Biomass burning emissions in Indo-Ganges and uncertainties

Krishna Prasad Vadrevu and Chris Justice

University of Maryland College Park
Maryland, USA

2007 IPCC Report – "Himalayan Glaciers could melt away by 2035".

2010 – IPCC retracted the statement due to high uncertainties in the GHG inventories, aerosol contribution, atmospheric models, etc.

guardian.co.uk

News | Sport | Comment | Culture | Business | Money | Life & style

Environment › Glaciers

IPCC officials admit mistake over melting Himalayan glaciers

Senior members of the UN's climate science body admit a claim that Himalayan glaciers could melt away by 2035 was unfounded

Damian Carrington
guardian.co.uk, Wednesday 20 January 2010 14.26 GMT
Article history

The Himalayas. The row centres on the IPCC's 2007 report, which said 'glaciers in the Himalayas are receding faster than in any other part of the world.' Photograph:

Recent findings suggest GHG's alone may not be responsible for Glacier Melt!

News | Articles | Videos | Images | Books

Health & Medicine | Mind & Brain | Plants & Animals | Earth & Climate | Space & Time | Matter & E...

Science News — Share | Blog | Cite

Black Carbon Deposits on Himalayan Ice Threaten Earth's 'Third Pole'

ScienceDaily (Dec. 15, 2009) — Black soot deposited on Tibetan glaciers has contributed significantly to the retreat of the world's largest non-polar ice masses, according to new research by scientists from NASA and the Chinese Academy of Sciences. Soot absorbs incoming solar radiation and can speed glacial melting when deposited on snow in sufficient quantities.

See Also:
Earth & Climate
- Global Warming
- Air Quality
- Ice Ages
- Environmental Issues
- Climate
- Air Pollution

Reference

Temperatures on the Tibetan Plateau -- sometimes called Earth's "third pole" -- have warmed by 0.3°C (0.5°F) per decade over the past 30 years, about twice the rate of observed global temperature increases. New field research and ongoing quantitative modeling suggests that soot's warming influence on Tibetan glaciers could rival that of greenhouse gases.

"Tibet's glaciers are retreating at an ...

enlarge

To better understand the role that black soot has on glaciers, researchers trekked high into the Himalayas to collect ice cores that contain a record of soot deposition that spans back to the 1950s. (Credit: Institute of Tibetan Plateau Research, Chinese Academy of Sciences)

In the Tibetan Glaciers, during the last 20 years, the black soot concentration has increased two- to three-fold relative to its concentration in 1975 (Cao et al., PNAS, 2009).

← UK Greenpeace director calls for new IPCC chairman – meanwhile Pachy comments on the use of makeup | Lord Monckton wows Melbourne →

LBNL on Himalayas: "greenhouse gases alone are not nearly enough to be responsible for the snow melt"

Posted on February 3, 2010 by Anthony Watts

From Lawrence Berkeley National Labs, and announcement that comes at a very inconvenient time for IPCC and Pachauri while their "Glaciergate" issue rages. Aerosols and black carbon are tagged as the major drivers. And no mention of disappearance by 2035.

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

Black Carbon a Significant Factor in Melting of Himalayan Glaciers

The fact that glaciers in the Himalayan mountains are thinning is not disputed. However, few researchers have attempted to rigorously examine and quantify the causes. Lawrence Berkeley National Laboratory scientist Surabi Menon set out to isolate the impacts of the most commonly blamed culprit—greenhouse gases, such as carbon dioxide—from other particles in the air that may be causing the melting. Menon and her collaborators found that airborne black carbon aerosols, or soot, from India is a major contributor to the decline in snow and ice cover on the glaciers.

Questions Addressed

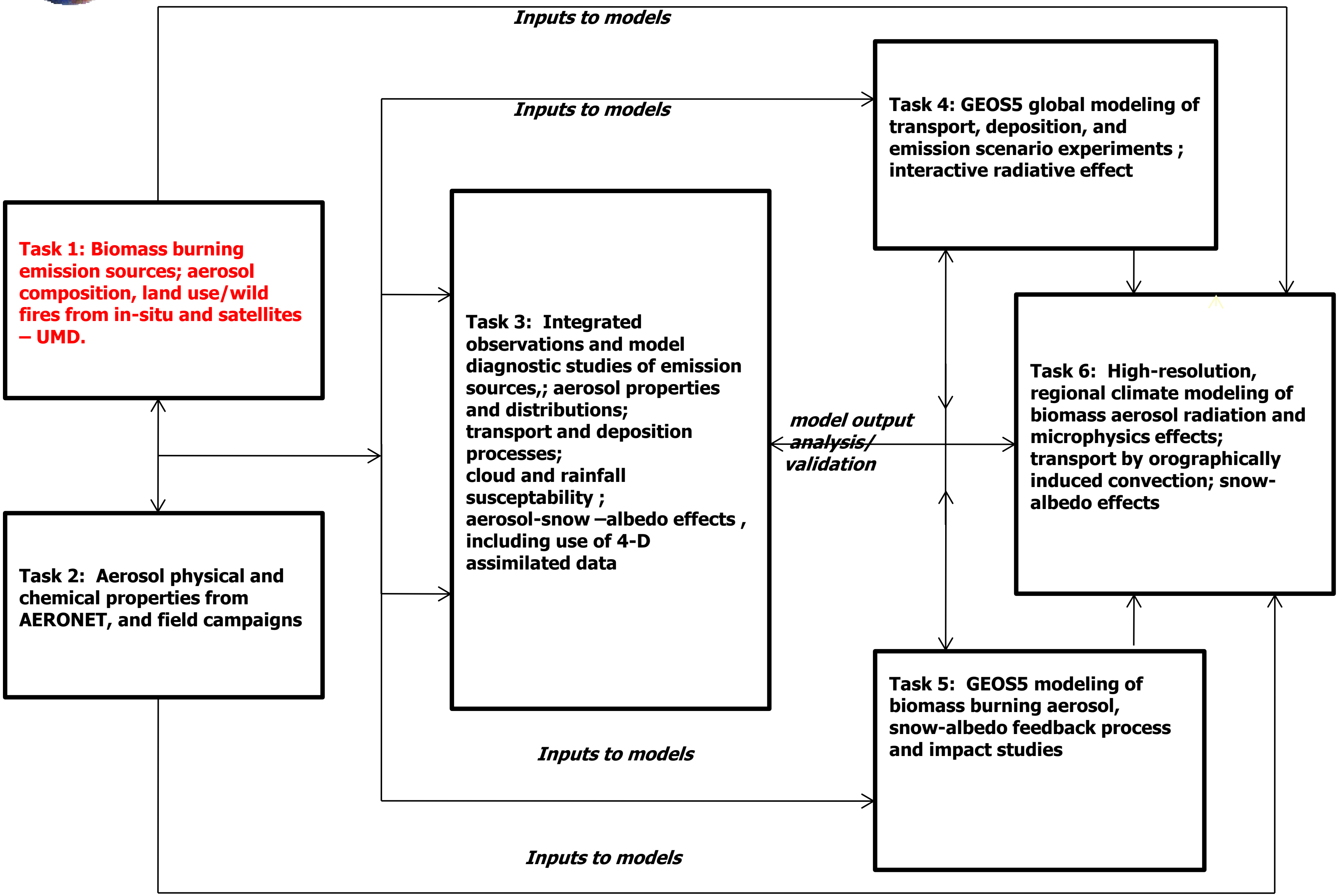
What are the important sources of biomass burning in the Asian Region? Which countries dominate with respect to open biomass burning activities impacting LU change in the Asian region?

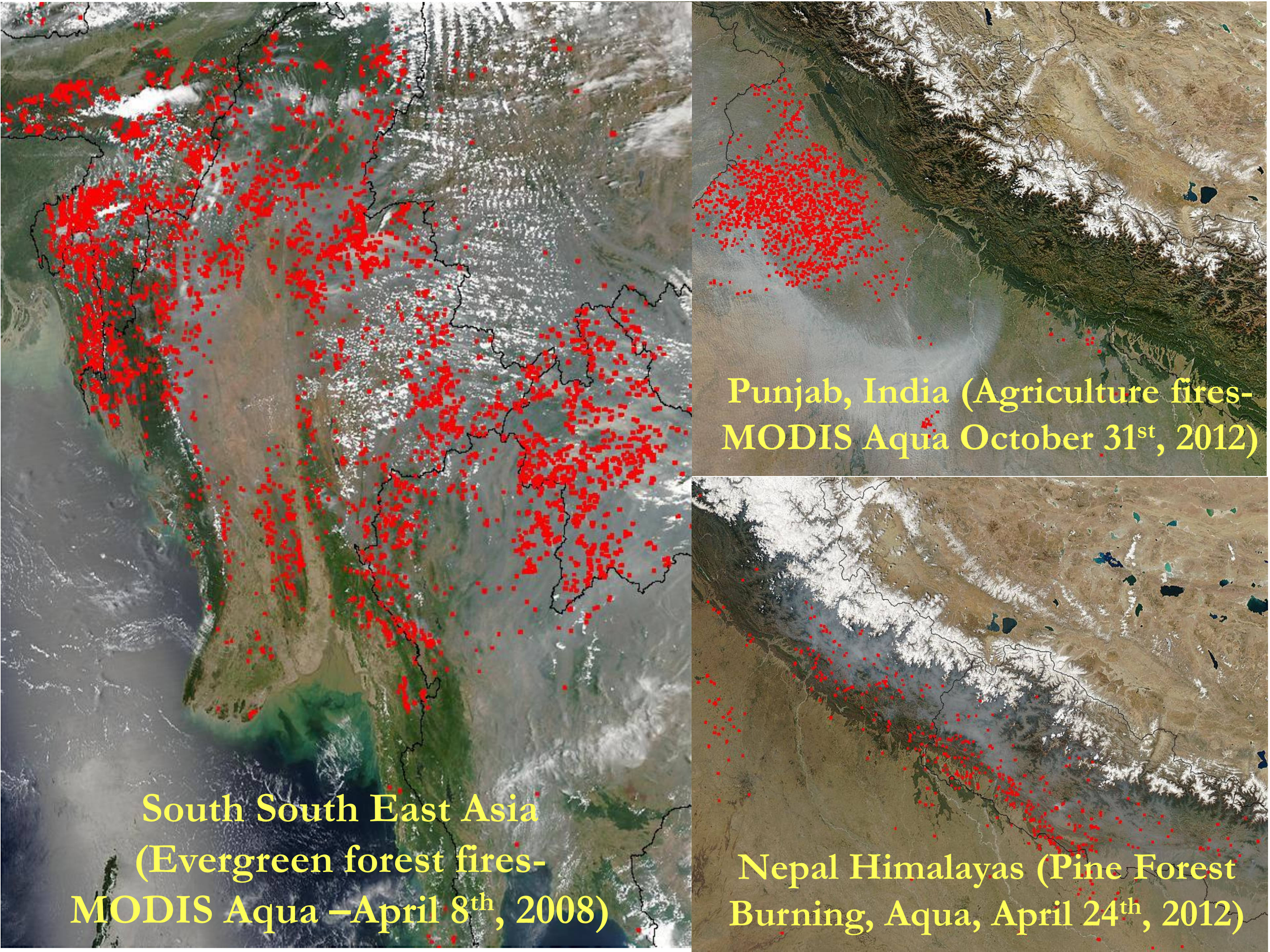
What are the typical agricultural and forest biomass loads in the region?

What are the typical smoke plume heights of evergreen forest and agriculture fires?

Can tropospheric satellites MOPITT (CO), OMI and SCIAMACHY detect pollutant signals from biomass burning?

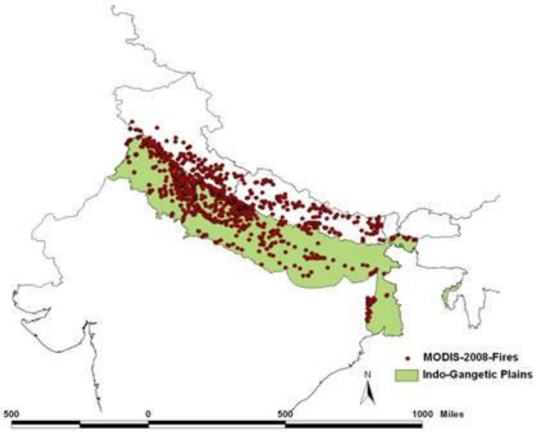
Integrated Modeling for addressing the effects of Biomass Burning on Asian Monsoon Water Cycle and Climate – UMD-NASA Collaboration



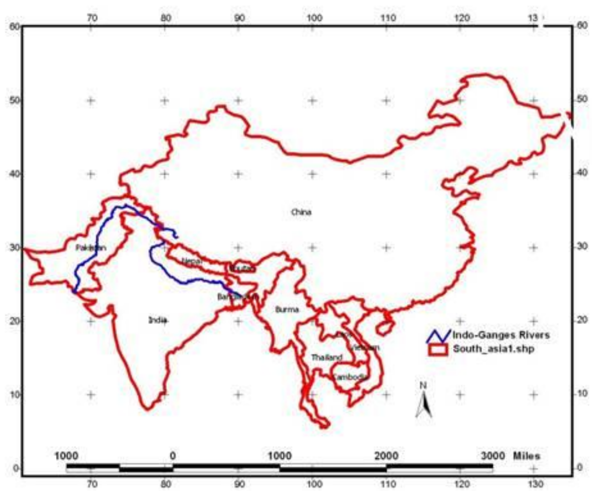


South South East Asia (Evergreen forest fires- MODIS Aqua –April 8th, 2008)
Punjab, India (Agriculture fires- MODIS Aqua October 31st, 2012)
Nepal Himalayas (Pine Forest Burning, Aqua, April 24th, 2012)

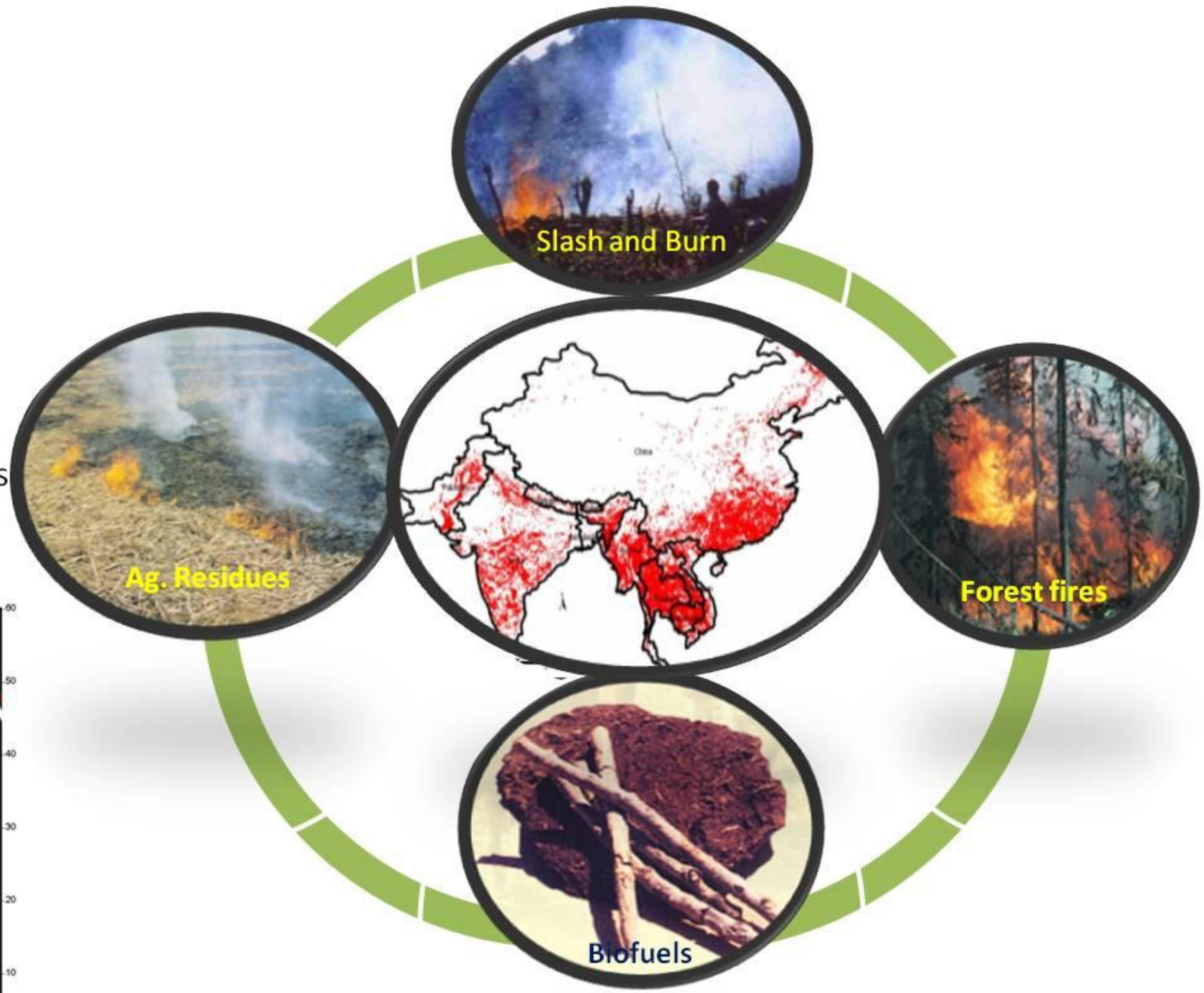
Integrated Modeling for addressing the effects of Biomass Burning on Asian Monsoon Water Cycle and Climate – UMD-NASA Collaboration



Task 1. Focus area – Indo-Gangetic plains (May, 2010 – May,2011)

