Evaluation of Tropospheric Remote Sensing Satellites in Relation to Fires

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Biomass burning emissions

Seiler and Crutzen, 1980 – Emissions estimation

- M (quantity of gas emitted) = Area x Biomass Density x Burning Efficiency x Emission Factor

- Area – Satellite based mapping;

- Biomass density/fuel loading – (vegetation type mapping);

- Burning efficiency - (most uncertain - field measurements);

- Emission factors (field or lab based) satellite based surrogate measures combined with inverse modelling.

Advances in remote sensing methodologies: Fire Radiative Energy Products replacing the - Burning Efficiency and Biomass density.

Tropospheric Emissions from Satellites

How effective are the satellites in detecting pollutant signals from open biomass burning?

Among the fire counts versus FRP which one relates better to pollutant concentrations?

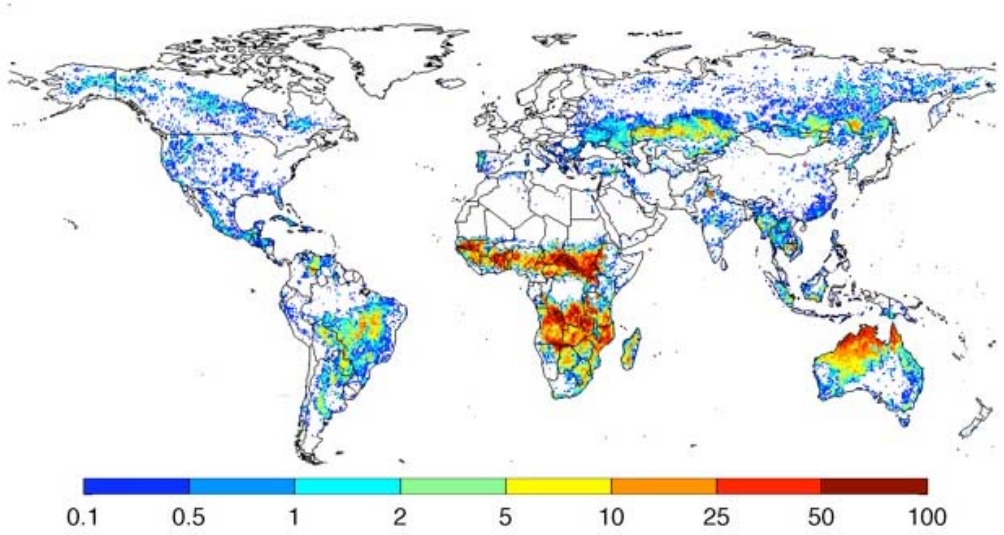
Carbon monoxide – MOPITT
Carbon dioxide – GOSAT
NO2 – SCIAMACHY and Ozone Monitoring Instrument (OMI)
Aerosol Optical Depth

GFED vs GFAS Emissions intercomparison

How does GFED based emissions compare with GFAS based emission estimates?

Global Fire Emissions Database

GFED3 provides monthly estimates of burned area and emissions at a 0.5° spatial resolution.

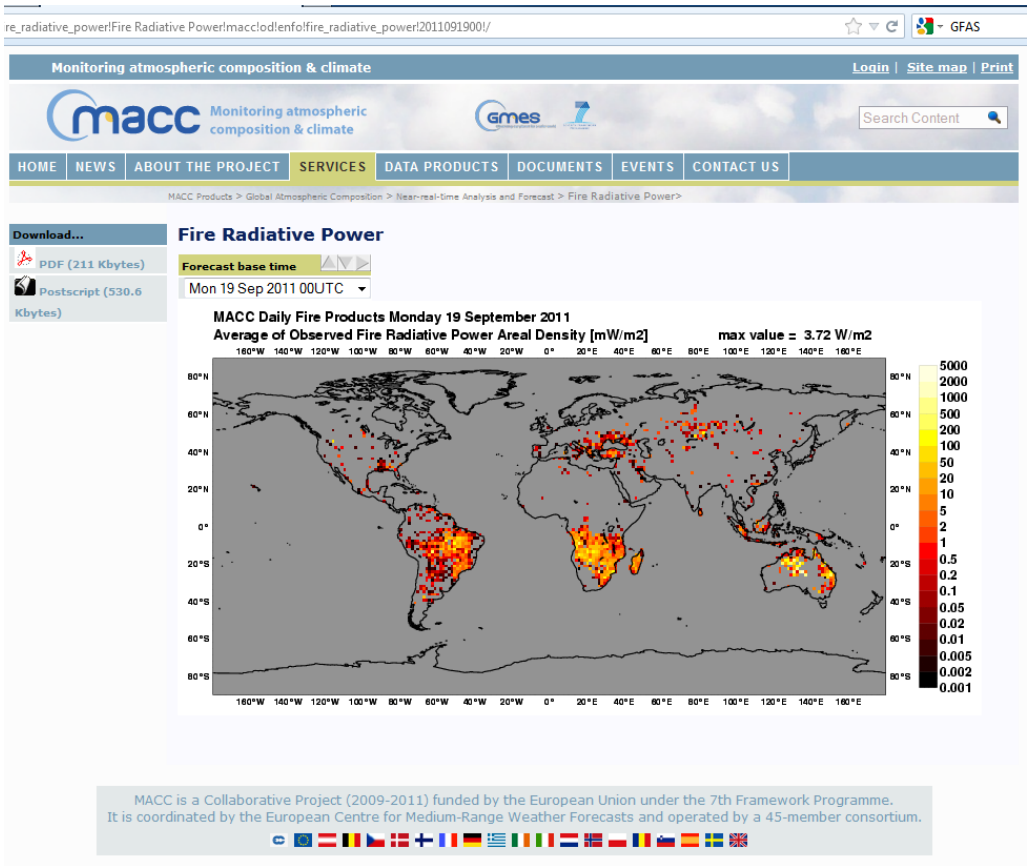


- Burned areas was derived primarily from 500m maps of surface reflectance from the MODIS (Giglio et al., 2010)

Global Fire Assimilation System (GFAS)

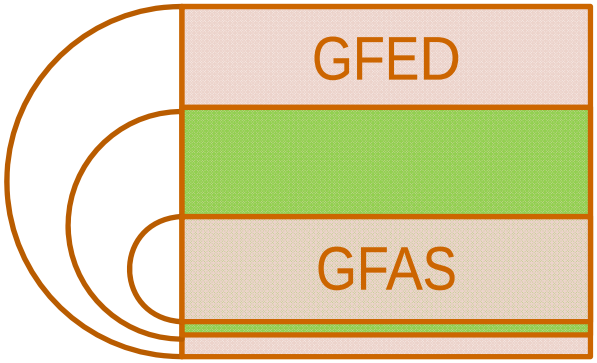
- GFASv1.0 has a 0.5 degree spatial resolution.

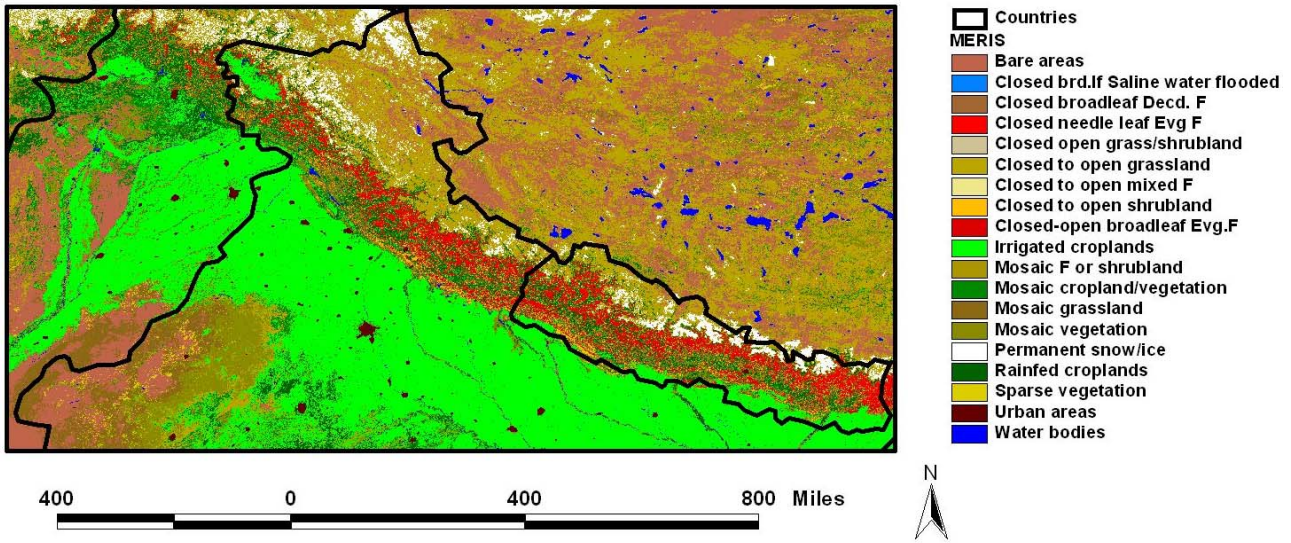
- Daily average emissions are estimated based on Fire Radiative Power (FRP) using Andreae and Merlet (1991) Emission factors.



- Thermal radiation is detected from biomass burning and other open fires using observations from SEVIRI (North America) and MODIS. (FRP directly proportional to the amount of biomass consumed x emission factors). The Fire Radiative Power product (FRP, in MWatts) provides information on the measured radiant heat output of detected fires.

Intercomparison GFED vs GFAS Emissions





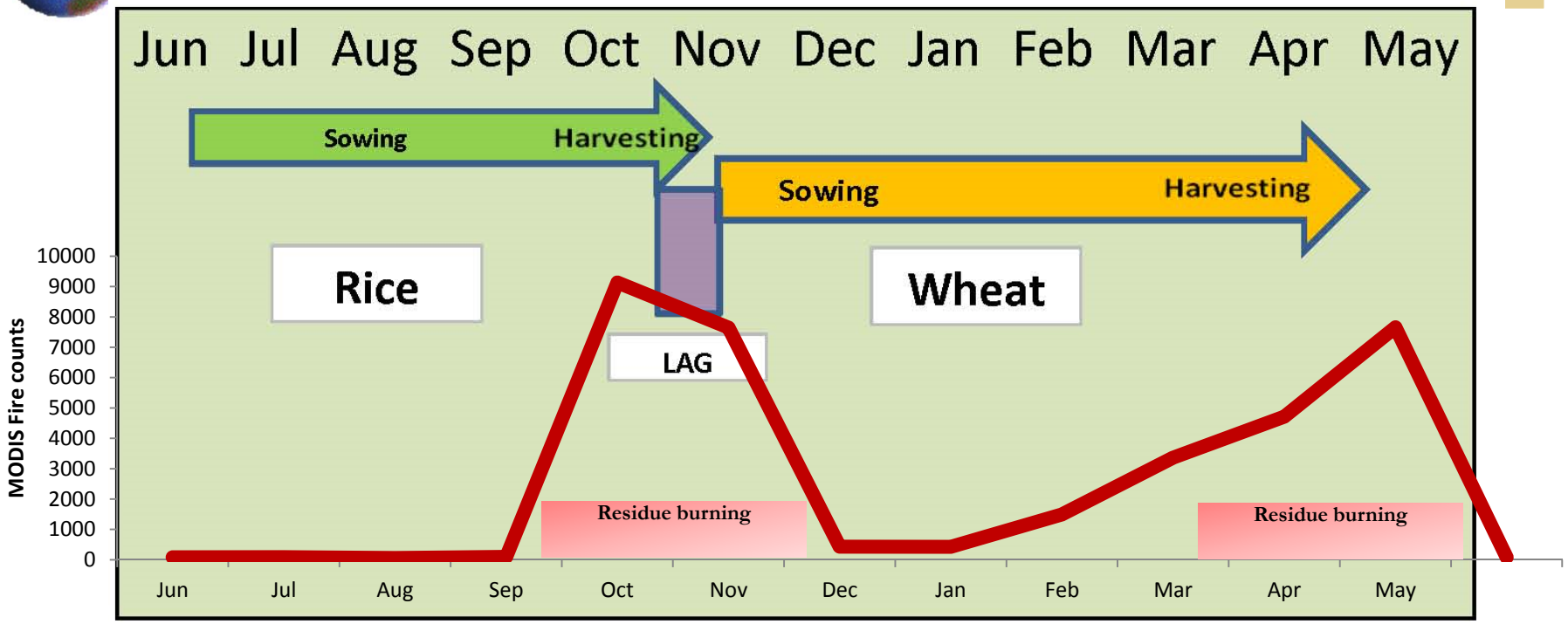
Agricultural focus as the IG region is dominated by the same;

Most of the emissions seems to be under-estimated from Agriculture as they occur rapidly, small scale and due to satellite under-detection.

Seasonal component seems important; Wheat due to relatively large residues seems to release more pollutants compared to Rice; however, Rice is grown in several small patches and burnt subsequently (number of fires more, but with less strength).

Area: 500,000 sq.km; Equivalent to Texas area!

Bimodal trend correspond to Rice-Wheat Residue Burning



The main rice growing season is the 'Kharif'. It is known as Winter rice as per the harvesting time. The sowing time of winter (Kharif) rice is July-August and is harvested in October-November.

Wheat is sown during November-December and harvested during April-May.

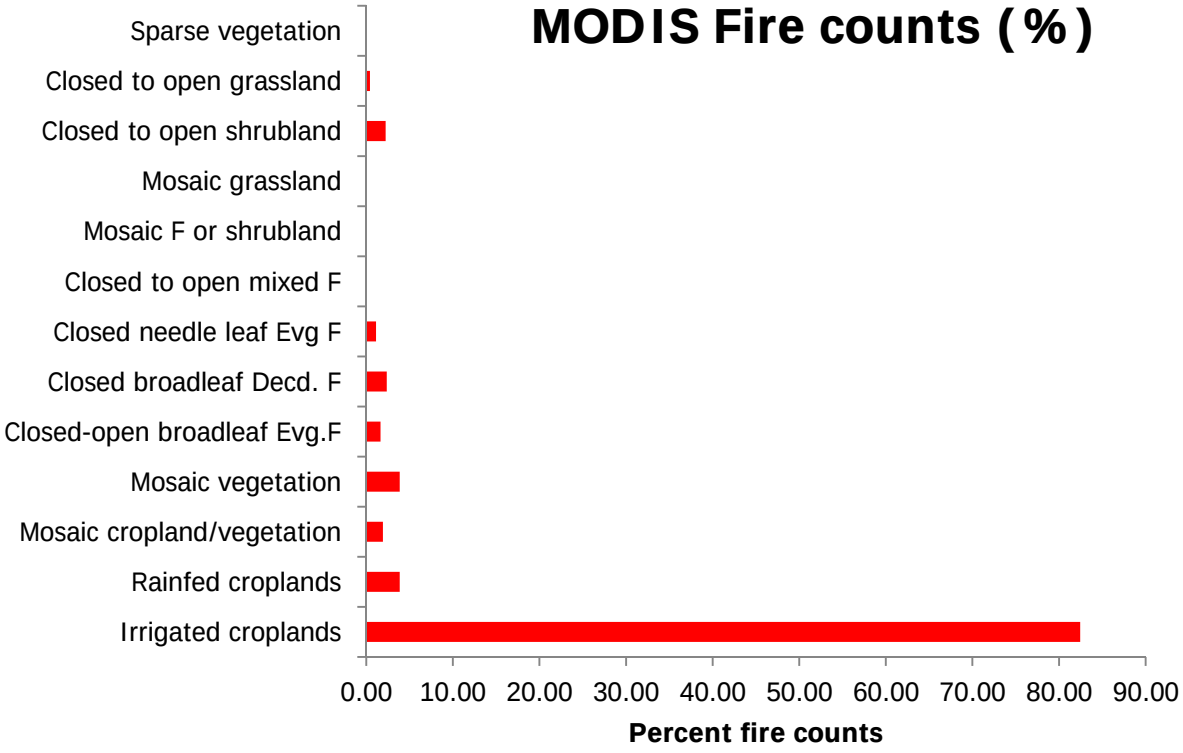
High fire counts from MODIS correspond to Residue burning season.

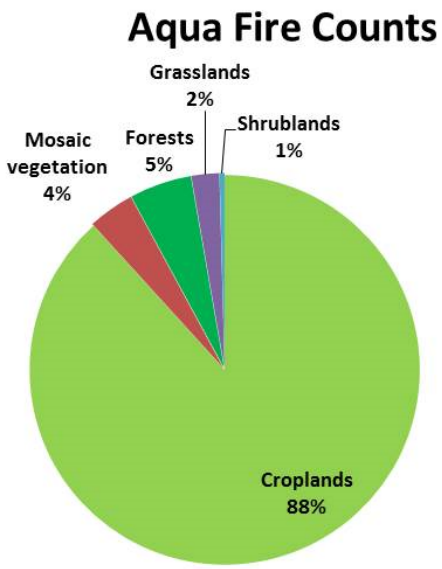
Vadrevu et al., 2011. 159(6)1560–1569.

