Trial by Fire: FATES-Spitfire

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Importance of Fire

• Fires affects most ecosystems globally from tropics to tundra, but many active fires in savanna

• Fire regimes determine species composition and biomass accumulation, and structure (crown fires, forest/savanna) (Pellegrini et al. 2017, Rogers et al. 2015, Staver et al. 2011, Hoffman et al. 2012)

• Biomass burning influences spatial and interannual variability of emissions (CO$_2$, CO, CH$_4$, NO$_x$, and black carbon) (van der Werf et al. 2004, Andrea & Merlet 2001, Galanter et al. 2000)

• Causes and consequences of fire require understanding of interaction of climate, vegetation (fuel) and fire: fuel load and rainfall savanna; temperature and fire season length boreal and temperate (Randerson et al. 2005, Schimel & Granstrom 1997, French et al. 2002, Sukhinin et al. 2004)
• Large inter- and intra-annual variation in burned area
• Annual burned area responds to inter-annual temperature variation (French et al. 2002; Sukhinin et al. 2004)
• Largest burn areas across the tropics
• Diurnal cycle, most active at midday with minimum humidity and high wind speed (Pyne et al. 1996)
Vegetation has connection to climate and to fire occurrence
Forest/Savanna bi-stability

Staver et al. 2011 Science
Infrequently burned areas have thin bark

- Annual burned area explained 20% global variation in bark thickness
- Tropics bark 3 times thicker in fire prone savanna than fire infrequent forests
- Future predictions of increased fire in “thin bark” areas
Increased Fire in low bark investment areas

LPJ-GUESS-SIMFIRE RCP 8.5 future 2070

Pellegrini et al. 2017 Ecology Letters
• Critical trait determining vulnerability of plant bole biomass to fire (Harmon 1984; Van Nieuwstadt and Sheil; Hoffman et al. 2009; Brando et al. 2012; Pellegrini et al. 2016)

• Intensity of fire and flame height (local fuels and wind) important determinant in tree mortality

• Opportunity for veg models – few models represent separate PFTs for forest and savanna species (differ in growth rate, bark thickness, stature and crown density)

50% survival: Low-intensity fire 5.9 mm
High-intensity fire 9.1 mm
Low-intensity fire char height ≤ 2m

Hoffman et al. 2012 Ecology Letters
Multiple scales of feedback

- Land-atmosphere feedback
- Wind speed feedback
- Flammability feedback
- Demographic feedback

(adapted from concepts in Hoffman et al., 2012, 2013)
FATES-Spitfire

**Ignition**

**Fire Danger Index per Nesterov**

Fuel State: load, bulk density, moisture, SA to Vol, PFT details

**Fuel Combustion**

Rate of Spread

Duration burn

Size of Ellipse

Area Burnt

**Fire Spread**

Moderate risk = NI 300 to 1000

High risk = NI 1000 to 4000

Extreme risk = NI above 4000

\[ NI(N_d) = \sum_{d=1}^{N_d} T_{daily}(d) \times (T_{daily}(d) - T_{dew}(d)) \]

\[ if \ P(d) \leq 3mm \]

\[ \geq 50 \text{ kW/m} \]

ignites fire

Adapted from Thonicke et al. 2010 Biogeosciences
Spitfire code review and update

- **Fuel State and Combustion (patch level):**
  - 6 fuel classes (dead leaves, twig, small and large branches, trunk, live grass)
  - Updated drying ratio, wind effect, burning parameters and moisture calculation (Lasslop et al. 2014, Thonicke et al. 2010, Peterson and Ryan 1986)

- **Rate of Spread (ROS) front and back (daily for patch):**
  - Corrected: burning calculations, ROS back (Thonicke et al. 2010)
  - Updated reaction intensity (kJ/m²/min)