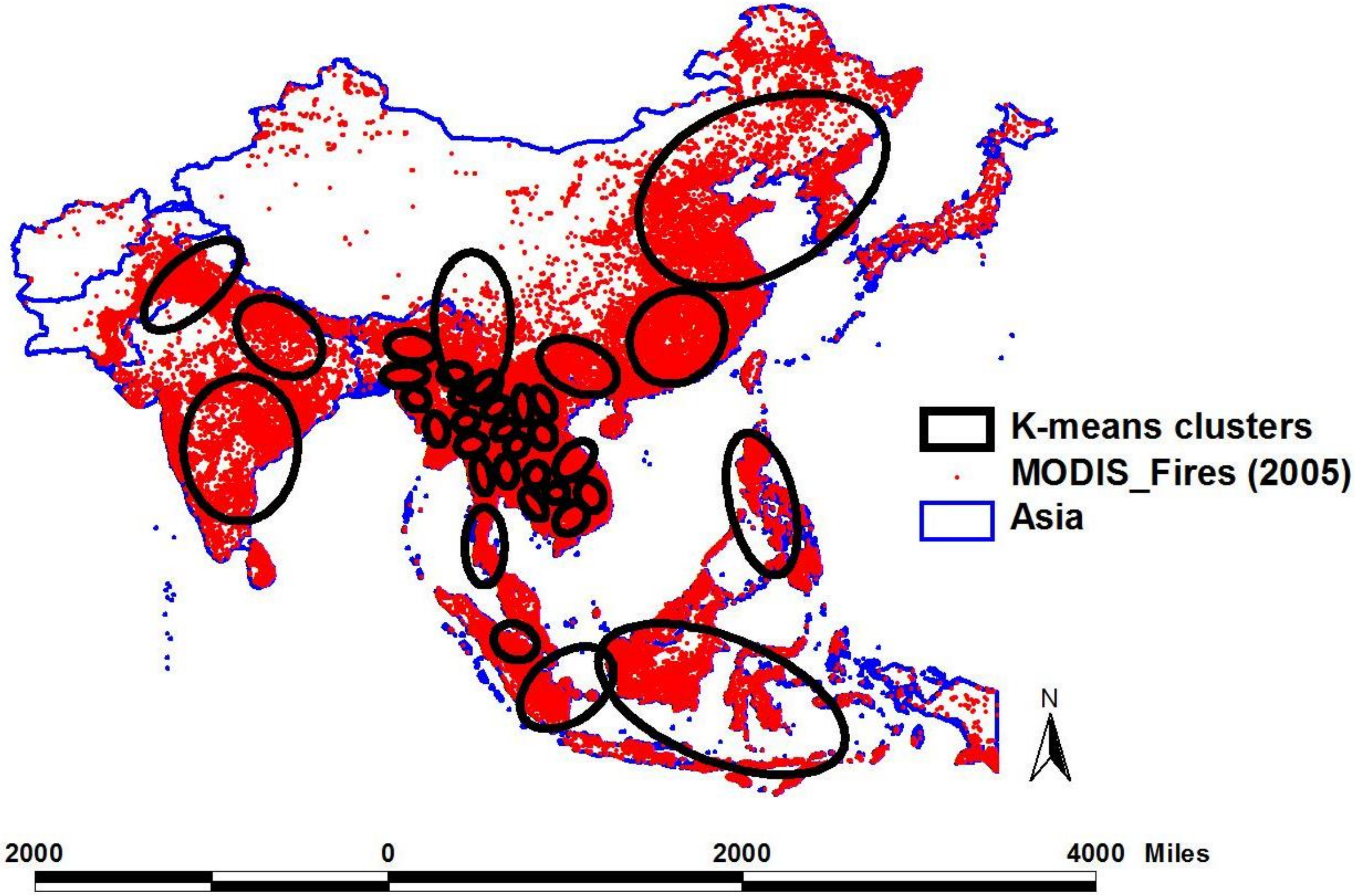


Task 1a. Focus area – Indo- China



Biomass Burning Emission Sources

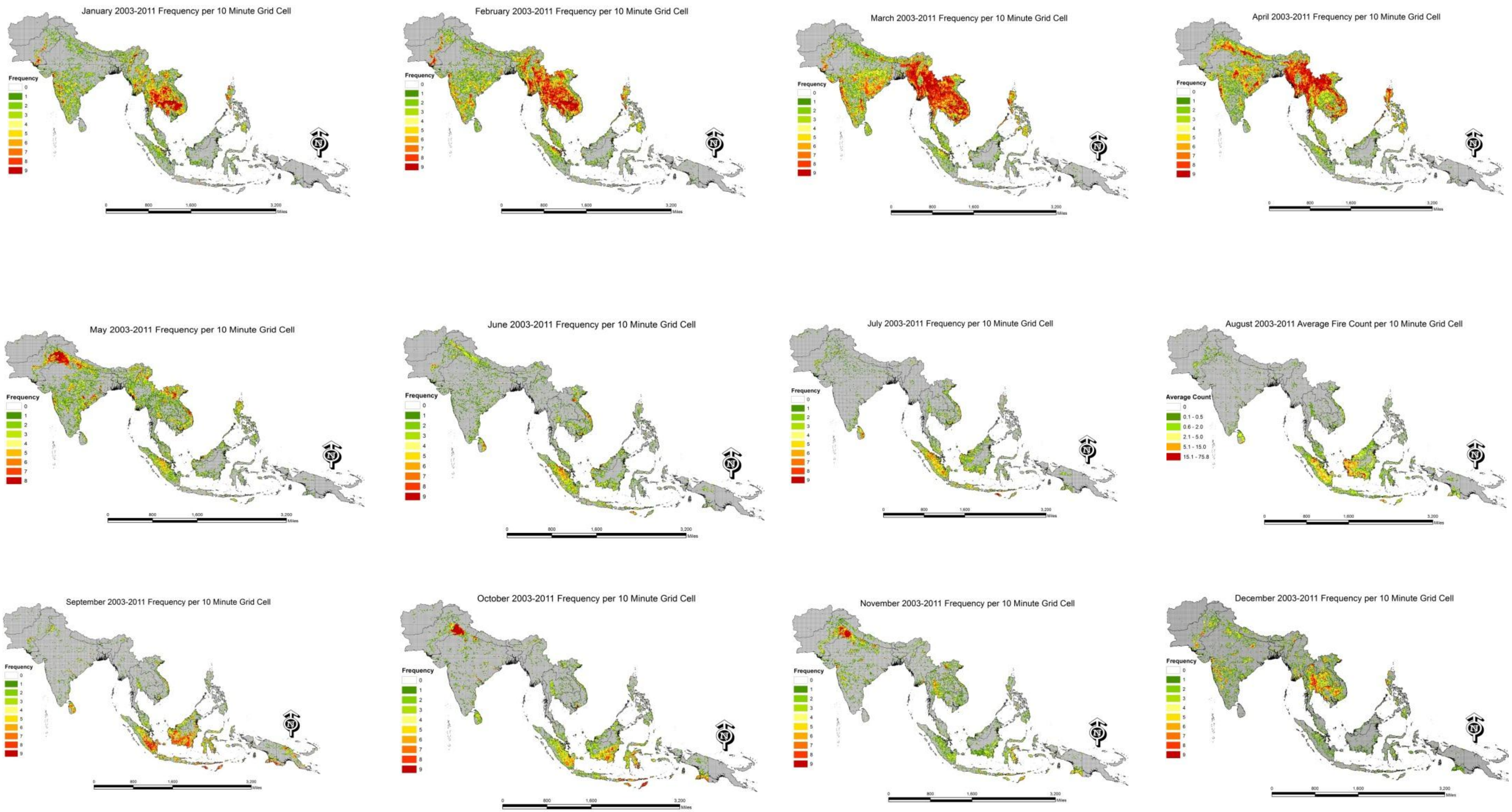
Hotspot regions of vegetation fires in the Asian Region



Fire clusters in the Asian region for the year 2005. K-means algorithm has been used to detect the fire clusters and the hotspot areas in the region.

Vadrevu et al. 2012. IEEE JSTARS. 99-1-15.

Monthly Fire Frequencies per 10minute grid cells (2003-2011)

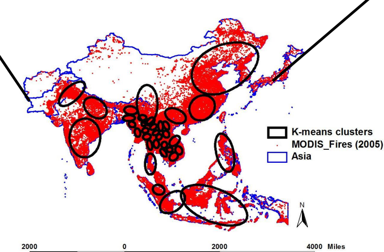


Fire Frequency Maps (2003-2011) with the highest fire frequency during March.

Country	Annual Fire counts	% contribution
Afghanistan	248	0.065
Bangladesh	3113	0.814
Bhutan	209	0.055
Brunei	35	0.009
Cambodia	25360	6.631
China	**56668**	**14.817**
East Timor	1128	0.295
Hong Kong	69	0.018
India	**63696**	**16.654**
Indonesia	**60224**	**15.747**
Japan	1771	0.463
Laos	**32601**	**8.524**
Macao	0	0.000
Malaysia	4515	1.181
Maldives	0	0.000
Myanmar	**68279**	**17.853**
Nepal	2230	0.583
North Korea	1772	0.463
Pakistan	6748	1.764
Philippines	4926	1.288
Singapore	7	0.002
South Korea	578	0.151
Sri Lanka	1277	0.334
Taiwan	307	0.080
Thailand	**31643**	**8.274**
Vietnam	15051	3.935
Total	**382455**	**100**

Top 7 countries-Biomass burning (Active fires)

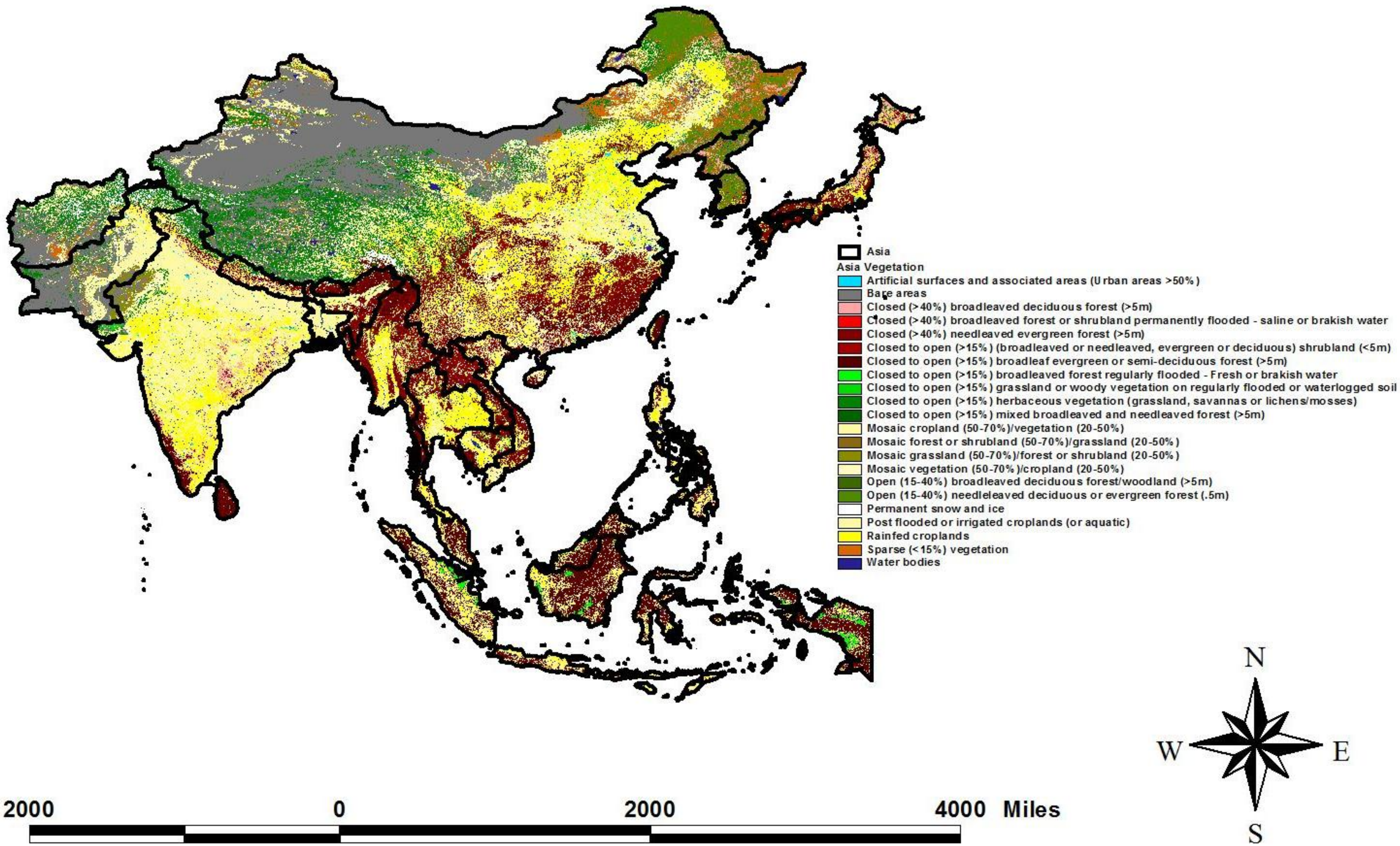
Myanmar – 17.8%
India – 16.65%
Indonesia – 15.74%
China – 15.81%
Laos – 8.52%
Thailand – 8.27%
Cambodia – 6.63%



Annual average fire occurrences (active fires) in different countries derived nine years of MODIS Active Fire data (2002-2011).

Vadrevu and Justice,2011. GER. 65-76

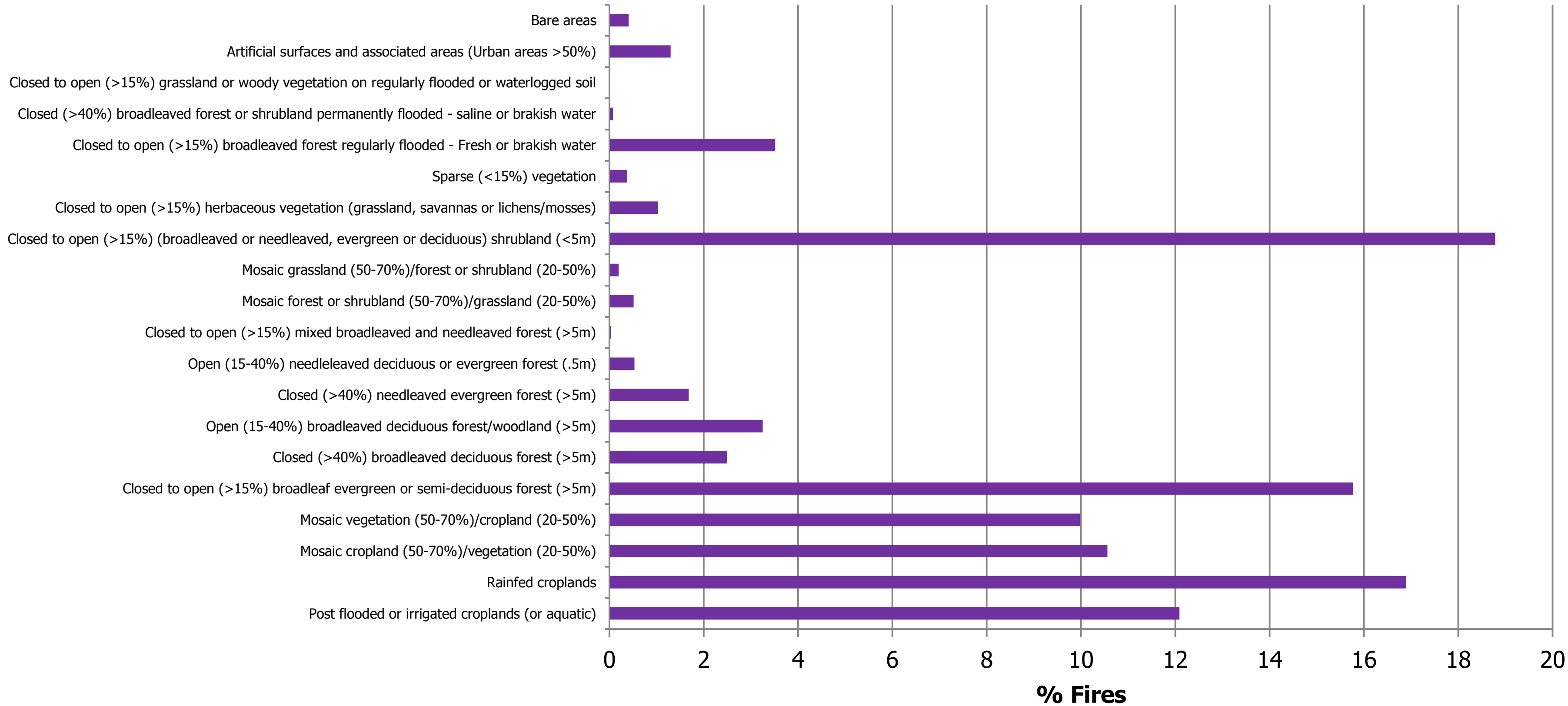
Fire-Vegetation Analysis – 300m MERIS data



MERIS (300m) derived vegetation map of the Asian region.

Vadrevu et al. 2012. IEEE JSTARS. 99-1-15.

Fire-Vegetation Analysis – 300m MERIS data



Percent fire occurrences in the diverse vegetation categories.

