Fire, fuels and competition: capturing tropical forests and savannas with FATES-SPITFIRE

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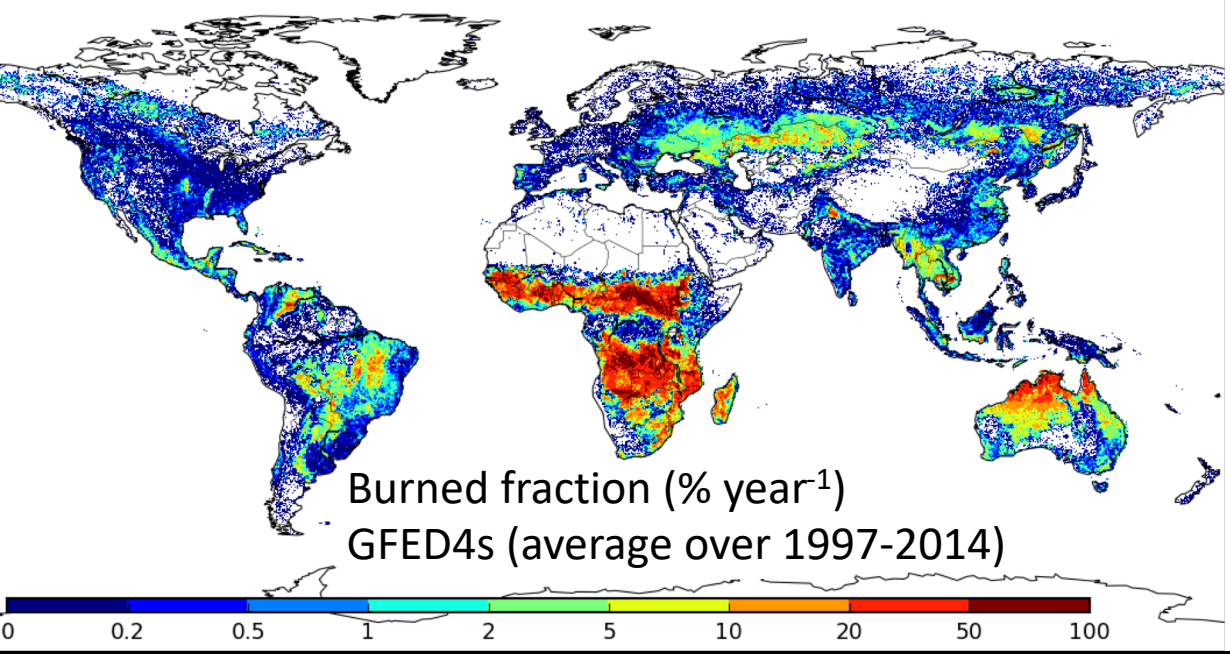
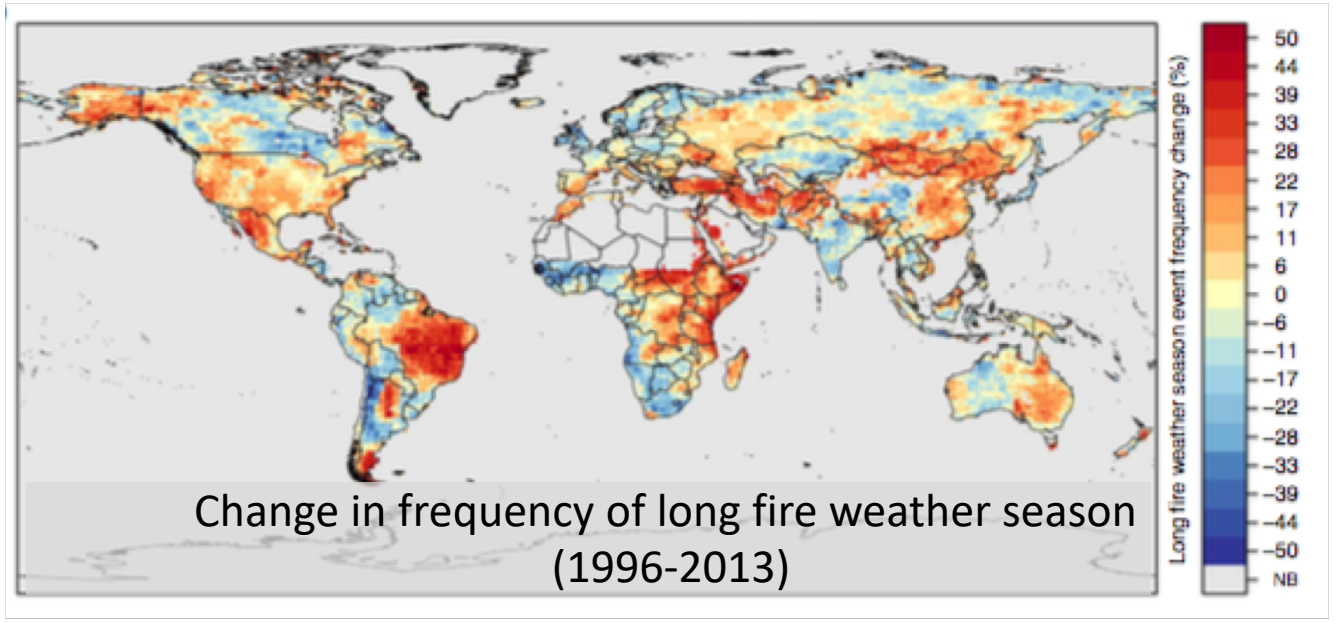
Importance of Fire regimes and Fire danger



Van der Werf et al. 2017

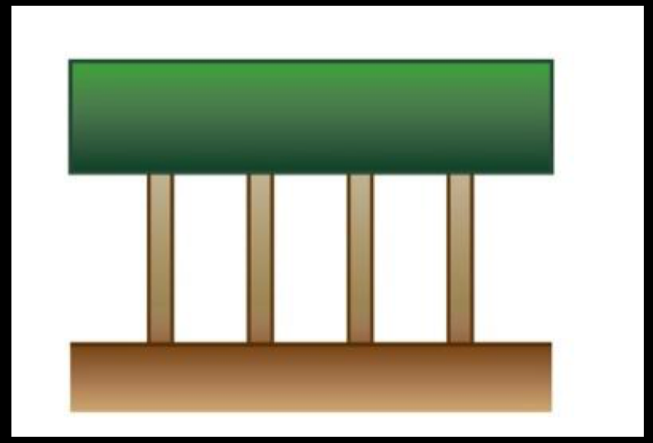


Jolly et al 2015 *Nature Communications*

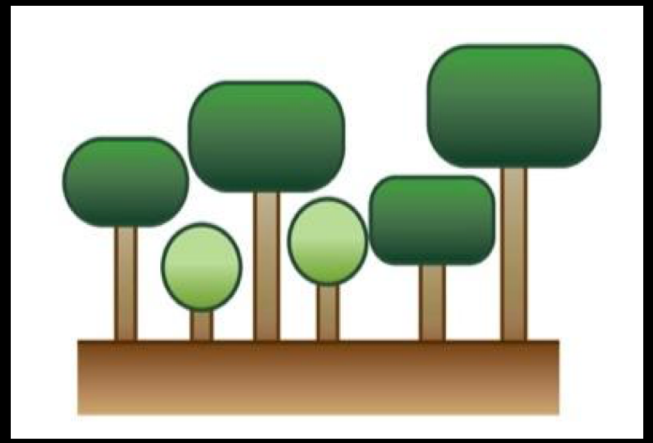
- Regime determines species composition, biomass accumulation, structure
- Role in long-term climate feedbacks, direct impact on net ecosystem exchange
- Interaction of climate, fuel, fire: fuel load and rainfall in savanna, temperature and fire season length in boreal and temperate, land-use pressure

What is FATES? (Functionally Assembled Ecosystem Simulator)

- Vegetation module designed to run within land surface model (CESM-CLM, E3SM-ELM), replacing bulk “big-leaf” with size- and age-structured plant dynamics
- Simulates plant physiology, competition processes, ecosystem assembly and distribution



“Big-Leaf” vegetation

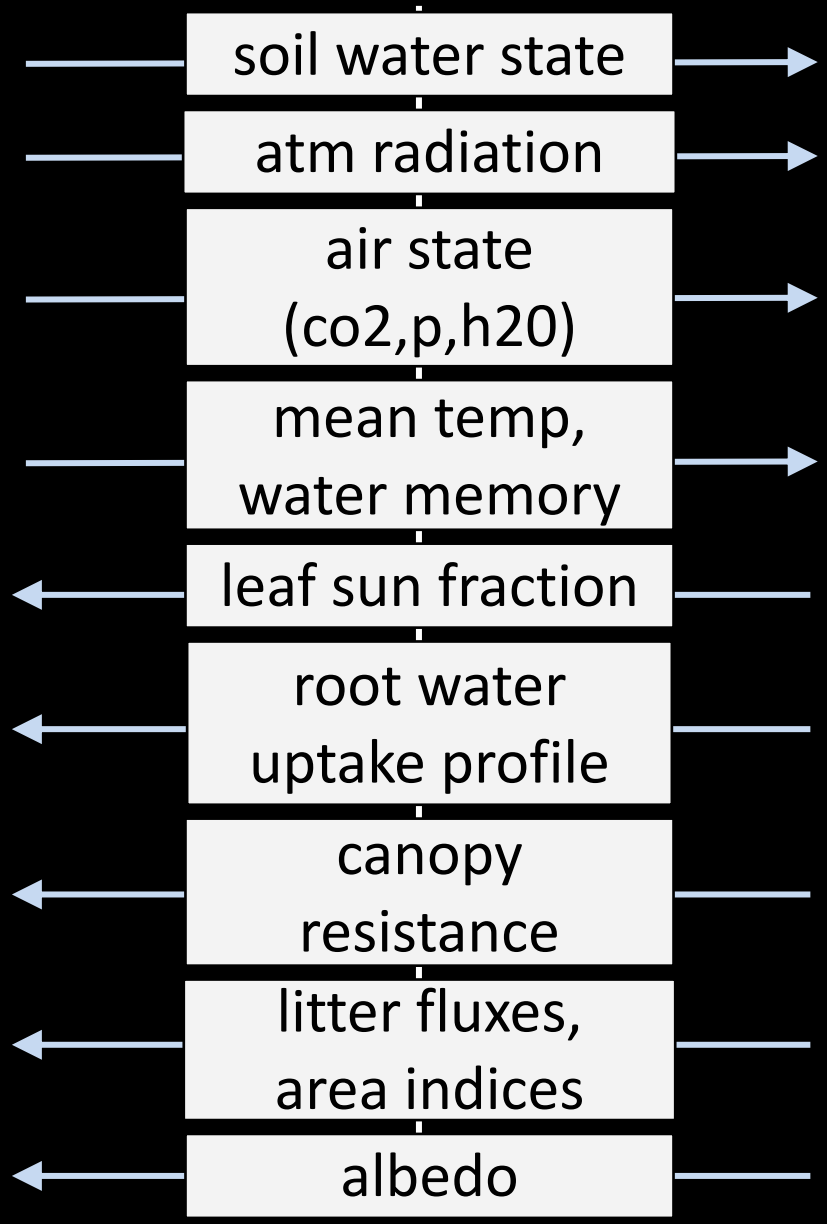


Demographic Vegetation

Host Land Model

hydrology
energy balancing
soil carbon
soil biogeochemistry

everything else



FATES

canopy radiation(hourly)

water stress (btran)(hourly)

photosynthesis / respiration (hourly)

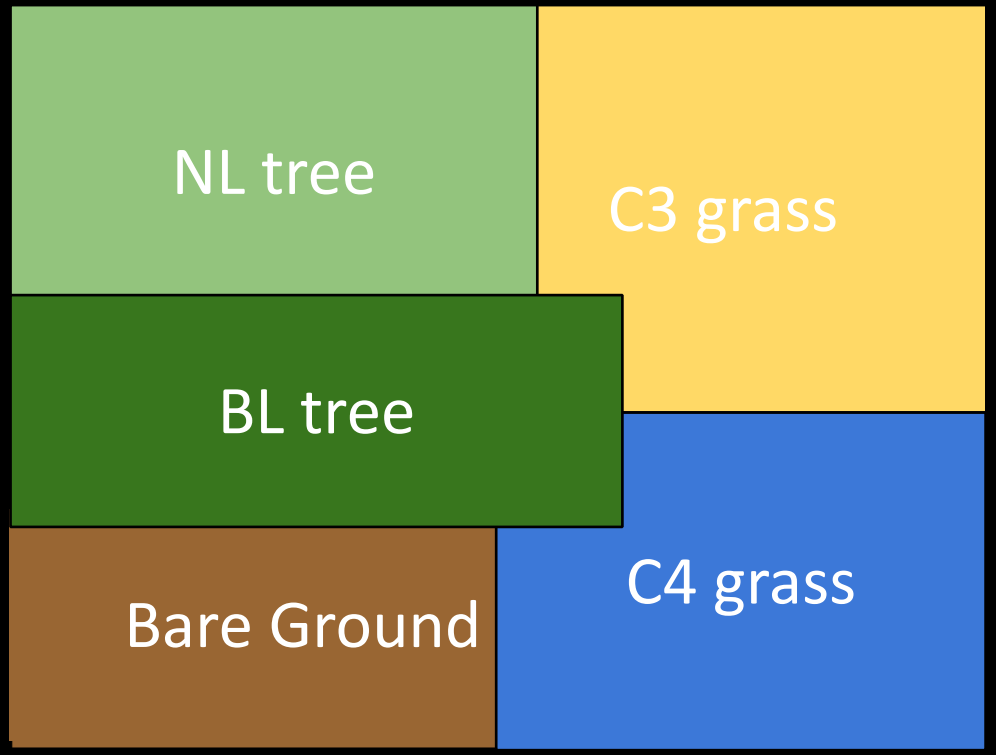
growth/allocation (daily)

mortality, recruitment(daily)