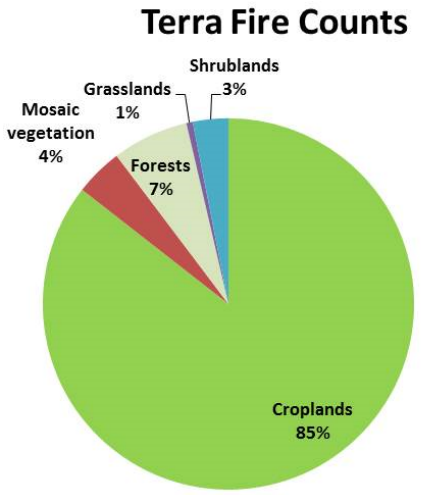
MODIS fire analysis

2010 Total Fire counts – 35318

Aqua – 23601 (66.82%) – Satellite pass (2.00 pm)
Terra – 11717 (33.18%) - Satellite pass (11.00 am)



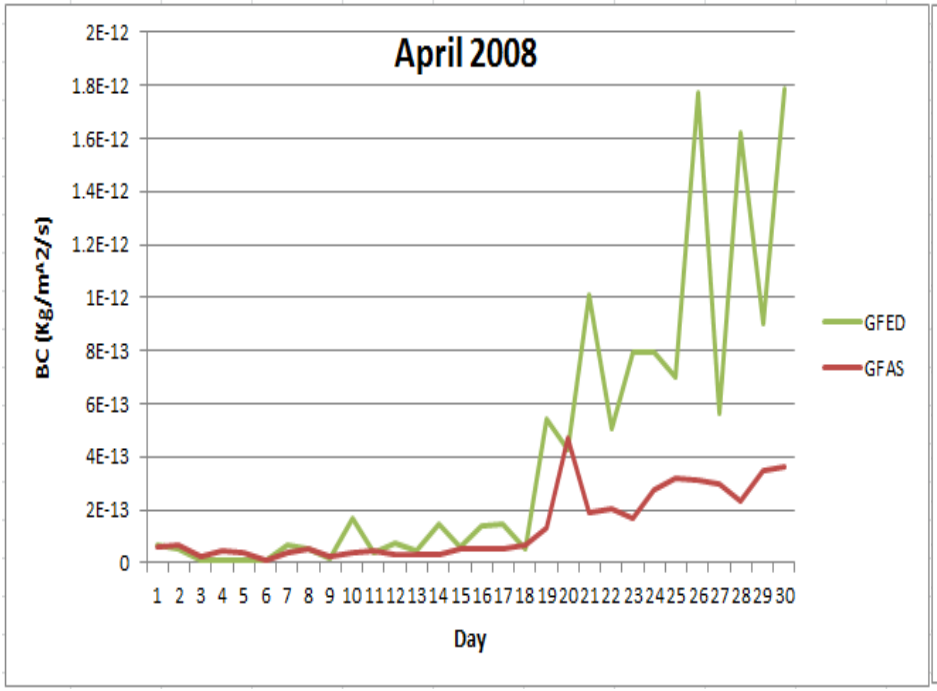


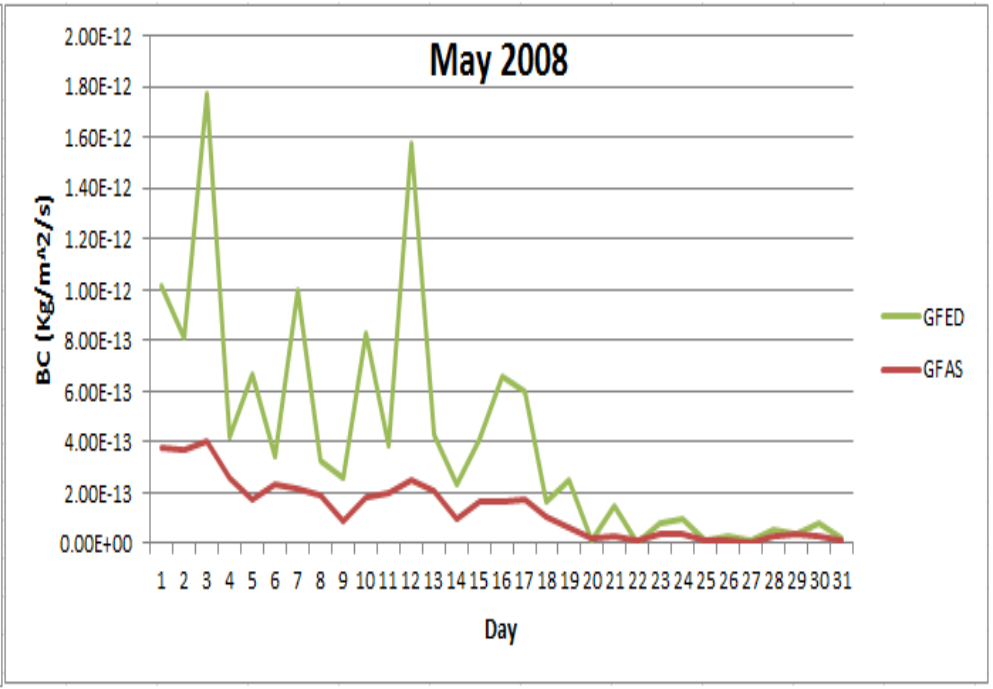


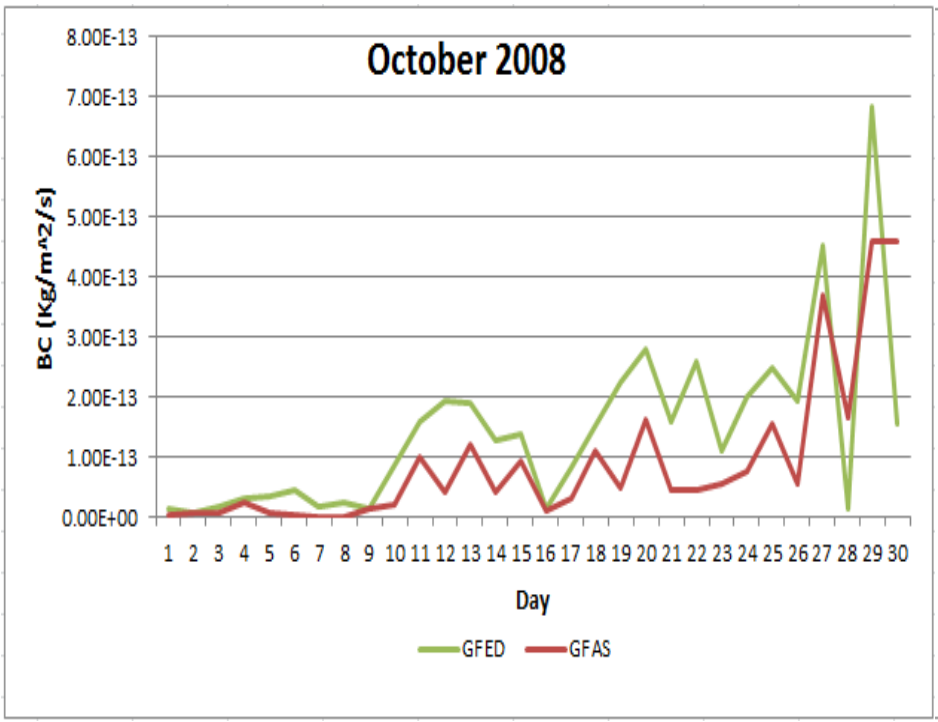
Vadrevu et al., IEEE JSTARS, 2012

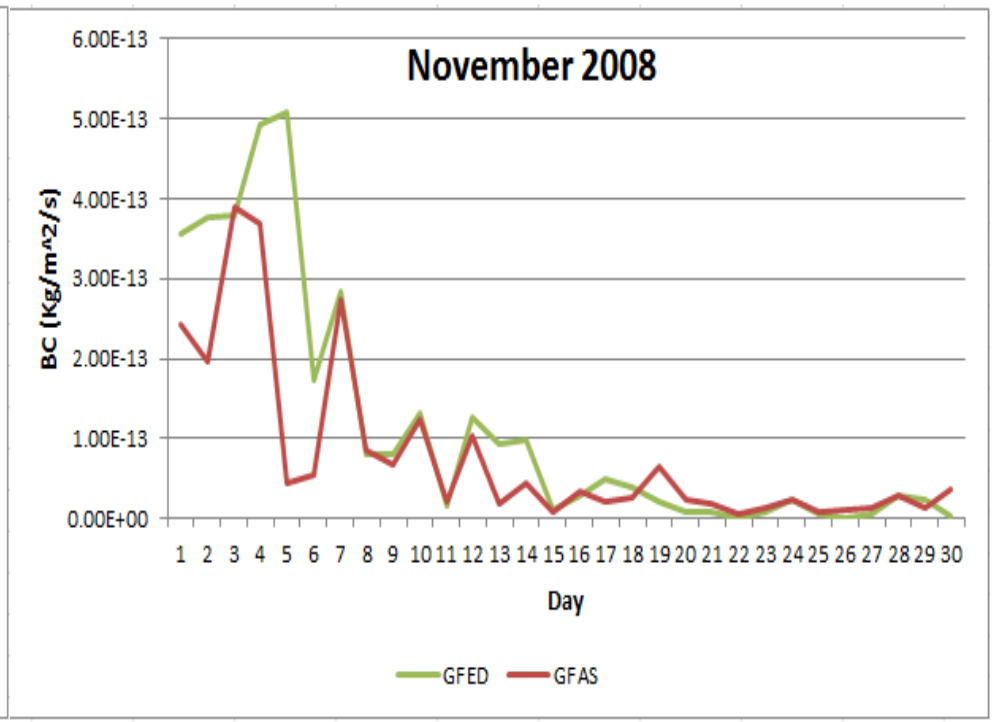
- How do GFAS and GFED compare with respect to BC emissions ($kg/m^2/s$) in the Indo-Ganges region?

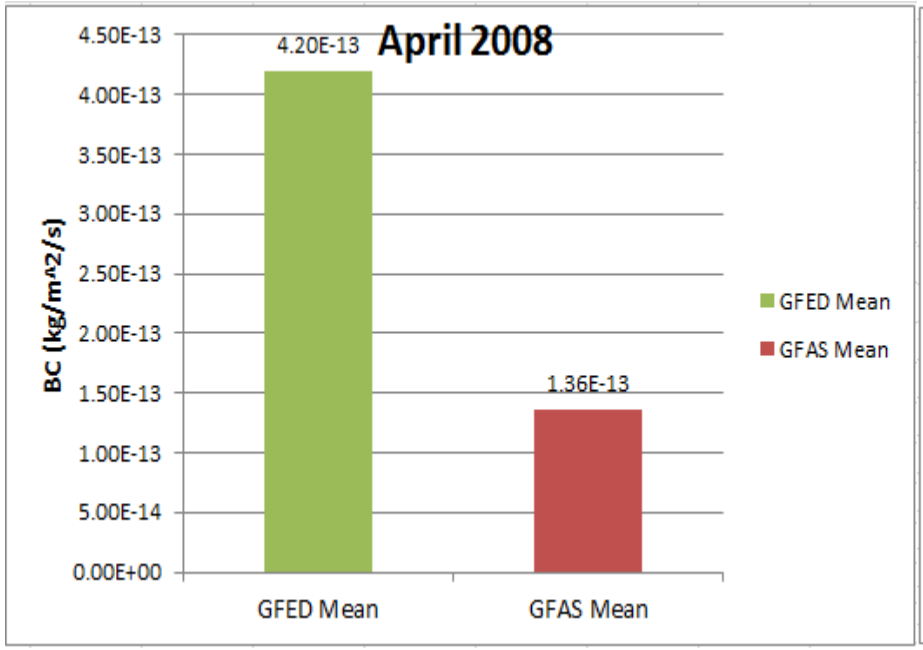
- What are the temporal trends (daily emissions) and yearly trends?

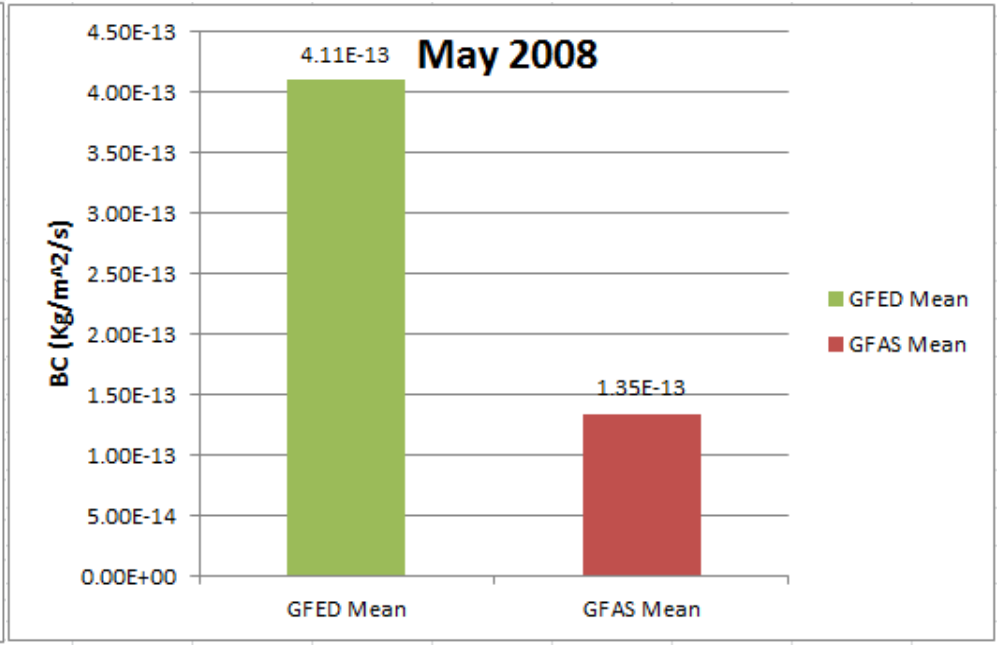

April 2008
BC (Kg/m^2/s)
2E-12
1.8E-12
1.6E-12
1.4E-12
1.2E-12
1E-12
8E-13
6E-13
4E-13
2E-13
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Day
GFED
GFAS

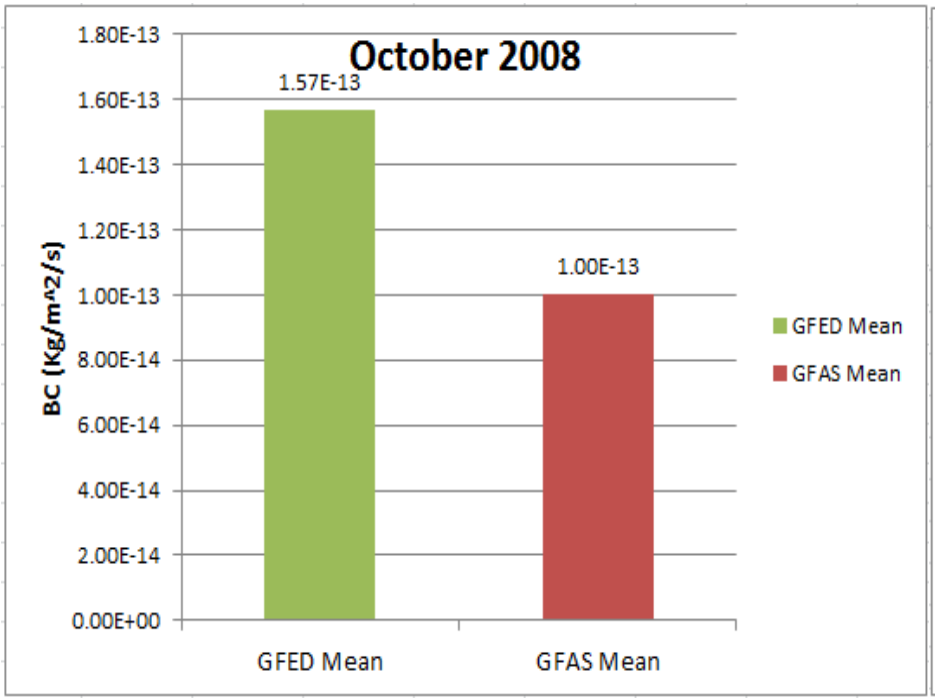

May 2008
BC (Kg/m^2/s)
2.00E-12
1.80E-12
1.60E-12
1.40E-12
1.20E-12
1.00E-12
8.00E-13
6.00E-13
4.00E-13
2.00E-13
0.00E+00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day
GFED
GFAS