- **Fire Intensity, duration and area burnt**
  - Probability of fire ignition (Venevsky et al. 2002)
  - Updated fire duration, fractional area burnt to include fire danger (Thonicke et al. 2010)
Updated fuel moisture parameter for twigs
Spitfire Vegetation Mortality – joint prob. of crown and cambial damage

- Updated equation for proportion of crown affected by fire (Thonicke et al. 2010)
- Crown Scorch ($CK$)
  \[
  CK = \frac{SH - H + CL}{CL}
  \]
  Scorch Height (SH), Height (H), Crown Length (CL)
- Cambial Damage ($\tau_{pm}$) depends on fire residence time, bark thickness, PFT (Peterson and Ryan 1986)
  \[
  \tau_{pm} = \begin{cases} 
  1.0 & \\
  0.563(\tau_l/\tau_c) - 0.125 & \\
  0.0 & 
  \end{cases}
  \]
  Heating time ($\tau_l$), Critical time for cambial kill ($\tau_c$)

Probability of Mortality ($P_m$)
\[
P_m = P_m(\tau) + P_m(CK) - P_m(\tau) \cdot P_m(CK)
\]
Preliminary Results

- 4 x 5 global runs
- GSWP3 (1991-2010)
- 1 PFT (Tropical Tree or Grass)
- 2 PFT (Tropical Tree & Grass)
- Fire ON and Fire OFF
- 6 runs

<table>
<thead>
<tr>
<th>Runs</th>
<th>Number PFTs</th>
<th>Fire?</th>
<th>DATM_MODE</th>
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</tr>
</tbody>
</table>
FATES-Spitfire impact on Trees

Fire Rate of Spread (log10 scale m/min)  Fire burned area (% grid cell)

- 40 years current climate GSWP3 (1991-2010), 4 x 5 run, Tropical Tree PFT
- Fire occurs globally
- Burned area located in areas of expected burning (tropics, western N.A. and taiga of boreal)
FATES-Spitfire impact on Grass

Fire Rate of Spread (log10 scale m/min)  Fire burned area (% grid cell)

- 40 years current climate GSWP3 (1991-2010), 4 x 5, Grass PFT
- Fire occurs globally
- **Increased ROS** and **increased burned areas** in areas of expected burning (tropics, western N.A. and taiga of boreal)
FATES-Spitfire impact on Biomass

- Fire has stronger impact on trees than grass
- Grass regenerates quickly
- Impacts on tree biomass in tropics
Next Steps

• Single point runs compared to data
• Combustion completeness of fuels regionally
• Ignition efficiency by PFT
• Impacts of altered climate
• Vegetation structure (stand age)
• Competing PFTs (Trees, shrub, grass)
• Forcing data (CRU, GSWP3, QIAN)
  – CRU more fire activity than GSWP3
Connections to data

Ignition

Fire Danger Index per Nesterov

Fuel State: load, bulk density, moisture, SA to Vol, PFT details

Rate of Spread

Fuel Combustion

Duration burn

Intensity

Flame height

Biomass burnt

Trace gas emissions

Area Burnt

Size of Ellipse

Duration burn

Rate of Spread

Fire Spread

Fuel loads and moisture for 1h, 10h, 100h classes

Fuel consumed 1h, 10h, 100h classes

2011-2015: Height, DBH
Live biomass >5cm
Chave et al. 2014
Mortality across plots

Burning Experiment in Tanguro, Brazil
(Paulo Brando)

Fuel Combustion

PFT, cohort

Cambial Damage

Crown Scorch

Vegetation Mortality

Fire Impact

Duration burn

Rate of Spread

Fuel Combustion

Fuel State: load, bulk density, moisture, SA to Vol, PFT details

Fuel loads and moisture for 1h, 10h, 100h classes

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Summary

• Spitfire updated to current literature
• Fire has variable impact based on fuels
• Fuel moisture (forcing data) important for combustion
• Flame height impacts stand structure
• Connections to data (burning, vegetation structure and characteristics)
Thank you.