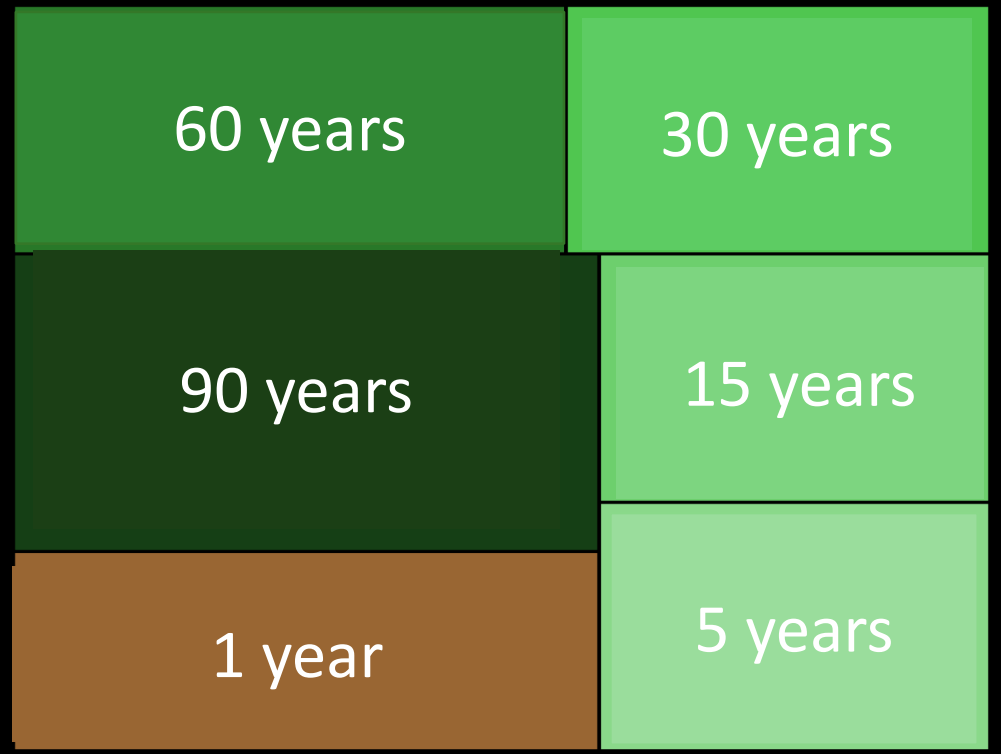
Vegetation structure and fuels in FATES-SPITFIRE

Mosaic of structure, fuels and vulnerability

Plant Functional Type tiling



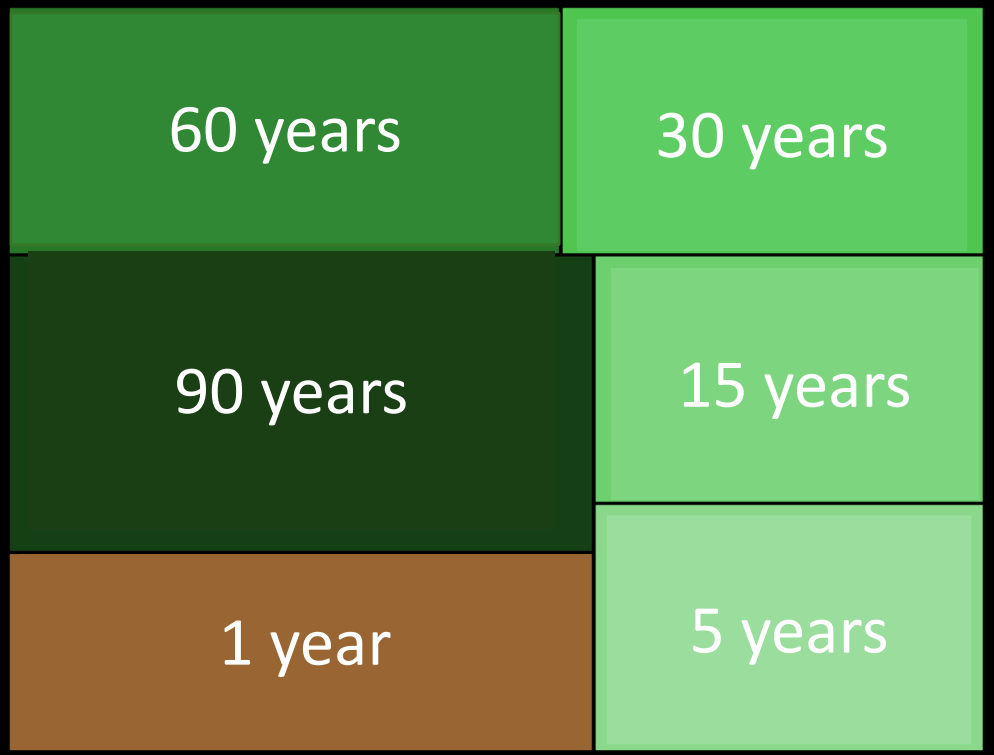
Time-since-disturbance tiling



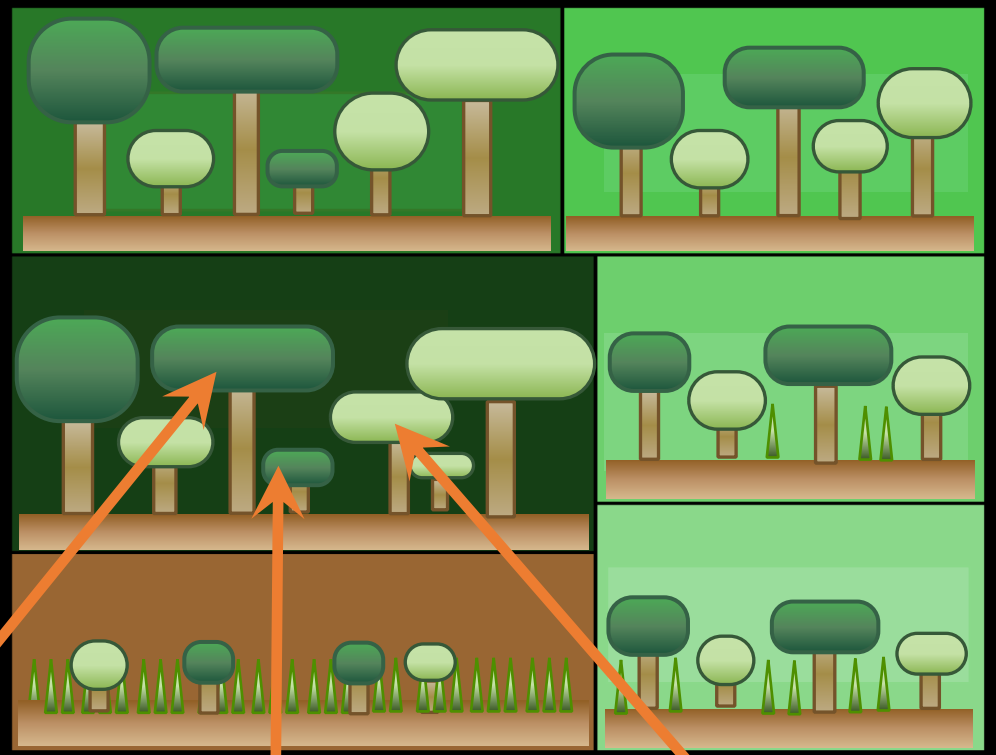
Coexistence and variable mortality in FATES

Each **time-since-disturbance** tile contains **cohorts** of plants, defined by **PFT** and **size**.

