CLM Tutorial 2019

Fire in CLM

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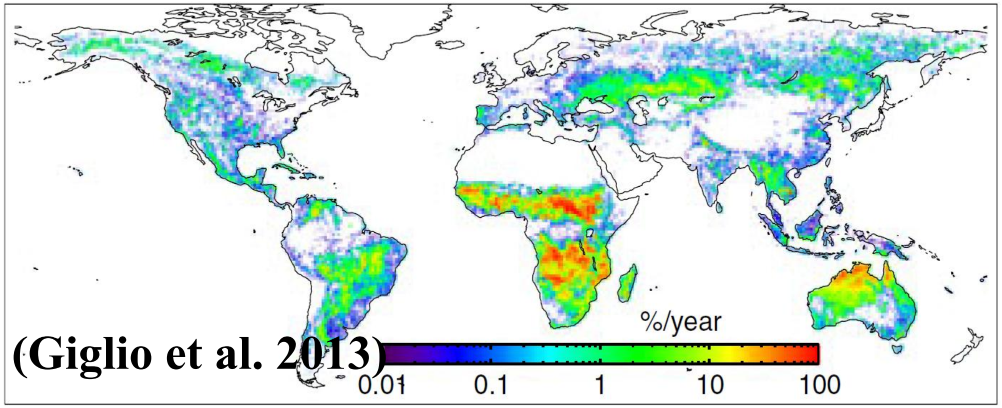
Ack.: S. Levis, X.-D. Zeng, D. M. Lawrence, F. Vitt, M. Val Martin, Q.-C. Zeng, E. Kluzek, B. Sacks, B. Bond-Lamberty, R. E., Dickinson, D. S. Ward

Motivation for fire modeling

Satellite-based annual burned area fraction



(Giglio et al. 2013)

Fire

- **primary form of terrestrial ecosystem disturbance on a global scale (~400 Mha vegetated land area burned each year)**

