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

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JULES Summer 2009 meeting

Quantifying and Understanding the Earth System

The University of Reading

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

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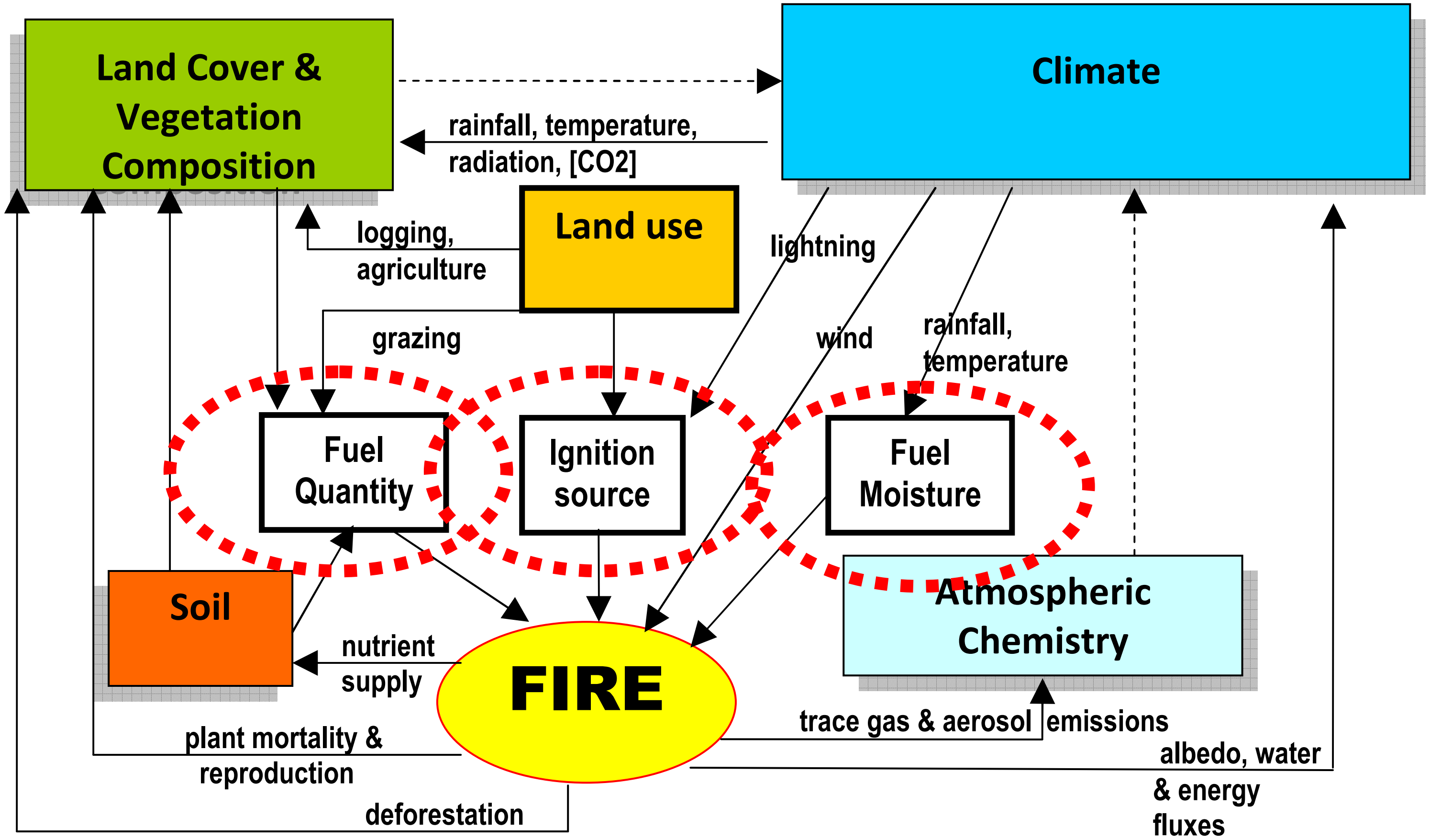
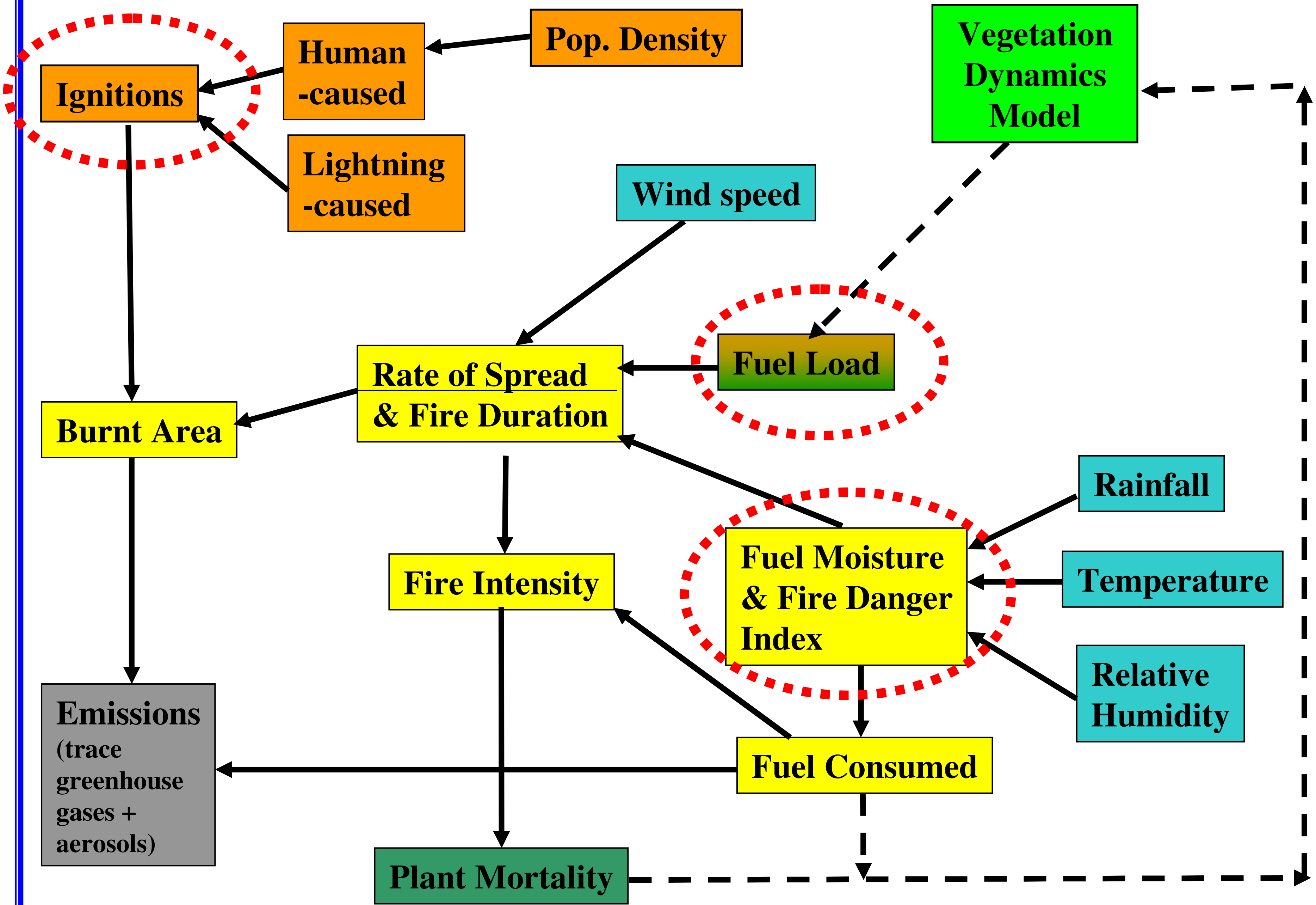
Fire Functioning & Feedbacks in the Earth System



