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A High-Resolution and Multi-Year Emission Inventory From Biomass Burning in Tropical Continents During 2001-2017

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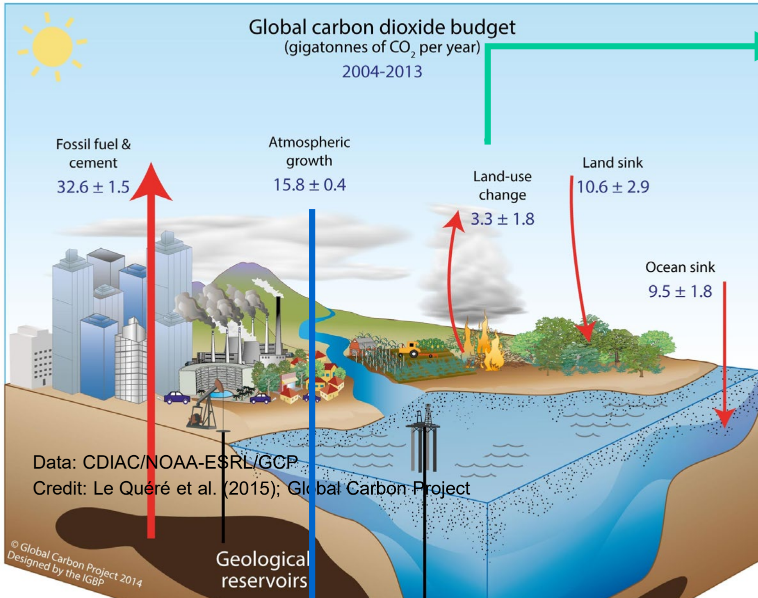
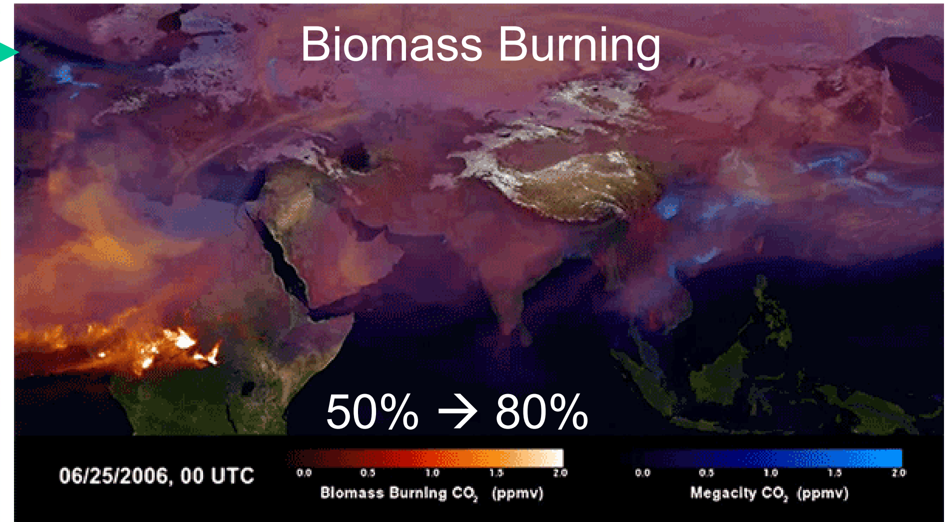
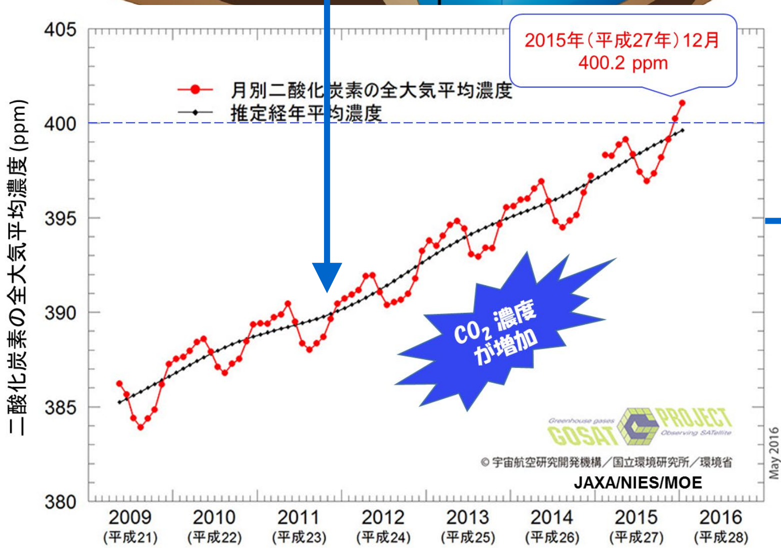
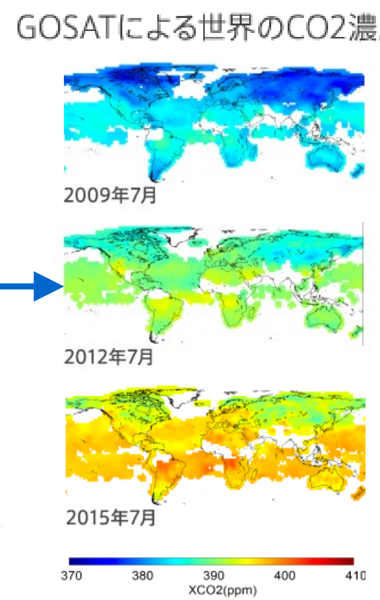
Background

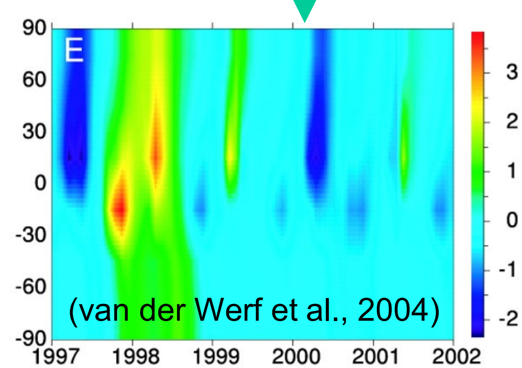
- Global carbon dioxide budget and fire.











Model-simulated CO anomalies caused solely by fire emissions.

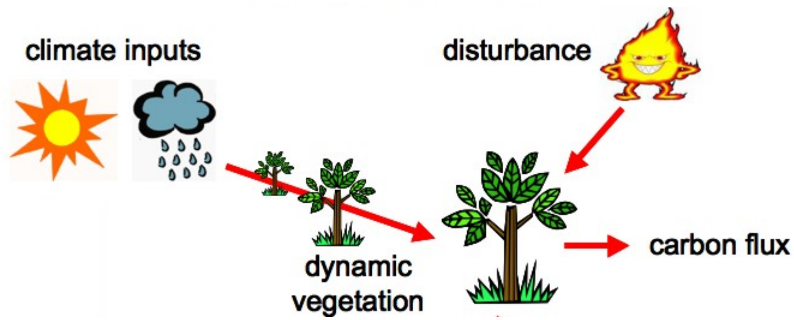
Background

- Fire and biomass burning are unique disturbances on ecosystem processes and dynamics (Carlson et al., 2012).

→ *losses of carbon stored in large terrestrial pools (live vegetation, dead vegetation, litter, organic soil)*

⬇

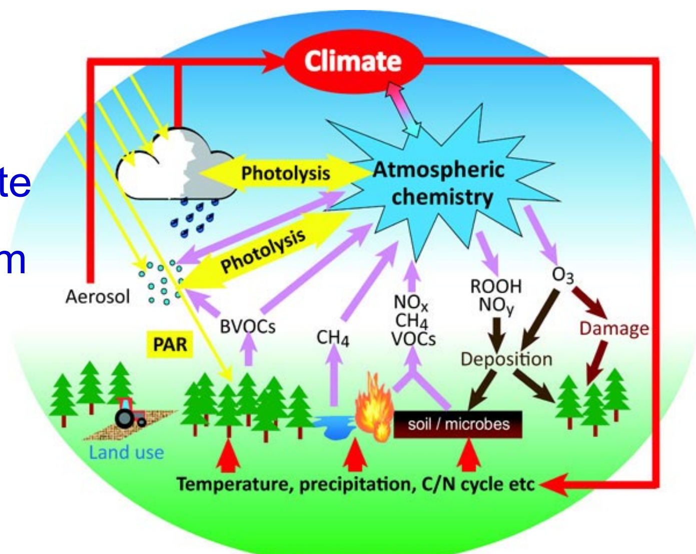
Ecosystem productivity

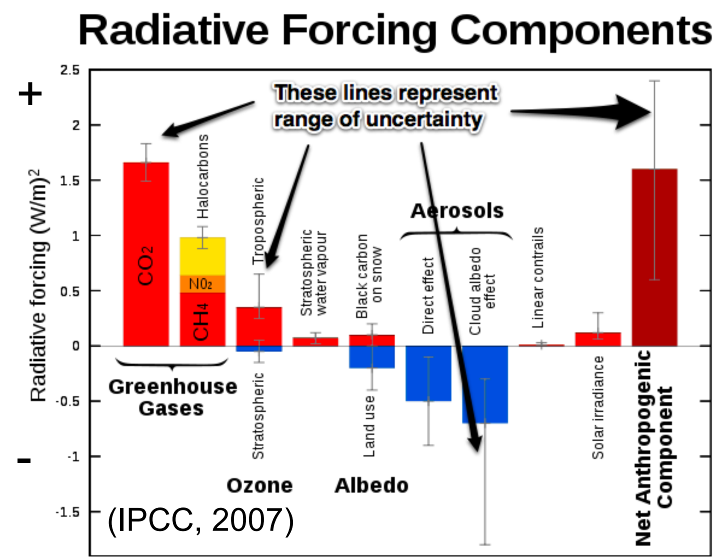


→ *release of huge numbers of greenhouse gases and aerosols into the atmosphere.*