- **important Earth system process**

- **regulated by:**


weather/climate

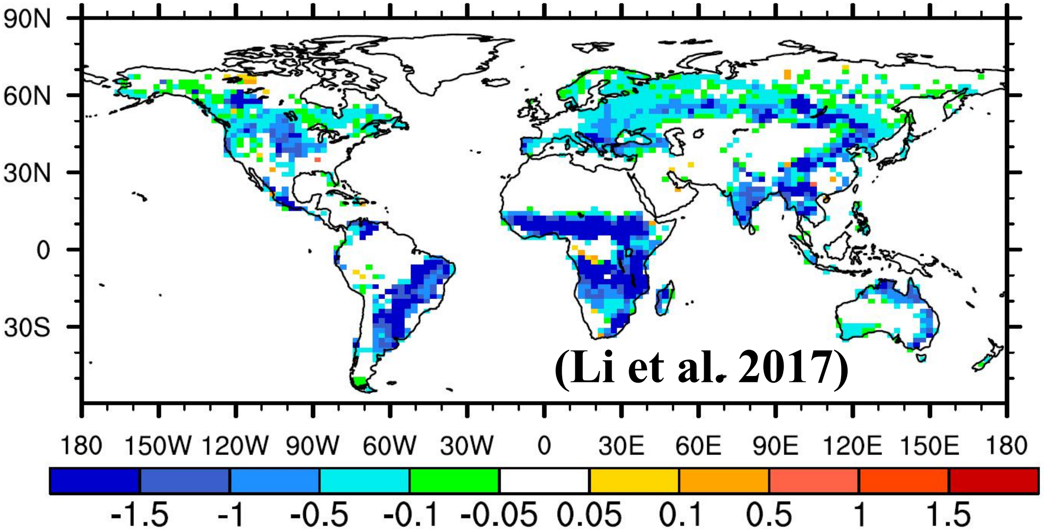
vegetation characteristics


Human activities

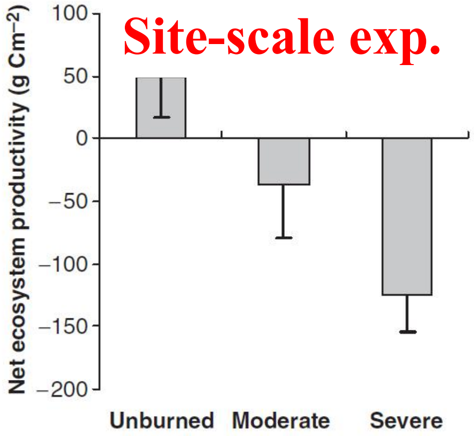
➢ also feeds back to them

• affects ecosystem structure and functioning

Fire decreases LAI

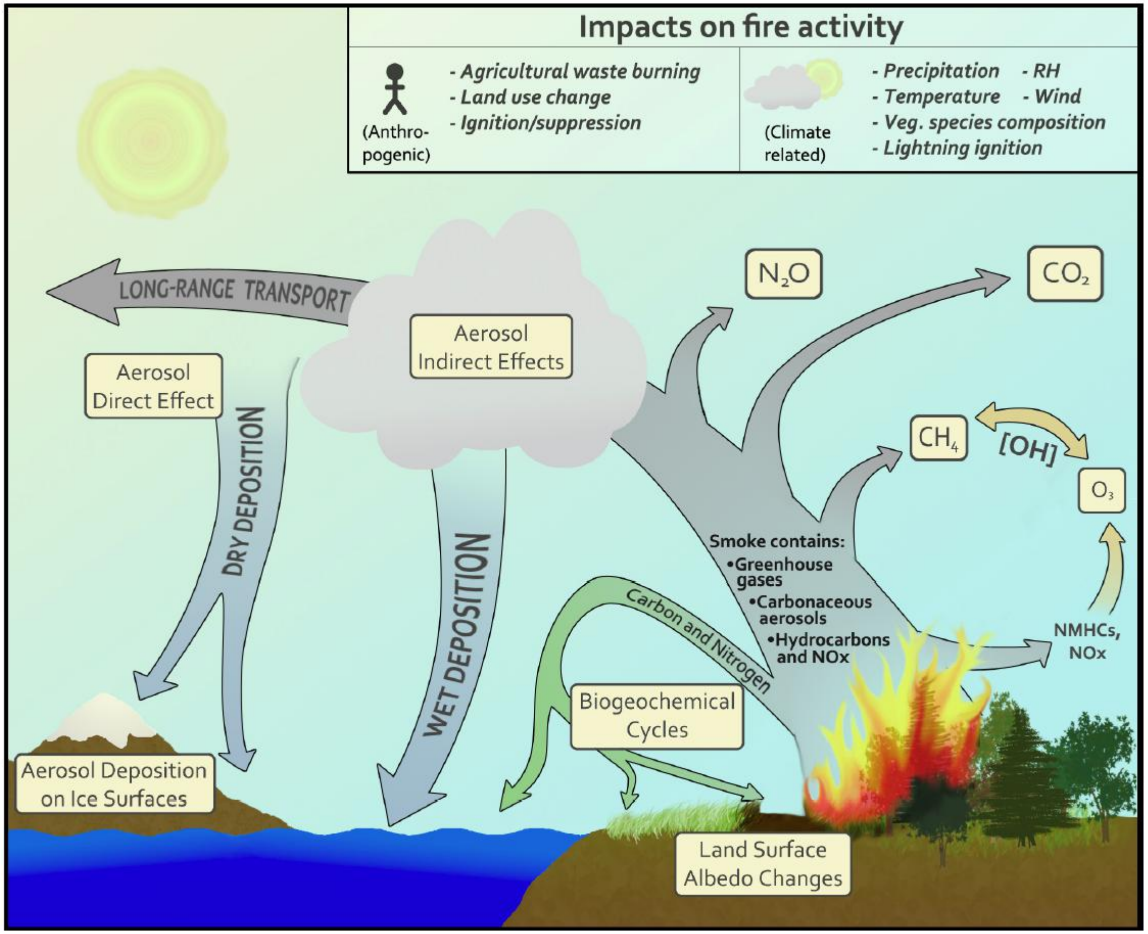


• key component of carbon cycle



Global: fire C emis.: ~2 Pg C/yr (present-day)

• Fire emissions

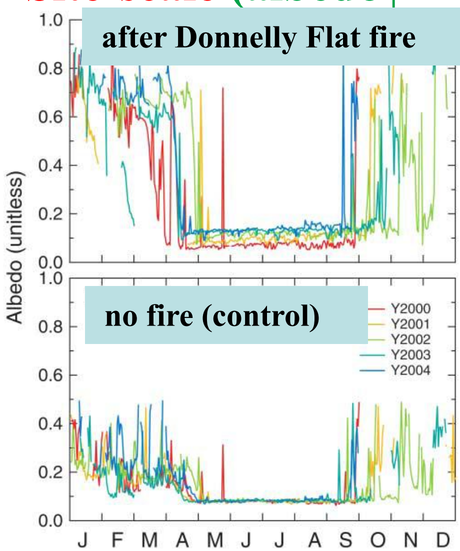


(Ward et al. 2012)

- contain important greenhouse gases (CO_2, CH_4, N_2O)
- modify CH_4 lifetime and increase [O3]
- largest source of primary carbonaceous aerosols globally

• Impact on climate

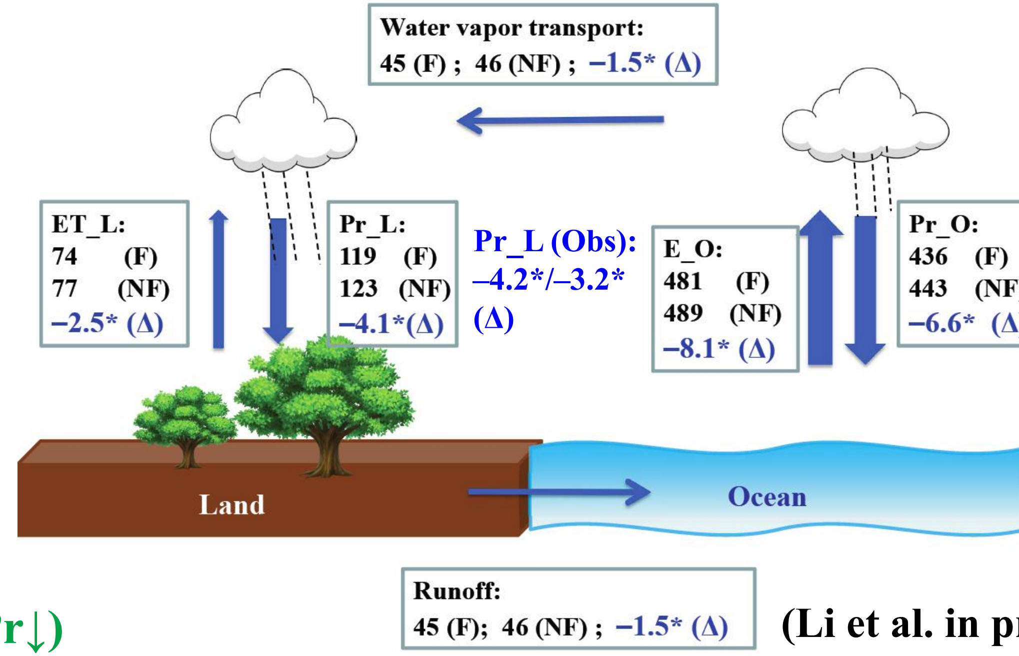
➢ **Site-scale (albedo↑→ Tas↓)**



(Randerson et al. 2006; 146ºW~64ºN)

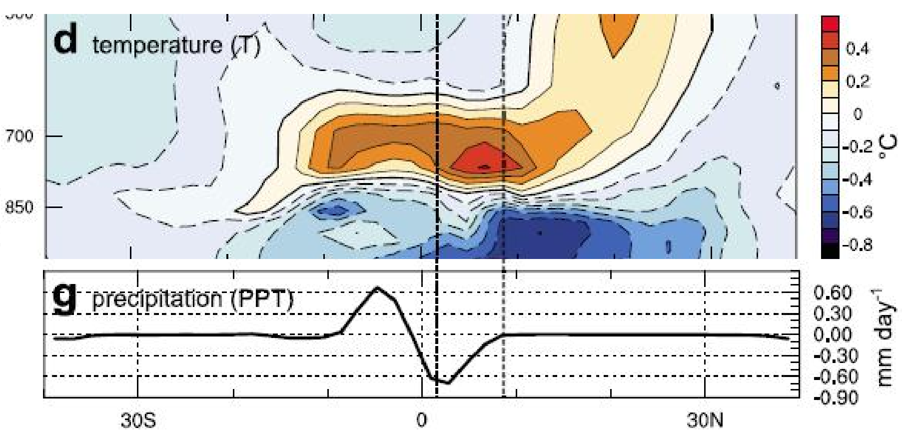
➢ **Global**

fire aerosols spin down global water cycle (Pr inclu.)