'Offline' SPITFIRE Systems Diagram



Coupling Dynamic Vegetation Models to SPITFIRE

1. LPJ-DGVM-SPITFIRE (Thonicke, Spessa, Prentice, et al GCB).
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

1. Patch dynamics. Opens possibility for realistic tracking of deforestation.
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.

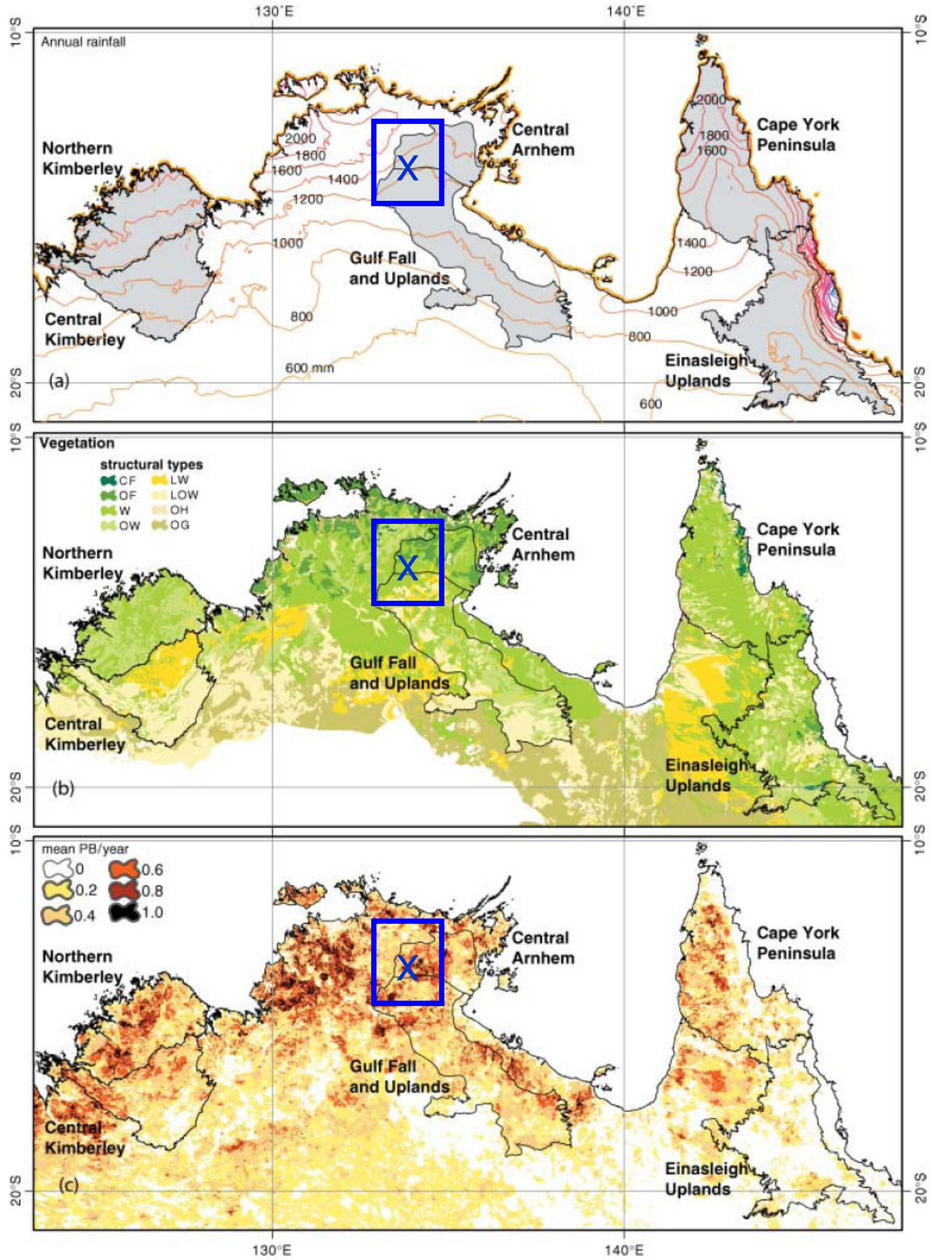
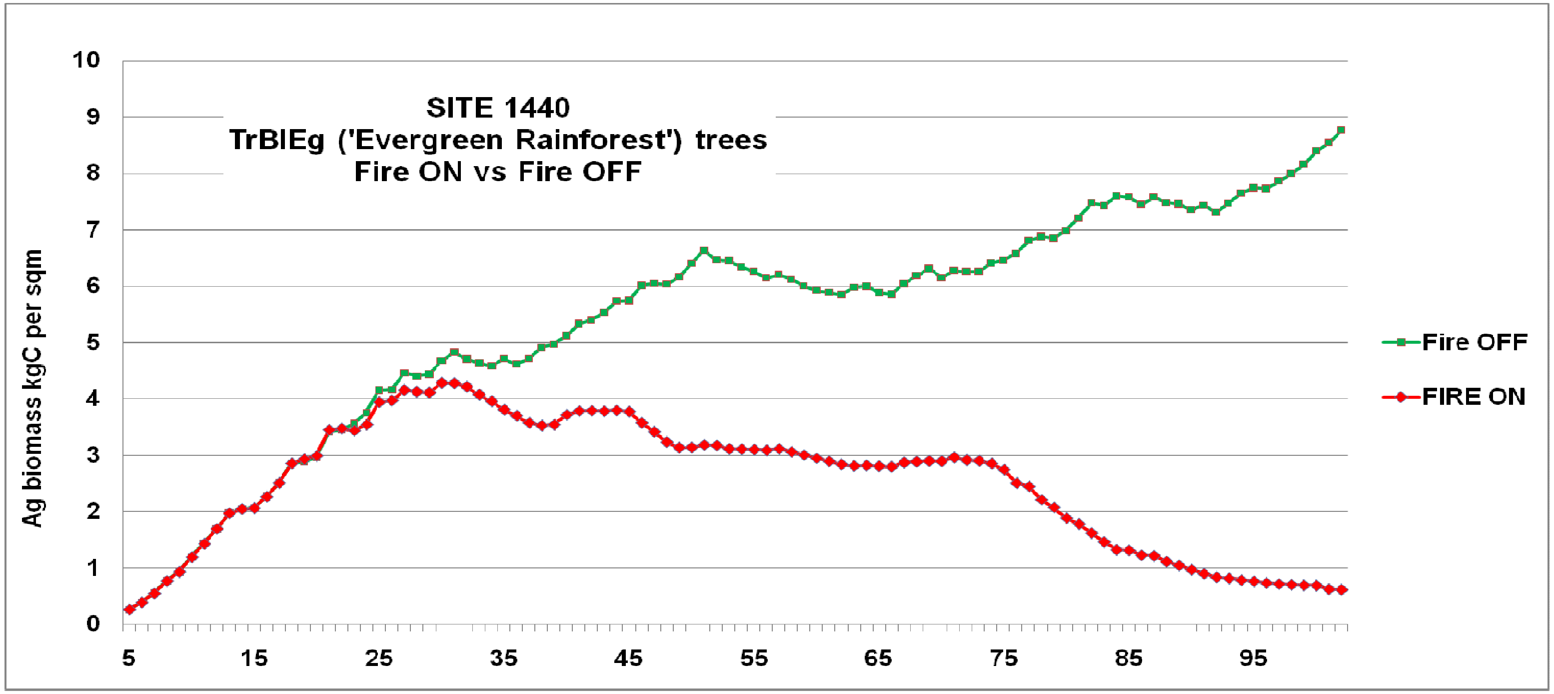
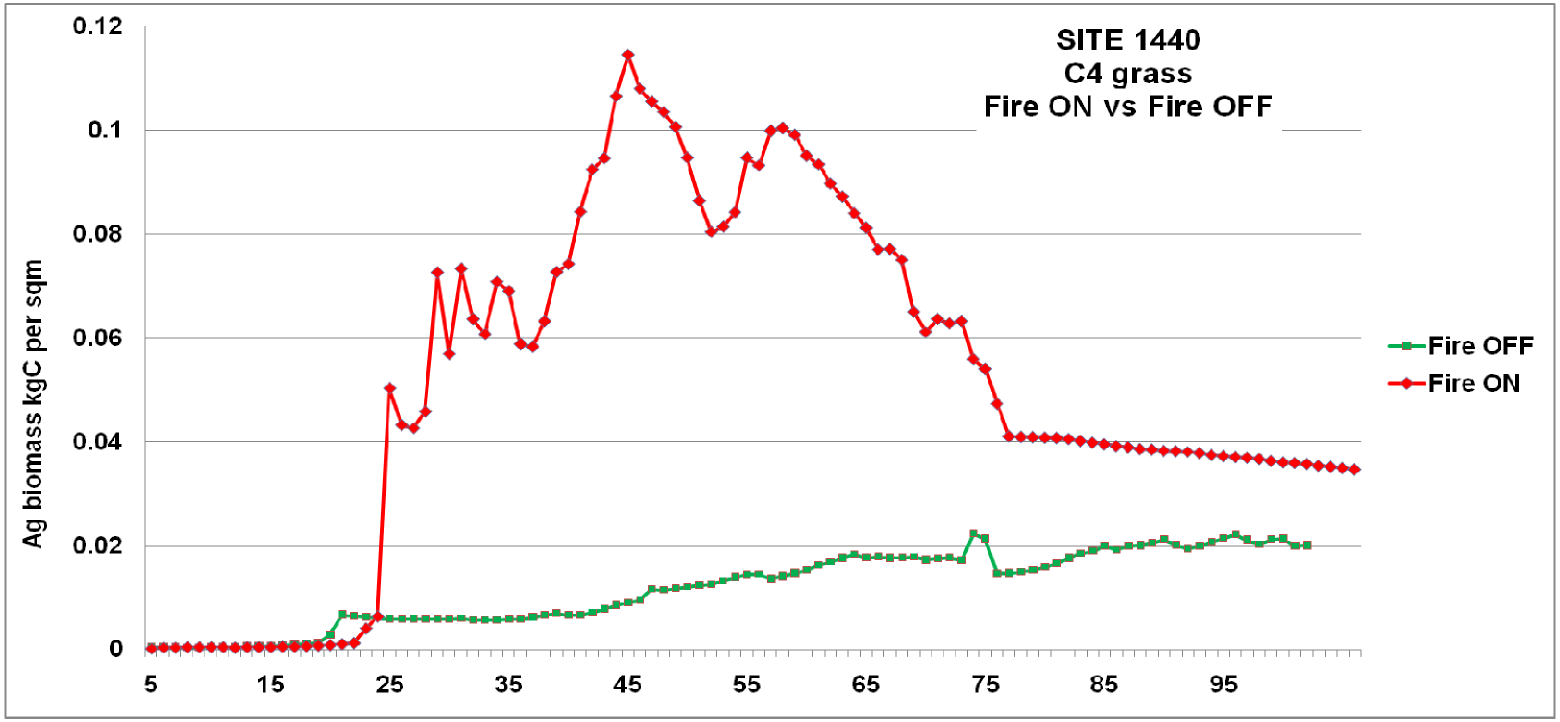
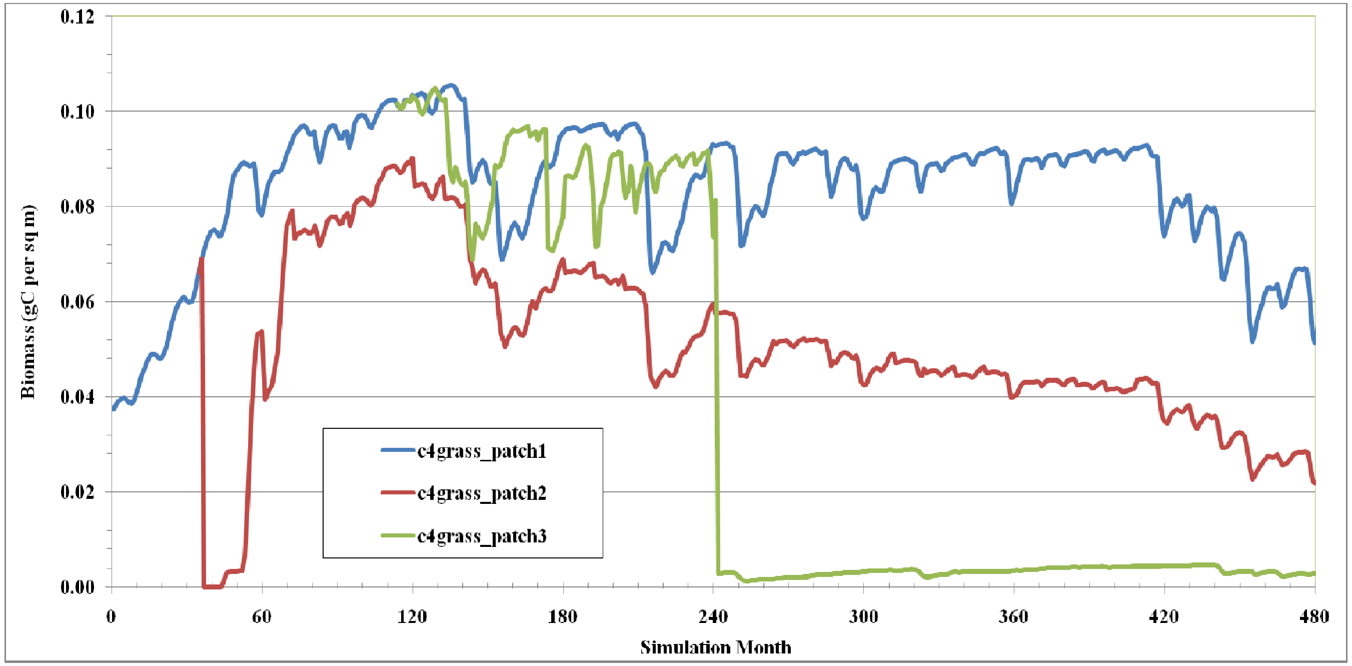


