Carbon emissions from North American wildland fires: a review of methods and comparison of results from five case studies

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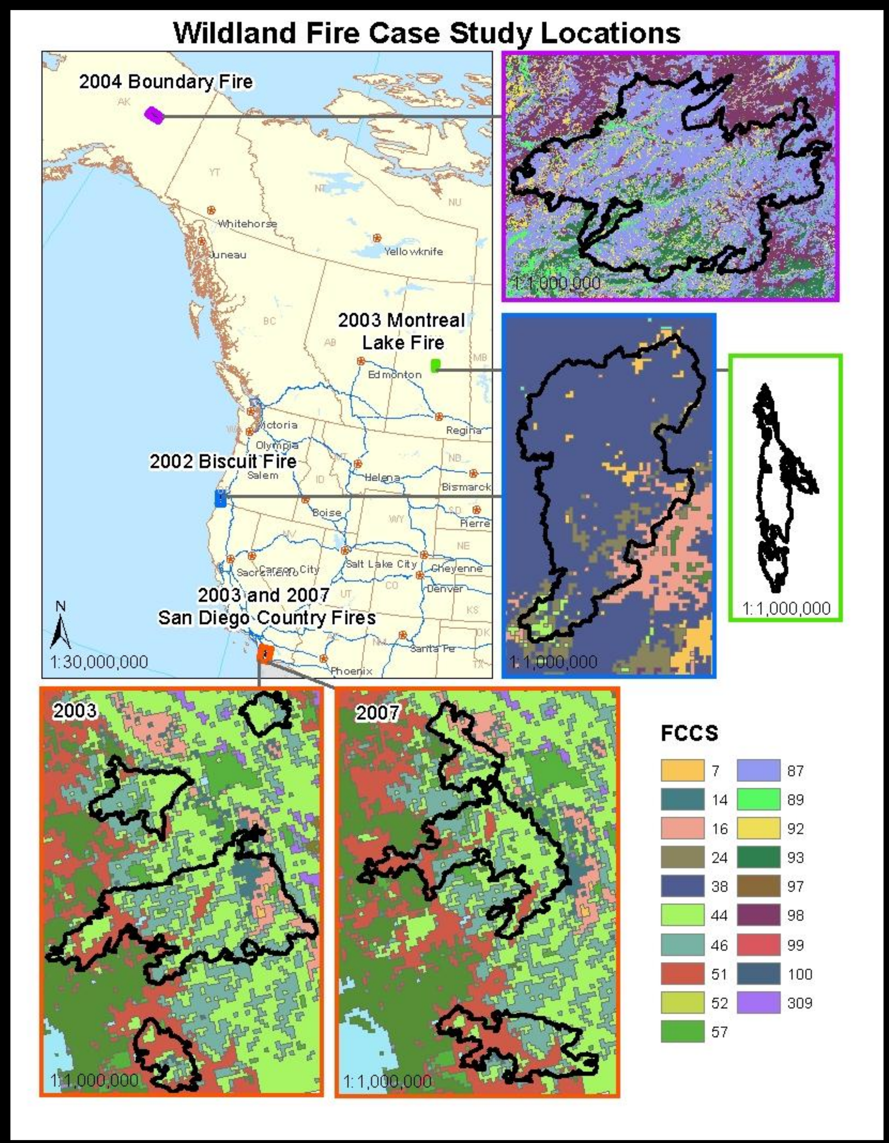
As part of the NACP Synthesis on the Impacts of Disturbance on the North American Carbon Budget, we have compiled results from several bottom-up models of fire emissions to compare the details of approaches used and the results found with the array of models currently in use for North American regions. The study included analysis of as many as five currently available models running with various data inputs and at several spatial scales.