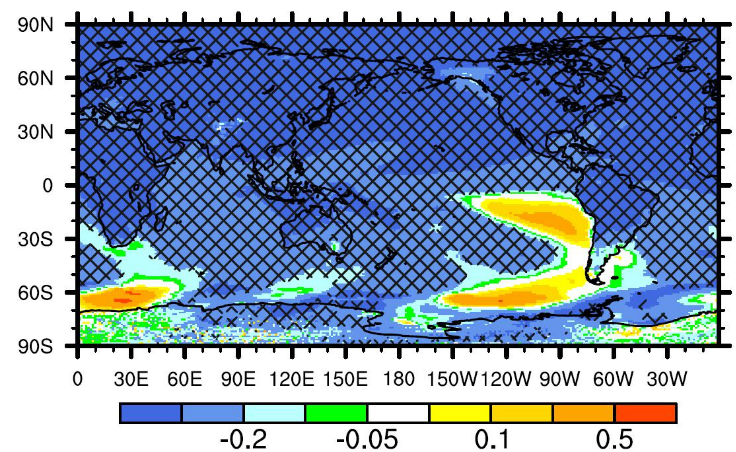
(Li et al. in prep.)

➢ **Regional (fire aerosols ↑→ Tas↓&Pr↓)**



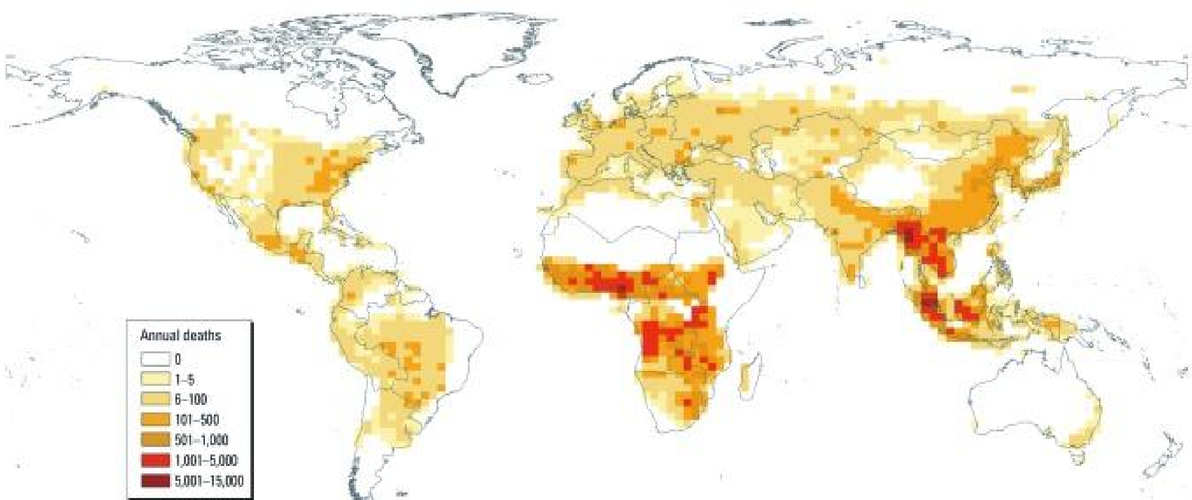
(Tosca et al. 2015; 10ºW~20ºE, 3ºS~10ºN)

fire aerosols decrease Tas



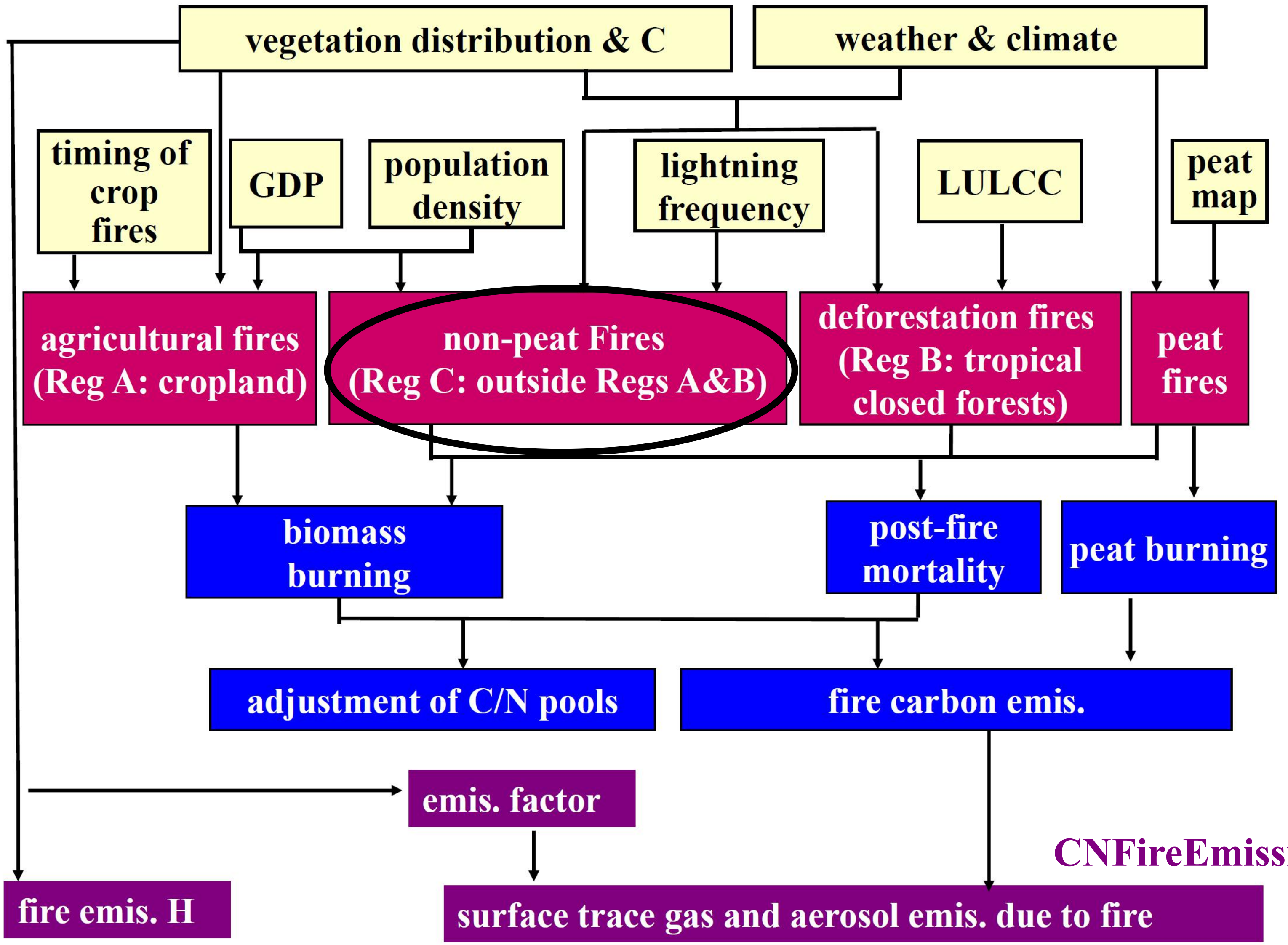
- # Impact on human and animals

estimated ~339,000 pre-mature deaths per year globally caused by fire emissions



(Johnston et al. 2012)