Figure 1 Distribution of (a) mean annual rainfall (MAR), (b) structural vegetation classes, and (c) mean proportion of area burnt per year (MPB) across the Australian wet–dry tropics. Study regions are shown in outline on each map. MAR and MPB have been calculated for the period December 1996 to November 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.

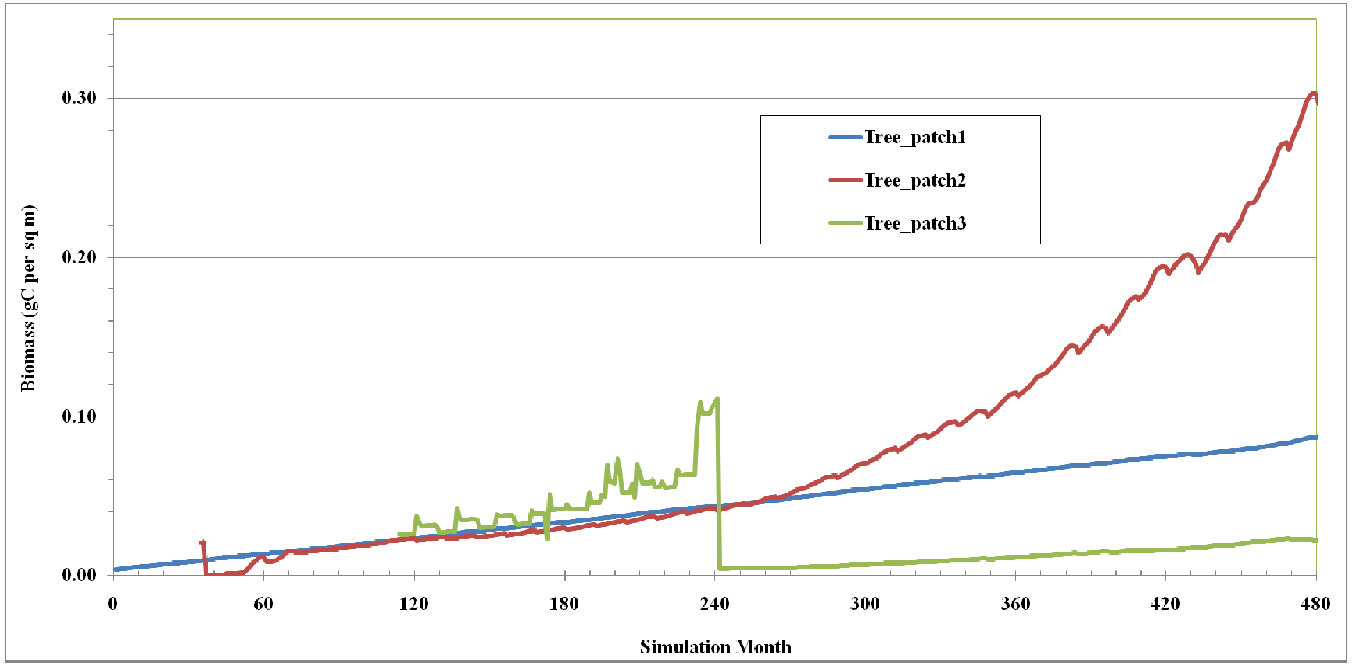
Spessa et al 2005 GEB


SITE 1440
TrBlEg ('Evergreen Rainforest') trees
Fire ON vs Fire OFF
Ag biomass kgC per sqm
Fire OFF
FIRE ON
10
9
8
7
6
5
4
3
2
1
0
5
15
25
35
45
55
65
75
85
95