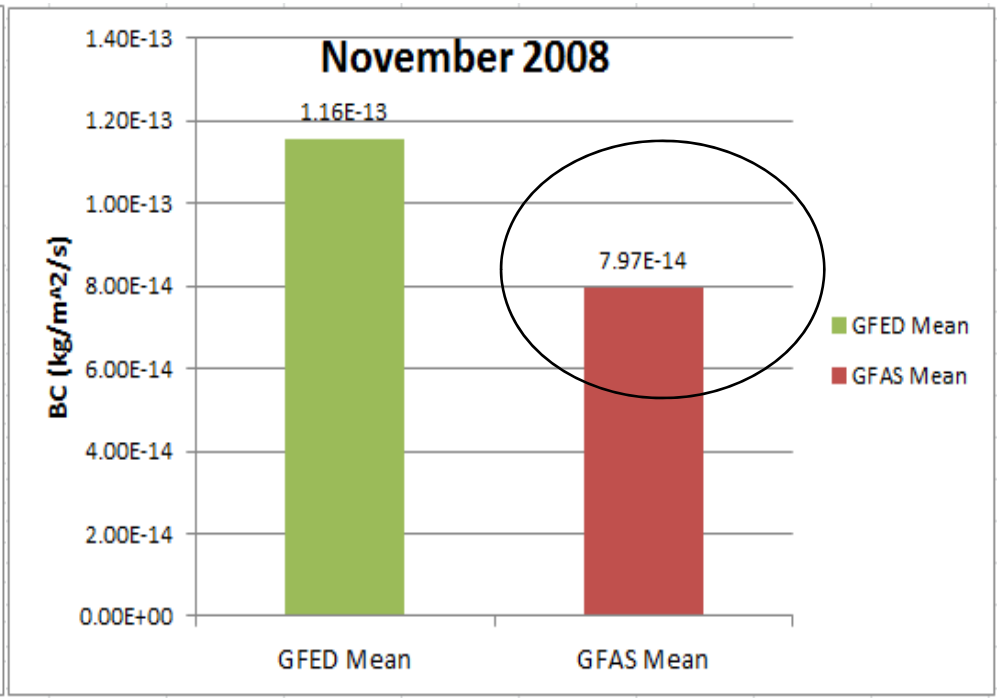

October 2008
BC (Kg/m^2/s)
8.00E-13
7.00E-13
6.00E-13
5.00E-13
4.00E-13
3.00E-13
2.00E-13
1.00E-13
0.00E+00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Day
GFED
GFAS

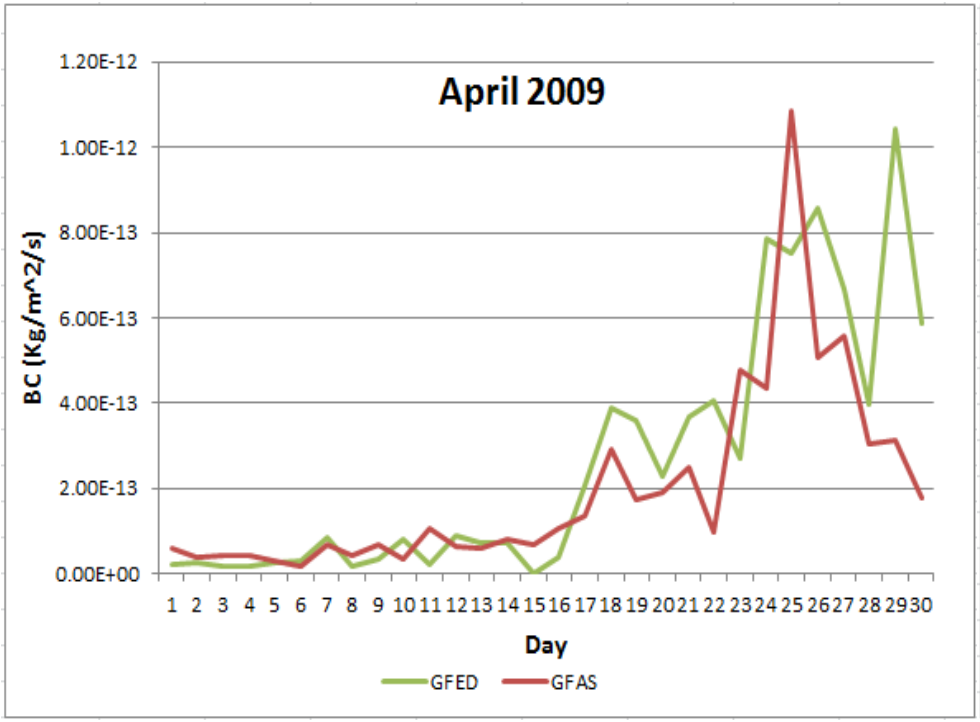

November 2008
BC (Kg/m^2/s)
6.00E-13
5.00E-13
4.00E-13
3.00E-13
2.00E-13
1.00E-13
0.00E+00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Day
GFED
GFAS

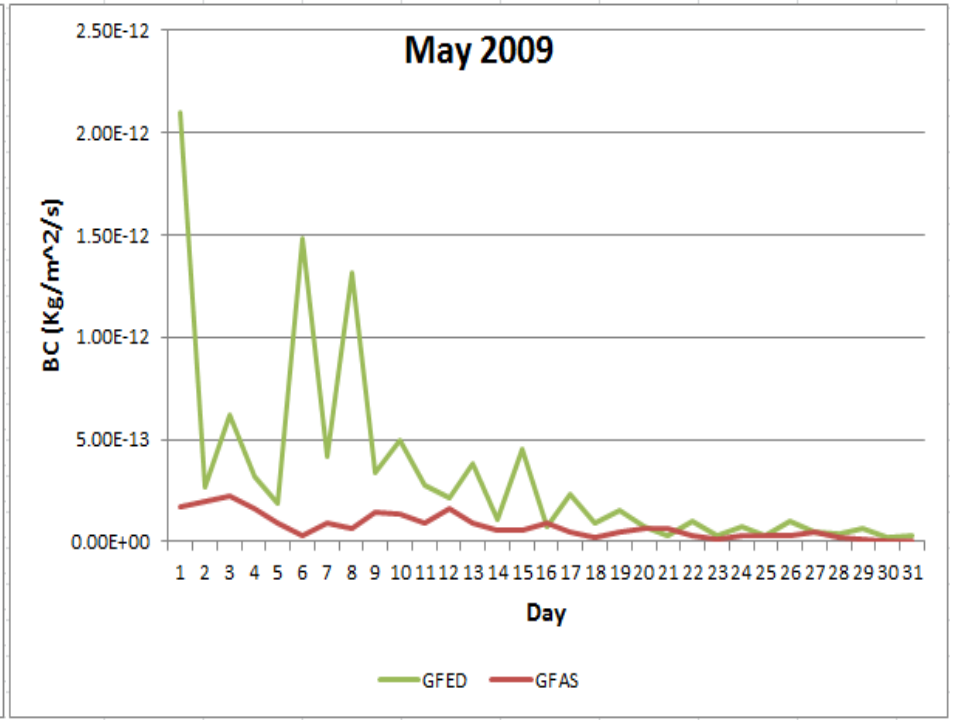

April 2008
4.20E-13
1.36E-13
4.50E-13
4.00E-13
3.50E-13
3.00E-13
2.50E-13
2.00E-13
1.50E-13
1.00E-13
5.00E-14
0.00E+00
BC (kg/m^2/s)
GFED Mean
GFAS Mean
GFED Mean
GFAS Mean

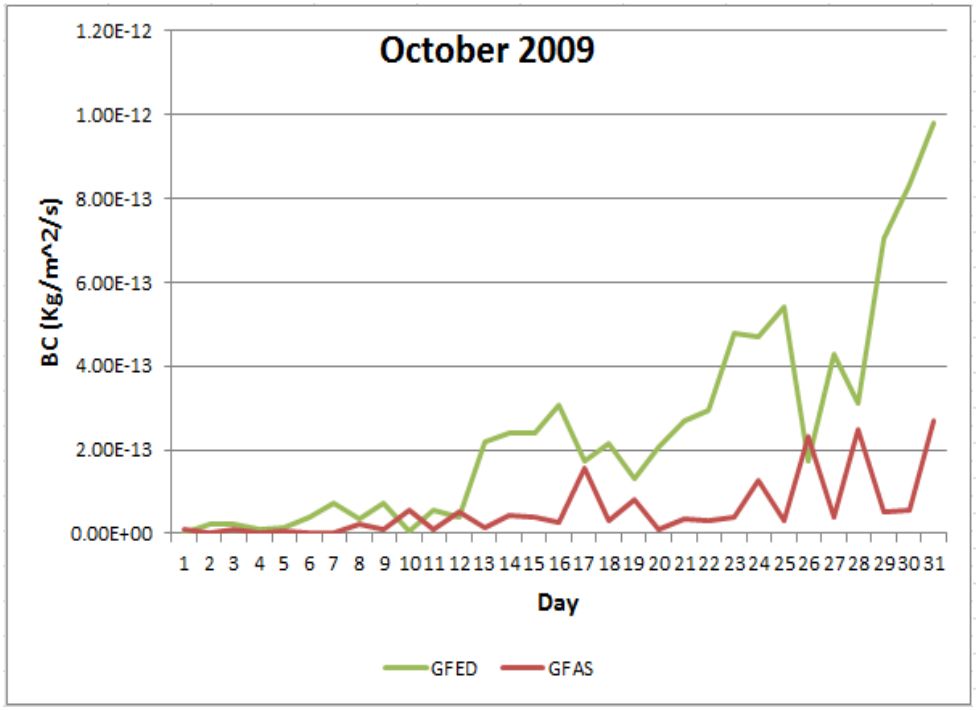

May 2008
4.11E-13
1.35E-13
4.50E-13
4.00E-13
3.50E-13
3.00E-13
2.50E-13
2.00E-13
1.50E-13
1.00E-13
5.00E-14
0.00E+00
BC (Kg/m^2/s)
GFED Mean
GFAS Mean
GFED Mean
GFAS Mean

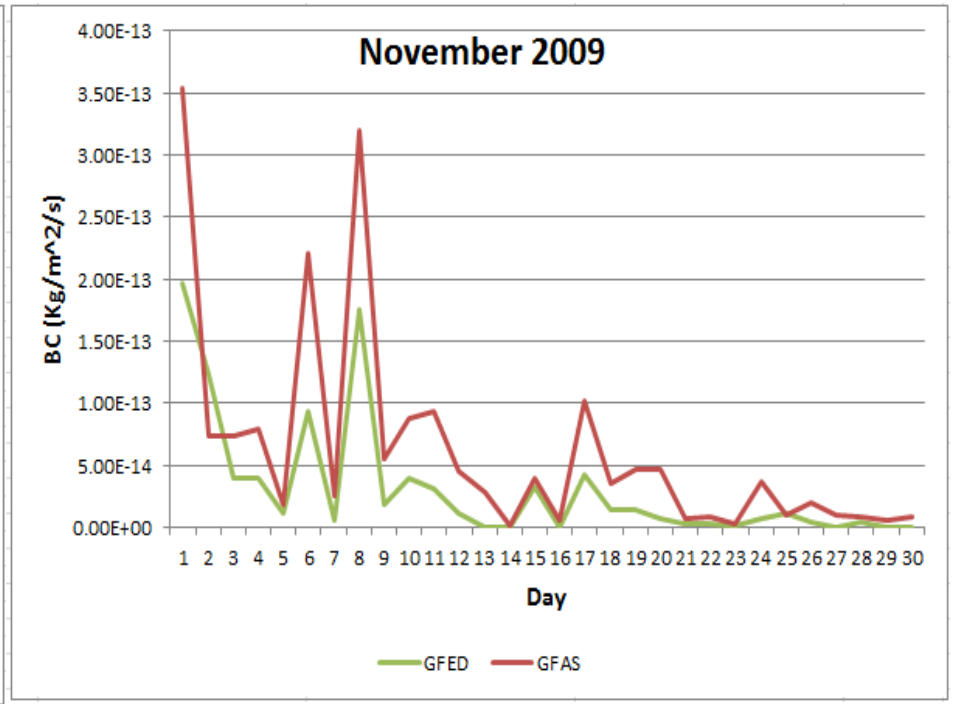

October 2008
1.57E-13
1.00E-13
1.80E-13
1.60E-13
1.40E-13
1.20E-13
1.00E-13
8.00E-14
6.00E-14
4.00E-14
2.00E-14
0.00E+00
BC (Kg/m^2/s)
GFED Mean
GFAS Mean
GFED Mean
GFAS Mean

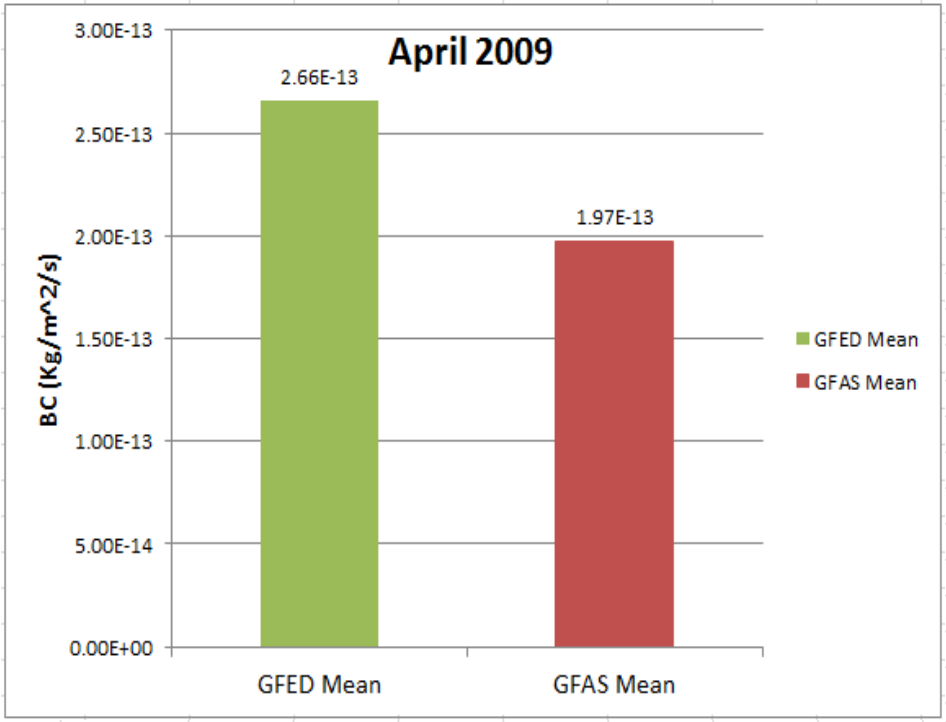

November 2008
1.16E-13
7.97E-14
1.40E-13
1.20E-13
1.00E-13
8.00E-14
6.00E-14
4.00E-14
2.00E-14
0.00E+00
BC (kg/m^2/s)
GFED Mean
GFAS Mean
GFED Mean
GFAS Mean

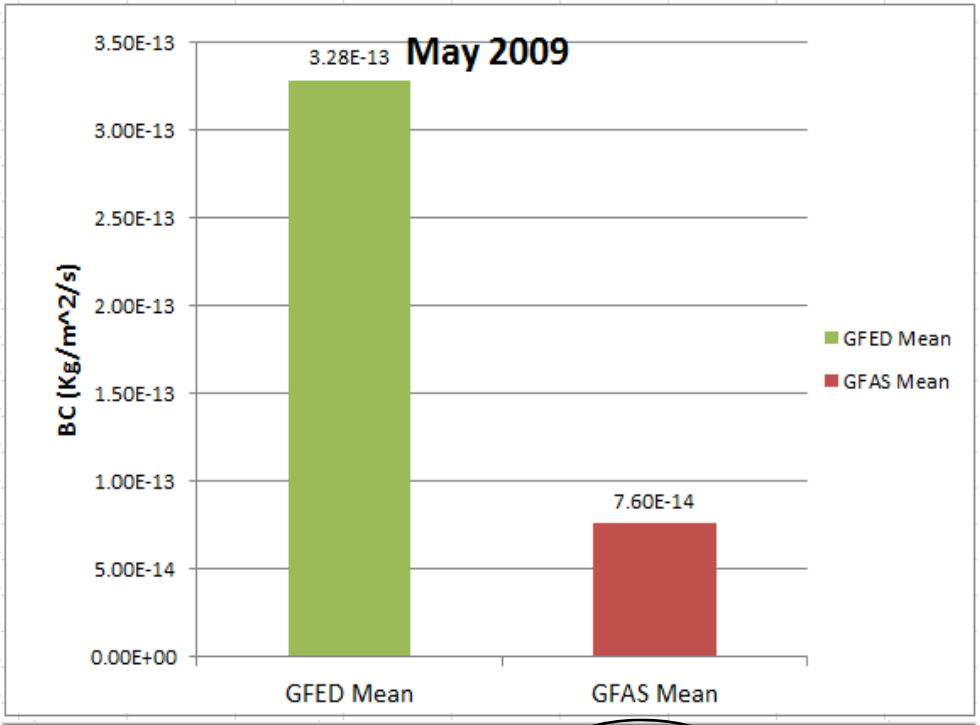

April 2009
BC (Kg/m^2/s)
1.20E-12
1.00E-12
8.00E-13
6.00E-13
4.00E-13
2.00E-13
0.00E+00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Day
GFED
GFAS