CLM fire scheme



CNFireArea in CNFireLi2016Mod.F90

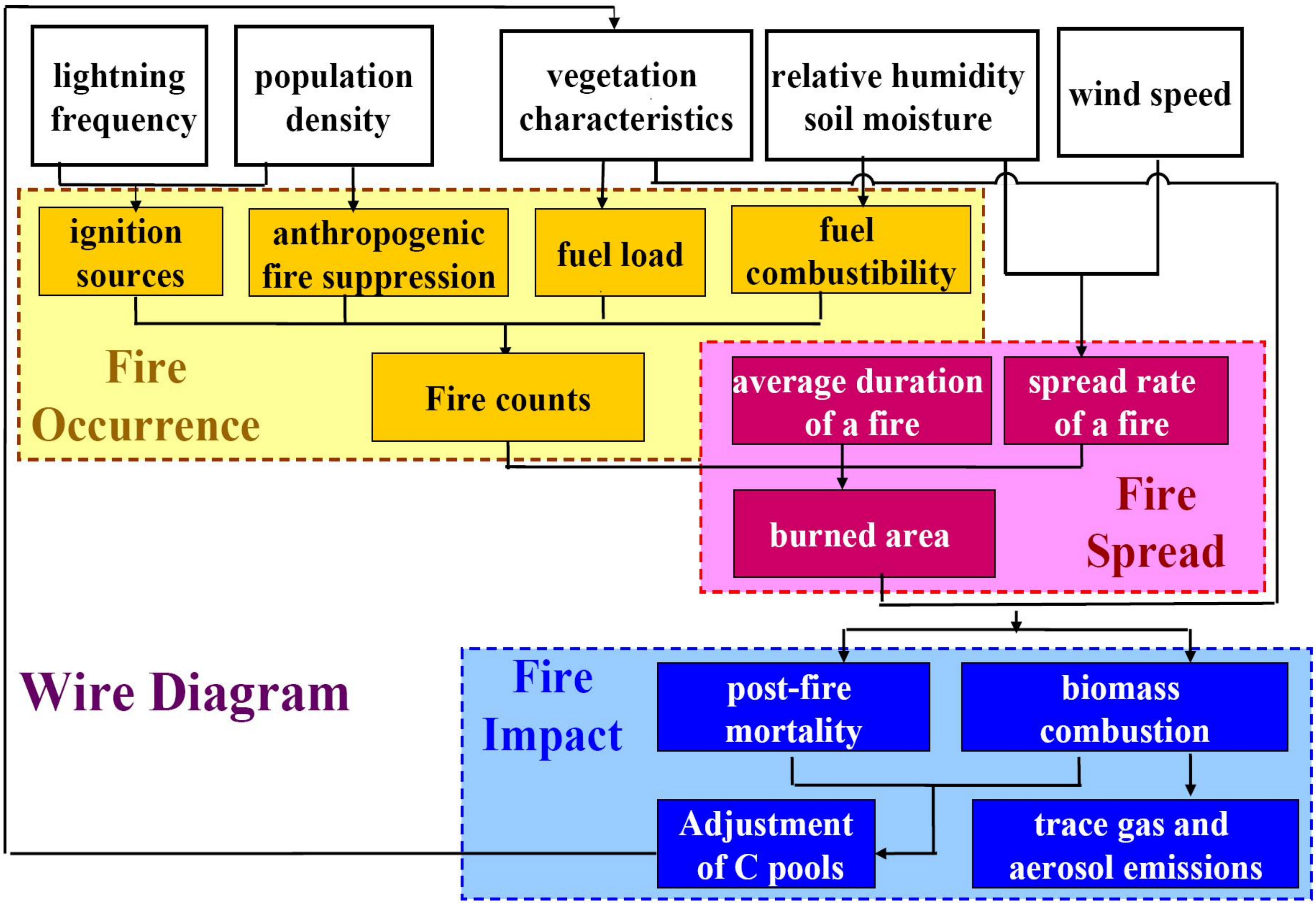
CNFireFluxes in CNFireBaseMod.F90

adjust C/N: CNCStateUpdate3Mod.F90/CNNStateUpdate3Mod.F90

CNFireEmissionsMod.F90

(Li et al. 2012, 2013; Li and Lawrence 2017; CLM5 Tech Note)

Non-peat fires in Reg. C (process-based, Intermediate complexity)



(Li et al. 2012)

•Fire occurrence

Fire counts in a grid cell :

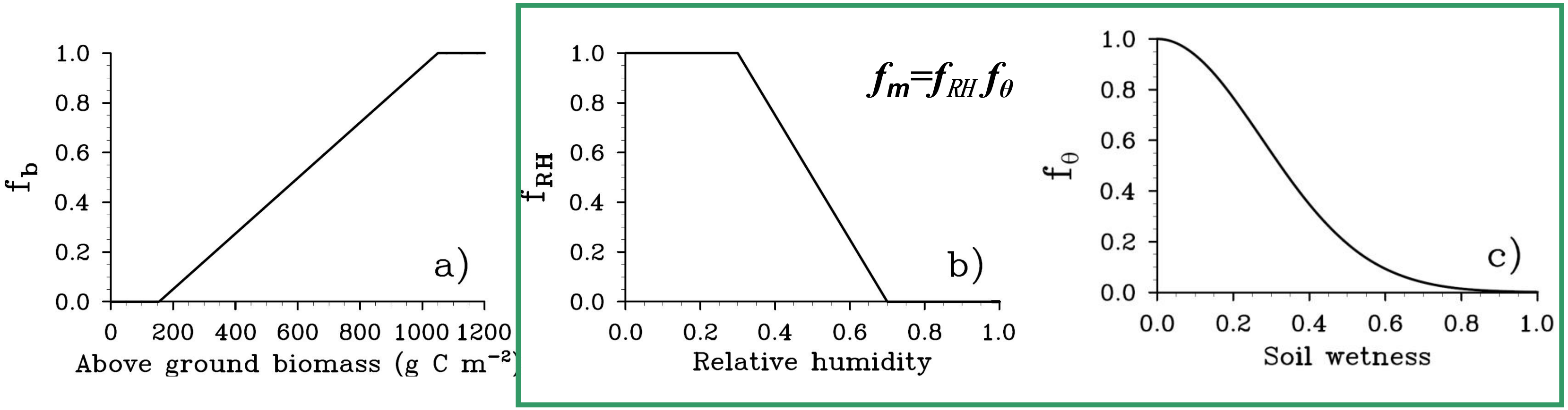
$$N_f = N_i f_b f_m f_{ns,PD} f_{ns,GDP}$$