Time-since-disturbance tiling



Time-since-disturbance tiling

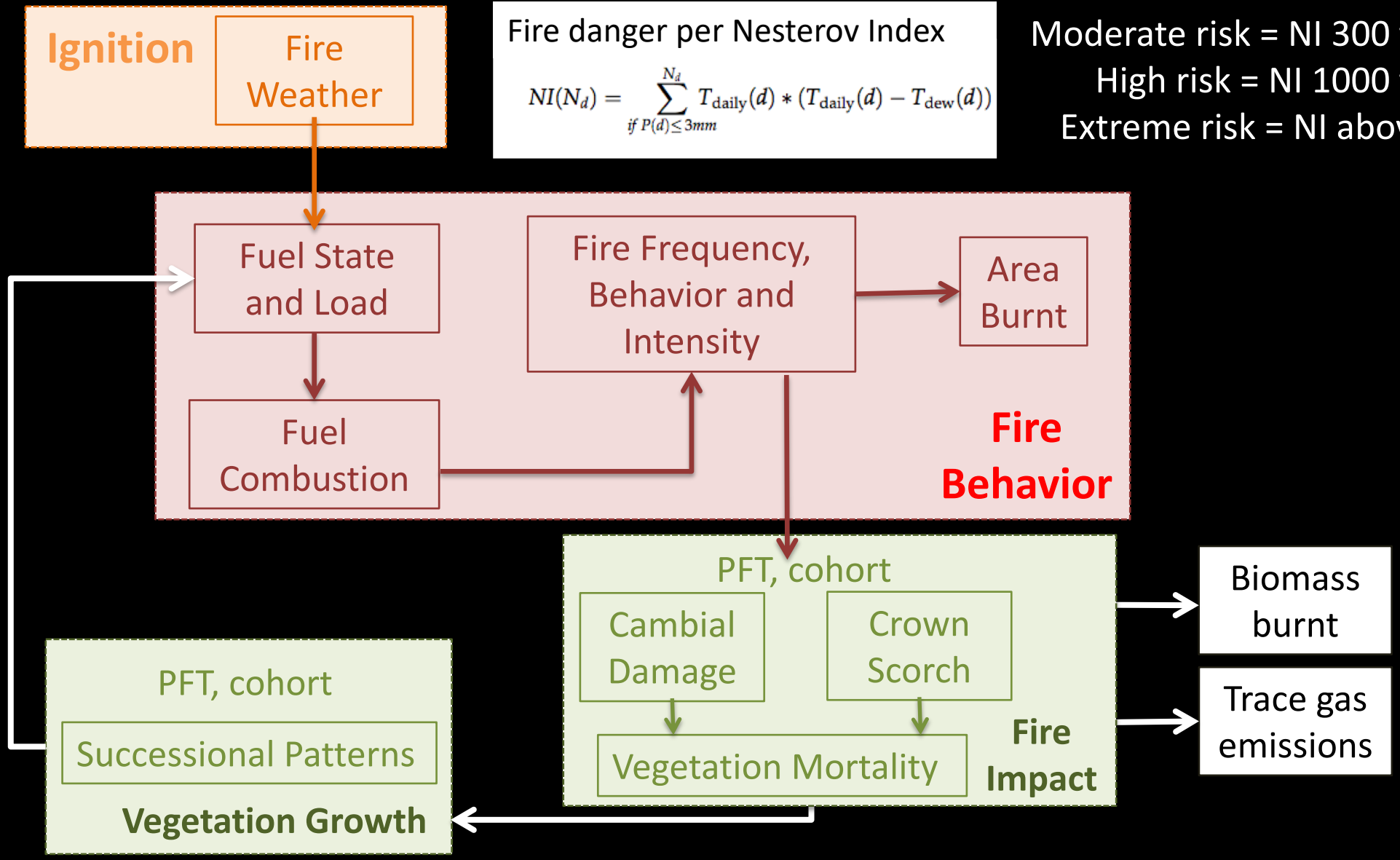


Cohort. PFT1. 10m

Cohort. PFT1. 2m

Cohort. PFT2. 4m

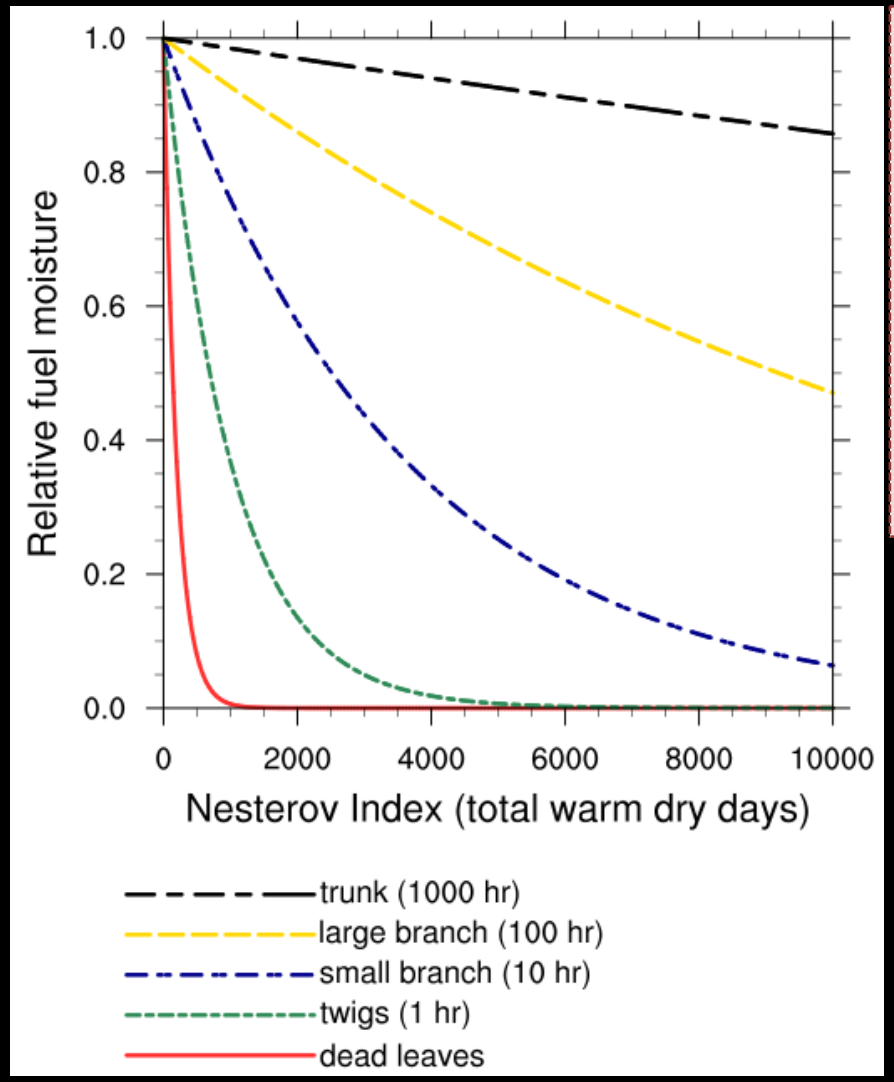
FATES-SPITFIRE



Adapted from Thonicke *et al.* 2010 *Biogeosciences*

Fire Behavior: evaluate fuels at patch level

6 fuel classes: dead leaves, twigs, small and large branches, trunk, live grass



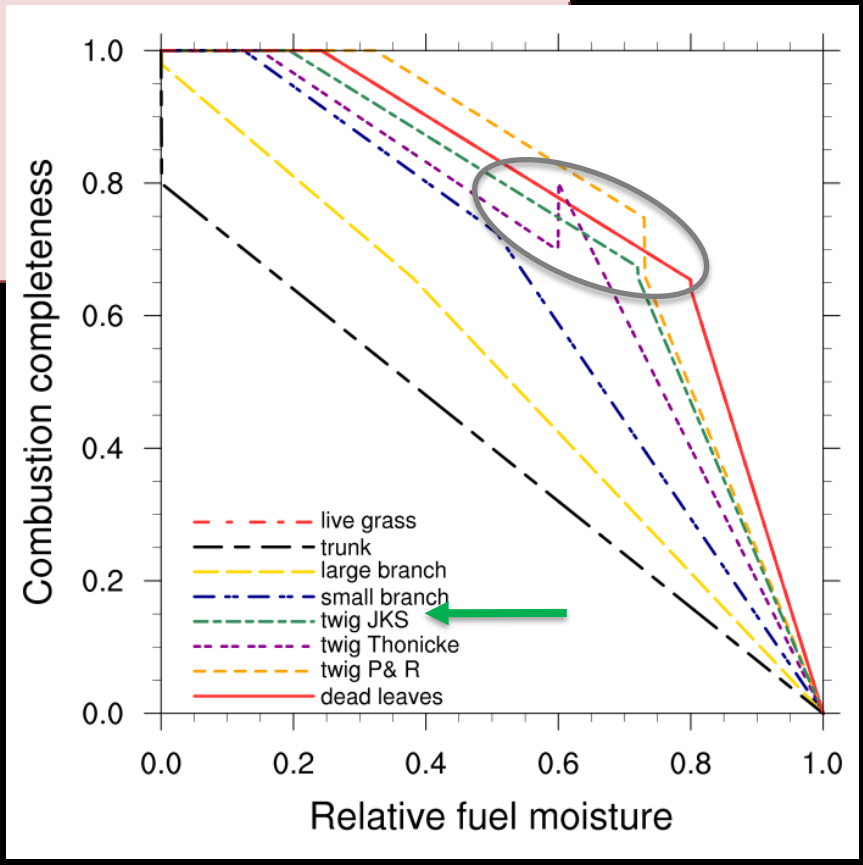
Fuel State: load, bulk density, moisture, SA to Volume

Fuel Combustion

Rate of spread, Duration of burn, and Intensity

Area Burnt

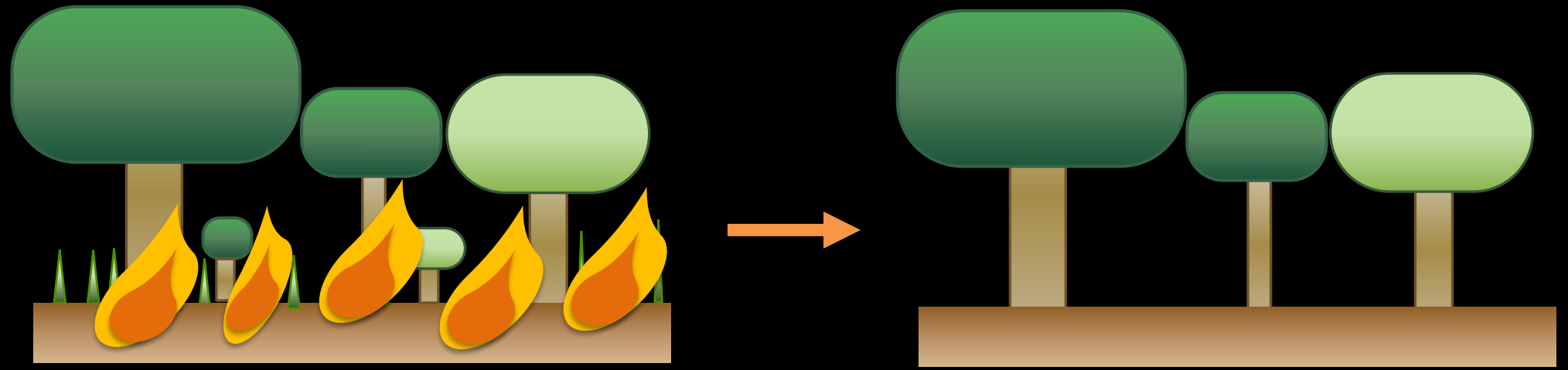
- Fuels dry based on climate per Nesterov
- Combustion responds to fuel moisture



SPITFIRE vegetation mortality

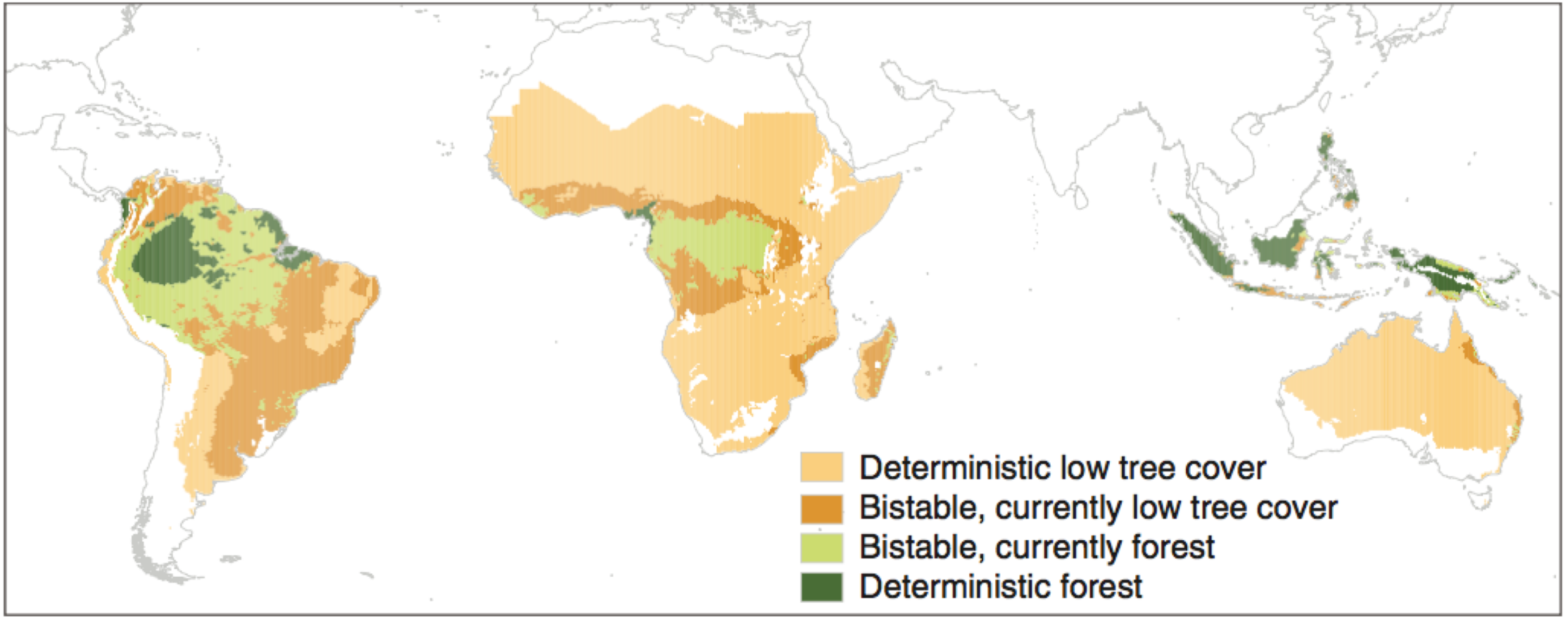
Tree mortality:
Flame height (relative to canopy height)
Bark thickness (varies by PFT)
Fire Intensity and residence time

Grasses are not protected, and burn with all fires.



FATES retains the fire-affected canopy structure, e.g. affecting future fire behavior

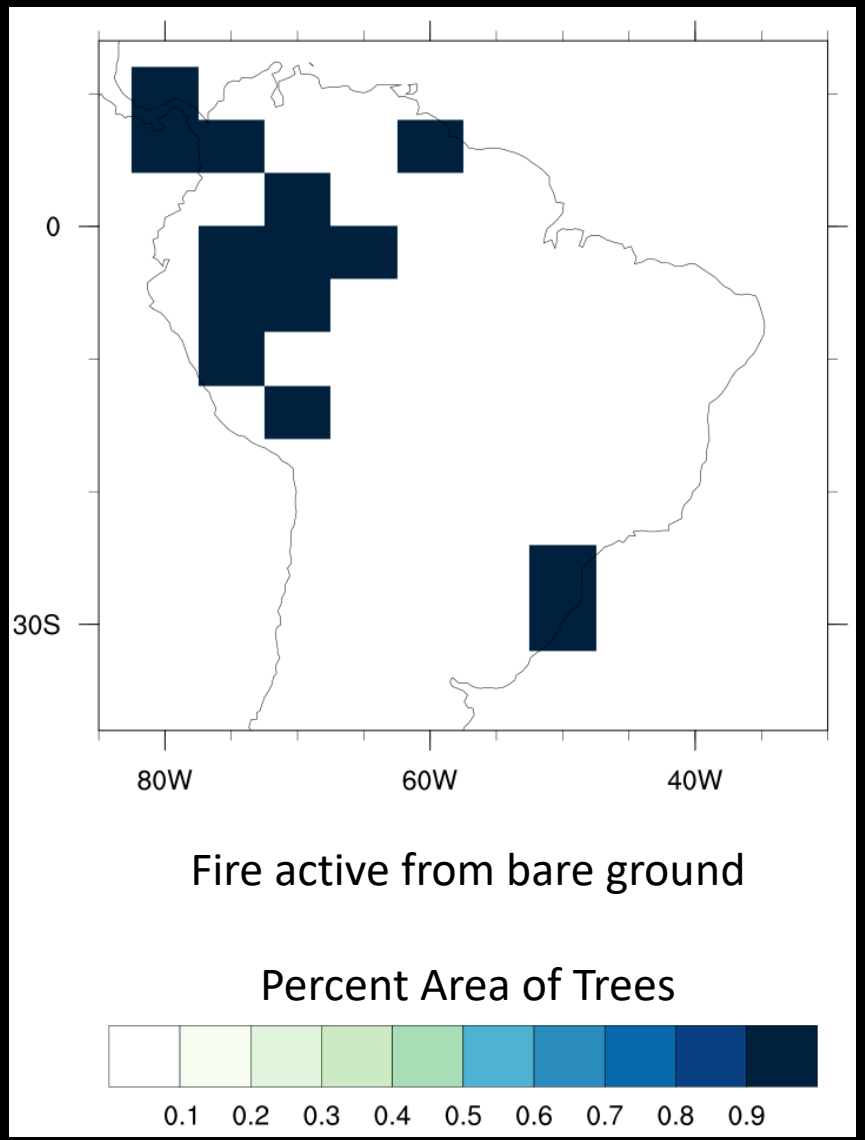
Can we capture forest/savanna bi-stability?

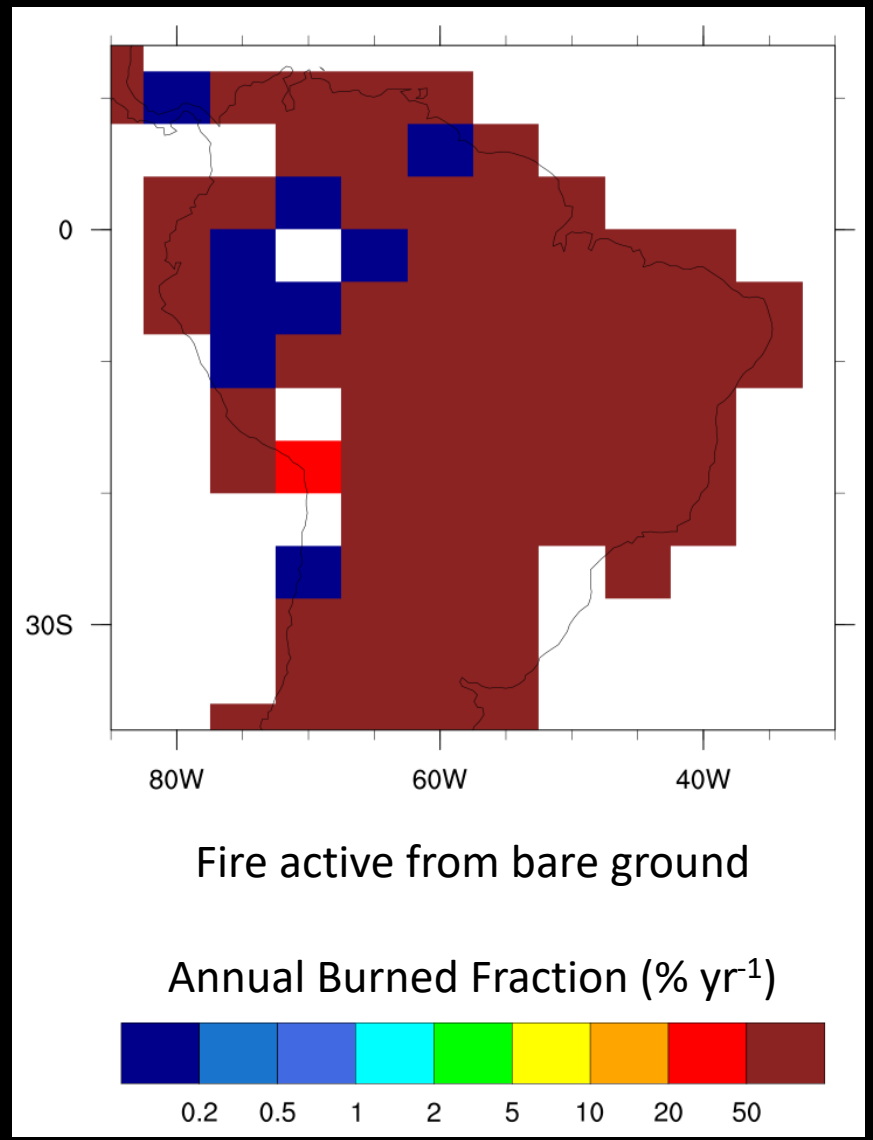


Staver *et al.* 2011 *Science*

Development exposed a few flaws

(master: tag: sci.1.21.0_api.7.0.0 mid January 2019)