Fires in the Broadleaved deciduous forests and shrublands followed by Rainfed croplands dominate in the Asian region

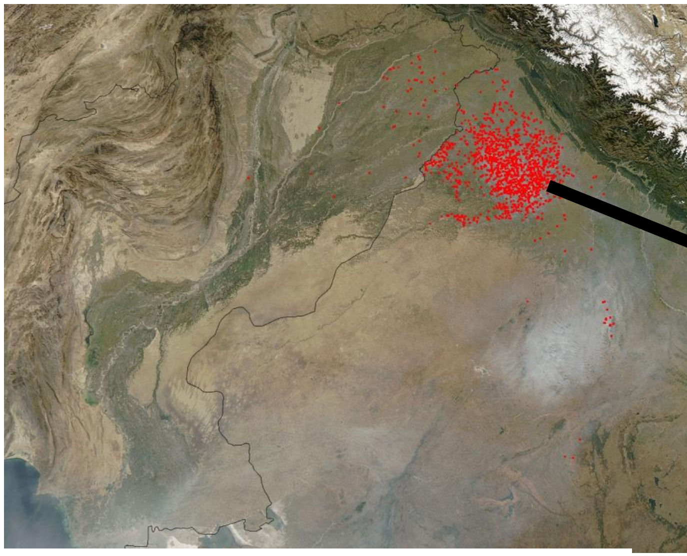
Biomass burning emissions

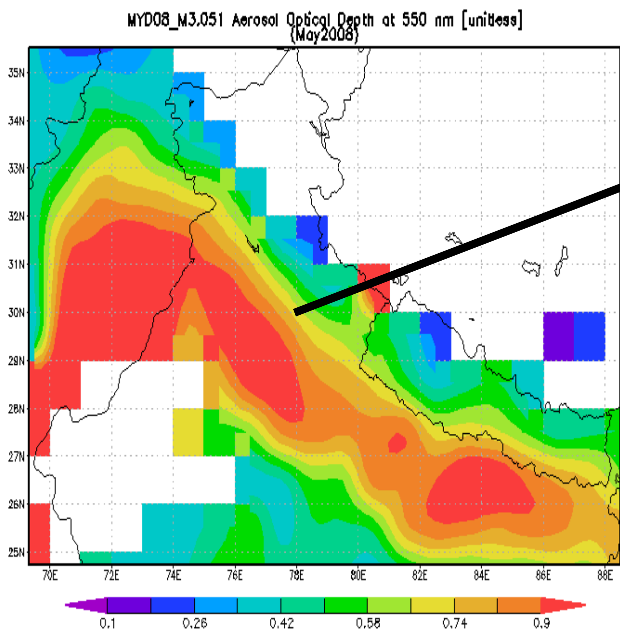
Seiler and Crutzen, 1980 – Emissions estimation

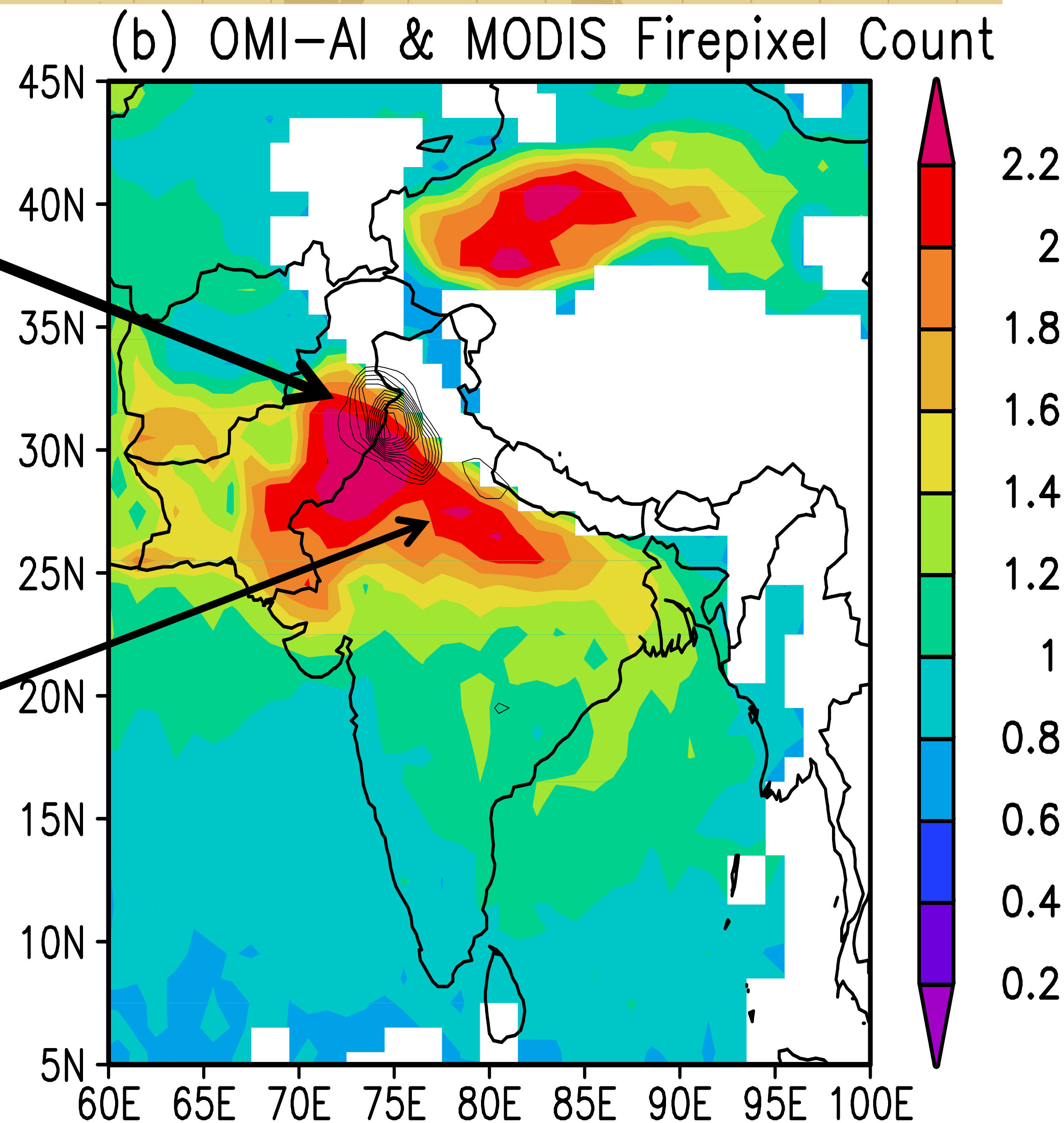
- **M (quantity of gas emitted) = Area x Biomass Density x Burning Efficiency x Emission Factor**
- **Area – Satellite based mapping;**
- **Biomass density/fuel loading – (vegetation type mapping);**
- **Burning efficiency - (most uncertain - field measurements);**
- **Emission factors (field or lab 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.

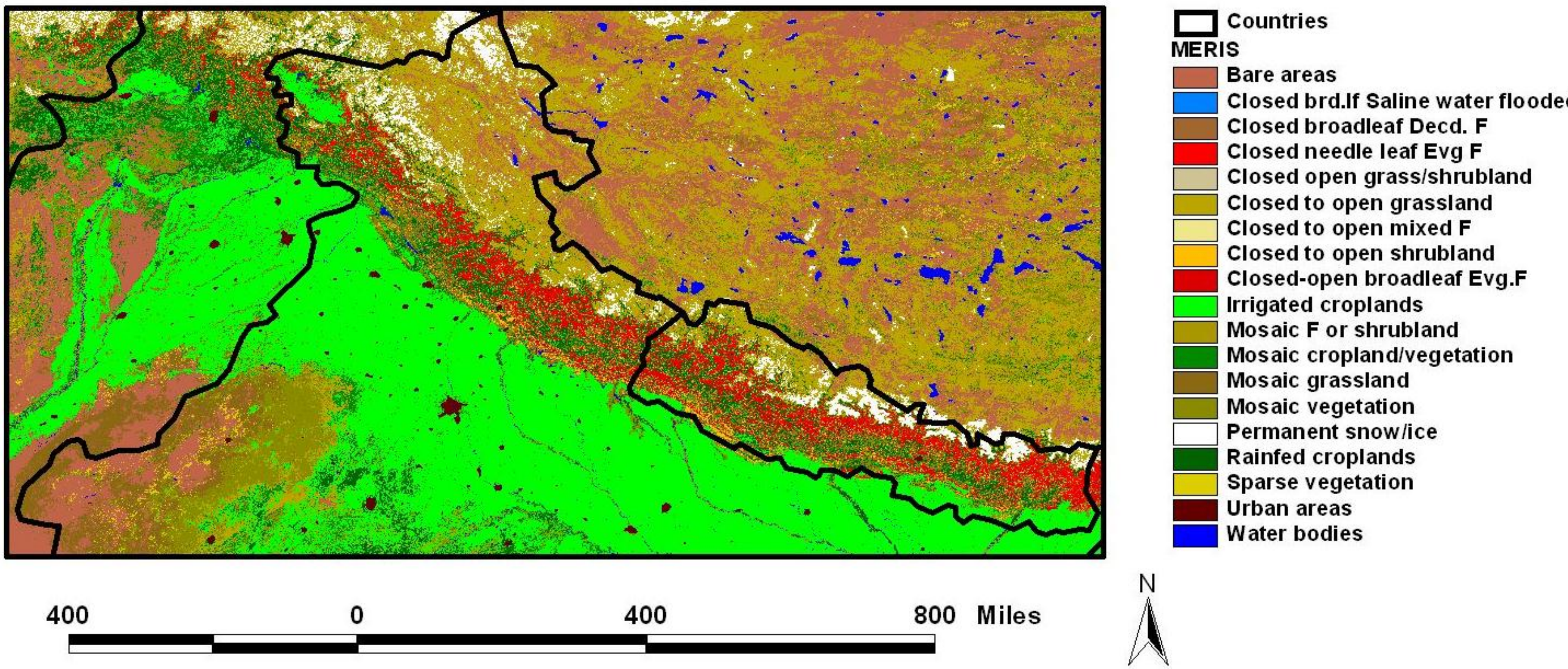
Intense Aerosol Optical Depth during Summer - IGP







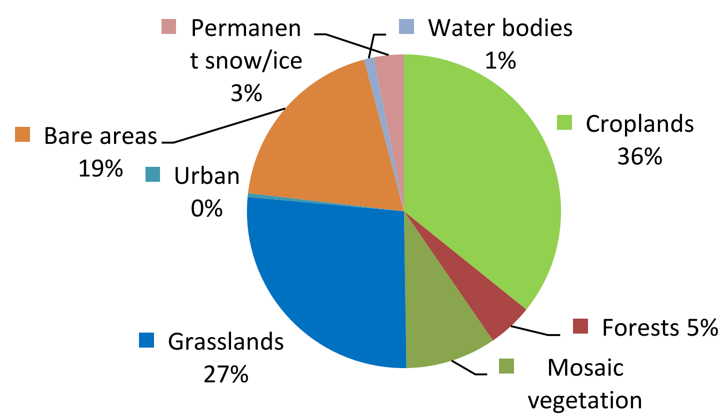
Vegetation Analysis MERIS – 300m



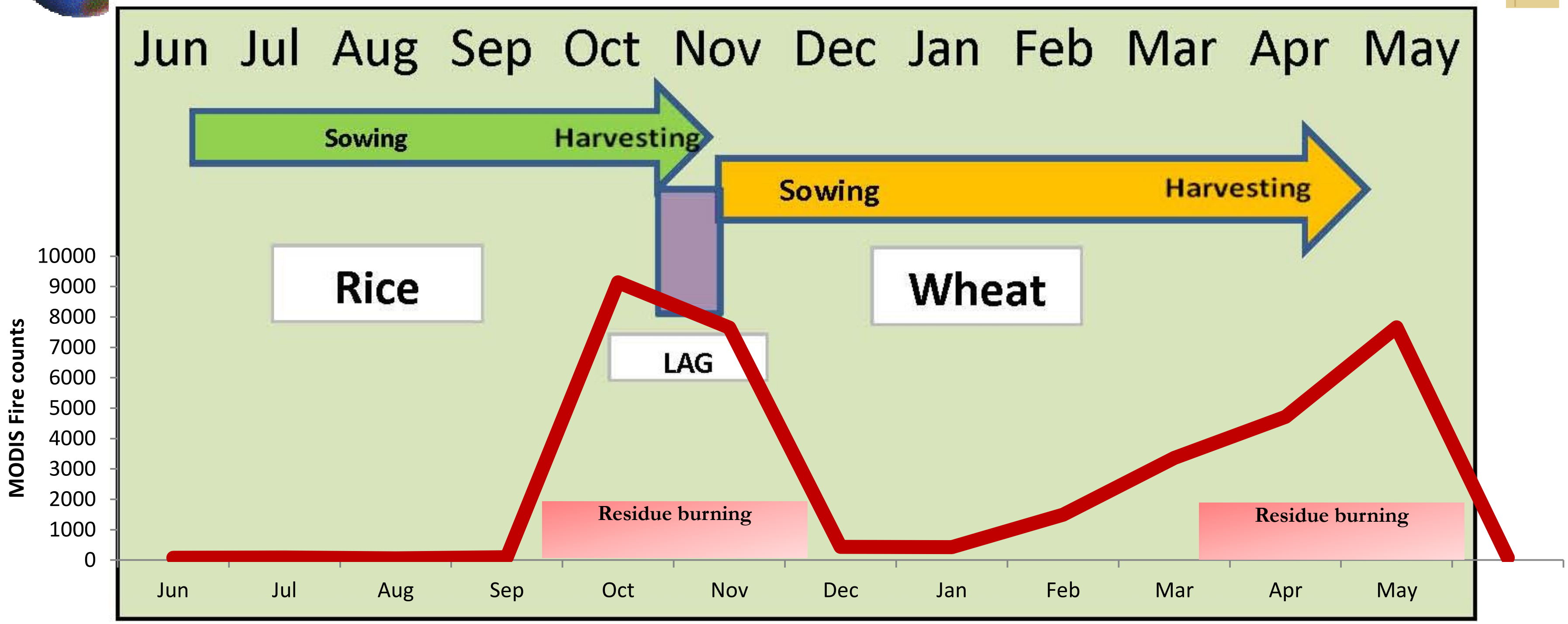
MERIS (300m) land cover product 2005-2006 has been used for land cover characterization.

Irrigated croplands (36%) dominate the study area followed by grasslands (27%).

Forests occupy ~5% of the total 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., EP, 2012;

Residue Burning Causes..

Residues are burnt because:

a). Manual harvesting and threshing of Rice/Wheat involve high labor costs.

b). Use of Combines allows rapid field preparation for the next crop (however, it leaves large amount of residues on field).

c). Use of rice residues as cattle feed is uncommon due to high silica. Wheat residues were partly fed (before Combine harvesters came), however, mostly burnt now-a-days.

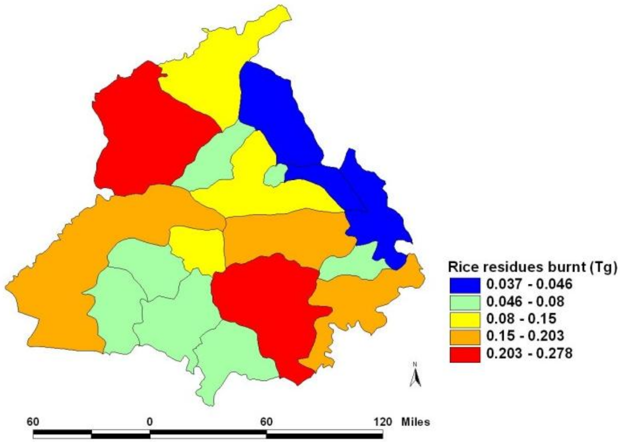
d). No significant income generating alternate use of rice residues.

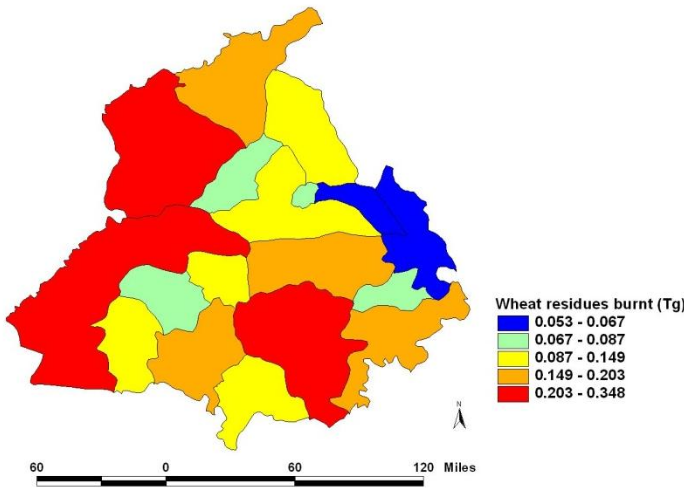
e). Burning residues is quicker way to clear the fields for next crop (sowing Wheat mostly).

How much quantity of Residues (Tg) are burnt in Punjab?

Districts	Rice residues	Wheat residues
Amritsar	0.251802	0.348506
Bathinda	0.076328	0.186617
Fairdkot	0.065803	0.08708
Fatehgarh Sahib	0.064105	0.081741
Firozpur	0.189434	0.293098
Gurdaspur	0.150328	0.168209
Hoshiapur	0.04601	0.109696
Jalandhra	0.107235	0.127218
Kapurthala	0.080315	0.08664
Ludhiana	0.203503	0.198412
Mansa	0.05984	0.126928
Moga	0.118534	0.131944
Muktsar	0.06403	0.14969
Nawanshahr	0.037739	0.05324
Patiala	0.192978	0.203813
Rupnagar	0.038662	0.06768
Sangrur	0.278943	0.304561
Total	2.02	2.72

Total Residues = 4.23 Tg or 4.23 million metric tonnes



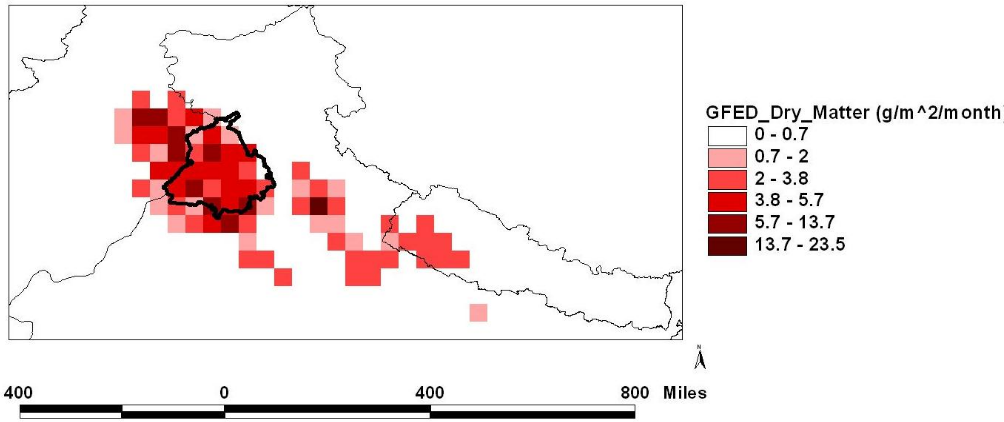


Rice and Wheat crop production data for 2000-2010 has been converted to Residues using Grain production to Residue ratios.

Typical field size = 4-8acres

15% of total residues were assumed to be burnt.

Comparison of Fuel Loads in GFED vs. Actual Crop Data



Mean = 4.925 g/m2/month

IPC C methodology for estimating Residue amounts in the field:

Crop Production X Residue to Crop Ratio X Dry matter Fraction

GFED based dry matter values seems to be relatively low for Agricultural region of Punjab, which is the hotspot region of Fires in the Indo Ganges region.

