The Use of Satellite-Measured Aerosol Optical Depth to Constrain Biomass Burning Emissions Source Strength in the Global Model GOCART

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Purpose of this study:
Constrain BB emissions source strength

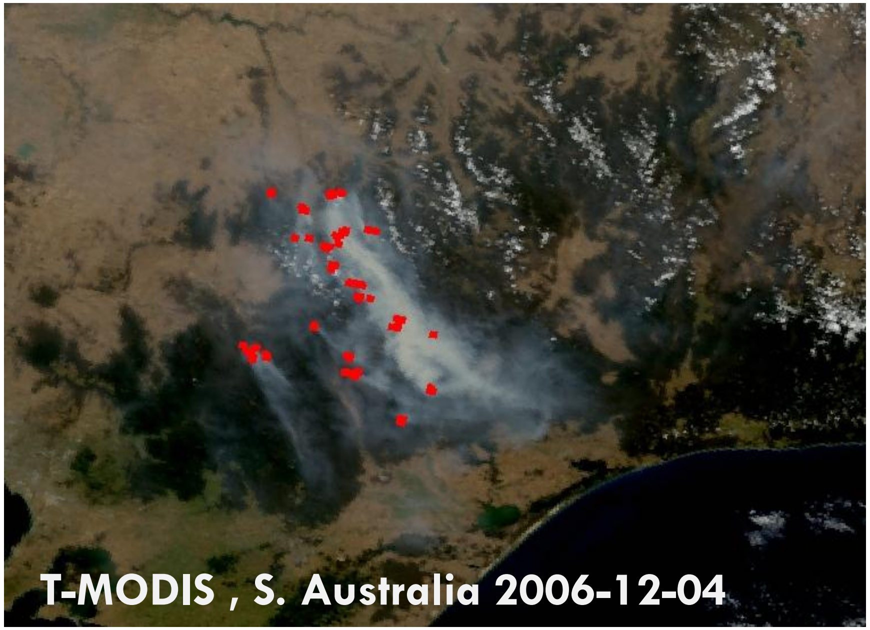
BB emissions in aerosol models are supplied by external emission inventories.

Many BB emission inventories have been developed

➔**Estimated** amounts of **BB emissions** are **different** in different inventories

Satellite observations are crucial to validate emissions on a global scale

➔Satellite **snapshot provides instantaneous constraint** on a source strength



MODIS = Moderate Resolution Imaging Spectroradiometer on NASA's Terra and Aqua satellites

Presented results have been published

Petrenko et al., 2012, J. Geophys. Res., doi:10.1029/2012JD017870

Outline

Motivation & Review of BB emission estimates

- Estimating BB emissions (2 approaches)
- Comparison of emission options and their individual components

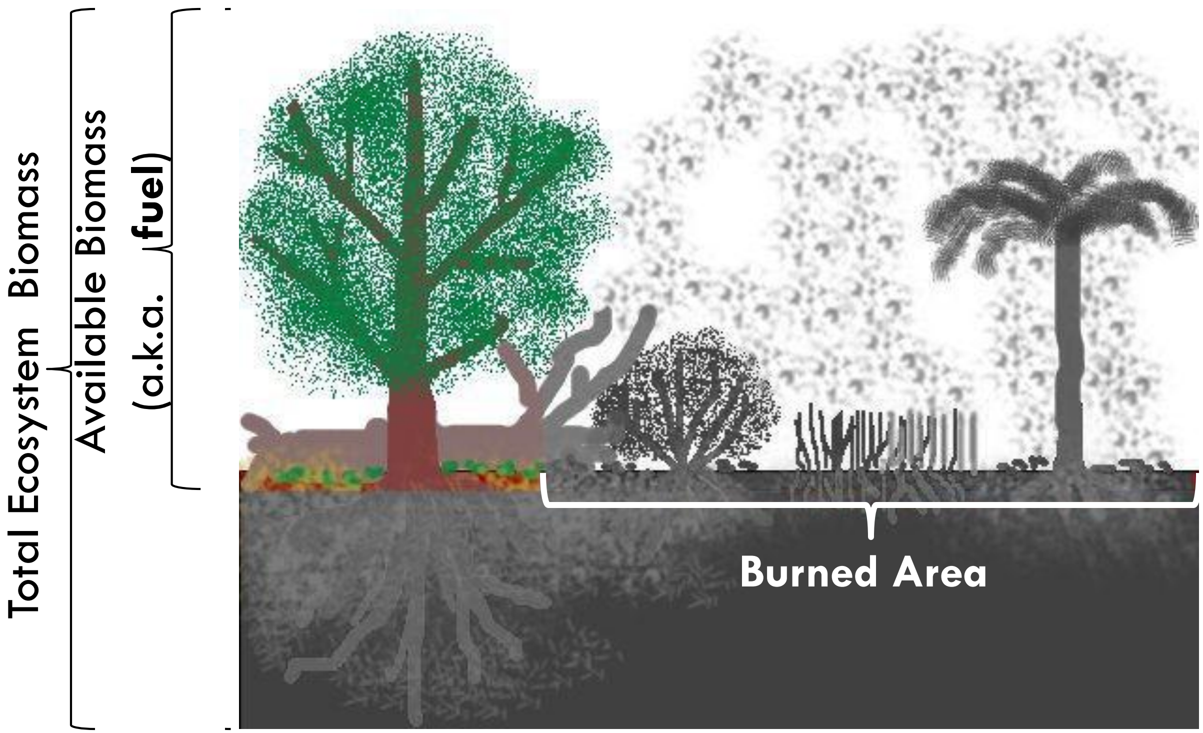
Critical tests of emission options

- Evaluating BB emission options by comparing GOCART model output with satellite observations
- Quantitative relationship between BB aerosol emissions and aerosol optical depth (AOD)

Implications for model parameterization

- Future work towards improving BB emissions for global models

Estimating BB emissions:
1. Burned area-based approach



***M_i* – mass of emitted gas/aerosol species *i* (g)

A – burned area (m^2)

B – fuel density (kg/m^2)

C – combustion completeness (unitless fraction)

F_i – species-specific emission factor; (g_i / kgDM); *i* = e.g., BC, OC, SO_2

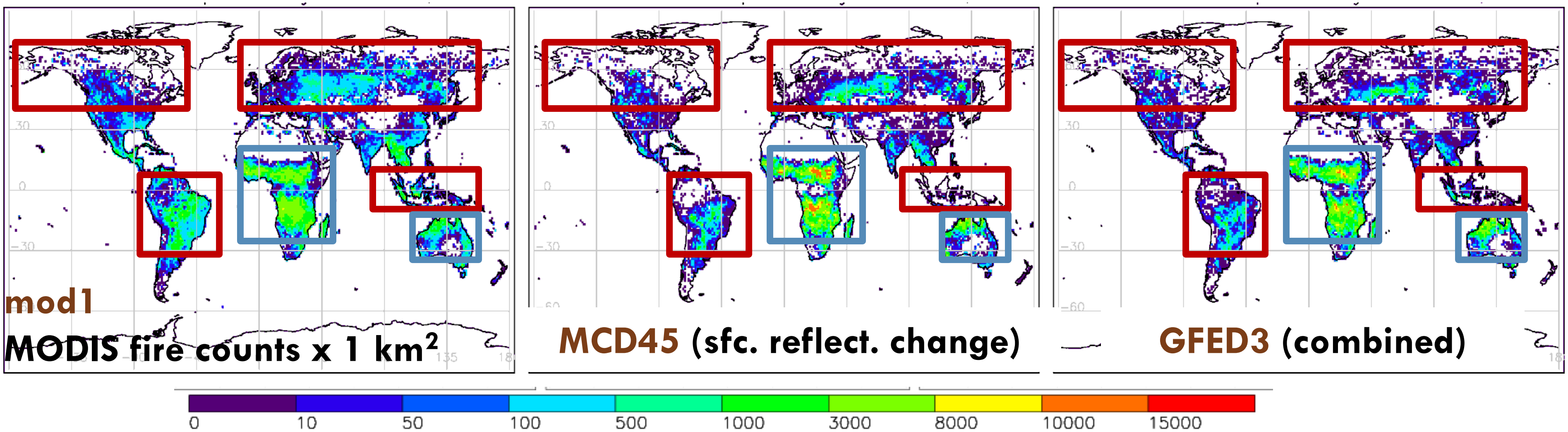
Effective fuel load (a.k.a. "fuel consumption")

$$M_i = A * B * C * F_i$$

Dry Mass burned (DM)

Method adapted from Seiler and Crutzen (1979 in *Climatic Change*)

