# 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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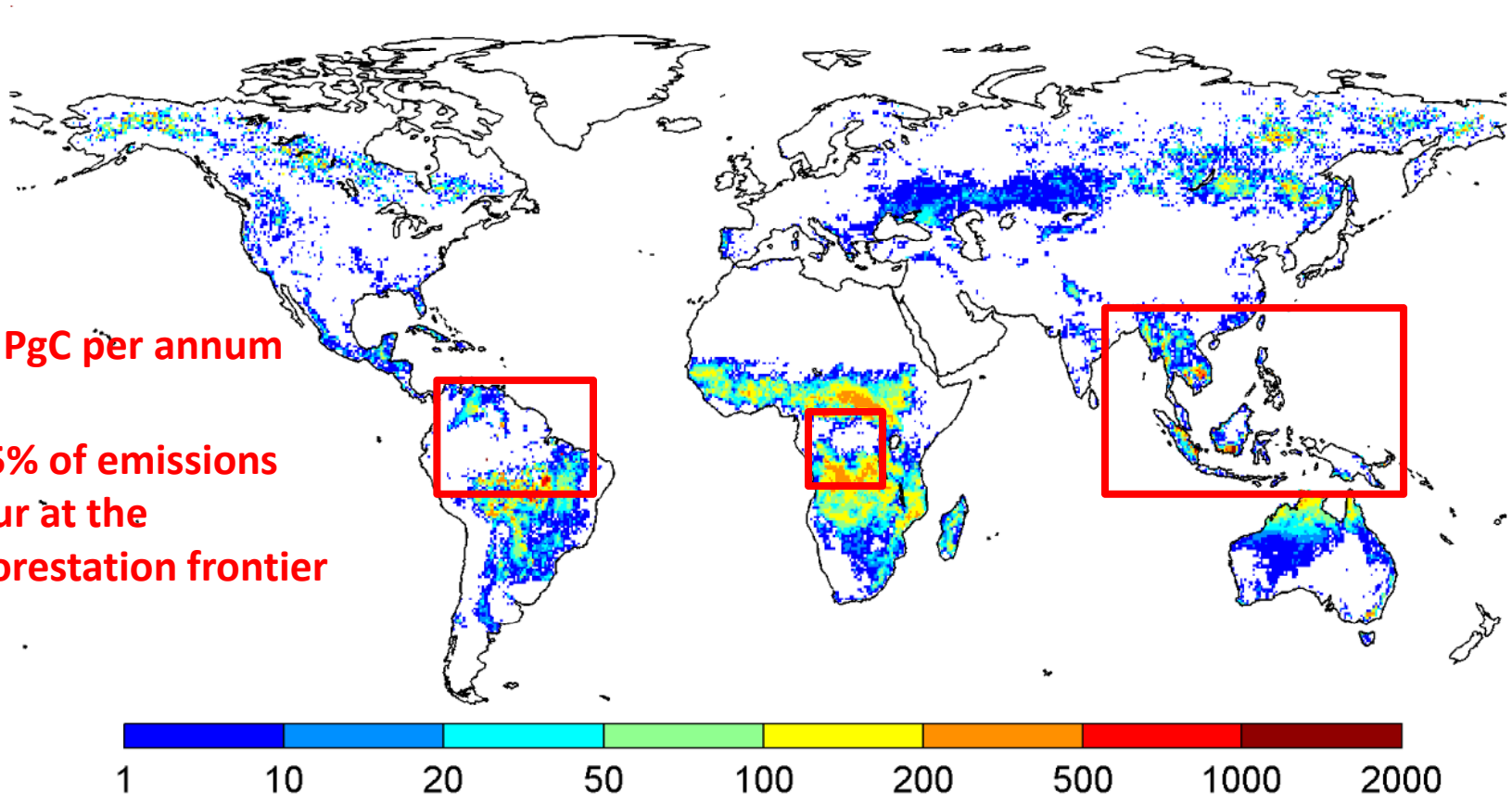
The Open University

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




**2.1 PgC per annum**

**~ 25% of emissions occur at the deforestation frontier**

**Global Fire and Emissions Database V3 (after van der Werf et al 2010 Atmos. Chem. Physics) http://www.falw.vu/~gwerf/GFED/index.html )**

20 June 2013 Last updated at 09:49

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# Singapore smog 'could last for weeks'

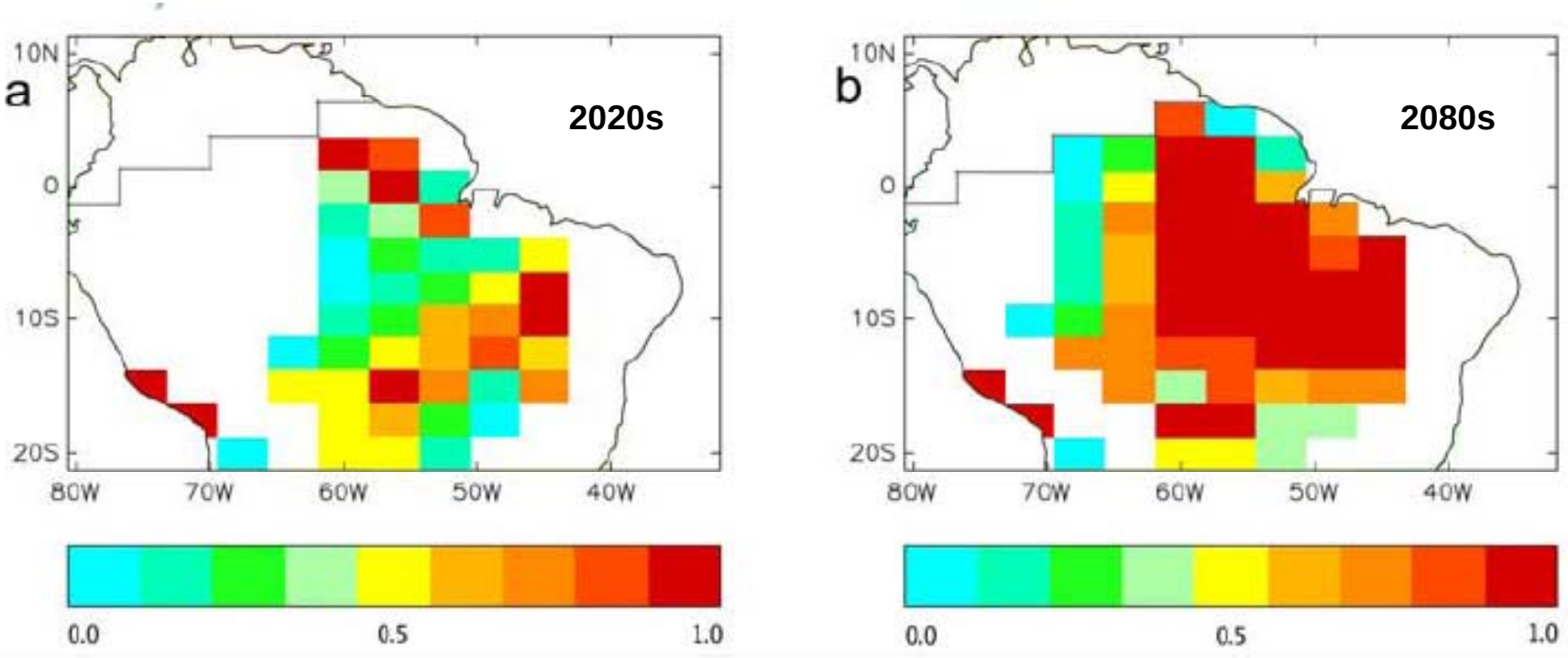
**Singapore's prime minister has warned that the haze engulfing the city could last for weeks, as air pollution in the city-state soared to record levels.**

