Evaluating the Coupled Dynamic Vegetation-Fire-Emissions Model, LPJ-GUESS-SPITFIRE, against EO-based Tropical Tree Biomass Data: Results and Implications for JULES

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Average carbon losses from above and below ground wildfires, 1997-2010 (gC m\(^{-1}\) year\(^{-1}\))

2.1 PgC per annum

\(\sim 25\%\) of emissions occur at the deforestation frontier

Singapore smog 'could last for weeks'

Singapore's prime minister has warned that the haze engulfing the city could last for weeks, as air pollution in the city-state soared to record levels.

At 13:00 local time (05:00 GMT) Singapore's pollution standards index reached 371, breaking all previous records and reaching hazardous levels.

The haze is caused by illegal forest fires in Indonesia's Sumatra Island.

Singaporeans have been warned to stay indoors where possible.
Projected increase in fire risk due to climate change in the Amazon: what does this mean for burnt area and emissions? *

Proportion of climate model simulations projecting “high” fire risk (McArthur fire danger index)


* Not much. Risk is only a first step. Need a coupled fire-vegetation model.
The EMAC-LPJ-GUESS-SPITFIRE project
Allan Spessa, Matt Forrest (BiK-F), Holger Tost (U Mainz), et al.

Project Aims

1. **Test, constrain and improve an existing dynamic fire-vegetation-emissions model for applications**
   (contemporary analyses, future climate impacts, paleo-climate scenarios).

2. **Examine the effects of land surface emissions, especially from wildfire on production of aerosols and reactive gases** (e.g. tropospheric ozone).

3. **Investigate feedbacks between reactive gases, aerosols, climate and vegetation.**

Model Development and Testing

1. **Benchmark coupled vegetation-fire model, LPJ-GUESS-SPITFIRE**

2. **Integrate LPJ-GUESS-SPITFIRE into atmosphere/atmospheric chemistry model EMAC via the MESSy coupling software interface.**

MODEL ACRONYMS: SPITFIRE (Spread and Intensity of Fires and Emissions), LPJ-GUESS (Lund-Potsdam-Jena Generalised Ecosystem Simulator), MESSy (The Modular Earth Submodel System), EMAC (ECHAM5 GCM/MESSy).
Total LAI in EMAC-LPJ-GUESS (after 2 years)

\[
LAI = \frac{\text{surface area of leaves}}{\text{surface area of ground}}
\]

So:
- LAI = 0 is barren/desert.
- LAI = 1-3 is grassland/savanna/open woodland
- LAI > 3 is a closed forest

(Matt Forrest @ BiK-F)
LPJ-GUESS

LPJ-GUESS is a Dynamic Global Vegetation Model (DGVM). Including:

- Biogeochemistry
- Biogeography
- Population and Community Ecology
- Plant Physiology

But it is not a land surface scheme, in particular it does not close the energy balance.

\[6\text{H}_2\text{O} + 6\text{CO}_2 \overset{h v}{\longrightarrow} (\text{CH}_2\text{O})_6 + 6\text{O}_2\]

LPJ-GUESS ‘cohort mode’ resolves plant individuals, canopy vertical structure and patch-scale heterogeneity

Modelled area (stand)
10 ha - 2500 km²
replicate patches in various stages of development

Average individual for plant functional type or species cohort in patch
- crown area
- leaves
- LAI
- stem diameter
- sapwood
- heartwood
- height
- 0-50 cm
- 50-100 cm
- fine roots
- leaves / LAI

SPITFIRE

Ignitions

- Human-caused
- Lightning-caused

Population Density & land-use

Wind speed

Rate of Spread & Fire Duration

Fuel Load & Fuel Structure

Fuel Moisture & Fire Danger Index

Rainfall

Temperature

Relative Humidity

Fuel Consumed

Fire Intensity

Area Burned & Fire Duration

Emissions (trace greenhouse gases + aerosols)

Plant Mortality

LPJ-GUESS simulates ecological succession

LPJ-GUESS-DGVM simulates differential fire-induced tree mortality

Smith et al (2001) GEB

LPJ-GUESS-SPITFIRE Burnt Area vs Observed Burnt Area

LPJ-GUESS-SPITFIRE

Mean annual fraction of 0.5 deg gridcell burnt, 1997-2009

GFEDv3 (Giglio et al 2010 Biogeosc.)
**SPITFIRE- driven by observed burnt area:**
Focus on model skill in simulating fire-vegetation interactions and biomass

**Daily Burnt Area Data:**
- Spinup and 1948-1995 decadal data Mouillot & Field (2005) GCB (distributed to daily by Nesterov Fire Danger Index)

