Forest Fire Emission Inventory: An Evaluation of Uncertainty Associated with Fuel Loading

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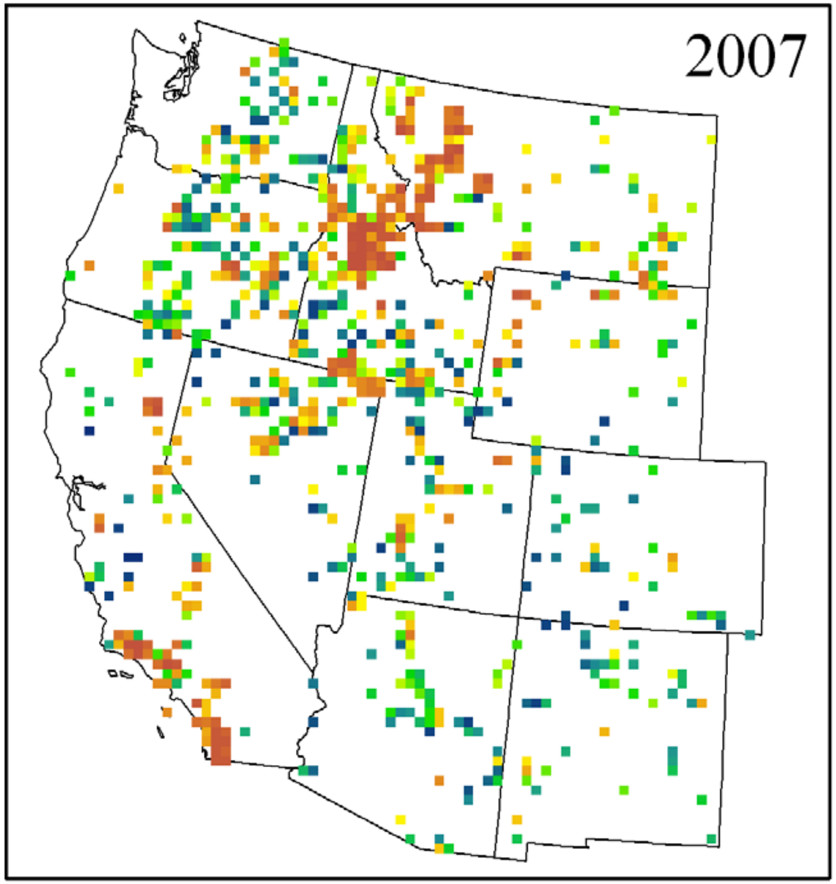
Biomass Burning Emission Inventory

CO emitted 2007



Emission Inventory resolution:
Δx = 1 km, Δt = 1 day

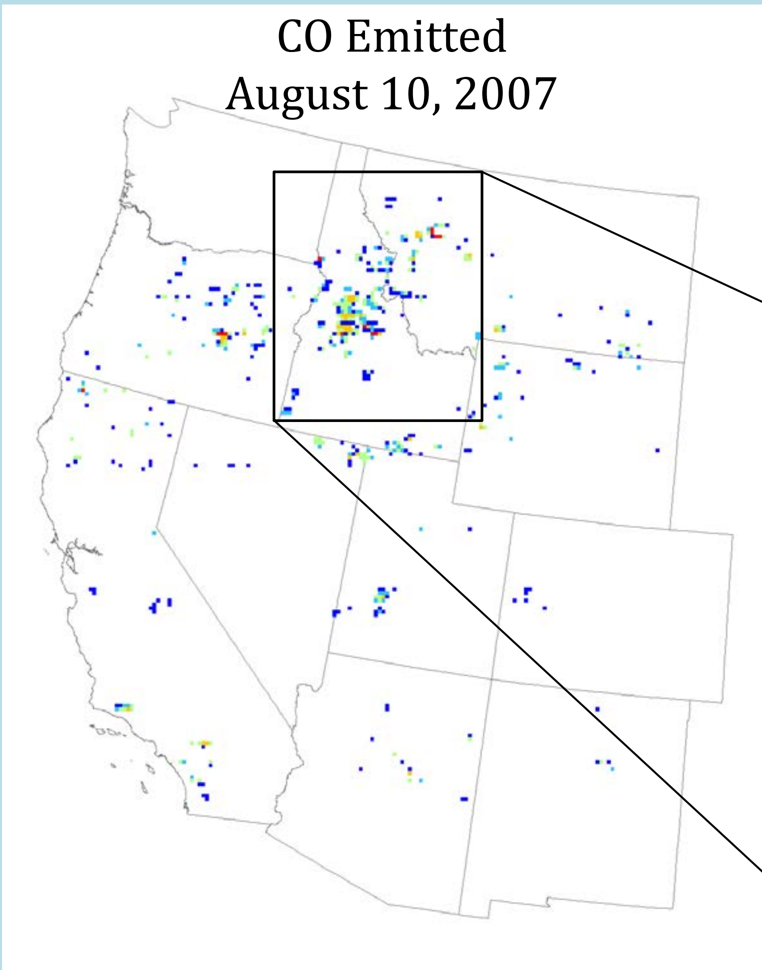
Reported Uncertainty:

ECO = 3107± 776 Gg-CO yr^{-1}

Δx = 2250 km, Δt = 1 year

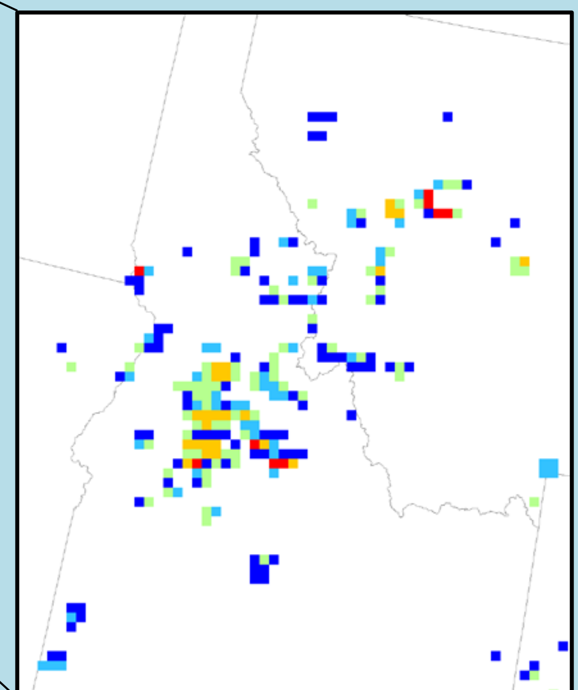
Urbanski et al., 2011

Biomass Burning Emission Inventory



Air Quality model resolution
Δx = 10 km, Δt = 1 hour

What's uncertainty for
ECO(1-hr, 10 km) ?



Study Goal

Quantify fuel loading related uncertainty in biomass burning emissions at temporal and spatial scale relevant to air quality modeling

Propose a figure of merit for EI uncertainty that:

- enables evaluation of EI at spatio-temporal scales relevant to AQM
- provides a consistent benchmark for comparing EI and guiding the development & improvement of BB emission models

Biomass Burning Emission Model

Biomass burning emission of pollutant X:

$$E_X = A \times FL \times CC \times EF_X$$

- A — Area burned
- FL — Fuel loading
- CC — Combustion Completeness
- EF_X — Emission Factor for pollutant X

$FL \times CC = CON$ (Fuel Consumption)

Biomass Burning Emission Model

In the U.S. fuel loading is considered the greatest uncertainty in estimating wildfire emissions[1,2,3]

Fuel loading , FL(t, x, y):

fuel loading model
+
fuel model map

Spatial variability of forest fuels is known to be very high, but is not well characterized[4]

Lack of knowledge w.r.t. fuel spatial variability hinders the development and application of fuel models and makes accurate mapping of fuel loading difficult[4]

[1]Ottmar, 2001; [2]French et al., 2004; [3]Larkin et al., 2009; [4]Keane et al., 2012

Objectives

Use newly available fuel loading data from ~13,140 forest inventory plots[1] to:

- Evaluate two widely used fuel loadings models
- Develop a new fuel loading model
- Characterize the uncertainty in ECO due to uncertainties in the fuel model and fuel model map at scales relevant to AQM

[1]USDA Forest Service Forest Inventory and Analysis (FIA) program

EI Model

$$ECO = A \times FL \times CC \times EF_{CO}$$

Domain: western U.S. **forests** over 2005 - 2008

Daily CO emissions (ECO)on 10-km grid

Burned area (A) based on MTBS[1] data

Temporal distribution approximated using MODIS hotspots

CC simulated with First Order Fire Effects Model (FOFEM)

EF_{CO} from recent measurements of western US wildfires[2]

[1]Monitorig Trends in Burn Severity Project, USFS, Remote Sensing Application center (RSAC); [2]Urbanski, 2012 (in preparation)

Forest Inventory and Analysis (FIA) Program Plot Data[1]

13,140 FIA forest inventory plots from the western U.S.