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)

Ensemble of simulations with HadCM3 climate model

**Golding and Betts (2008) *Glob. Biogeochem. Cycles***

*** 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

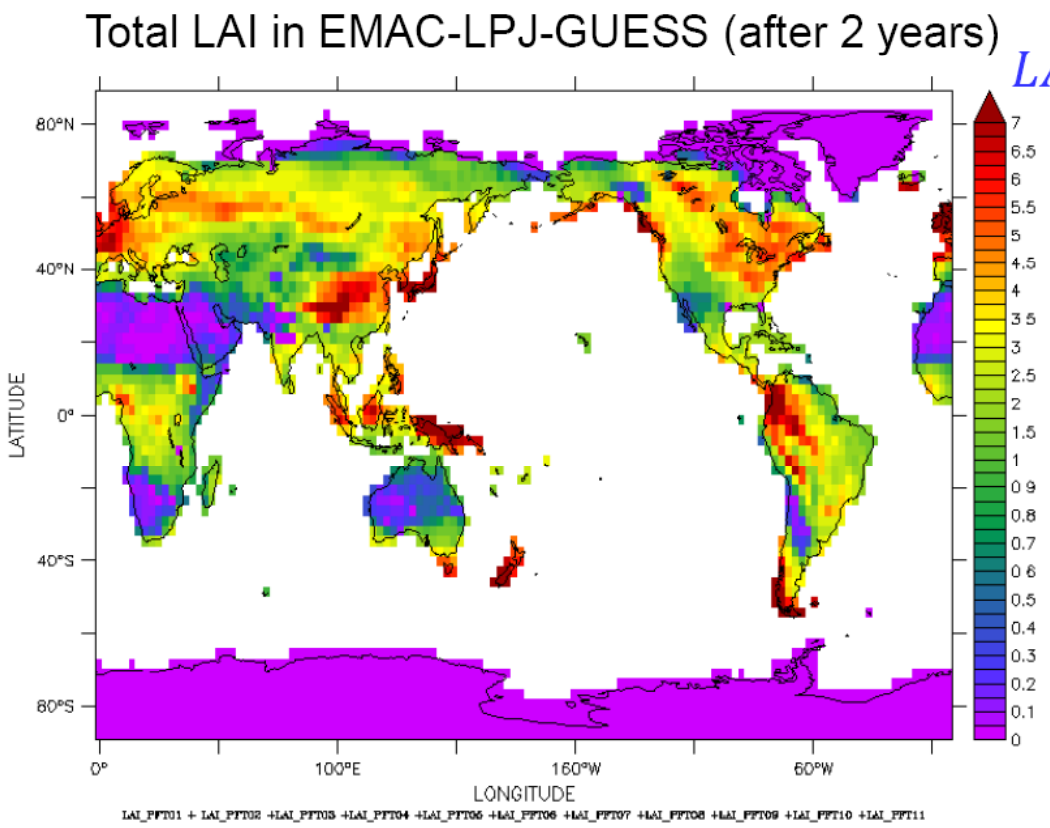
1. **Benchmark coupled vegetation-fire model, LPJ-GUESS-SPITFIRE**

   [**LPJ-GUESS** : Smith et al 2001 *Glob. Ecol. Biogeog.*; Hickler et al 2006 *Glob. Ecol. Biogeog.*.

   **SPITFIRE**: Lehsten et al (2008) *Biogeosc.*; Thonicke, Spessa, Prentice et al (2010) *Biogeosc.*; Gomez-Dans, Spessa et al (in review) *Ecol. Model.* ; Spessa et al (2012) Chapter XIV in Global Change and Wildfires. *Kessel*; Pfeiffer, Spessa, Kaplan (2013) GMD]

2. **Integrate LPJ-GUESS-SPITFIRE into atmosphere/ atmospheric chemistry model EMAC via the MESSy coupling software interface.** [**EMAC/MESSy**: Joeckel et al (2006) *Atmos. Chem. Phys.*; Tost et al (2006) *Atmos. Chem. Phys*.; Joeckel et al (2010) *Geosci. Model Dev.*] ***http://www.messy-interface.org***

**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).**




$$LAI = \frac{surface\ area\ of\ leaves}{surface\ area\ of\ ground}$$

So:

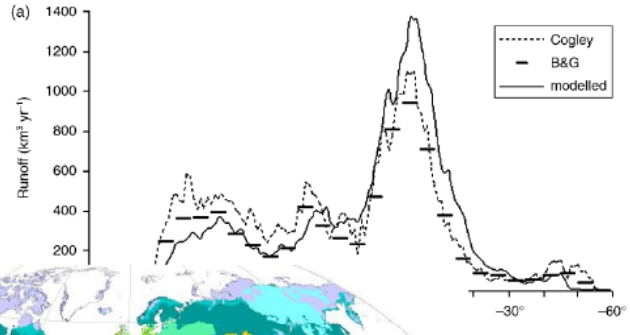
- LAI = 0 is barren/desert.
- LAI = 1-3 is grassland/savanna/open woodland
- LAI > 3 is a closed forest

**(Matt Forrest @ BiK-F)**

# LPJ-GUESS

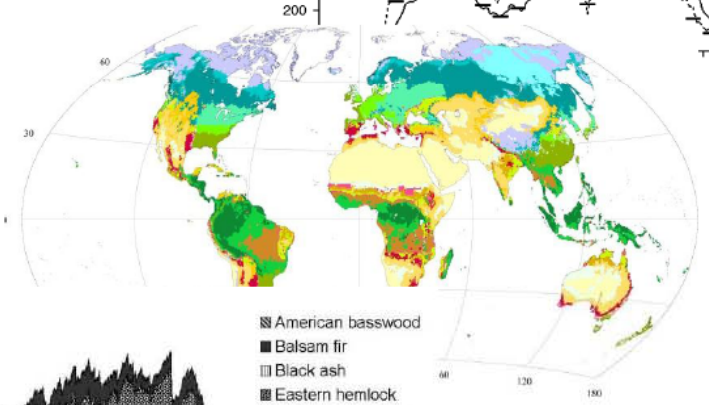
LPJ-GUESS is a Dynamic Global Vegetation Model (DGVM). Including:

*Biogeochemistry*

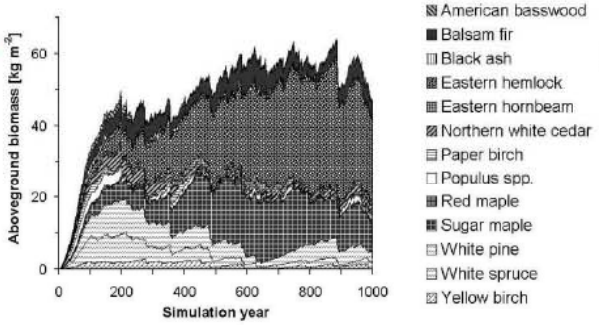



But it is not a land surface scheme, in particular it does not close the energy balance.

