Fire Modelling in JULES using SPITFIRE: ‘Spread and Intensity of Fires and Emissions’ Model

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Fire Functioning & Feedbacks in the Earth System

- Land Cover & Vegetation Composition
- Climate
- Fuel Quantity
- Ignition Source
- Fuel Moisture
- Atmospheric Chemistry
- Land use
- Soil
- Deforestation
- Nutrient supply
- Plant mortality & reproduction
- Logging, agriculture
- Grazing
- Lightning
- Wind
- Rainfall, temperature
- Albedo, water & energy fluxes
- Trace gas & aerosol emissions
'Offline' SPITFIRE Systems Diagram

- **Ignitions**
  - Human-caused
  - Lightning-caused

- **Burnt Area**
  - Rate of Spread & Fire Duration

- **Fuel Load**
  - Fire Intensity

- **Fuel Moisture & Fire Danger Index**
  - Fuel Consumed

- **Emissions** (trace greenhouse gases + aerosols)

- **Plant Mortality**

- **Pop. Density**

- **Vegetation Dynamics Model**

- **Wind speed**

- **Rainfall**
  - Temperature
  - Relative Humidity
Coupling Dynamic Vegetation Models to SPITFIRE

2. LPJ-DGVM-SPYTFIRE (Gomez-Dans, Spessa, Wooster, Lewis).
3. LPJ-GUESS-SPITFIRE (Lehsten, Thonicke, Spessa et al).
4. ED-SPITFIRE (Spessa and Fisher).

Why ED is potentially good for fire-vegetation interactions

2. Age cohorts. Opens possibility for differential tree mortality effects depending on stage of ecological succession.
3. Height classes. Opens possibility for active crown fires.
4. ED ⇔ SPITFIRE daily.

× But… ED has a shorter development history compared with other dynamic vegetation models e.g. wrt Plant Functional Types- ecological/physiological rules determining why plants grow where and when the do.
Figure 1 Distribution of (a) mean annual rainfall (MAR), (b) structural vegetation classes, and (c) mean proportion of area burned per year (MPB) across the Australian wet–dry tropics. Study regions are shown in outline on each map. MAR and MPB have been calculated for the period December 1996 to November 2001. CF = closed forest, OF = open forest, W = woodland, OW = open woodland, LW = low woodland, LOW = low open woodland; OH = open heathland and OG = open grassland.
Next Steps to Coupling SPITFIRE in QESM


2. *Seasonally-varying Emission Factors.* Fast moving fires (CO/CO2 ratio low) versus slow moving fires (CO/CO2 ratio high). Function of litter size (surface area to volume ratio) and moisture. **Done. In test phase.**

3. *Injection heights.* UKCA needs to know how high emissions go into the atmosphere? What controls this? Fire intensity, and meteorology. Can we model this? **[contact UKCA and MEGAN people]**

QESM v2.....

1. **Active crown fires.**

2. **Peat fires and emissions** (e.g. Kalimantan tropical peat fires in 1997-98, 2002, 2006 El Nino droughts→ on average, about 1 Pg C emitted each El Nino ‘year’. Spessa et al *unpubl.* **See poster outside**)

3. **Land use and fire ignitions.**
Lightning strikes/flashes: Observed (top panels) vs Simulated (bottom panels)

Spessa & Joshi in prep
The Big Questions about Fires in the Earth System
(looking to the future...)

1. How do changes in climate (mean + variability) affect fire activity? Emissions?

2. How might these climate impacts be exacerbated by human activities e.g. land use change?

3. Feedbacks? Example:
   * Strong coupling between drought and fires/deforestation in the tropics (Amazonia, Indonesia).
   * Ecosystems → more fire-adapted/tolerant vegetation, and more fire prone.
   * Ecosystems → characterised by a carbon storage potential lower than the rainforest ecosystems they replace.
   * Impact → lower terrestrial carbon uptake from atmosphere. Reduced mitigation of fossil fuel carbon emissions...

4. Can fires associated with deforestation in the tropics lead to regional climate effects? Changed albedo, aerosols on cloud formation..

5. How might efforts that (plan to) use forestry to manage carbon resources and mitigate climate change (e.g. REDD in Brazil, Indonesia; JI in Russia; Annex 1 projects in Canada) be vulnerable to fires in future?
EXTRAS
NERC/QUEST Funded Project - Fire Modelling and Forecasting System (FireMAFS):  
Ensemble climate model runs (50+) → statistical & dynamical downscaling →  
predict seasonal fire activity and emissions 1-6 months ahead in case study regions within Indonesia, southern Africa, Iberian Peninsula, Russia and Canada.