⬇

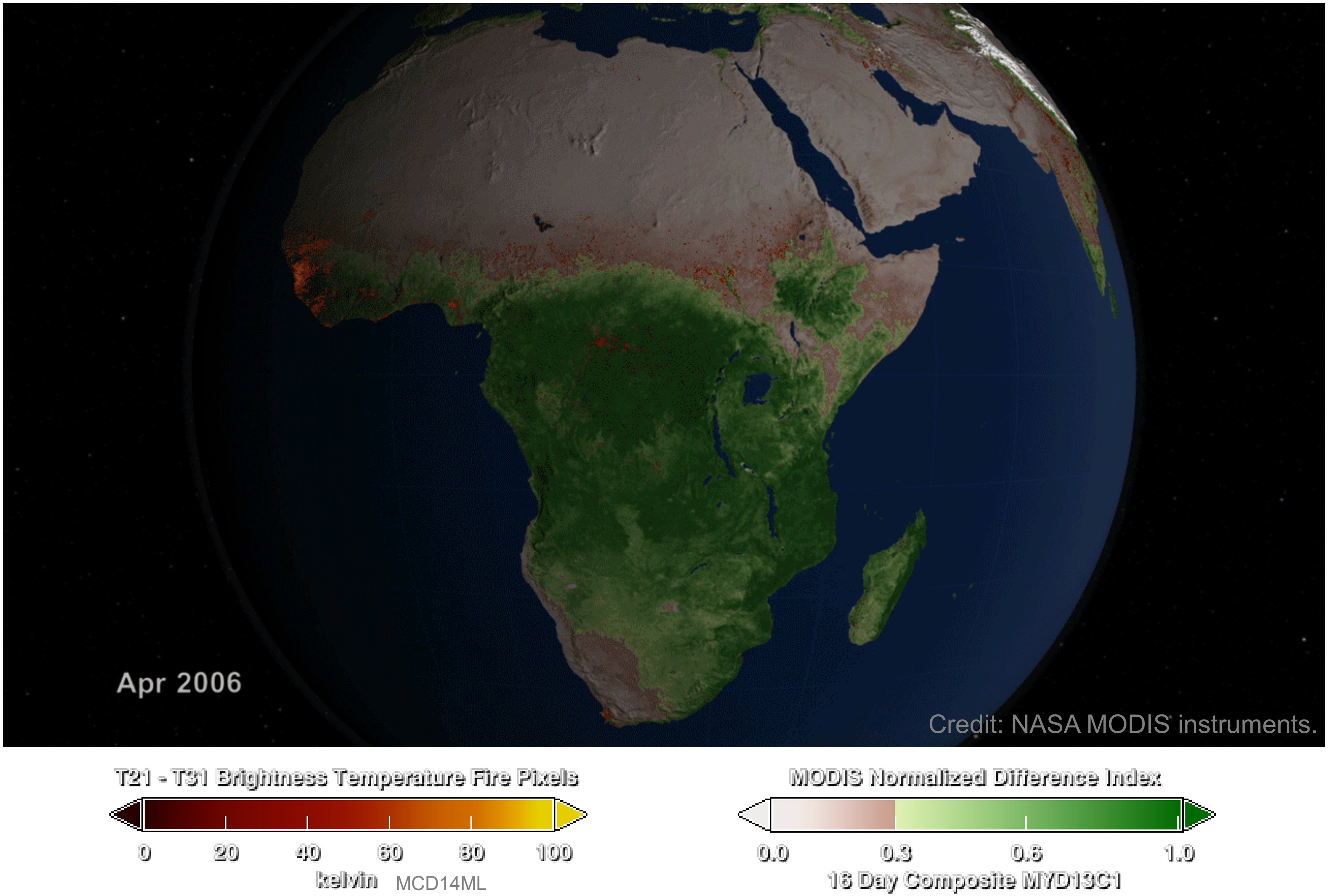
Climate system





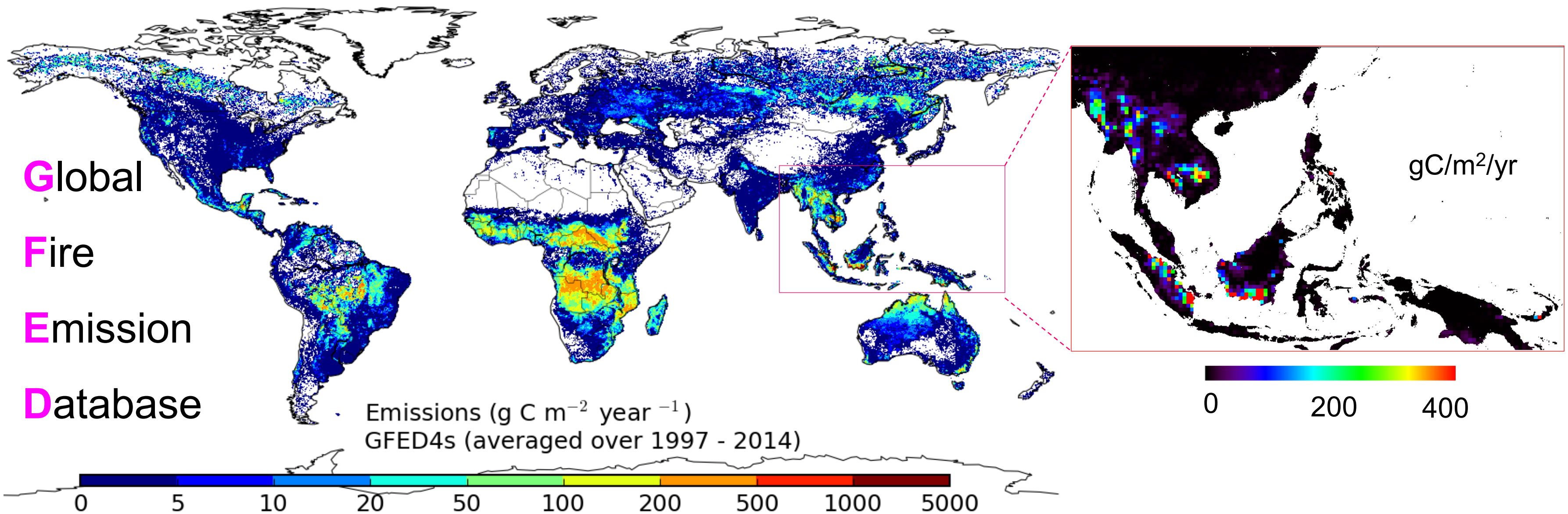
Background

- Strong characteristics of spatial and temporal variations in fire pixels.

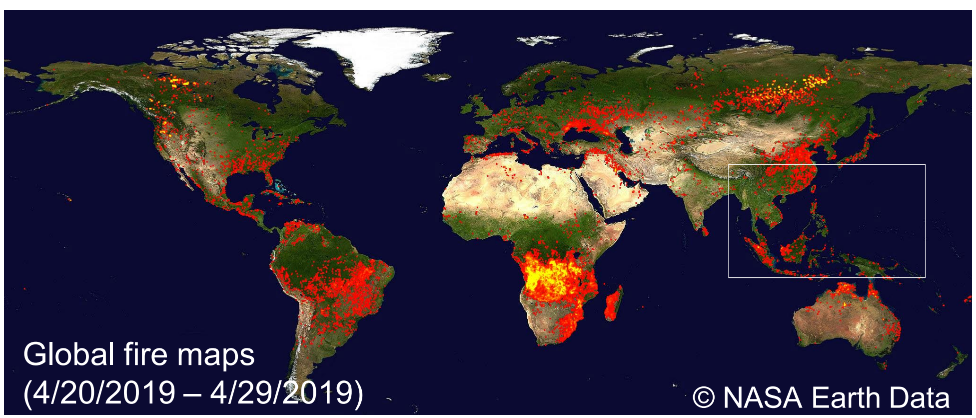


Background

- Global Fire Emission Database v4.1s (GFED4.1s), monthly/daily biomass burning emissions (1997 ~ now) (0.25° × 0.25°) (van der Werf et al., 2017).



- Fire size in Southeast Asia (SEA) is relatively small (Randerson et al., 2012).



→ slash-and-burn plantation & land clearing *(Myanmar, Laos, Cambodia, Thailand).*

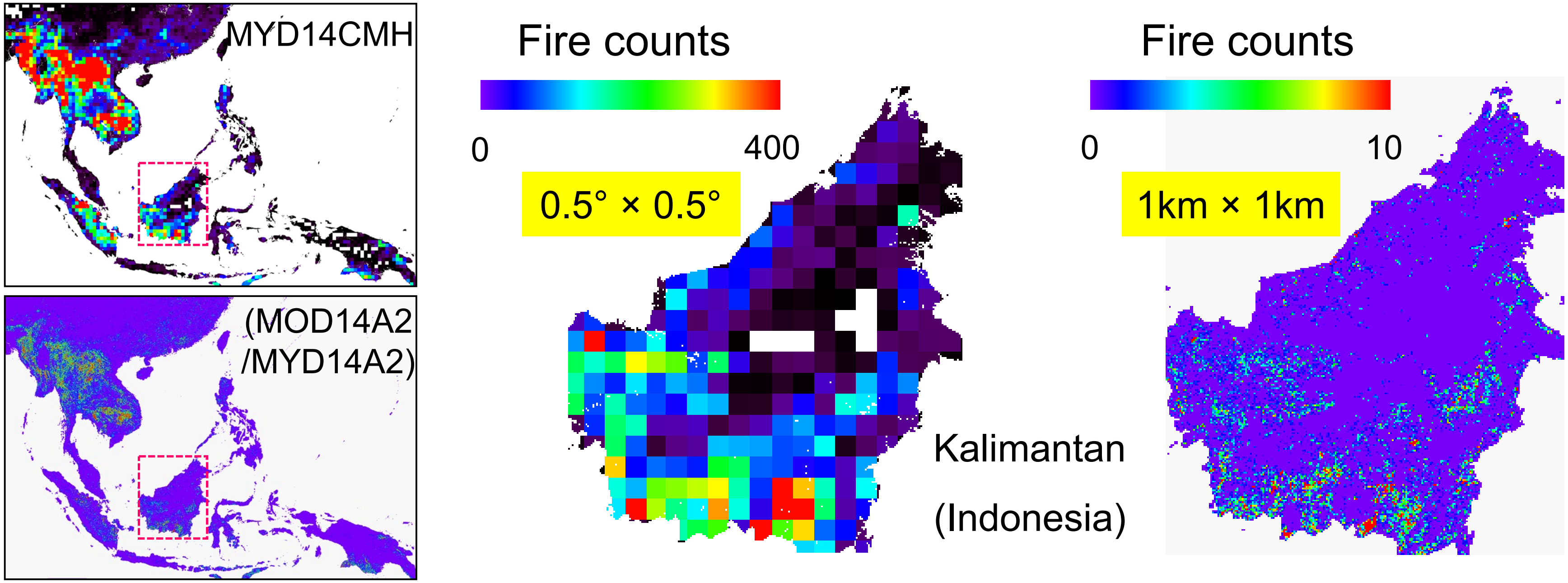
→ peat conversion for palm oil plantation *(Sumatra and Kalimantan)*

Background

- Fire types in Southeast Asia and their effects on air quality.

Problem

- The coarse grid data has difficulties in explaining small fire characters due to the heterogeneity and variability of the land surface process.

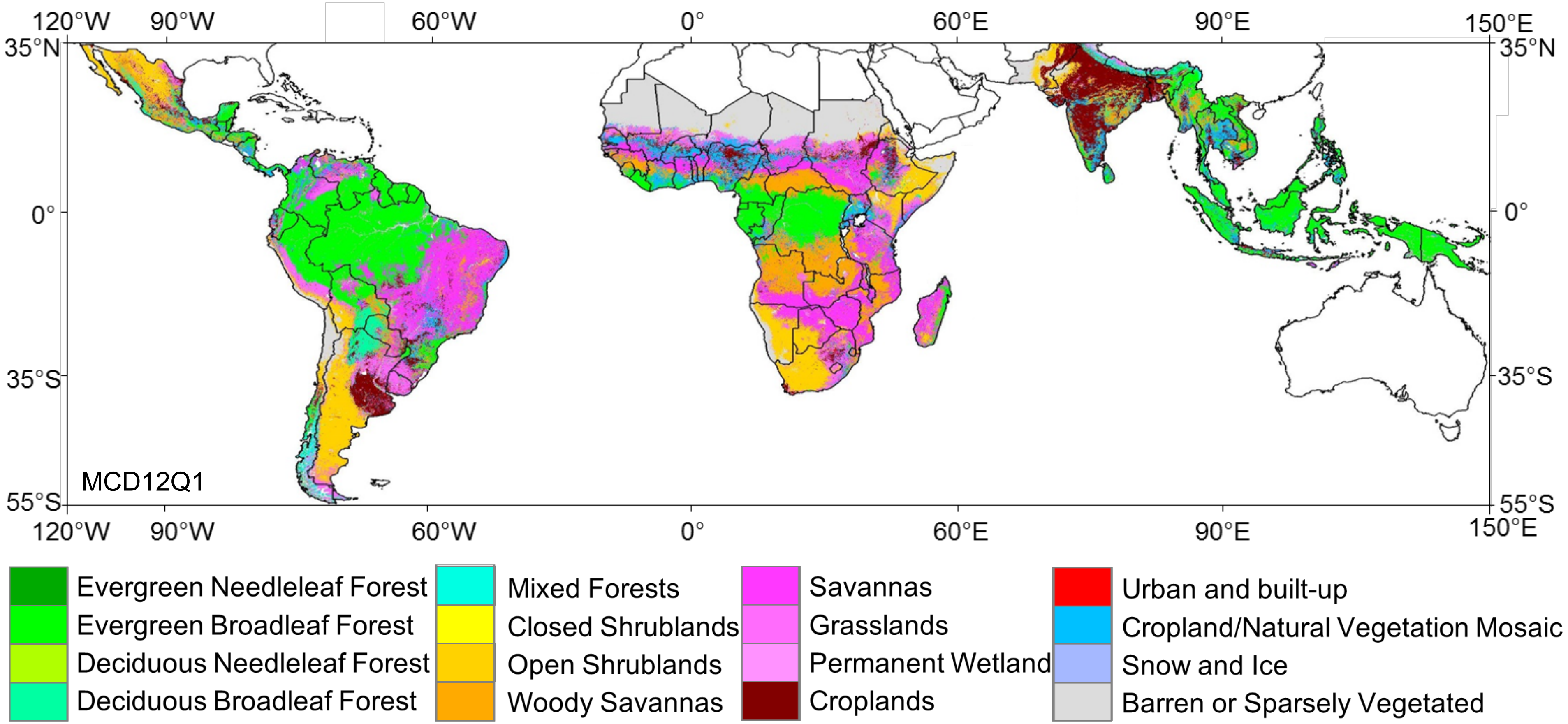


MODIS Fire counts products from 2001-2010 with different spatial resolution.

Objectives

To investigate the spatial and temporal patterns of fire carbon emissions with higher spatial resolution for more clear understanding of the contribution of fire to regional carbon cycle and budget and global warming forecasts.