*Biogeography*



*Population and Community Ecology*

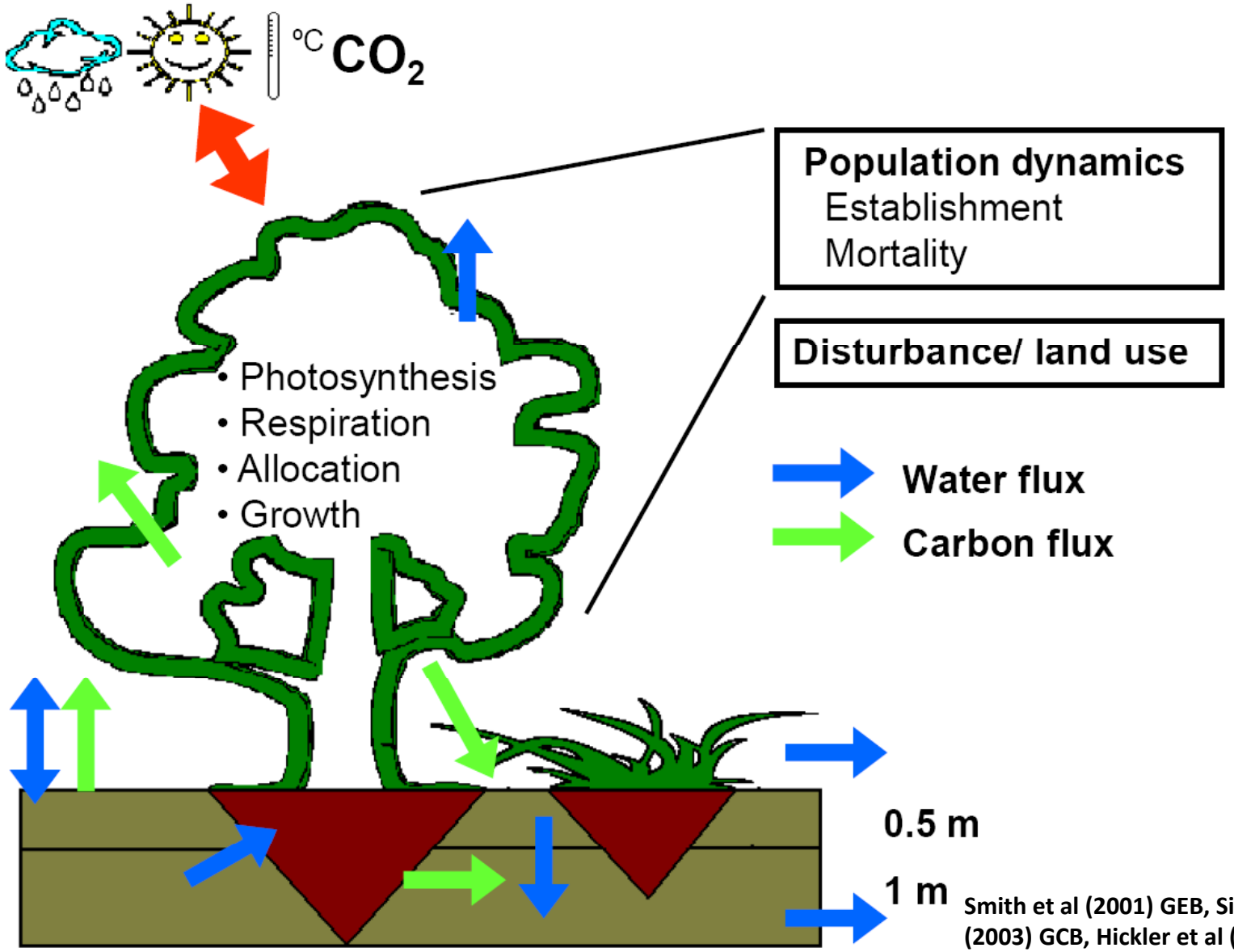



*Plant Physiology*

$$6H_2O + 6CO_2 \xrightarrow{h\upsilon} (CH_2O)_6 + 6O_2$$

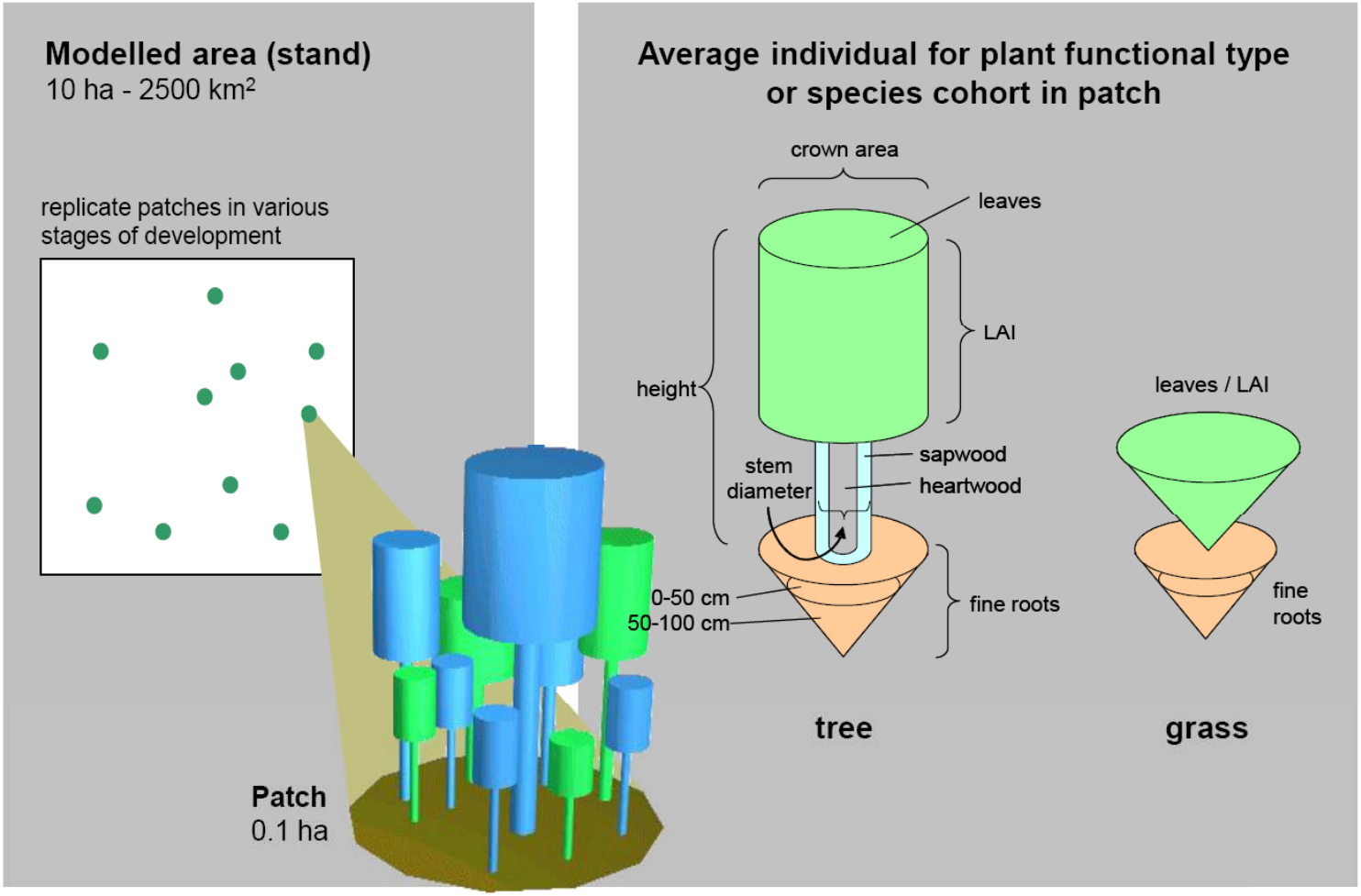
**Smith et al (2001) GEB, Hickler et al (2006) GEB**

