Fire behavior and effects: importance of feedbacks between vegetation structure and fire risk

Jacquelyn Shuman, Rosie Fisher, Ryan Knox, Charlie Koven, Lara Kueppers, Sam Levis, Chonggang Xu, and FATES team
Active fire counts
Global Burned fraction

• Fire regime is interaction of climate, vegetation and ignitions over decades to centuries

Van der Werf et al. 2017
Increasing Fire danger

- Anthropogenic change (heating, longer dry seasons, increasing land use) increases risk of more frequent and severe fires

Change in fire weather season length across 1979-2013 (days per year) Jolly et al. 2015

Extreme Fire Risk Ratio
Touma et al. 2021
Tropical forests hold 247 Gt C, with 193 Gt C aboveground.

Saatchi et al. 2011
Model projections must capture feedbacks

- Complex & dynamic feedback between vegetation structure and fire risk
- Adaptation of SPITFIRE (Thonicke et al 2010) into FATES (Fisher et al 2018)

Adapted from Hoffman et al 2011
FATES: The Functionally Assembled Terrestrial Ecosystem Simulator

FATES is a module, runs within a Host Land Model, replaces traditional process with more realistic vegetation that simulates: plant physiology, competition processes, ecosystem assembly vegetation distribution (cutting edge for these models)

Fisher et al. 2015; Fisher et al. 2018
FATES-SPITFIRE

Weather → Fire Weather → Ignition dataset → Fuel State & Load → Fuel Combustion → Fire Rate of Spread, Duration and Intensity → Area Burnt

Fire evaluated daily for each patch in grid cell

Ignition

Vegetation Growth

Biomass burnt

Trace gas emissions

Adapted from Thonicke et al. 2010 Biogeosciences
FATES-SPITFIRE vegetation mortality

Tree mortality:
- Fire intensity and duration
- Scorch height (relative to canopy height)
- Bark damage varies with bark thickness (varies by PFT & size)

Grasses are not protected, and burn with all fires.

FATES retains the fire-affected canopy structure thus affecting future fire behavior
Notable Fire updates

- EQ for fuel drying and fire intensity; decoupled seed decay and fire behavior
- Updated fire ellipse shape to be dynamic based on dominance of trees vs grasses
- Fixed typo for ellipse shape for grass fuels present in all SPITFIRE variants

\[ LB = 1.1 + WSV^{0.464}, \quad WSV \geq 1.0 \]  \hspace{1cm} (80)

Updates and Revisions to the 1992 Canadian Forest Fire Behavior Prediction System.
Wotton et al. 2009

\[ L_{B,\text{grass}} = 1.1 + U_{\text{forward}}^{0.464} \]  \hspace{1cm} (13)

Thonicke et al. 2010 (and all SPITFIRE variants, incl FATES)
Forest/Savanna bi-stability

Important Factors:
- Climate
- Seasonality (# dry months)
- Fire
- Vegetation Traits and state

x = forest (> 55% trees)
o = savanna

Staver et al. 2011 Science
Bark thickness as vulnerability indicator

- Annual burned area explained 20% global variation in bark thickness
- Tropics: bark 3 times thicker in savanna than forests
- Infrequently burned areas have thin bark – vulnerability for future

Pellegrini et al. 2017 Ecology Letters
How do vegetation traits impact ecosystem assembly and fire behavior?

0.9 x 1.25 km runs
GSWP3 climate data (1995-2013)
Lightning strikes (NASA LIS/OTD)
Average across final 10 years

<table>
<thead>
<tr>
<th>Vegetation Type</th>
<th>Crown and Leaves</th>
<th>Leaf lifespan</th>
<th>Fire resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moist Tropical Tree</td>
<td>Large crown, vulnerable foliage</td>
<td>Long (~1 yr)</td>
<td>vulnerable, thin bark</td>
</tr>
<tr>
<td>Dry Tropical Tree</td>
<td>Thin crown, tolerant foliage</td>
<td>Long (~1 yr)</td>
<td>fire-adapted, thick bark</td>
</tr>
<tr>
<td>C4 Grass</td>
<td>n/a</td>
<td>Short (~4 months)</td>
<td>None</td>
</tr>
</tbody>
</table>
Fire acts to limit tree extent

Moist & Dry Trees, Grass
No Fire

Moist & Dry Trees, Grass
Fire from bare ground

Observations Landsat

Hansen, M. C., et. al. (2013) *Science*

Shuman et al (in prep)

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Biomass of forest

Moist & Dry Trees, Grass
Fire from bare ground

Moist & Dry Trees, Grass
Fire from bare ground

Observations
Saatchi et al 2011
Precipitation as determinant of forest

Moist & Dry Trees, Grass
Fire from bare ground

Climate Reanalysis
GSWP3

Staver et al 2011

Area of Trees [fraction]

Precipitation [mm yr⁻¹]

Deterministic low tree cover
Bistable, currently low tree cover
Bistable, currently forest
Deterministic forest

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Fire as a limit on forest

Observations

FATES Trees

FATES Mean

GFED4s
Fire as determinant of forest

Observations

FATES Mean

GFED4s

Fire Intensity [kW m\(^{-1}\)]

Burned Fraction [% yr\(^{-1}\)]
Fire Season: Observations GFED4s

- month = 1
- month = 2
- month = 3
- month = 4
- month = 5
- month = 6
- month = 7
- month = 8
- month = 9
- month = 10
- month = 11
- month = 12

Burned Fraction [% yr⁻¹]
Fire Season

Observations
GFED4s
Burned Fraction
[% yr⁻¹]

FATES
Burned Fraction
[% yr⁻¹]

FATES Fire Intensity
[kW m⁻¹]

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Vegetation traits as determinant of forest
Size-structure and bark thickness

Fire mortality [fraction yr⁻¹]
CTSM-FATES-SPITFIRE: Dynamic disturbance and forest structure

- Assembles ecosystem dynamically with plant interactions, degradation & loss
- Fire interacts with climate, fuel & vegetation
- Increased fire feedback in grass areas
- Size and bark matters for fire survival

Biomass observations
Saatchi et al 2011 PNAS

Burned area observations (1997-2014)
Van der Werf et al 2017

Burned fraction [% per year]
Total Biomass [MgC per ha]

Total Biomass Carbon (MgC ha$^{-1}$)
- 0-12
- 12-25
- 25-37
- 37-50
- 50-62
- 62-75
- 75-87
- 87-100
- 100-125
- 125-150
- 150-175
- 175-200
- >200

Forest
Grass

FATES Mean

(references and figures)
Vegetation traits as determinant of forest
Size-structure and bark thickness

![Maps showing fire mortality for different bark thickness classes.](image-url)