Ignition counts (N_i) · **Fuel availability** (f_b) · **Fuel combustibility** (f_m) · **Non-suppression rate** ($f_{ns,PD} f_{ns,GDP}$)

Ignition counts: N_i= lightning ignitions + human ignitions

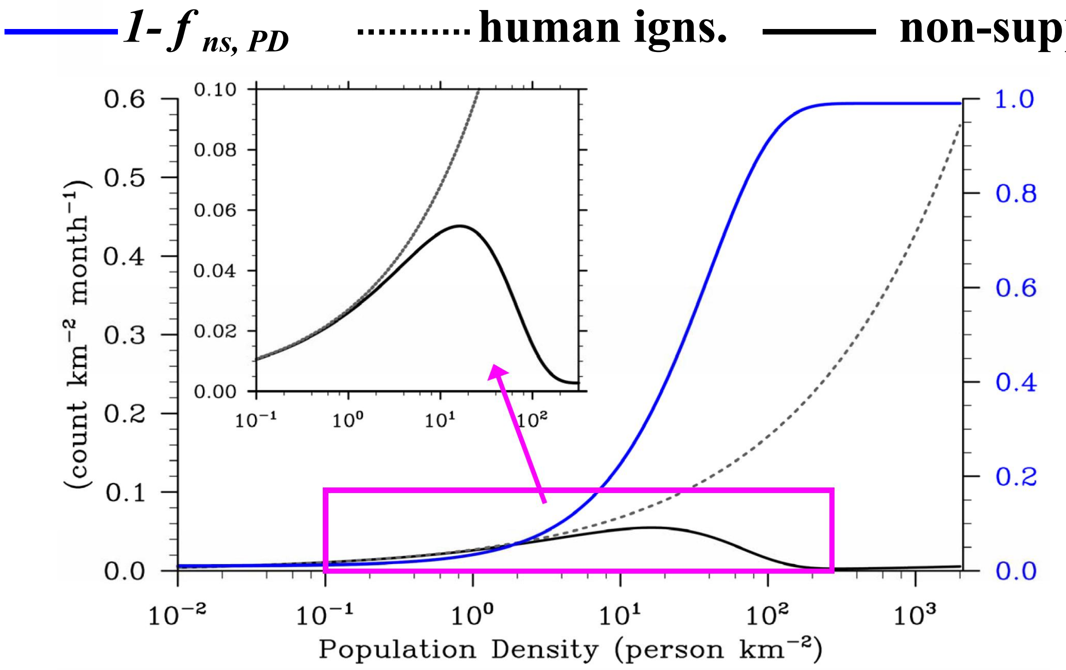
biomass↑→ fuel availability↑

dryer atm & soil→ fuel combustibility↑



(Li et al. 2012, 2013; Li and Lawrence 2017)

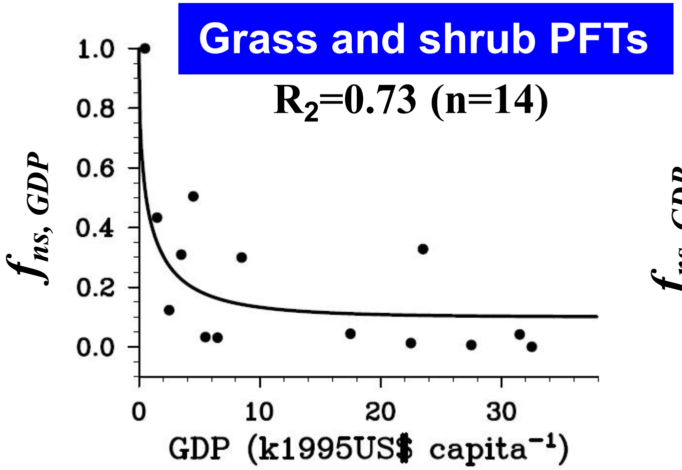
Human ignitions and fire suppression

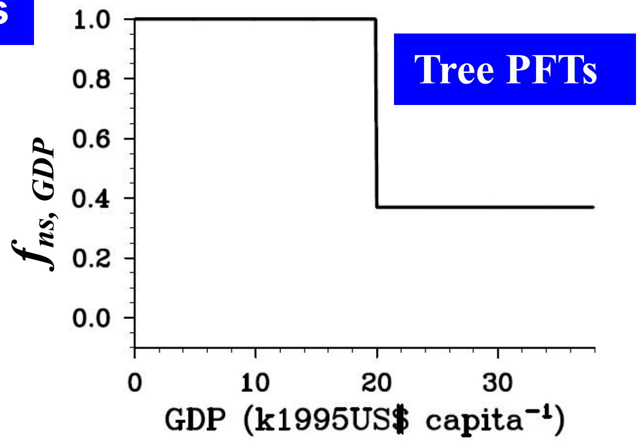


relationship with population density

supported by relationship between MODIS fire counts and HYDE pop. den /GDP

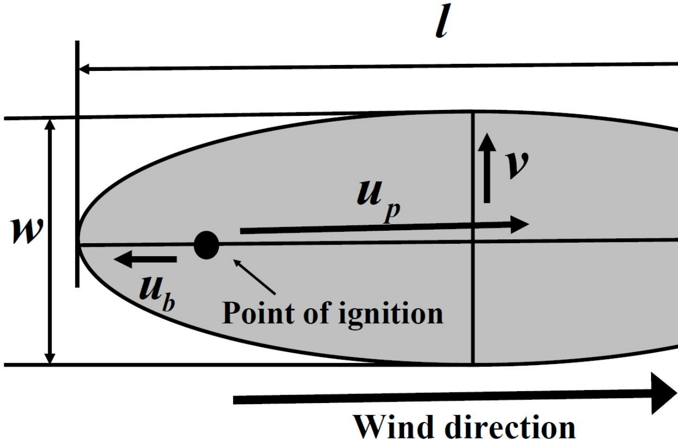
relationship with GDP





(Li et al. 2012, 2013)

• Fire spread



Average potential burned area of a fire (average fire duration τ =1day) :

$$a_1 = \pi \frac{l}{2}\frac{w}{2}\times 10^{-6} = \frac{\pi u_p^2 \tau^2}{4L_B}\left(1+\frac{1}{H_B}\right)^2 \times 10^{-6}$$

Fire spread rate in the downwind direction:

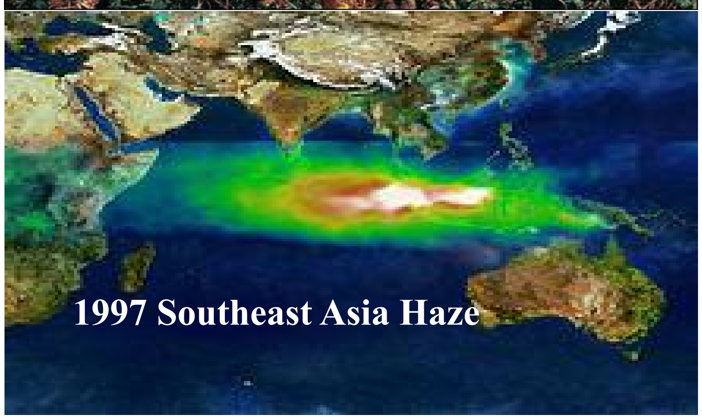
$u_p = f$ **(fuel wetness) g(wind speed)**

Average spread area of a fire

$$a = a_1 F_{ns,\ PD}\ F_{ns,\ GDP}$$

More developed /densely populated → higher firefightning capability

(Li et al. 2012, 2013)



Agricultural fires (Reg. A)

Bruned area frac. Fire seasonality

$$f_{ba} = a\, f_{se}\, f_t\, f_{crop}$$

← Area frac. of cropland

Socioeconomic factor

Deforestation fires (escaped fire inc., Reg. B)

Fuel combustibility

$$f_{ba} = b f_{lu}\, f_{cli,d}$$

Deforestation rate

Peat fires

Fuel combustibility Area frac. of peatland

$$f_{ba} = c f_{cli,p}(1 - f_{sat}) f_{peat}$$

Frac. area with water table at the surface or higher

(Li et al. 2013)

•Fire impact

- **Fire C/N emissions**

C/N pools × combustion completeness factor × burned area frac.

- **Fire-induced veg. mortality**

C/N pools × tissue mortality factor × burned area frac.

- **Adjustment of C/N pools**

Adjusted C/N pools for live veg. tissue= Original C/N pool – C/N loss due to biomass burning and mortality

Adjusted litter and CWD pools =original C/N pools – C/N burning + C/N loss from fire-induced mortality

- **Trace gas and aerosol emissions due to fire (52 species)**

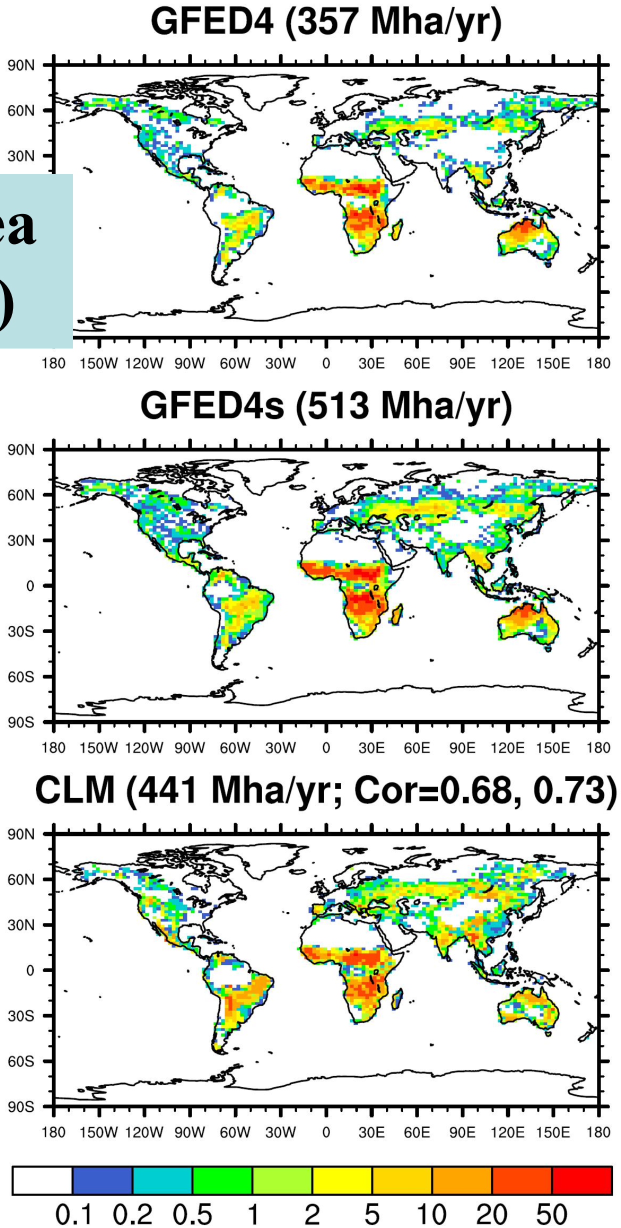
Fire C emis. × emission factors (EFs)

Emission height (top of vertical fire emissions distribution): depends on vegetation types

(Li et al. 2012, 2013; Li et al. submitted; Val Martin in prep.; CLM5 Tech Note)

Performance

Burned area (1997-2004)



CLM4.5 with CLM5 fire (for FireMIP)

global total of burned area is between GFED4 and GFED4s (small fires included)

overally reproduce observed global spatial pattern

(Li et al. 2018)

Fire emissions

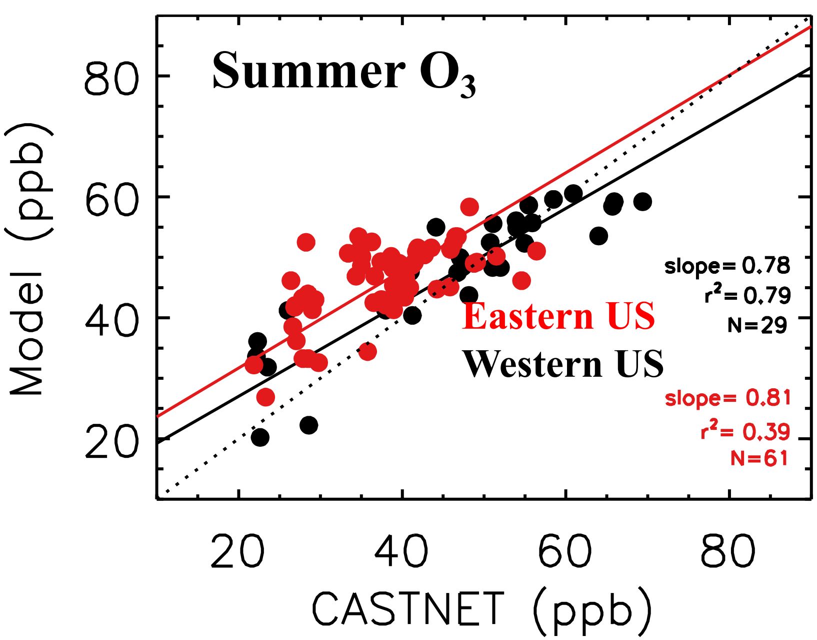
2003-2008
global totals
(units:Pg/yr)