# LPJ-GUESS Processes

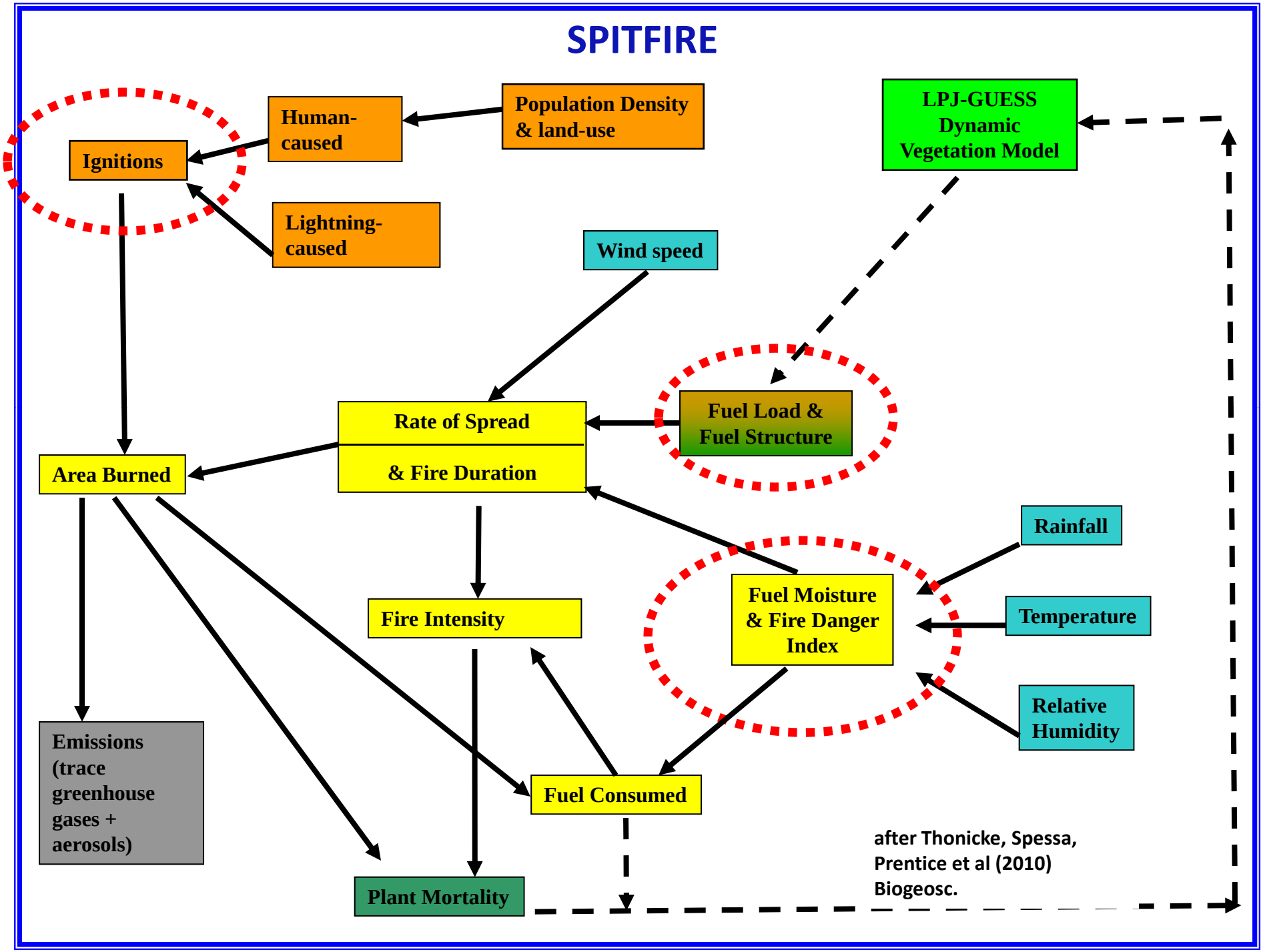


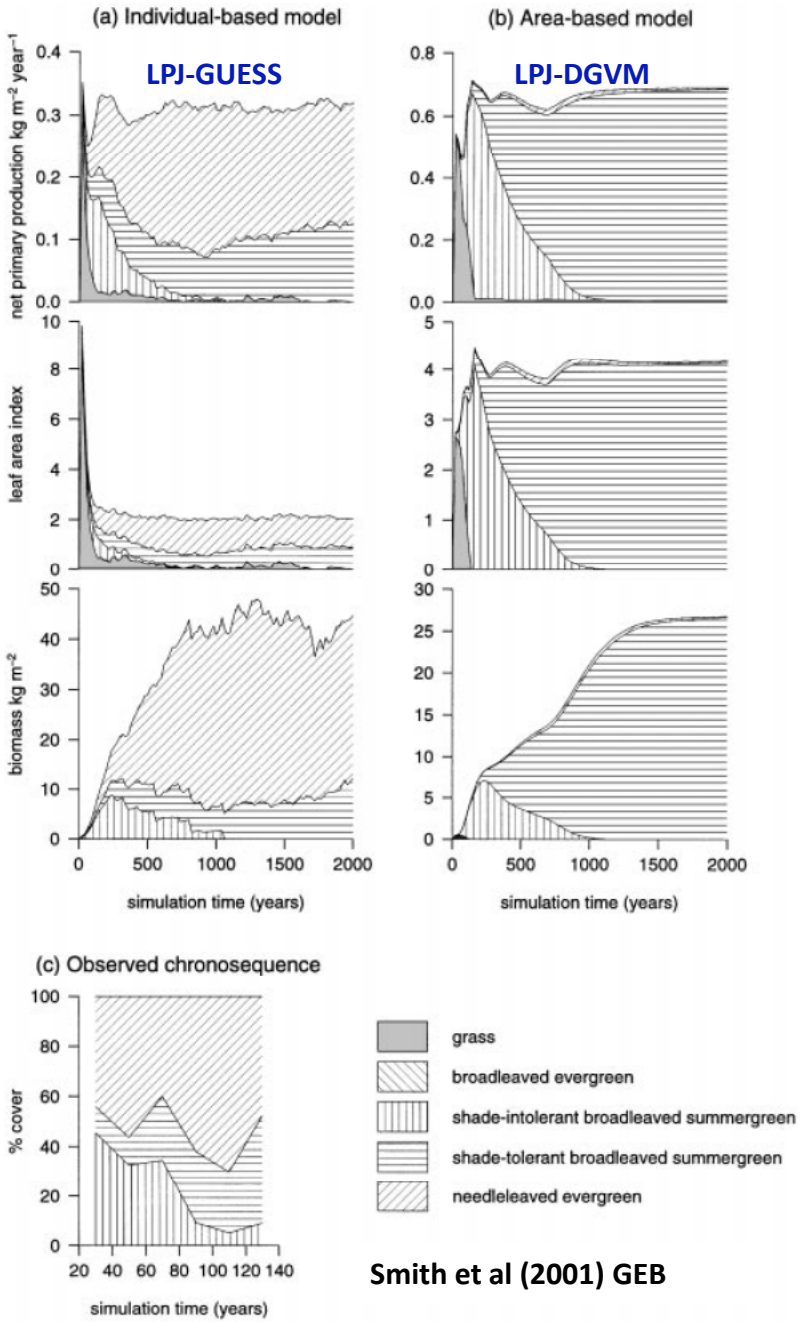

Smith et al (2001) GEB, Sitch et al (2003) GCB, Hickler et al (2006) GEB

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




Smith et al (2001) GEB, Hickler et al (2006) GEB

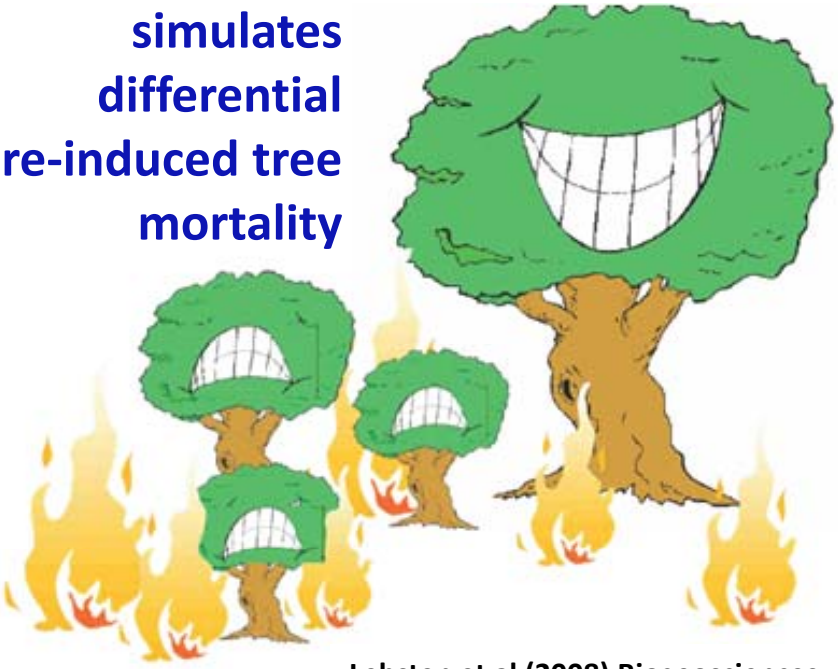

SPITFIRE
Human-caused
Population Density & land-use
LPJ-GUESS Dynamic Vegetation Model
Ignitions
Lightning-caused
Wind speed
Rate of Spread
& Fire Duration
Fuel Load & Fuel Structure
Area Burned
Rainfall