Five specific fire events:

- 2002 Biscuit fire in southern Oregon
- 2003 Montreal Lake fire in central Saskatchewan
- 2004 Boundary fire in interior Alaska
- Two sets of fires in San Diego Country, California in Oct. 2003 and Oct. 2007

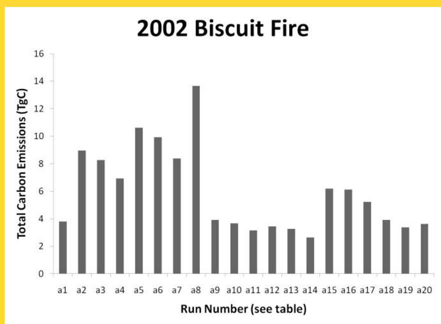
The six models:

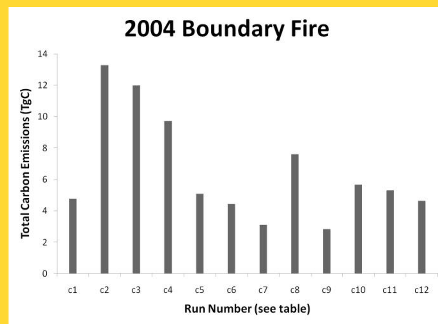
- CONSUME 3.0
- FOFEM 5.7
- WFEIS
- CanFIRE
- Canadian FBP system approach
- GFED

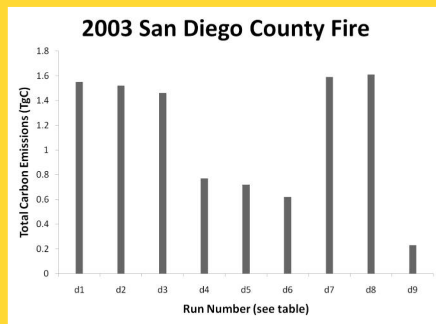


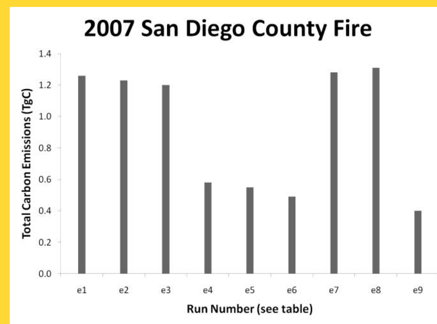
Estimates of carbon emitted for case studies