Year	Wheat Area (ha)	Production (tons)	Residue fraction	Dry matter	g/m2/month
1996-97	3229000	13672000	1.5	0.83	43.93
1997-98	3300000	12715000	1.5	0.83	39.98
1998-99	3338000	14460000	1.5	0.83	44.94
1999-2000	3388000	15910000	1.5	0.83	48.72
2000-01	3408000	15551000	1.5	0.83	47.34
2001-02	3420000	15499000	1.5	0.83	47.02
2002-03	3375000	14175000	1.5	0.83	43.58
2003-04	3444000	14489000	1.5	0.83	43.65
2004-05	3482000	14698000	1.5	0.83	43.79
2005-06	3468000	14493000	1.5	0.83	43.36
2006-07	3467000	14596000	1.5	0.83	43.68
2007-08	3488000	15720000	1.5	0.83	46.76
					44.54
Year	Rice Area (ha)	Production	Residue fraction	Dry matter	g/m2/month
1996-97	2159000	7334000	1.5	0.83	35.24
1997-98	2281000	7904000	1.5	0.83	35.95
1998-99	2519000	7940000	1.5	0.83	32.70
1999-2000	2604000	8716000	1.5	0.83	34.73
2000-01	2611000	9154000	1.5	0.83	36.37
2001-02	2487000	8816000	1.5	0.83	36.78
2002-03	2530000	8880000	1.5	0.83	36.42
2003-04	2614000	9656000	1.5	0.83	38.32
2004-05	2647000	10437000	1.5	0.83	40.91
2005-06	2642000	10193000	1.5	0.83	40.03
2006-07	2621000	10138000	1.5	0.83	40.13
2007-08	2610000	10489000	1.5	0.83	41.69
					37.43

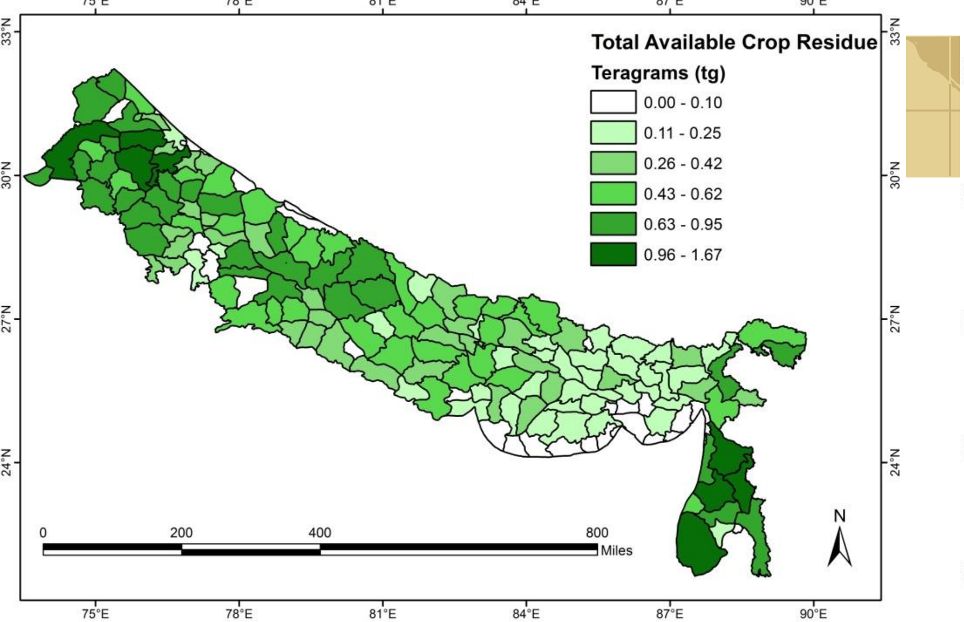
MODIS NPP to Crop yield

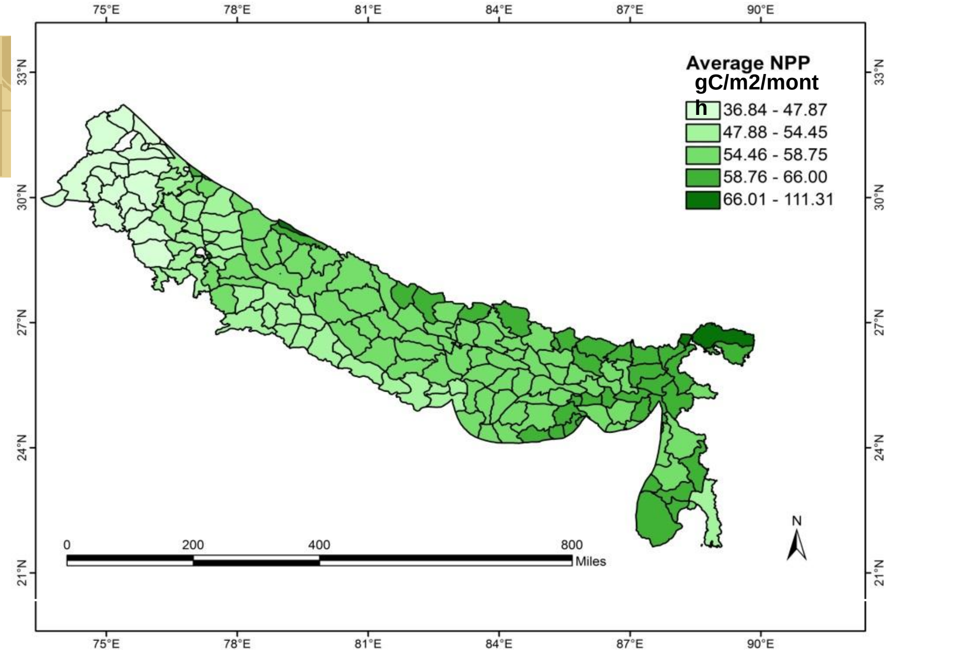
MODIS crop NPP has been converted to yield as:

$$EY_i = NPP_i x \, HI_i / D_i \, x \, C \, x \, (RS_i + 1)$$

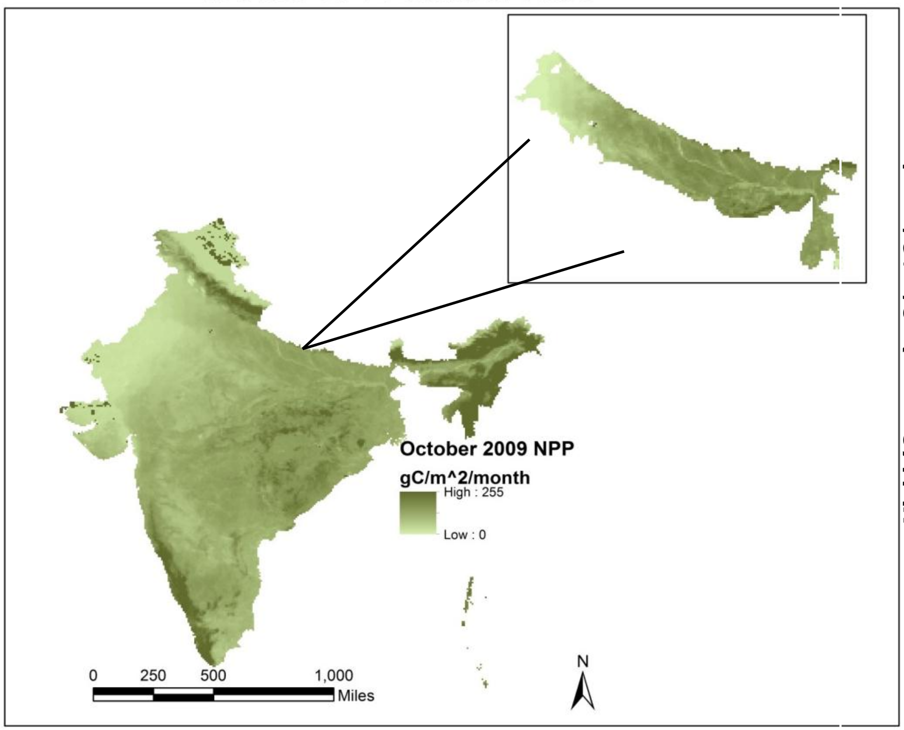
where, NPP = net primary production;
i = specific food crop;
EY = is the economic yield;
HI = harvest index, which measures the proportion of total aboveground;
biologic yield allocated to the economic yield of the crop;
D = is the dry proportion of the EY;
C = carbon content in the dry matter;
RS = root to shoot ratio.

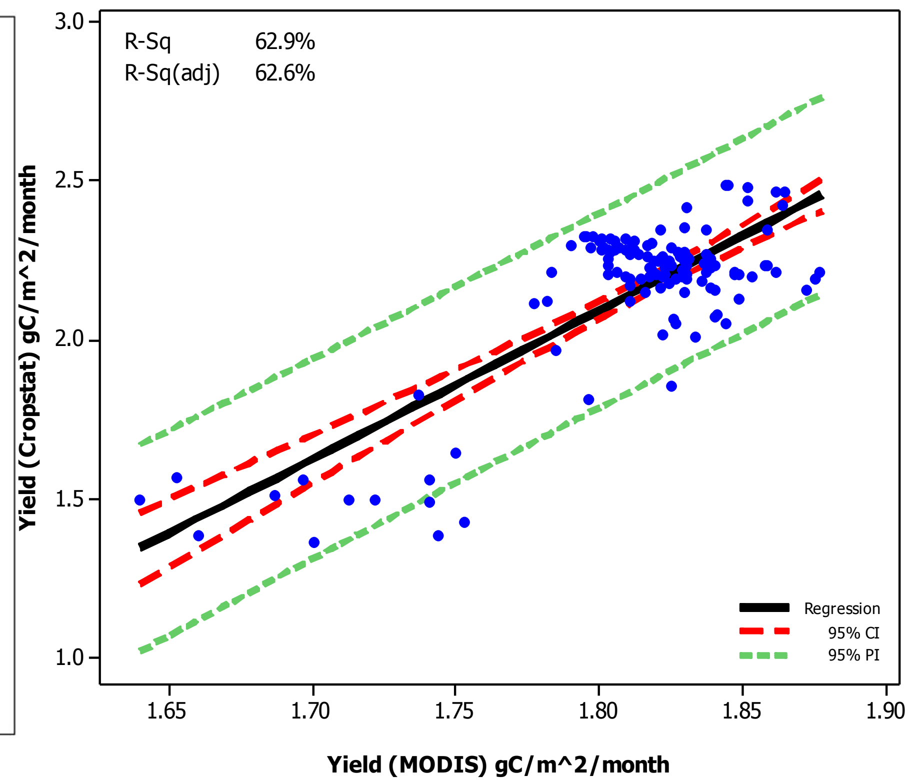
MODIS yield then has been related to crop yield (from field data) for relative accuracy:



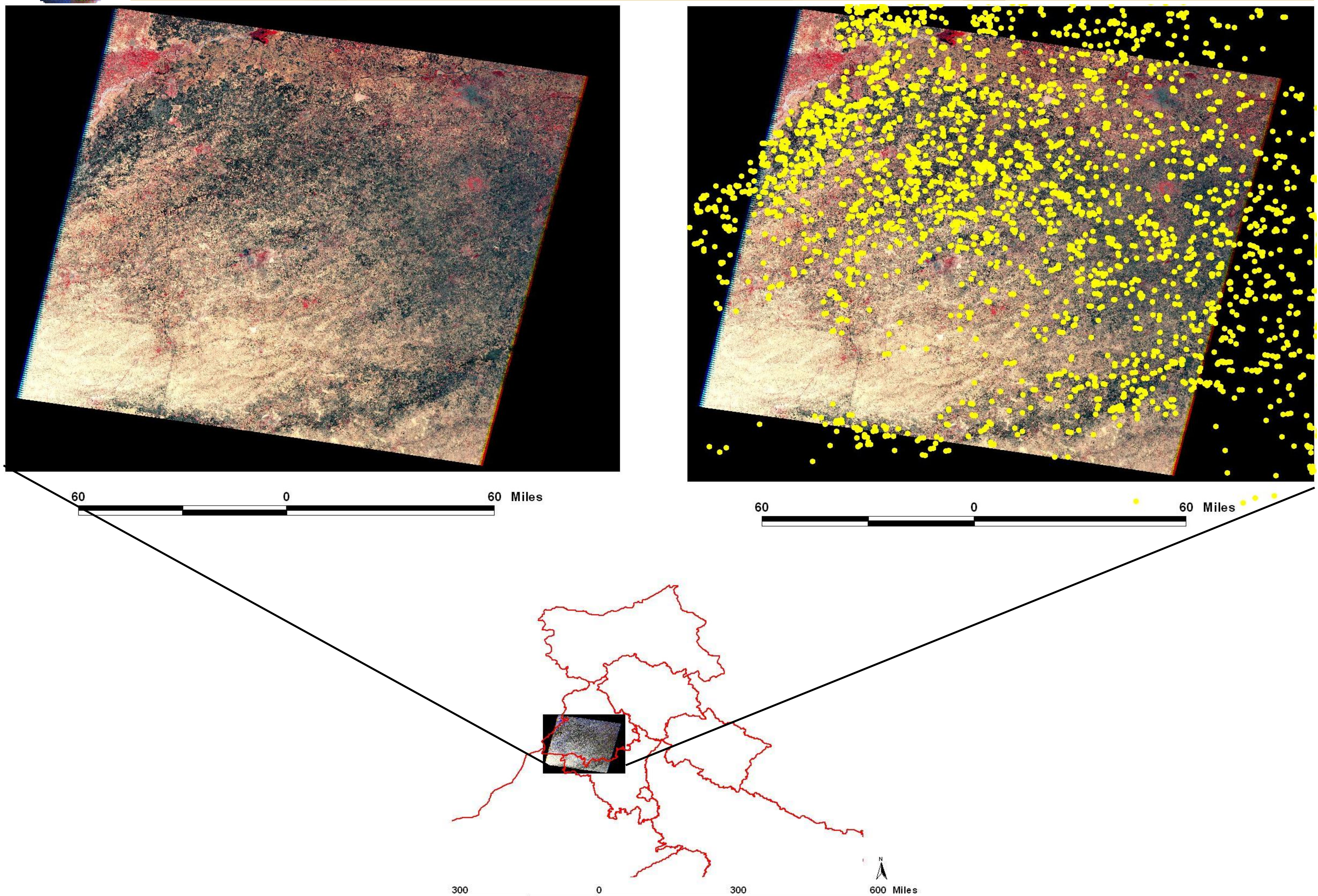


MODIS NPP: October 2009

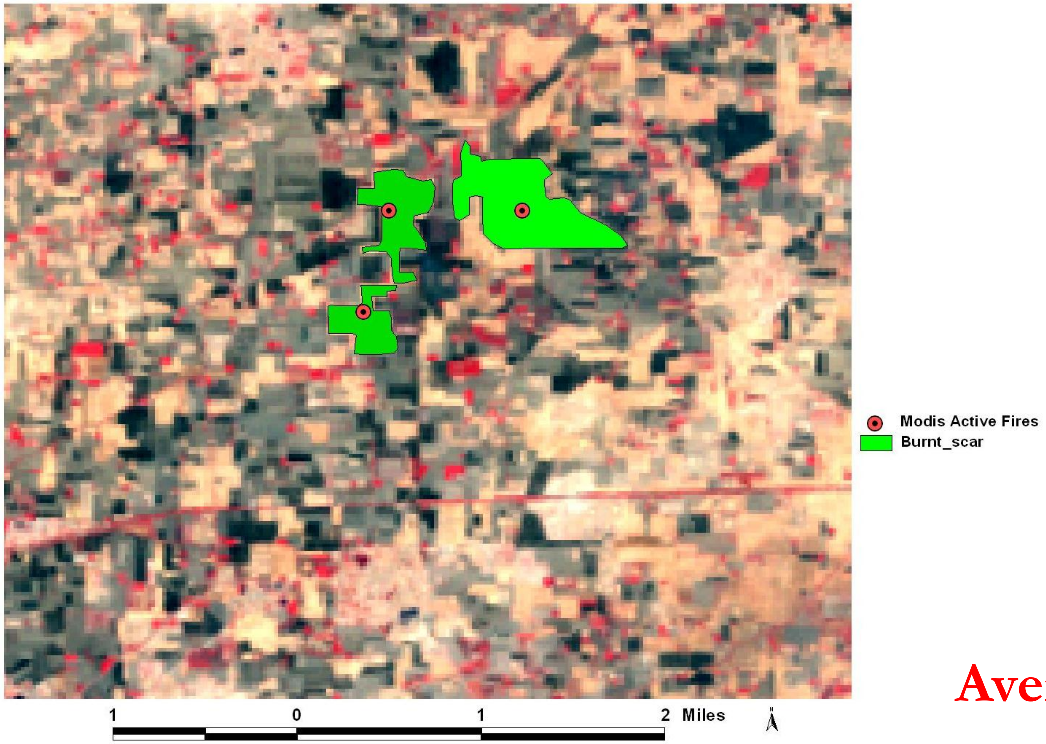




LANDSAT Burnt Areas (March-05, 2003)–Pre-scanline correction problem



Digitizing Field Sizes from Landsat data to arrive at Burn scars for merging with MCD-45A1



Since, MCD-45A1 product underestimated the burnt area in the study area, LANDSAT data (March-05 -2003 pre-scan-line correction image) has been used to digitize Burnt scars for obtaining the averaged field size.

Average field size burnt – 4.29 acres

Non-Overlapping areas were than merged with MCD-45A1 product to arrive at the total corrected burnt area for the region.

Burnt Area Products Merge using Weighted Least Square Method

The two independent Burnt area products (GFED and MCD45A1) along with their respective zero-mean errors (ε_{GFED} and $\varepsilon_{MCD45A1}$) and variances (σ^2_{GFED} and $\sigma^2_{MCD45A1}$) can be represented as:

$$BA_{GFED} = \alpha\, BA_{GFED} + \varepsilon_{GFED}$$
$$BA_{MCD45A1} = \alpha\, BA_{MCD45A1} + \varepsilon_{MCD45A1}$$

where α is the measure of the relation between the realization and the assumed truth (Burnt Areas characterization from MODIS satellite).