Fuel Moisture & Fire Danger Index
Temperature
Fire Intensity
Relative Humidity
Emissions (trace greenhouse gases + aerosols)
Fuel Consumed
Plant Mortality
after Thonicke, Spessa, Prentice et al (2010) Biogeosc.




Smith et al (2001) GEB

## LPJ-GUESS simulates ecological succession

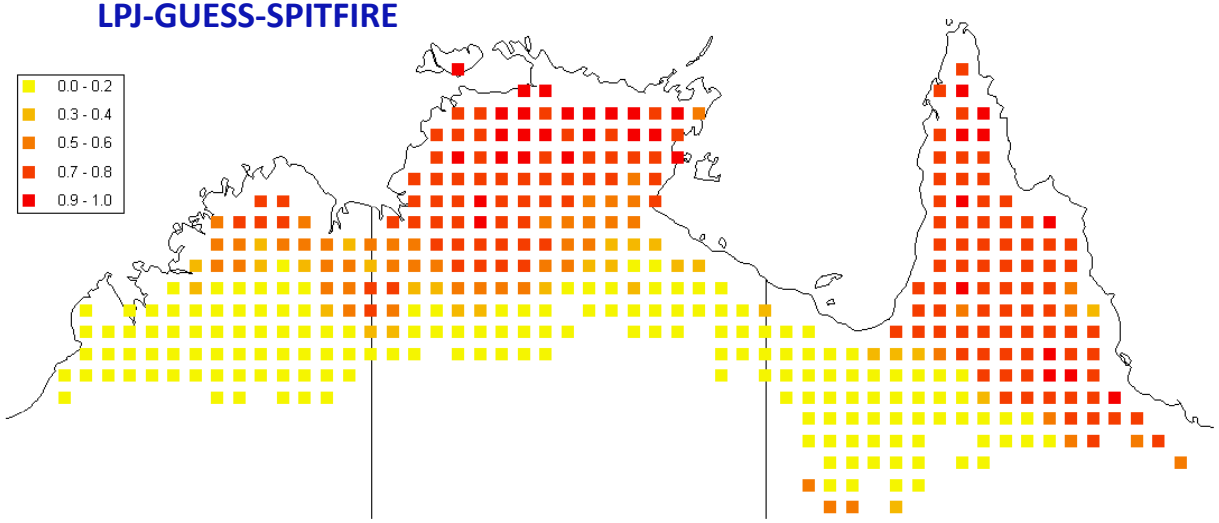
## LPJ-GUESS-SPITFIRE simulates differential fire-induced tree mortality



Lehsten et al (2008) Biogeosciences

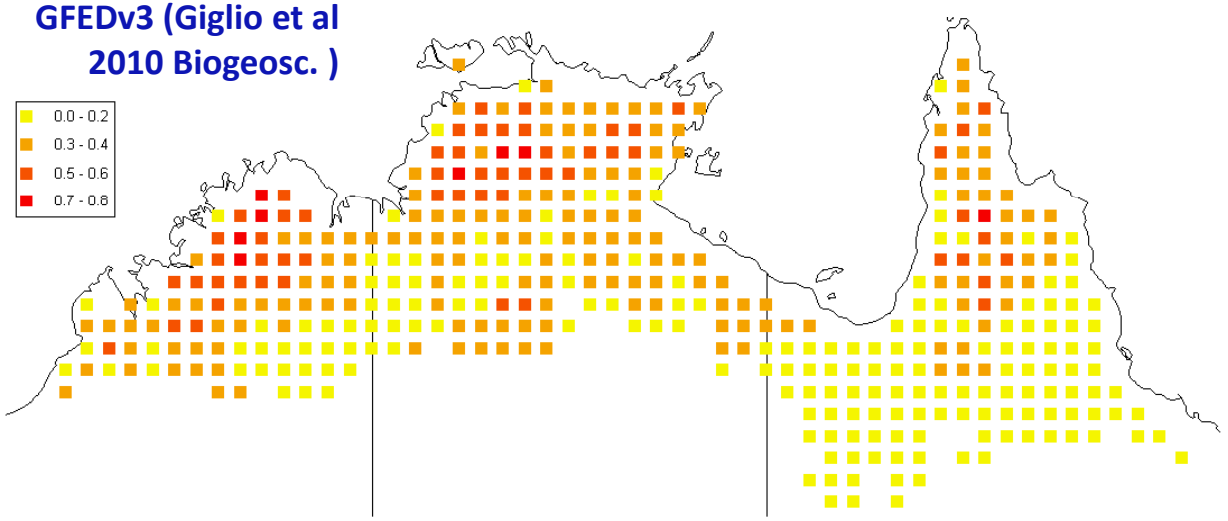
# LPJ-GUESS-SPITFIRE Burnt Area vs Observed Burnt Area