- Massive tree death
- Too much fire. Why?
- Iterative parameter sensitivity analysis

FATES parameters in CLM

FATES has **187** parameters:

Hydro (18), Fire (23), Nitrogen/Phos (6), Obvious/Developer (23), Special Modes (i.e. logging, prescribed physiology, etc.) (14), Allometry (leaf, height, aboveground biomass, sapwood, root) (27)

66 remaining parameters including:

Vcmax

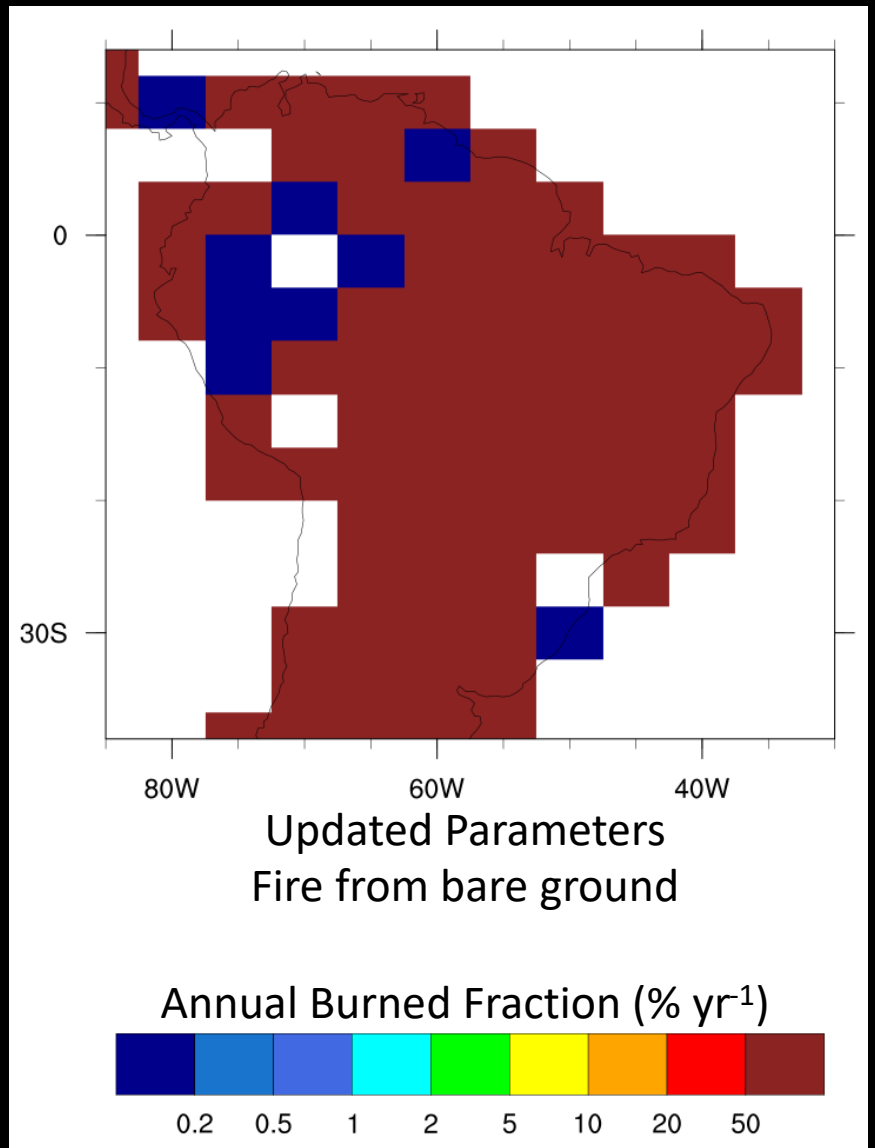
Specific Leaf Area

Leaf Longevity

Wood Density

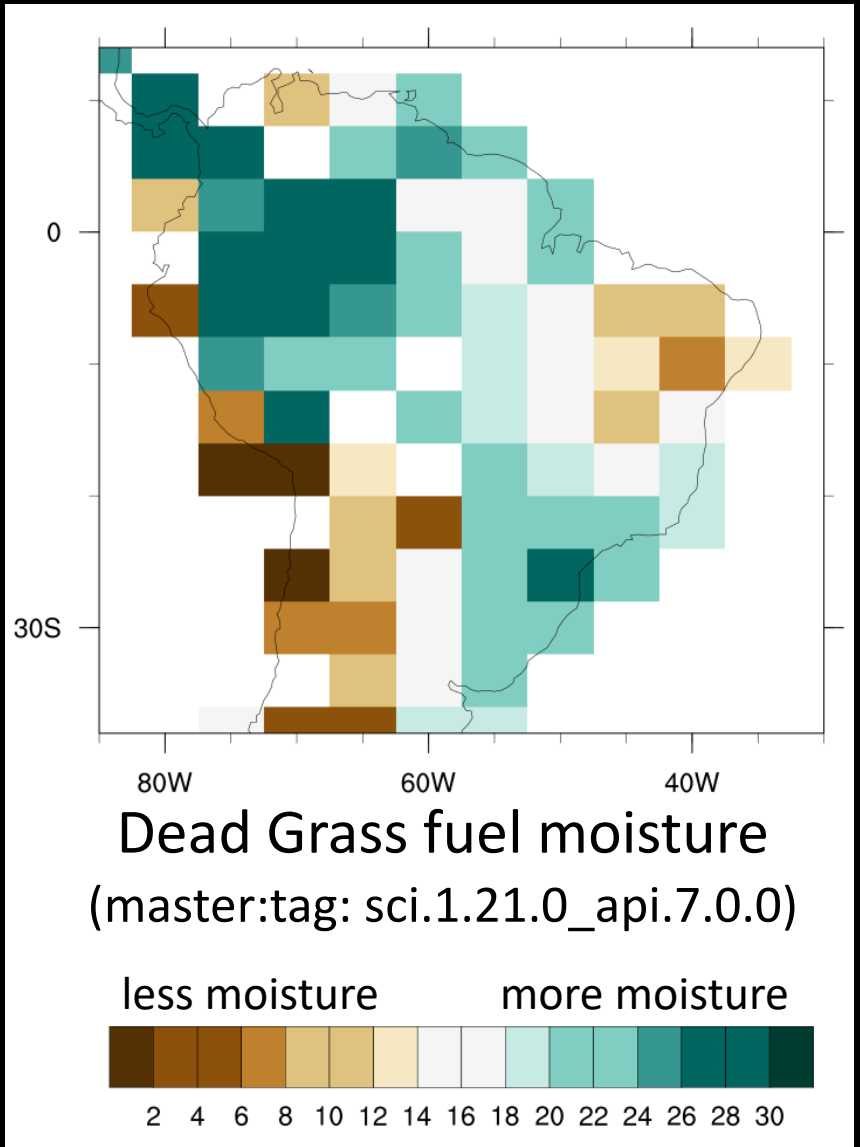
Leaf C:N ratio

Sensitive parameters (Leaf longevity, Specific leaf area, Vcmax, …)



- Parameters set according to allometric calculations, literature (Kattge 2009,2011; Hoffman et al 2003; Thonicke et al 2010; …) and FATES tropics values
- Burned fraction still not realistic
- Parameter updates not enough to solve this
- Fuel moisture?
- Fire behavior equations?

Live Grass fuel moisture too dry



Dead Grass fuel moisture

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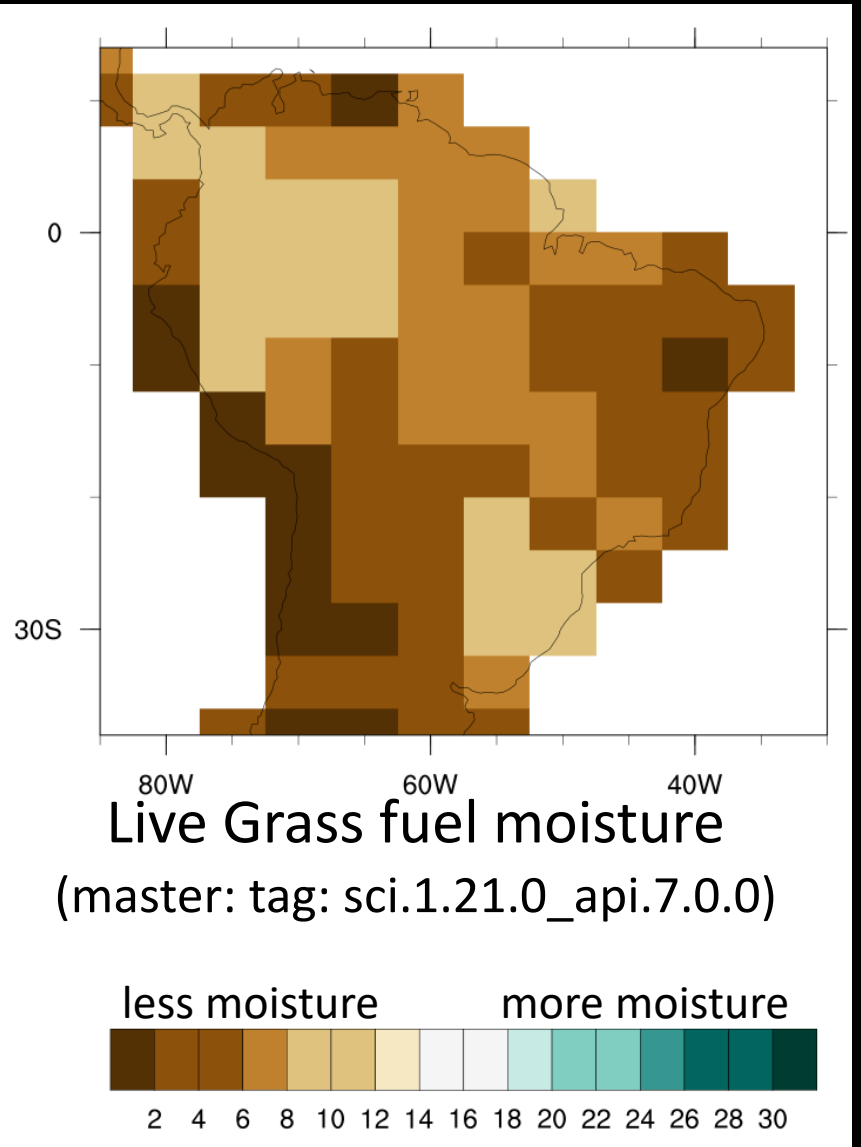
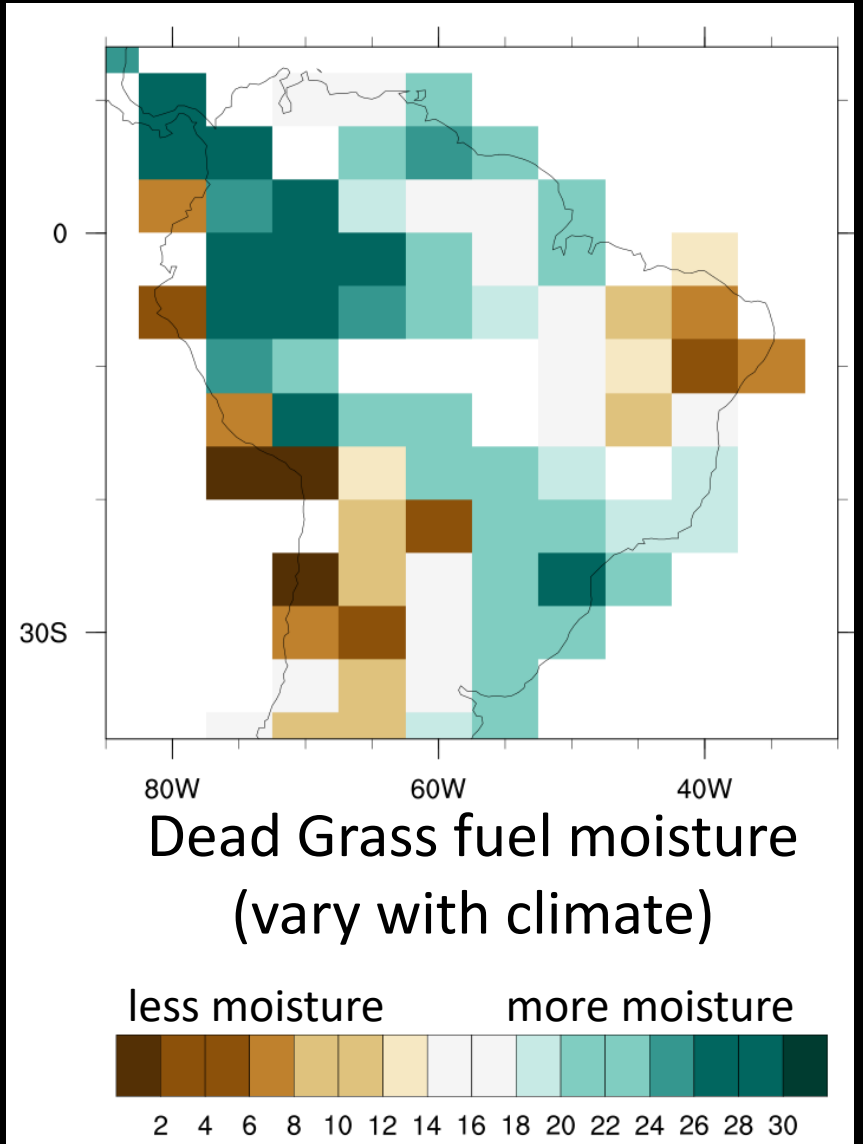