Desired merge estimate is obtained as:

$$BA_{merge} = \omega_{GFED}\, BA_{GFED} + \omega_{MCD45A1}\, BA_{MCD45A1}$$

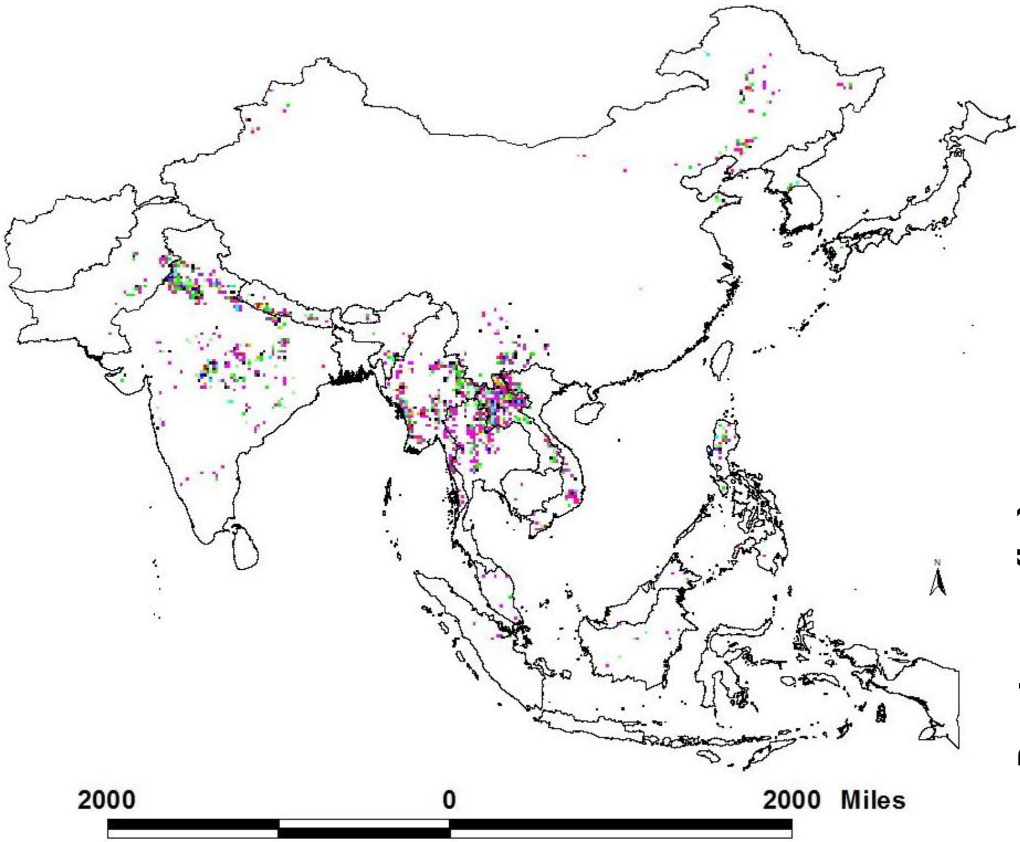
where ω_{GFED} and $\omega_{MCD45A1}$ are the relative weights of the satellite burnt area observations.

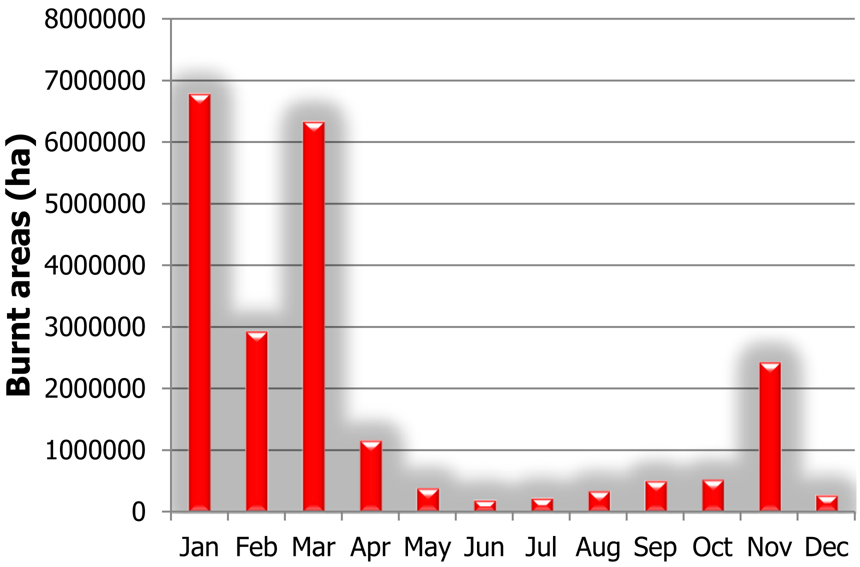
With the known variances, the weight coefficients were obtained as:

$$\omega_{GFED} = \frac{(1/\sigma^2_{GFED})}{(1/\sigma^2_{GFED} + 1/\sigma^2_{MCD45A1})}$$

$$\omega_{MCD45A1} = \frac{(1/\sigma^2_{MCD45A1})}{1/\sigma^2_{MCD45A1} + 1/\sigma^2_{GFED})}$$

Burnt areas – Annual sum across 3 years- ~8.3million ha per year





~8.3 Million ha per year burnt in south Asia

Local Emission Factors

Residue type /study	CH_4	CO_2	CO	N_2O	NO_x	NO	NO_2	OC	BC	TC
Wheat straw/NPL	3.55±2.6	1787±35	28± 20	0.74±0.46	1.70±1.68	0.78±0.71	0.56±0.47	0.29±0.12	0.16±0.07	0.53± 0.21
Rice/NPL	5.32±3.08	-	82±20	0.48±0.45	-	-	-	-	-	-
Agricultural residues / Andreae and Merlet (2001)	2.7	1515±177	92±84	0.07	2.5±1			3.3	0.69	4

Sahai et al., Atmospheric Environment. 2007.

BC / OC ratios - Biofuels

TABLE 1. OC and BC Emission Factors, OC/PM2.5, BC/PM2.5, and OC/BC Ratios from Biofuel Combustion

location	fuel	number of repeated tests	fire power (kW)	thermal efficiency (%)	OC (g/kg)[a]	BC (g/kg)	$PM_{2.5}$	$OC/PM_{2.5}$ (%)	$BC/PM_{2.5}$ (%)	BC/OC
	rice straw	2	19.7–24.4	13.4–13.8	1.06–1.07	0.09–0.11	1.66–1.94	54.64–64.46	4.64–6.63	0.08–0.10
	maize residue	2	21.4–25.0	13.1–13.5	0.85–3.21	0.21–0.68	2.45–3.85	34.69–83.38	8.57–17.66	0.21–0.25
	bean straw	3	23.0 ± 0.9	14.2 ± 0.9	0.89 ± 0.15	0.94 ± 0.04	3.28 ± 0.87	27.74 ± 5.91	29.69 ± 6.32	1.08 ± 0.22
	fuel wood	2	19.9–21.0	14.6–15.7	0.41–1.43	1.03–3.26	2.21–4.58	18.53–31.22	46.55–71.18	2.28–2.51
Chongqing[b]	branch	2	24.7–24.8	13.8–13.9	1.56–1.73	1.59–1.65	2.95–3.97	39.31–58.59	40.06–55.88	0.95–1.02
	cotton stalk	3	17.2 ± 1.2	18.4 ± 0.7	2.75 ± 0.76	0.60 ± 0.16	6.04 ± 0.52	45.27 ± 9.58	9.88 ± 1.76	0.22 ± 0.05
	wheat residue	2	15.2–17.6	17.2–18.2	2.01–2.77	0.28–0.44	5.61–8.39	33.02–35.84	4.99–5.25	0.14–0.16
Henan[b]	kaoliang stalk	2	16.6–20.1	19.9–21.5	3.30–3.97	0.59–0.76	6.27–7.19	52.64–55.21	9.41–10.57	0.18–0.19
Beijing[b]	branch	3	30.8 ± 4.4	14.8 ± 1.5	0.98 ± 0.32	1.32 ± 0.39	3.04 ± 0.85	32.33 ± 1.29	43.28 ± 4.19	1.36 ± 0.32
	wheat residue	3	32.6 ± 2.7	13.9 ± 1.4	1.34 ± 0.26	0.12 ± 0.03	3.21 ± 0.32	41.96 ± 9.21	3.70 ± 0.74	0.09 ± 0.01
	maize residue	3	30.9 ± 4.6	15.6 ± 1.4	1.80 ± 0.30	0.16 ± 0.10	4.54 ± 0.97	41.75 ± 14.71	3.48 ± 1.63	0.10 ± 0.08
Shandong	fuel wood	3	25.3 ± 0.7	16.0 ± 0.7	1.07 ± 0.16	1.14 ± 0.24	2.67 ± 0.42	40.25 ± 6.01	42.85 ± 6.46	1.07 ± 0.09
	crop residue[e]	20	23.55 ± 6.40	15.85 ± 2.60	1.93 ± 1.00	0.43 ± 0.32	4.43 ± 1.87	44.20 ± 14.93	10.40 ± 9.31	0.29 ± 0.35
average	woody fuel[f]	10	25.85 ± 4.40	15.04 ± 1.14	1.14 ± 0.40	1.49 ± 0.69	3.08 ± 0.82	36.54 ± 10.78	47.20 ± 10.13	1.41 ± 0.57

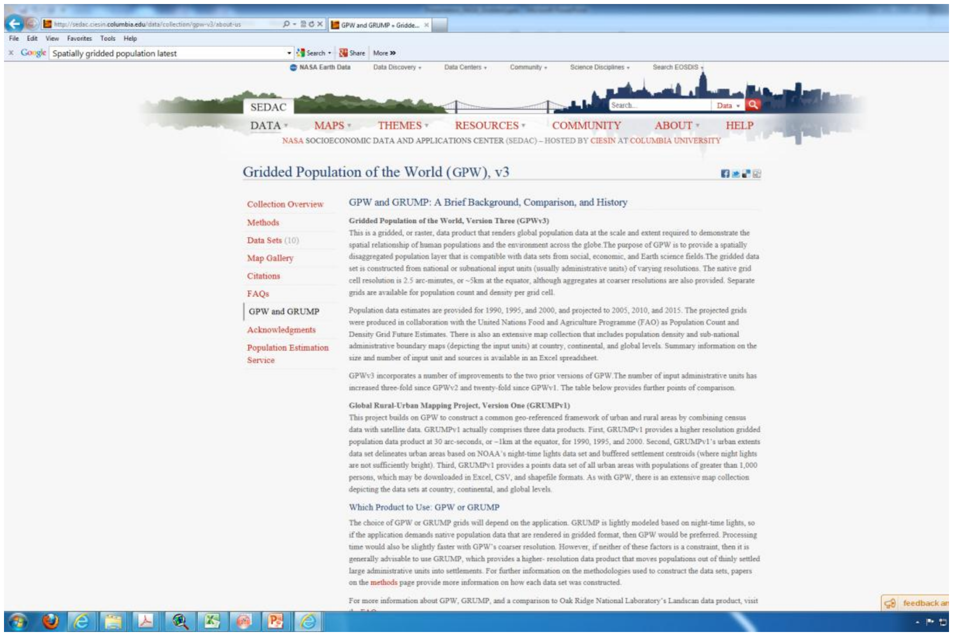
[a] Dry fuel mass basis. [b] The emission factors of $PM_{2.5}$ are from ref *20*. [c] Two repeated tests, the results are given as a range. [d] Three repeated tests, the results are given as means ± one standard deviations ($x \pm 1\sigma$). [e] Crop waste refers to rice straw, maize residue, wheat residue, bean straw, cotton stalk, and kaoliang stalk in this study. [f] Woody fuel refers to fuel wood and branch in this study.

Li et al., 2010; Carbonaceous Aerosol Emissions from Household Biofuel Combustion in China. *Environ. Sci. Technol.*, 2009, *43* (15), pp 6076–6081.

Agriculture residues: more OC than BC

Woody/tree species residues: more BC than OC; Attributed to Lignin content which is resistant to burning and thus more Soot.

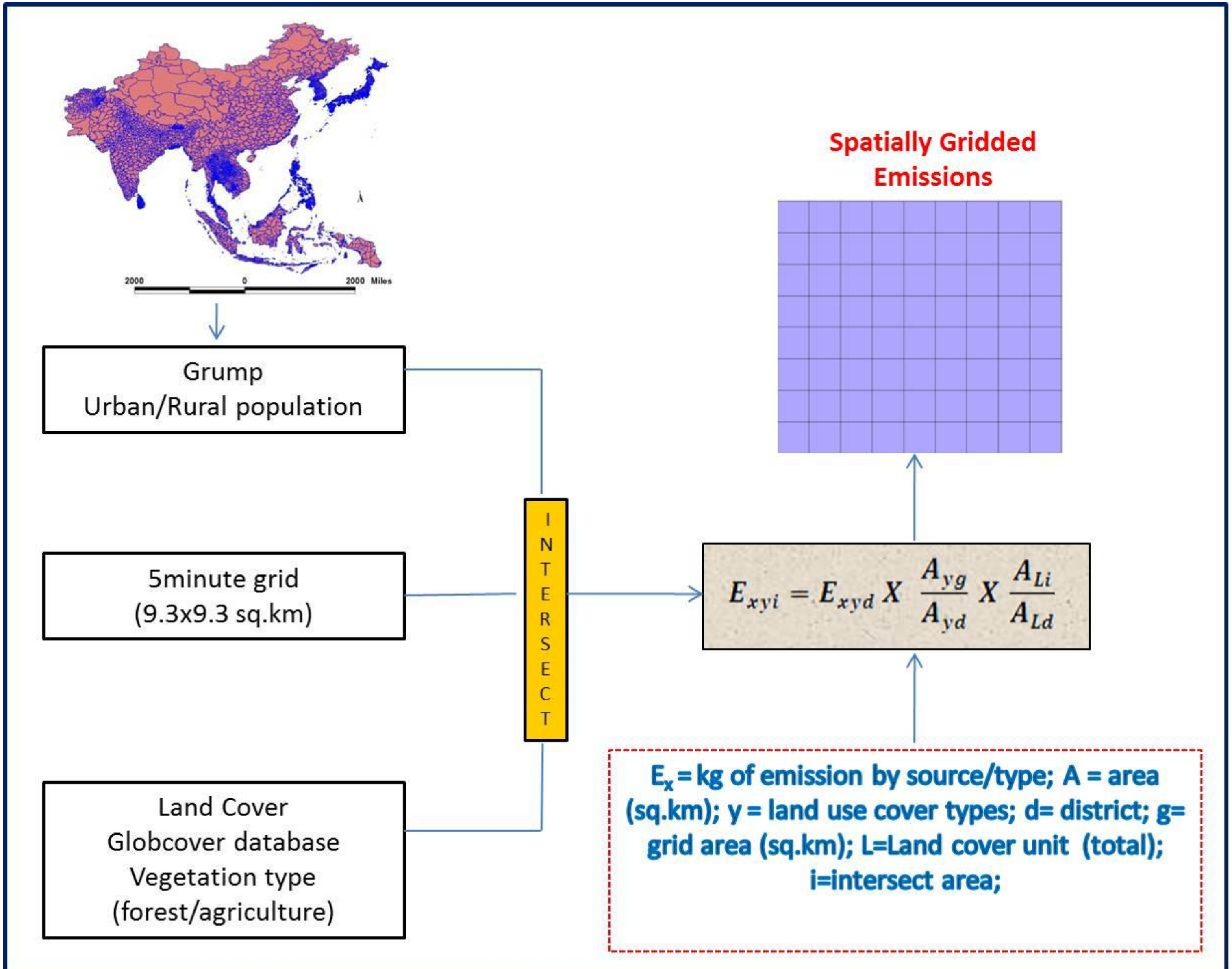
Global Rural/Urban Mapping Project
(Grump – 30arc seconds (~1km) aggregated to ~9-km cells)



	GPWv1	GPWv2	GPWv3	GPW fe	GRUMPv1
Grid Data sets *(bil, ascii, and zipped ArcInfo workspace formats)*					
Grid Resolution	2.5 arc-minute	2.5 arc-minute	2.5 arc-minute 1/4 degree 1/2 degree 1 degree	2.5 arc-minute	30 arc-second
Population Grid	Country Continent World	Country Continent World	Country Continent World	Country Continent World	Continent World
Population Density Grid	Country Continent World	Country Continent World	Country Continent World	Country Continent World	Continent World
Land Area Grid	Country Continent World	Country Continent World	Country Continent World		Continent World
Mean Geographic Unit Area Grid		Country Continent World	Country Continent World		Continent World
National Identifier Grid			Country Continent World		
Urban Extents Grid					Country Continent World
Vector Polygon Data sets *(shp format)*					
Coastlines			World		
National Boundaries			World		
Vector Points Data sets *(csv, shp, xls (settlement points only) formats)*					
Centroids			World		
Settlement Points					Country Continent World
Maps *(pdf format)*					
Population Density			Country Continent World		
Sub-national Administrative Boundaries			Country Continent World		

Recent - Global rural/urban mapping project data on population has been used for dis-aggregation of emissions.

Spatial disaggregation approach (Biofuels (Ag+Forest Residues)



Biofuel use in kg/capita/day (Indo-Ganges sub-regions)

	Indo-Ganges sub-regions	Firewood	Dung cake	Ag. Residues
1	Western Himalayan zone	1.27	0.01	0.21
2	Eastern Himalayan zone	1.9	0.19	0.37
3	Lower Gangetic zone	1.1	0.65	0.16
4	Middle Gangetic zone	0.45	0.41	0.3
5	Upper Gangetic zone	0.89	0.25	0.14
6	Trans-Gangetic plains	0.38	0.46	0.34
7	Eastern Plateau and hills	3.36	0.01	0.24
	Mean	**1.33**	**0.28**	**0.25**

a). Literature review (30 different references for Asia)
b). Personal interview/field trip (December, 2010)
c). Spatial disaggregation based on Rural and Urban Population

Vadrevu et al., 2012. ERL. In Revision.