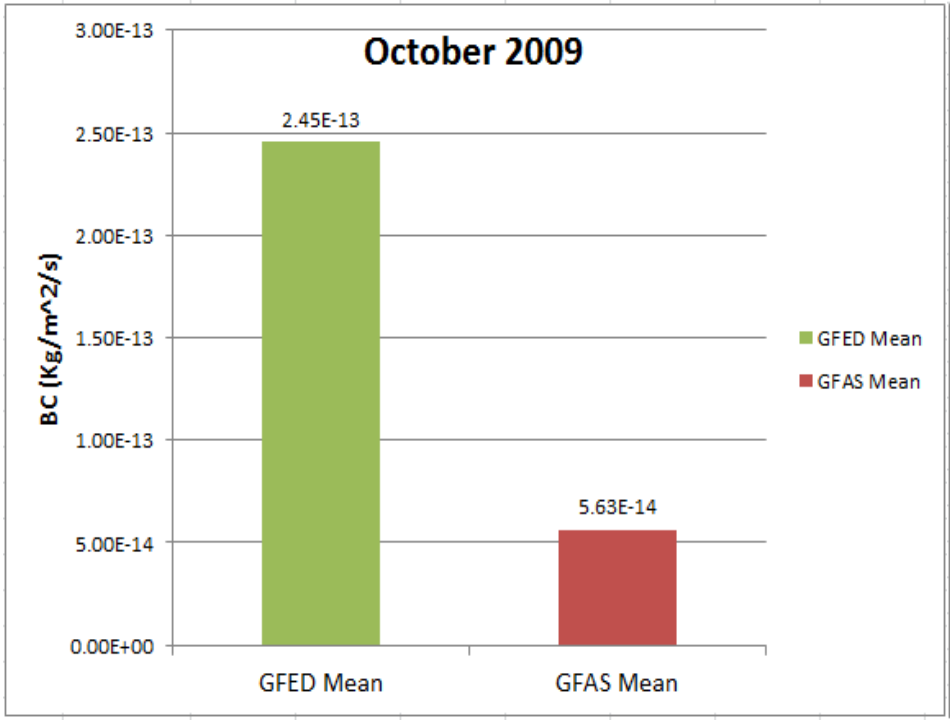

May 2009
BC (Kg/m^2/s)
2.50E-12
2.00E-12
1.50E-12
1.00E-12
5.00E-13
0.00E+00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day
GFED
GFAS

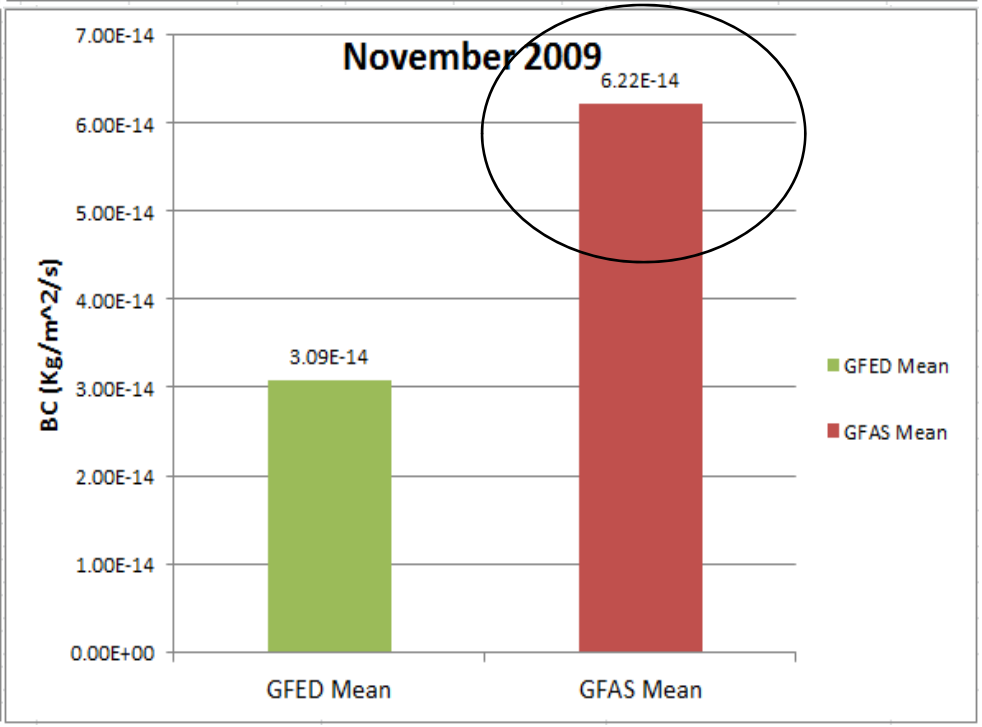

October 2009
BC (Kg/m^2/s)
1.20E-12
1.00E-12
8.00E-13
6.00E-13
4.00E-13
2.00E-13
0.00E+00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day
GFED
GFAS

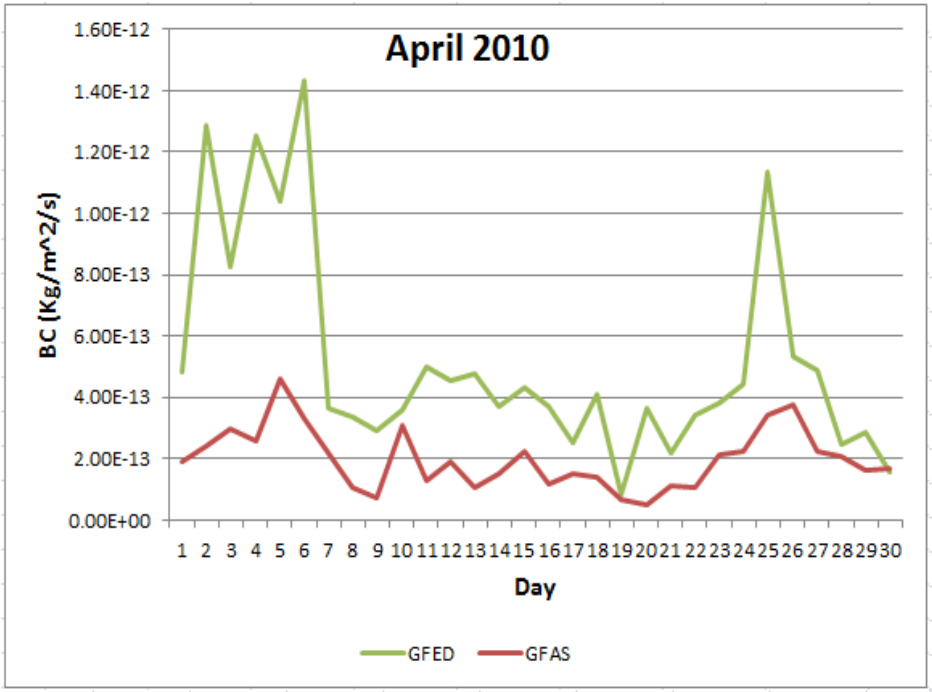

November 2009
BC (Kg/m^2/s)
4.00E-13
3.50E-13
3.00E-13
2.50E-13
2.00E-13
1.50E-13
1.00E-13
5.00E-14
0.00E+00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Day
GFED
GFAS

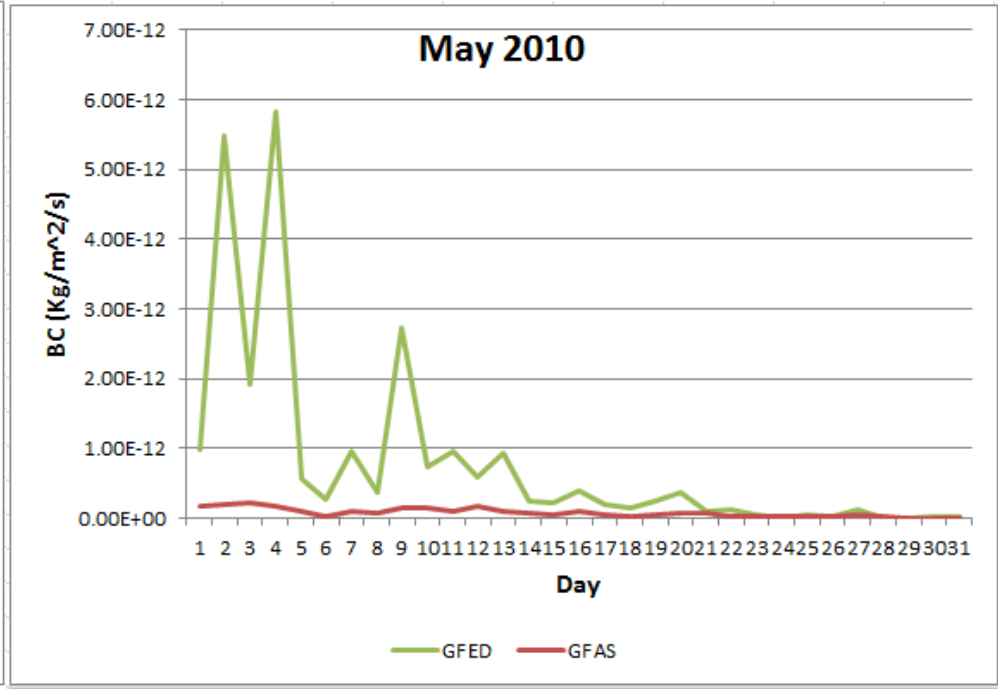

April 2009
BC (Kg/m^2/s)
3.00E-13
2.50E-13
2.00E-13
1.50E-13
1.00E-13
5.00E-14
0.00E+00
2.66E-13
1.97E-13
GFED Mean
GFAS Mean
GFED Mean
GFAS Mean

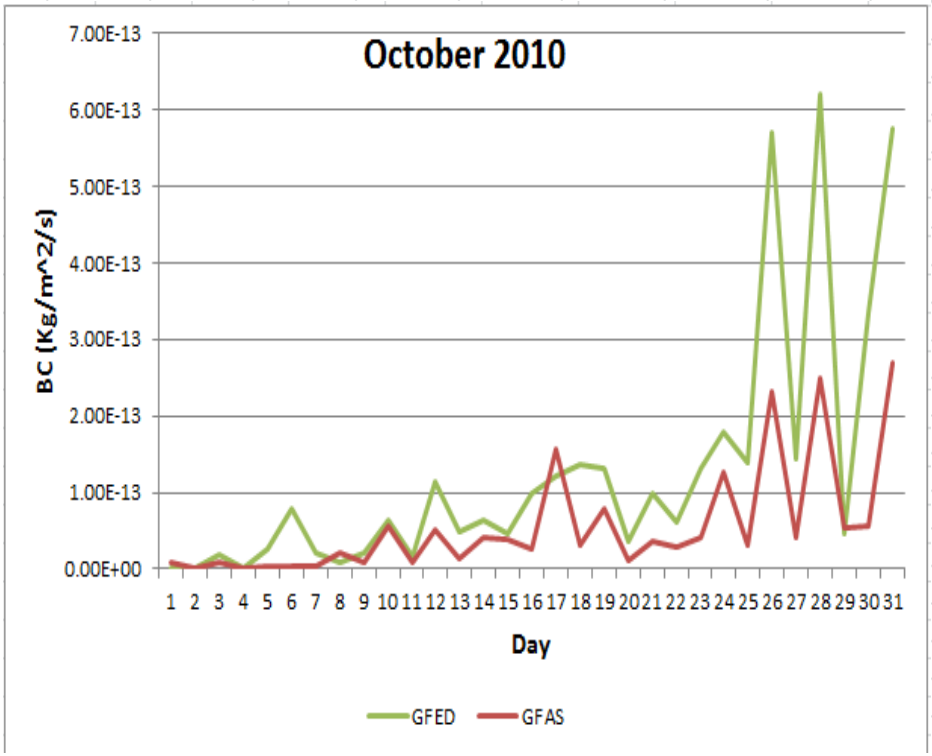

May 2009
BC (Kg/m^2/s)
3.50E-13
3.00E-13
2.50E-13
2.00E-13
1.50E-13
1.00E-13
5.00E-14
0.00E+00
3.28E-13
7.60E-14
GFED Mean
GFAS Mean
GFED Mean
GFAS Mean

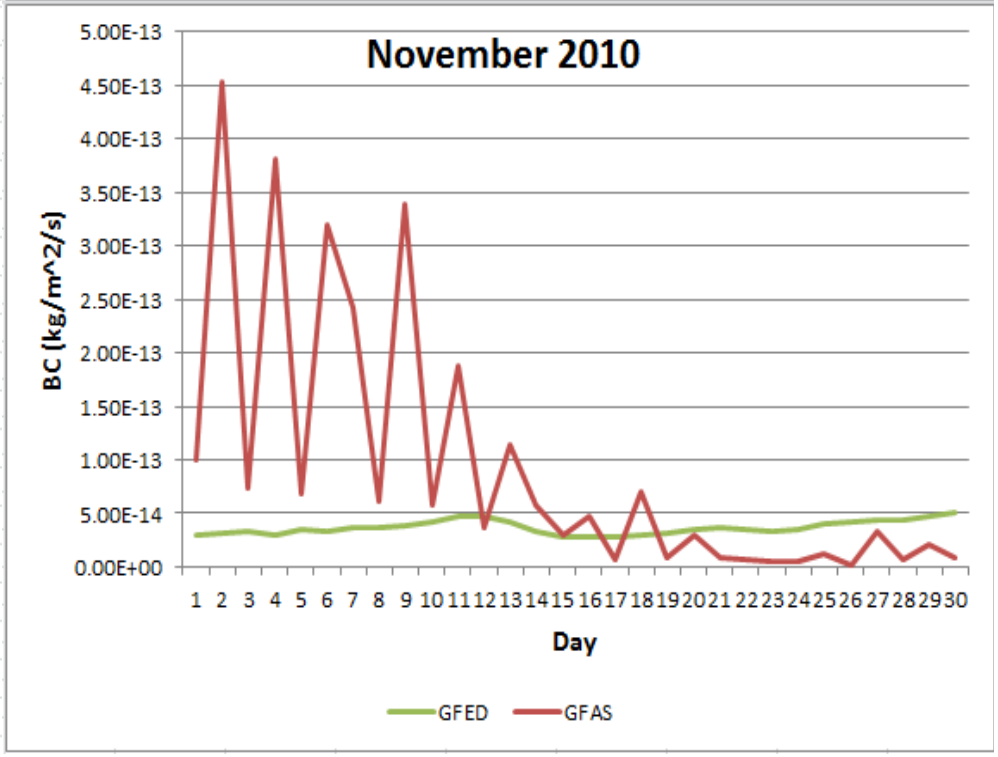

October 2009
BC (Kg/m^2/s)
3.00E-13
2.50E-13
2.00E-13
1.50E-13
1.00E-13
5.00E-14
0.00E+00
2.45E-13
5.63E-14
GFED Mean
GFAS Mean
GFED Mean
GFAS Mean

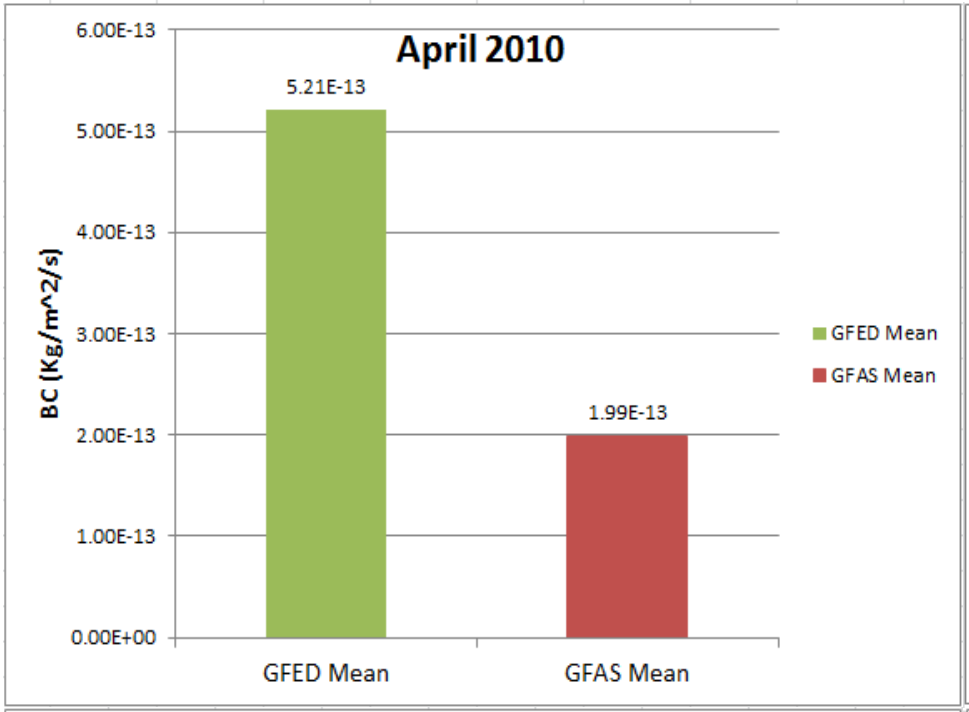

November 2009
BC (Kg/m^2/s)
7.00E-14
6.00E-14
5.00E-14
4.00E-14
3.00E-14
2.00E-14
1.00E-14
0.00E+00
3.09E-14
6.22E-14
GFED Mean
GFAS Mean
GFED Mean
GFAS Mean