Burned area estimates for 2006

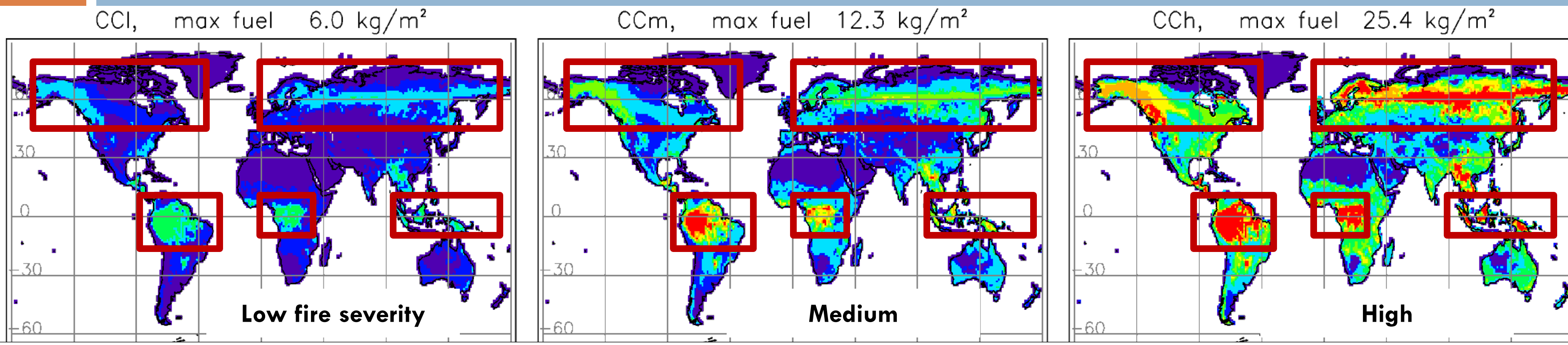


Burned area per GOCART grid box, km^2

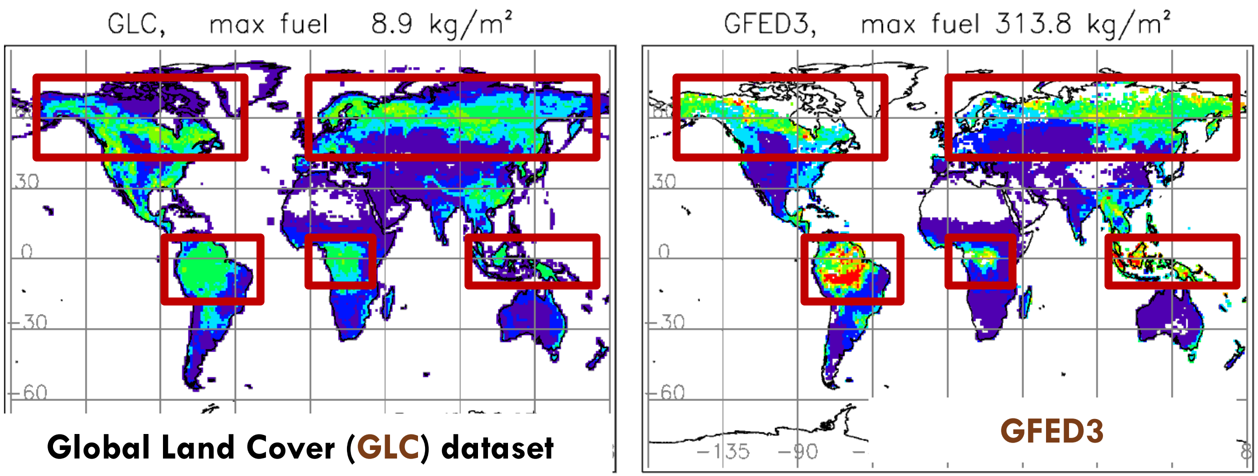
- Higher Leaf Area Index (trees) → mod1 BA > MCD45
- Lower LAI (shrubs, grasses) → MCD45 > mod1
- Croplands is exception: mod1 > MCD45 > GFED3
- GFED3 resembles MCD45 in many regions

More detailed comparisons are by Roy et al. (2008, *RSE*), van der Werf et al. (2010, *ACP*)

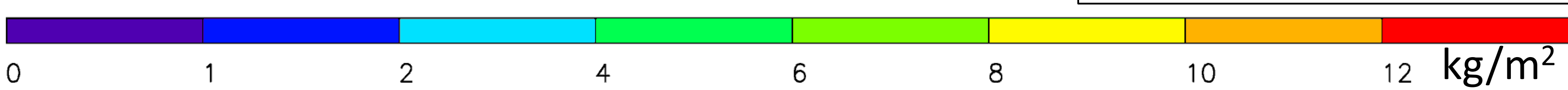
Effective fuel load, a.k.a. fuel consumption (*B**C) estimates



Carbon Consumption database CC[l/m/h] from Weather and Ecosystem-Based Fire Emissions (WEB-FE)



- Largest absolute values and **largest differences** are in the **forested areas**
- **Grass/shrubs** differences **not so large, but most burning** happens in Africa, Latin America, Australia



Emission factors (F_i)

1. Standard GOCART configuration
(Chin et al., 2007)

F_{BC}=1.00 g/kgDM
F_{OC}=8.00 g/kgDM
F_{SO2}=1.12 g/kgDM

2. GLC (Liousse et al., 2003, 2010)

GLC code	GLC vegetation type description	Biomass density, kg/m^2	Burning efficiency	F_{BC}, g(BC)/ kg(DM)	F_{OC}, g(OC)/ kg(DM)	F_{SO2}, g(SO_2)/ kg(DM)
1	Tree Cover broadleaved evergreen	23.35	0.25	0.70	6.40	0.57
2	Tree Cover broadleaved deciduous closed	20.00	0.25	0.60	6.00	1.00
3	Tree Cover broadleaved deciduous open	3.30	0.40	0.62	4.00	0.35
4	Tree Cover needle-leaved evergreen	36.70	0.25	0.60	6.00	1.00
5	Tree Cover needle-leaved deciduous	18.90	0.25	0.60	6.00	1.00
6	Tree Cover mixed leaf type	14.00	0.25	0.60	6.01	0.99
7	Tree Cover regularly flooded fresh water	27.00	0.25	0.70	6.40	0.57
8	Tree Cover regularly flooded saline water	14.00	0.60	0.65	5.15	0.46
9	Mosaic: Tree Cover / Other natural vegetation	10.00	0.35	0.61	5.00	0.68
10	Tree cover, burnt	0	0	0.00	0.00	0.00
11	Shrub Cover closed-open evergreen	1.25	0.90	0.62	4.00	0.35
12	Shrub Cover closed-open deciduous	3.30	0.40	0.62	4.00	0.35
13	Herbaceous Cover closed-open	1.43	0.90	0.62	4.00	0.35
14	Sparse herbaceous or sparse shrub cover	0.90	0.60	0.67	3.11	0.37
15	Regularly flooded shrub and/or herbaceous cover	0	0	0.00	0.00	0.00
16	Cultivated and managed areas	0.44	0.60	0.73	2.10	0.40
17	Mosaic: Cropland / Tree Cover / Other natural v.	1.10	0.80	0.64	3.64	0.36
18	Mosaic: Cropland / Shrub and/or grass cover	1.00	0.75	0.65	3.35	0.37

3. GFED3 (van der Werf, 2010)

	Deforestation	Savanna and Grassland	Woodland	Extratropical forest	Agricultural waste burning	Peat fires
OC	4.30	3.21	3.76	9.14	3.71	4.30
BC	0.57	0.46	0.52	0.56	0.48	0.57
SO_2	0.71	0.37	0.54	1.00	0.40	0.71

Estimating BB emissions:
2. Fire Radiative Power (FRP) - based approach

$$E_i = c_{region,i} * FRP$$

E_i – emission rate of gas/aerosol species *j* (g/sec)

$c_{region,i}$ – region- and species-specific conversion factor

FRP – MODIS-measured Fire Radiative Power (MJ/s)

(Kaufman et al., 1996;

Ichoku and Kaufman, 2005;