**LPJ-GUESS-SPITFIRE**

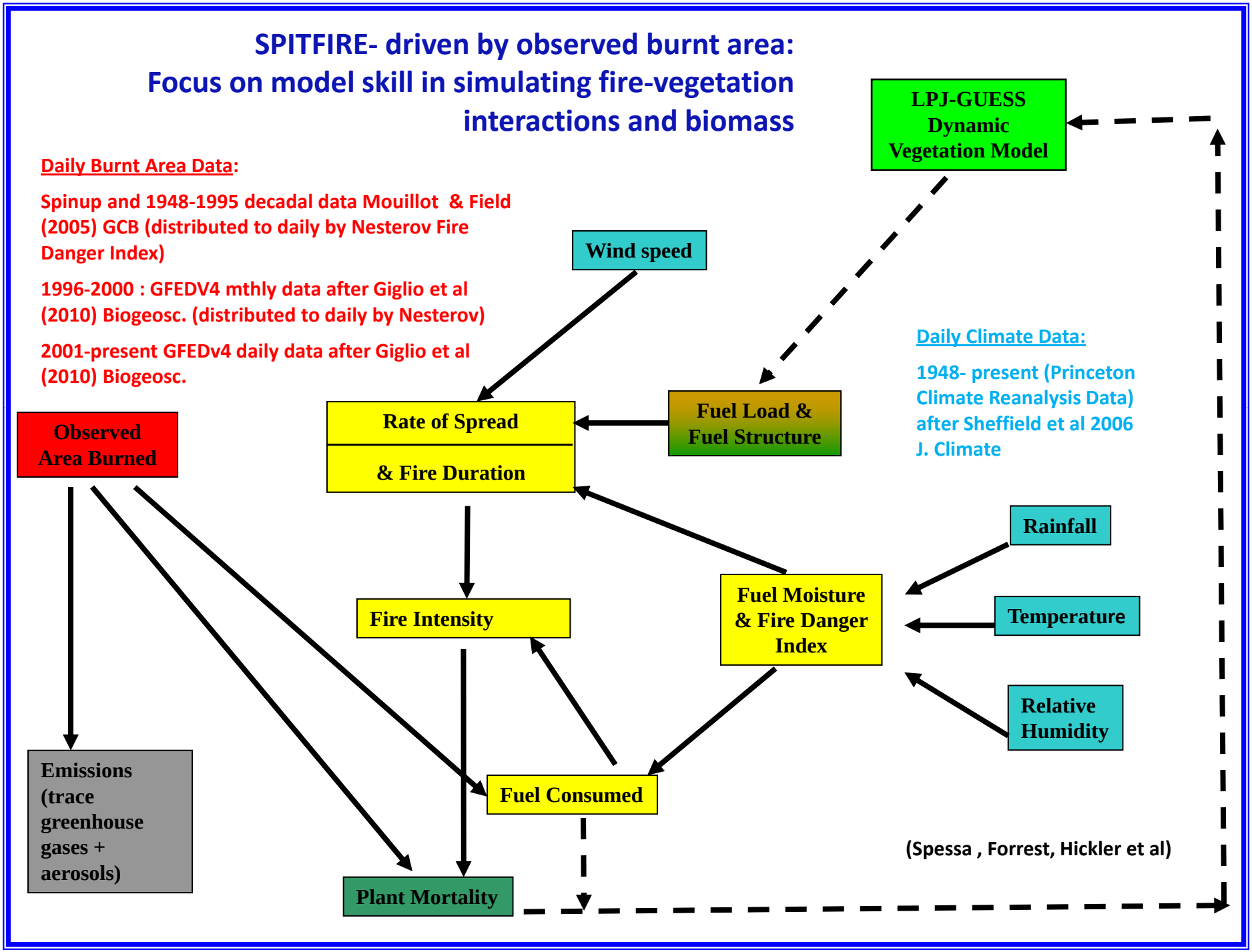



**Mean annual fraction of 0.5 deg gridcell burnt, 1997-2009**

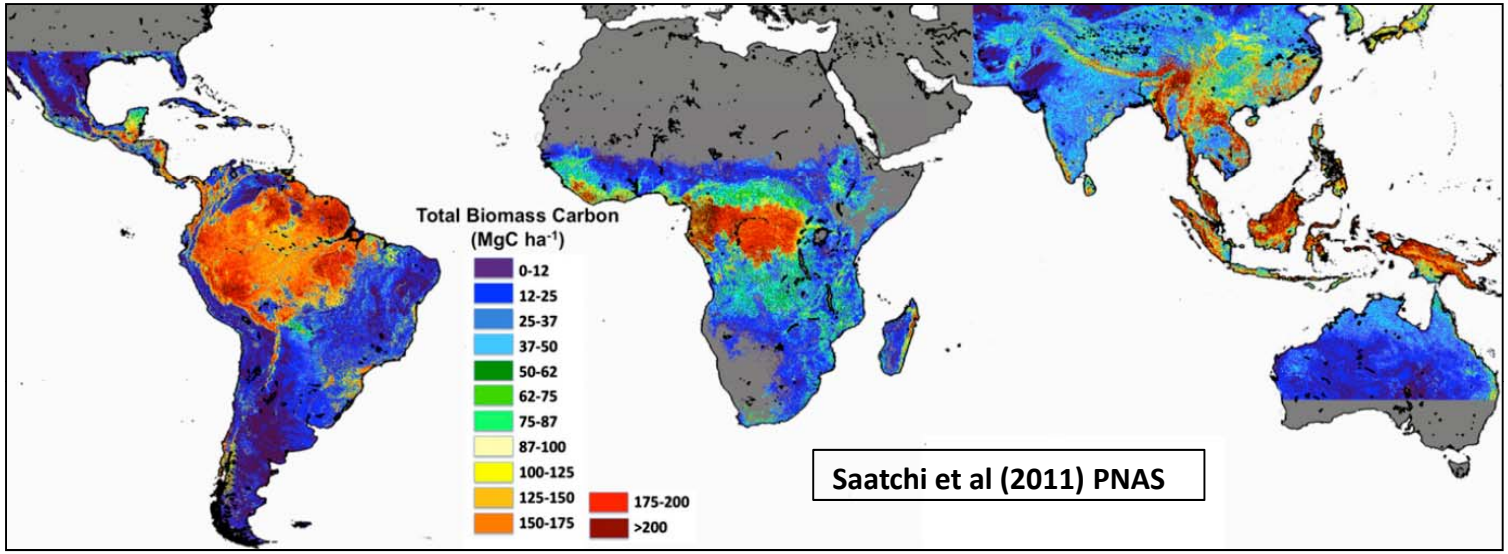
**GFEDv3 (Giglio et al 2010 Biogeosc. )**



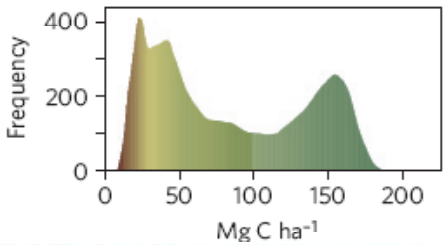
# SPITFIRE- driven by observed burnt area: Focus on model skill in simulating fire-vegetation interactions and biomass

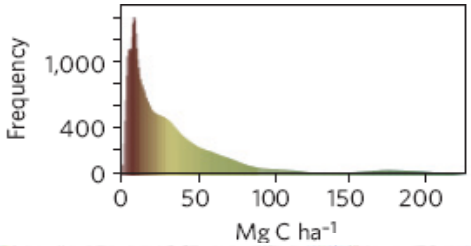


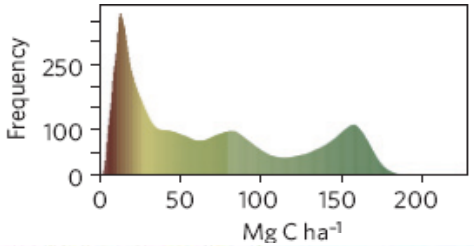
# Two recent EO-based datasets of pan-tropical tree biomass @ 1 sq km