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LPJ-SPIFIRE  
Simulations

Mean Annual Area Burnt, 1998 to 2002 (hectares)  
- 100
0 - 100
100 - 500
501 - 1000
1001 - 5000
5001 - 100000
10001 - 150000
50001 - 300000
500001 - 3000000

MODIS satellite hotspots
ED-SPITFIRE (NT, Australia)

![Graphs showing NPP, Fire On vs. Fire Off, SMC %, LAI, and Area Burnt km² day⁻¹ over the course of the year.](image-url)
Key Features of current *offline* SPITFIRE

1. **Human-caused ignition rates** = Function of population density & mean number ignitions per person per fire season day, which is parameterised from satellite and/or ground-based data.

2. **Lightning-caused ignition rates**. Parameterised from satellite data on lightning flash rates.

3. **Dead Fuel moisture** = Function (fire danger index).

4. **Grass phenology** (‘green-up’ and curing) = Function (upper soil moisture).

5. **Fuel combustion** (by fine and coarse fuel classes) = Function (fuel moisture).

6. **Fire intensity** = Function (fuel combustion, ROS).

7. **Surface rate of spread (ROS)** based on USDA forest fire ‘fighting’ equations.
   
   a. **ROS** is directly proportional to energy produced by ignited fuel (fuel load & wind).
   
   b. **ROS** is inversely proportional to the amount of energy required to ignite fuels (fuel moisture & fuel bulk density).

8. **Tree mortality** = Function (fire intensity, crown scorch height, cambial kill or ‘girdling’, vegetation-specific attributes).

9. Emission factors (CO2, CO, CH4, VOC, PM2.5, TPM, NOx).

   \[\text{Emissions} \ (\text{tonnes.} \ \text{km}^{-2}) \times \text{trace species} \times \text{Plant Functional Type} \times \text{time step (day)}.\]
Why is Fire Important in the Earth System?

1. **Atmosphere forcing, atmospheric chemistry, and land-atmosphere feedbacks**
   - Global cooling: Fires → aerosols → scattering and absorption of incoming solar radiation.
   - Globally, fires in forest, grasslands and peatlands → 2 to 4 Pg of carbon into the atmosphere per annum.
   - Clouds: Smoke and haze can reduce rain droplet formation.
   - Global warming: Fire → greenhouse gases CO2, CO, CH4 etc → absorb thermal infrared radiation.
   - Burnt areas are darker (lower albedo) → increase in radiation absorbed → increase convective activity.
   - Black carbon from boreal forest fires falling on snow/ice, thereby reducing its reflective capacity.

2. **Plant reproduction & survival**
   - Hot fires kill grasses and trees, but many plant species need intense fires to help germination.

3. **Carbon sinks, sources and biogeochemistry**
   - Increase fire frequency → more grass and fewer trees i.e. less carbon; & vice-versa.
   - Peat is a below ground carbon sink. Vulnerable to droughts & fires → potentially very large carbon source.
   - Fires → decrease soil Nitrogen (volitisation and consumption of litter), and
   - Fires → increase soil Nitrogen (stimulation of legumes, nitrifying bacteria).
Fire Functioning & Feedbacks in the Earth System

- Land Cover & Vegetation Composition
- Fuel Quantity
- Ignition source
- Fuel Moisture
- Soil
- Atmospheric Chemistry
- Climate

Factors:
- rainfall, temperature, radiation, [CO2]
- logging, agriculture
- grazing
- nutrient supply
- plant mortality & reproduction
- deforestation
- lightning
- wind
- rainfall, temperature
- trace gas & aerosol emissions
- albedo, water & energy fluxes

Processes:
- Logging, agriculture
- Grazing
- Nutrient supply
- Plant mortality & reproduction
- Deforestation
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Patch Succession in ED.

REFER EXAMPLE BELOW… Five PFTs are represented. Grasses are light and dark green triangles. Broadleaf trees are light and dark green circles on sticks, and needleleaf trees are dark green triangles on sticks.

- **Figure 2a**… ED is typically spun-up from bare ground. At the start, there is only a single patch.
- **Figure 2b**… On this patch, seedlings of each plant functional type are ‘planted’.
- **Figure 2c**… Over time, these seedlings grow. As an approximation, grasses grow fastest at first, due to their low construction costs.
- **Figure 2d**… At some point, there is a fire disturbance event. The vegetation is destroyed by the disturbance (exact amount consumed depends on litter moisture, fire intensity, fire residence time, vegetation height and bark thickness). A new patch is created.
- **Figure 2e**… This patch is then again seeded by cohorts of each PFT.
- **Figure 2f**… To maintain computational efficiency, ED compares the new patch with the next oldest patch, and decides whether these two patches have similar vegetation structure. If they are only slightly different, then the two patches are ‘fused’ together and the combined vegetation is spread evenly around the newer larger patch.
- **Figure 2f**… Patches are destroyed when their area is reduced (by disturbance) to a negligible size. Eventually, the disturbance routines form a dynamic equilibrium along the successional gradient.