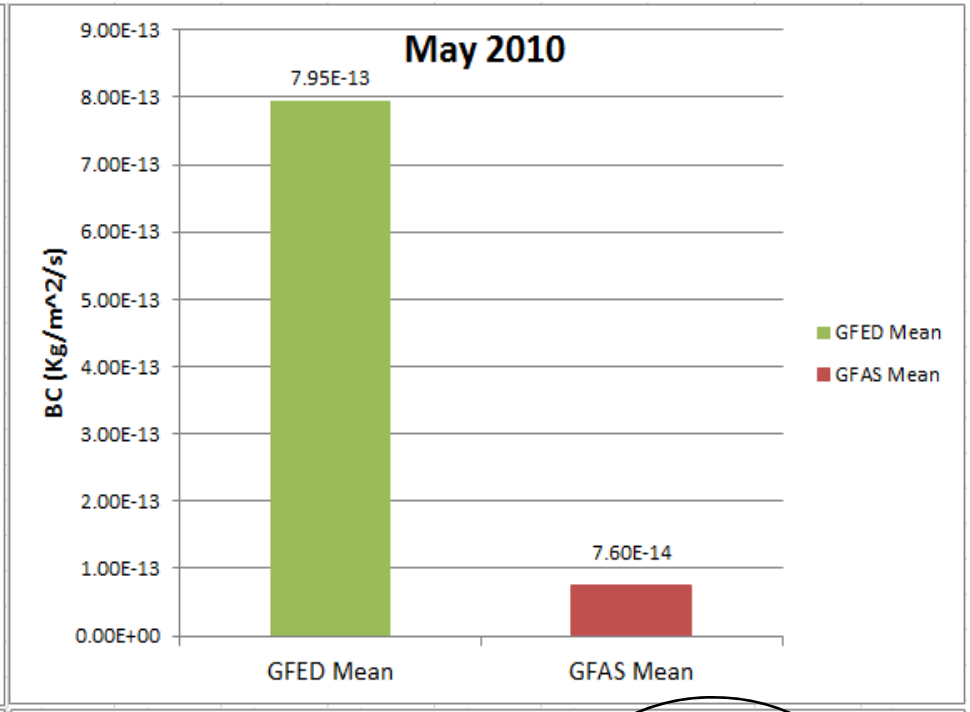

April 2010
BC (Kg/m^2/s)
1.60E-12
1.40E-12
1.20E-12
1.00E-12
8.00E-13
6.00E-13
4.00E-13
2.00E-13
0.00E+00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Day
GFED
GFAS

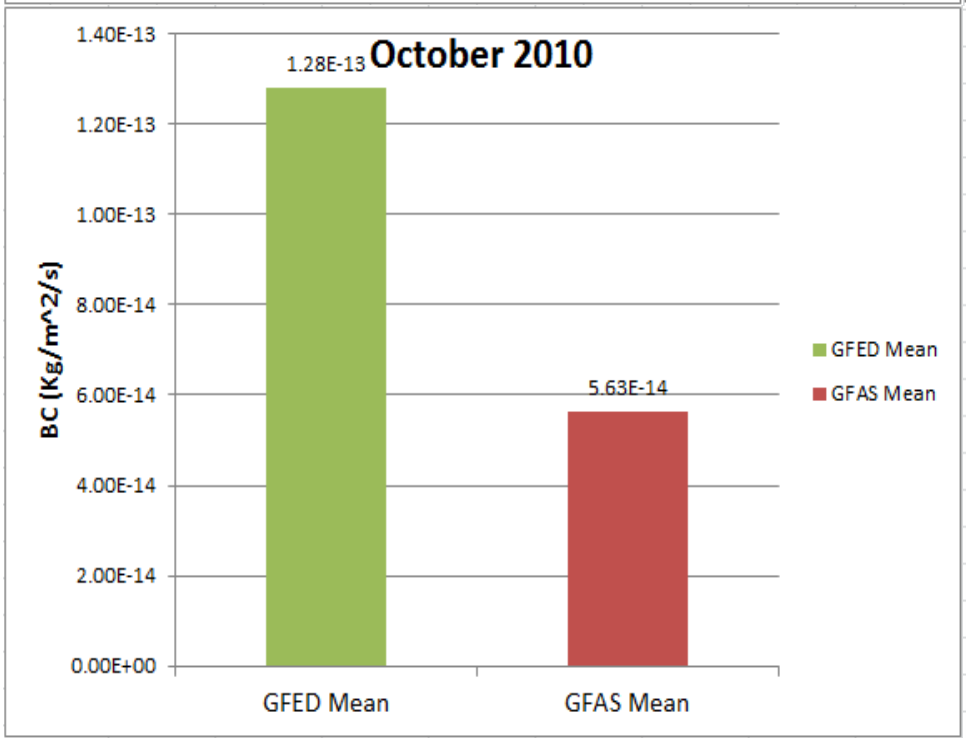

May 2010
BC (Kg/m^2/s)
7.00E-12
6.00E-12
5.00E-12
4.00E-12
3.00E-12
2.00E-12
1.00E-12
0.00E+00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day
GFED
GFAS

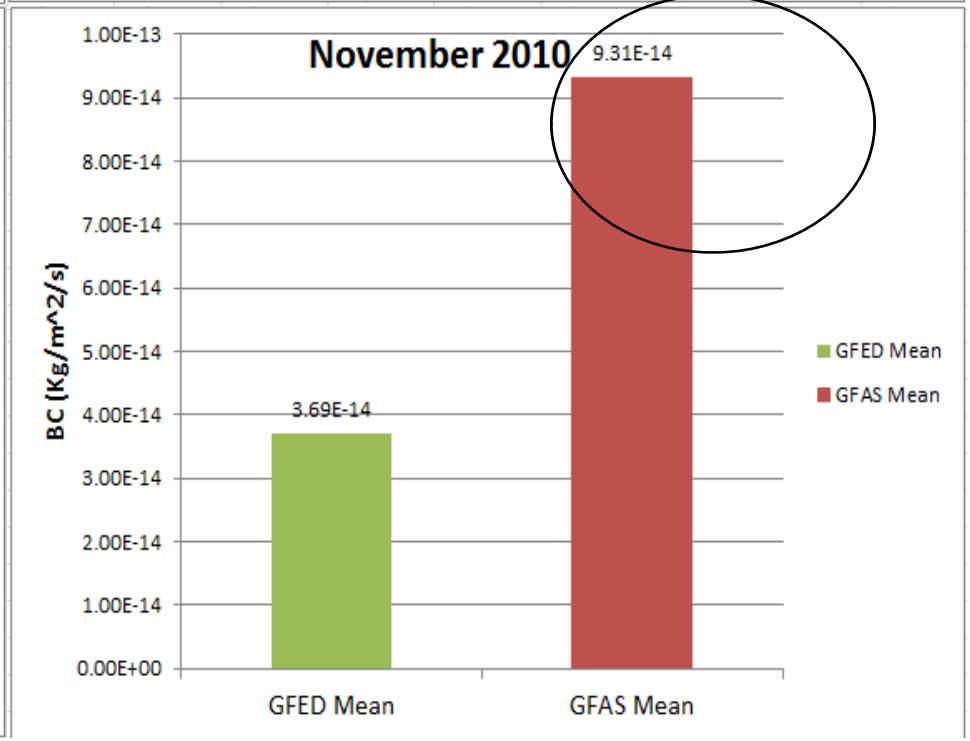

October 2010
BC (Kg/m^2/s)
7.00E-13
6.00E-13
5.00E-13
4.00E-13
3.00E-13
2.00E-13
1.00E-13
0.00E+00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day
GFED
GFAS


November 2010
BC (kg/m^2/s)
5.00E-13
4.50E-13
4.00E-13
3.50E-13
3.00E-13
2.50E-13
2.00E-13
1.50E-13
1.00E-13
5.00E-14
0.00E+00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Day
GFED
GFAS


April 2010
BC (Kg/m^2/s)
6.00E-13
5.00E-13
4.00E-13
3.00E-13
2.00E-13
1.00E-13
0.00E+00
5.21E-13
1.99E-13
GFED Mean
GFAS Mean

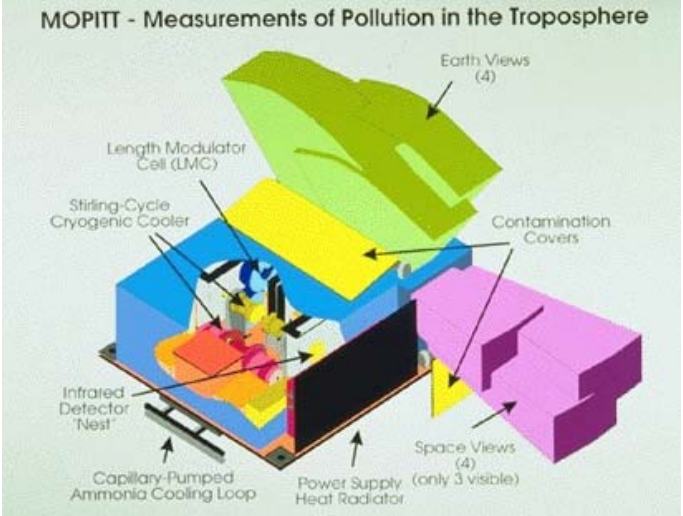

May 2010
BC (Kg/m^2/s)
9.00E-13
8.00E-13
7.00E-13
6.00E-13
5.00E-13
4.00E-13
3.00E-13
2.00E-13
1.00E-13
0.00E+00
7.95E-13
7.60E-14
GFED Mean
GFAS Mean

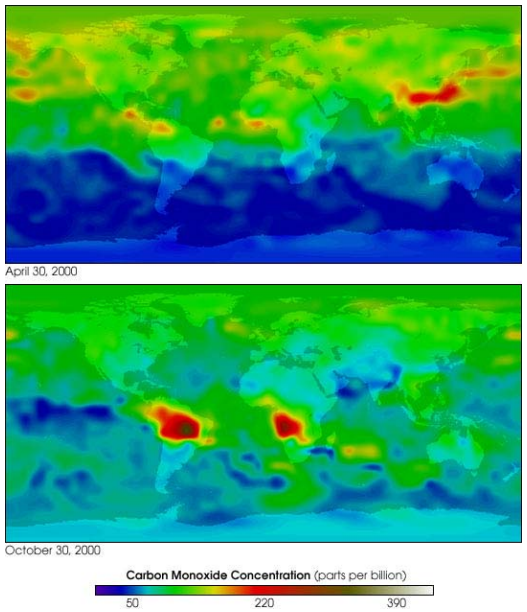

October 2010
BC (Kg/m^2/s)
1.40E-13
1.20E-13
1.00E-13
8.00E-14
6.00E-14
4.00E-14
2.00E-14
0.00E+00
1.28E-13
5.63E-14
GFED Mean
GFAS Mean


November 2010
BC (Kg/m^2/s)
1.00E-13
9.00E-14
8.00E-14
7.00E-14
6.00E-14
5.00E-14
4.00E-14
3.00E-14
2.00E-14
1.00E-14
0.00E+00
9.31E-14
3.69E-14
GFED Mean
GFAS Mean

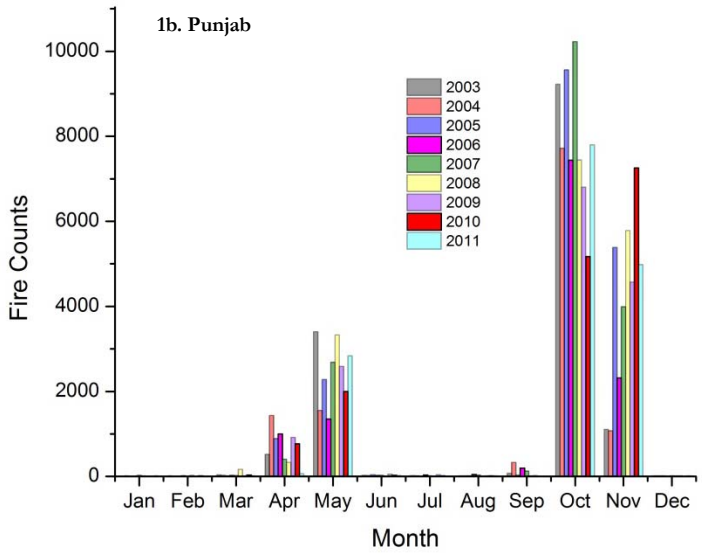
MOPITT Carbon Monoxide

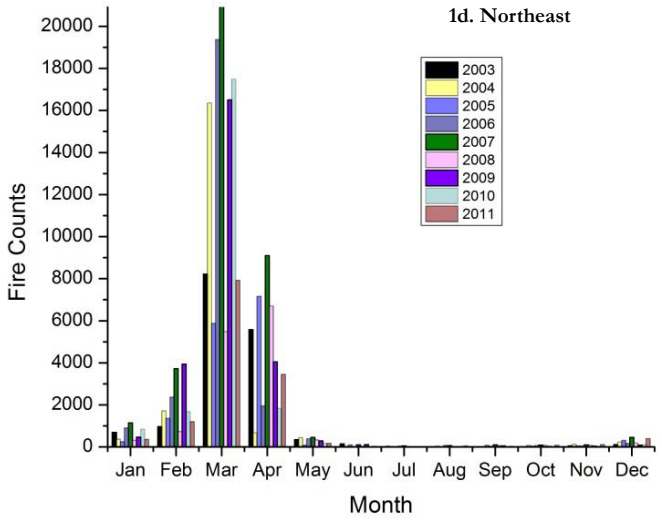
- Mounted on EOS Terra with a daily equatorial pass (10:30 a.m.)
- Measures global columnar CO and CO volume mixing ratio profiles with near-IR (2.3um) and Thermal-IR (4.7um) bands

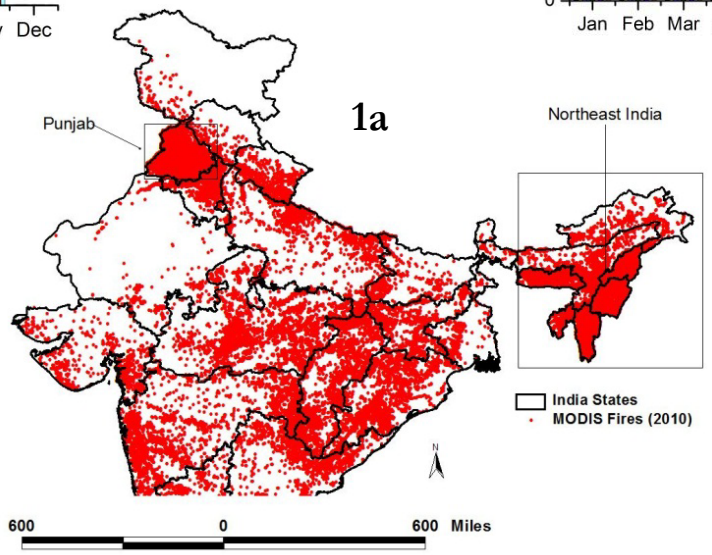


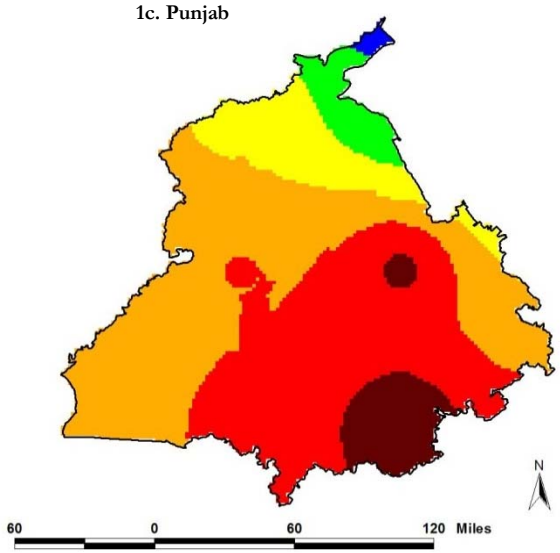


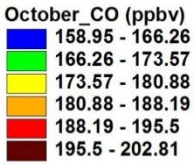
Resolution Summary	CO profile: 4 km vertical, 22 x 22 km horizontal, CO, CH4 column: 22 x 22 km horizontal
Swath Summary	616 km
Accuracy Summary	Carbon monoxide (4 km layers): 10%
Waveband Summary	SWIR-MWIR: 2.3 µm, 2.4 µm and 4.7 µm
	NIR (~0.75 µm - ~1.3 µm)
	MWIR (~3.0 µm - ~6.0 µm)