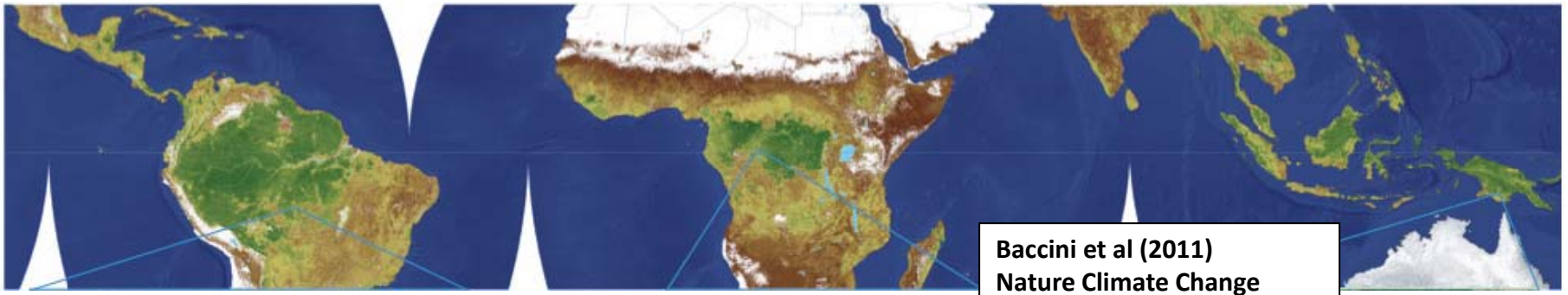



Saatchi et al (2011) PNAS



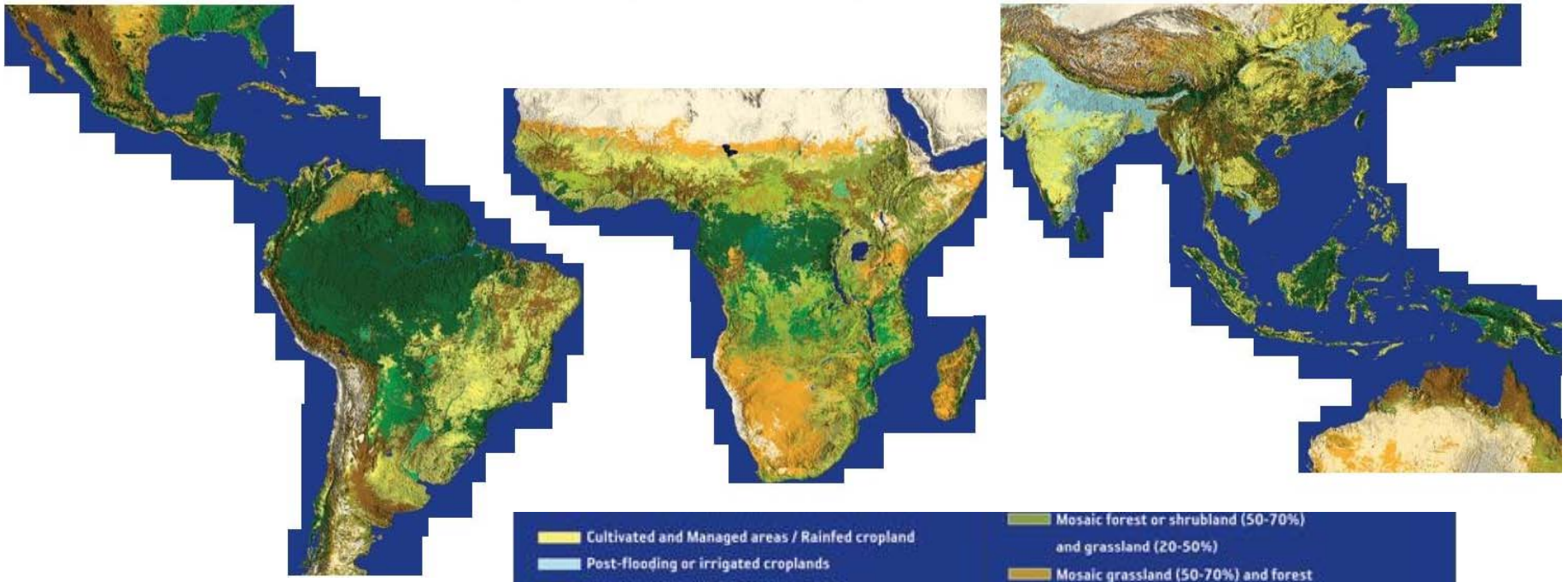



Baccini et al (2011)
Nature Climate Change

# ESA GLOBCOVER 2009 @ 1sq km



- Cultivated and Managed areas / Rainfed cropland
- Post-flooding or irrigated croplands
- Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)
- Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)
- Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)
- Closed (>40%) broadleaved deciduous forest (>5m)
- Open (15-40%) broadleaved deciduous forest/woodland (>5m)
- Closed (>40%) needle-leaved evergreen forest (>5m)
- Closed (>40%) needle-leaved deciduous forest (>5m)
- Open (15-40%) needle-leaved deciduous or evergreen forest (>5m)
- Closed to open (>15%) mixed broadleaved and needleaved forest
- Mosaic forest or shrubland (50-70%) and grassland (20-50%)
- Mosaic grassland (50-70%) and forest or shrubland (20-50%)
- Closed to open (>15%) shrubland (<5m)
- Closed to open (>15%) grassland
- Sparse (<15%) vegetation
- Closed (>40%) broadleaved forest regularly flooded, fresh water
- Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded, saline water
- Closed to open (>15%) grassland or shrubland or woody vgt on regularly flooded or waterlogged soil, fresh, brackish or saline water
- Artificial surfaces and associated areas (Urban areas >50%)
- Bare areas
- Water bodies

**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-intepretation 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

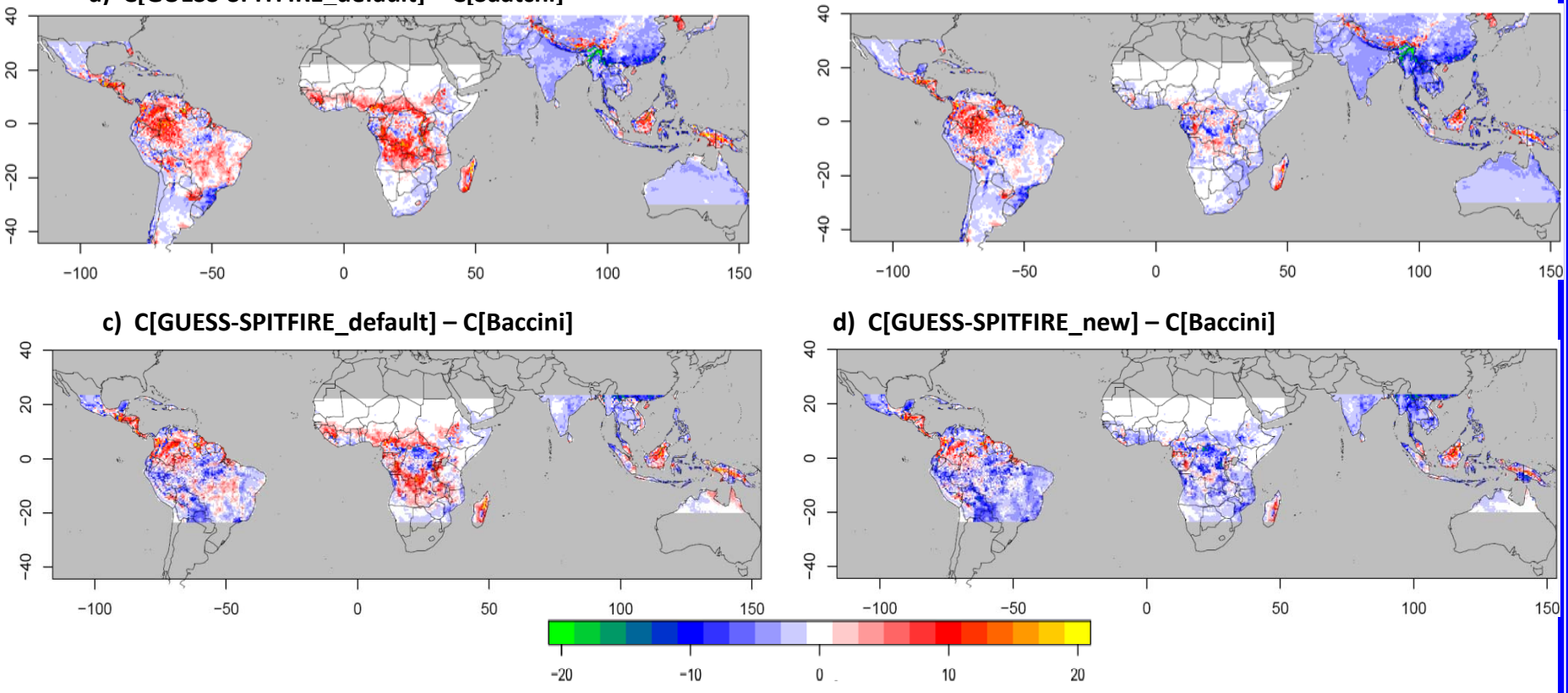
# GUESS-SPITFIRE simulated tree carbon versus two EO-based datasets