Plot data include:

Fuel loading: litter, duff, and dead wood by size class (1-hr, 10-hr, 100-hr, 1000-hr)

FIA forest type and forest group type assignments (e.g. white fir and fir/spruce/mountain hemlock group)

[1]USDA Forest Service Forest Inventory and Analysis (FIA) program

Widely Used Fuel Loading Models & Maps

Fuel loading models

Fuel Loading Models (FLM)[1]

Fuel Characteristics Classification System (FCCS)[2]

Fuel model map

LANDFIRE National Map 2001 Refresh[3] (30 m resolution)

FIA plots overlay with LANDFIRE maps (assess mapped fuel loading)

FIA plots keyed to FLM (assess map accuracy)

[1]Lutes et al., 2009; [2]Ottmar et al., 2007; [3] LANDFIRE Project, USDOI, 2011, www.landife.gov

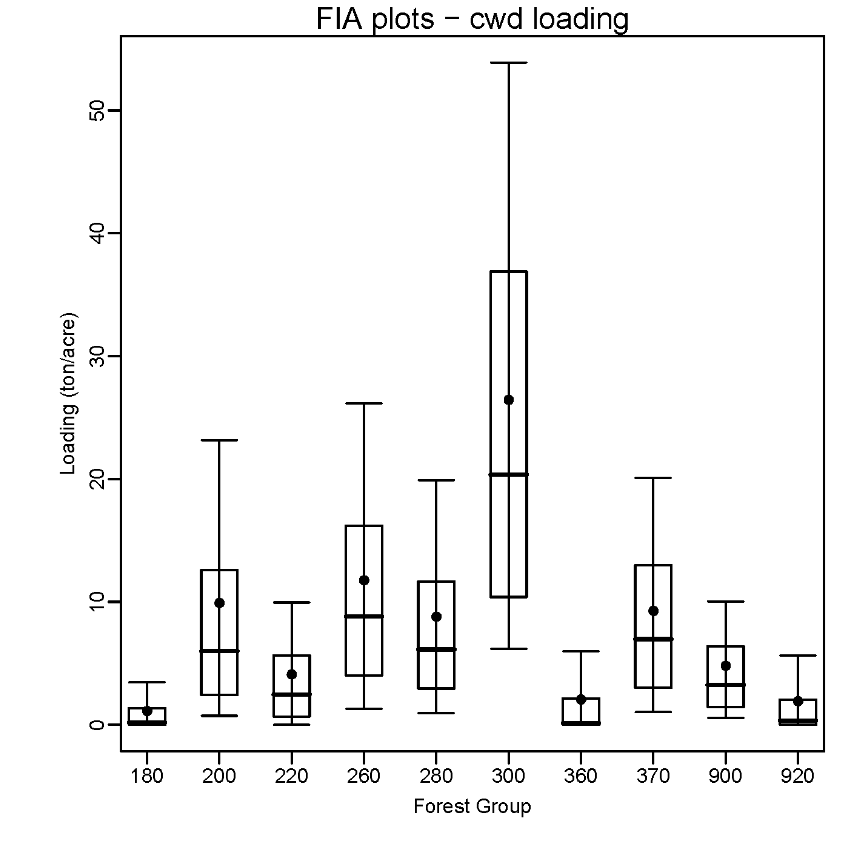
Forest Group Type (FGT) Fuel Model

- Fuel classes are FIA forest group types
- FGT mapped (Δx = 250 m) by USFS FIA and the Remote Sensing Application Center (RSAC) with overall accuracy of 69%[1]
- 22 FGT in the western U.S. (EI domain)
- 10 FGT comprise 97% of western forest area
- FIA data plots include FGT designation

[1]Ruefenacht et al., 2008; http://fsgeodata.fs.fed.us/rastergateway/forest_type/index.php