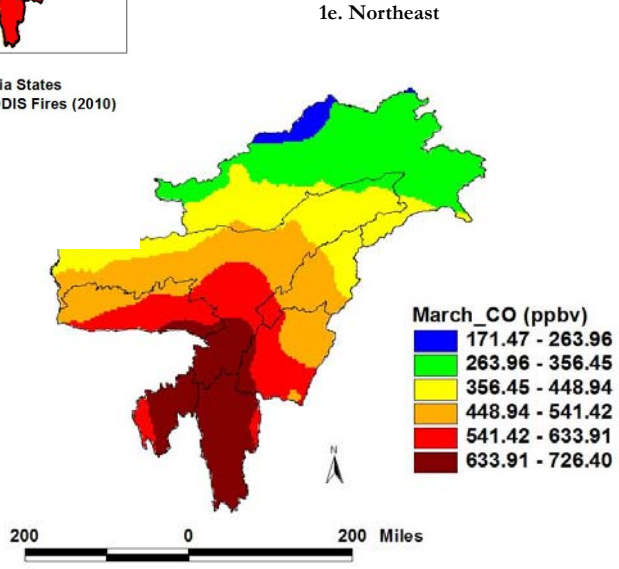

1b. Punjab
Fire Counts
Month
2003
2004
2005
2006
2007
2008
2009
2010
2011
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


1d. Northeast
Fire Counts
Month
2003
2004
2005
2006
2007
2008
2009
2010
2011
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

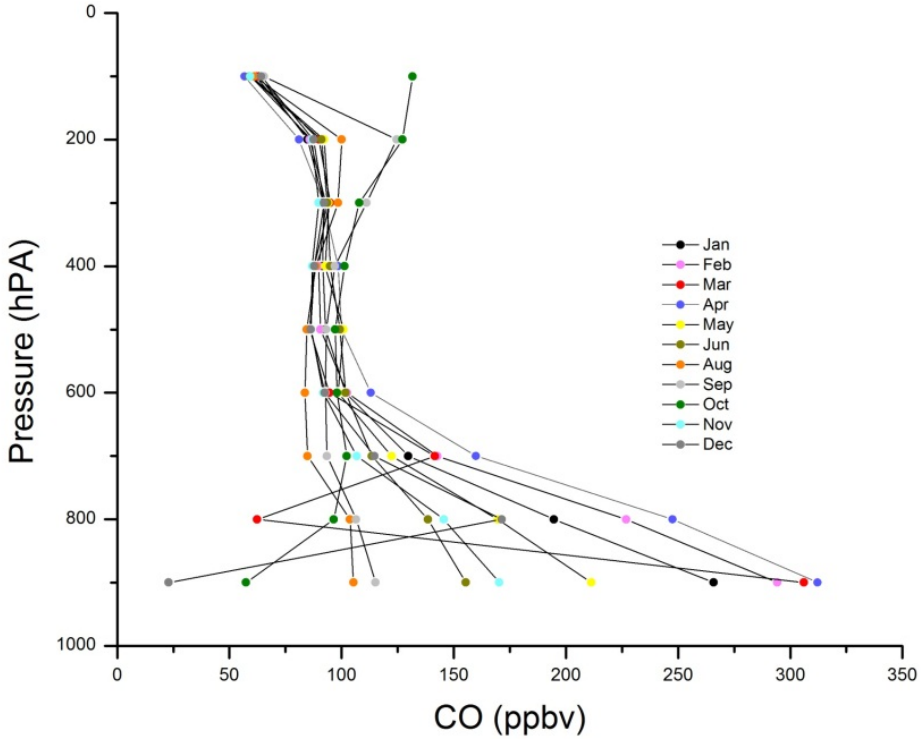

1a
Punjab
Northeast India
India States
MODIS Fires (2010)
600 0 600 Miles


1c. Punjab
60 0 60 120 Miles

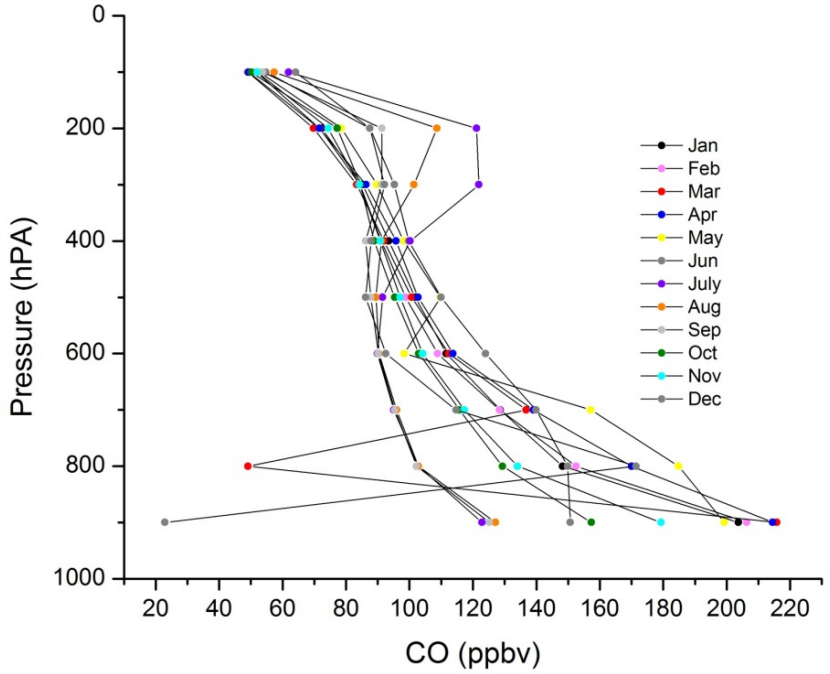

October_CO (ppbv)
158.95 - 166.26
166.26 - 173.57
173.57 - 180.88
180.88 - 188.19
188.19 - 195.5
195.5 - 202.81


1e. Northeast
March_CO (ppbv)
171.47 - 263.96
263.96 - 356.45
356.45 - 448.94
448.94 - 541.42
541.42 - 633.91
633.91 - 726.40
200 0 200 Miles