BC emissions – Fuel wood + Crop residues

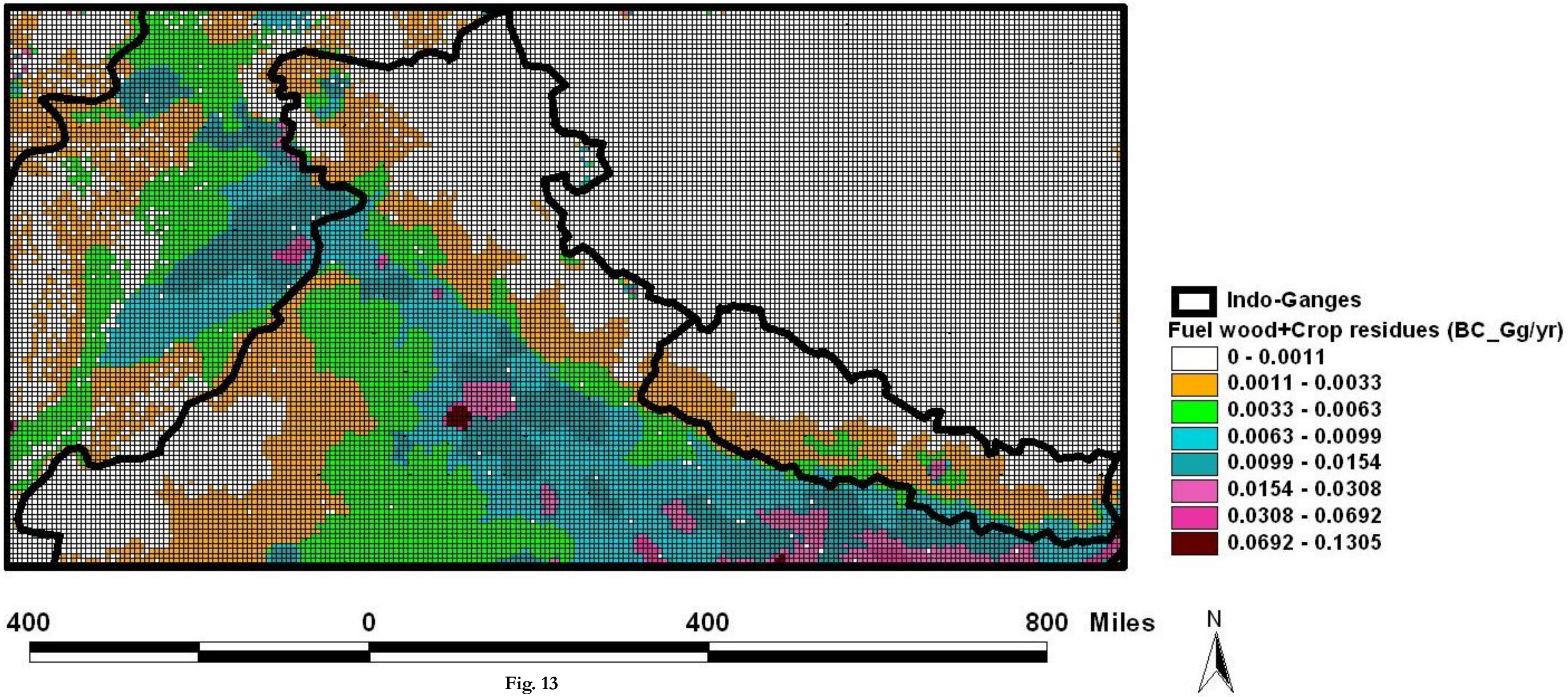
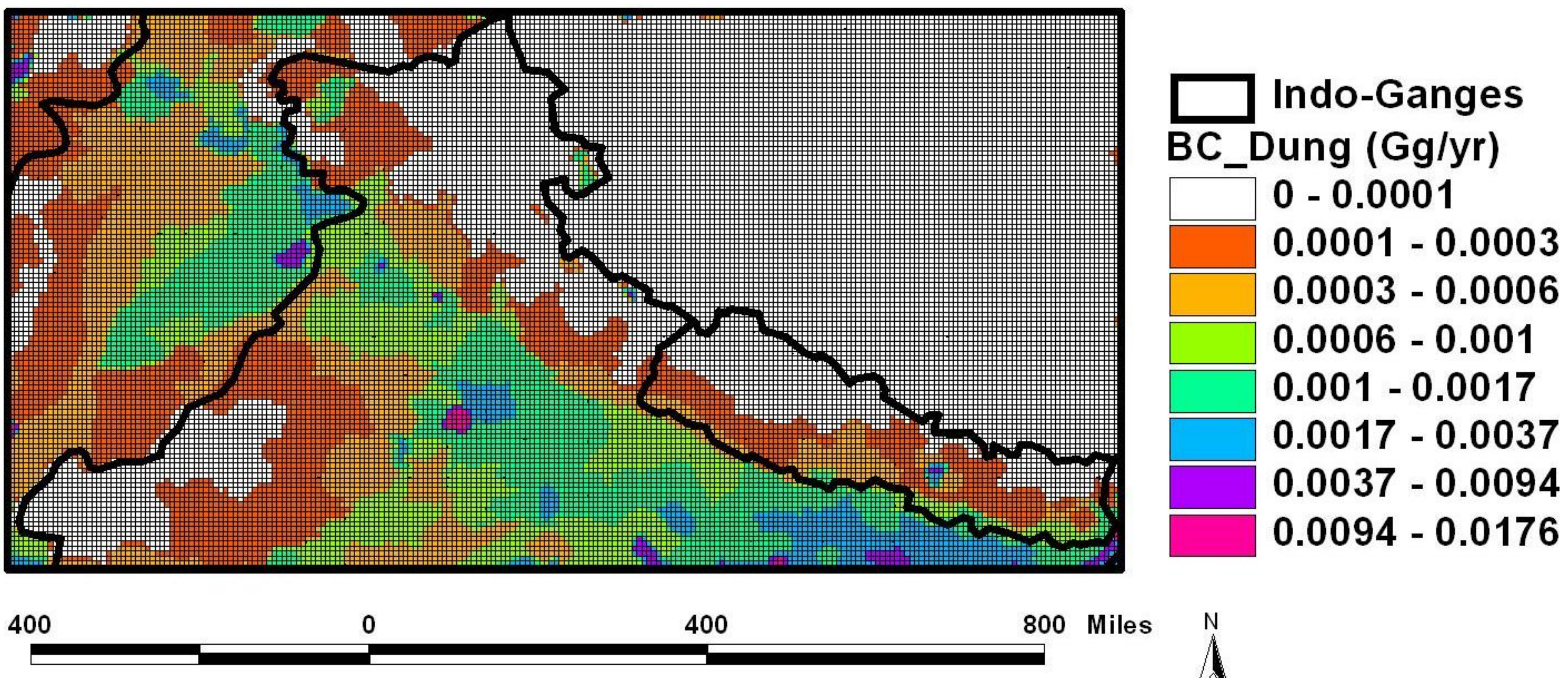
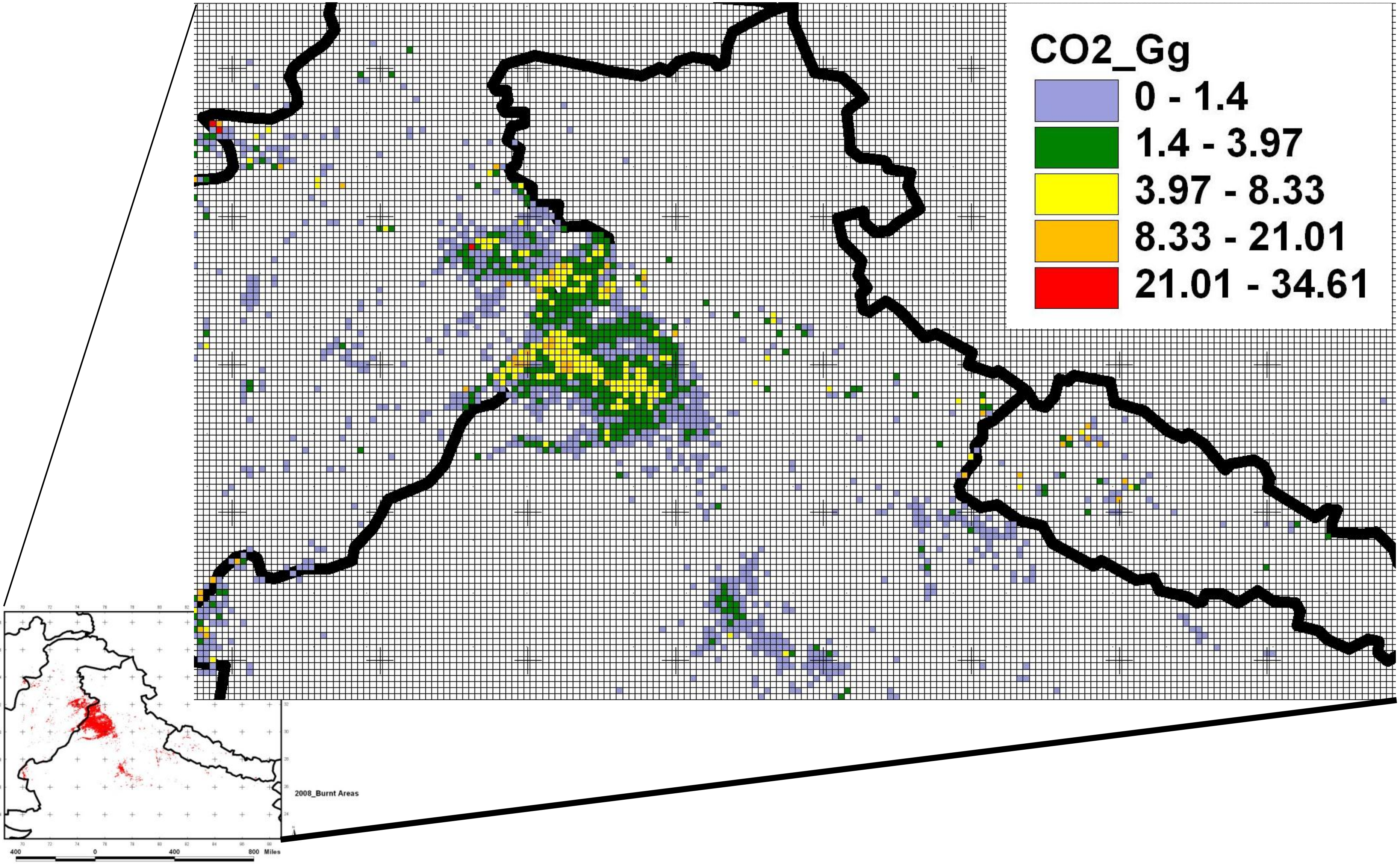


Fig. 13

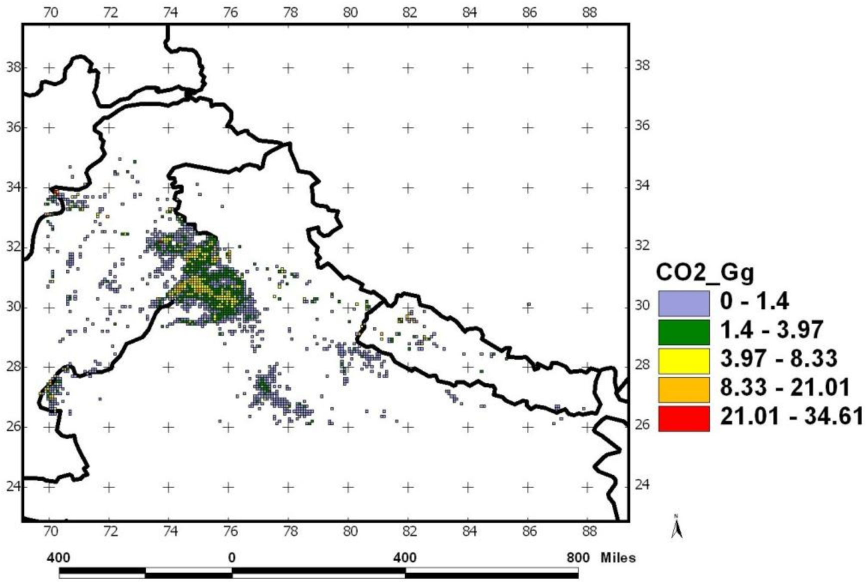
BC emissions – Dung biofuel

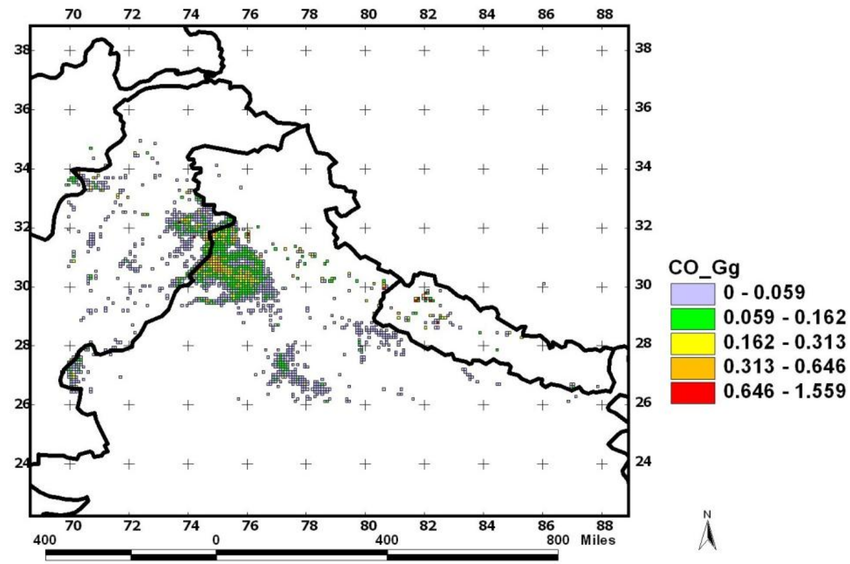


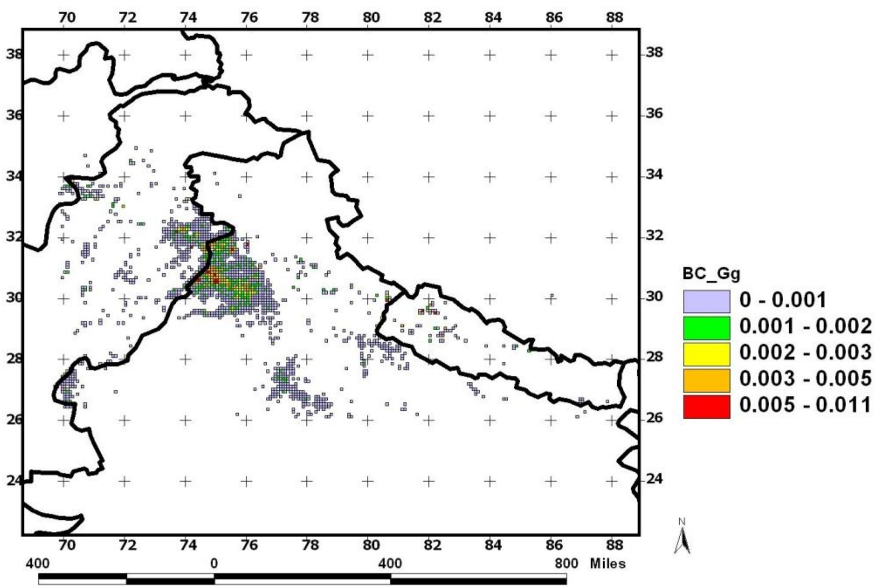
Spatially Gridded Emissions – 5-minute interval

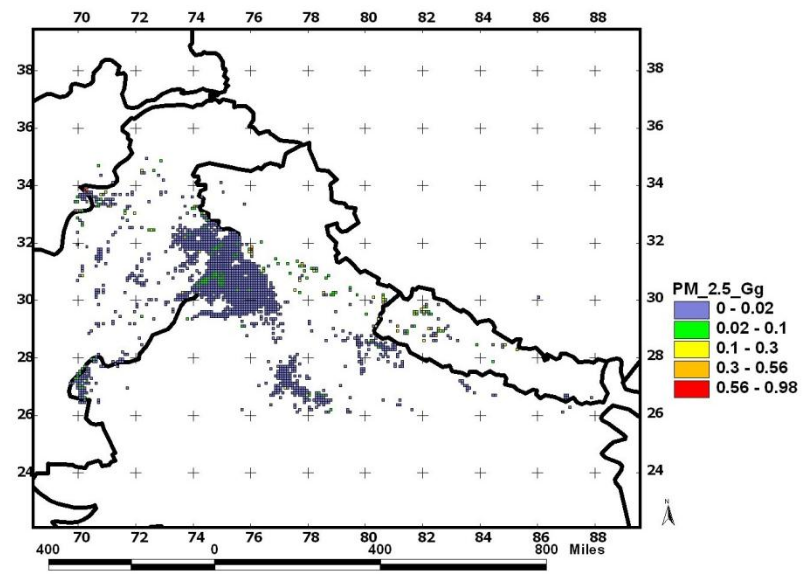


Biomass Burning Spatially Gridded Emissions Inventory (5-minute interval)

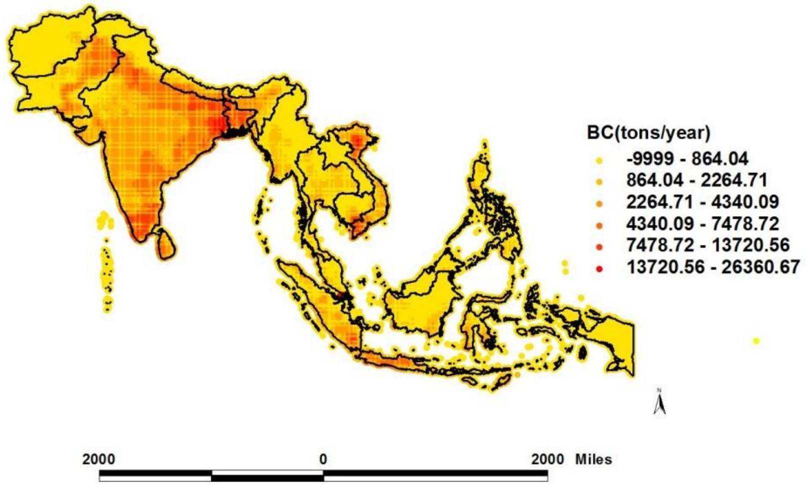


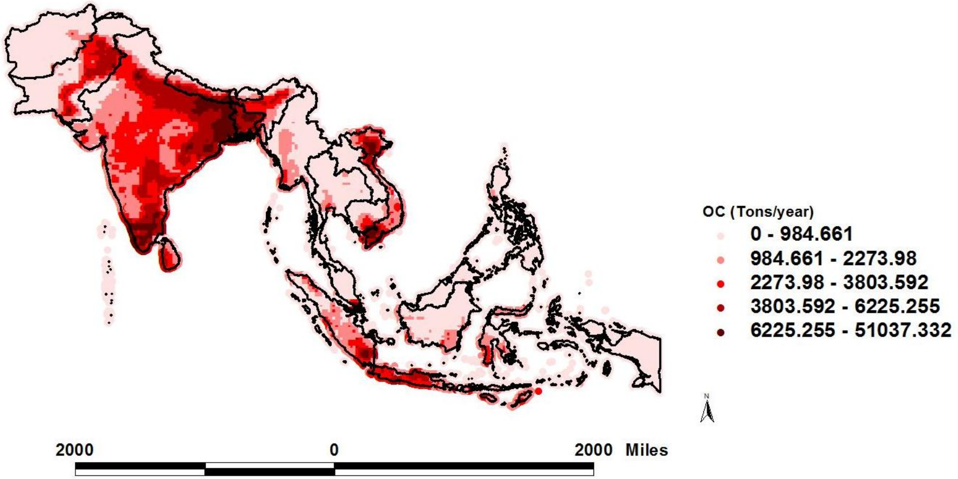




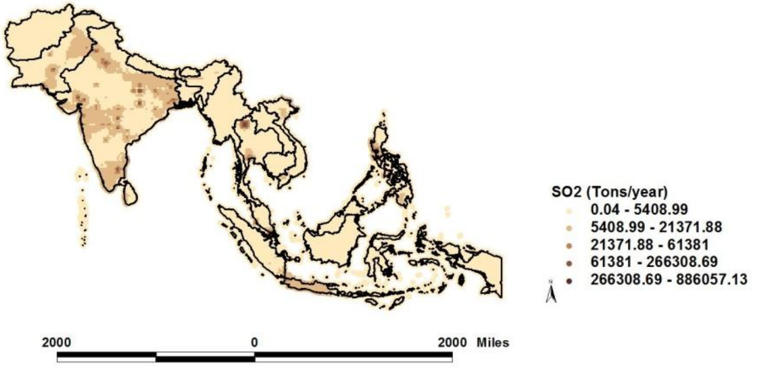


(Spatially Gridded Emissions (per 5-minute grid cells)





