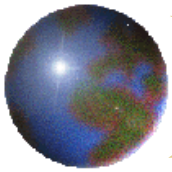
Vegetation Fires and Air Pollution in South/Southeast Asia – Analysis from Multi-Satellite Datasets

Krishna Prasad Vadrevu

NASA Marshall Space Flight Center
Huntsville, Alabama

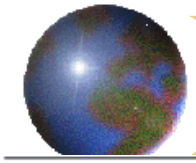


Questions Addressed

-How effective are the tropospheric GHG monitoring satellites in capturing pollution events? Is the data ready to be included in real-time operational fire monitoring systems to quantify emissions?

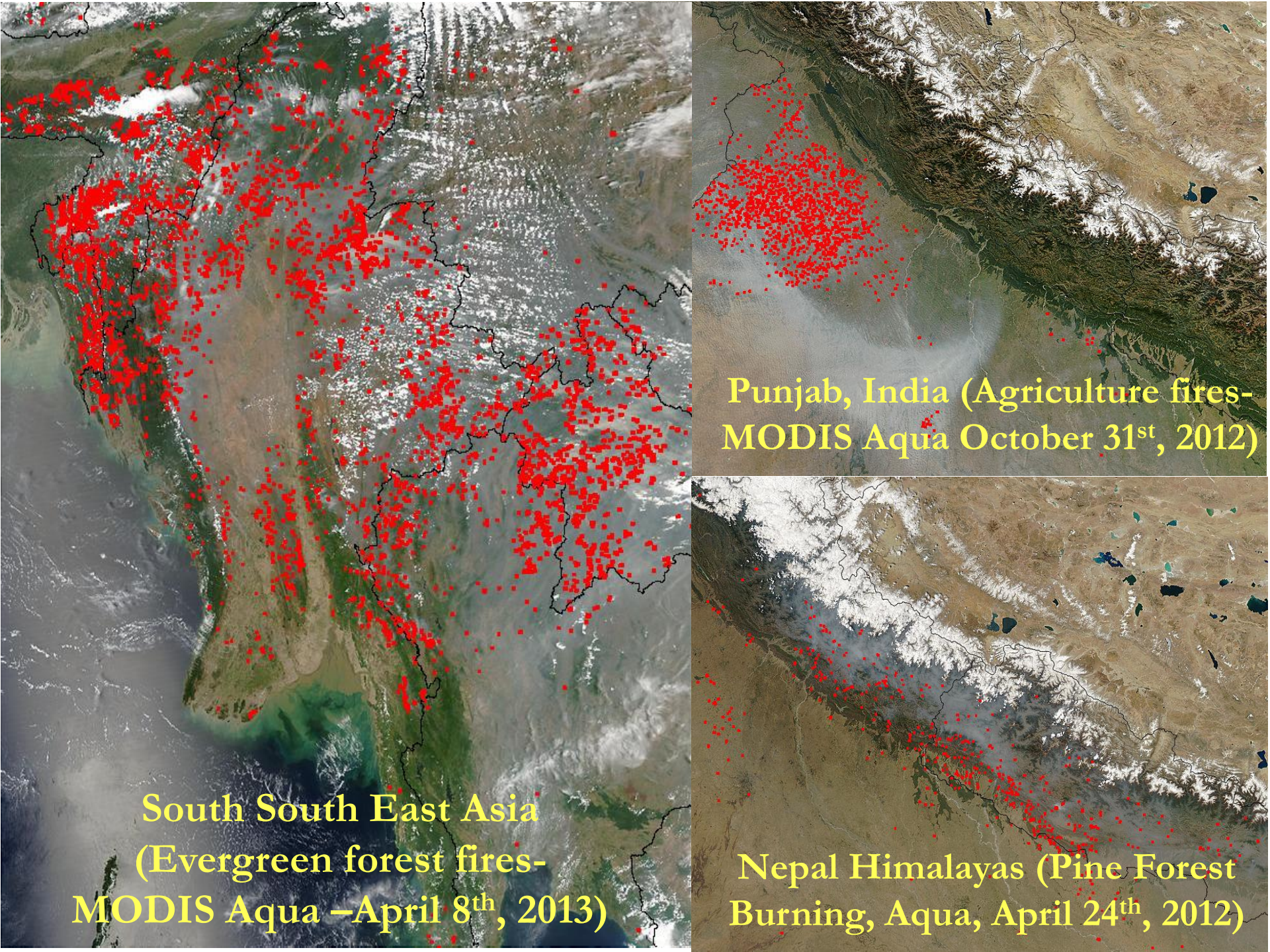
-What are the important sources of biomass burning in the Asian region?