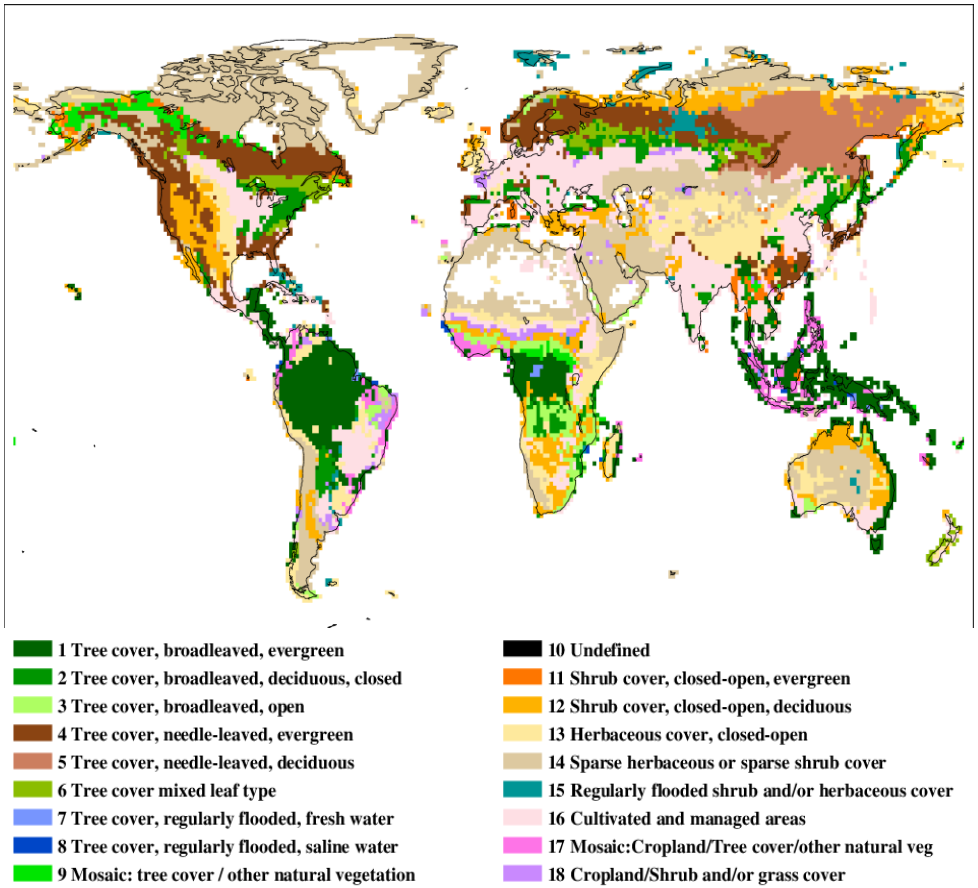
Wooster et al., 2003, 2005)

Quick Fire Emissions Dataset (**QFED2**)

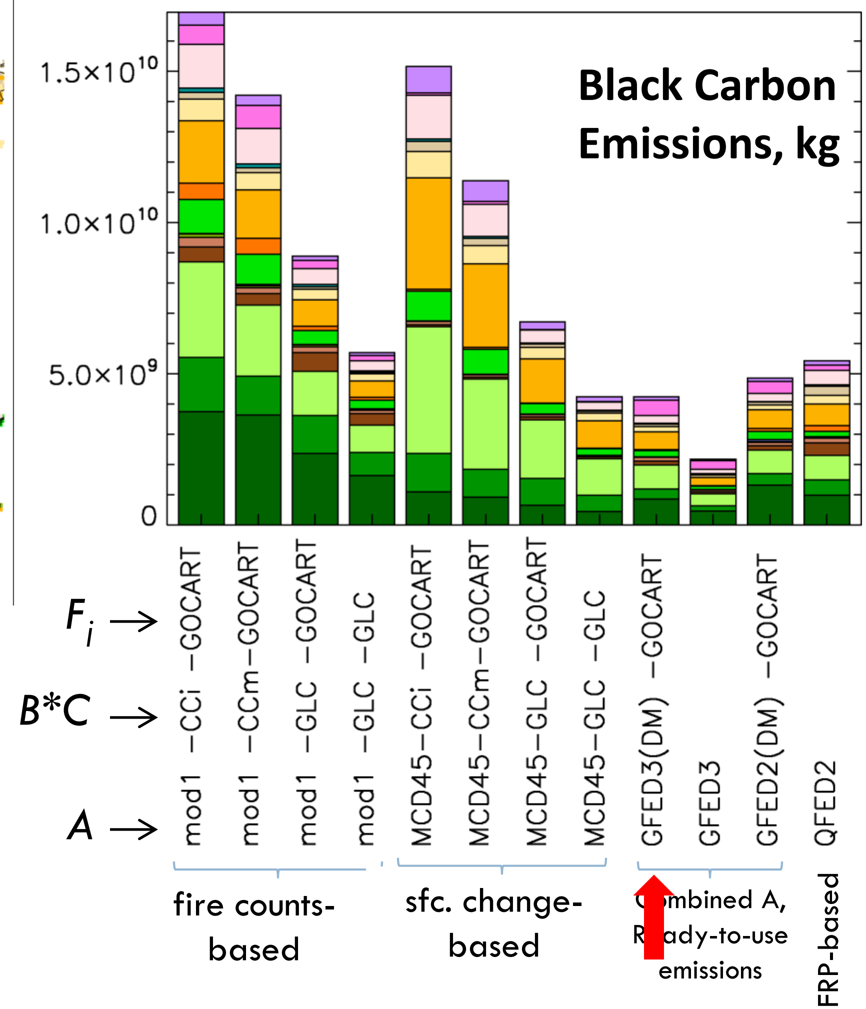
- Developed at NASA's Global Modeling and Assimilation Office for GEOS-5 model
- Uses GFED3 emissions and MODIS AOD as parameters to derive $c_{region,i}$

(Darmenov and da Silva, 2012, manuscript in preparation)

Global total BC estimates for 2006



Vegetation types from Global Land Cover (GLC) dataset



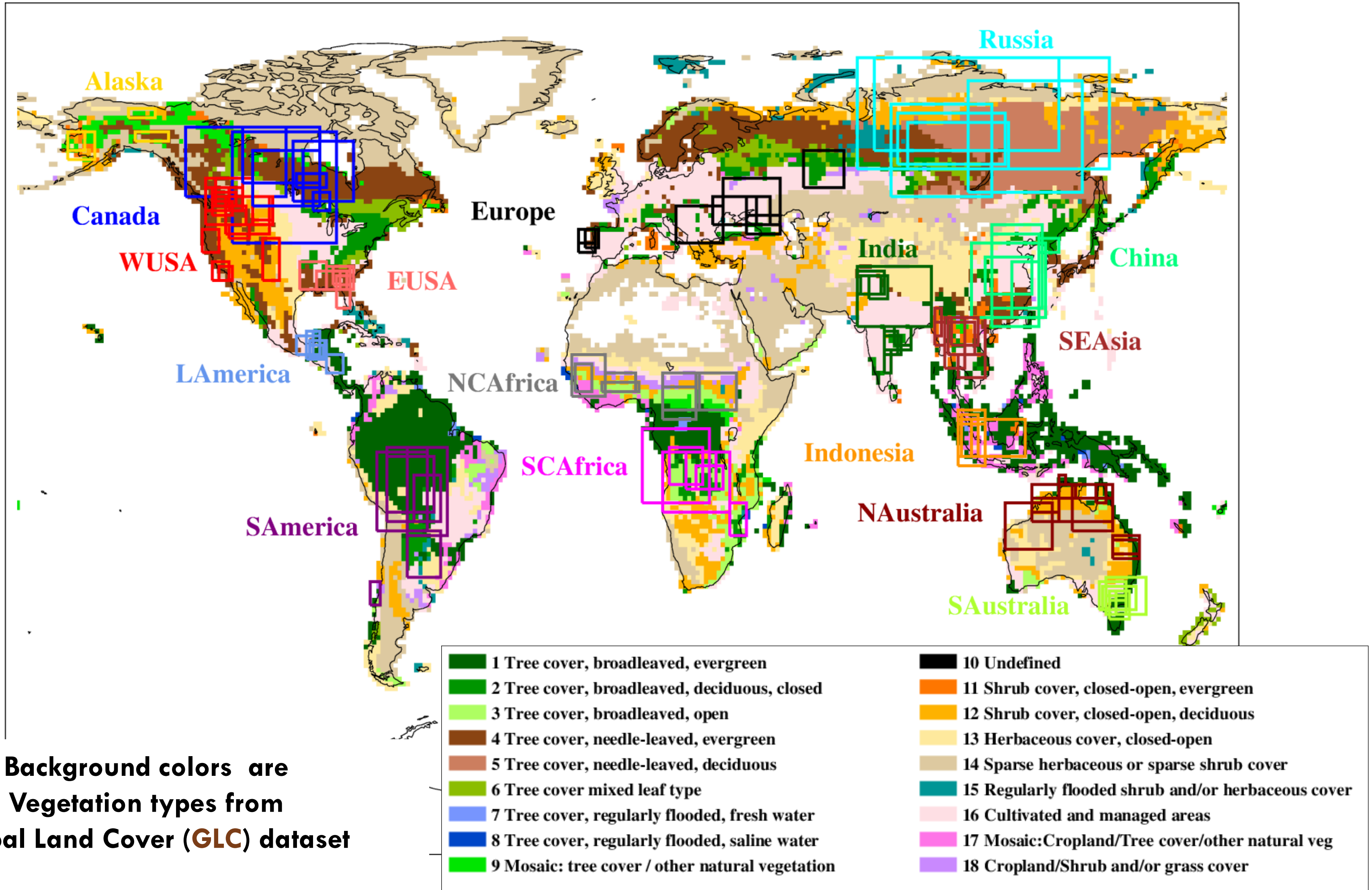
Goddard Chemistry Aerosol Radiation and Transport (**GOCART**) model