MOPITT Carbon Monoxide Profiles

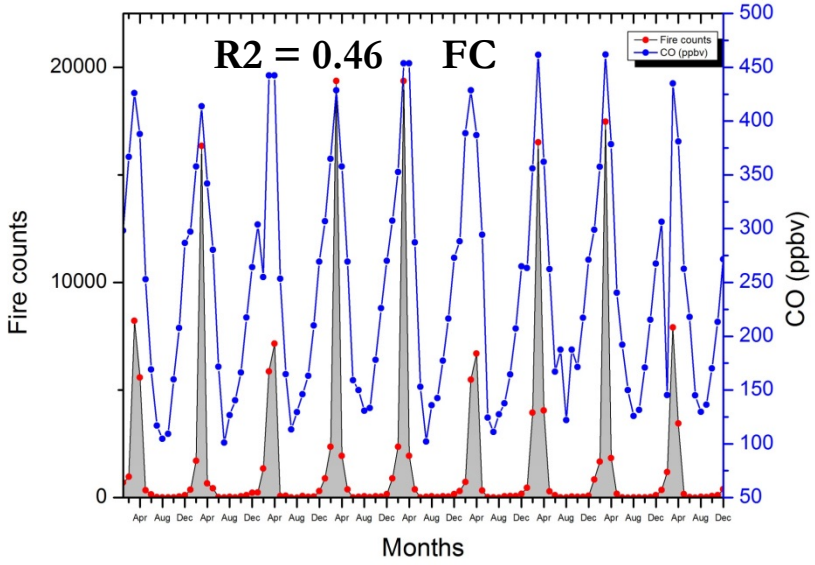


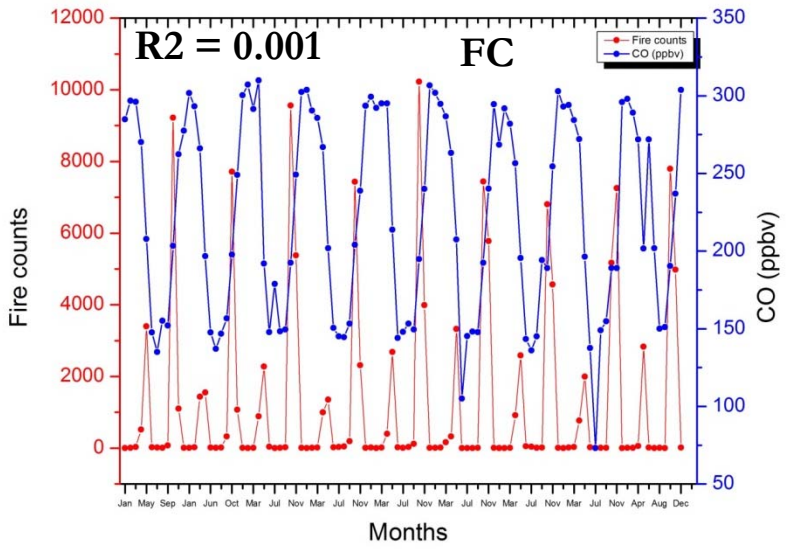
Forest fires

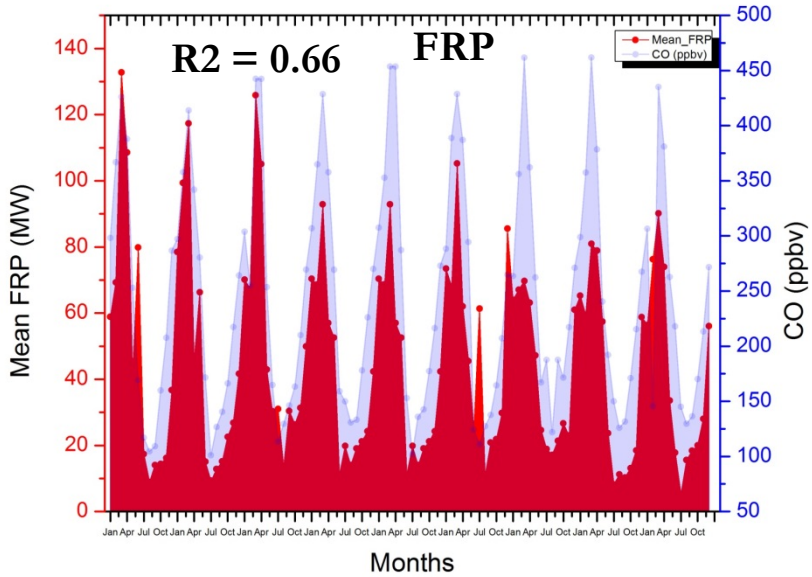


Agriculture fires

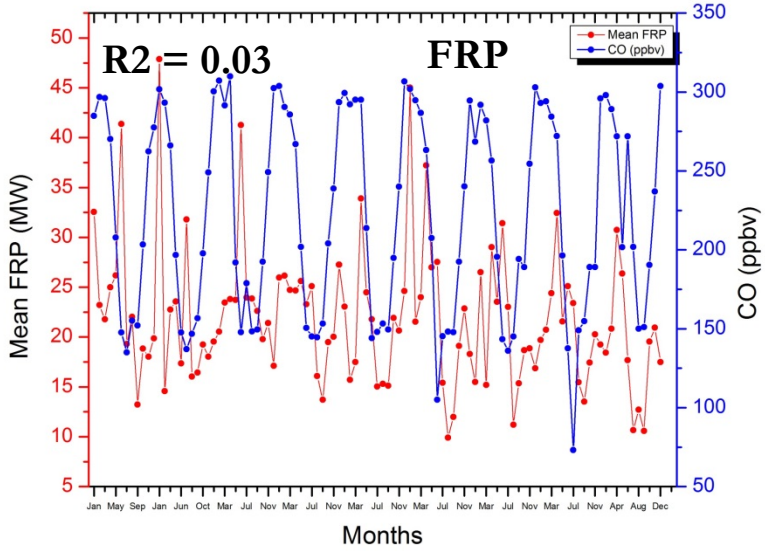
Fire counts/FRP time series plots





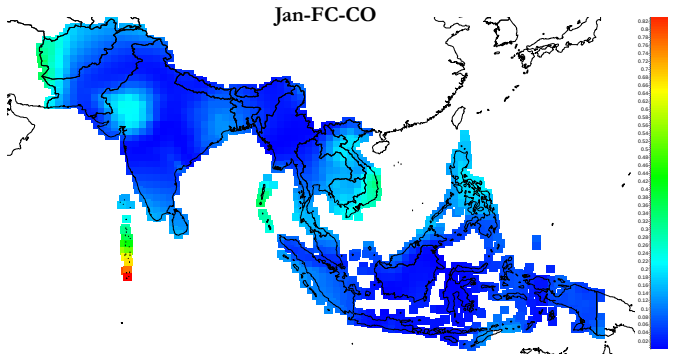


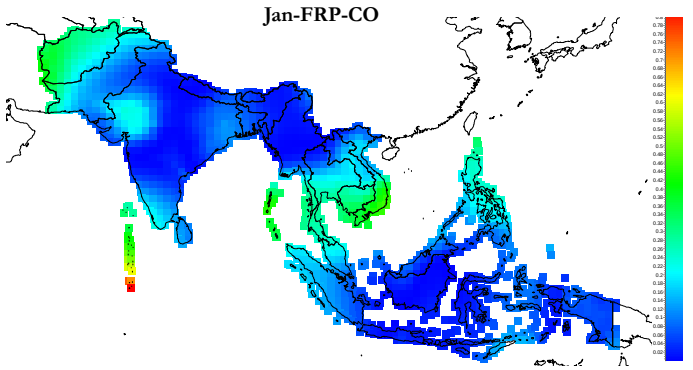
Forest fires

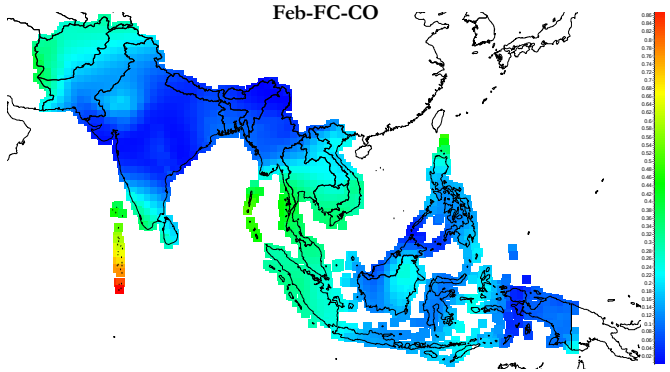


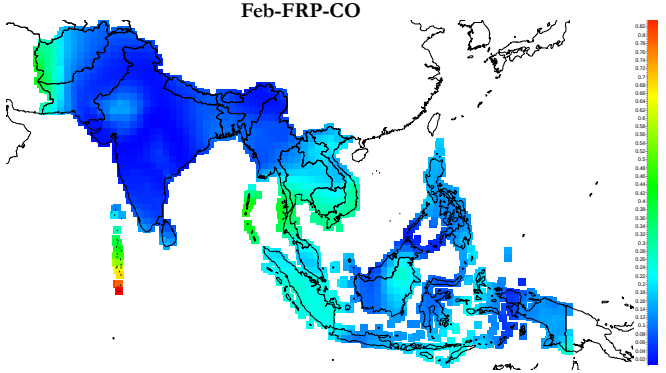
Agriculture fires

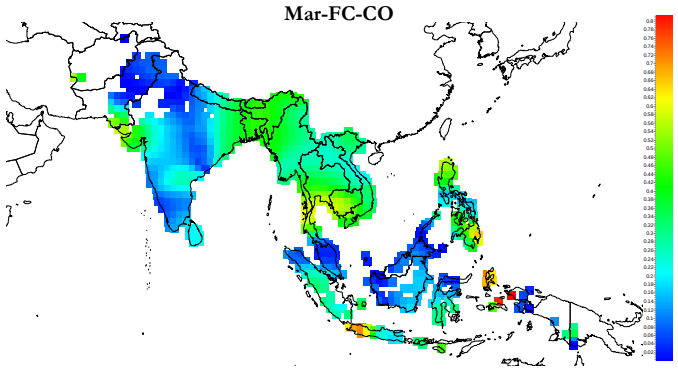
Fire counts/FRP MOPITT CO correlations

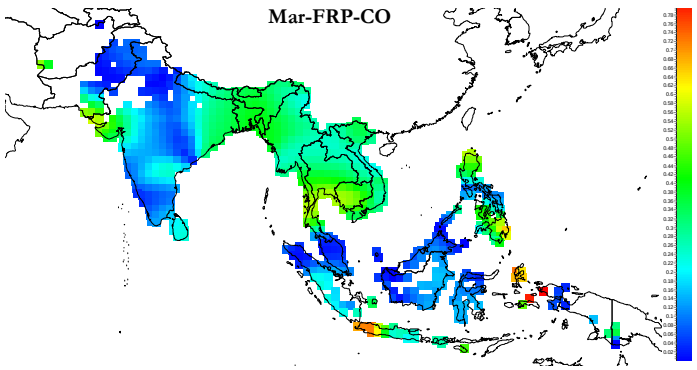




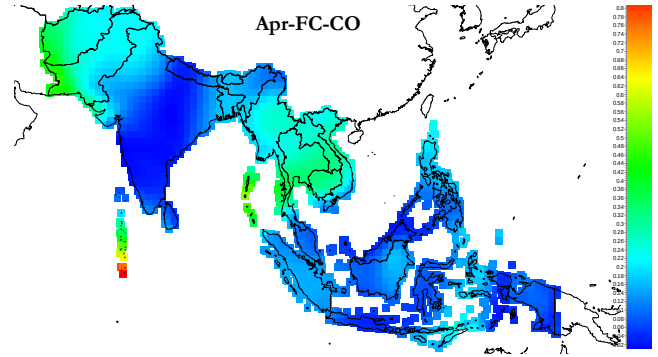


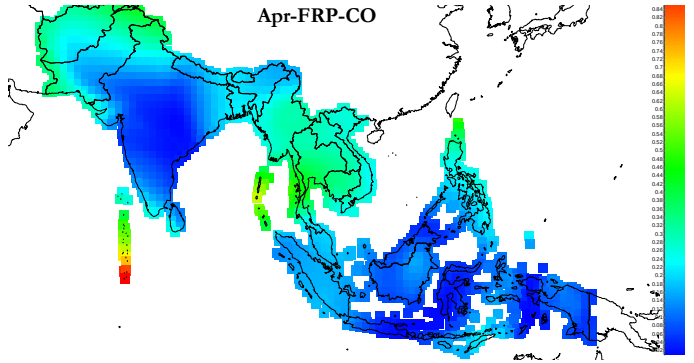


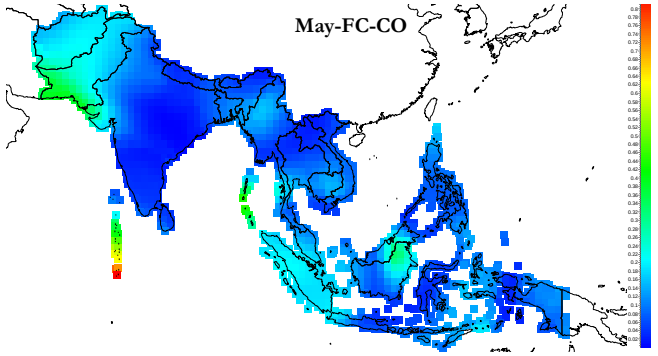


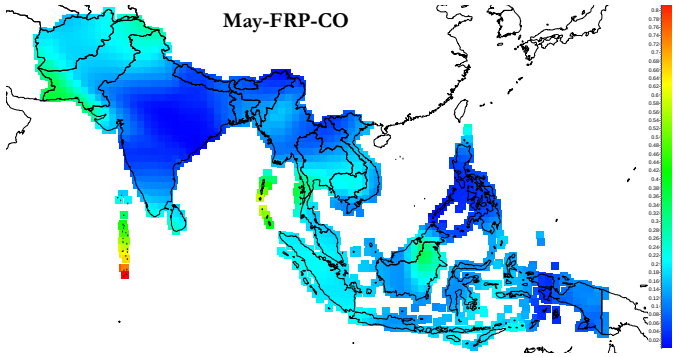


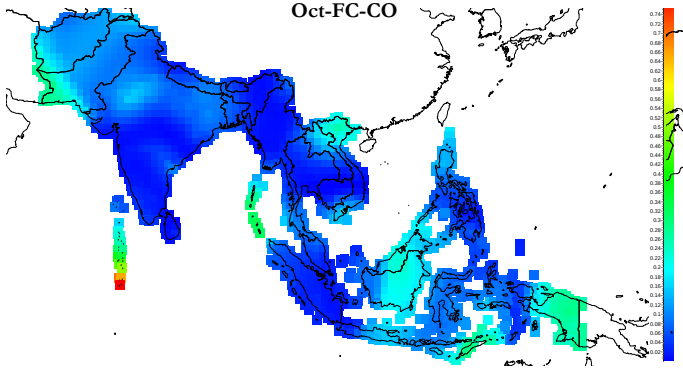
Fire counts/FRP MOPITT CO correlations

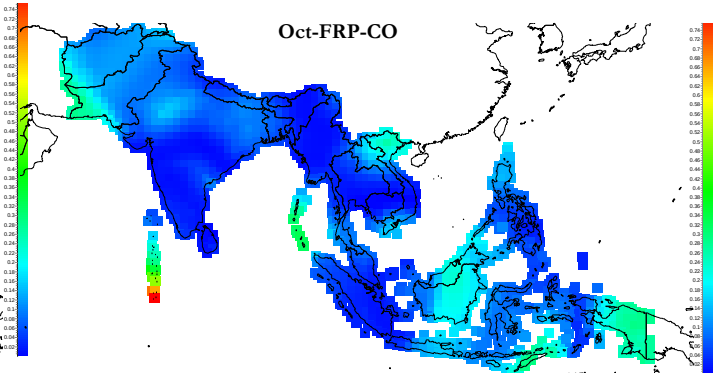




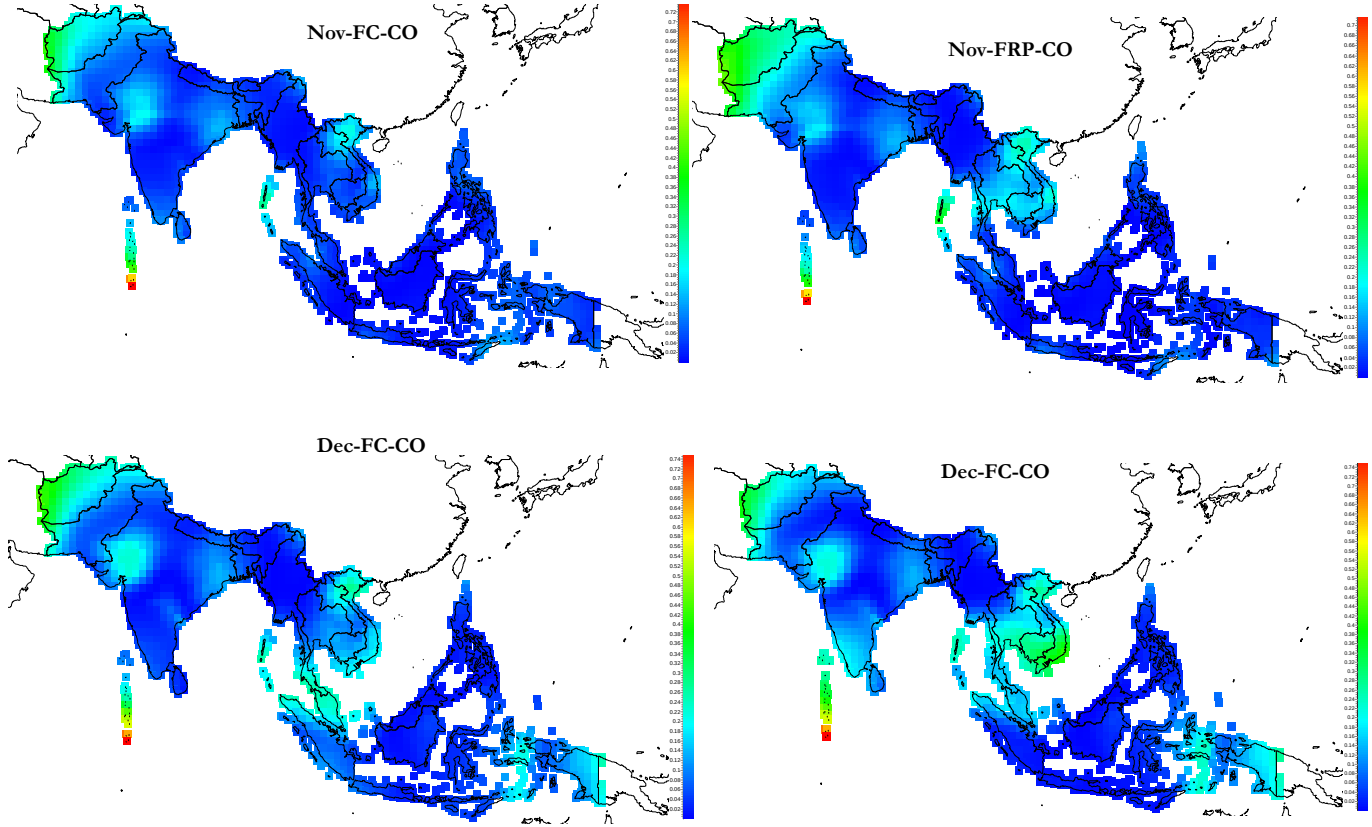








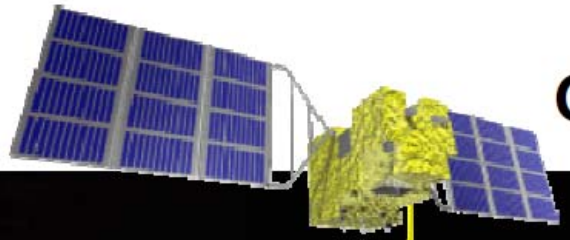
Fire counts/FRP MOPITT CO correlations



Fire counts/FRP MOPITT CO correlations

Months	Fire counts vs CO (r^2)	FRP vs CO (r^2)
Jan	0.702 (0.028)	0.715 (0.112)
Feb	0.696 (0.135)	0.705 (0.178)
Mar	0.822 (0.37)	0.786 (0.14)
Apr	0.696 (0.184)	0.709 (0.315)
May	0.575 (0.044)	0.595 (0.149)
Oct	0.388 (0.008)	0.401 (0.034)
Nov	0.64 (0.008)	0.641 (0.004)
Dec	0.764 (0.033)	0.768 (0.054)

GOSAT CO2 Data



GOSAT (launched in January 2009)

666 km

10 km diameter

3-day
recurrent observations

Solar Radiation

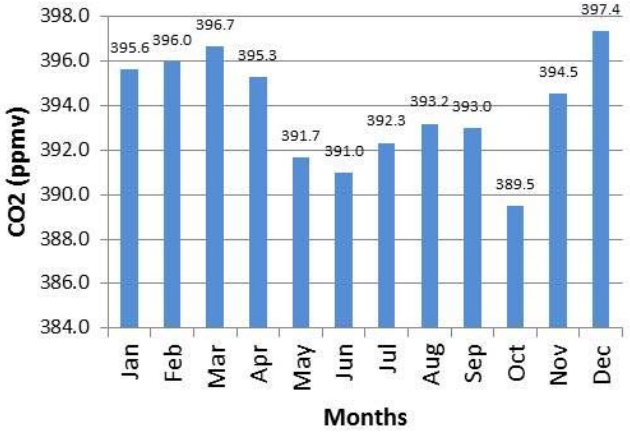
TANSO-FTS
(Fourier Transform Spectrometer)
-SWIR reflected on the earth's surface
-TIR radiated from the ground and the atmosphere

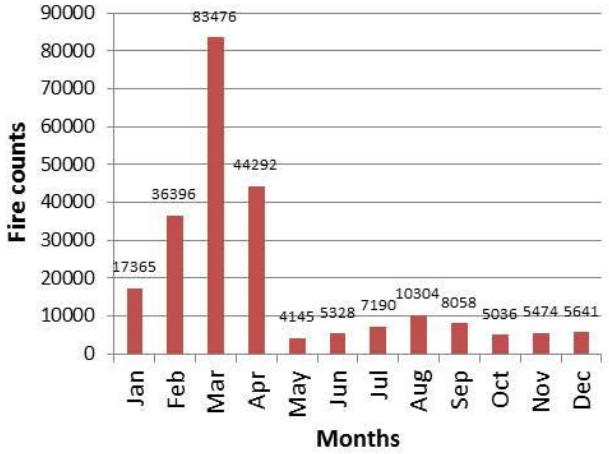
TANSO-CAI
(Cloud and Aerosol Imager)
-UV : 0.38μm
-V : 0.67μm
-NIR : 0.87μm
-SWIR : 1.6μm

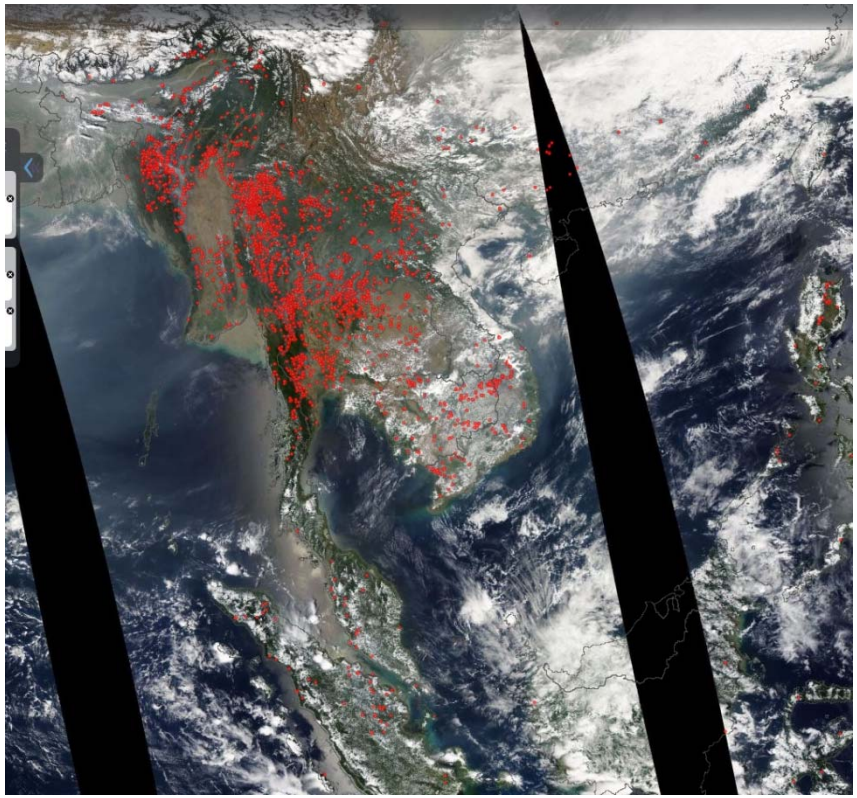
Outcomes (Data Products)

-"First Light" images and spectra obtained on 9 Feb 2009
-First Level 1 products (radiance and spectral) released in Oct 2009
-First Level 2 XCO_2 and XCH_4 products released in Feb 2010
-Level 4A product (sources and sinks) product to be released in 2012

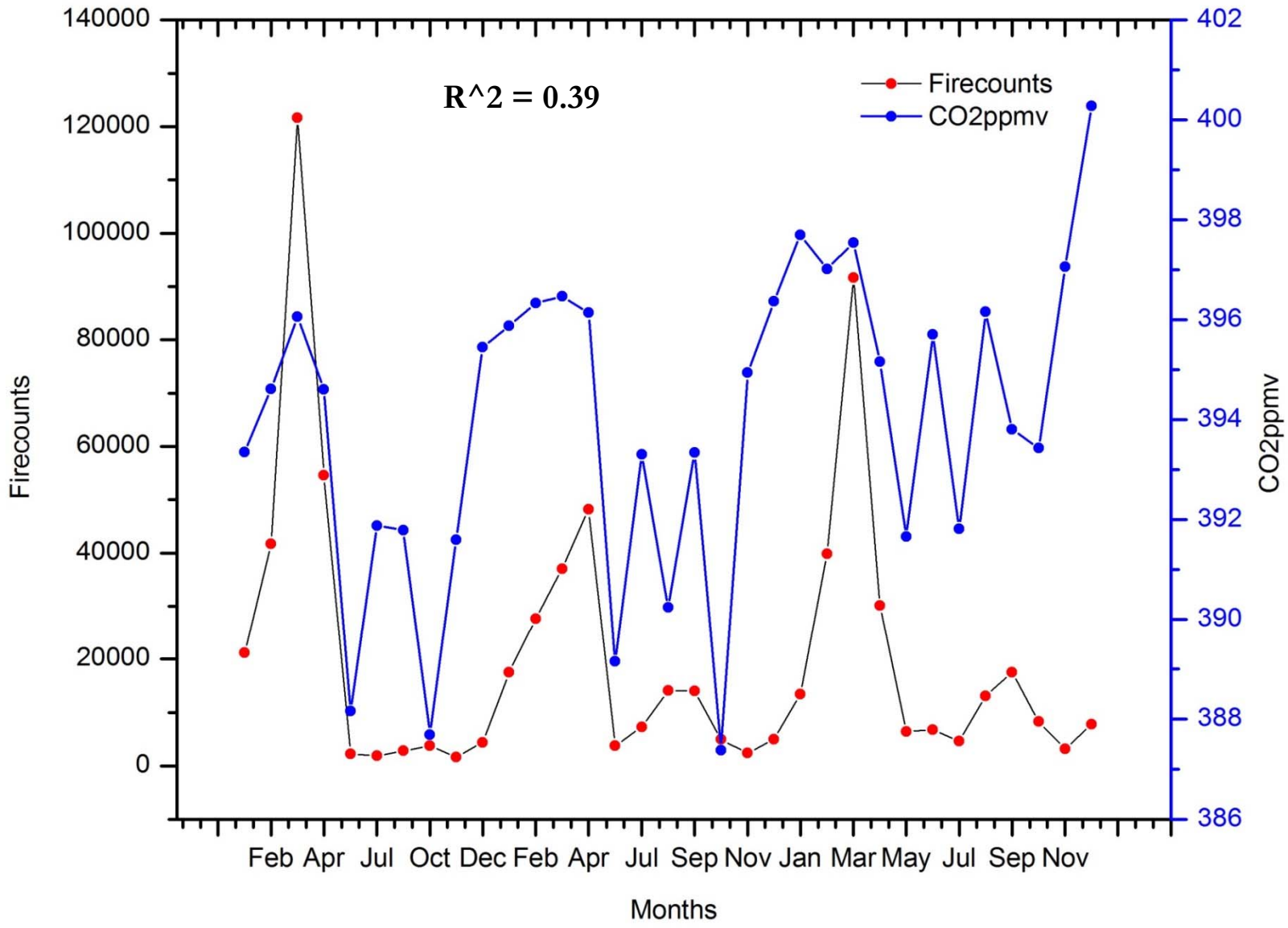
GOSAT CO2 Data Evaluation over Southeast Asia Fires