**Observed Area Burned**

**Rate of Spread**

**Fuel Load & Fuel Structure**

**Wind speed**

**Fuel Moisture & Fire Danger Index**

**Fire Intensity**

**Fuel Consumed**

**Plant Mortality**

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

**Daily Climate Data:**
- 1948-present (Princeton Climate Reanalysis Data) after Sheffield et al 2006 J. Climate

- **Temperature**
- **Relative Humidity**
- **Rainfall**

(Spessa, Forrest, Hickler et al)
Two recent EO-based datasets of pan-tropical tree biomass @ 1 sq km

Saatchi et al (2011) PNAS

GUESS-SPITFIRE simulated tree carbon versus two EO-based datasets (Saatchi et al 2011, Baccini et al 2012) (mean 1997-2008) (GC 2009 land cover corrected) (kgC.m\(^{-2}\))

Two run scenarios: default model (ca. 2010 version), and a new model version with improved formulations for:

I. **Tropical tree allometry** (more realistic growth forms following Feldpausch et al 2011 Biogeosc.),

II. **Sunlight penetration through the canopy** (increased for savanna trees reflecting their ‘sparse’ canopies, after Higgins et al 2010 Ecology permitting grasses to grow underneath, and thus more fire),

III. **Sapling size at recruitment** (reduced to produce a more realistic initial size, after Lehsten et al 2008),

IV. **Fire mortality as a function of bark thickness** (BT of tropical saplings made very thin, after Hoffman et al 2009 Ecology), and

V. **Fire mortality as a function of crown scorch height** (increased mortality for savanna trees, re-interpretation of Williams et al 1998 IJWF).

(Spessa, Forrest, Hickler et al)
Tropical Savanna Trees

Allowing more sunlight through Tropical Savanna trees canopies in LPJ-GUESS is more realistic.

Tropical Rainforest Trees
GUESS-SPITFIRE simulated tree carbon versus two EO-based datasets
(Saatchi et al 2011, Baccini et al 2012)
(mean 1997-2008) (GC 2009 land cover corrected) (kg C m\(^{-2}\))
Dominant PFT

On the left standard v2.1, red circles show areas which are grasslands in which no trees can grow.

On the right, bioclimactic limits changed back to Sitch et al. 2003, allow trees again.

(Matt Forrest @ BiK-F)
Observed Biomass

Green circles show disagreement in v2.1 which is lessened with ‘new’ parameters

(Matt Forrest @ BiK-F)
Conclusions from Benchmarking Study

1. GUESS-SPITFIRE tree biomass simulations improved against EO-based tropical tree biomass estimates, following new formulations based on recent literature/field studies (tree allometry, canopy light penetration, initial sapling size, and fire-induced mortality as a function of bark thickness and crown scorch height).

2. Discrepancies between simulated and observed biomass highlight potential areas for further work on GUESS-SPITFIRE (e.g. interaction between forest fragmentation and fires, eco-hydrology, and impact of land cover change (despite having implemented a ‘linear proportional fix’ to downscale GUESS tree biomass to reflect observed land cover).

(Spessa, Forrest, Hickler et al)
Current LPJ-GUESS Development Activities
(Lund University, BiK-F Frankfurt, IMK Garmisch-Partenkirchen, Open University)

- Improved fire activity prediction, fire-vegetation interactions, emissions from biomass burning
- Land use & agriculture (based on LPJ-mL)
- Forest management module
- Herbivore module
- Wetland hydrology, wetland PFTs and methane emissions
- Coupled Nitrogen-Carbon dynamics
- BVOC parameterisation for global PFTs
- Tropospheric ozone effects on plants
- ....
Improving Vegetation and Fire Dynamics in JULES: Suggested Approach

- Replace TRIFFID with LPJ-GUESS-SPITFIRE. Why?
- TRIFFID does not simulate patches or cohorts; it is not a gap model. Not suited to process-based simulation of fire with a model like SPITFIRE.
- LPJ-GUESS actively developed/used by several groups in Europe. But it is not a land surface model. SPITFIRE actively developed and used by about 10 groups world-wide (Europe, USA, Australia).
- Advantage of using *stand-alone* – it allows back-checking and promotes traceability. Compare JULES-GUESS-SPITFIRE with GUESS-SPITFIRE results – e.g. vegetation cover, NPP, LAI, biomass etc.
- Recode GUESS routines from C++ to F90. But only need to consider *growth* and *dynamics* modules in GUESS, so maybe not too tough. F90 version of SPITFIRE exists (CLM-ED-SPITFIRE Spessa & R. Fisher).
- JULES → GUESS-SPITFIRE: LAI, NPP, soil temperature, soil moisture (surface temperature, RH, precipitation, windspeed for fires).
- GUESS-SPITFIRE → JULES: fractional cover of each PFT, biomass and litter (e.g. from turnover, post-fire).
- Matching GUESS PFTs with JULES PFTs? 12 PFTs in GUESS, with fairly easy scope for new PFTs.
- Phenology in drought-deciduous trees and grasses in GUESS has been improved (better match to soil moisture fluxes). Results in improved fire dynamics.