Live Grass fuel moisture

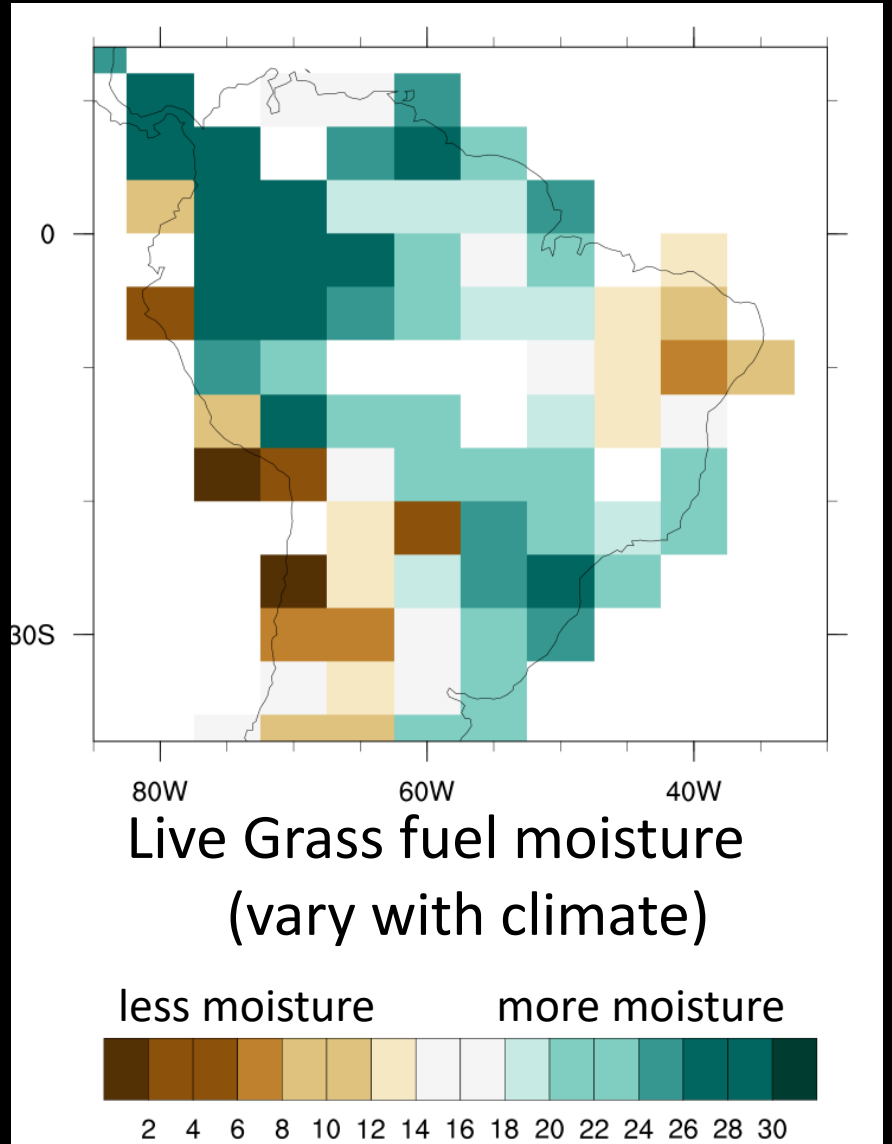
(master: tag: sci.1.21.0_api.7.0.0)

- Live grass drier than dead grass
- Live grass fuel moisture varies with the top soil layer
- In CLM this layer is very thin and dries quickly

Update: Live Grass fuel moisture vary with climate



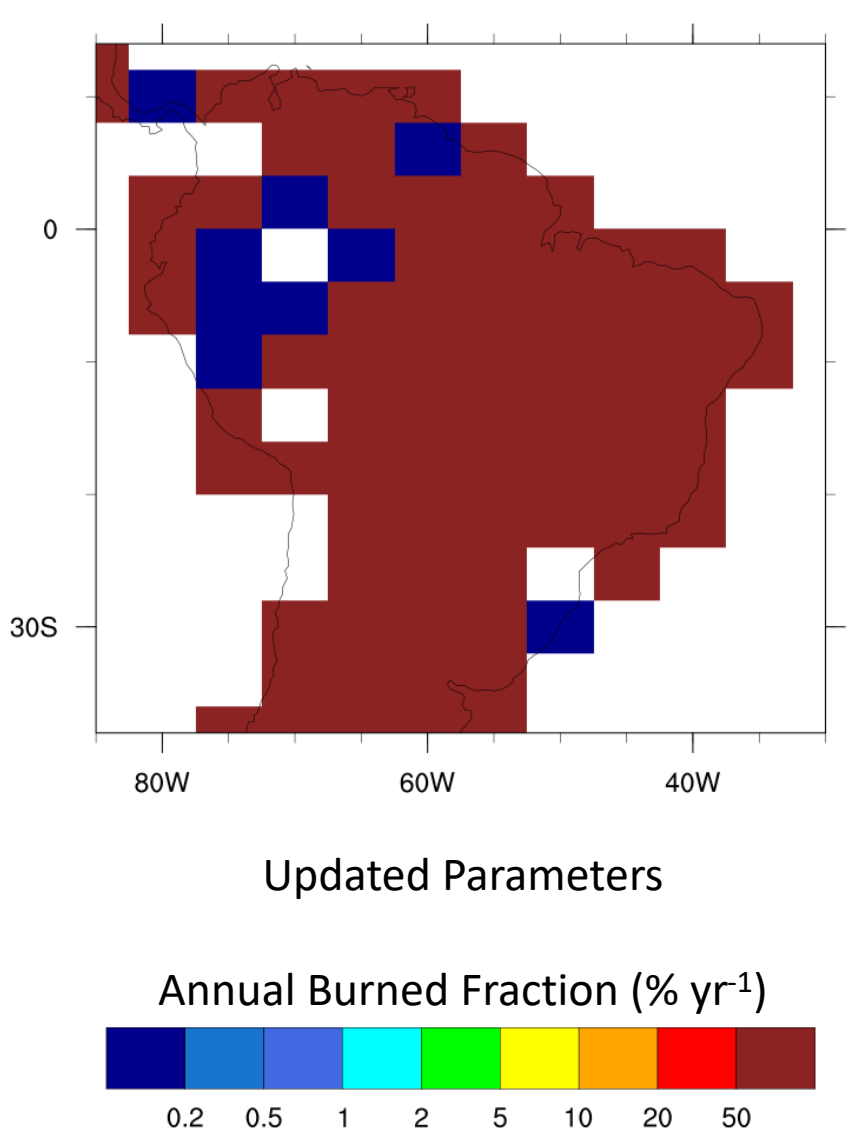
Dead Grass fuel moisture (vary with climate)

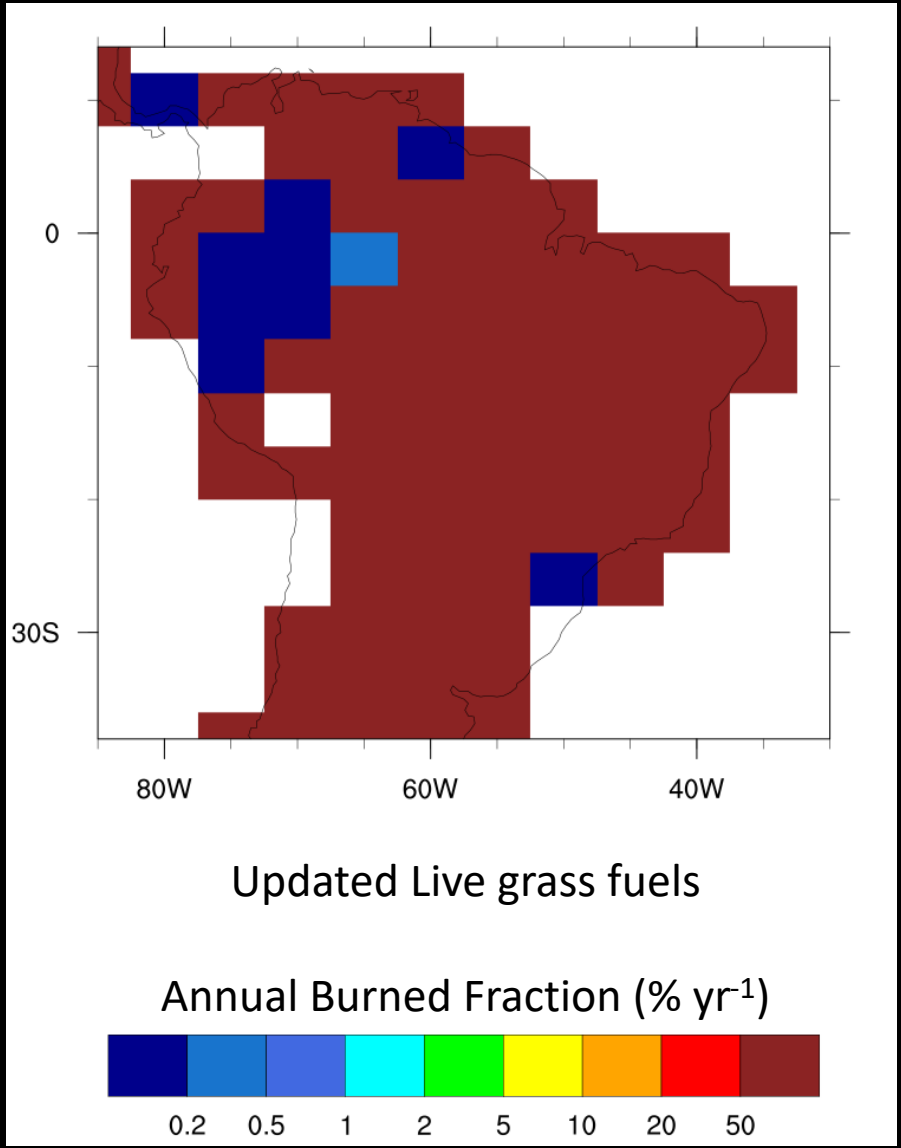


Live Grass fuel moisture (vary with climate)

- Live grass has more moisture than dead grass
- Live grass fuel moisture set to vary with Nesterov Index (# warm days) based on (SAV) Surface Area to Volume ratio

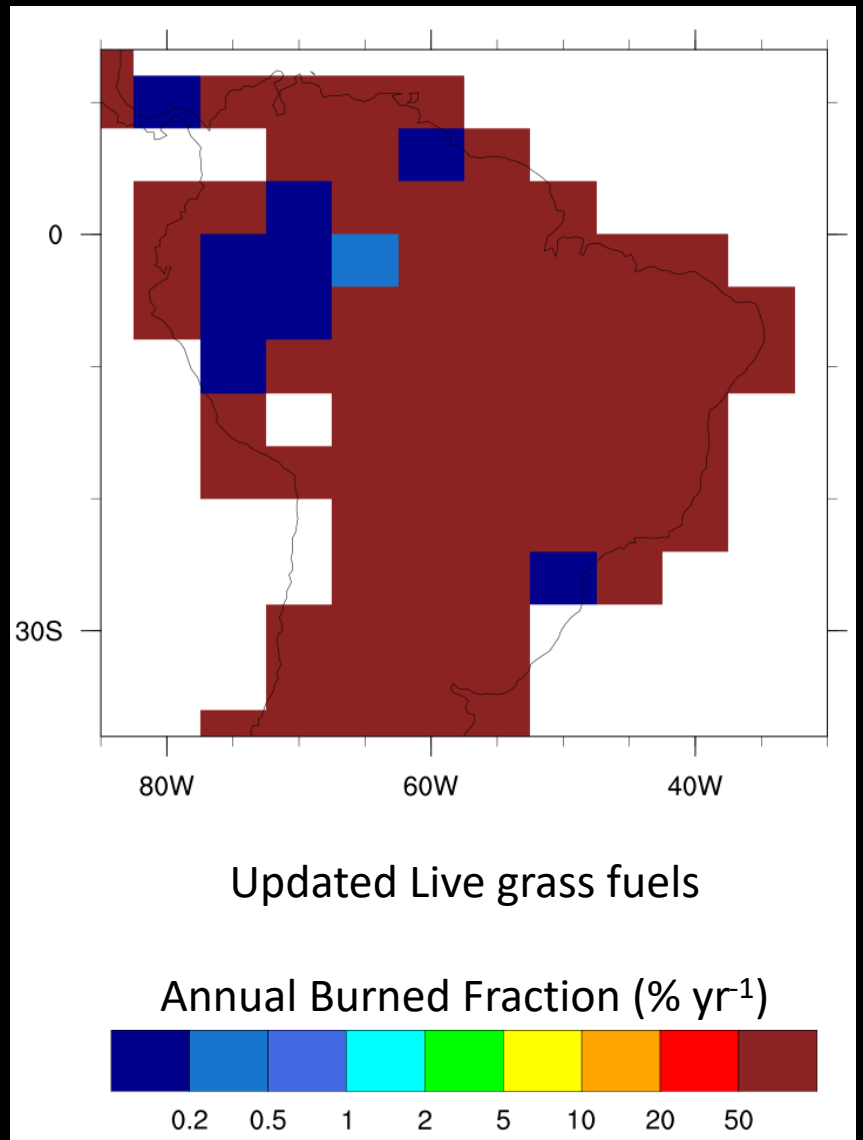
Fire behavior is worse…

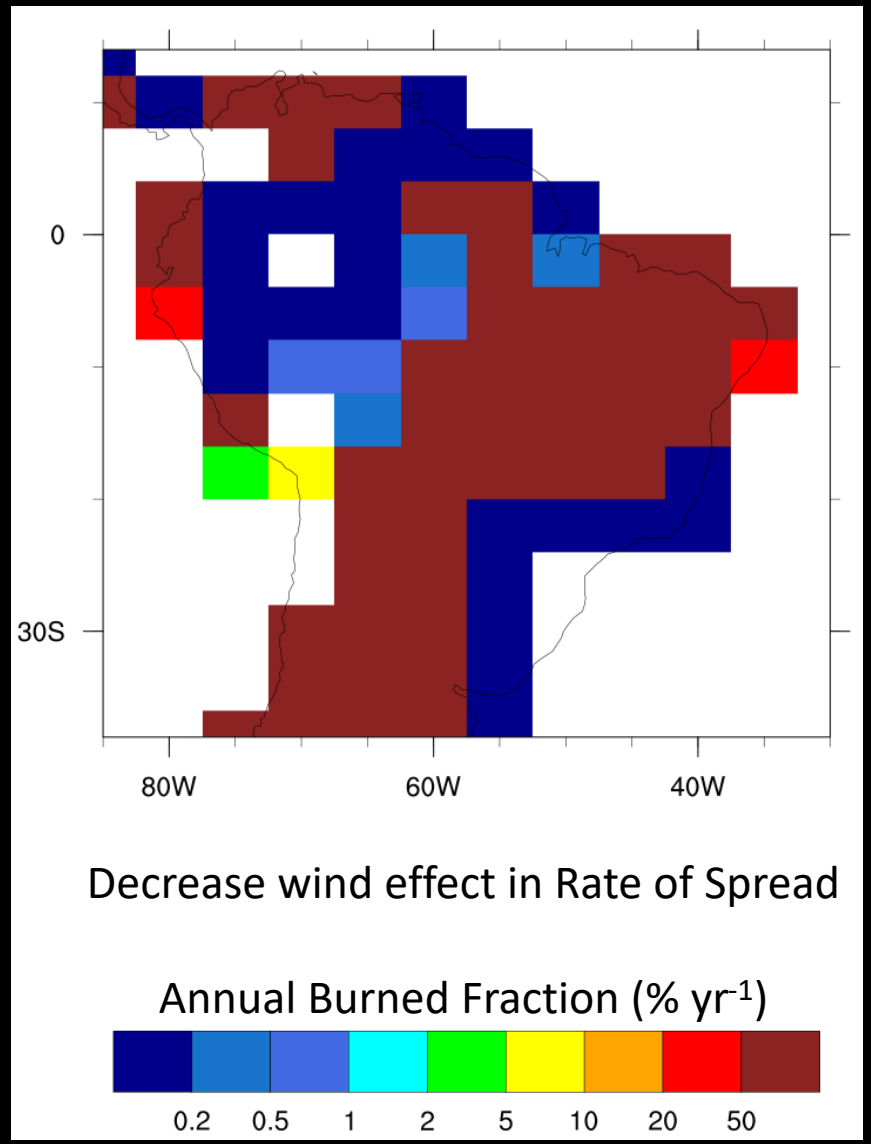




- Look at fire behavior equations for rate of spread
- Influence of vegetation fraction on wind and fire behavior?