2. Study area



America: 20

Argentina, Belize, Bolivia, Brazil, Chile, Costa Rica, Colombia, Ecuador, French Guiana, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Uruguay, Venezuela,

Africa: 41

Angola, Benin, Botswana, Burkina Faso, Burundi, Guinea, Cameroon, Central African Republic, Chad, Congo, Cote d'Ivoire, Demo. Rep. Congo, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Ghana, Guinea-Bissau, Kenya, Lesotho, Liberia, Malawi, Madagascar, Mauritania, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra, Somalia, South Africa, Sudan, Swaziland, Togo, Mali, Uganda, Tanzania, Zambia, Zimbabwe,

Asia: 15

Bangladesh, Bhutan, Cambodia, India, Indonesia, Laos, Malaysia, Myanmar, Nepal, Pakistan, Papua New Guinea, Philippines, Sri Lanka, Thailand, Vietnam.

All countries in tropical regions across the three continents are developing countries (World Bank, 2010).

2.1 Data and method

Fire induced biomass burning emissions:

Burned area (B), **Fuel loads** (F), **Combustion Factor** (CF) and **Emission Factor** (EF).

$$Emissions = \sum_{i=1}^{11} B \times F \times CF \times EF$$

i : land types.

----- Data sources -----

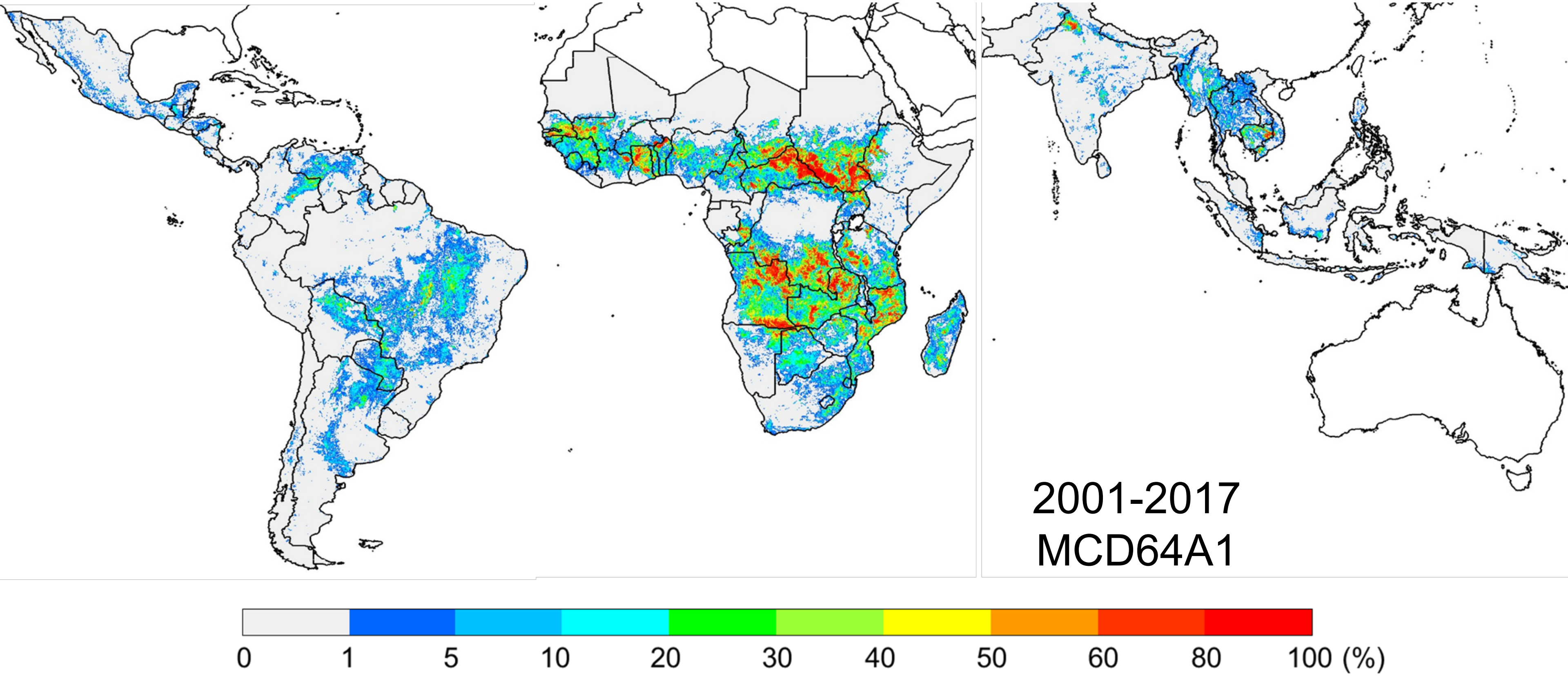
B : MCD64A1 burned area product.

F : BEAMS biomass, surface litter, and soil organic matter.

CF: The fraction of available fuels exposed to fires that are actually burned (%). They were linearly scaled by water scalar/soil moisture in the model (Andreae and Merlet, 2001).

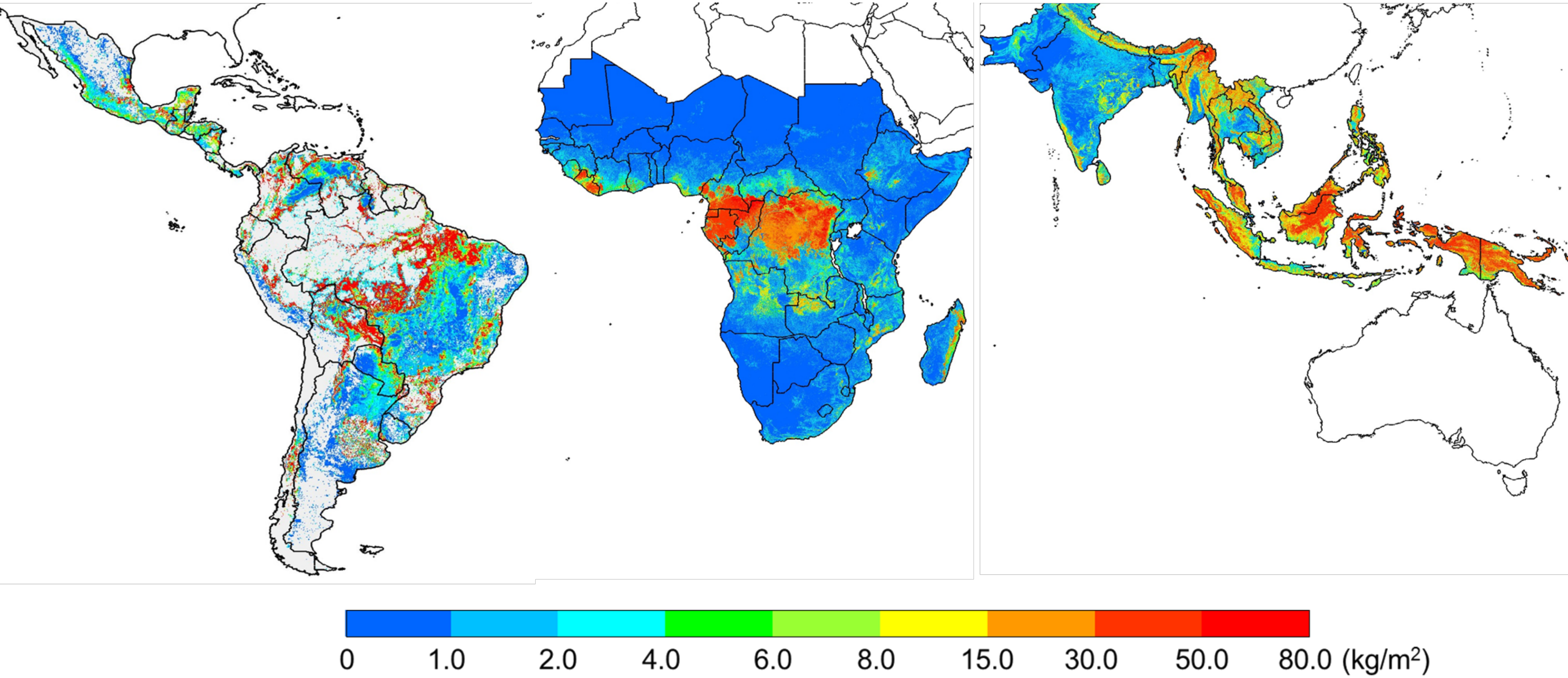
EF: Emitted trace gases and aerosols per kg dry matter burned.

2.2 Percentage of burned area (BA)



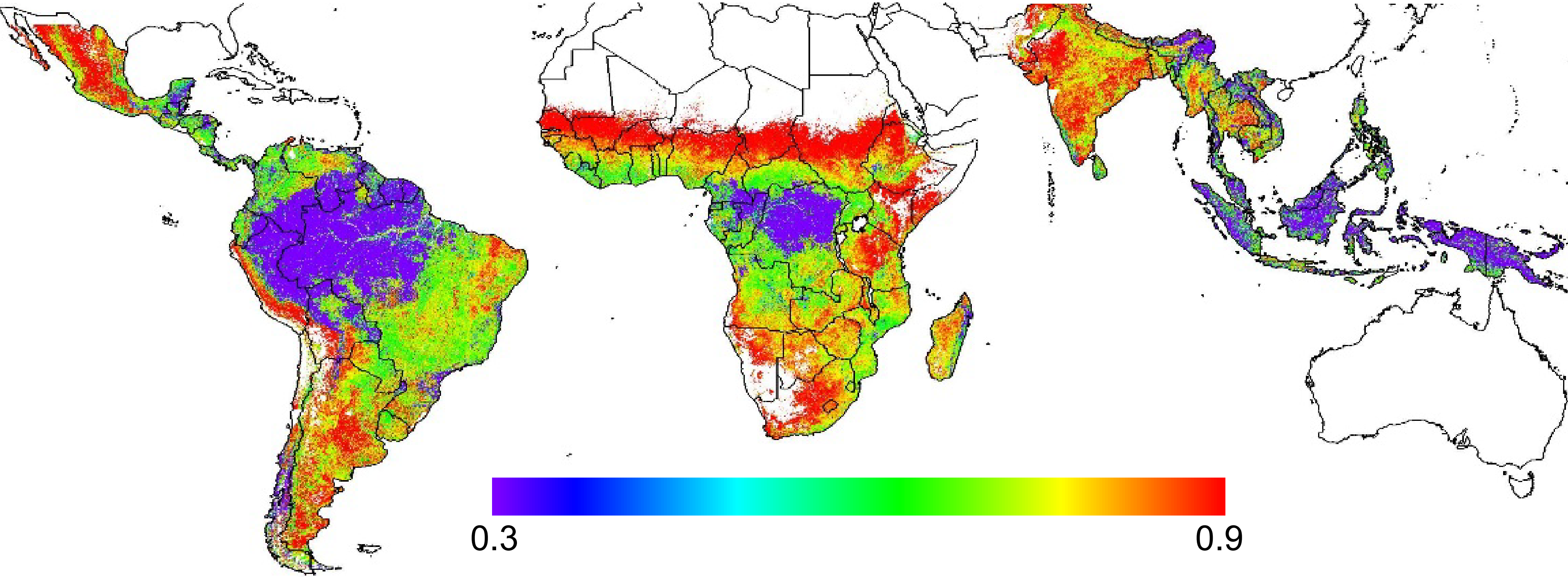
- Percentage of BA were high in Amazon, Central & Southern Africa, SE Asia.

2.3 Aboveground biomass (F)



- AGB was generated by combining two existing datasets from field observation and Lidar (Saatchi et al., 2011; Baccini et al., 2012; Avitabile et al., 2016) (1 km × 1 km).