- Global aerosol model
- **Resolution:**
  1°(lat) x 1.25°(lon) x 30 vert. layers
- **Meteorological fields** from Goddard Earth Observing System Data Assimilation System (GEOS DAS) version 4
- 3-hourly output
- **Emissions** include: dust, sea salt, anthropogenic, sulfate & precursors, BB emissions
- **BB emissions** are input from **external** inventories

GOCART runs with 13 introduced emission options

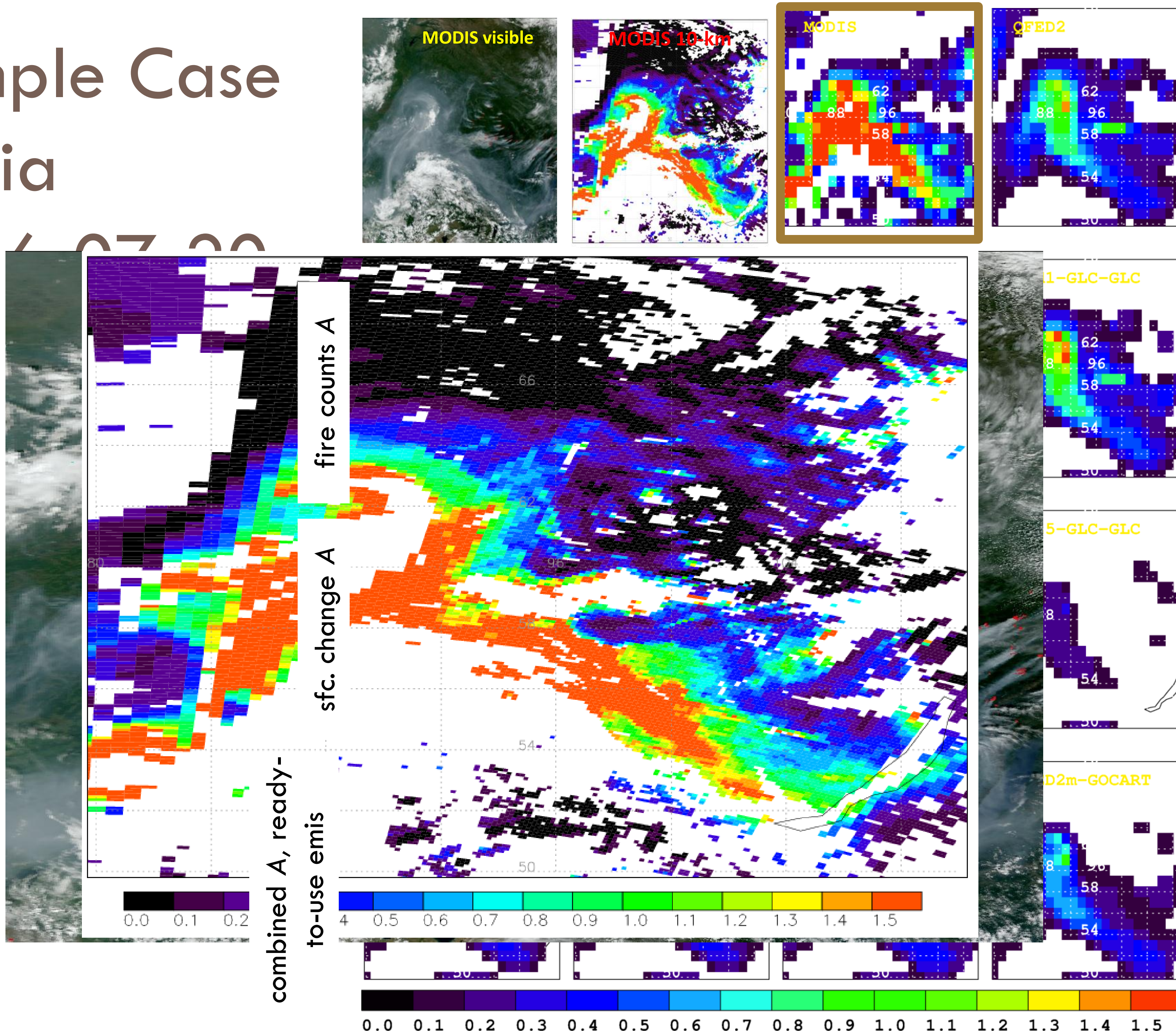
- **Study period:** June 2006-June 2007 (+3 months spin-up)
- **13 emission options** are used as BB emissions in separate GOCART runs
- FRP-based QFED inventory uses MODIS AOD as a calibration dataset during development → will not compare to MODIS AOD