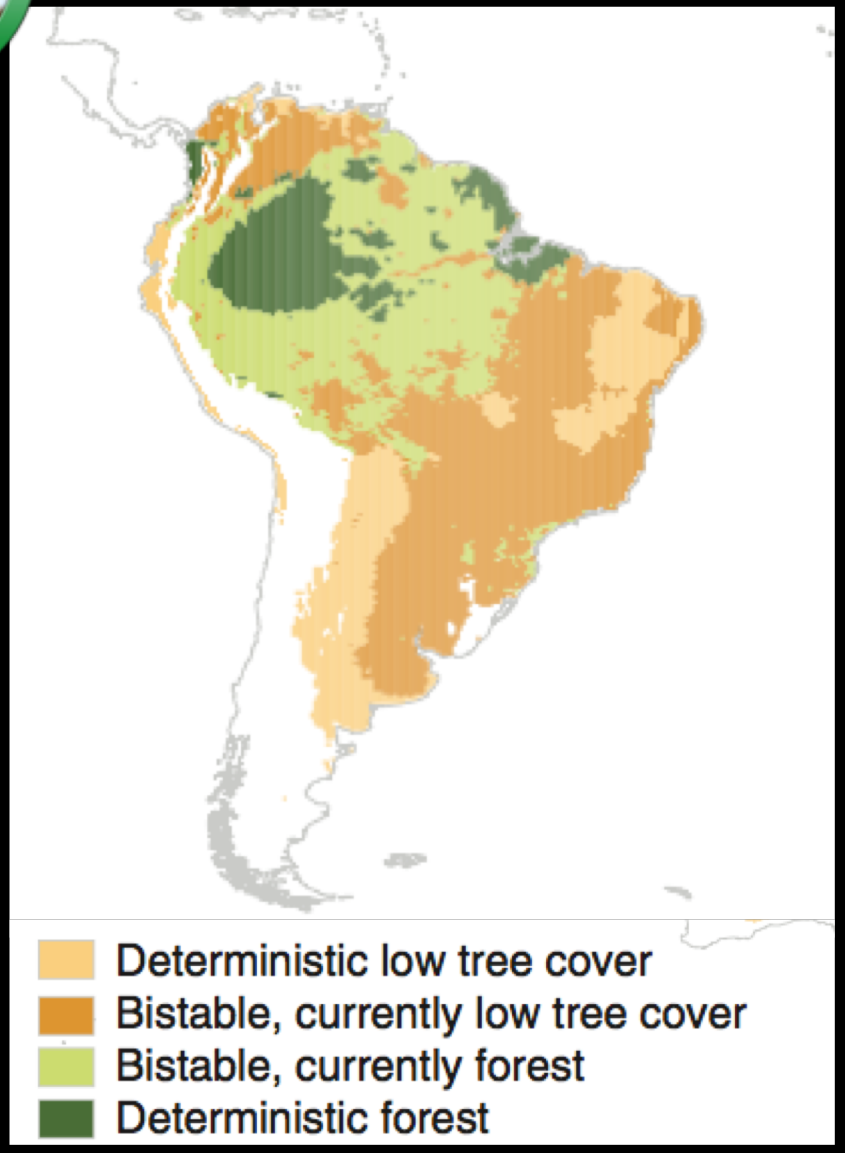
Fire Behavior: Wind effect on rate of spread

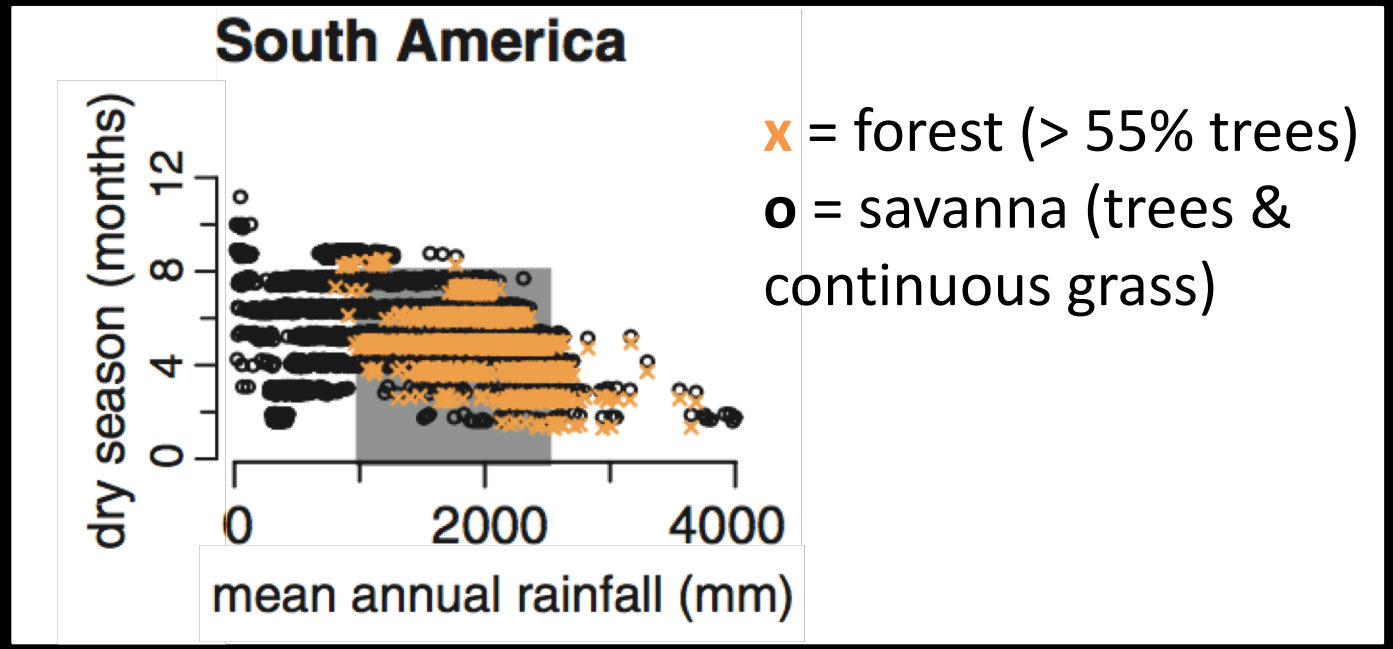




- Decrease wind effect in rate of spread calculation
- Rate of spread determines burned area, fire duration, and vegetation mortality
- All influence balance of trees and grasses

Forest/Savanna bi-stability





x = forest (> 55% trees)
o = savanna (trees & continuous grass)

Important Factors:

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

Staver *et al.* 2011 *Science*

Can we capture forest/savanna bi-stability?

Trees & Grass + 50 years →

Trees & Grass + Fire →

- 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

Fire-free period

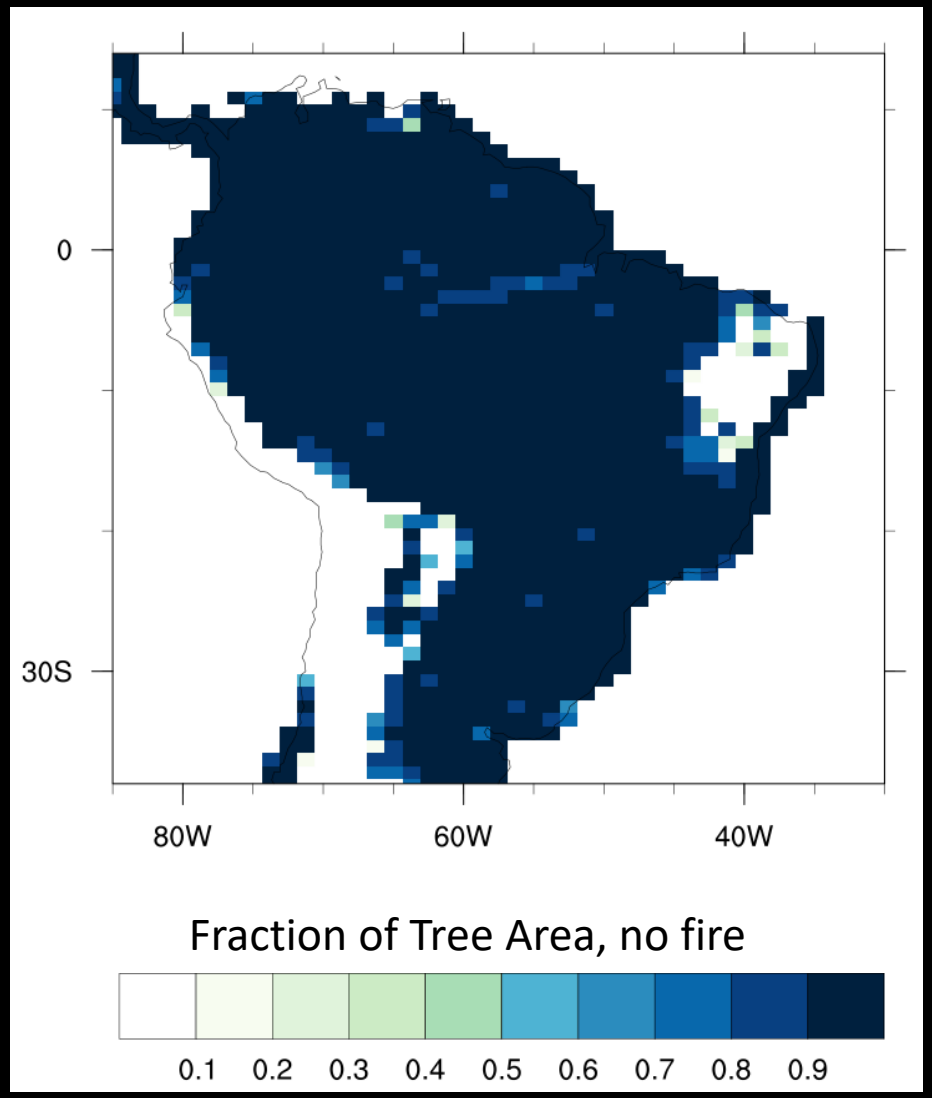
Trees & Grass + 10 years + Fire 50 years →

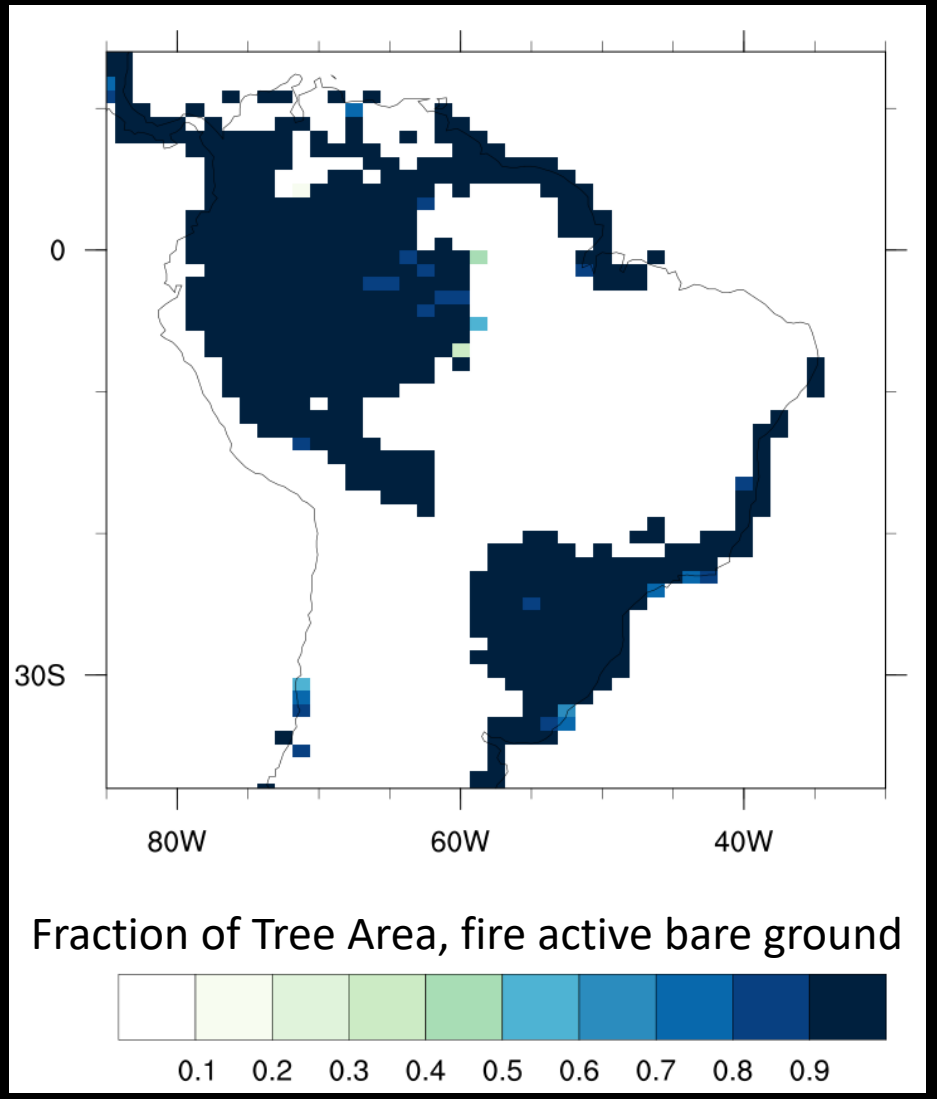
+ 20 years + Fire 50 years →

Model version:
Modified Wind effect on rate of spread
(includes updated live grass fuel moisture)