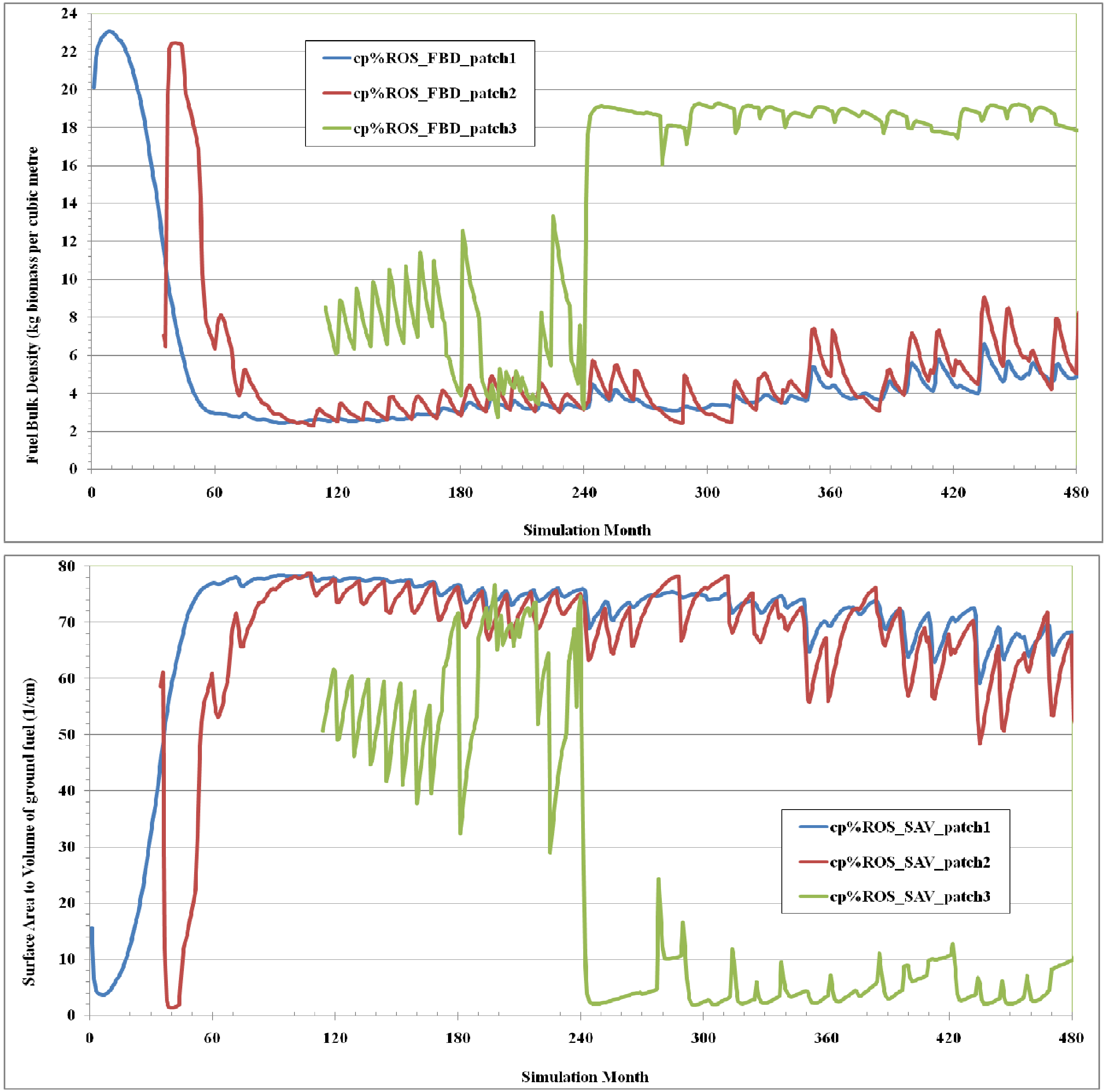

SITE 1440
C4 grass
Fire ON vs Fire OFF
Ag biomass kgC per sqm
Fire OFF
Fire ON
0.12
0.1
0.08
0.06
0.04
0.02
0
5
15
25
35
45
55
65
75
85
95



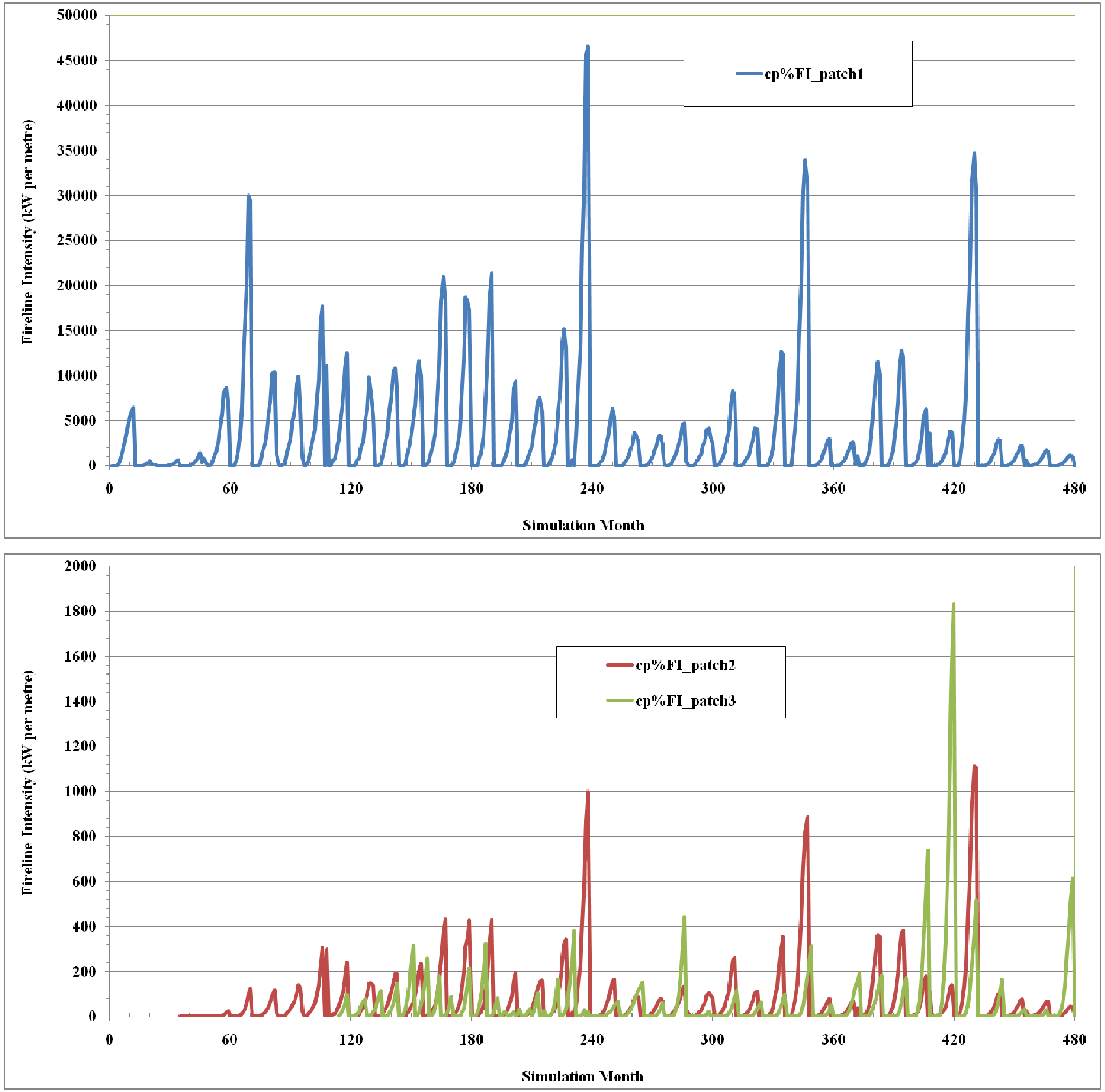
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Biomass (gC per sq m)
0
60
120
180
240
300
360
420
480
Simulation Month
c4grass_patch1
c4grass_patch2
c4grass_patch3