124 studied fire cases in 2006-2007

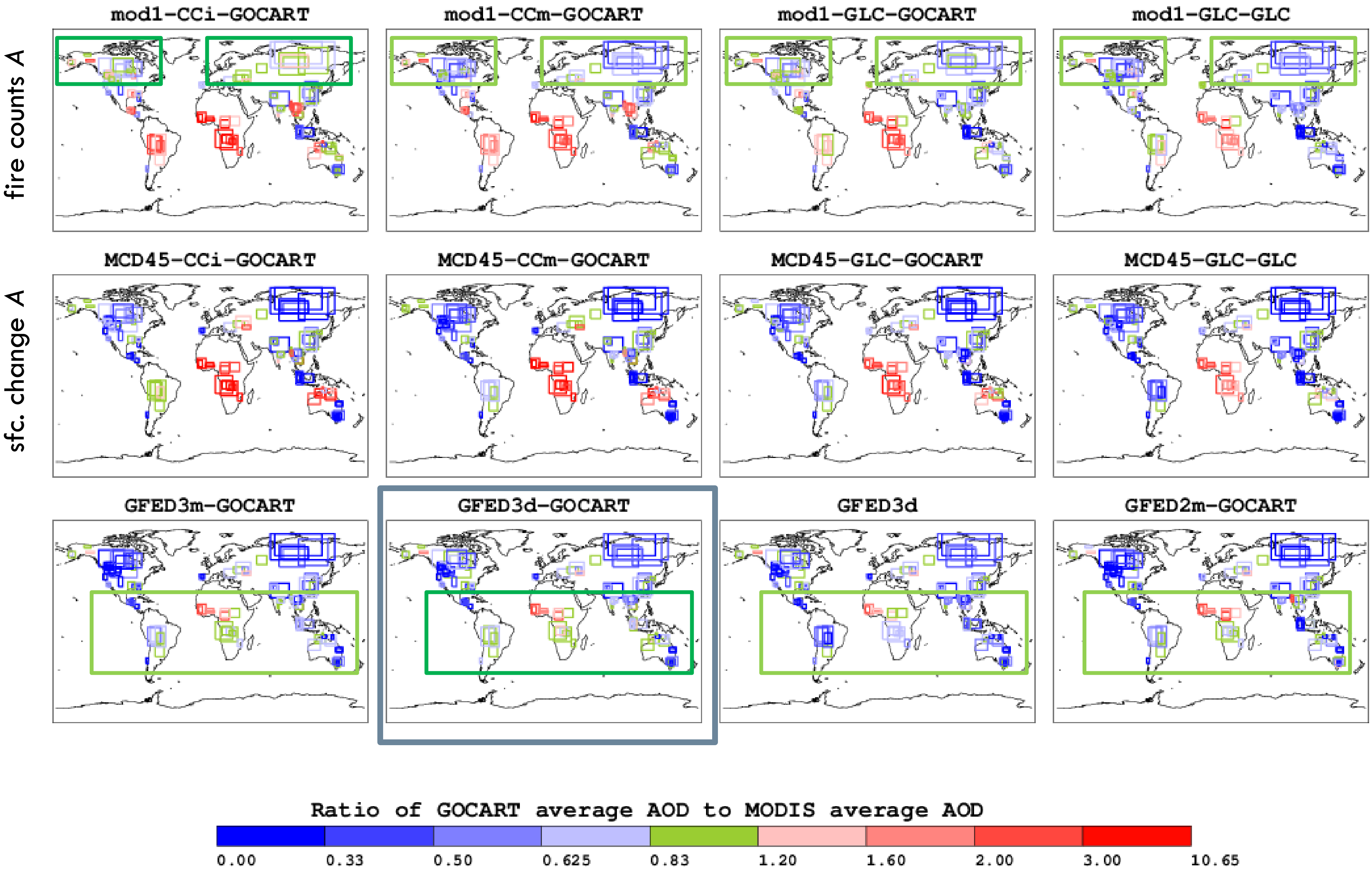


Background colors are Vegetation types from Global Land Cover (GLC) dataset

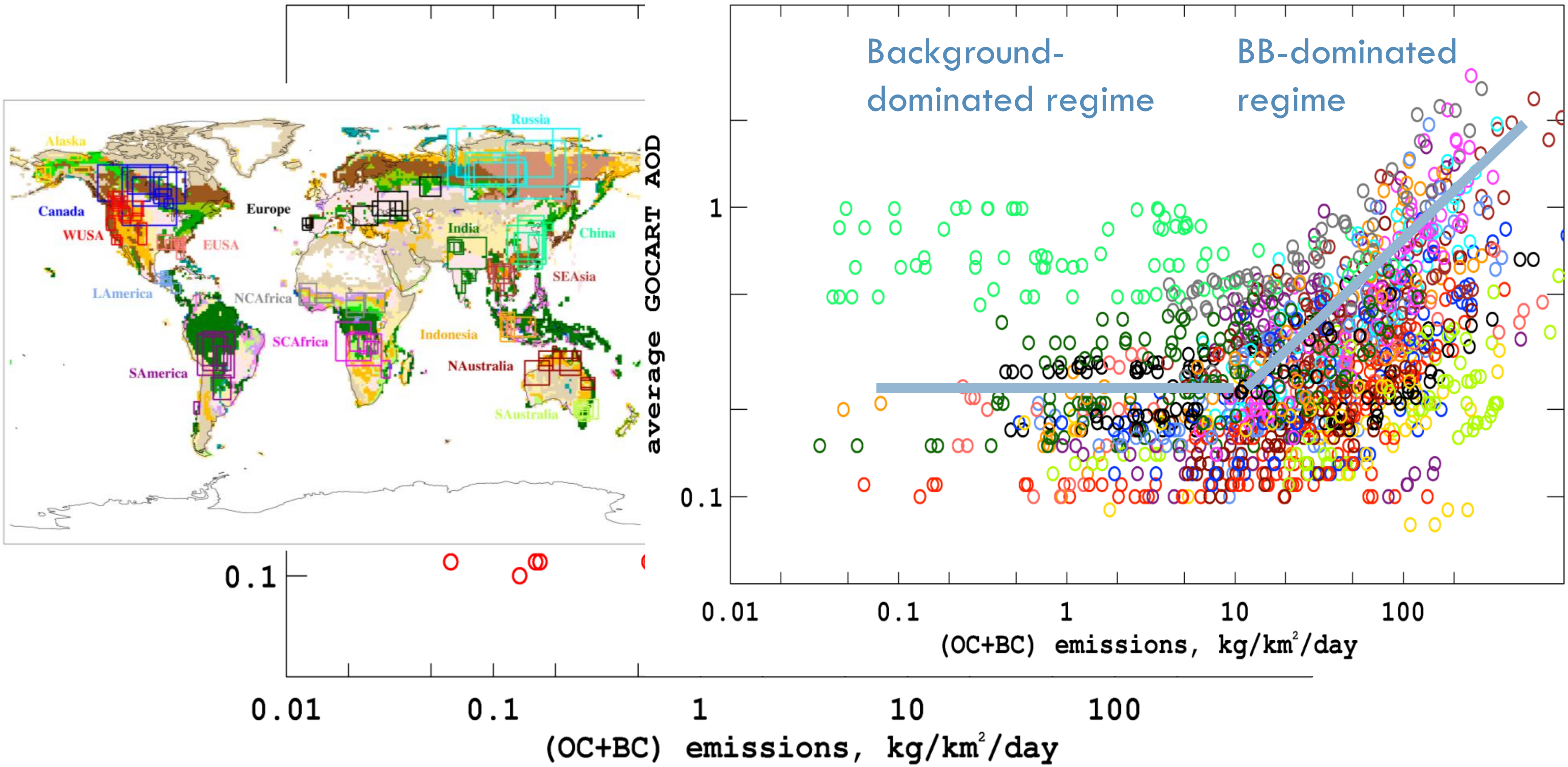
Sample Case Russia 200[illegible]