How does the satellite retrieved signals vary with respect to Agriculture and Forest fires in the Asian region?

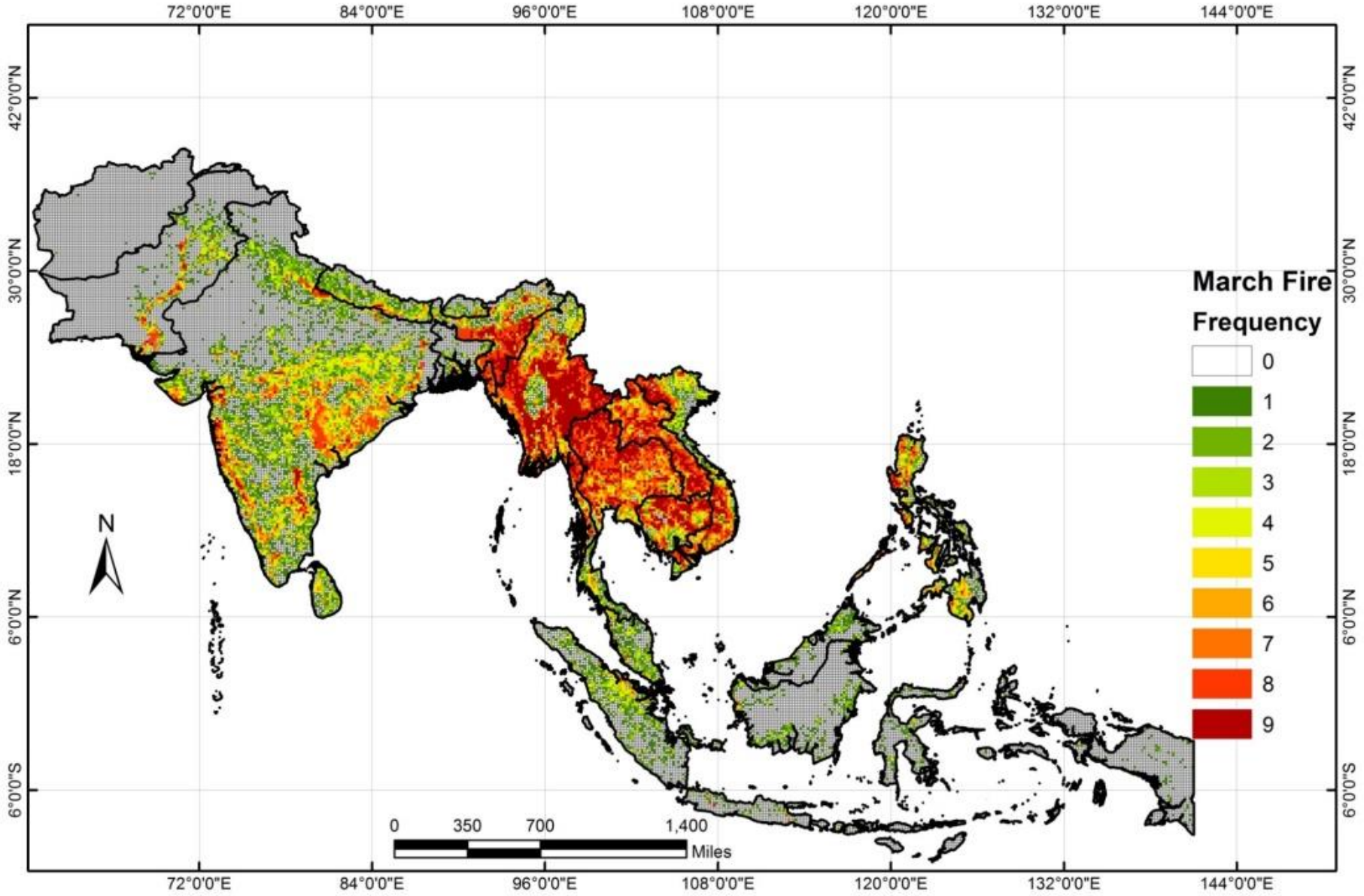


Satellite Data Useful for Biomass burning studies (Ichoku et al., 2013)