Model used (run number)	Burn area used in estimate (ha)	Total Carbon emissions (TgC)	Area normalized carbon emissions (kgC m⁻²)
a. Biscuit Fire			
Field-based [*Campbell et al.,* 2007] (a1)	200,000	3.80	1.9 0.2
FOFEM 5.7[a]			
(a2) Very dry[b]	199,500[c]	8.97	4.50
(a3) Dry[b]	199,500[c]	8.26	4.14
(a4) Moderate[b]	199,500[c]	6.93	3.48
CONSUME 3.0[a]			
(a5) Very dry[b]	199,500[c]	10.62	5.32
(a6) Dry[b]	199,500[c]	9.93	4.98
(a7) Moderate[b]	199,500[c]	8.37	4.19
WFEIS[a]			
(a8)	200,444[c]	13.65	6.81
FOFEM 5.7[d]			
(a9) Very dry[b]	199,500[c]	3.92	1.97
(a10) Dry[b]	199,500[c]	3.67	1.84
(a11) Moderate[b]	199,500[c]	3.16	1.58
CONSUME 3.0[d]			
(a12) Very dry[b]	199,500[c]	3.44	1.72
(a13) Dry[b]	199,500[c]	3.26	1.63
(a14) Moderate[b]	199,500[c]	2.63	1.32
WFEIS[d]			
(a15) Landsat burn area	200,444[c]	6.20	3.10
(a16) "daily progression"[d]	200,154[e]	6.13	3.06
(a17) MODIS burn area[d]	169,916[f]	5.22	3.07
CanFIRE[d]			
(a18)	200,124[c]	3.92	1.96
FBP System[d,g]			
(a19)	200,124[c]	3.38	1.69
GFED			
(a20)	167,351[f]	3.63	2.17
b. Montreal Lake Fire[h]			
Canadian FBP System [de Groot et al., 2007] (b1)	21,652	0.26	1.20
BORFIRE[i] [*de Groot et al.,* 2007] (b2)	21,652	0.37	1.70
FOFEM 5.7			
(b3) Very dry[b]	21,655	1.41	6.51
(b4) Dry[b]	21,655	1.27	5.88
(b5) Moderate[b]	21,655	1.03	4.76
CONSUME 3.0			
(b6) Very dry[b]	21,655	0.72	3.32
(b7) Dry[b]	21,655	0.62	2.86
(b8) Moderate[b]	21,655	0.48	2.23
CanFIRE[i]			
(b9)	21,652	0.44	2.32
FBP System[j]			
(b10)	21,652	0.17	0.79
WFEIS			
(b11) Landsat burn area	21,656	0.35	1.60
GFED			
(b12)	24,137	0.30	1.26
c. Boundary Fire[k]			
Field-based study (Kasischke unpublished data, 2010) (c1)	184,755[l]	4.78	2.59
FOFEM 5.7			
(c2) Very dry[b]	217,232	13.27	6.11
(c3) Dry[b]	217,232	11.99	5.52
(c4) Moderate[b]	217,232	9.71	4.47
CONSUME 3.0			
(c5) Very dry[b]	217,780	5.09	2.34
(c6) Dry[b]	217,780	4.44	2.04
(c7) Moderate[b]	217,780	3.10	1.42
CanFIRE			
(c8)	210,074	7.60	3.62
FBP System			
(c9)	210,074	2.84	1.35
WFEIS			
(c10) Landsat burn area	211,465	5.68	2.68
(c11) "daily progression"	211,260	5.30	2.51
GFED			
(c12)	207,050	4.64	2.24
d. San Diego County Oct 2003[m]			
FOFEM 5.7			
(d1) Very dry[b]	143,757	1.55	1.06
(d2) Dry[b]	143,757	1.52	1.04
(d3) Moderate[b]	143,757	1.46	1.01
CONSUME 3.0			
(d4) Very dry[b]	144,657	0.77	0.53
(d5) Dry[b]	144,657	0.72	0.50
(d6) Moderate[b]	144,657	0.62	0.43
WFEIS			
(d7) Landsat burn area	150,896	1.59	1.05
(d8) "daily progression"	150,619	1.61	1.07
GFED			
(d9)	100,642	0.23	0.23
e. San Diego County Oct 2007			
FOFEM 5.7			
(e1) Very dry[b]	119,565	1.26	1.08
(e2) Dry[b]	119,565	1.23	1.06
(e3) Moderate[b]	119,565	1.20	1.02
CONSUME 3.0			
(e4) Very dry[b]	122,165	0.58	0.47
(e5) Dry[b]	122,165	0.55	0.45
(e6) Moderate[b]	122,165	0.49	0.40
WFEIS			
(e7) Landsat burn area	127,381	1.28	1.01
(e8) "daily progression"	127,347	1.31	1.03
GFED			
(e9)	115,476	0.40	0.35