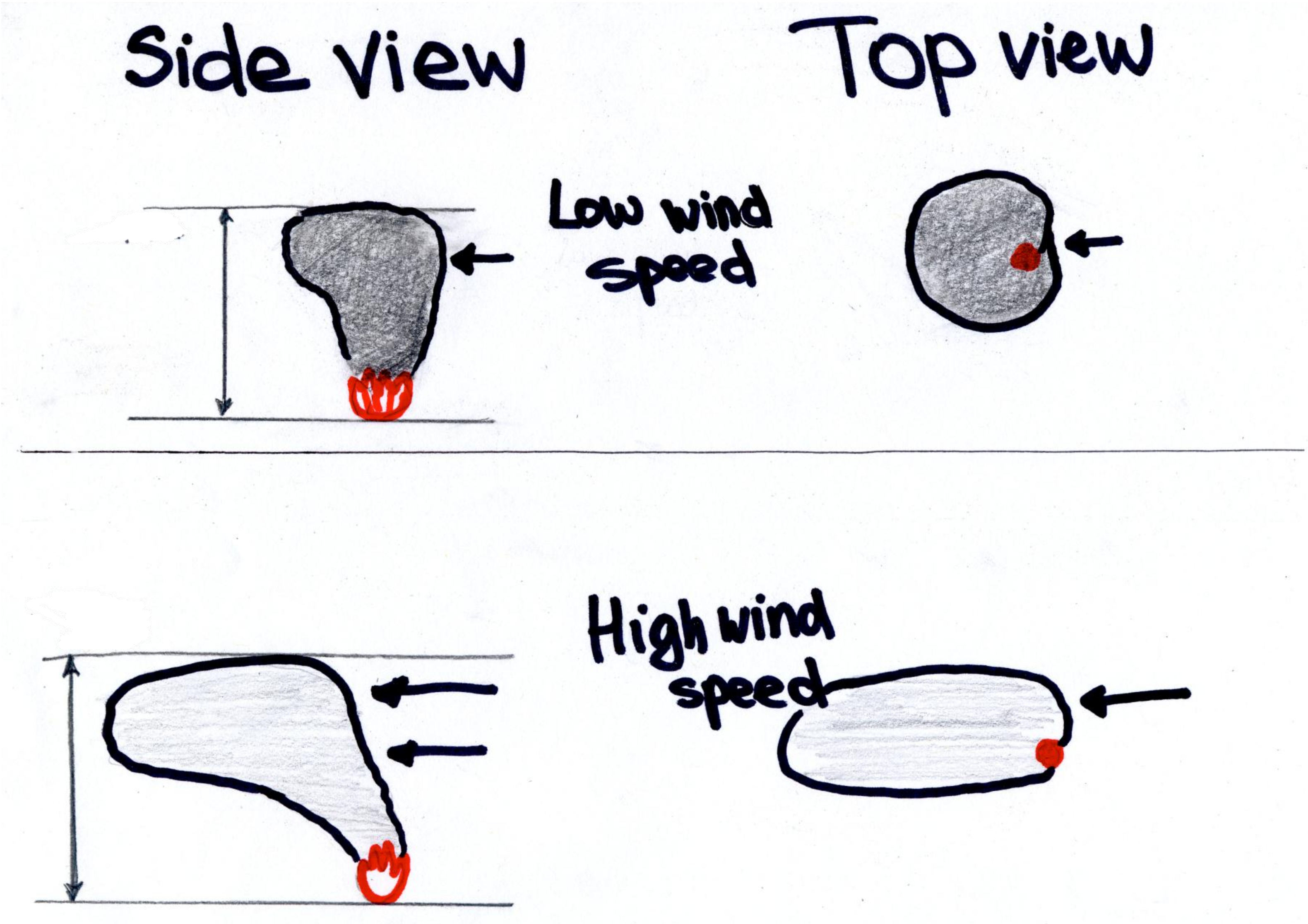
GOCART ave AOD /MODIS ave AOD



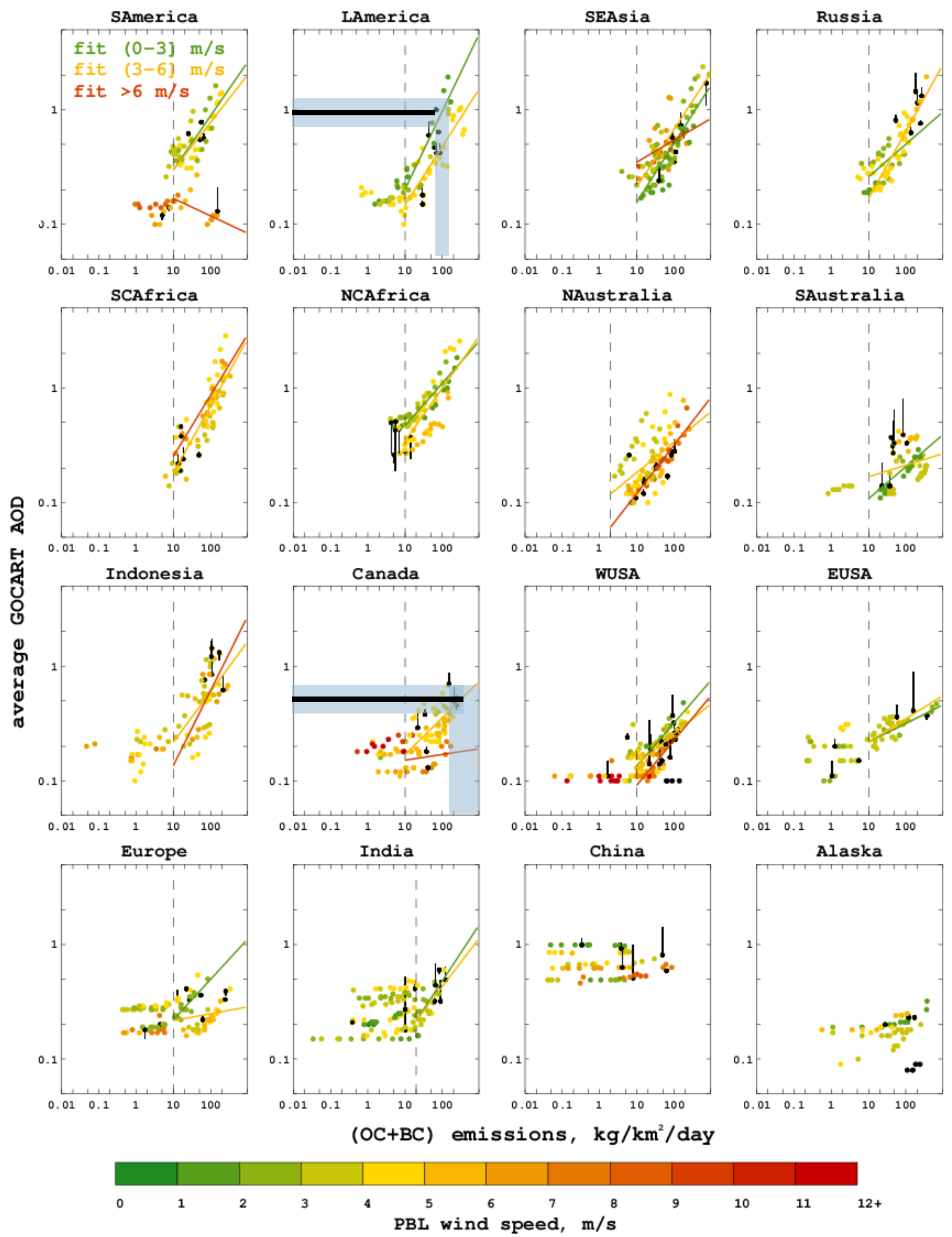
AOD vs. emissions



Plume dispersion



AOD vs emissions



Y= a + bX

X is the OC+BC daily-integrated fire emission in kg per km^2,

Y is the average GOCART AOD within the plume,

a (related to the background aerosol loading) and ***b*** (related to the plume environment) are wind-regime-dependent regional fit coefficients

Fit is performed for 3+ data points above the emissions cutoff (~10 kg/km^2/day usually) in each wind speed category

Limitations of using MODIS AOD to constrain BB emissions source strength

- We **assume** that **AOD under- or overestimation** is mostly a **result of emissions** deficit or excess, and errors in aerosol removal and optical properties are smaller.

- Total AOD provides **poor constraint** in heavily polluted environments or for thin plumes (**background-dominated regime**).

- Only one year of BB has been explored. **Interannual variability** and different burning regimes are needed to refine the method.
  + more cases in Alaska during stronger burning year.

- **Coarse spatial resolution of the model**, the method is insensitive to small variations in AOD during averaging and aerosol concentration changes.

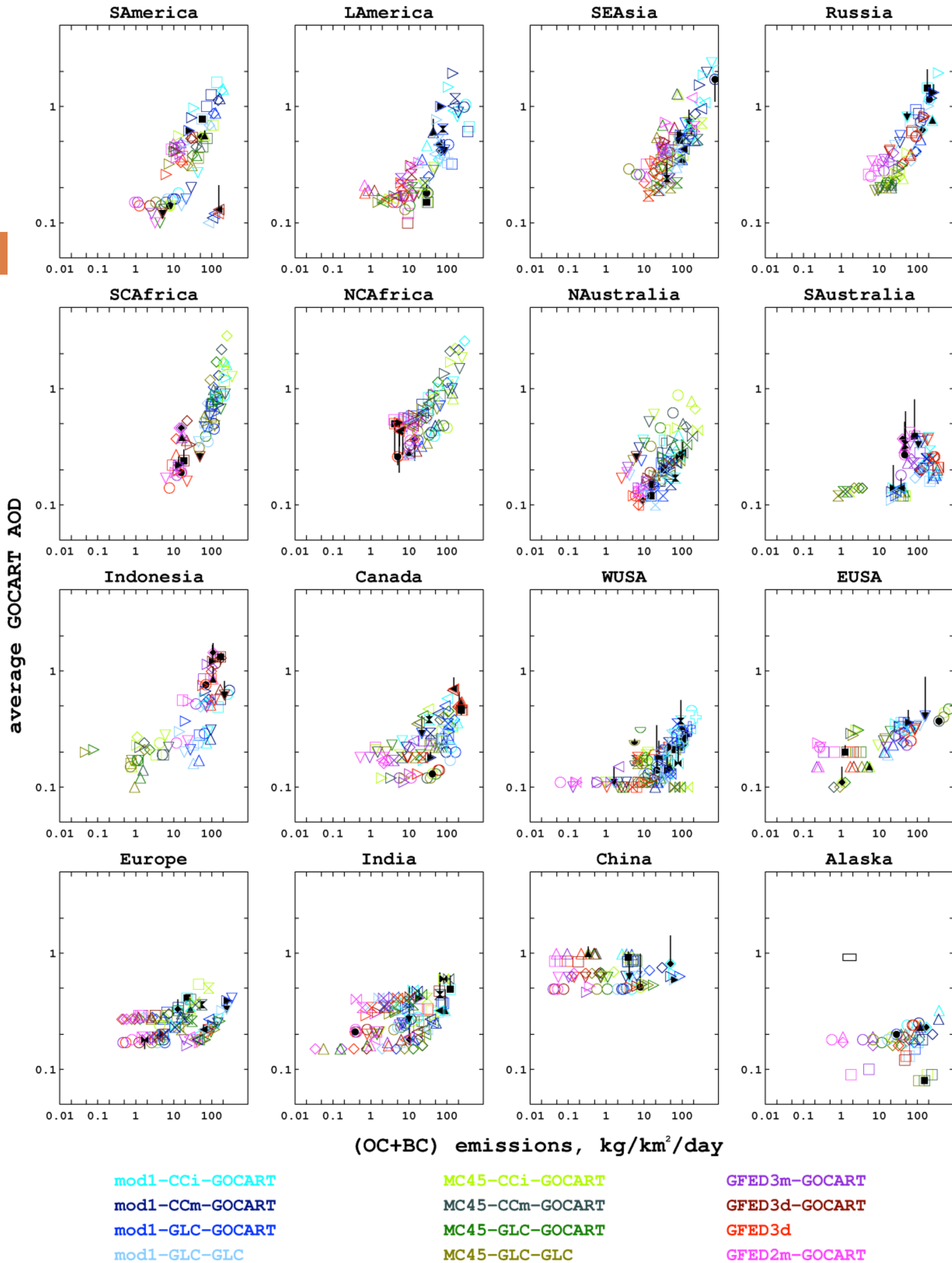
- **MODIS AOD** product brings a set of its own **limitations** (omitting retrievals in thick plume cores, in cloudy scenes, omissions and biases above bright surfaces).