Fire acts to limit tree cover

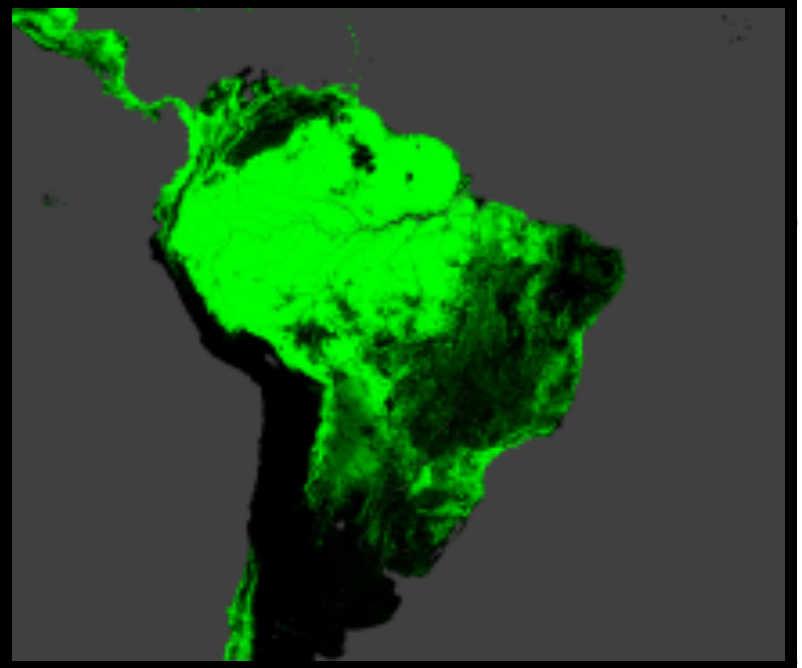
Model version:
Modified Wind effect on rate of spread
(includes updated live grass fuel moisture)





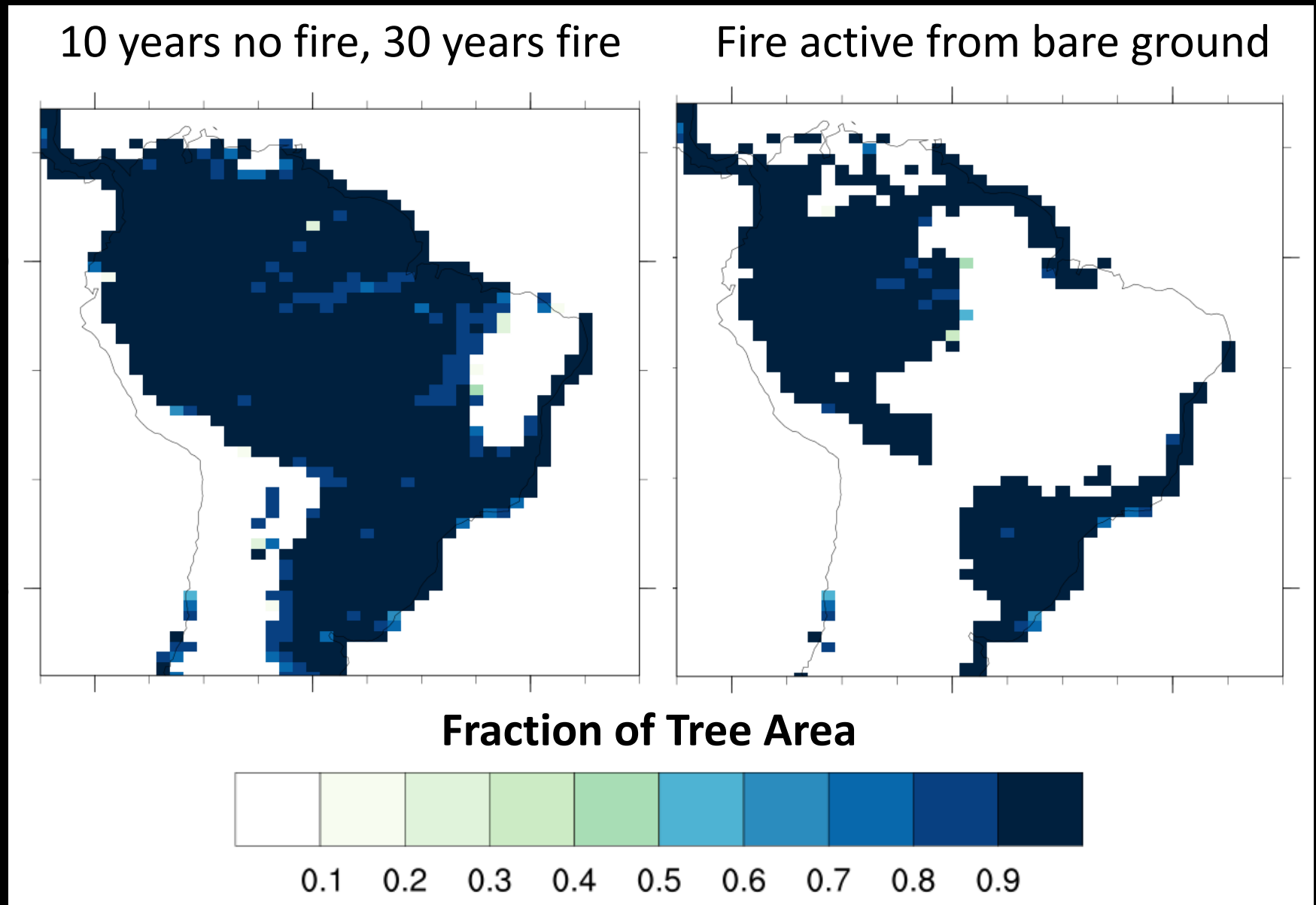
- 50 years current climate GSWP3 (1991-2010) , Trees and Grass

Initial state is important for tree survival



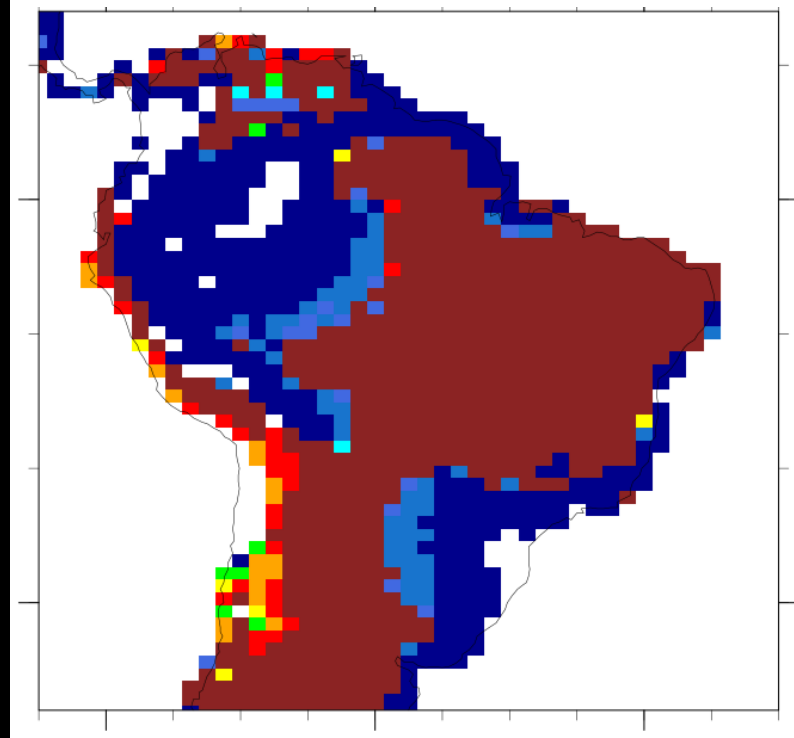
Hansen, M. C., et. al. (2013) *Science*

- Initial fire-free period allows trees to escape "fire-trap" Hoffman et al 2012

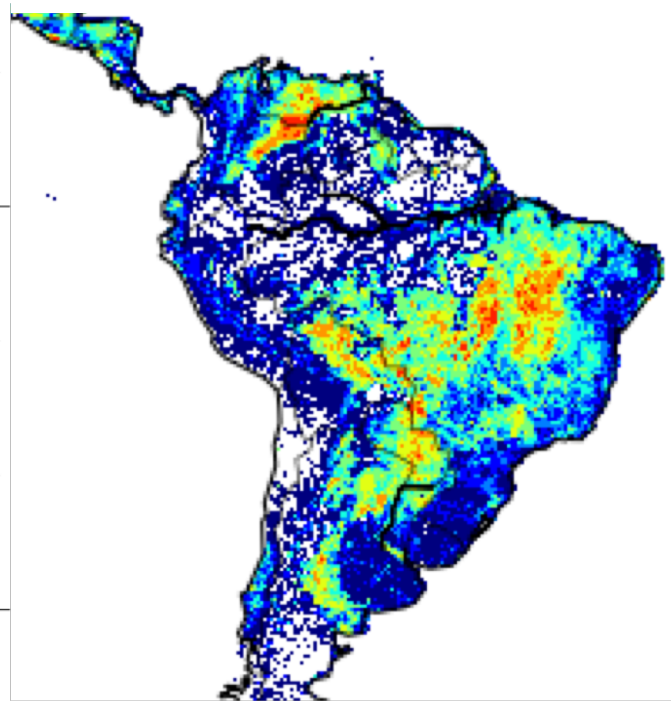


Initial state influences fire behavior

FATES-SPITFIRE
fire active bare ground

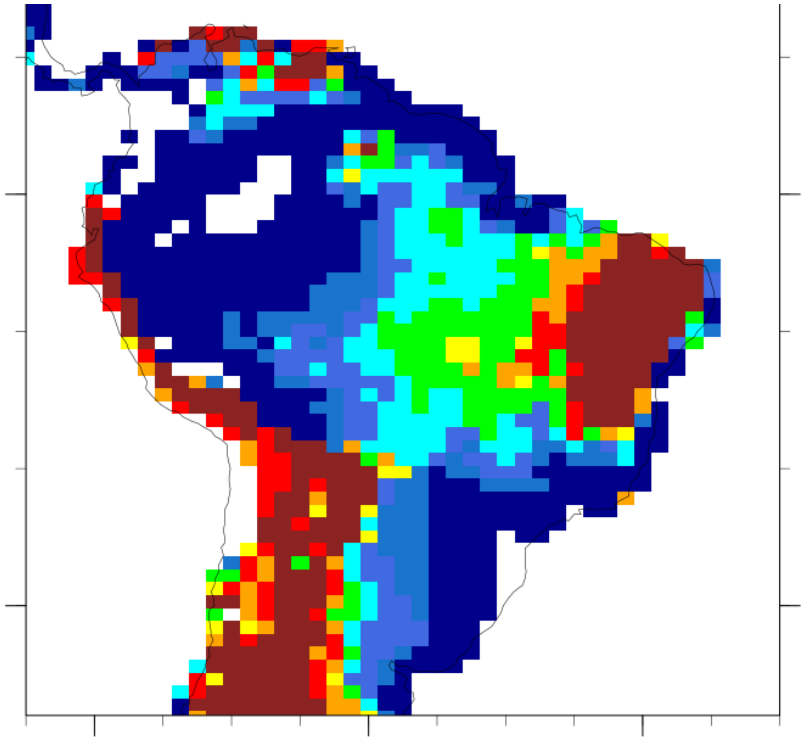


GFED4s
(avg 1997-2014)



Van der Werf *et al.* 2017

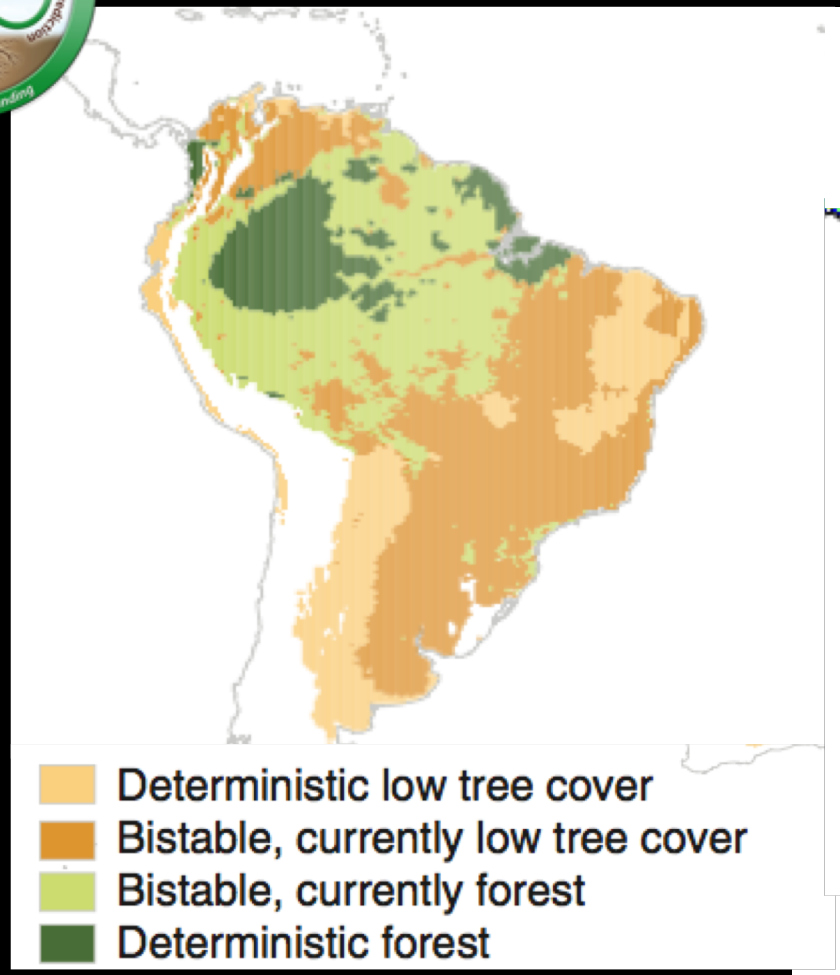
FATES-SPITFIRE
10 years no fire, then fire