Lat	Long	Open burning	Fuel wood + crop residues	Dung
XXX	XXX	XXX	XXX	XXX
XXX	XXX	XXX	XXX	XXX
XXX	XXX	XXX	XXX	XXX

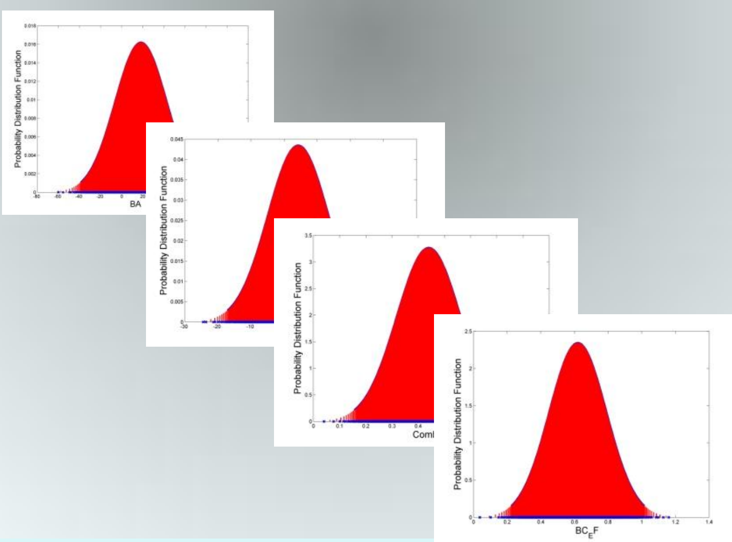


Vadrevu et al., 2012. ERL. In Revision.

Quality Control (sensitivity analysis)

Define parameter distributions

Burnt areas
Biomass values
Combustion factor
Emission factor



Generate distribution samples based on Latin Hypercube sampling

Sensitivity Analysis
(Kolmogorov Smirnov Test)

Identify important variables
Most influencing variables by rank
P-values

Emission factor>combustion efficiency>Biomass>Burnt areas (as identified by KS statistic and p-values.)

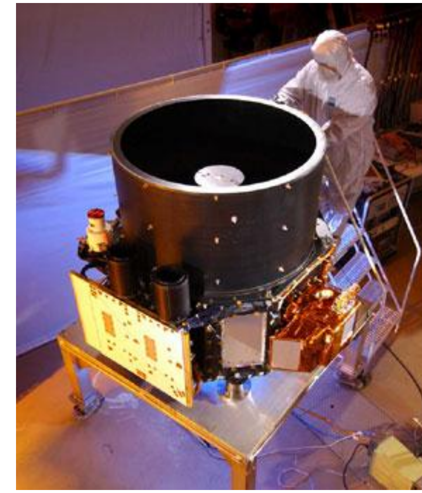
What are the typical smoke plume heights of evergreen forests and agriculture fires?

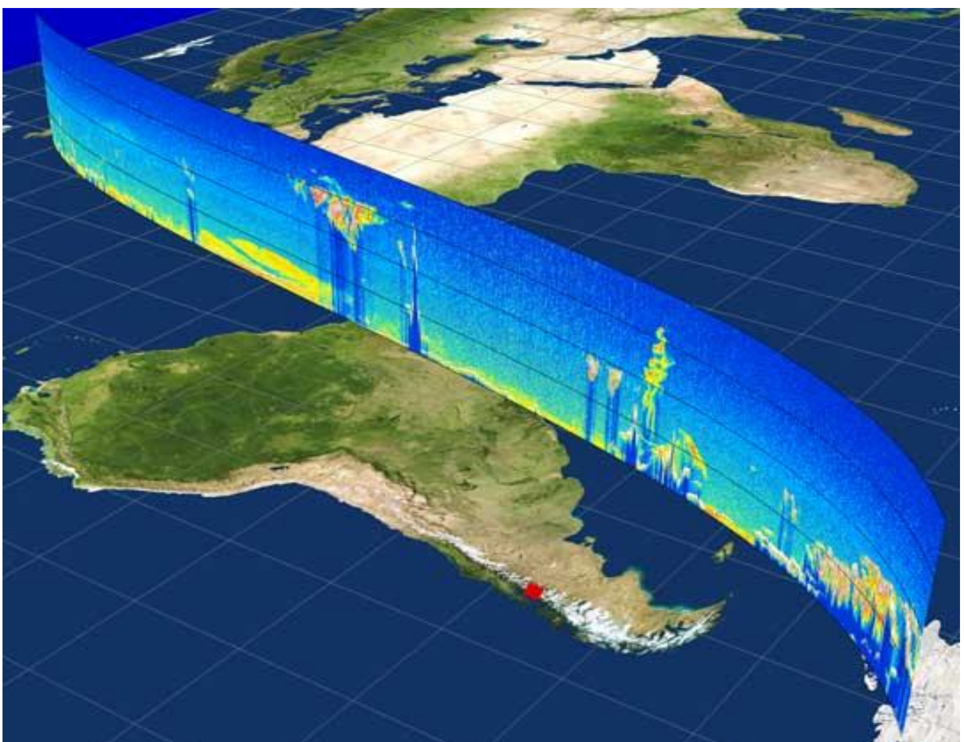
Can fire plumes reach the heights of Himalayas (so as to impact ice melt) ?

CALIPSO-CALIOP LIDAR Data

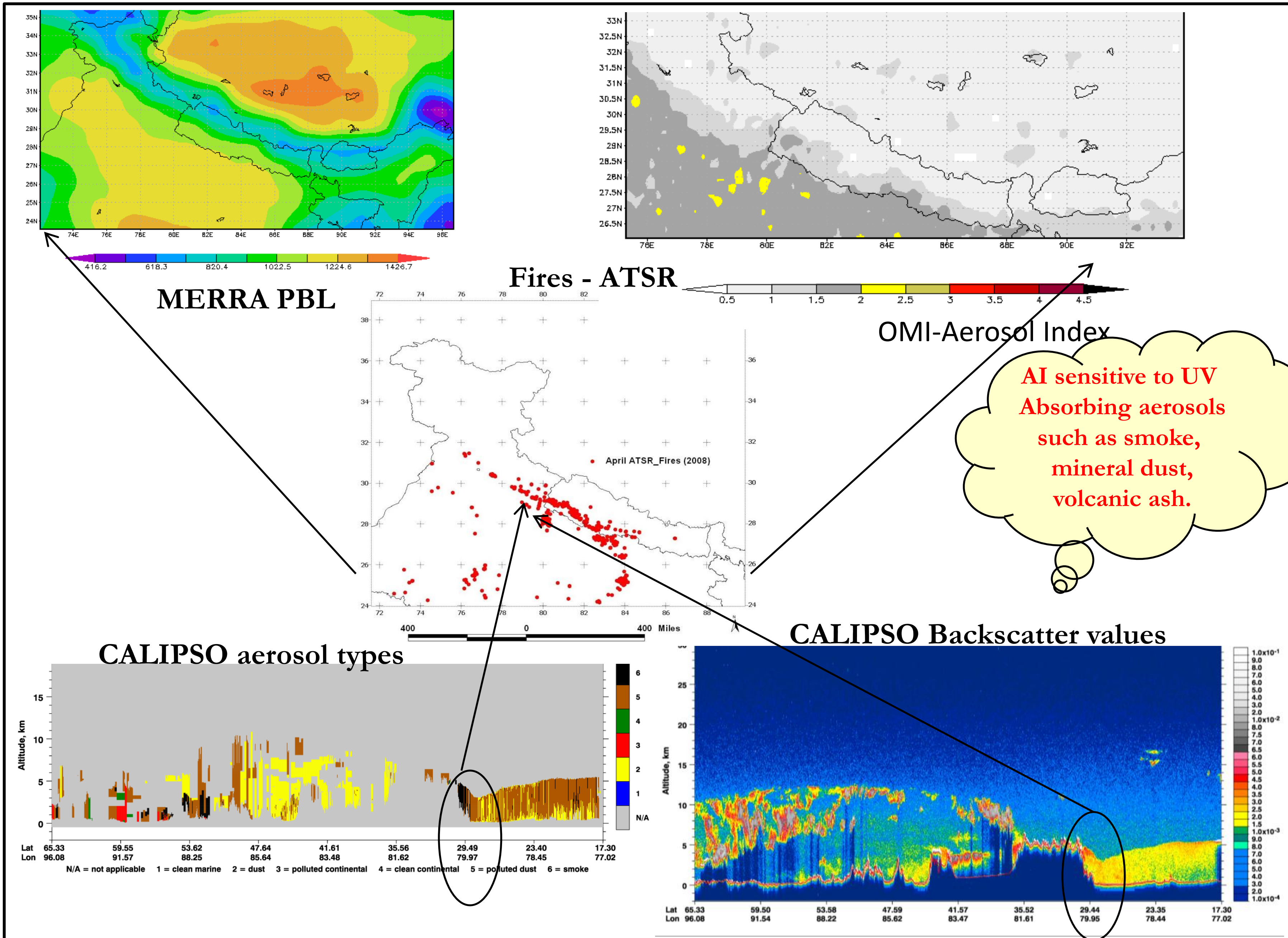
- Contains CALIOP, IIR, and WFC sensors

- CALIOP: Two wavelength polarization-sensitive LiDAR providing vertical profiles of aerosols and clouds with 30-60m vertical & 333m horizontal spatial resolution. A daily & monthly mean product is available.





CALIOP	
laser:	Nd: YAG, diode-pumped, Q-switched, frequency doubled
wavelengths:	532 nm, 1064 nm
pulse energy:	110 mJoule/channel
repetition rate:	20.25 Hz
receiver telescope:	1.0 m diameter
polarization:	532 nm
footprint/FOV:	100 m/ 130 µrad
vertical resolution:	30-60 m
horizontal resolution:	333 m
linear dynamic range:	22 bits
data rate:	316 kbps



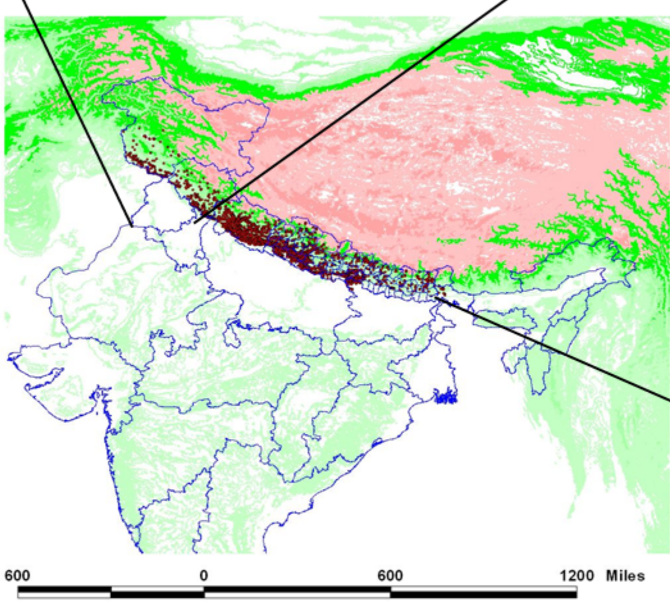
CALIPSO data shows biomass burning plumes reaching more than 5-km ht beyond the Planetary Boundary Layer.

Vadrevu et al., 2012. AE.47:241-251

CALIOP-Agriculture vs Forest Fires

Punjab Agriculture Fires

Punjab	Date	Lat	Long	Altitude
1	4-Oct-10	76.88	29.35	1.8
2	11-Oct-10	76.09	32.29	2.5
3	18-Oct-10	74.0	30	2.8
4	20-Oct-10	77.0	30	2
				2.28 km



Himalayan Forest Fires

Date	Lat	Long	Smoke altitude (km)
4/2/2008	28	84.02	4.3
4/5/2008	32.5	78	9.3
4/7/2008	29.59	80.01	2.5
4/9/2008	28.78	82.88	3.7
4/11/2008	28.4	86.2	7.2
4/12/2008	31.62	76.32	8
4/18/2008	28.4	84	4.2
4/21/2008	31	77	4.2
4/23/2008	29.47	79.97	3.8
4/25/2008	29	82.97	6
4/27/2008	29.11	86.2	7.3
4/29/2008	28.65	88	4
4/30/2008	30	78	5
Mean smoke altitude			**5.35km**

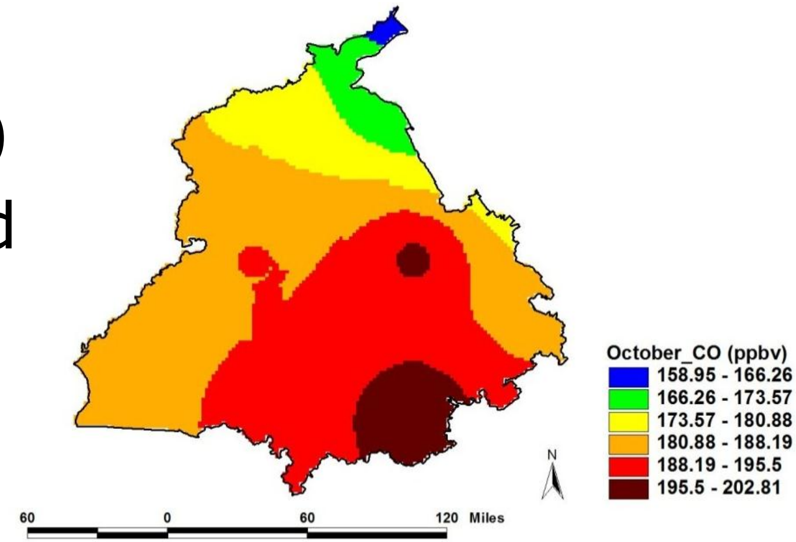
Sub-Himalayas (500-1900m); Lower Himalayas (1901-4000m); Greater Himalayas (4001-8700m).

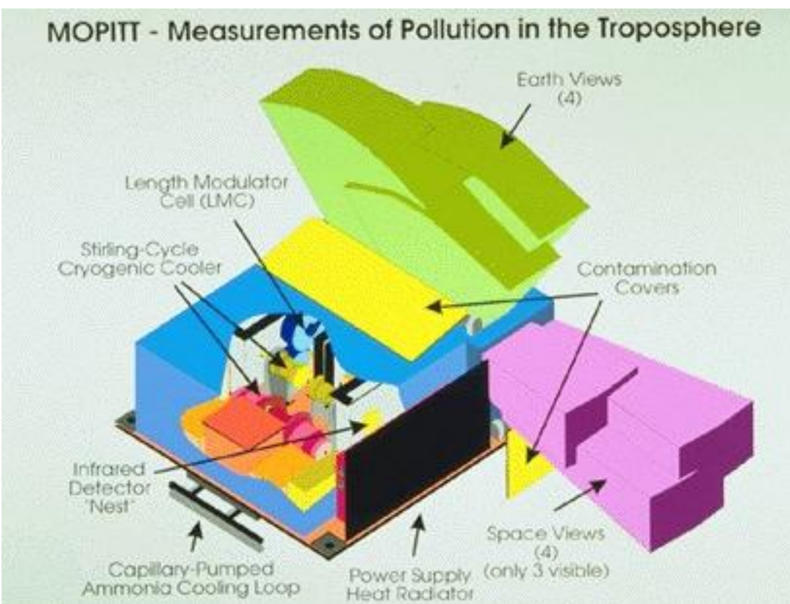
Vadrevu et al., AE, 2011; 2012.

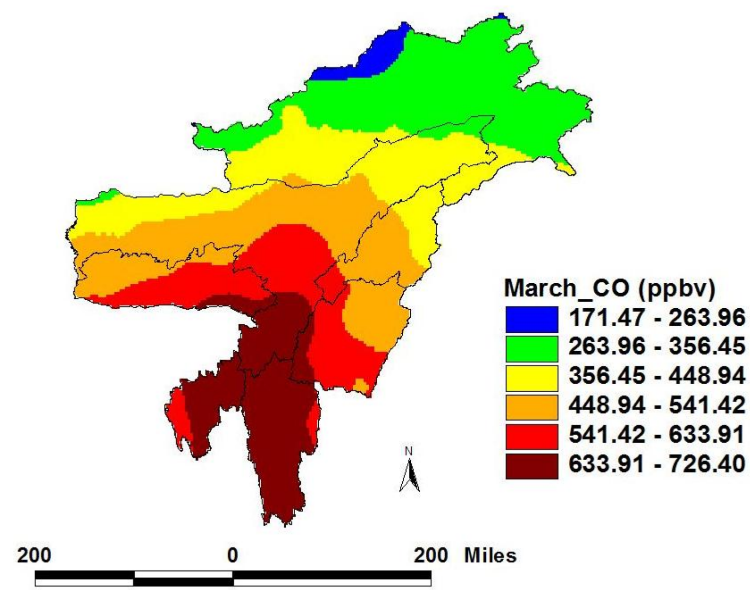
How effective are the tropospheric satellites MOPITT (CO), OMI (NO2) and SCIAMACHY (NO2) in detecting pollutant signals from open biomass burning?