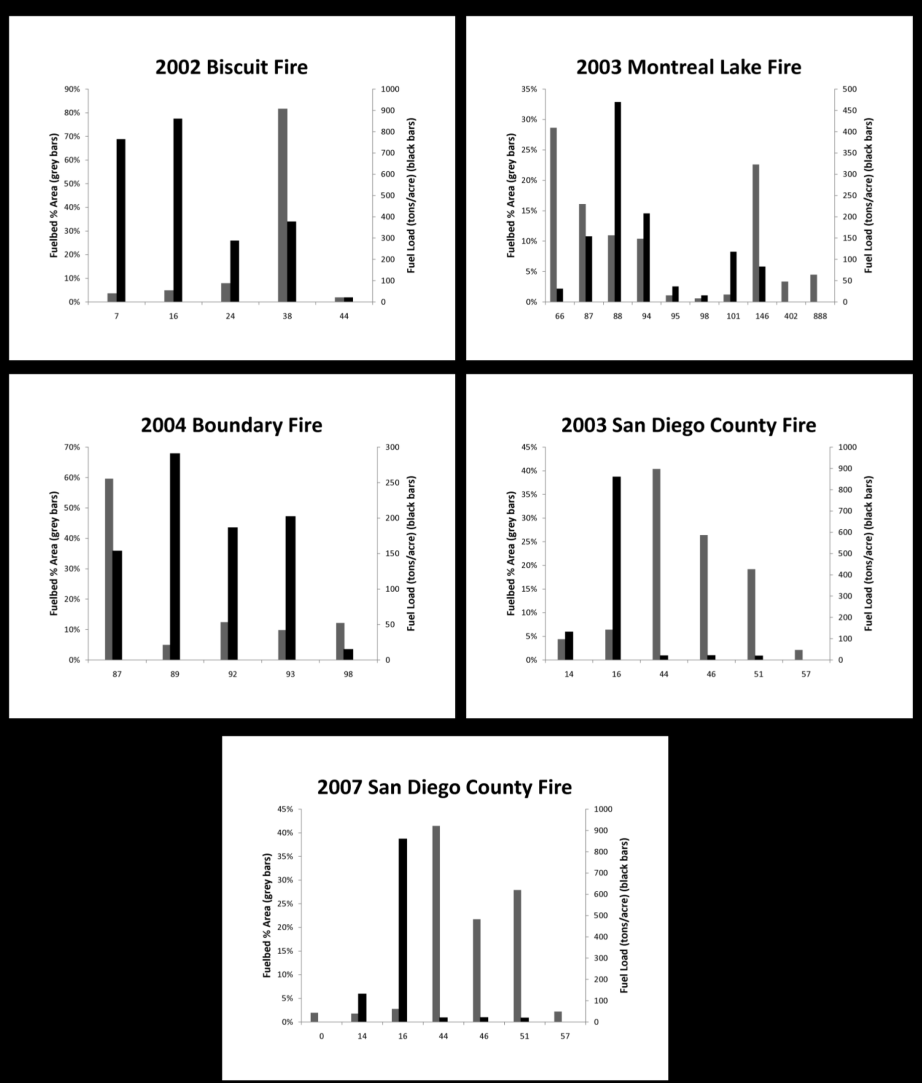




[a] based on proportions from original 1-km FCCS map; fuel loadings range from 10.33 to 386.03 kg fuel m^{-2}
[b] See Table 3 for fuel moisture inputs used for scenarios
[c] Landsat-derived burn area
[d] based on proportions from revised 1-km FCCS map; fuel loadings range from 21.37 to 860.82 kg fuel m^{-2}
[e] MODIS-derived progression burn area
[f] MODIS-derived DBBAP burn area
[g] Based on C-7 ponderosa pine-Douglas fir FBP System fuel type
[h] fuel loadings range from 6237.10 to 80552.56 kg fuel m^{-2}
[i] BORFIRE [*de Groot et al.* 2007] and CanFIRE used the same fuel consumption algorithms for these simulations
[j] fuels inventory improved from *de Groot et al.* [2007]
[k] fuel loadings range from 2614.51 to 26397.1 kg fuel m^{-2}
[l] the Kasischke study excluded areas of cloud and cloud shadow in their Landsat-derived vegetation and burn area assessment
[m] fuel loadings range from 56.58 to 147581.7 kg fuel m^{-2}