- Stable forest areas have low fire
- More fire in forest/savanna bi-stable areas of South America

Annual Burned Fraction (% yr^{-1})

Initial state limits fire in forest/savanna transition



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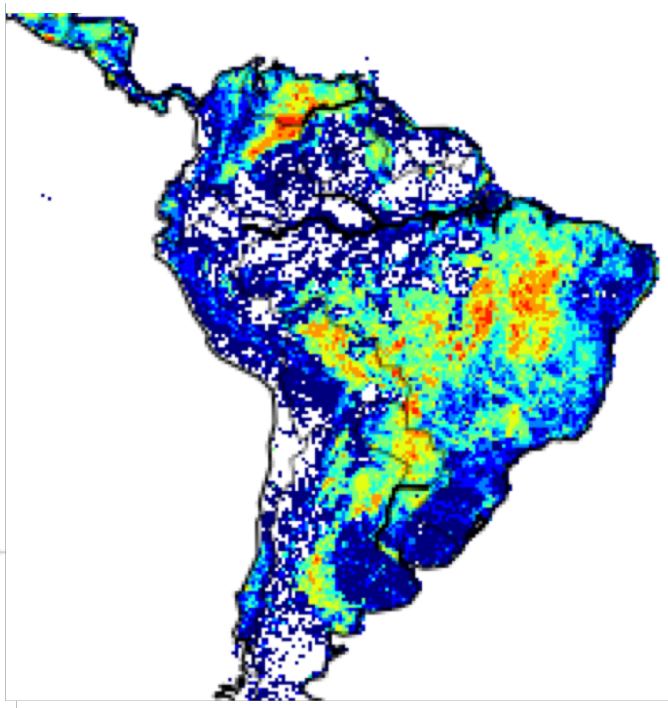

Van der Werf *et al.* 2017

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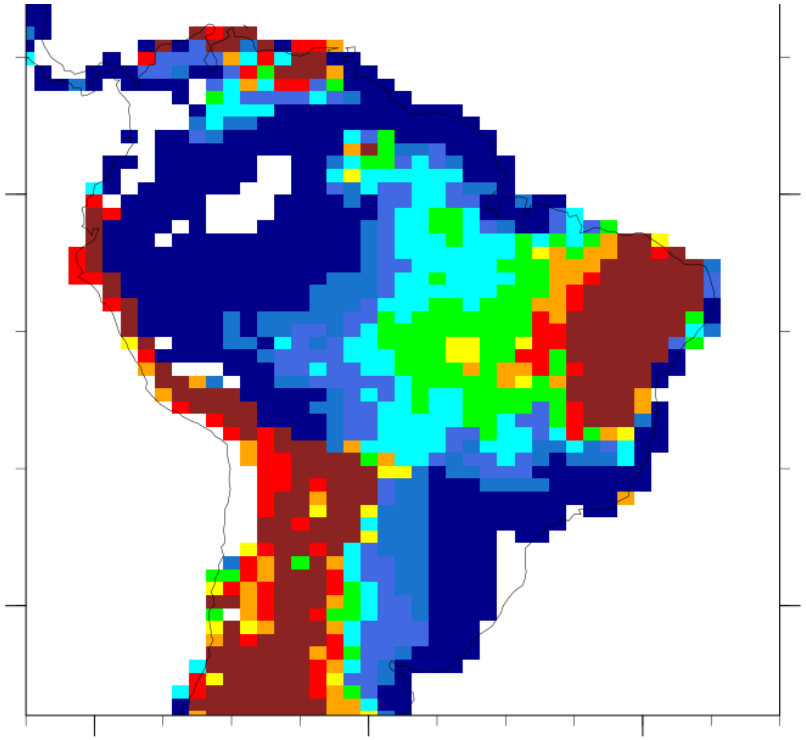
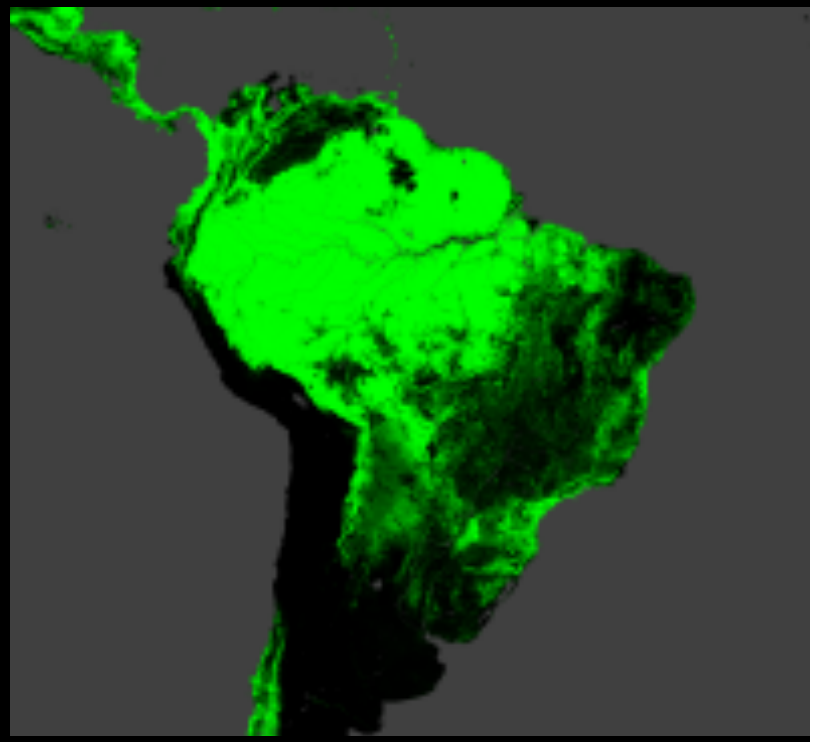


Annual Burned Fraction (% yr^{-1})

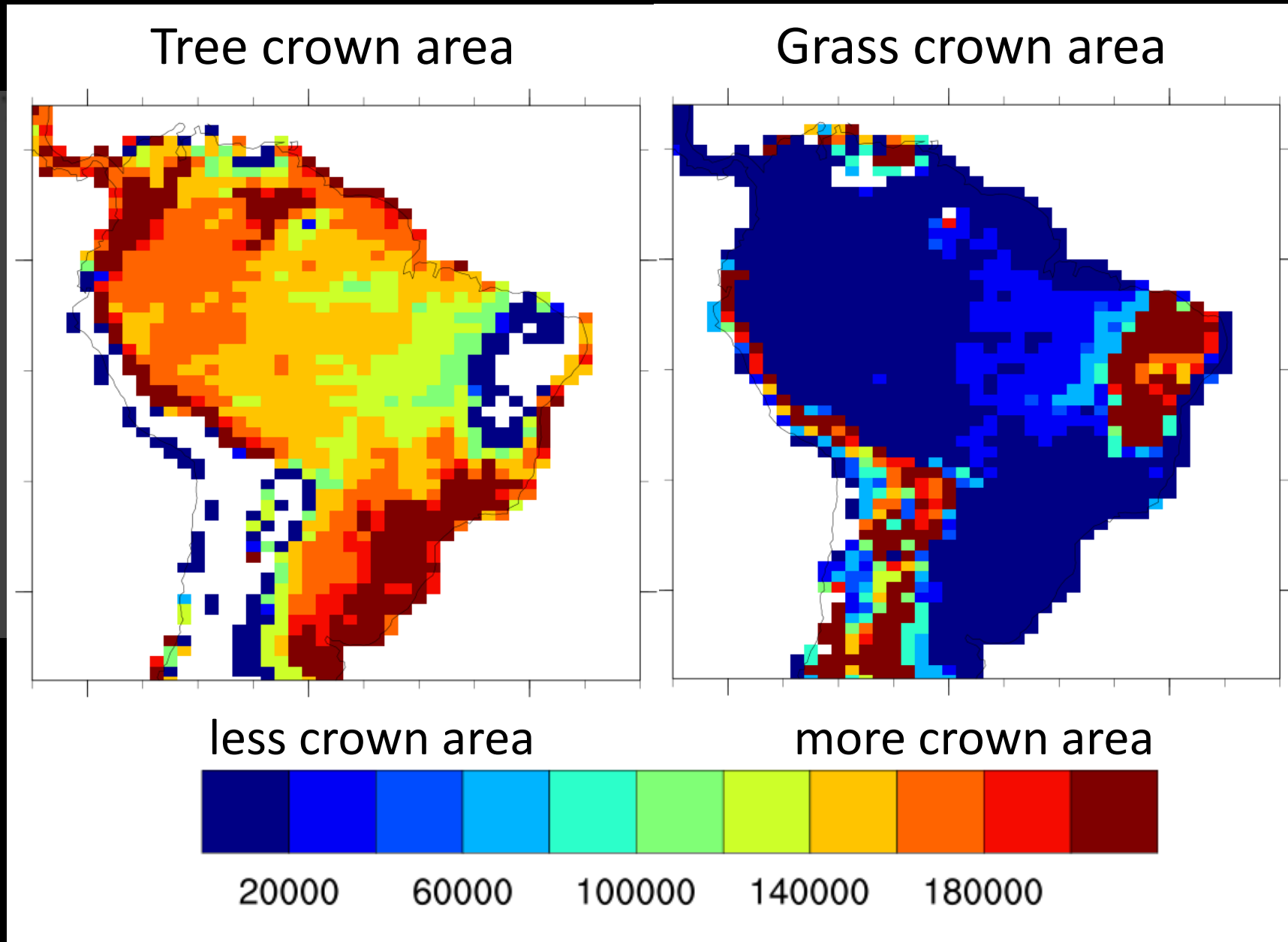
- SPITFIRE captures low fire in stable forest, and more fire in low tree cover areas

Crown area (m^2 per ha) 10 years no fire, then 30 yrs fire



Hansen, M. C., et. al. (2013) *Science*

SPITFIRE captures mixed tree cover in transition areas and grass dominated areas



Conclusion and future directions

- Progress in ability to capture forest savanna transition
- Initial stand structure enhances tree survival
- Grasses drive increased burnt fraction
- Further investigate wind effect on fire behavior

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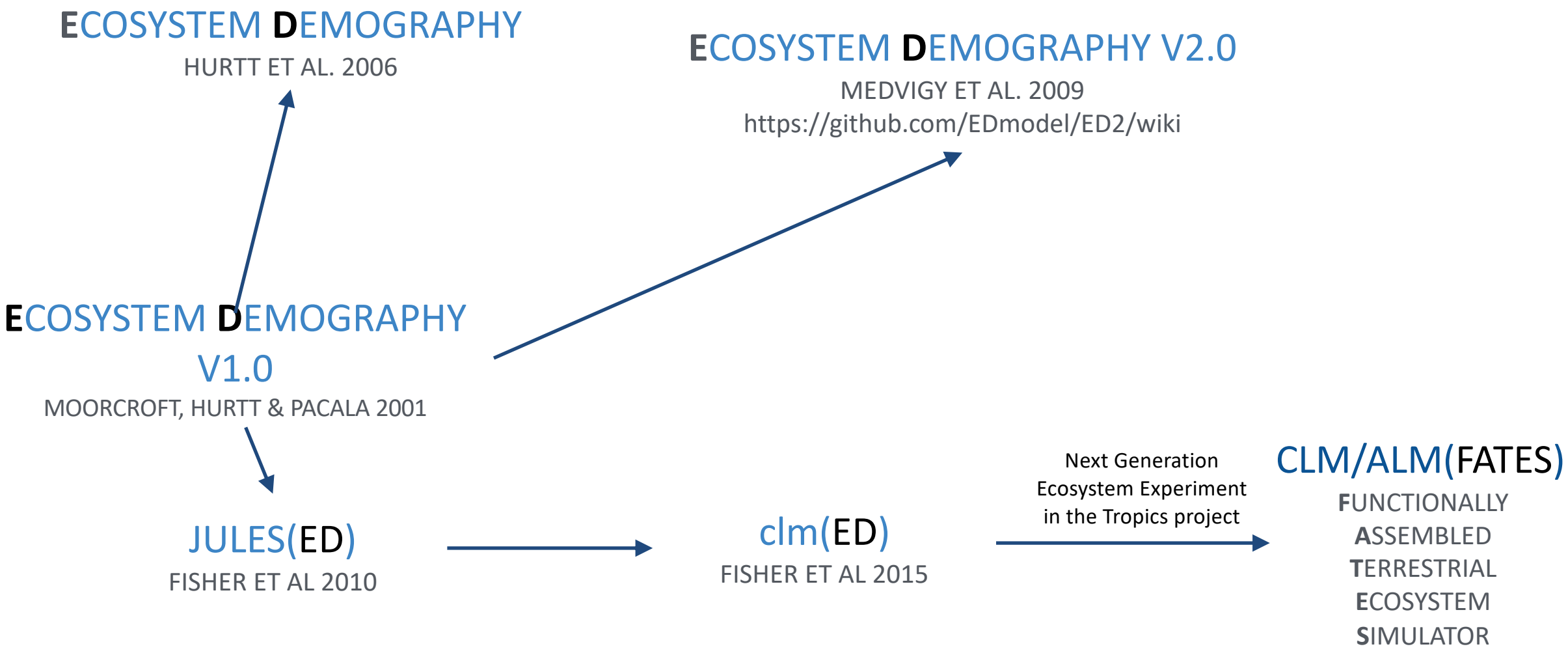
“What is ‘FATES’? Is it the same as ED?”



Fisher et al (2017) “Vegetation Demographics in Earth System Models”. *Global Change Biology*.