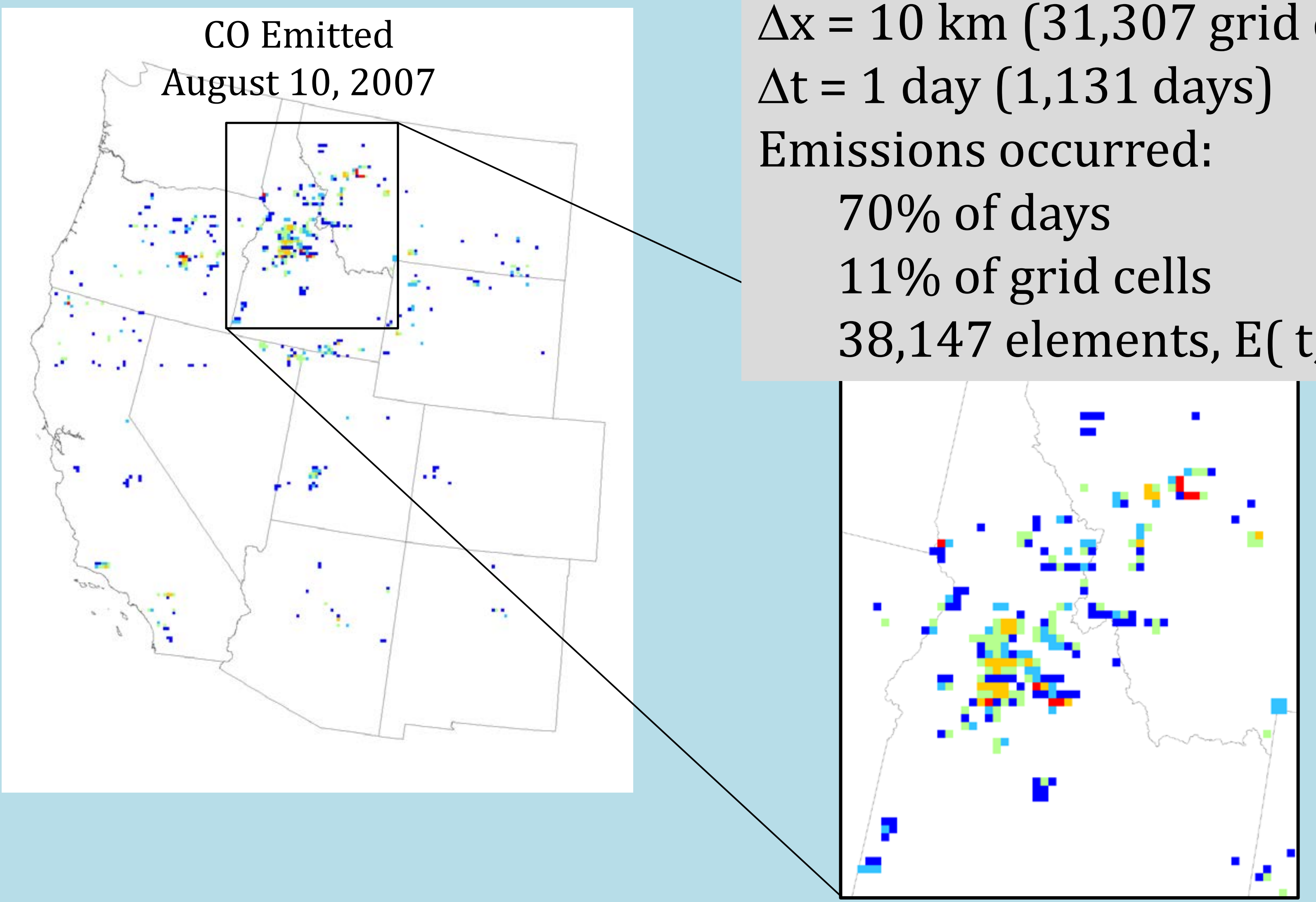
FGT Fuel Model

- 20 model fuel classes (FC)
- 6 fuel components (litter, duff, 4 dead wood size classes)
- Model loadings taken as mean of plot data
- Fuel loading data generally right skewed with long-tail

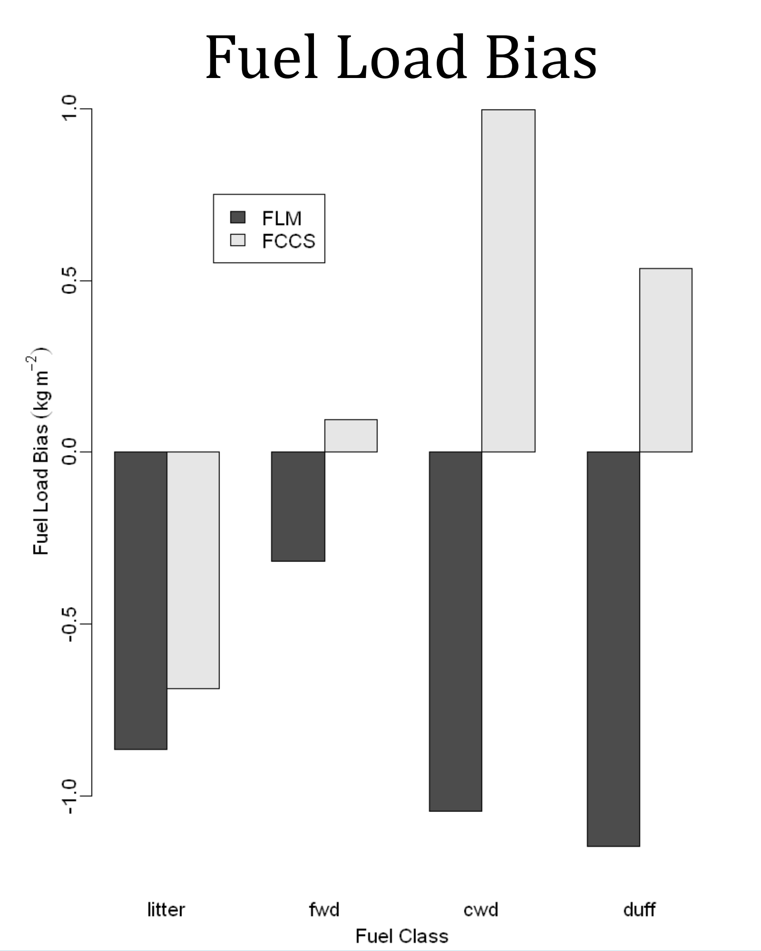


Emission Inventory Domain

Inventory Resolution E(t, k)
Δx = 10 km (31,307 grid cells)
Δt = 1 day (1,131 days)
Emissions occurred:
- 70% of days
- 11% of grid cells
- 38,147 elements, E(t, k)