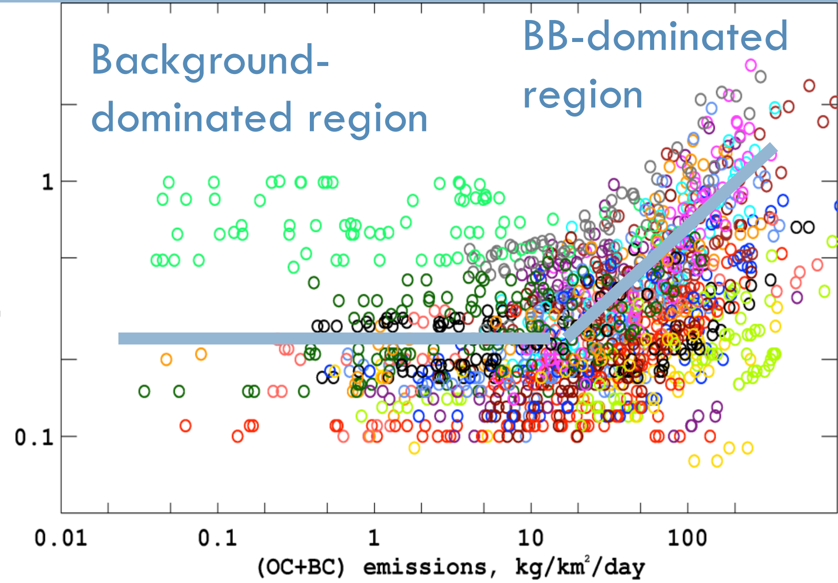
Method Refinement and Application: Towards Improved BB Emissions for Global Models

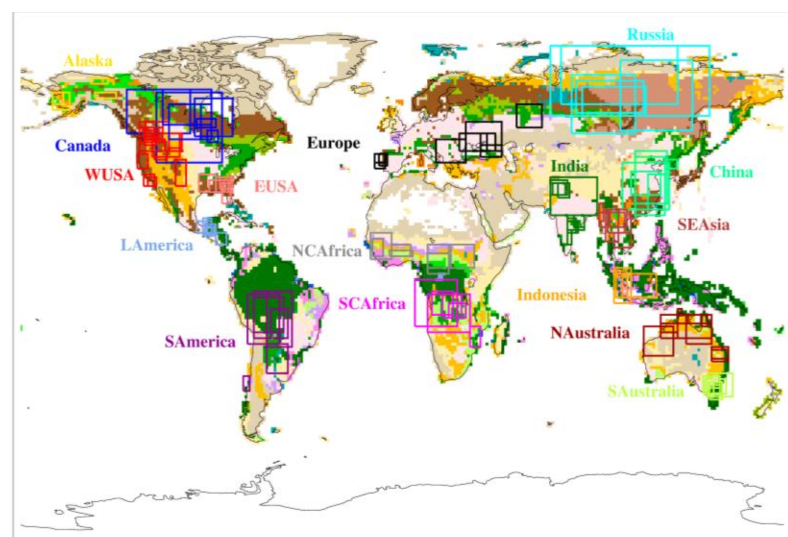
- **Expand the dataset of test cases** to account for inter-annual variability of biomass burning and add cases to BB regions where too little burning was detected in 2006-2007 (Alaska)
  - Severe vs. "regular" fires
  - Consider plume height w.r.t. PBL (use MISR plume height climatology)
- Improve the **MODIS AOD** validation dataset by developing a multi-sensor **correction procedure** in the regions of known bias [*Levy et al. 2010; Hyer et al., 2011*]
- Define the criteria, develop and test an approach to merge the best-performing BB emission inventories for different regions
- Estimate the **role of the model configuration** on the BB emissions-AOD relationship and subsequent analysis

AeroCom contribution

- Estimate the role of the model configuration on the BB emissions-AOD relationship and subsequent analysis (..test the emissions-AOD relationship in other models ..)
- **Suggested runs (2008):**
  - Standard model run with no BB emissions
  - Standard model run with your own emissions
  - Standard model run with provided new BB emissions, your emission injection height (EIH)
  - Standard model run with prescribed new emissions, prescribed EIH
- **Desired output:** daily
  - 3D: AOD, concentration, winds, Temperature, pressure
  - 2D: emissions (BC, OC, SO_2, other)


SAmerica
LAmerica
SEAsia
Russia
SCAfrica
NCAfrica
NAustralia
SAustralia
Indonesia
Canada
WUSA
EUSA
Europe
India
China
Alaska
average GOCART AOD
(OC+BC) emissions, kg/km²/day
mod1-CCi-GOCART
mod1-CCm-GOCART
mod1-GLC-GOCART
mod1-GLC-GLC
MC45-CCi-GOCART
MC45-CCm-GOCART
MC45-GLC-GOCART
MC45-GLC-GLC
GFED3m-GOCART
GFED3d-GOCART
GFED3d
GFED2m-GOCART