0.30
0.20
0.10
0.00
Biomass (gC per sq m)
0
60
120
180
240
300
360
420
480
Simulation Month
Tree_patch1
Tree_patch2
Tree_patch3



Fuel Bulk Density (kg biomass per cubic metre)
Simulation Month
cp%ROS_FBD_patch1
cp%ROS_FBD_patch2
cp%ROS_FBD_patch3
Surface Area to Volume of ground fuel (1/cm)
Simulation Month
cp%ROS_SAV_patch1
cp%ROS_SAV_patch2
cp%ROS_SAV_patch3



cp%FI_patch1
Fireline Intensity (kW per metre)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
60
120
180
240
300
360
420
480
Simulation Month
cp%FI_patch2
cp%FI_patch3
Fireline Intensity (kW per metre)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
60
120
180
240
300
360
420
480
Simulation Month

Next Steps to Coupling SPITFIRE in QESM

1. *Ignitions from lightning.* Use approximation given by Allen & Pickering (2002) JGR. Lightning flashes = non-linear function of convective mass flux. ***Done. In test phase.***

2. *Seasonally-varying Emission Factors.* Fast moving fires (CO/CO_2 ratio low) versus slow moving fires (CO/CO_2 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]***

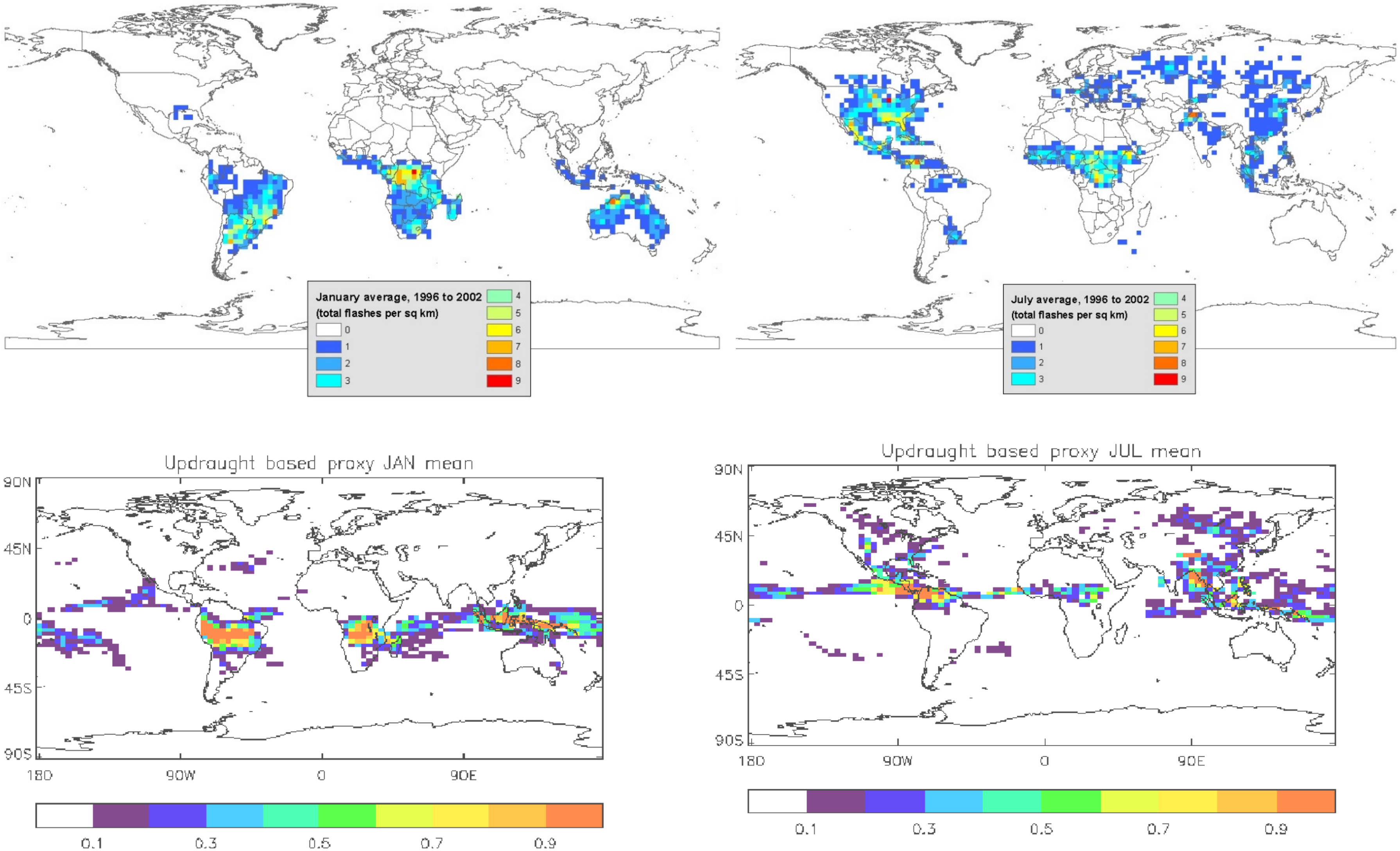
QESM v2.....

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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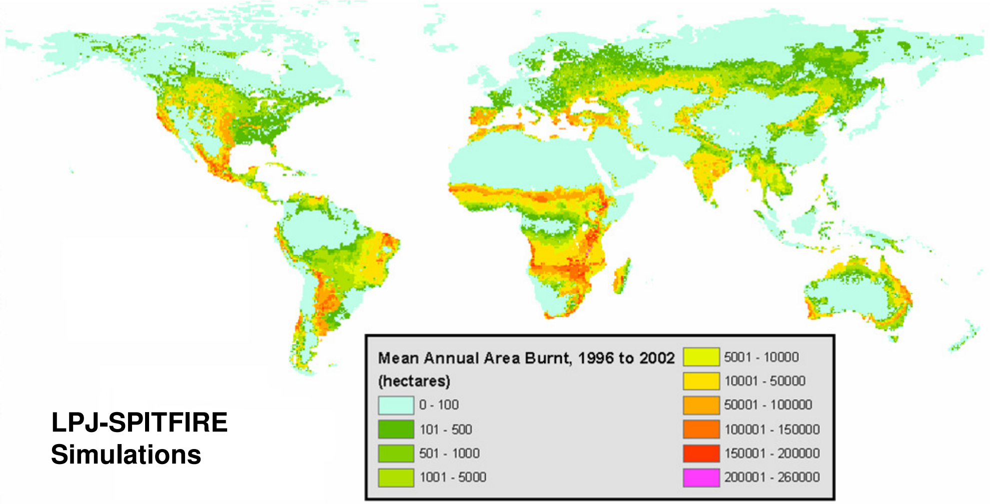
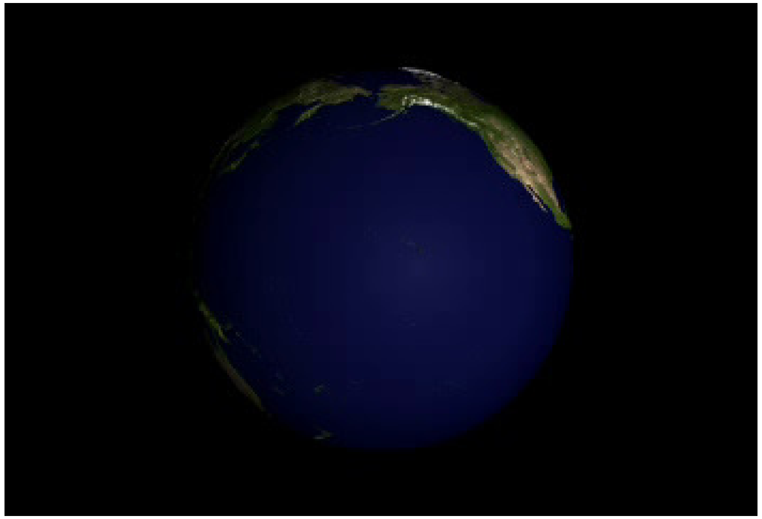
University of Reading