MOPITT Carbon Monoxide

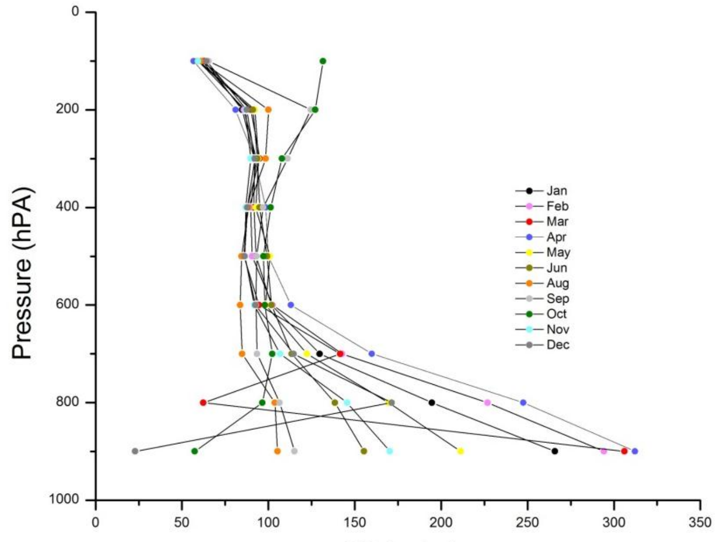
- Mounted on EOS Terra with a daily equatorial pass (10:30 a.m.)
- Measures global columnar CO and CO volume mixing ratio profiles with near-IR (2.3um) and Thermal-IR (4.7um) bands

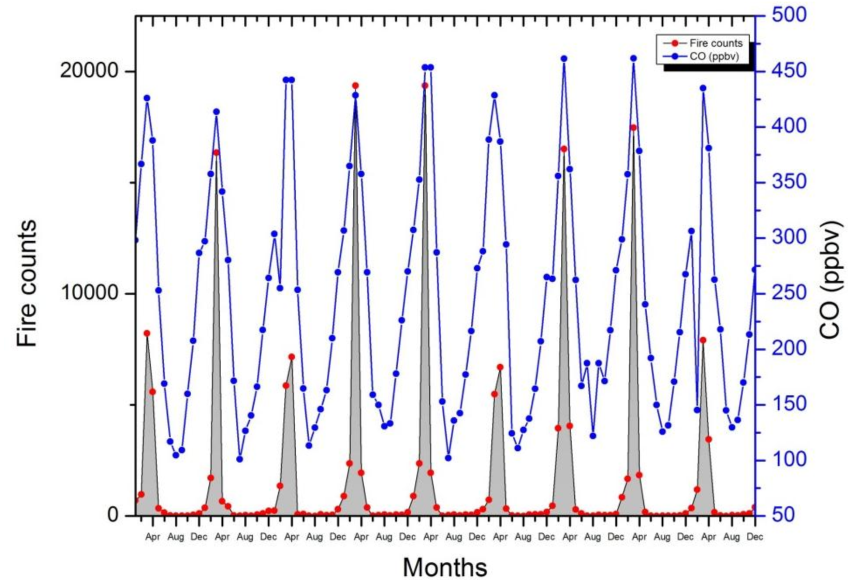


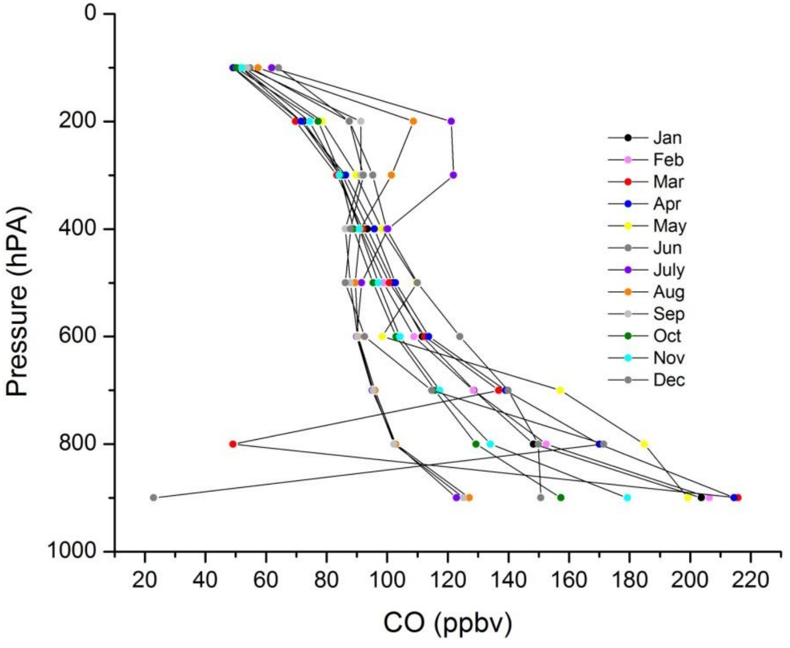


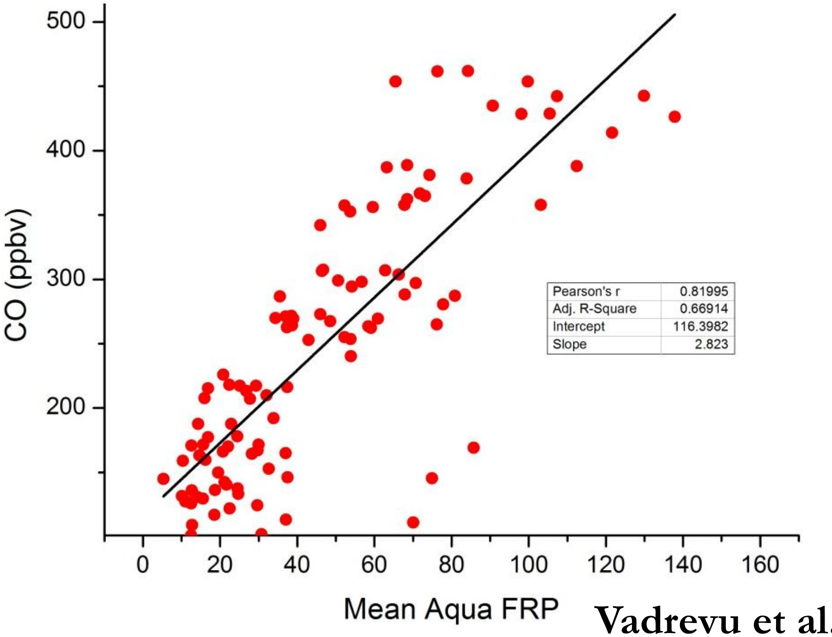


MOPITT Carbon Monoxide Profiles









Pearson's r	0.81995
Adj. R-Square	0.66914
Intercept	116.3982
Slope	2.823

Vadrevu et al., AE. 2013

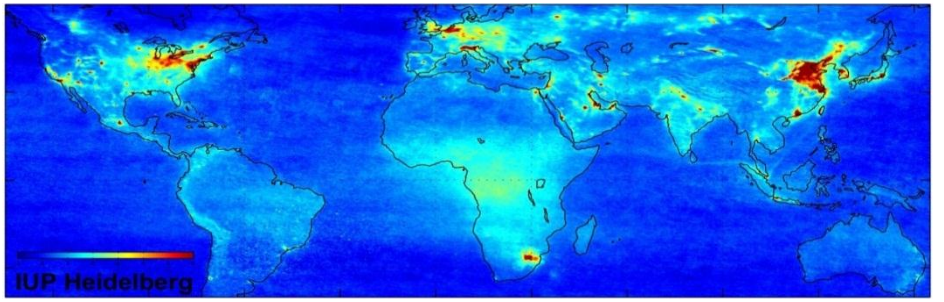
OMI and SCIAMACHY NO2

Ozone Monitoring Instrument

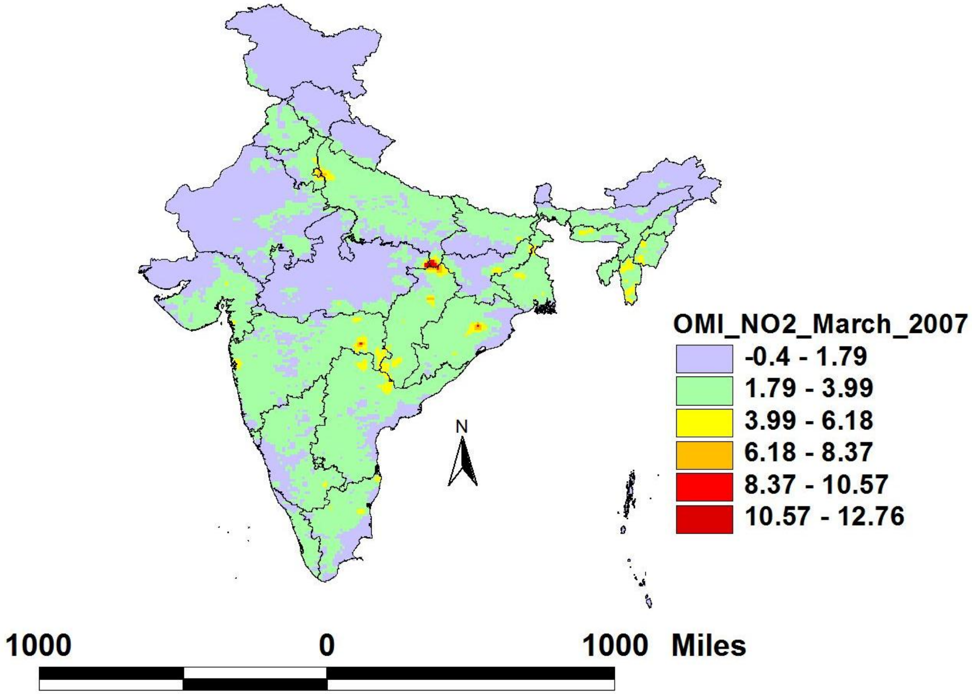
- Mounted on the EOS Aura Platform
- Observes back-scattered radiation with a Hyperspectral (UV-Visible), nadir-viewing, with daily global coverage.
- Measures total column amount of O_3, NO_2, SO_2 and aerosols (Nadir – 13x24km)

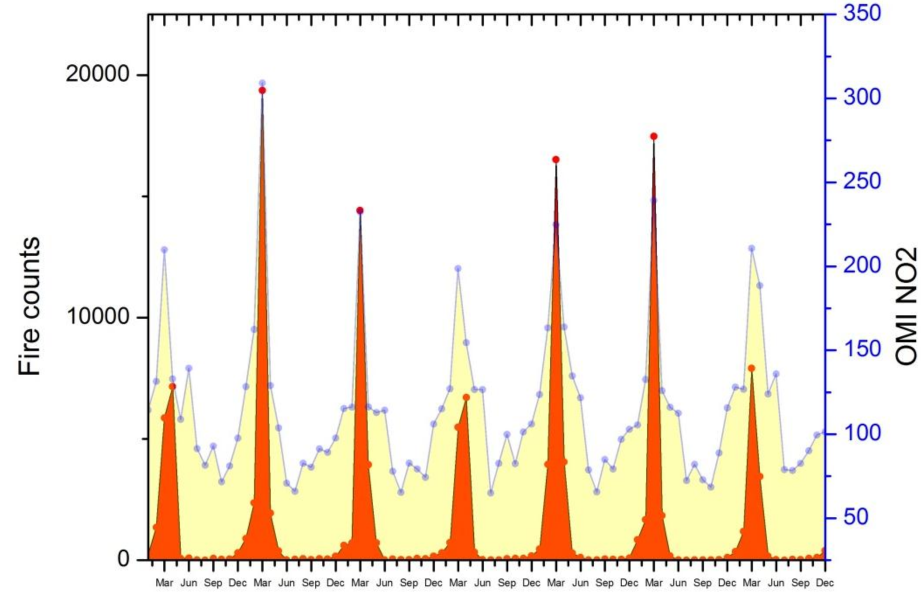
SCIAMACHY Instrument

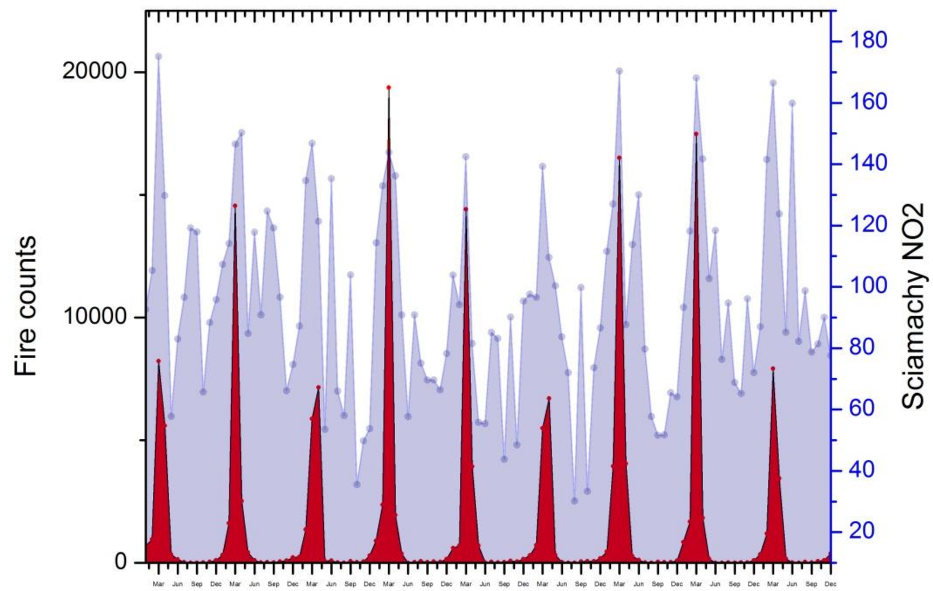
- Onboard ENVISAT, operational from 2002- April 2012
- 0.24 – 2.38um spectral range, Polar Orbit, 35 day repeat cycle, 10:00 a.m. mean local solar time descending node.
- Measures trace gases, aerosols, and clouds through backscattered, reflected, and transmitted solar radiation



Fires and OMI versus SCIAMACHY NO2



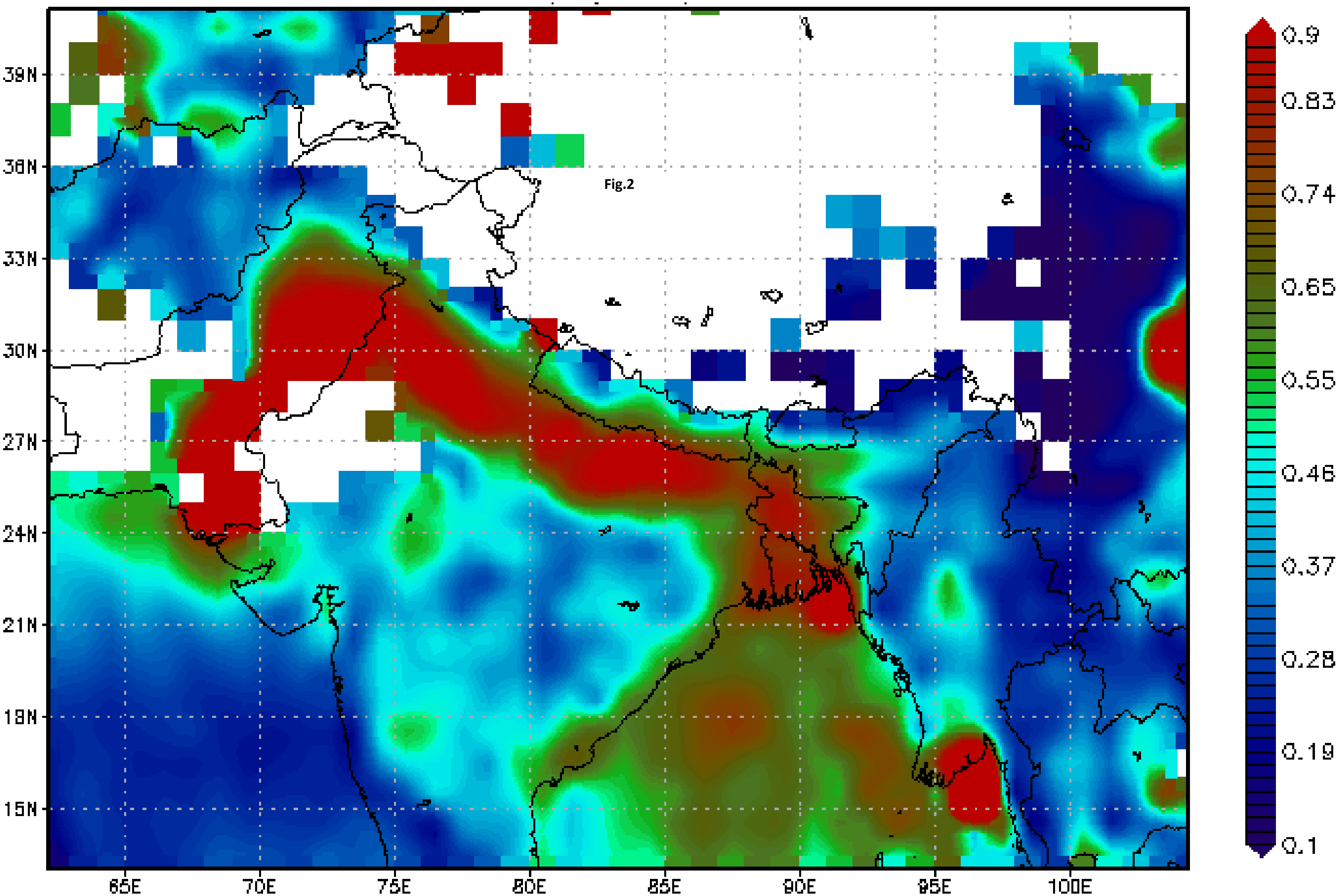




OMI NO2 better correlates with Active Fires than SCIAMACHY.

Vadrevu et al., AE. 2013.

MODIS Aqua AOD – May-2010



How much of the increased AOD is due to Fires/Biomass burning/and Dust?

Summary

- In Asia, after the forest/shrublands, biomass burning emissions from agriculture seems highly relevant.
- Spatially gridded emissions from biomass burning at a higher resolution (9.3 sq.km) are made available through refining the agricultural burnt areas, local emission factors and combustion factors.
- When compared to the earlier estimates of (300-727 Tg), burnt areas in the Asian region are found to be relatively higher (i.e., ~830 Tg).
- Uncertainty analysis in the residential biofuel emissions seem much complex compared to open biomass burning due to inherent data quality.

Species	Emissions (Tg)
OC	0.38-0.52
BC	0.035-0.058
SO2	0.043-0.055
CO2	98-153

- Urban vs population data (Grump)
- Fuel consumption
- Emission factors
- Combustion efficiency