Model Fuel Loading vs. FIA Plot Data 2005 Forest Fires



Mean bias forest burned area:
FLM bias = -3.4 kg m^{-2}
FCCS bias = +0.9 kg m^{-2}

FLM error:
ECO underestimate of 1,840 Gg-CO (1.7 million short tons)

FLM LANDFIRE map:
accuracy = 22%

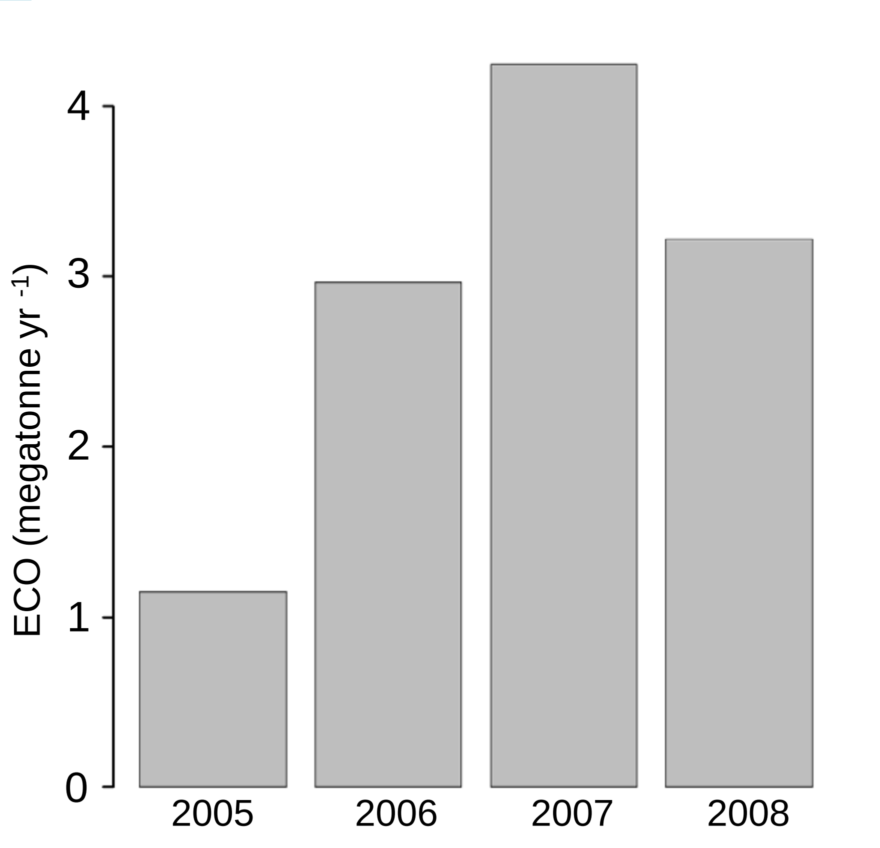
FGT Fuel Model & ECO Uncertainty

- FLM and FCCS fuel models have large bias
- FLM LANDFIRE map accuracy is very low (22%)
- Unable to assess FCCS map accuracy due to lack of suitable key
- So, on to the FGT Fuel Model…..

Uncertainty Analysis

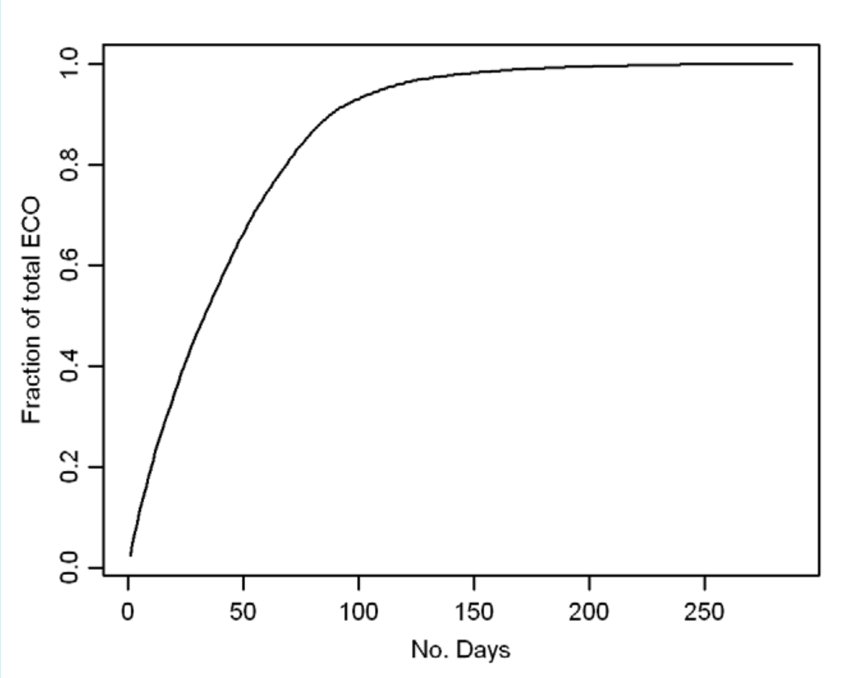
- Estimate uncertainty in ECO, uECO, at the scale of the emission inventory: Δ t = 1day and Δx = 10 km
- Use Monte Carlo style analysis
- Compare model (inventory) ECO vs. population of "true" ECO* based on fuel loadings sampled from FIA plots
- Note: really assessing model fuel consumption, CON (CON = FL × CC) since uncertainties in A, CC, EF_{CO} are ignored