Prof. Martin Wooster
King's College London

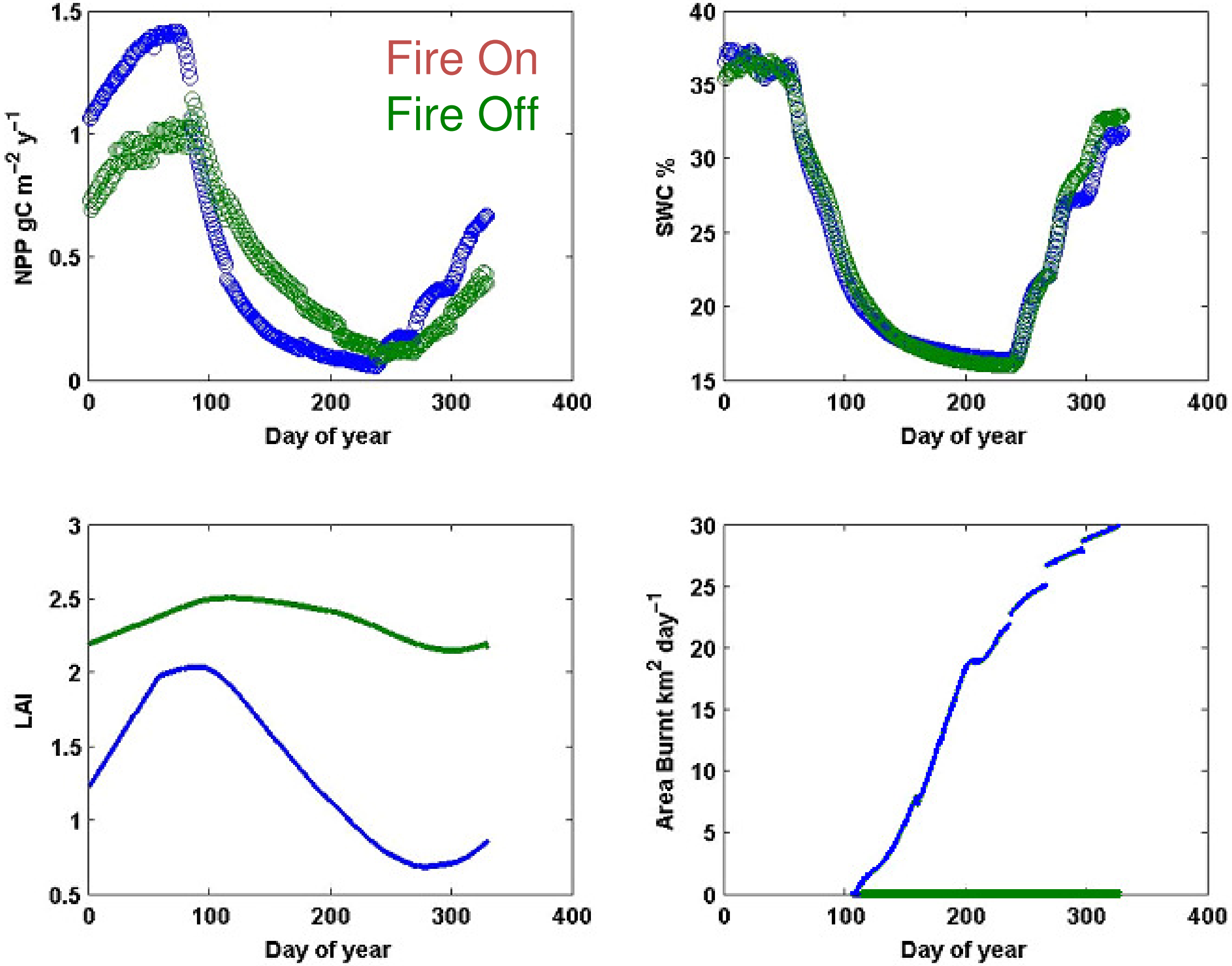


LPJ-SPITFIRE Simulations



MODIS satellite hotspots

ED-SPITFIRE (NT, Australia)



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 (CO_2, CO, CH_4, VOC, PM2.5, TPM, NOx).**

→ *Emissions* **(tonnes. km^{-2}) × trace species × Plant Functional Type × 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 CO_2, CO, CH_4 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.**