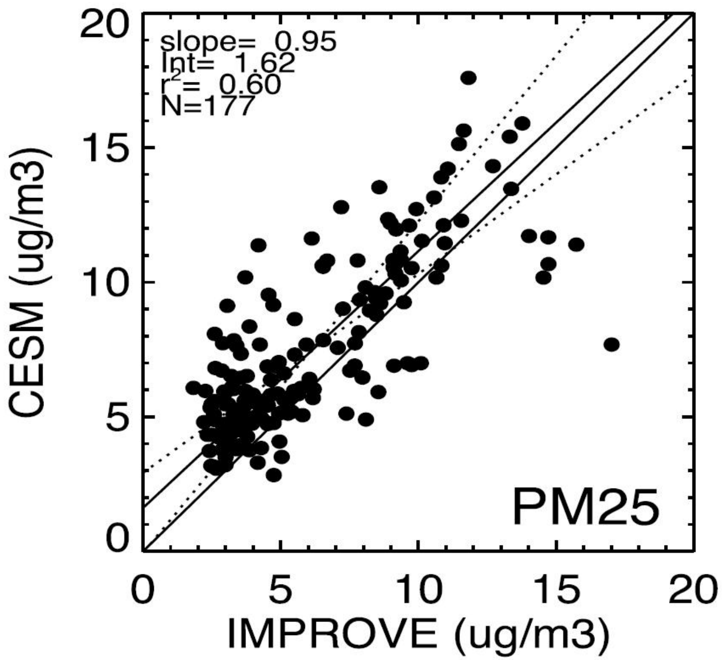
(Li et al. submitt

Source	C	CO_2	CO	CH_4	BC	OC	$PM_{2.5}$
CLM4.5	2.0	6.5	0.34	0.016	0.0022	0.018	0.037
GFED4	1.5	5.4	0.24	0.011	0.0013	0.012	0.025
GFED4s	2.2	7.3	0.35	0.015	0.0019	0.016	0.036
GFAS1	2.1	7.0	0.36	0.019	0.0021	0.019	0.030
FINN1.5	2.0	7.0	0.36	0.017	0.0021	0.022	0.039
FEER1	4.2	14.0	0.65	0.032	0.0042	0.032	0.054
QFED2.5	----	8.2	0.39	0.017	0.0060	0.055	0.086

America

(Val Martin
et al. in prep.)





- # Interannual variability

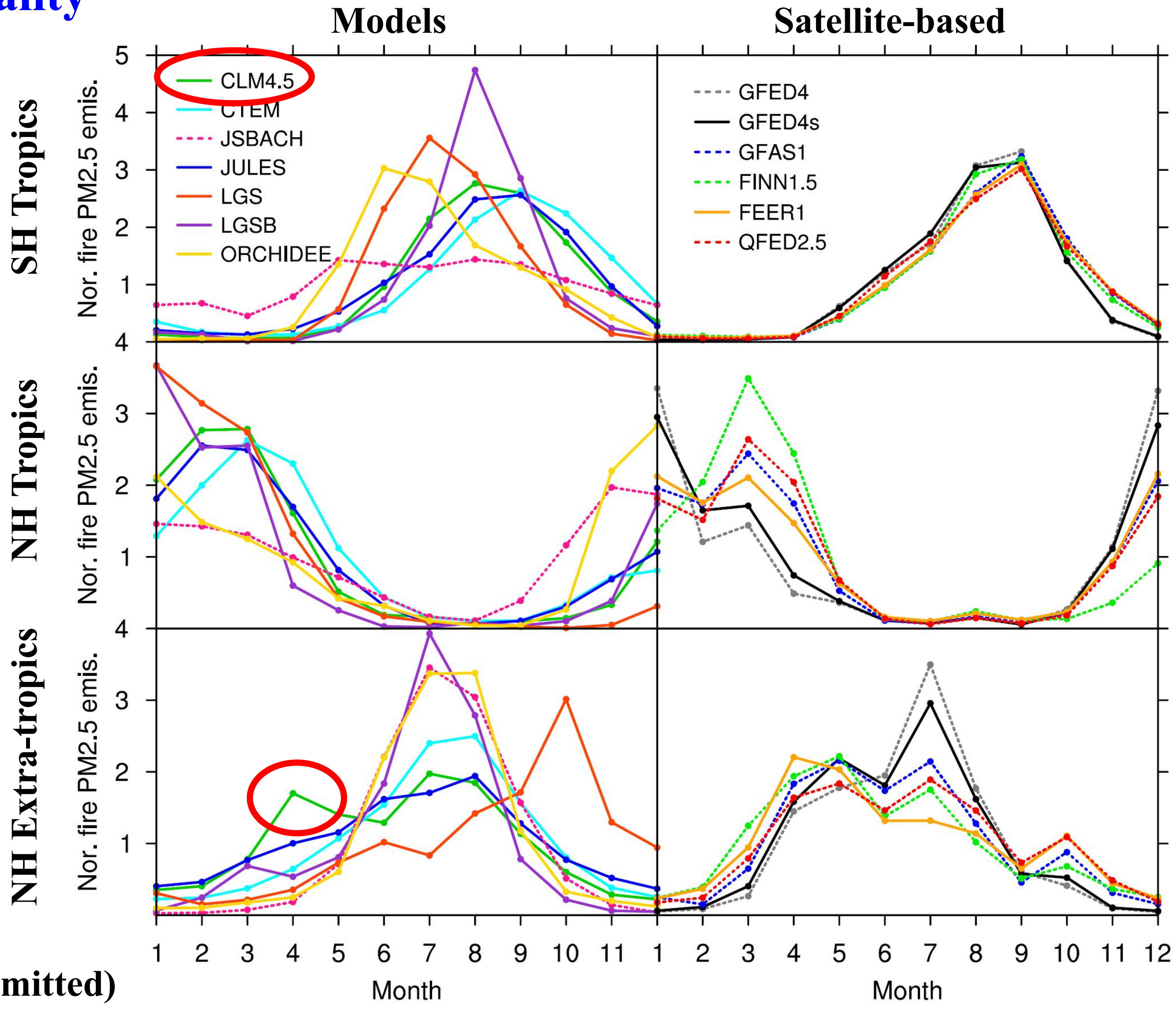
Temporal correlation of annual global fire PM2.5 emissions between FireMIP models and satellite-based products , *, **, ** for 0.1, 0.05, 0.01 sig. lev.**