Western U.S. forest fire annual ECO 2005-2008



Western U.S. forest fire annual ECO 2005-2008

ECO Temporal Distribution

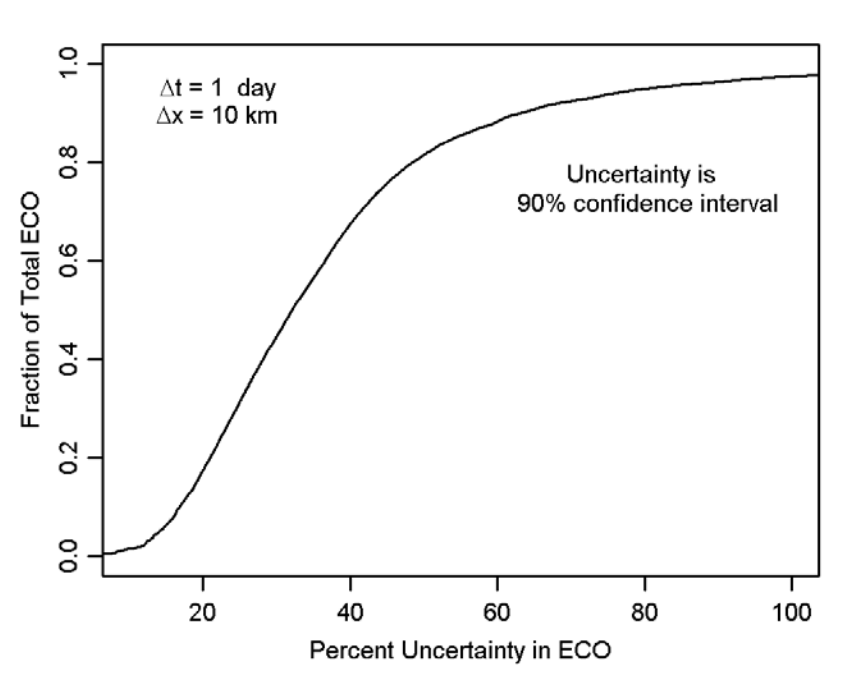


ECO highly concentrated temporally & spatially:

- 10% of ECO over 4 days
- 25% of ECO over 13 days
- 33% of ECO over 18 days
- 50% of ECO over 33 days

Uncertainty estimates at an aggregate scale not particularly useful for AQ modeling applications

Uncertainty in ECO(Δt, Δx)



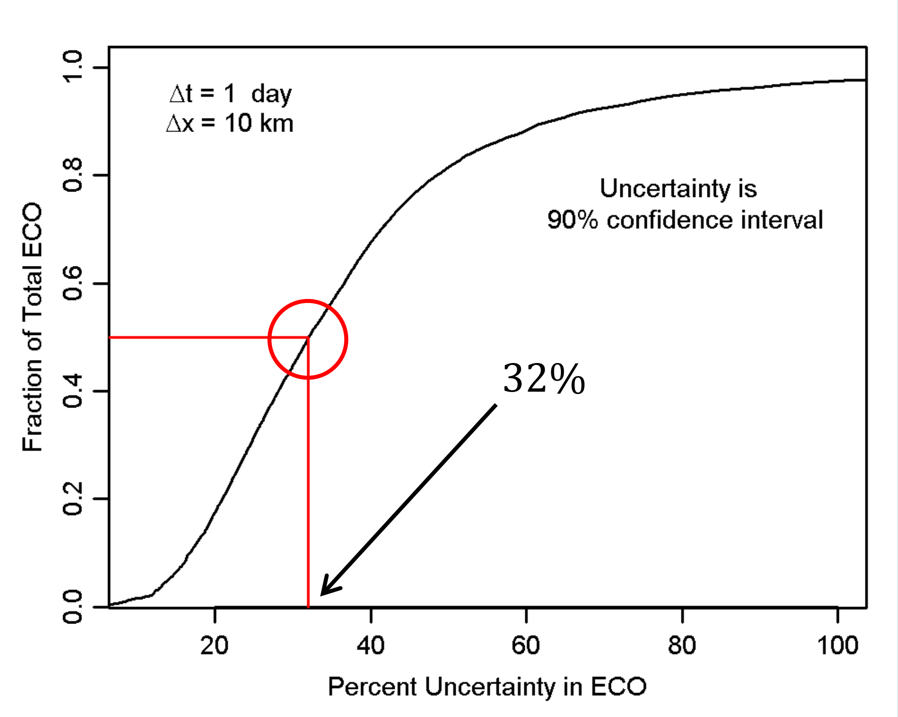
- Cumulative distribution function of ECO, F(X), vs. uECO
- Select comparison value, e.g. 50% of total ECO
- Figure of merit:

  FOM_{50} = uECO

  where F(X) = 0.5

50% of CO emitted from elements ECO(d, k) with an uncertainty < FOM_{50}

Uncertainty in ECO(Δt, Δx)



$FOM_{0.5}$ = 32%

For this EI, 50% of total ECO are estimated with an uncertainty < 32% at scale

Δt = 1 day, Δx = 10 km

Conclusions

- Two widely used fuel models (FLM & FCCS) as mapped by the LANDFIRE Project exhibited significant bias
- Mapping accuracy is very low FLM, 22%
- New fuel model, Forest Group Type(FGT), was developed and used to assess fuel related uncertainty in ECO
- At AQM scales 50% of ECO is estimated with an uncertainty < 32% (90% confidence interval)

Acknowledgements

Chris Toney of the LANDFIRE program for supplying and preparing the FIA plot data and overlays with geospatial products

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“True” Emissions

Population of “true” Fuel Consumption (CON) simulated with FOFEM for all FIA plots: CON_i (no. i = 13,140)

For each burned pixel, p (Δx = 250 m):

Sample FIA plot - RSAC map overlay for “true” FC: $FC_b^*(p)$

Sample plot CON_i with $FC_i = FC_b^*(p)$ for “true” CON: $CON_b^*(p)$

Calculate “true” ECO: $ECO_b^*(p) = A \times CON_b^*(p) \times EF_{CO}$

Repeat B times to generate population of “true” ECO (ECO_1, ECO_2,…ECO_B)

Uncertainty Analysis

For each 10-km grid cell with fire:

- Sum model emissions for all pixels:

$ECO(d,k) = \sum ECO(p)$

- Sum 'true' emissions for all pixels on sample basis:
- $ECO_b^*(d,k) = \sum_p ECO_b^*(p)$

Sort ECO*b(d, k) and extract 90% confidence interval: $ECO_{lower}(d,k) = ECO_b^*(d,k)[B \times .05]$
$ECO_{upper}(d,k) = ECO_b^*(d,k)[B \times .95]$

Uncertainty in inventory ECO for element (d, k):

uECO = max(abs(uECOlower),uECOupper)

where:

uECOlower(d,k) = ECOlower(d,k) - ECO(d,k)

uECOupper(d,k) = ECOupper(d,k) - ECO(d,k)

Uncertainty Analysis (cont.)

For each 10-km grid cell (k) with fire on day = d:

Sum model emissions for all pixels

$$ECO(d,k) = \sum ECO(p)$$

Sum "true" emissions for all pixels on sample basis

$$ECO_b^*(d,k) = \sum_p ECO_b^*(p)$$

Sort $ECO_b^*(d,k)$ and extract 90% confidence interval

$$ECO_{.05}(d,k) = ECO_b^*(d,k)[B \times .05]$$

$$ECO_{.95}(d,k) = ECO_b^*(d,k)[B \times .95]$$

Uncertainty Analysis (Cont.)

Uncertainty in inventory ECO for element (d, k):

$$uECO(d,k) = \max(|uECO_{.05}(d,k)|, uECO_{.95}(d,k))$$

where:

$$uECO_{.05}(d,k) = ECO_{.05}(d,k) - ECO(d,k)$$

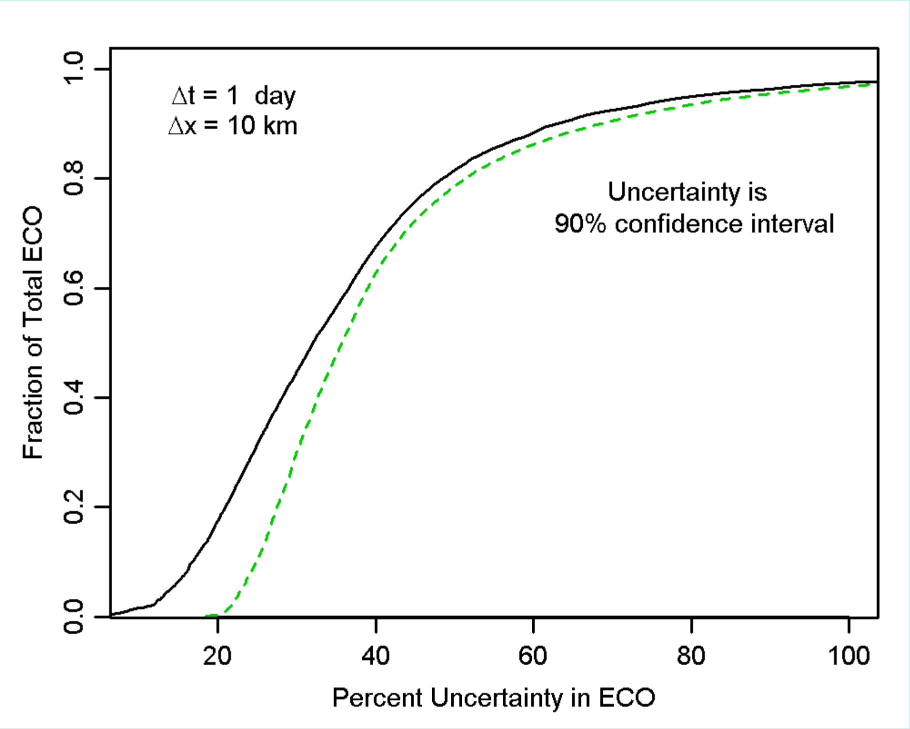
$$uECO_{.95}(d,k) = ECO_{.95}(d,k) - ECO(d,k)$$

Wildfire Impact on Air Quality

- Contribution to O_3 in urban areas during NAAQS exceedances: Pfister et al. (2008); Jaffe et al., (2008); Jaffe (2011)
- Contribution to $PM_{2.5}$ (24-hour and annual) and Regional Haze in Class I Area (e. g. Park et al., 2007; Brewer & Moore, 2006)
- Exceptional Event Demonstrations resulting in EPA concurrence wrt NAAQS for O_3 and $PM_{2.5}$[1]

[1] http://www.epa.gov/ttn/analysis/exevents.htm

Uncertainty in ECO(Δt, Δx)

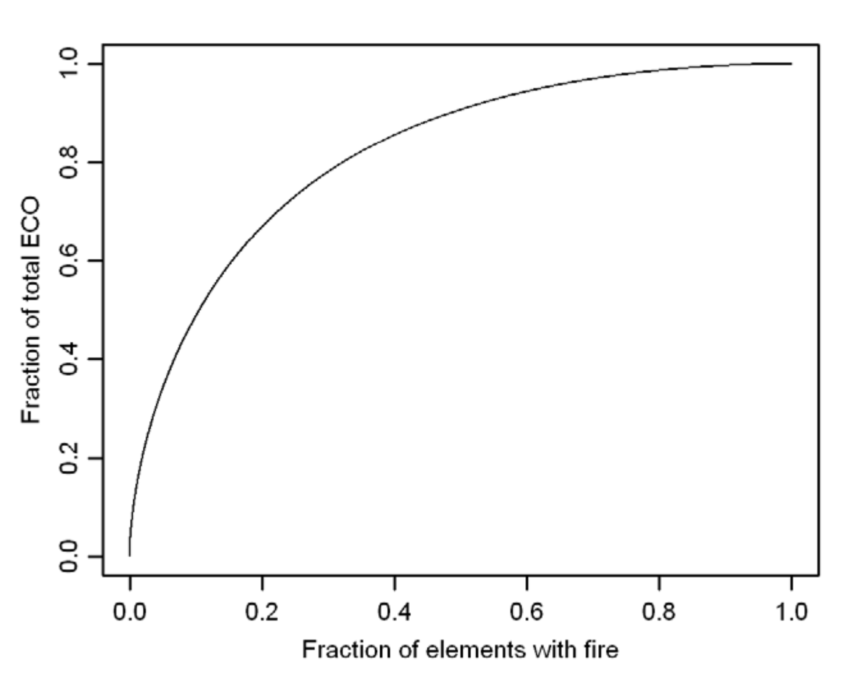


- Assess uncertainty at scales pertinent to AQM
- Useful for comparing EI
- Benchmark to guide development and improvements to EI

Uncertainty in fuel model / fuel map
vs.
Uncertainty in fuel model / fuel map /burned area

Western U.S. forest fire annual ECO 2005-2008

ECO Spatial – Temporal Distribution



- 10% of ECO over 1% of elements
- 25% of ECO over 3% of elements
- 33% of ECO over 4% of elements
- 50% of ECO over 10%of elements

Uncertainty estimates at an aggregate scale not particularly useful for AQ modeling applications