2.4 Combustion factors (CF)



→ CF: fuel types were classified into three kinds (forest, woodland and grassland) based on the tree cover fraction from MODIS Vegetation Continuous Fields MOD44B.

forest $CF = (1 - e^{-1})^{mcf}$ $T_c > 60\%$

woodland $CF = \exp(-0.013 \times T_c)$ $40\% < T_c \leq 60\%$

grassland $CF = \frac{1}{100} \times (-213 \times \mathrm{PGREEN} + 138)$ $T_c \leq 40\%$

$$\mathrm{PGREEN}_t = \frac{NDVI_t - NDVI_{min}}{NDVI_{max} - NDVI_{min}}$$

(Ito and Penner, 2004)

The *mcf* value: moisture category factors

very dry: 0.33	moist: 2
dry: 0.5	wet: 4
moderate: 1	very wet: 5

VCI: Vegetation Condition Index

T_c: Tree cover, *PGREEN*: percentage of green grass to the total grass, *NDVI*: Normalized Difference Vegetation Index

2.5 Emission factors (EF)

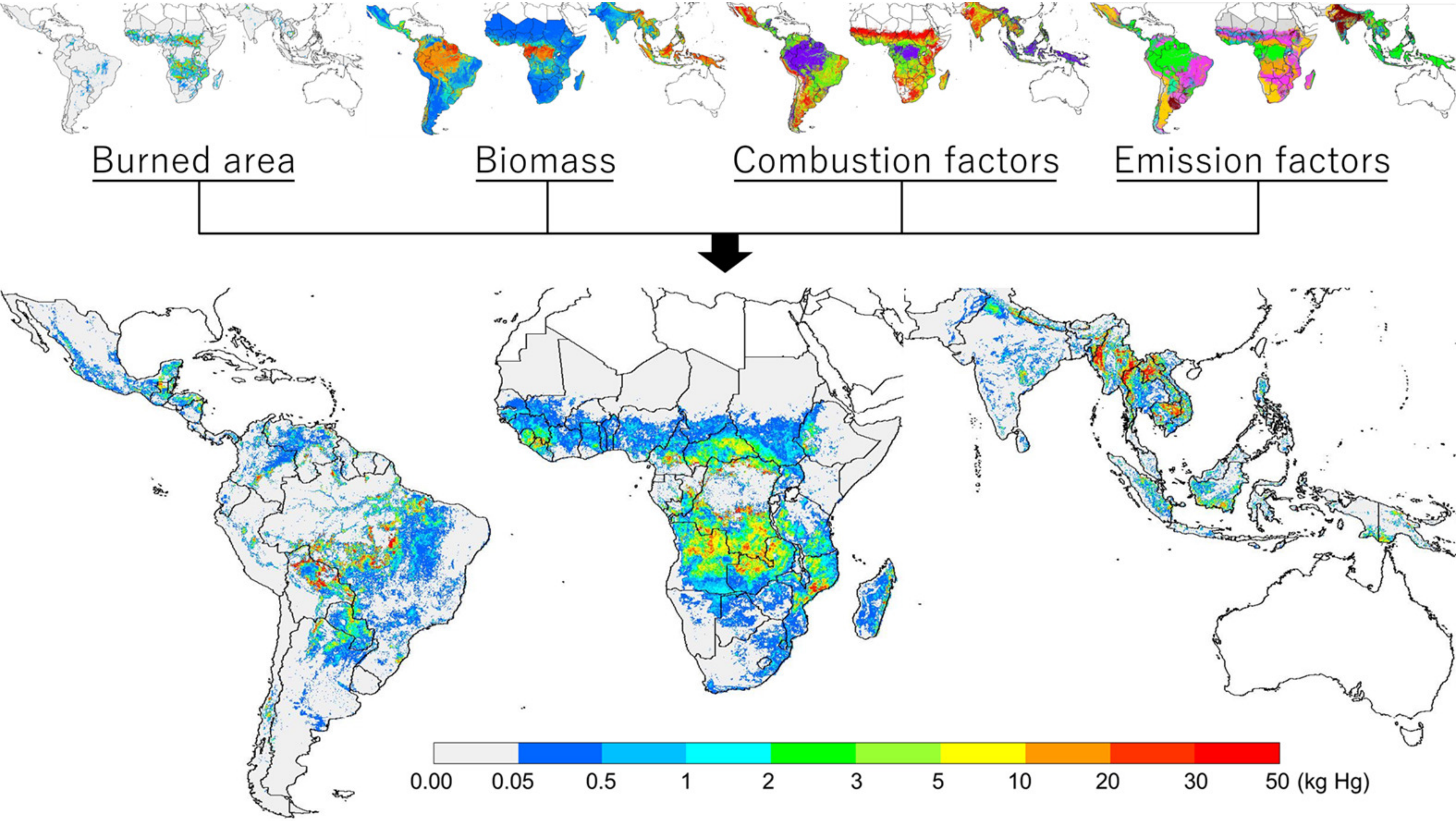
Land use/land cover classifications as assigned by the MODIS Land Cover Type (LCT), assigned generic land cover class, and emission factors (g kg^{-1} Dry Matter).

LCT classes	Generic vegetation type	CO_2	CO	CH_4	NO_x	NMOC	SO_2	NH_3	$PM_{2.5}$	OC	BC
Evergreen Needleleaf Forest	FORE	1514	118	6	1.8[a]	28	1[a]	3.5	13	7.8[b]	0.2[b]
Evergreen Broadleaf Forest	FORE	1643	92	5.1	2.6	24	0.45	0.76	9.7	4.7	0.52
Deciduous Needleleaf Forest	FORE	1514	118	6	3[a]	28	1[a]	3.5	13	7.8[b]	0.2[b]
Deciduous Broadleaf Forest	FORE	1630	102	5	1.3	11	1[a]	1.5	13[a]	9.2[a]	0.56[a]
Mixed Forests	FORE	1630	102	5	1.3	14	1[a]	1.5	13[a]	9.2[a]	0.56[a]
Closed Shrublands	WS	1716	68	2.6	3.9	4.8	0.68	1.2	9.3	6.6[b]	0.5[b]
Open Shrublands	WS	1716	68	2.6	3.9	4.8	0.68	1.2	9.3	6.6[b]	0.5[b]
Woody Savannas	WS	1716	68	2.6	3.9	4.8	0.68	1.2	9.3	6.6[b]	0.5[b]
Savannas	SG	1692	59	1.5	2.8	9.3	0.48	0.49	5.4[c]	2.6	0.37
Grasslands	SG	1692	59	1.5	2.8	9.3	0.48	0.49	5.4[c]	2.6	0.37
Permanent Wetlands	SG	1692	59	1.5	2.8	9.3	0.48	0.49	5.4[c]	2.6	0.37
Croplands	CROP	1537	111	6	3.5	57	0.4[c]	2.3	5.8	3.3[c]	0.69[c]
Cropland/Natural Vegetation Mosaic	SG	1692	59	1.5	2.8	9.3	0.48	0.49	5.4[c]	2.6	0.37
Barren or Sparsely Vegetated	SG	1692	59	1.5	2.8	9.3	0.48	0.49	5.4[c]	2.6	0.37

Akagi et al. (2011) | Andreae (2008) | McMeeking (2008) | Andreae and Merlet (2001)

WS: Woody Savannah/Shrubland; SG: Savannah/Grassland

3. Biomass burning emissions (Hg)

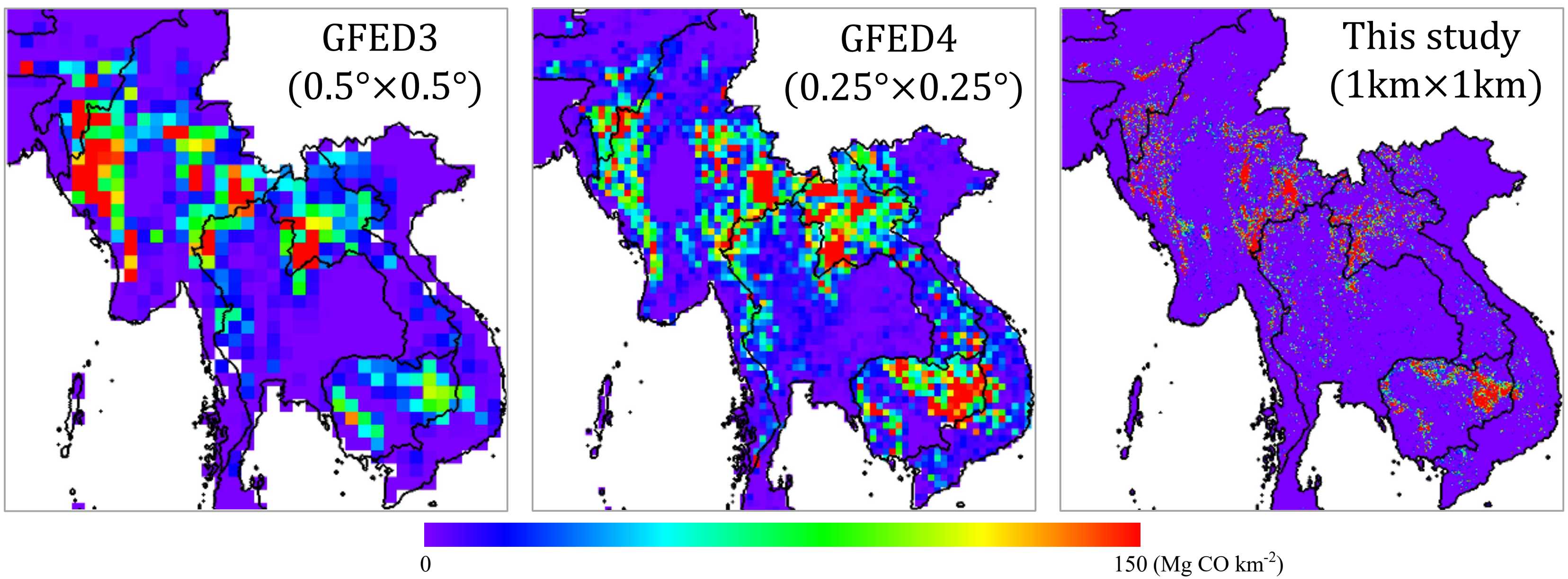


3. Biomass burning emissions

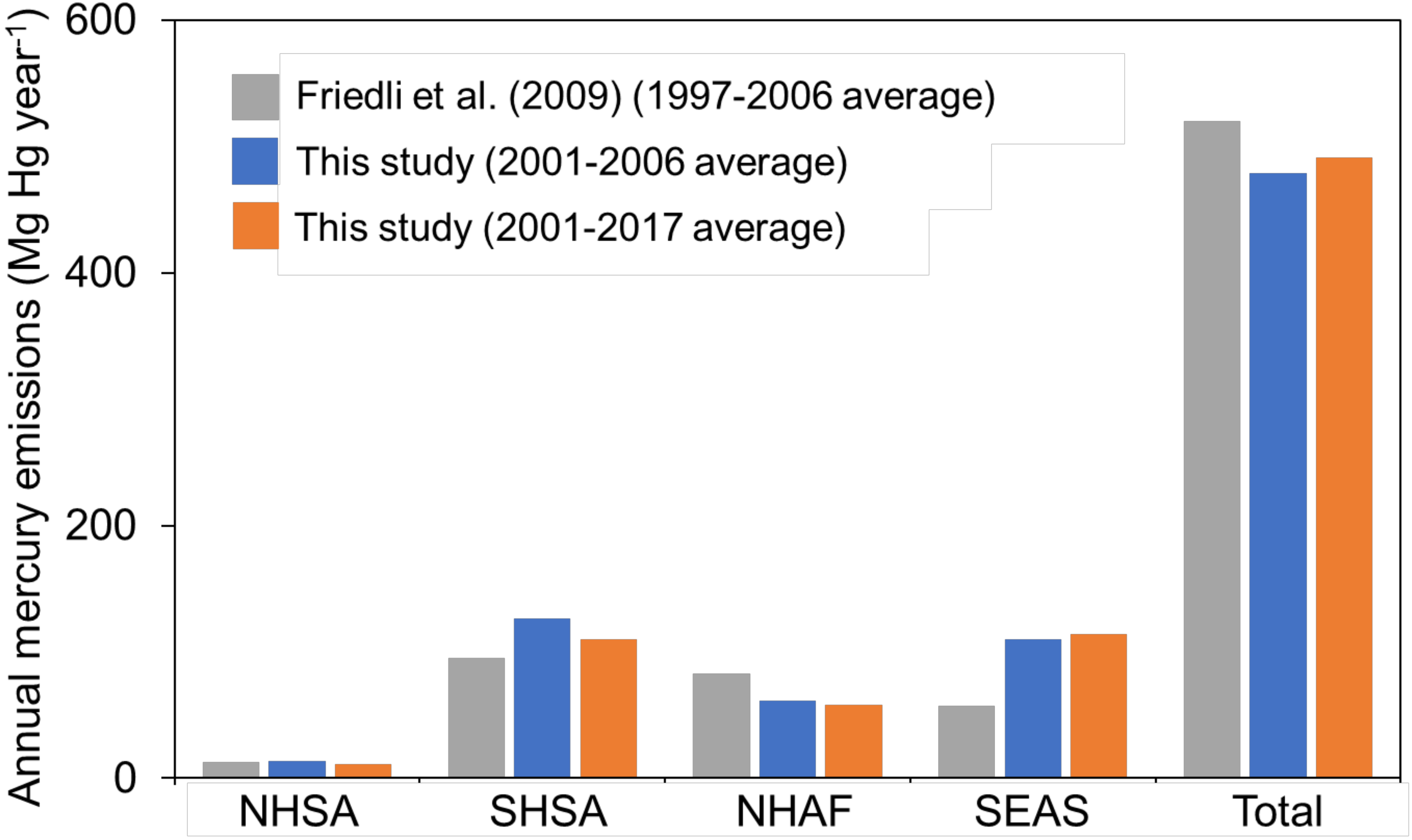
Table 1. Biomass burning emissions (Tg) in tropical continents during 2001-2017.

