FATES-SPITFIRE: Interaction of climate, fire, and vegetation state for coexistence of trees and grass

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Land Model and Biogeochemistry Working Group Meeting
February 7, 2018

What is FATES?

• Vegetation model, which replaces the unstructured bulk canopy representation in CLM with the size- and age-structured ED approximation of individual plant dynamics

• Modularized from CLM(ED) in order to: plug into multiple land models (CLM, E3SM/ALM)
Vegetation structure in FATES

Plant Functional Type tiling
- NL tree
- BL tree
- Bare Ground
- C3 grass
- C4 grass

Time-since-disturbance tiling
- 60 years
- 90 years
- 1 year
- 30 years
- 15 years
- 5 years
Each **time-since-disturbance** tile contains **cohorts** of plants, defined by **PFT** and **size**.

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**Vegetation structure in FATES**

- **Cohort. PFT1. 10m**
- **Cohort. PFT2. 4m**
- **Cohort. PFT1. 2m**
Importance of Fire

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

• Causes and consequences of fire require understanding of interaction of climate, vegetation (fuel) and fire: fuel load and rainfall in savanna; temperature and fire season length in boreal and temperate (Randerson et al. 2005, Schimel & Granstrom 1997, French et al. 2002, Sukhinin et al. 2004)
FATES-SPITFIRE

Ignition

Fire Danger Index per Nesterov

Fuel State and Load: bulk density, moisture, PFT details

Fuel Combustion

Rate of Spread

Duration burn

Size of Ellipse

Intensity

Area Burnt

Fire Spread

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

Moderate risk = NI 300 to 1000
High risk = NI 1000 to 4000
Extreme risk = NI above 4000

Fuel Combustion

PFT, cohort

Successional Patterns

Vegetation Growth

Vegetation Mortality

PFT, cohort

Cambial Damage

Crown Scorch

Fire Impact

Biomass burnt

Trace gas emissions

Adapted from Thonicke et al. 2010 Biogeosciences
Preliminary Results

- 0.9 x 1.25 runs
- GSWP3 climate data (1991-2010)
- Fire ON and Fire OFF
- Multiple fire-free and fire periods
- Average across final 10 years

Trees & Grass + 300 years

Trees & Grass + Fire

Fire-free period

Trees & Grass + 10 years + Fire 10 years

+ 10 years + Fire 50 years

+ 10 years + Fire 150 years
Fire acts to limit tree cover
Trees and Grass competing

- Fire reduces tree area across South America and Africa
- 150 years current climate GSWP3 (1991-2010), Trees and Grass
Fire acts to limit tree cover
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- Fire reduces tree area across South America and Africa
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Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, et. al. (2013) *Science*
Fire acts to limit tree cover
Trees and Grass competing

• Fire reduces tree area across South America and Africa
• Initial fire free period allows trees to escape “fire-trap”

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, et. al. (2013) *Science*
Burned fraction (% year$^{-1}$)

Captures low fire in forest
More fire in Forest/Savanna bi-stable areas
South America versus Africa

Van der Werf et al. 2017
Forest/Savanna bi-stability

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

Forest = +55% trees, minimal grass

Savanna = partial trees (20-80%), continuous grass

Staver et al. 2011 Science
Tropical Coexistence of Trees and Grass biomass

Tree biomass in areas of high MAR
Grass expands with fire

Tree biomass without Fire
150 yrs with Fire
10 yrs no Fire, 150 yrs Fire

Grass biomass without Fire
150 yrs with Fire
10 yrs no Fire, 150 yrs Fire
Tropical Coexistence of Trees and Grass leaf biomass

Tree leaf biomass higher than grass
High grass leaf biomass in high MAR

Mean Annual Rainfall (mm)

Tree leaf biomass without Fire
150 yrs with Fire
10 yrs no Fire, 150 yrs Fire

Grass leaf biomass without Fire
150 yrs with Fire
10 yrs no Fire, 150 yrs Fire
Tree-Grass coexistence (Total biomass)

Fire after period without: Disturbance important for coexistence

Fire from Bare Ground: Co-existence within 1000 to 2500 mm MAP

No Fire: Grass dominates below 1000 mm MAP

Grass

Trees

Percentage dominance

MAT:°C

MAP:mm
Tree-Grass coexistence (leaf biomass)

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Fire after period without: Initial veg state maintains tree leaf biomass
Fire Trap and Bark Thickness

Multiple feedbacks due to vegetation structure

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
Fire in the Savanna

Capture low burned fraction in stable forest areas
Fire-Free period for Trees to escape fire-trap
S.A. versus Africa:
  separate forest and savanna trees (resprouting)
diversity of bark thickness (within and across PFTs)
  update critical time of cambial heating
Shift to drier conditions would favor grasses
Future Directions:

Application within temperate and boreal regions
Coupling with social (agent based) models
Paleo applications