## (Saatchi et al 2011, Baccini et al 2012)

## (mean 1997-2008) (GC 2009 land cover corrected) (kgC.m$^{-2}$)

a) C[GUESS-SPITFIRE_default] – C[Saatchi]

b) C[GUESS-SPITFIRE_new] – C[Saatchi]

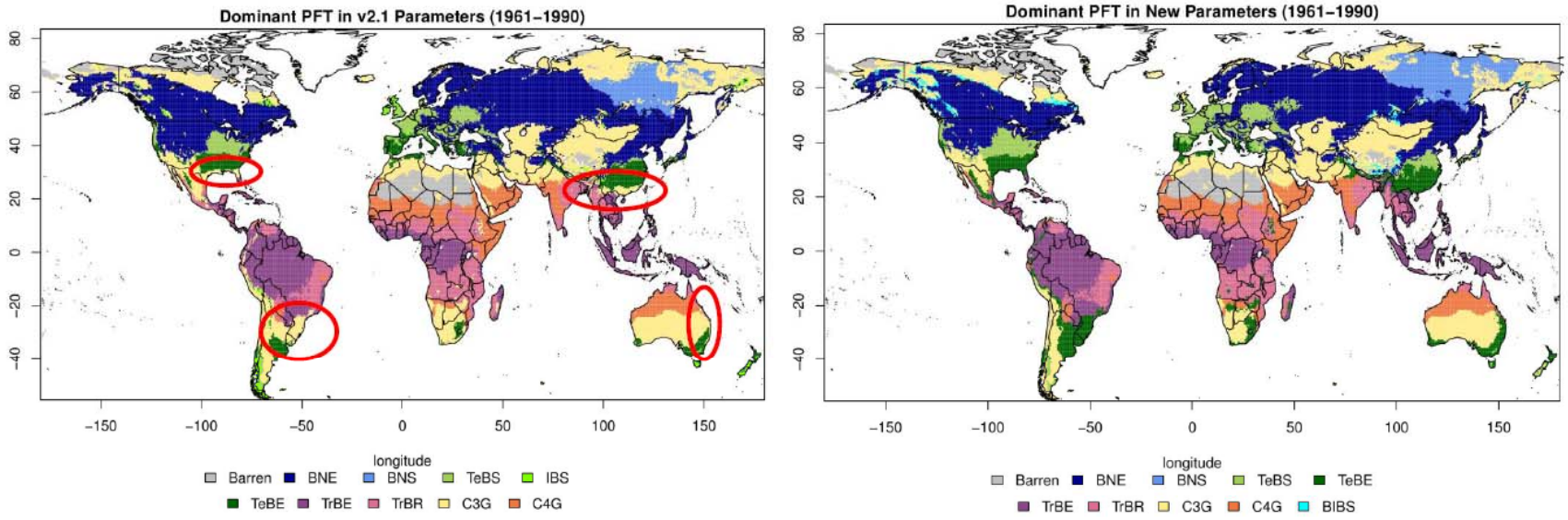



c) C[GUESS-SPITFIRE_default] – C[Baccini]

d) C[GUESS-SPITFIRE_new] – C[Baccini]

(Spessa , Forrest, Hickler et al)

# Dominant PFT

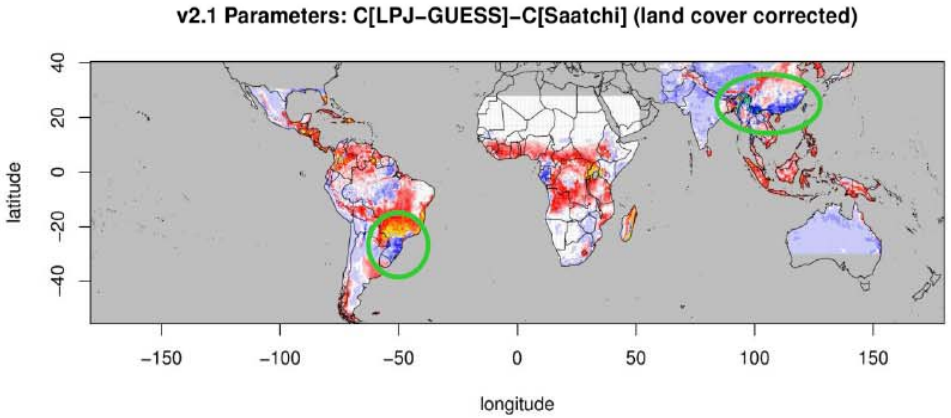


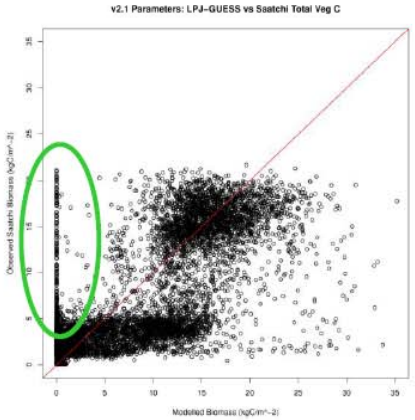

On the left standard v2.1, red circles show areas which are grasslands in which no trees can grow.

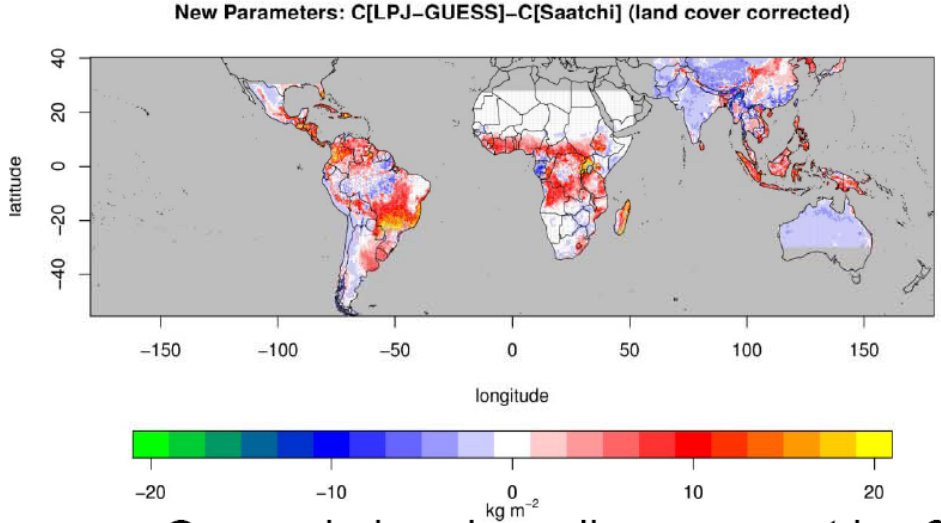
On the right, bioclimactic limits changed back to Sitch et al. 2003, allow trees again.

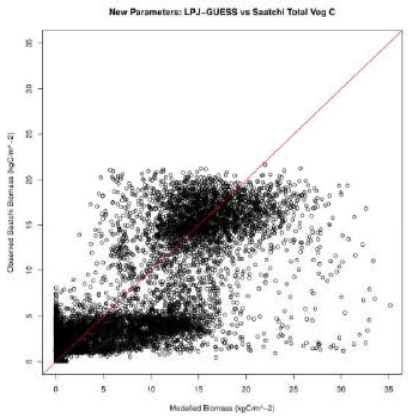
**(Matt Forrest @ BiK-F)**

# 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.