Species	Forest	WS	SG	Crop	Peat	Total	Americas	Africa	Asia
BC	0.32	0.92	0.39	0.09	0.02	1.73	0.31	1.05	0.37
CH_4	3.18	4.79	1.46	0.76	0.66	10.85	2.13	5.51	3.21
CO	57.89	125.28	57.51	14.04	6.69	261.41	50.22	149.00	62.19
CO_2	1024.38	3161.43	1649.16	194.44	54.27	6083.69	1113.68	3765.41	1204.60
NH_3	0.53	2.21	0.49	0.29	0.08	3.60	0.53	2.25	0.82
NMOC	14.41	8.84	9.06	7.21	0.22	39.75	10.67	16.25	12.83
NO_x	1.56	7.19	2.73	0.44	0.07	11.99	1.88	7.87	2.24
OC	3.15	12.16	2.53	0.42	0.14	18.40	2.70	12.15	3.55
$PM_{2.5}$	6.21	17.13	5.26	0.73	0.29	29.63	5.09	18.43	6.11
SO_2	0.34	1.29	0.49	0.05	0.02	2.19	0.36	1.41	0.42

WS: woody savanna/shrubland, SG: savanna/grassland.



3.1 Comparison with other studies (Hg)



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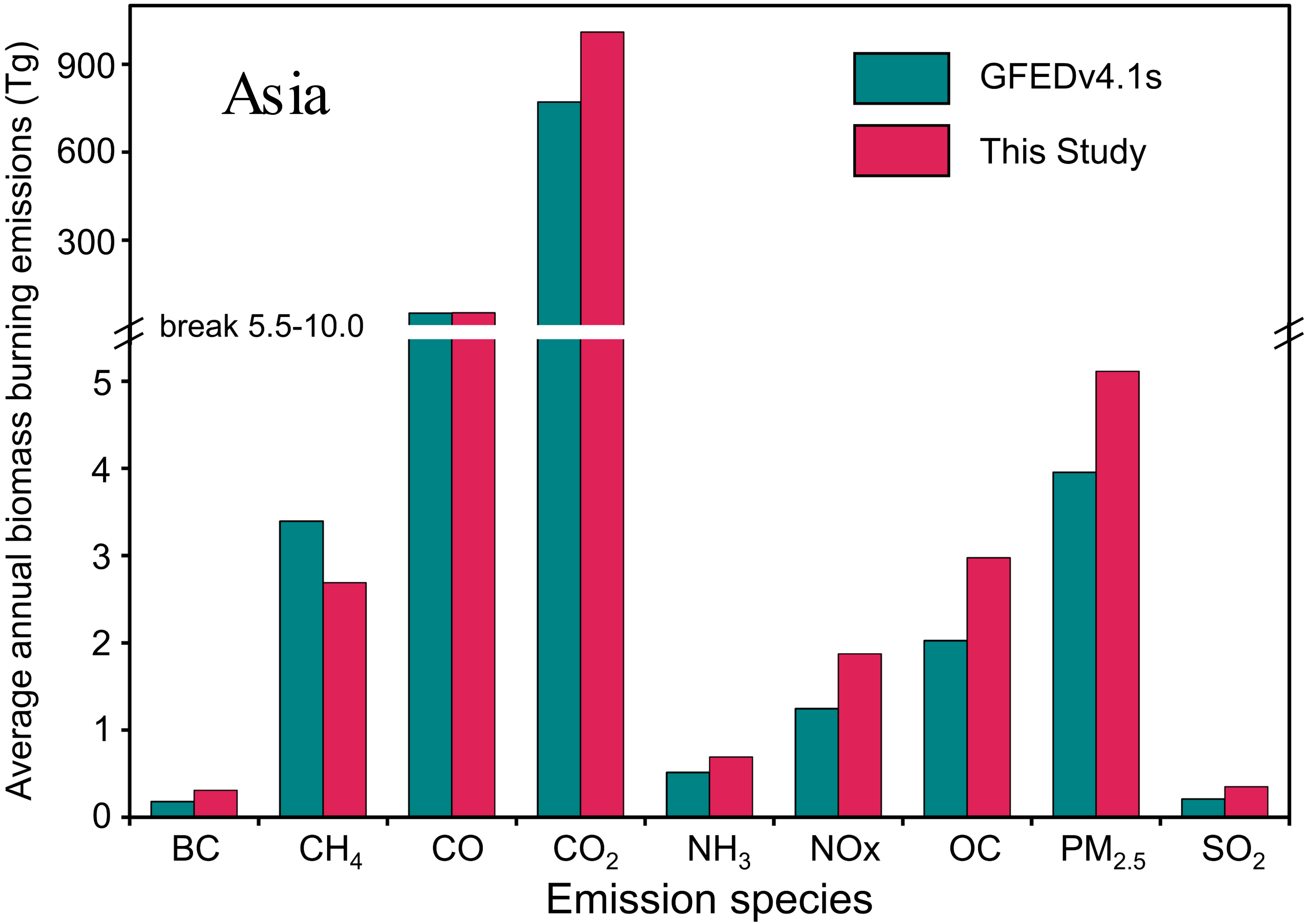

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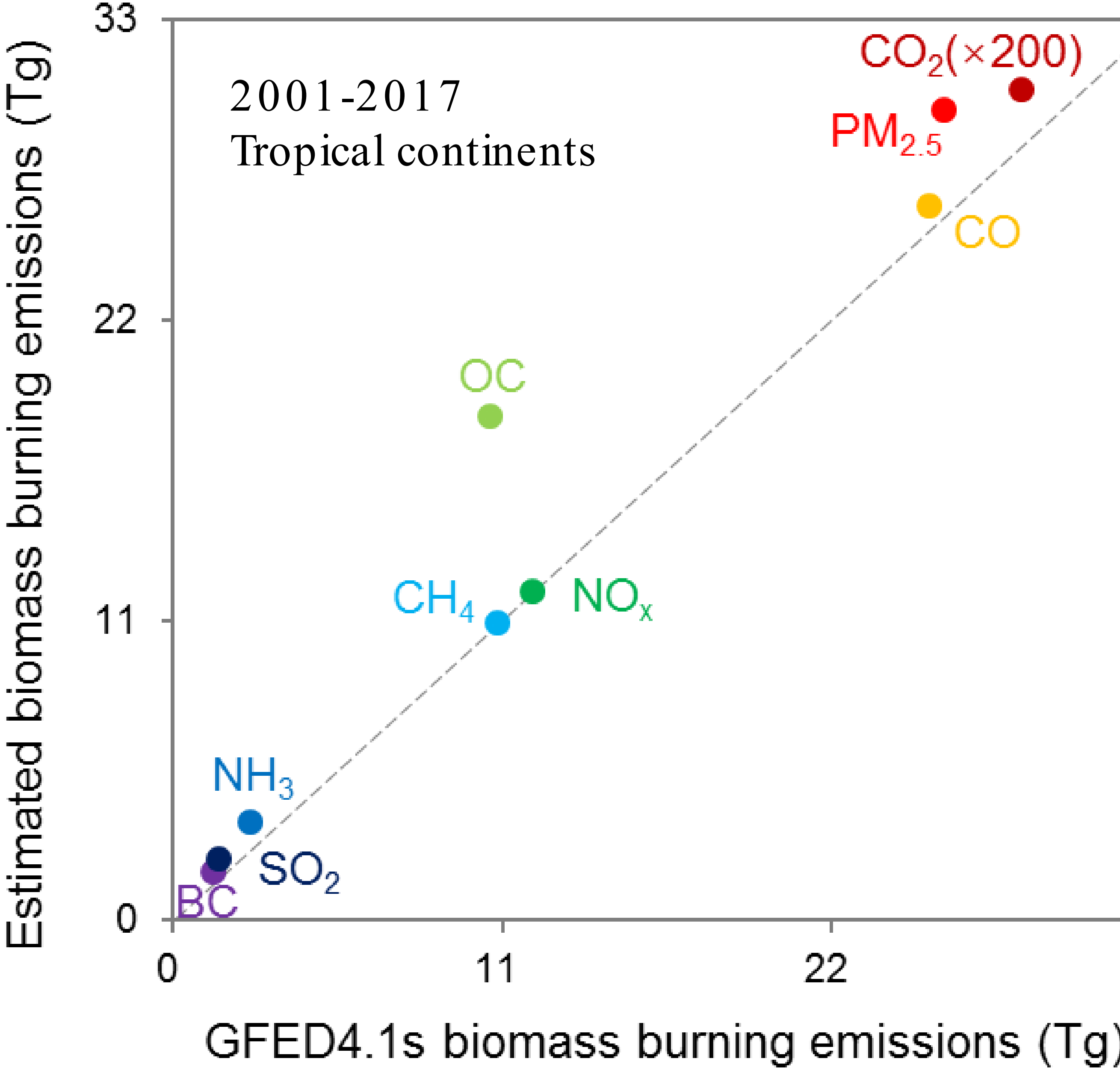
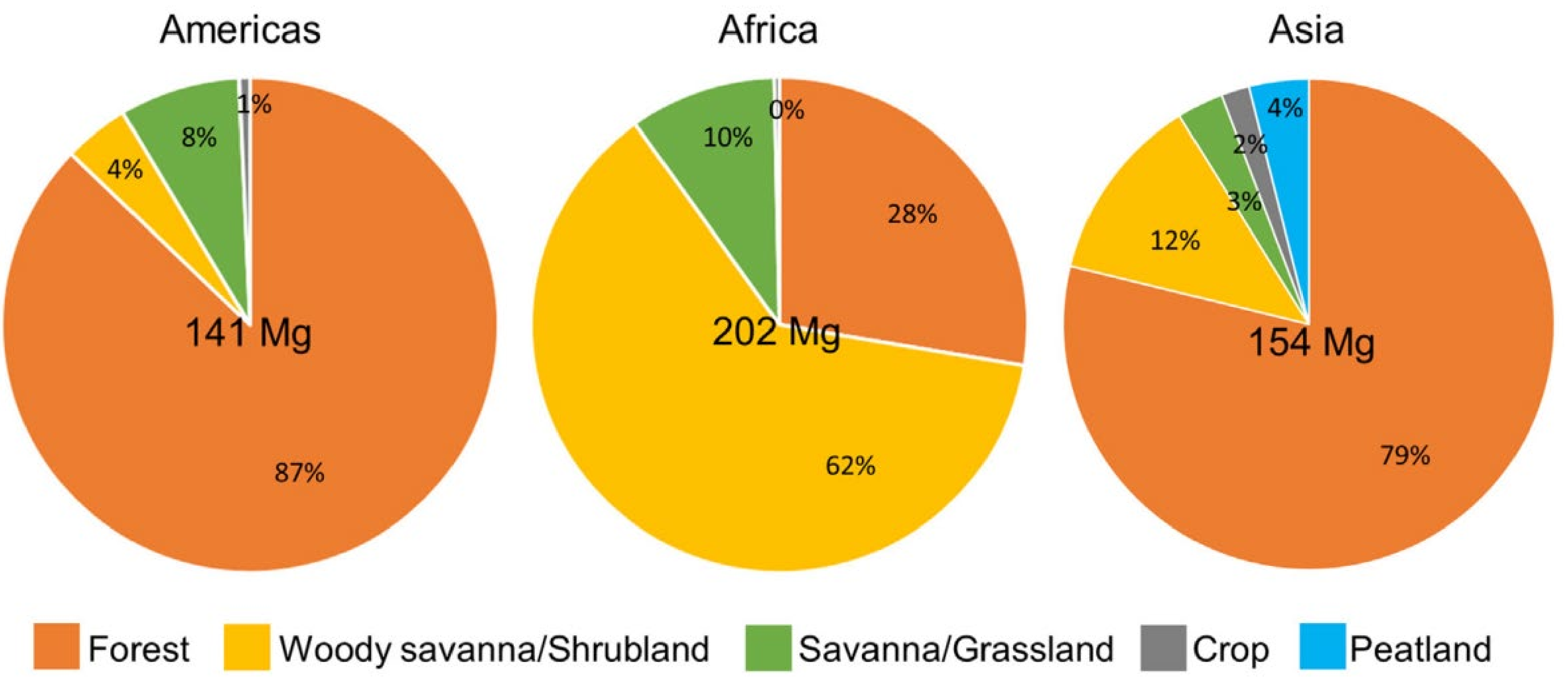
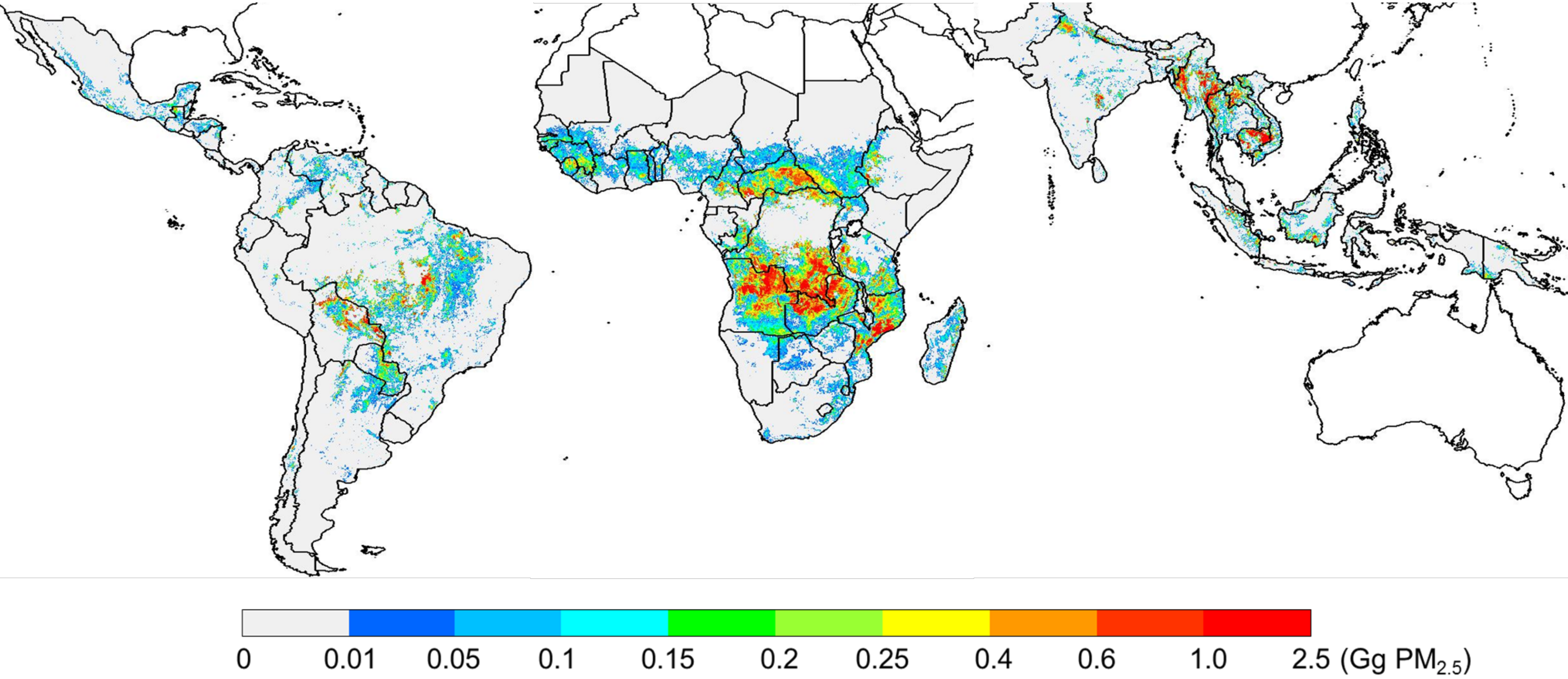


