Carbon Emissions Estimation
Temperate & Boreal Forest Regions

Models and Information Requirements
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Altarum
Overview

- Approaches and Models used for estimating direct C emission
- Input data sources and samples
- Sample results
- Key Issues
- Summary
Emission Estimation Approaches

- Using average fire, biomass, and consumption statistics by country/region
- Dividing fuel components
- Incorporating landscape/regional-scale spatial distribution of fire and fuels
- Considering temporal variation in fuel moisture → fire severity → fuel consumption
General Equations:

Total Carbon Flux, TCF:

\[ TCF_{\rho,t1} = DF_{\rho,t1} + PDF_{\rho,t<t1} \]

Where:

- \( DF_{\rho,t1} \) is the direct flux [direct fire emissions] in year \( t1 \)
- \( PDF_{\rho,t<t1} \) is the post-disturbance, as a rule biogenic, flux [post fire flux] generated by disturbance \( \rho \) that occurred in previous years \( t<t1 \)

\[ DF_{\rho,t1} = C_t = C_{CO_2} + C_{CO} + C_{CH_4} + C_{NMHC} \]
Total Carbon Emissions from Fires - $C_t$

$C_t = A B f_c \beta$

- $A$ is the total area burned (ha)
- $B$ is the biomass density (t ha$^{-1}$)
- $f_c$ is the fraction of the biomass that is carbon
- $\beta$ is the fraction of biomass consumed during biomass burning
Trace Gas Emissions - $E_g$

\[ E_g = C_t E_{fg} \]

where $E_{fg}$ is the emission factor (in weight of gas released per weight of carbon burned) for a specific gas species
Implementing C Emissions Models

1. \( C \) and \( \beta \) are divided into aboveground and ground-layer components

\[ C_t = A(C_a \beta_a + C_g \beta_g) \]

Area burned
Aboveground (plant) C
Ground (soil) C

2. Gas emissions are divided for two combustion scenarios – flaming (f) and smoldering (s)

\[ E_g = C_{t-f} E_{fg-f} + C_{t-s} E_{fg-s} \]
Key Elements

1. Fire databases by region & location (remote sensing & GIS)
2. Spatial databases of fuels – vegetation and organic soil (RS & GIS)
3. Fuel consumption estimates (measurements & models) – based on variations in fire type, fuel type, and fuel moisture conditions
4. Emission factor data for each gas species (direct measurement)
5. Integrate information from 1-4 within GIS modeling framework to estimate emissions
Boreal Fire Location Data

GIS-based fire locations and boundaries from fire records
Boreal Fire Location Data

Satellite-derived fire locations & boundaries

Official Fire Statistics

Fire Statistics for Eurasian Russia

- Official Statistics
- Satellite (AVHRR) Estimates

Area burned (million ha)

<table>
<thead>
<tr>
<th>Year</th>
<th>Area Burned (million ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>2.5</td>
</tr>
<tr>
<td>2002</td>
<td>12.5</td>
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</table>
Area Burned in Boreal Forest Regions

Area burned (million ha)

North America
Eurasia

Vegetation Carbon (CFS)

Fuel (Carbon) Maps North America

Soil Carbon (CanSIS)

Regional-scale

Landscape-scale

Aboveground and organic soil C for an Alaskan fire

Vegetation Carbon (CFS)
Fuel (Carbon) Maps

Soil Carbon
(IIASA)

Vegetation Carbon
(WHRC)

Russia
Estimating Fuel Consumption

- Based on experimental/prescribed burns – soil pins
- Assessed using aerial photos or on-site ocular estimation combined w/allometric equations
- Estimated with burn/unburn site comparisons
- Estimated using fire behavior/fuel moisture models

- Mapped by modeling individual sites or extrapolating site data to region (remote sensing & GIS)

Carbon Consumption
Gerstle River, Alaska
Sources of Variations in $\beta_a$ & $\beta_g$