DGVMs	GFED4	GFED4s	GFAS1	FINN1.5	FEER1	QFED2.5
CLM4.5	0.72***	0.82***	0.59**	0.60*	0.56*	0.53*
CTEM	0.48*	0.49*	0.61**	0.59*	0.51	0.68**
JSBACH-SPITFIRE (JSBACH)	–0.22	–0.47*	0.07	–0.01	–0.04	0.27
JULES-INFERNO (JULES)	0.34	0.33	0.31	0.58*	0.30	0.38
LPJ-GUESS-GlobFIRM (LGG)	0.10	0.07	–0.14	0.07	–0.17	–0.01
LPJ-GUESS-SPITFIRE (LGS)	0.12	0.04	–0.00	0.40	–0.01	0.09
LPJ-GUESS-SIMFIRE-BLAZE(LGSB)	0.42	0.61**	0.22	0.68**	0.57	0.45
ORCHIDEE-SPITFIRE (ORCHIDEE)	–0.16*	–0.26	–0.16	0.28	–0.09	–0.10

Note: 1997-2012 for GFED4 and GFED4s, and 2001-2012 for GFAS1 and QFED2.5, 2003-2012 for FINN1.5 and FEER1

(Li et al. submitted)

- **Seasonality**



(Li et al. submitted)

Ongoing works

- dependence of peat/deforestation fires on climate
- dependence of deforestation fires on human defor. rate
- estimates of fuel wetness
- emission factors

Future plans

- parameter optimization for regional use
- agricultural fires
- add fire severity

Thanks!

Application of the fire model

- **CAS-ESM (Zeng et al. 2014)**
- **CESM (CLM4.5:Oleson et al. 2013; CLM5: Lawrence et al. submitted)**
- **GFDL-ESM (Rabin et al. 2017)**
- **E3SM (Hoffman et al. 2016)**
- **CanESM (Melton and Arora, 2016)**
- **BCC-CSM (Li et al. in prep.)**
- **DLEM DGVM (Yang et al. 2015)**
- **SSiB (Xue et al. in prep.)**

Related publications

Li, F., Zeng, X.-D., Levis, S., 2012. A process-based fire parameterization of intermediate complexity in a Dynamic Global Vegetation Model. Biogeosciences 9, 2761–2780.

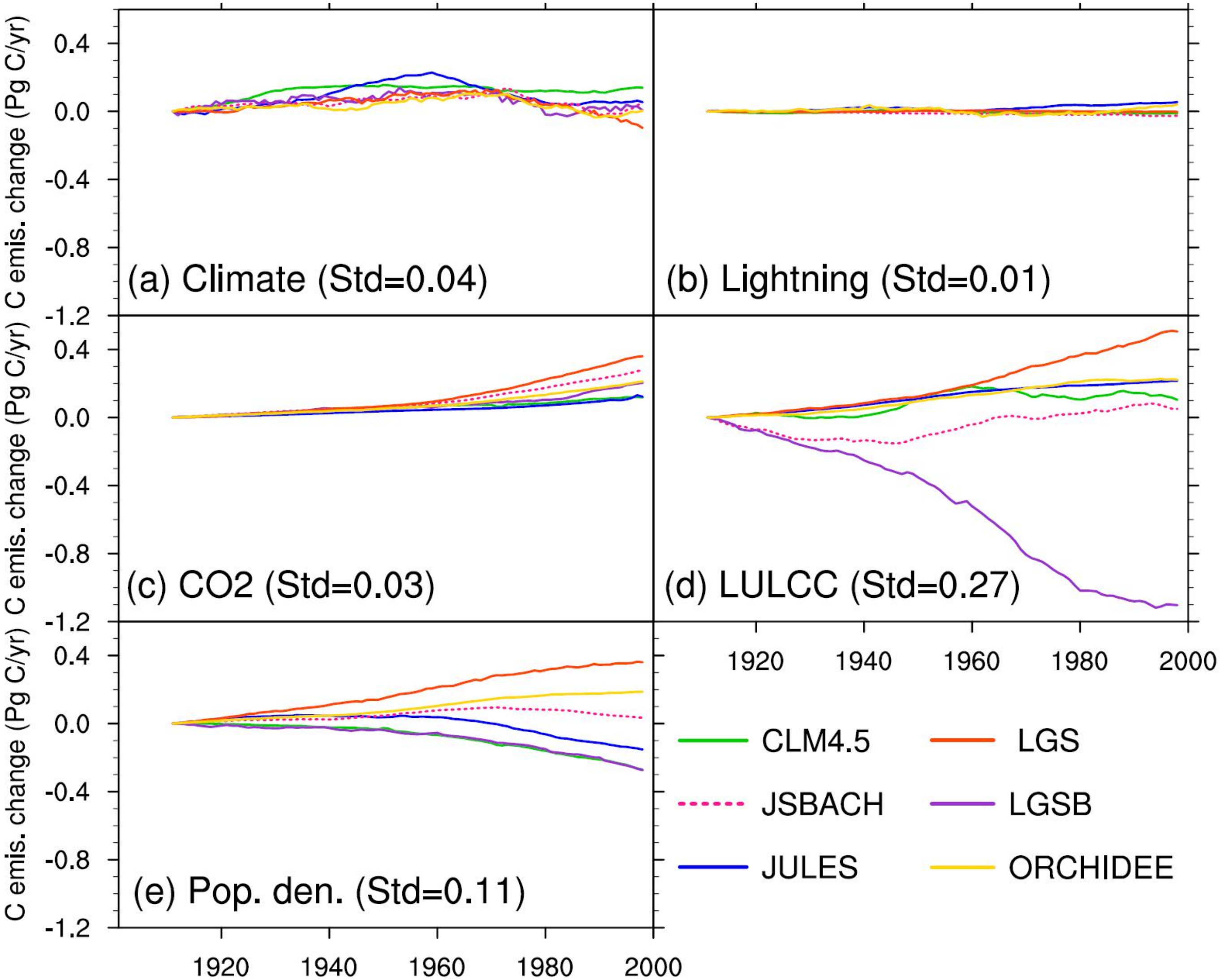
Li, F., Levis, S., Ward, D.S., 2013. Quantifying the role of fire in the Earth system—Part 1: Improved global fire modeling in the Community Earth System Model (CESM1). Biogeosciences 10, 2293–2314.

Li, F., Bond-Lamberty, B., Levis, S., 2014. Quantifying the role of fire in the Earth system—Part 2: Impact on the net carbon balance of global terrestrial ecosystems for the 20th century. Biogeosciences 11, 1345–1360.

Li, F., Lawrence, D.M., 2017. Role of fire in the global land water budget during the 20th century through changing ecosystems. J. Clim. 30, 1893–908.

Li, F., Lawrence, D.M., Bond-Lamberty, B., 2017. Impact of fire on global land surface air temperature and energy budget for the 20th century due to changes within ecosystems. Environ. Res. Let. 12, 044014.

Uncertainty in long-term trends mainly comes from discrepancy in their simulated responses to human pop. density change and land-use and land-cover change (LULCC).



(Li et al. submitted)