3.2 Emissions in each continents

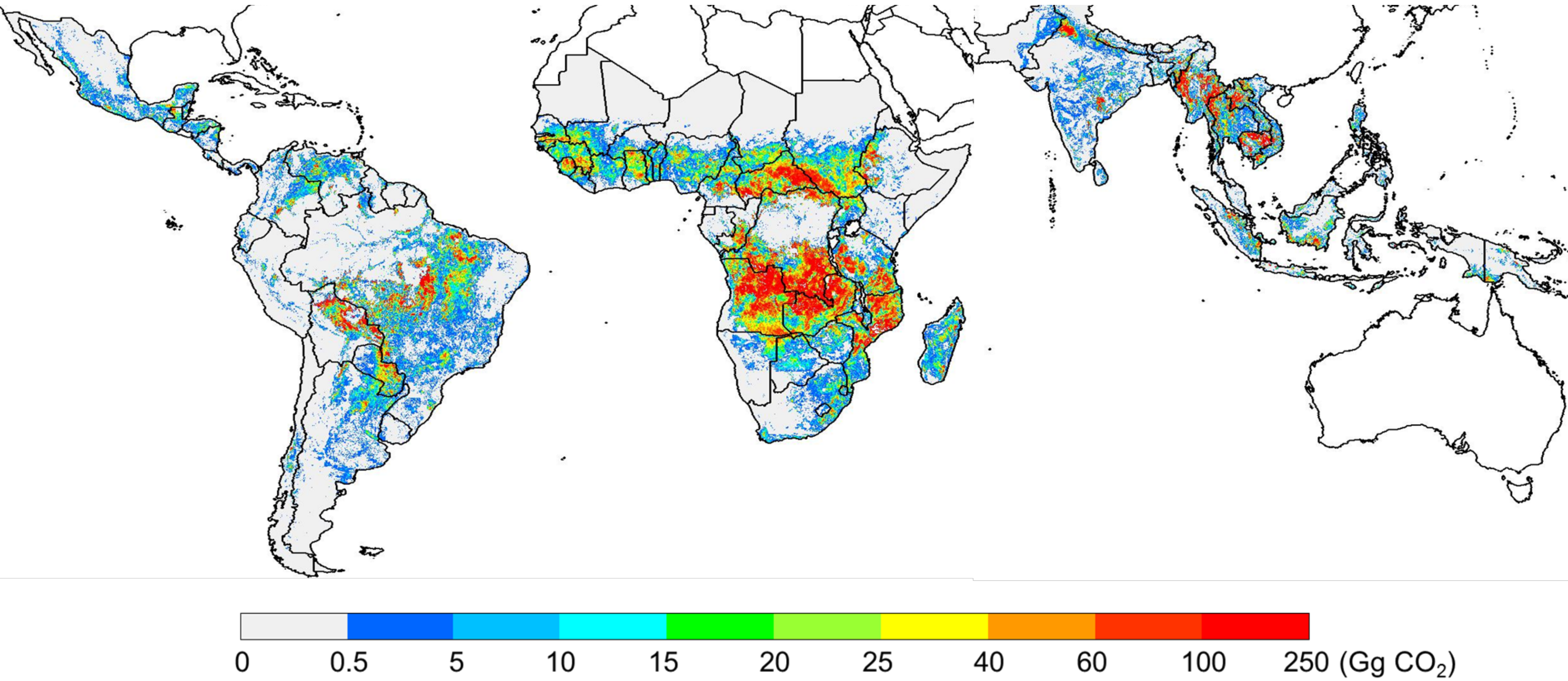


- The average annual mercury emissions from biomass burning in tropical continents was 497 Mg and ranged from 289 Mg to 681 Mg during 2001-2017.
- Forest fires were the largest contributor, accounting for 61% (300 Mg) of the total, followed by woody savanna/shrubland (30%, 151 Mg), savanna/grassland (7%, 35 Mg), peatland (1%, 6 Mg), and cropland (1%, 5 Mg).
- Africa released 41% of the emissions (202 Mg/yr), Asia released 31% (154 Mg/yr), and the Americas released 28% (141 Mg/yr).