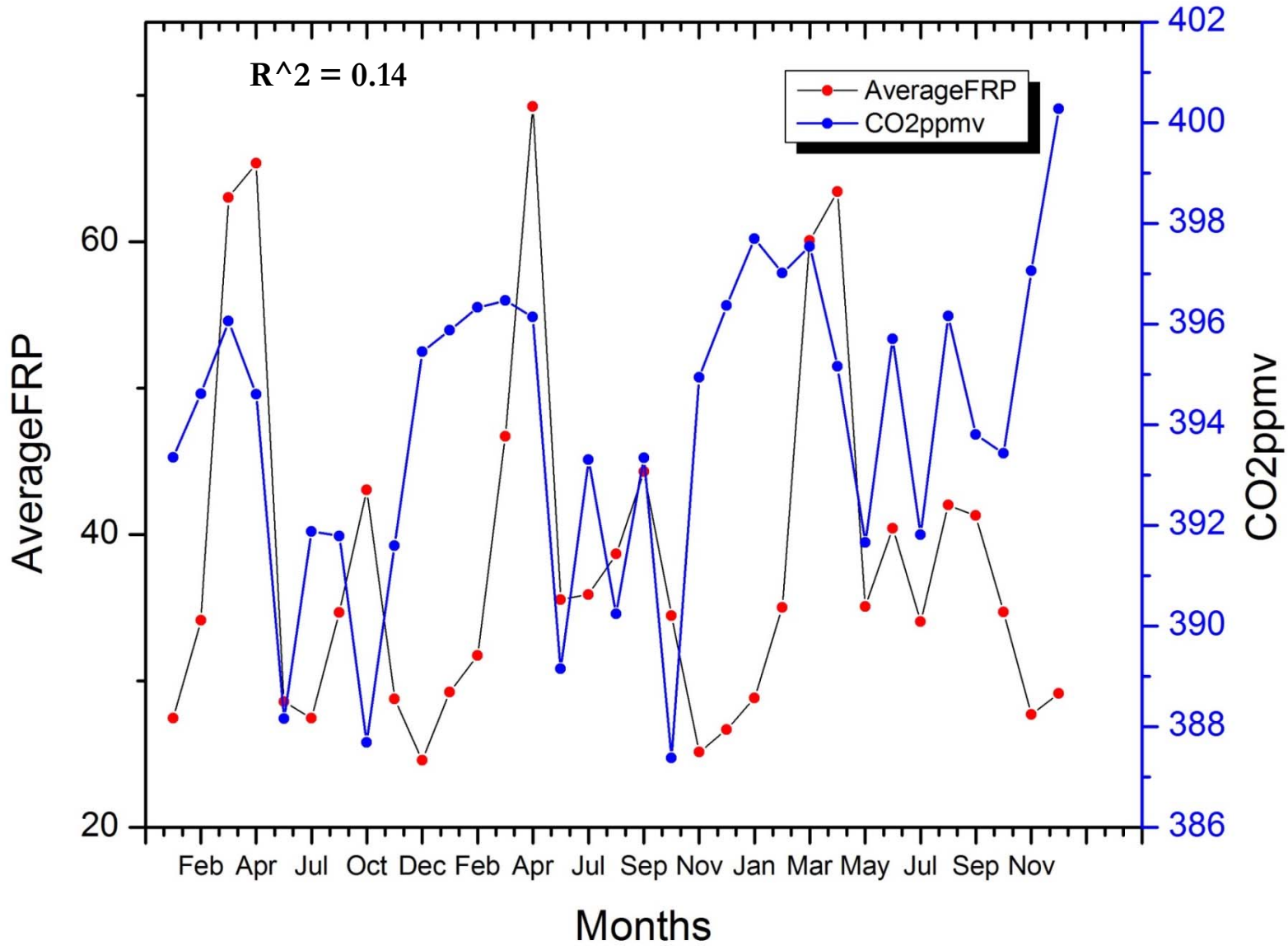




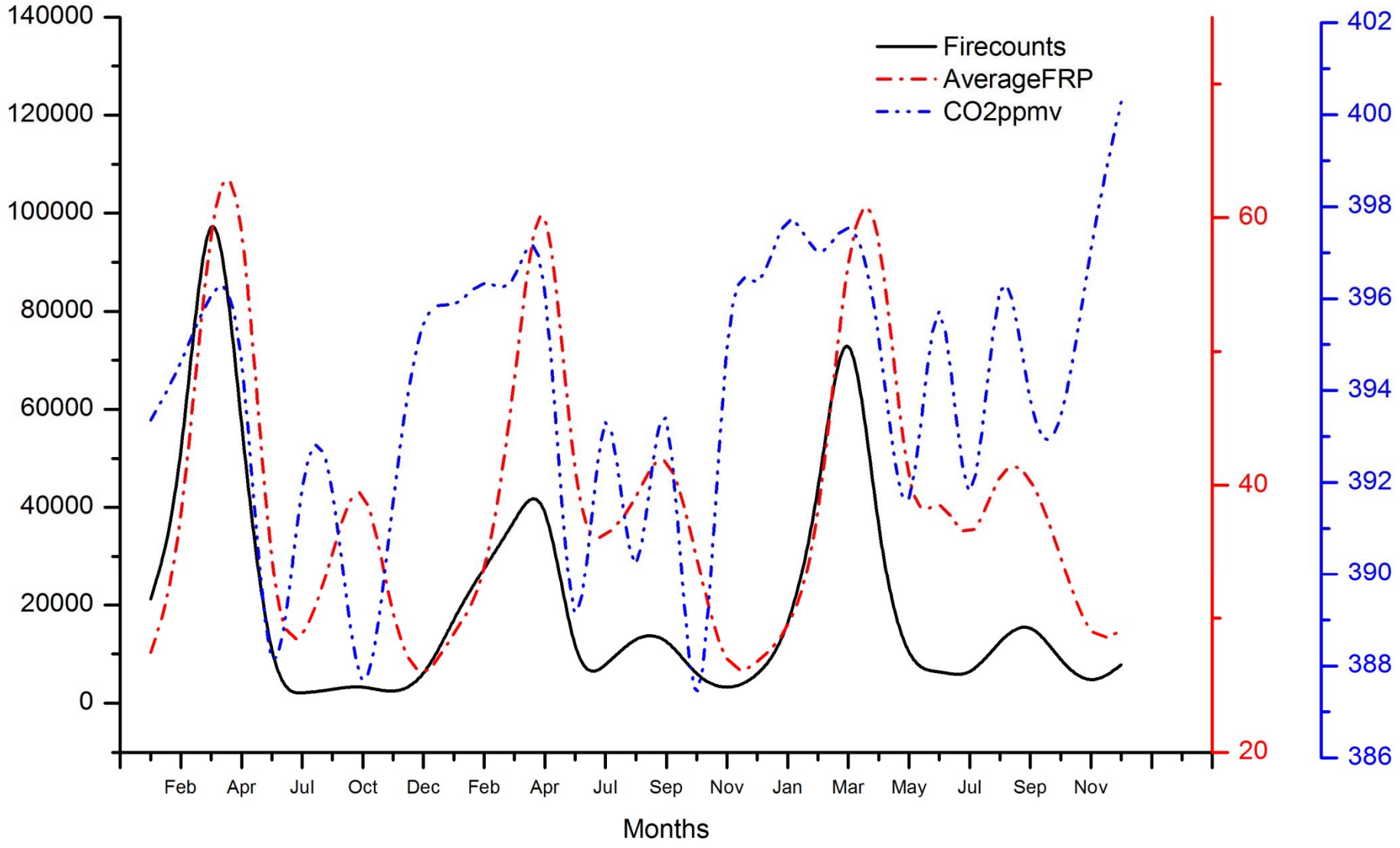
Fire counts vs GOSAT CO2 Data (2010-2012)



FRP vs GOSAT CO2 Data (2010-2012)



Fire counts/FRP vs GOSAT CO2 Data (2010-2012)



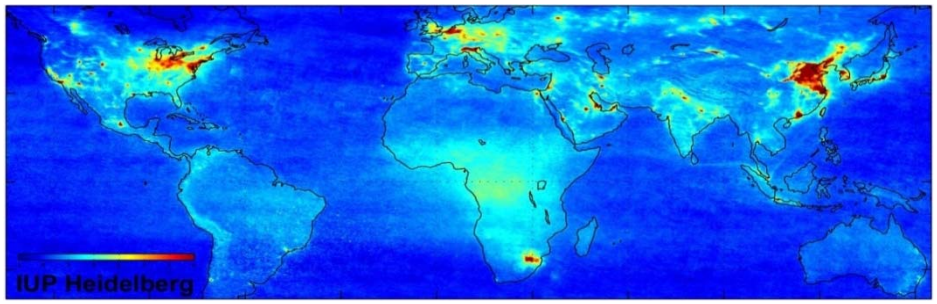
OMI and SCIAMACHY NO2

Ozone Monitoring Instrument

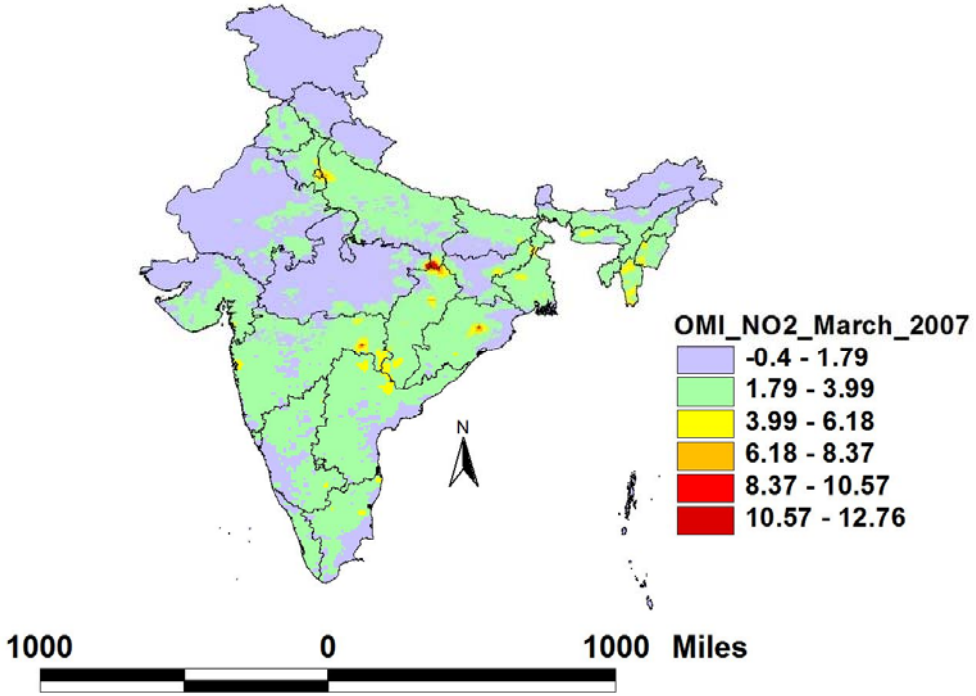
- Mounted on the EOS Aura Platform
- Observes back-scattered radiation with a Hyperspectral (UV-Visible), nadir-viewing, with daily global coverage.
- Measures total column amount of O_3, NO_2, SO_2 and aerosols

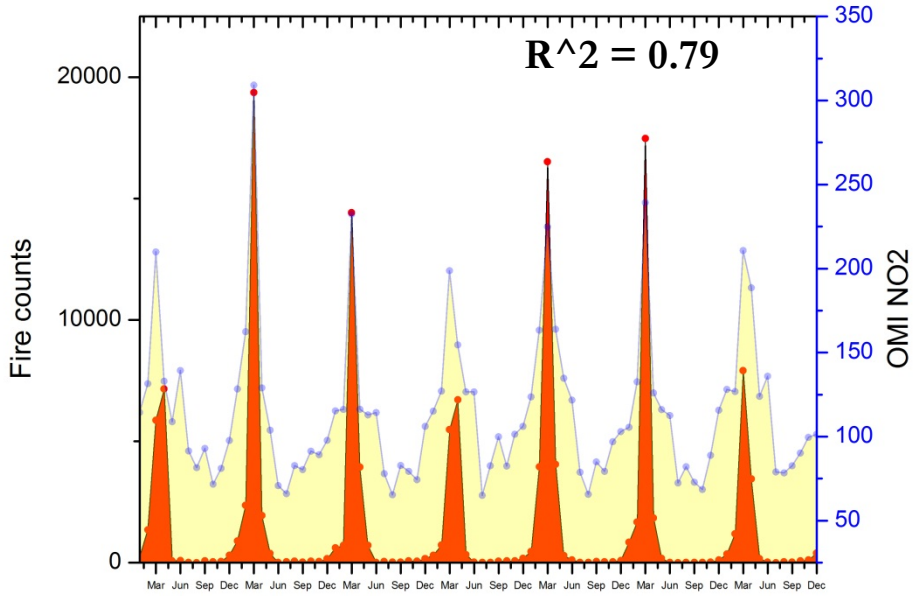
SCIAMACHY Instrument

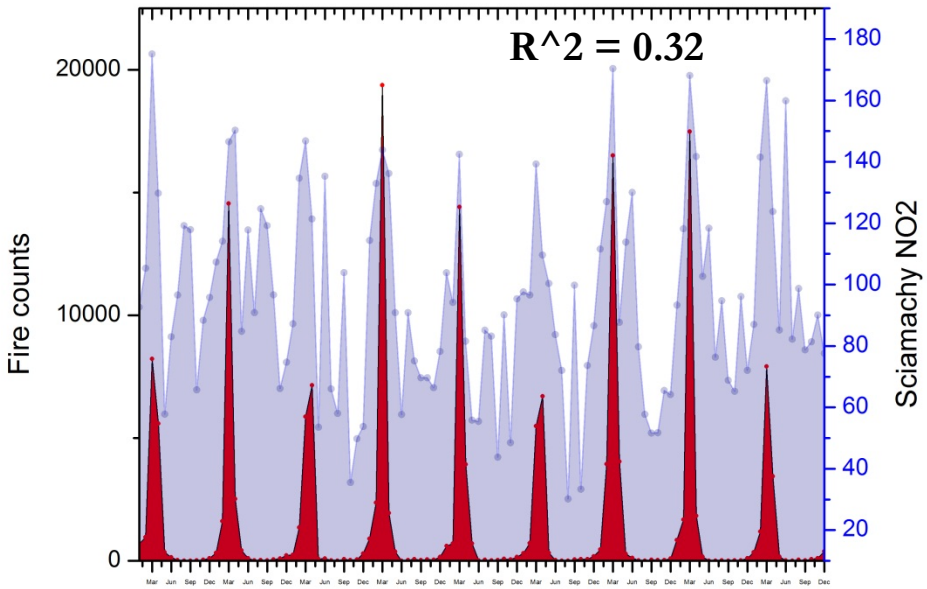
- Onboard ENVISAT, operational from 2002- April 2012
- 0.24 – 2.38um spectral range, Polar Orbit, 35 day repeat cycle, 10:00 a.m. mean local solar time descending node.
- Measures trace gases, aerosols, and clouds through backscattered, reflected, and transmitted solar radiation



Fires and OMI versus SCIAMACHY NO2







OMI NO2 better correlates with Active Fires than SCIAMACHY