Variable	Sensor (Satellites)	Nominal spatial res	Spatial coverage	Data period[a]	References[b]
PH	MISR (Terra)	1.1 × 1.1 km	Global	2000–present	Kahn et al. (2007, 2008); Val Martin et al. (2010)
PVP	CALIOP (Calipso)	N/A	Global (curtains)	2006–present	Winker et al. (2007, 2009)
AI	OMI (Aura)	13 × 24 km	Global	2004–present	Torres et al. (2010)
	TOMS (Nimbus-7, Meteor-3, Earth Probe)	50 × 50 km	Global	1978–present	Hsu et al. (1996, 1999)
AOD	MODIS (Terra and Aqua)	10 × 10 km	Global	2000–present	Remer et al. (2005, 2008), Levy et al. (2010).
	MISR (Terra)	18 × 18 km	Global	2000–present	Kahn et al. (2009, 2010)
	OMI (Aura)	13 × 24 km	Global	2004–present	Torres et al. (2010)
	POLDER (ADEOS1, ADEOS2, PARASOL)	19 × 19 km	Global (Ocean only)	1996–2010	Tanré et al. (2011)
	SEAWiFS (SeaStar)	4 × 4 km	Global	1997 - 2010	
	AVHRR (NOAA)	8 × 8 km	Global (Ocean only)	1988–present	Ignatov et al. (2004); Mishchenko et al. (1999)
	SEVIRI (MSG)	3 × 3 km	Africa, Europe		Popp et al. (2007)
	IMG (GOES)	4 × 4 km	N/S America		Zhang et al. (2001)
	CALIOP (Calipso)	5 × 5 km	Global (curtains)	2006–present	Winker et al. (2007, 2009)
CO_2	AIRS (Aqua)	90 x 90 km	Global	2002–present	Chahine et al. (2008)
	SCIAMACHY (Envisat)	30 x 120 km	Global	2003–present	Buchwitz et al. (2005a,b, 2006)
CO	MOPITT (Terra)	22 km × 22 km	Global	2000–present	Edwards et al. (2004)
	AIRS (Aqua)	50 × 50 km	Global	2002–present	McMillan et al. (2005)
	TES (Aura)	5 × 8 km	Global	2004–present	Lopez et al. (2008)
	SCIAMACHY (Envisat)	30 × 120 km	Global	2003–present	Buchwitz et al. (2005a,b, 2006)
CH_4	MOPITT (Terra)	22 km × 22 km	Global	2000–present	Edwards et al. (2004)
	AIRS (Aqua)	50 × 50 km	Global	2002–present	Xiong et al. (2008)
	TES (Aura)	5 × 8 km	Global	2004–present	
	SCIAMACHY (Envisat)	30 × 120 km	Global	2003–present	Buchwitz et al. (2005a,b, 2006)
NO_x	GOME (ERS-2)	40 km × 40 km	Global	1995–present	Martin et al. (2003, 2004)
	SCIAMACHY (Envisat)	30 × 120 km	Global	2003–present	van der A et al. (2008)
HCHO	OMI (Aura)	13 × 24 km	Global	2004–present	Millet et al. (2008)
	GOME (ERS-2)	40 km × 40 km	Global	1995–present	Martin et al. (2004)
	SCIAMACHY (Envisat)	30 × 60 km	Global	2003–present	Dufour et al. (2009)
O_3	OMI (Aura)	13 × 24 km	Global	2004–present	McPeters et al. (2008)
	TOMS (Nimbus-7, Meteor-3, Earth Probe)	50 × 50 km	Global	1978–present	Bhartia (2007)
	SCIAMACHY (Envisat)	30 × 120 km	Global	2002–present	Brinksma et al. (2006)
	TES (Aura)	5 × 8 km	Global	2004–present	Bowman et al. (2002)
	GOME (ERS-2)	40 km × 40 km	Global	1995–present	Liu et al. (2006)

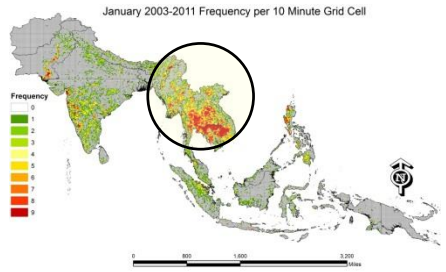

South South East Asia
(Evergreen forest fires-
MODIS Aqua –April 8th, 2013)
Punjab, India (Agriculture fires-
MODIS Aqua October 31st, 2012)
Nepal Himalayas (Pine Forest
Burning, Aqua, April 24th, 2012)

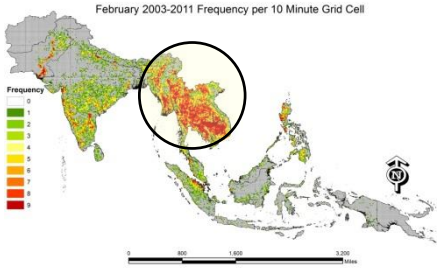
Fire Frequencies (2003-2011) – 10-minute (18km) grid