Background-
dominated region
BB-dominated
region
(OC+BC) emissions, kg/km²/day


Alaska
Russia
Canada
WUSA
Europe
EUSA
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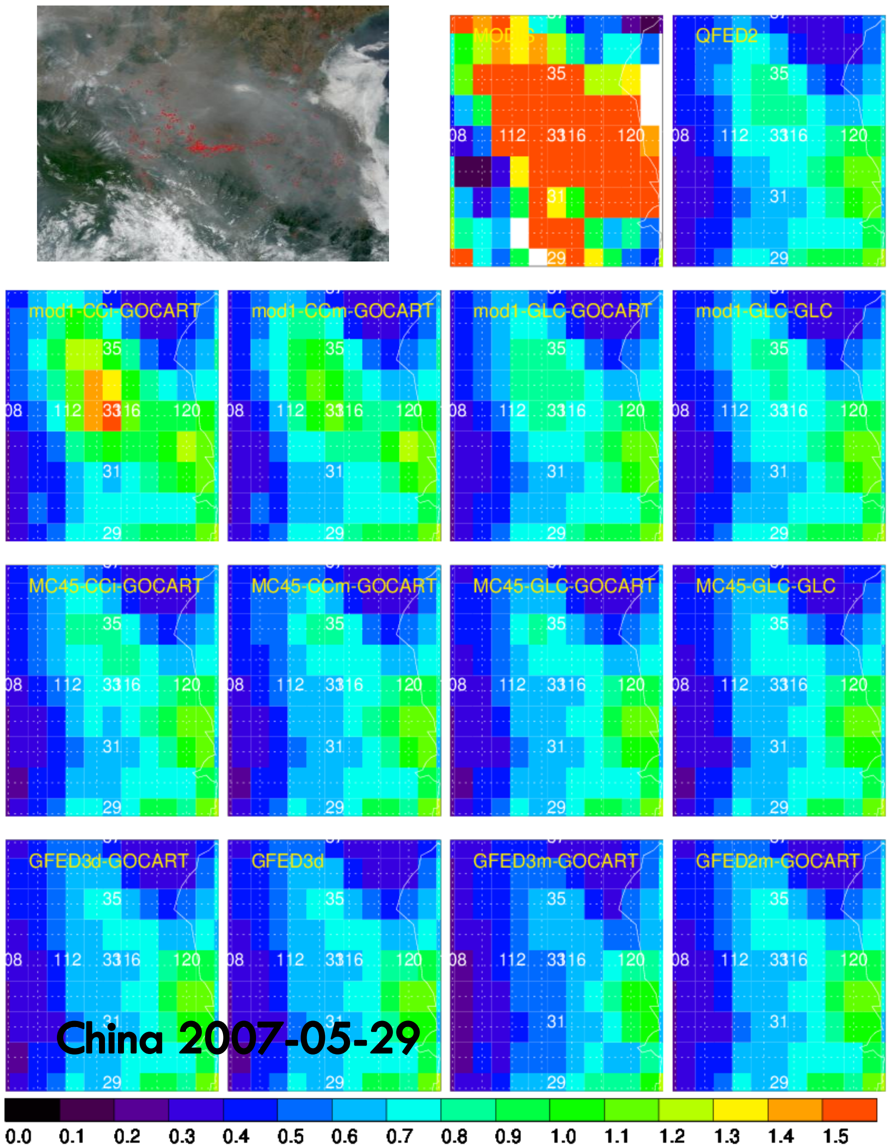
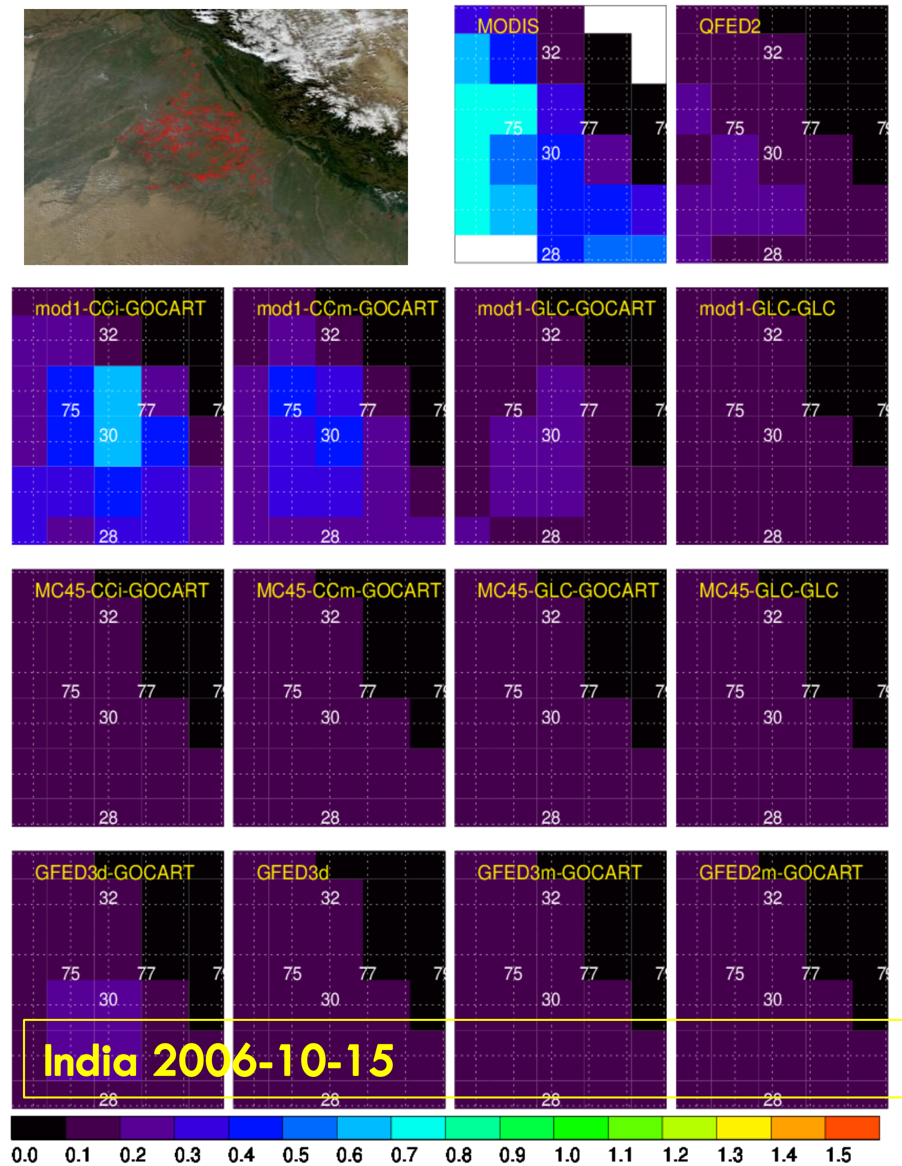
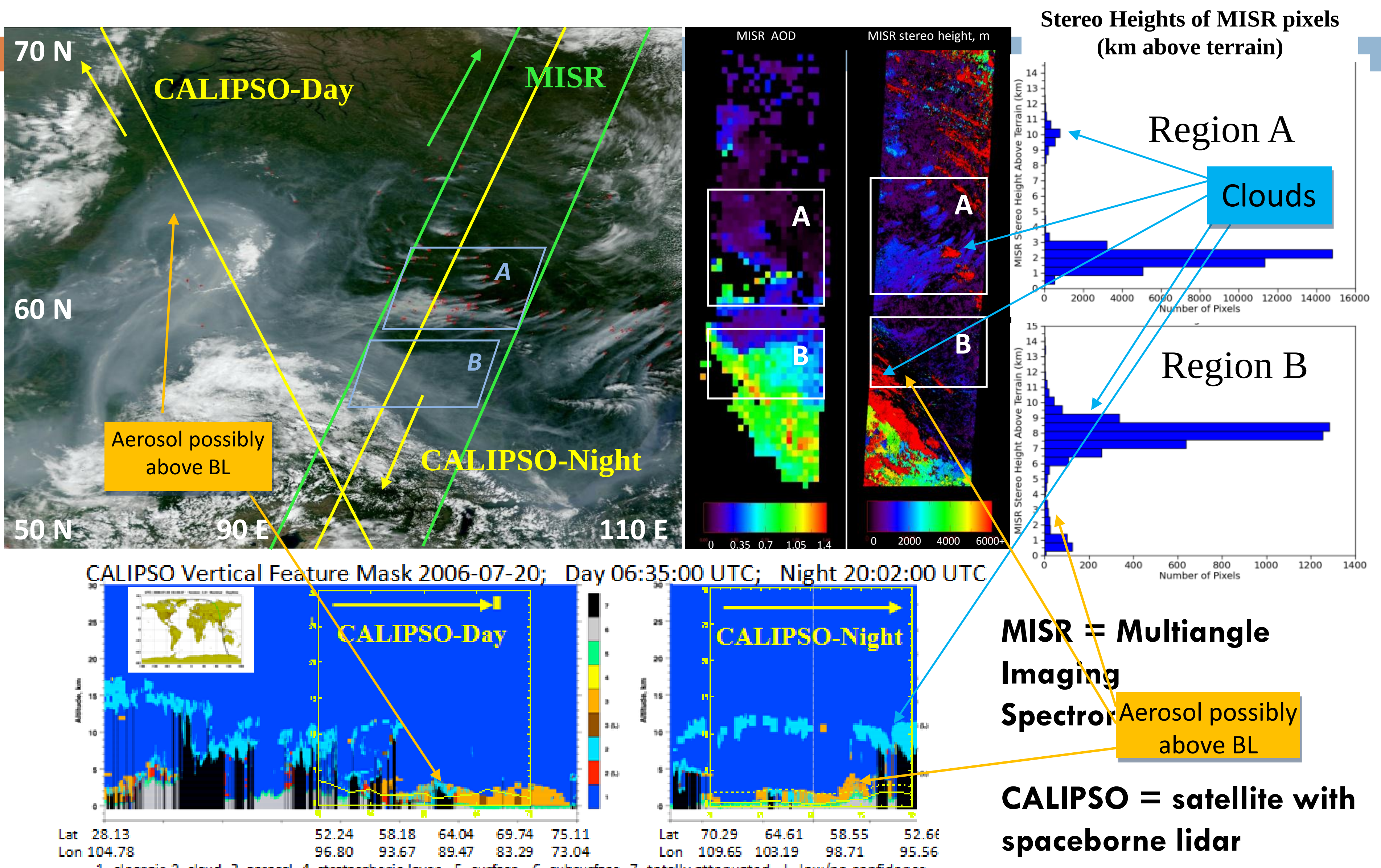
China
SEAsia
LAmerica
NCAfrica
SCAfrica
Indonesia
NAustralia
SAmerica
SAustralia

Background-dominated regions





Plume heights check (want to see most in PBL)



Part 1 summary

- We have a representative **set** of commonly used BB aerosol **emission estimates** based on different approaches, *but* **yielding a broad range** of estimated emission amounts
- Choice of **burned area** dataset has the **greatest effect** (up to an order of magnitude) on resultant emission estimates difference; emission factor or fuel consumption – contribute factor of 2-3 difference each

Part 2

- **Critically test performance** of each emission option in the model: compare GOCART-simulated Aerosol Optical Depth (AOD) with satellite-measured smoke AOD

Part 2 summary

- **Regional analysis** of emission inventories and their performance is essential
- **AOD-emissions relationship** forms **2 regimes**: background-dominated, and BB-dominated
- In BB-dominated regime, **wind speed defines the AOD-emissions** relationship

Part 3

- **Future work:** Apply the current method to improve BB emission estimates for the global models