3.3 Biomass burning emissions ($PM_{2.5}$)

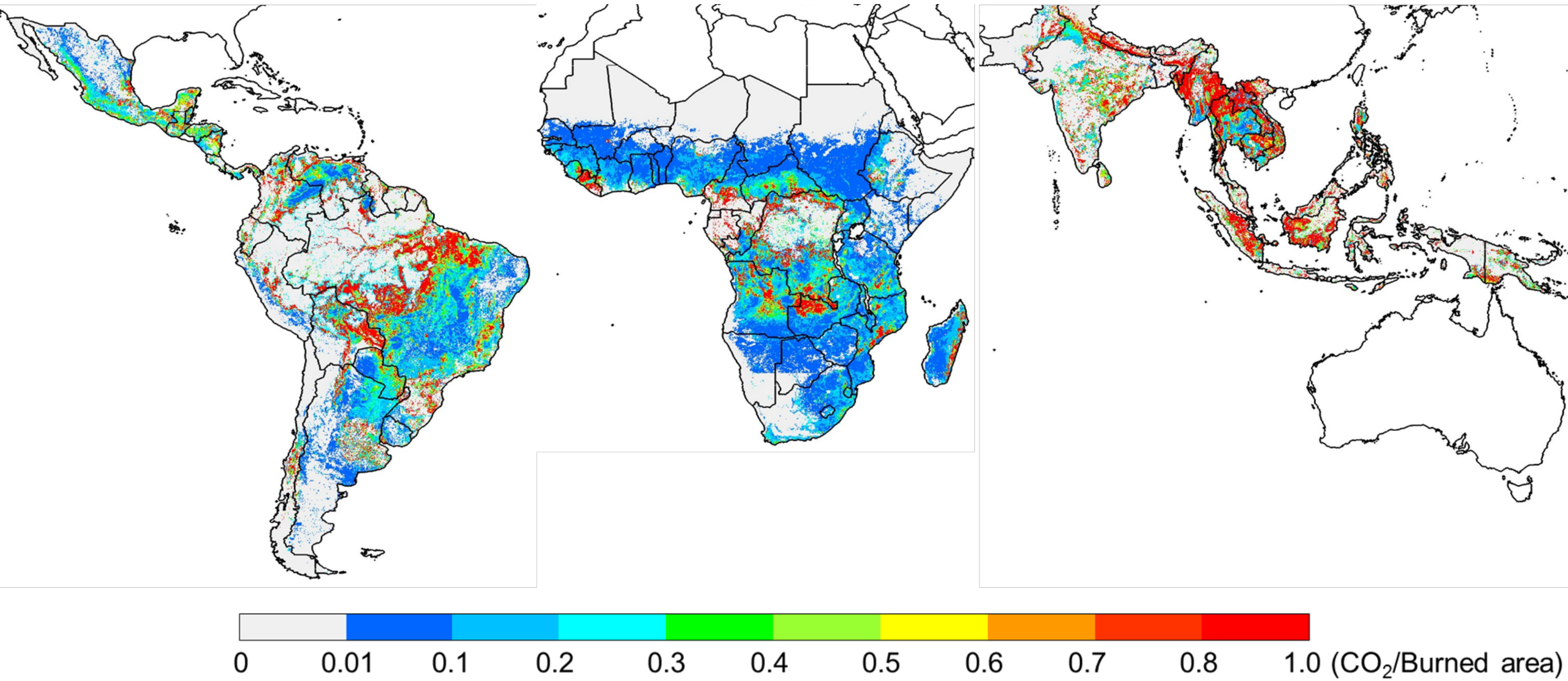


3.4 Biomass burning emissions (CO_2)



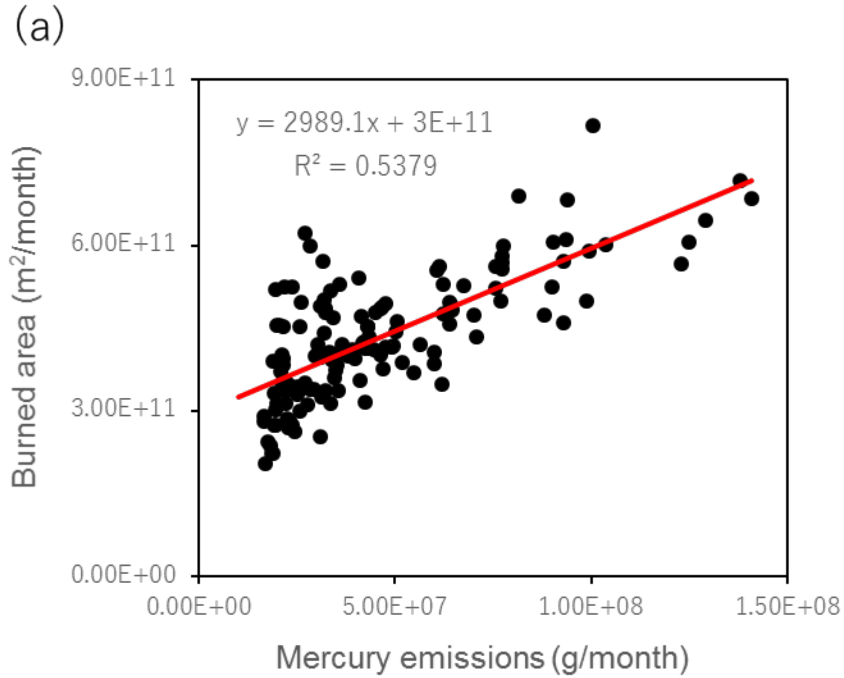
3.4 Biomass burning emissions intensity

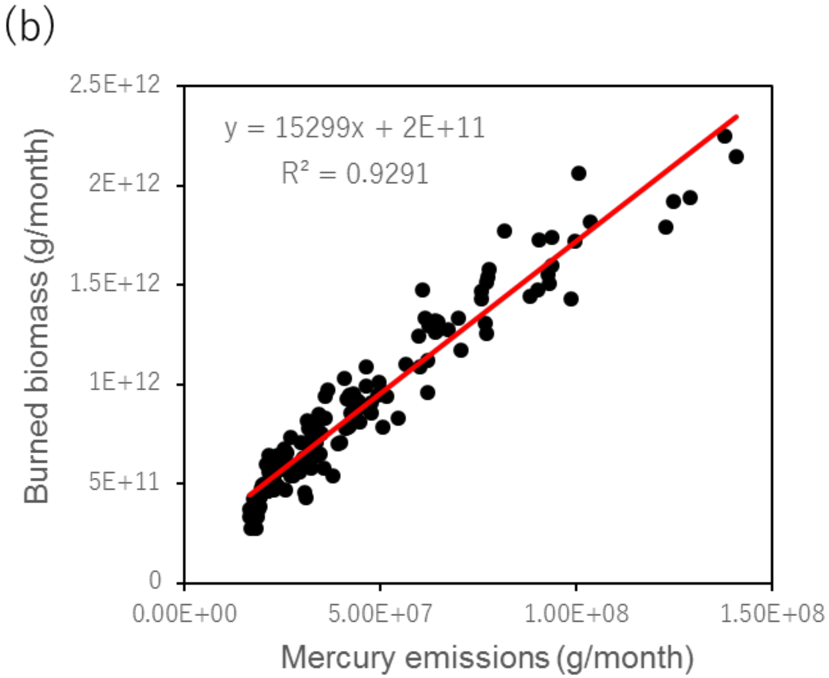
Biomass burning emissions intensity = CO_2 / burned area



Southeast Asia presented more emissions for each unit of burned area, indicating more burned biomass when fire occurs.

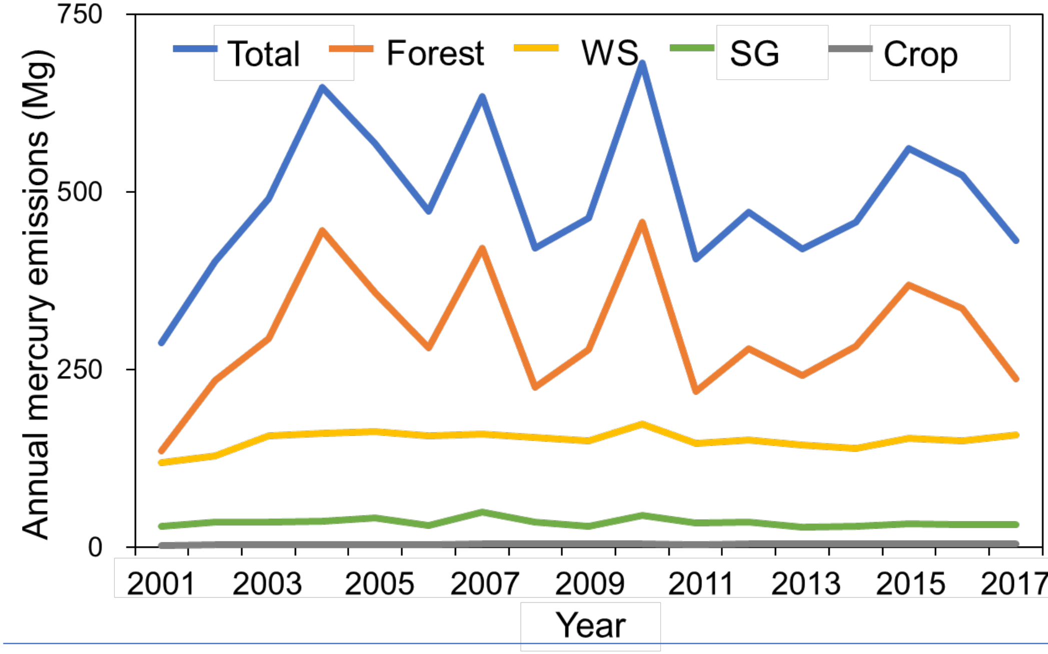
3.4 Biomass burning emissions intensity





The spatial distributions of mercury emissions correlated well with burned areas ($r = 0.73$).
This suggests that burned area is the decisive parameter that controls the spatial patterns of mercury emissions; however, the actual amount of emissions was ultimately determined by a combination of the burned biomass ($r = 0.96$), jointly constrained by the available fuels, combustion factors, and emission factors of all land types.

3.5 Temporal variations (LULC)

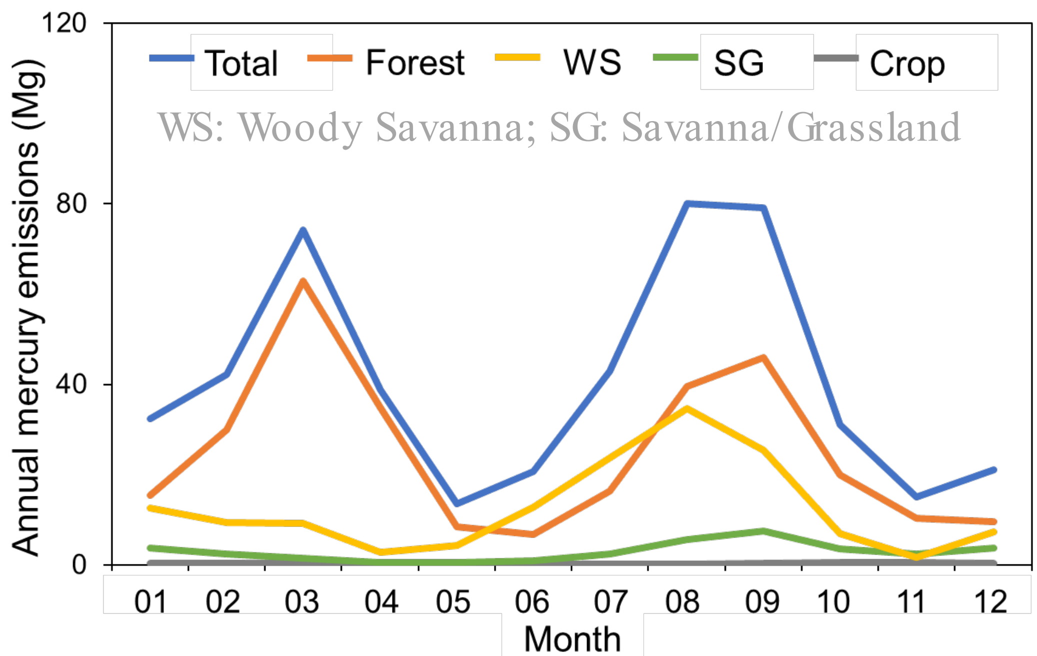


Interannual variations:
2004, 2007, 2010, 2015

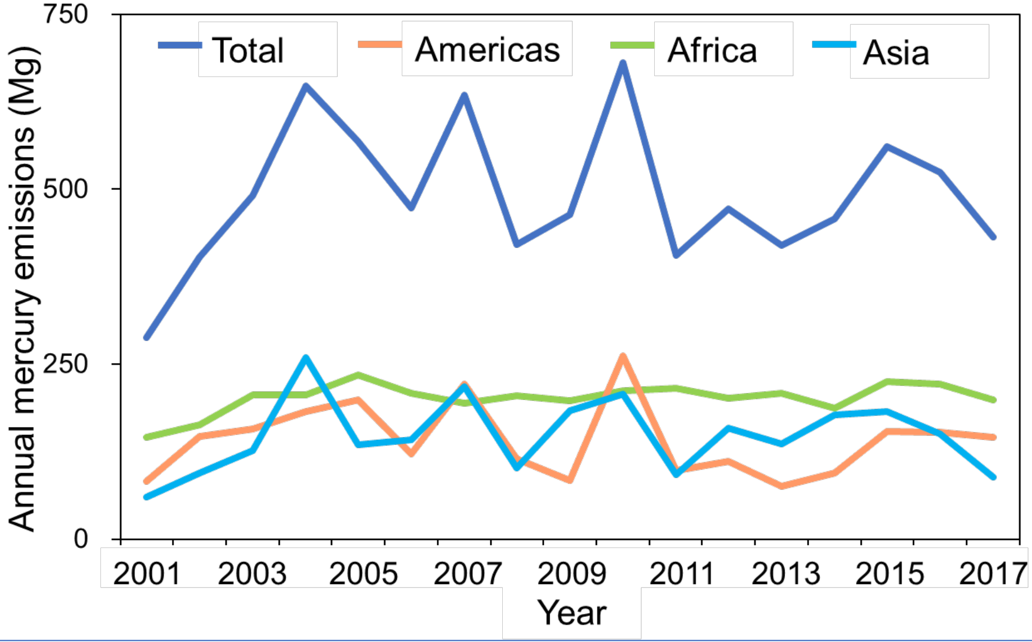
Peak burned area of Forest:
2004, 2007, 2010, 2015

Intraannual variations:
March, August-September

Peak burned area:
March (Forest),
Aug-Sep (Forest and WS)