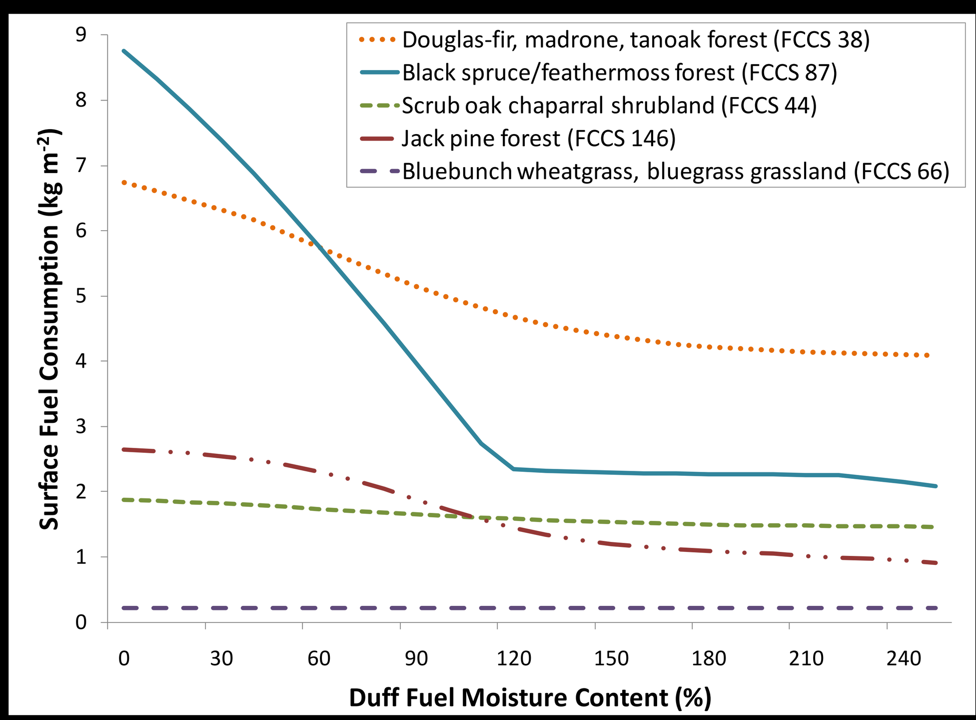
Effects of Fuelbed/Fuel Load on Carbon Emissions

Area and fuel load (mass) differences across sites are presented in the graphs below. Sites where fuel loads (biomass) are low, such as San Diego, show lower emissions per unit area in all models compared where fuel loads are higher (see inset table, far right). The type of fire (e.g. crown vs. surface fire) also influences the magnitude of emissions.



Effect of Fuel Moisture on Carbon Emissions

Fuel moisture influences fuel consumption differently for different fuel types. The graph below shows that forested types are more dynamic across moisture conditions than shrublands and grasslands.