**Fuel moisture conditions**
- Seasonal climatic patterns
- Seasonal permafrost melting
- Levels of pre-fire tree mortality

**Forest/vegetation type**
- Forests vs. peatlands
- Conifer vs. deciduous and mixed
- Forest structure (biomass density)

# Emissions Factors

(From direct emission measurements)

<table>
<thead>
<tr>
<th>Vegetation/Fire Type</th>
<th>CO₂</th>
<th>CO</th>
<th>CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Boreal Forest – Flaming</strong></td>
<td>3.145</td>
<td>0.190</td>
<td>0.0055</td>
</tr>
<tr>
<td><strong>Boreal Forest – Smoldering</strong></td>
<td>2.590</td>
<td>0.460</td>
<td>0.0152</td>
</tr>
<tr>
<td><strong>Temperate Forests/Prescribed Burns – Combined</strong></td>
<td>3.138</td>
<td>0.214</td>
<td>0.0094</td>
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</tbody>
</table>
Carbon Release Estimates
Canada:
Average of 27 Tg C/yr
(20% of Canada’s fossil fuel emissions)

(B. Stocks & others)
Carbon Release Estimates (Cont)

Regional-scale
(5 Tg C/yr)

Alaska

GIS-based estimate of annual C released

Landscape-scale
(0.19 Tg C)

(N. French & others)

Landsat-derived estimate of C released from 1994 Gerstle River burn

Mean annual C release 1950-1999 (x 10^6 grams)

Study area extent

- 0
- >0 - 20
- >20 - 40
- >40 - 70
- >70 - 100
- >100 - 200

ESTIMATED CARBON RELEASED (T/ha)

- ≤ 20
- 21 - 40
- 41 - 60
- 61 - 80

Scale 1:100,000

Kilometers
Carbon Release Estimates (Cont)

Russia:
Average of 58 Tg C/yr
(A. Shvidenko & others)

Temperate North America (lower 48)
approx. 35 TgC/year
(E. Kasischke)
Temperate & Boreal Combined

Total C Emission
234 Tg C/yr
(Boreal 180 TgC/yr
Temperate 54 TgC/yr)

CO Emission

(E. Kasischke)
Percent emissions from HNH fires

(E. Kasischke)

Total Carbon Emissions

Carbon Monoxide Emissions

(E. Kasischke)
Key Issues

- **Burn Area Maps**
  - Good information except for Russia and Pre-1940-50’s for NA
  - Temperate region data not as consistent

- **Fuel (Carbon) Maps**
  - Good information from forest inventory data (except Alaska)
  - General underestimation from lack of surface and ground-layer estimates
  - Spatial resolution variable
Key Issues (continued)

- Fuel Consumption
  - Difficult to quantify - not directly measured
  - Variability generally unknown
  - Few measurements in some ecosystems & fire conditions

- Emission Factors
  - Based on few measurements
  - Flaming/smoldering ratios poorly known
  - Non-spatial information

- A need for consistent measurement techniques

- Misconception of how well some items are known & how variables are related
Temperate & Boreal Fire Types

**Well Understood**
- Crown fires – aboveground fuels consumed
- Surface vegetation fires – understory & surface fuels consumed

**Moderately Understood**
- Smoldering surface fires – litter/duff consumed

**Poorly Understood**
- Peatland/bog fires – deep organic soils consumed
- Forest re-burns – dead fuels consumed
12% of area burned in portions of western Canada occur in forested (spruce) peatlands (Turetsky, M., et al. in press.)
Sakhalin Island, Russia
C Emission VS Area Burned

HNH Total C emissions from fire

Total C (Tg) vs Area burned (million ha)
Summary

- Modeling approaches range from general to more complex versions with spatial/temporal variations included in model.
- Quality of available data varies - some regions/ecosystems/fire situations well documented, others are poorly understood.
- Emission results vary due to analysis scale, input data, & model parameterization & implementation.
- A need for consistent data & measurement techniques.