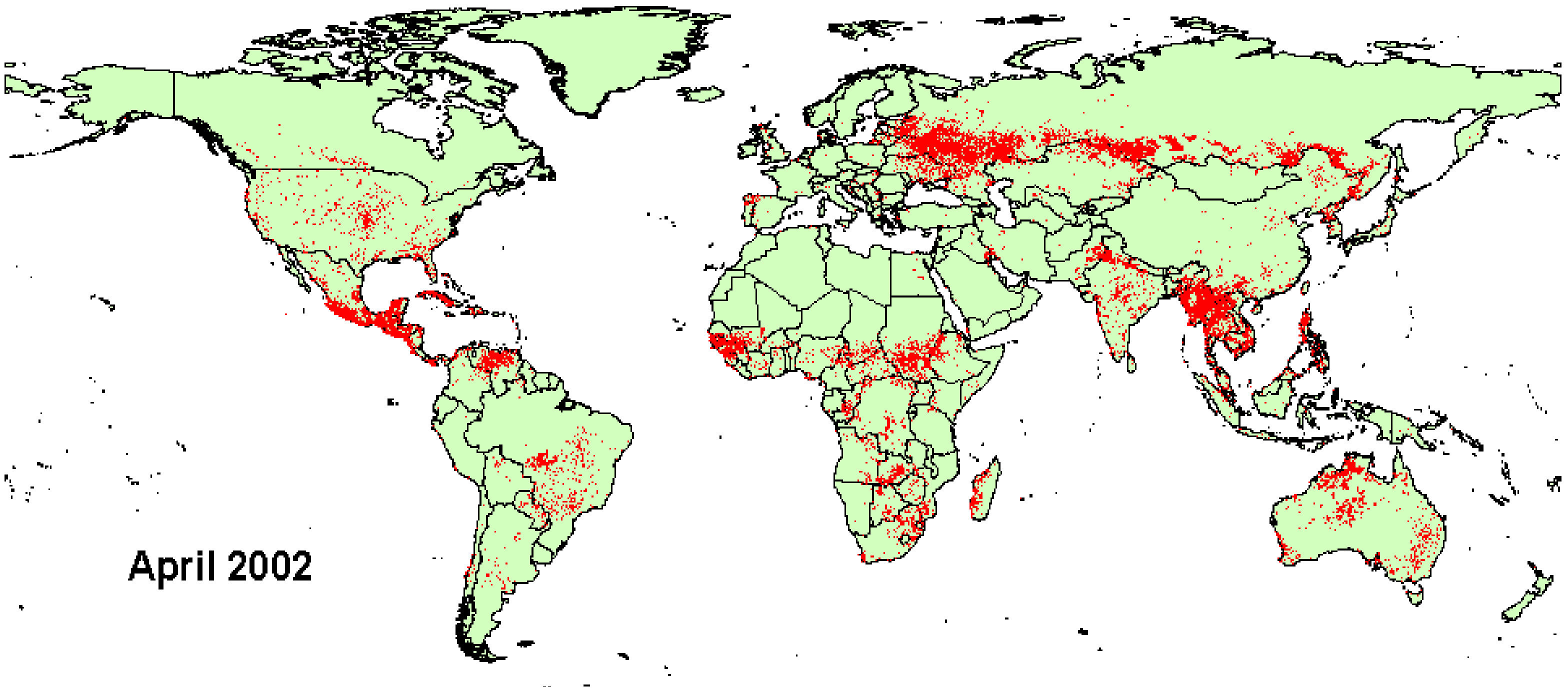
3. *Carbon sinks, sources and biogeochemistry*

❖ **Increase fire frequency → more grass and fewer trees i.e. less carbon; & vice-versa.**

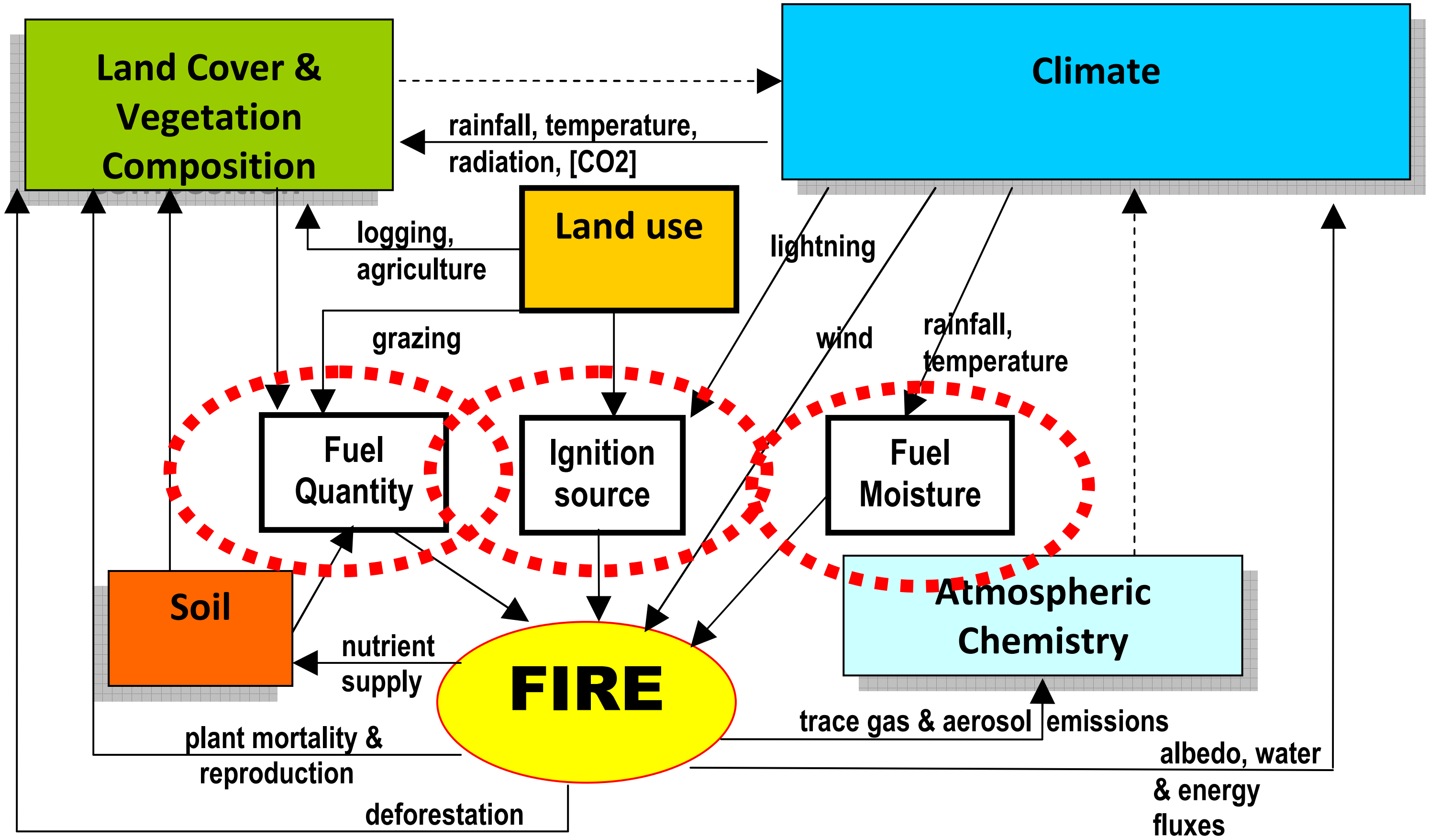
❖ **Peat is a below ground carbon sink. Vulnerable to droughts & fires → potentially very large carbon source.**

❖ **Fires → decrease soil Nitrogen (volitisation and consumption of litter), and**
Fires → increase soil Nitrogen (stimulation of legumes, nitrifying bacteria).

MODIS Land Rapid Response Fire Detections



Fire Functioning & Feedbacks in the Earth System



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Patch Sucession 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.
- 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.