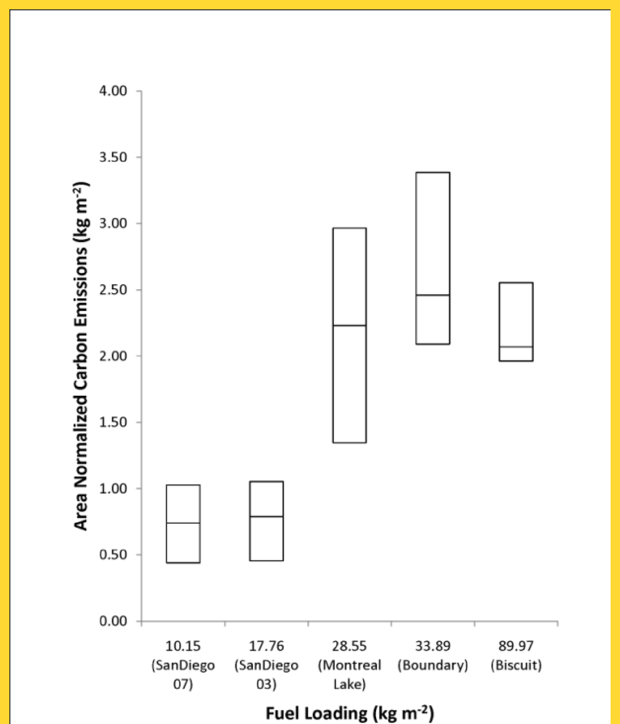


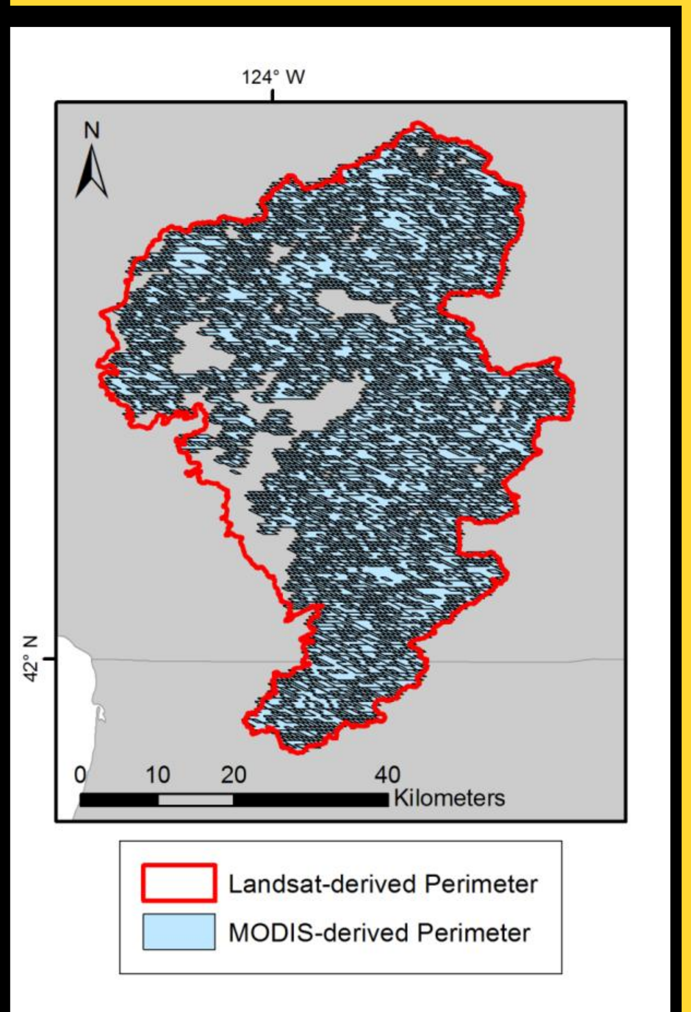
Effect of Burned Area on Carbon Emissions

For the Biscuit fire case, the WFEIS model was run with two burn area maps (see figure, right). The area-normalized emissions are similar (**3.06 and 3.07 kgC m⁻²**), but the total carbon emitted is higher with the Landsat-based map by about 17% (6.13 TgC with Landsat and 5.22 TgC with MODIS).

Discussion and Conclusions:

- Models generally agree (within 25% of each other, see graph, right)
- Vegetation fuel density, structure, and condition (fuel moisture) are important drivers of emissions variability
- 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
- Improvements in input data is required for accurate emissions quantification beyond burn area maps:
  - Weather data and improved characterization of fuel moisture conditions
  - Field data on combustion for critical types, such as peatlands and deep organic soils and for underrepresented regions, such as tropical and sub-tropical fuel types
  - Better quantification of shrub fuel loadings and shrub consumption
  - Data on live fuel fractions and live fuel moisture
  - Additional testing of model performance and inter-model comparisons

Co-Authors

Ernesto Alvarado, Brian Amiro, Bernardus de Jong, Scott Goetz, Elizabeth Hoy, Edward Hyer, Robert Keane, Bev Law, Donald McKenzie, Steven McNulty, Roger Ottmar, Diego Pérez-Salicrup, James Randerson, Kevin Robertson, Merritt Turetsky

For a full description of methods, models, and results, please see:
French, Nancy et al (2011). Carbon emissions from North American wildland fires: A comparison of modeling approaches. Journal of Geophysical Research, Biogeosciences. (In Press)