3.6 Temporal variations (Continent)

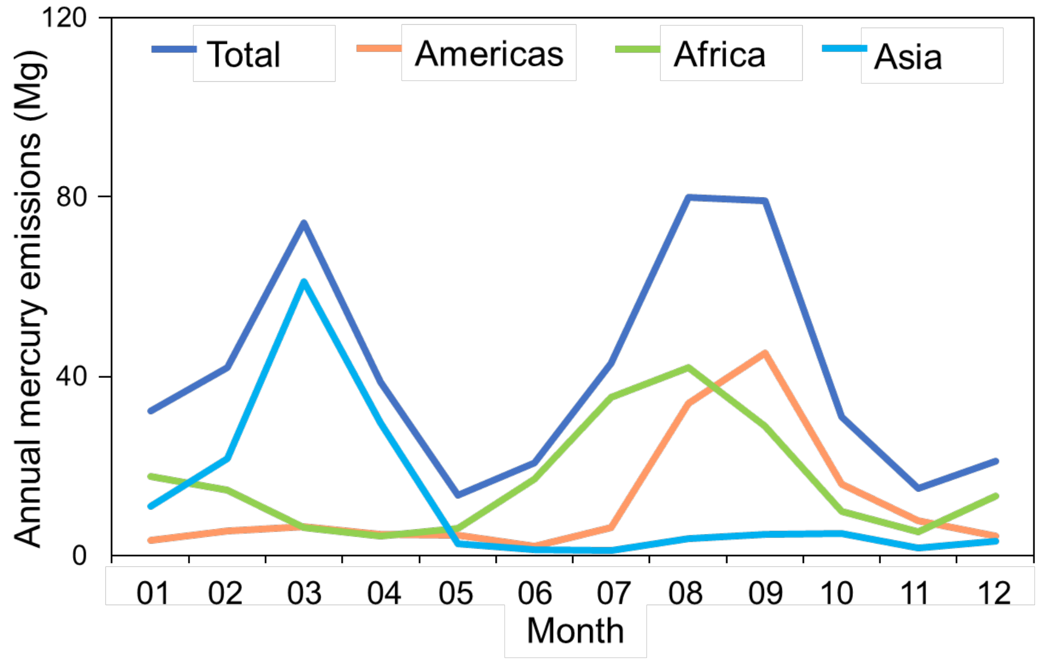


Interannual variations:
2004, 2007, 2010, 2015

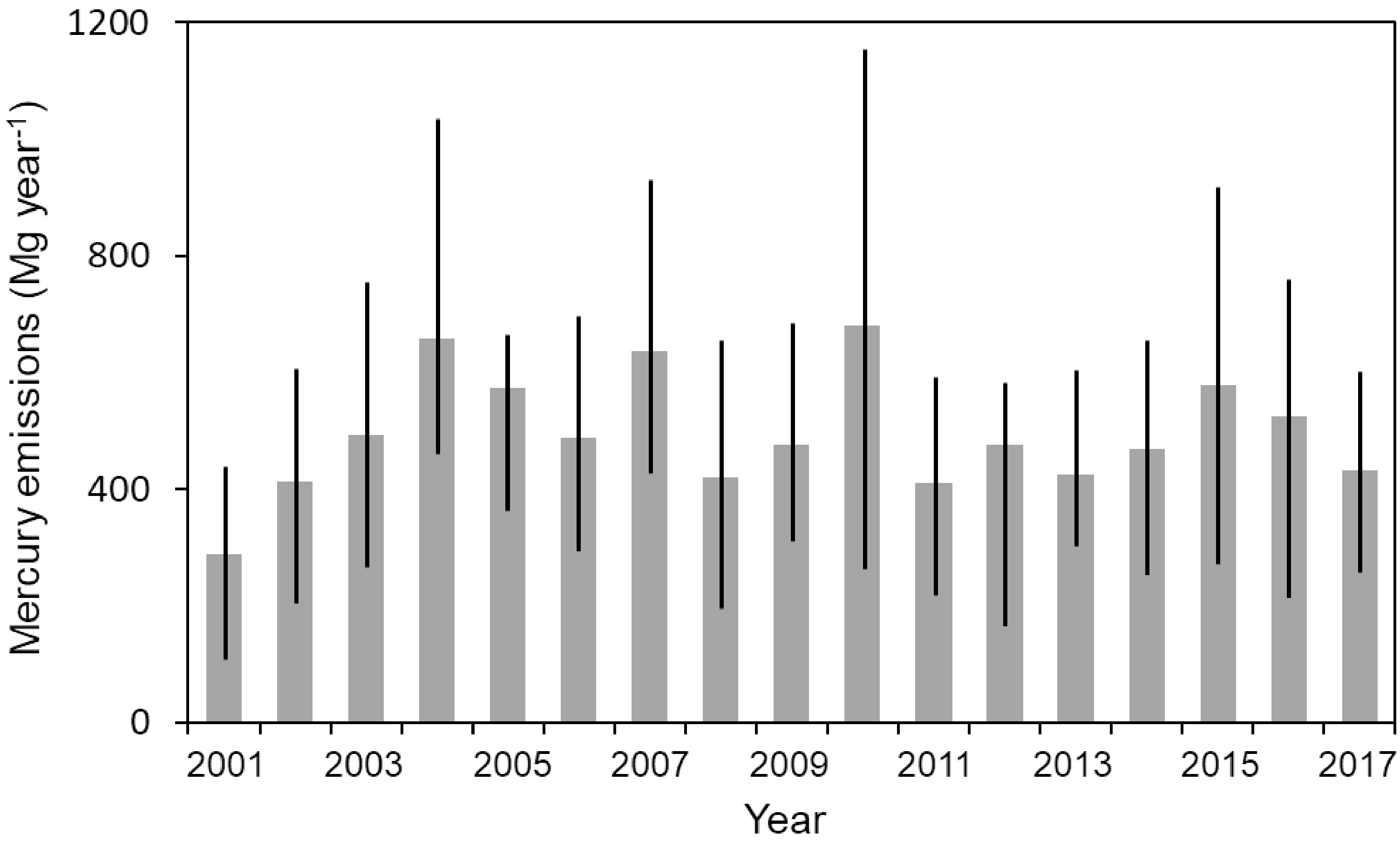
Peak burned area:
As, Am/As, Am/As, Af/As/Am

Intraannual variations:
March, August-September

Peak burned area:
March (As),
Aug-Sep (Af/Am, Am/Af)



3.7 Uncertainty (Hg)



4.1 Comprehensive emissions inventory

General Emission Equations

$$E_{m,k} = \sum_{m,k} M_{m,k} \times EF_{m,k}$$

❶

$$M_{veg} = BA \times F \times CF$$

BA: burned area of land cover/vegetation type m.

F : fuel loads (biomass density).

CF: combustion factor.

❷

$$M_{waste} = P \times P_{frac} \times MSW_P \times B_{frac}$$

$\boldsymbol{P}$: national population,

$\boldsymbol{P_{frac}}$: fraction of the population assumed to burn some of their waste.

$\boldsymbol{MSW_P}$: the mass of annual per capita waste production.

$\boldsymbol{B_{frac}}$: fraction of waste available to be burned that is actually burned.

❸

$$M_{fuel} = W \times P$$

W: national fuelwood use per capita.

P: national population.

$E_{m,k}$ = emissions for fuel type m and land type k. $M_{m,k}$ = burned biomass. $EF_{m,k}$ = emission factors.

Overall framework of estimation methodology

4.2 Total Burned Biomass

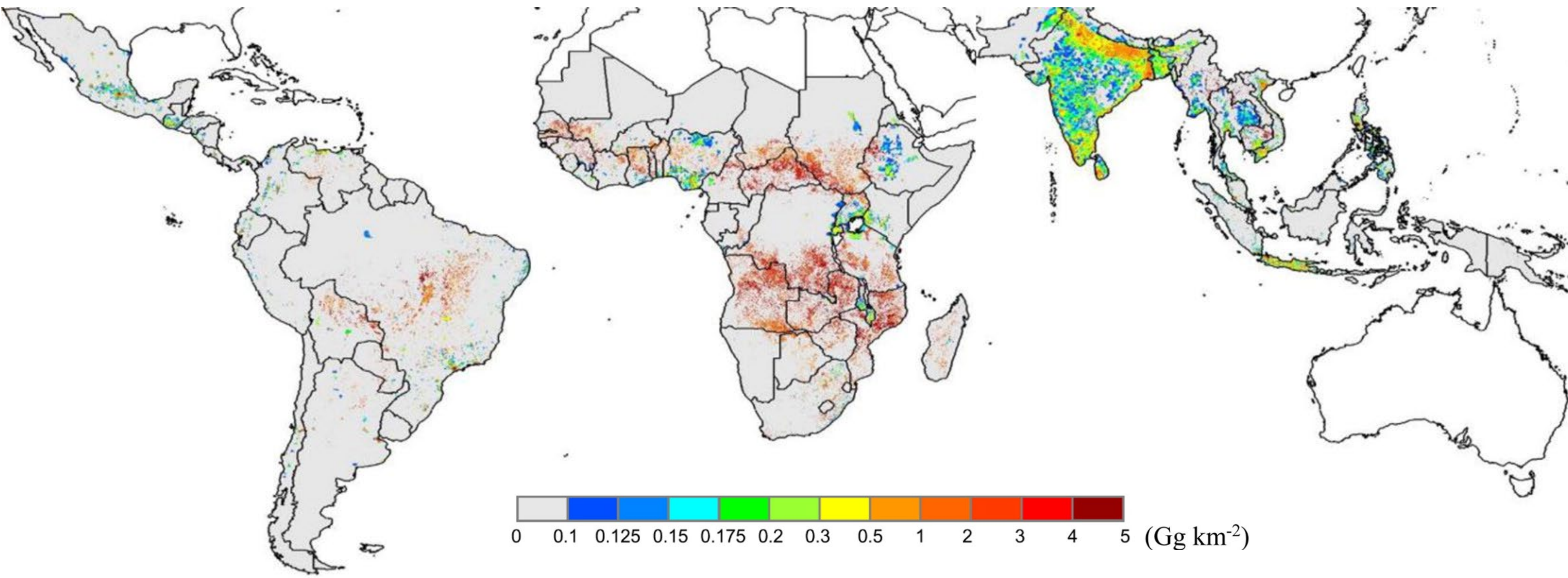
General Emission Equations

$$E_{m,k} = \sum_{m,k} M_{m,k} \times EF_{m,k}$$

1. $M_{veg} = BA \times F \times CF$
2. $M_{waste} = P \times P_{frac} \times MSW_P \times B_{frac}$
3. $M_{fuel} = W \times P$

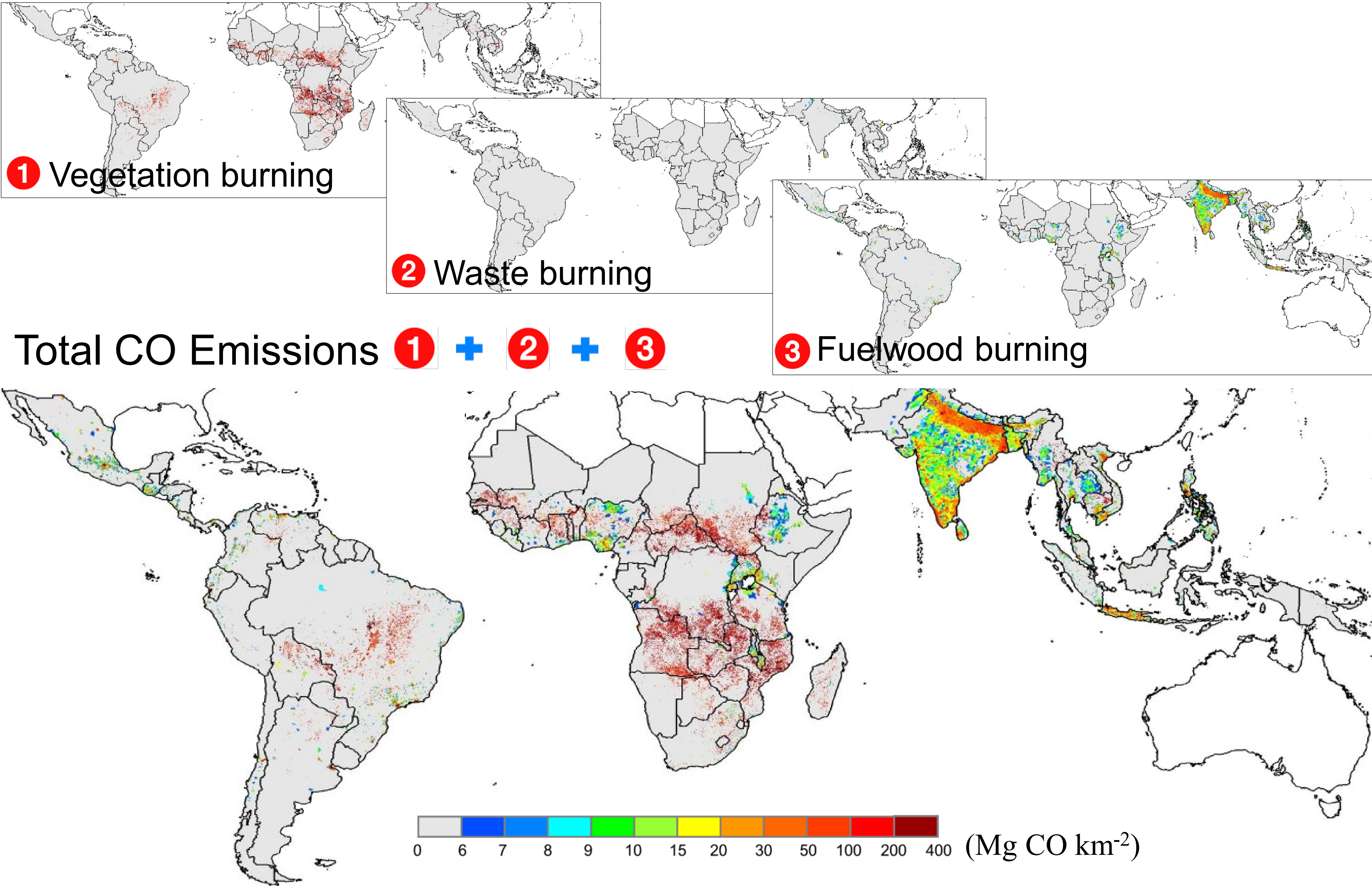
(1 km × 1 km)

1 + 2 + 3



Estimated annual burned biomass (vegetation, waste and fuelwood).

4.3 Biomass Burning Emissions (CO)



Publications

<u>Shi, Y.</u>*, Zhao, A., Matsunaga, T., Yamaguchi, Y., Zang, S., Li, Z., Yu, T., Gu, X. 2019. High-resolution inventory of mercury emissions from biomass burning in tropical continents during 2001-2017. ***Science of the Total Environment***, 653, 638-648.

<u>Shi, Y.</u>*, Matsunaga, T., Yamaguchi, Y. 2015. High-resolution mapping of biomass burning emissions in three tropical regions. ***Environmental Science & Technology***, 49(18), 10806-10814.

<u>Shi, Y.</u>*, Yamaguchi, Y. 2014. A high-resolution and multi-year emissions inventory for biomass burning in Southeast Asia during 2001-2010. ***Atmospheric Environment***, 98, 8-16.

<u>Shi, Y.</u>*, Sasai, T., Yamaguchi, Y. 2014. Spatio-temporal evaluation of carbon emissions from biomass burning in Southeast Asia during the period 2001-2010. ***Ecological Modelling***, 272, 98-115.

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