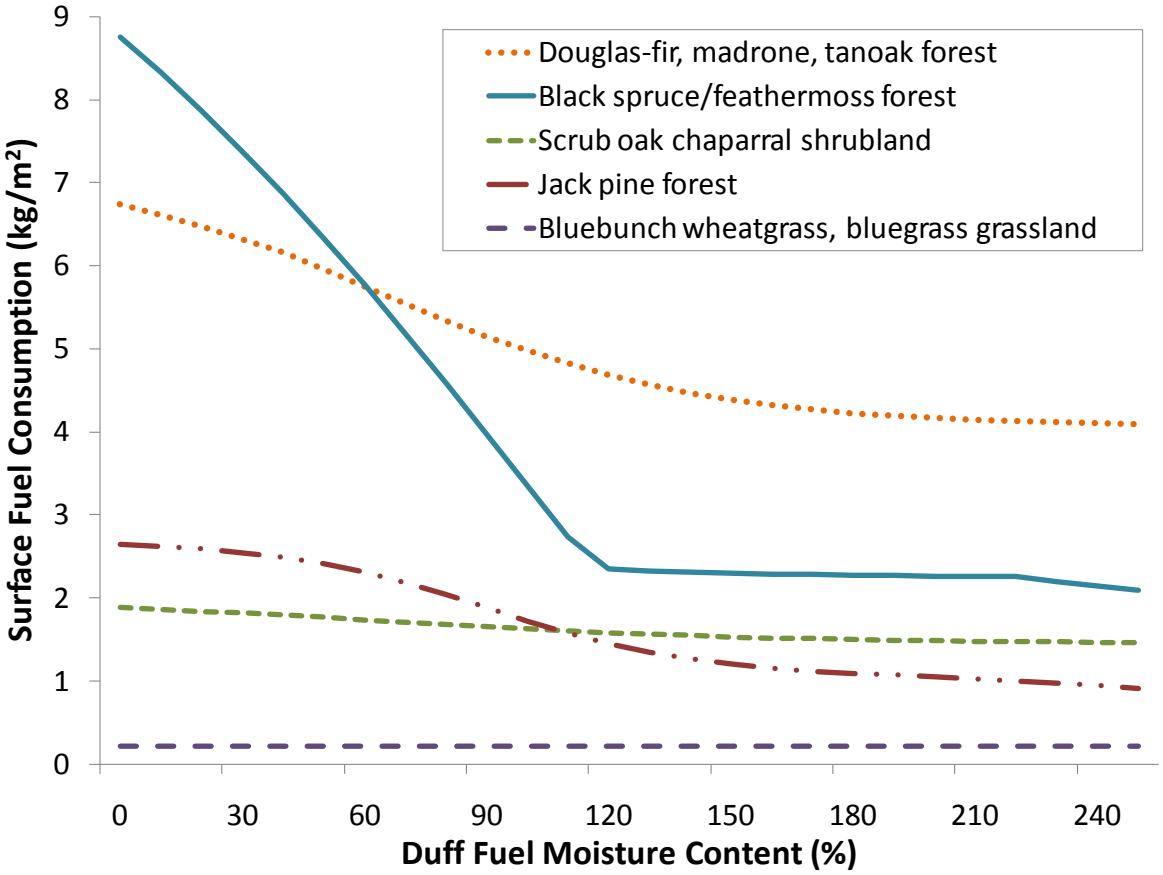
Plots (66 ft spacing)
16 fire pins/plot

Pre-fire

Post-fire

CONSUME Fuel Consumption

- Using spatial inputs from WFEIS and FCCS, CONSUME estimates fuel consumption and emissions for prescribed and wildland fire.
- CONSUME can be used for all forest, shrub, and grassland types in North America.
- Some types are better modeled than others.



Fuel Consumption and Emissions: CONSUME

- Python-consume
  - What we did:
    - Recoded Consume 3.0 in python ulitizing the User's Guide, original source code, and consultation with Susan and Roger where discrepancies were found
    - **Main purpose** of python-consume was to **integrate w/ WFEIS**

      This meant:
      - » Infrastructure and flexibility to handle very large and redundant input datasets
      - » Reduced emphasis on GUI development (handle by WFEIS front-end)
      - » Emphasis on "natural" as opposed "activity" equations (although later added for separate project)

Fuel Consumption and Emissions: CONSUME

- Python-consume
  - Where python-consume get its **inputs** in WFEIS:
    1) **Fuel loadings**: FCCS raster dataset and associated loadings table
    2) **Area**: user-selected burn area dataset (DBBAP/MTBS) subset to a user-selected geographic area (bounding box/ROI) and time
    3) **Ecoregion**: Derived from user-selected geographic area
    4) **1000-hr fuel moisture**: ecoregion level interpolation of RAWS data
    5) **Duff fuel moisture**: ecoregion level interpolation of Canadian FWI derived from NARR data
    6) **Percent canopy consumed**: algorithm based on FCCS-derived crown fire potential
    7) **Shrub blackened**: default to 50% (expert opinion)
    8) **Emissions factor set**: auto-selected from the SAR/SRM cover types associated w/ a specific FCCS fuelbed according to tables used by the official Consume 3.0 code.

Ecoregions for Fuel Moisture Mapping