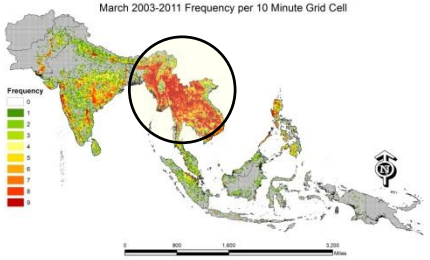


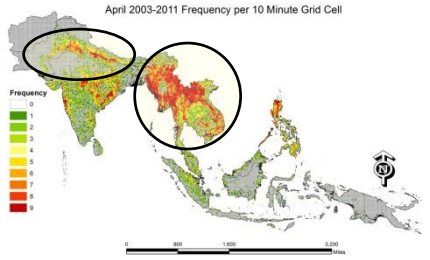
Vadrevu et al. 2012. IEEE JSTARS. 99-1-15.

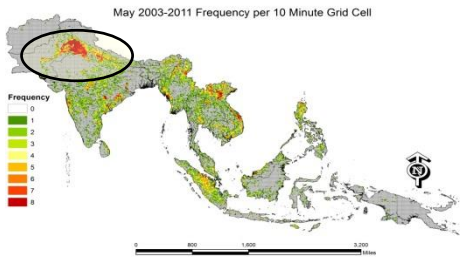
Monthly Fire Frequencies per 10minute grid cells (2003-2011)

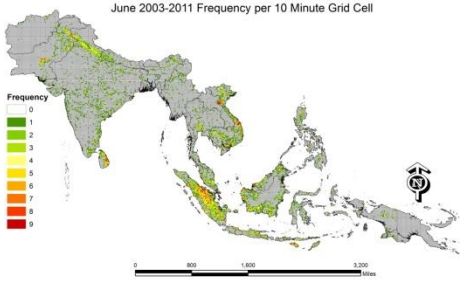


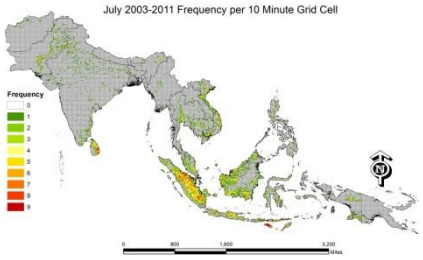


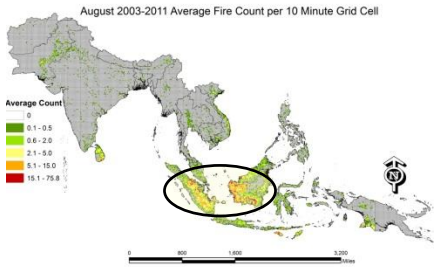


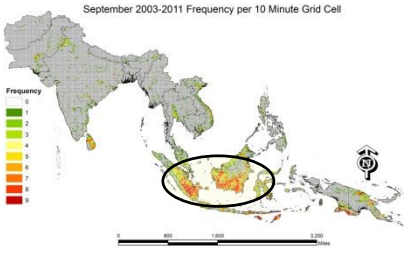


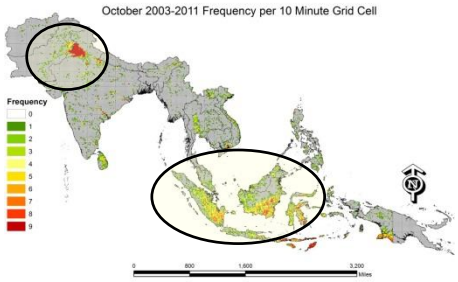


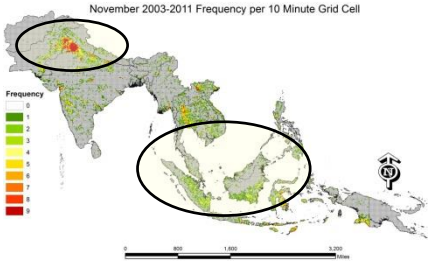


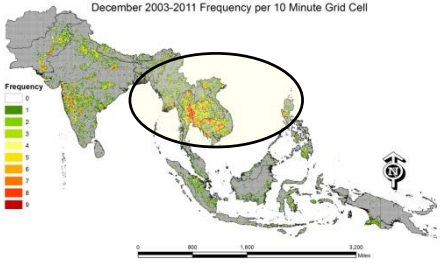






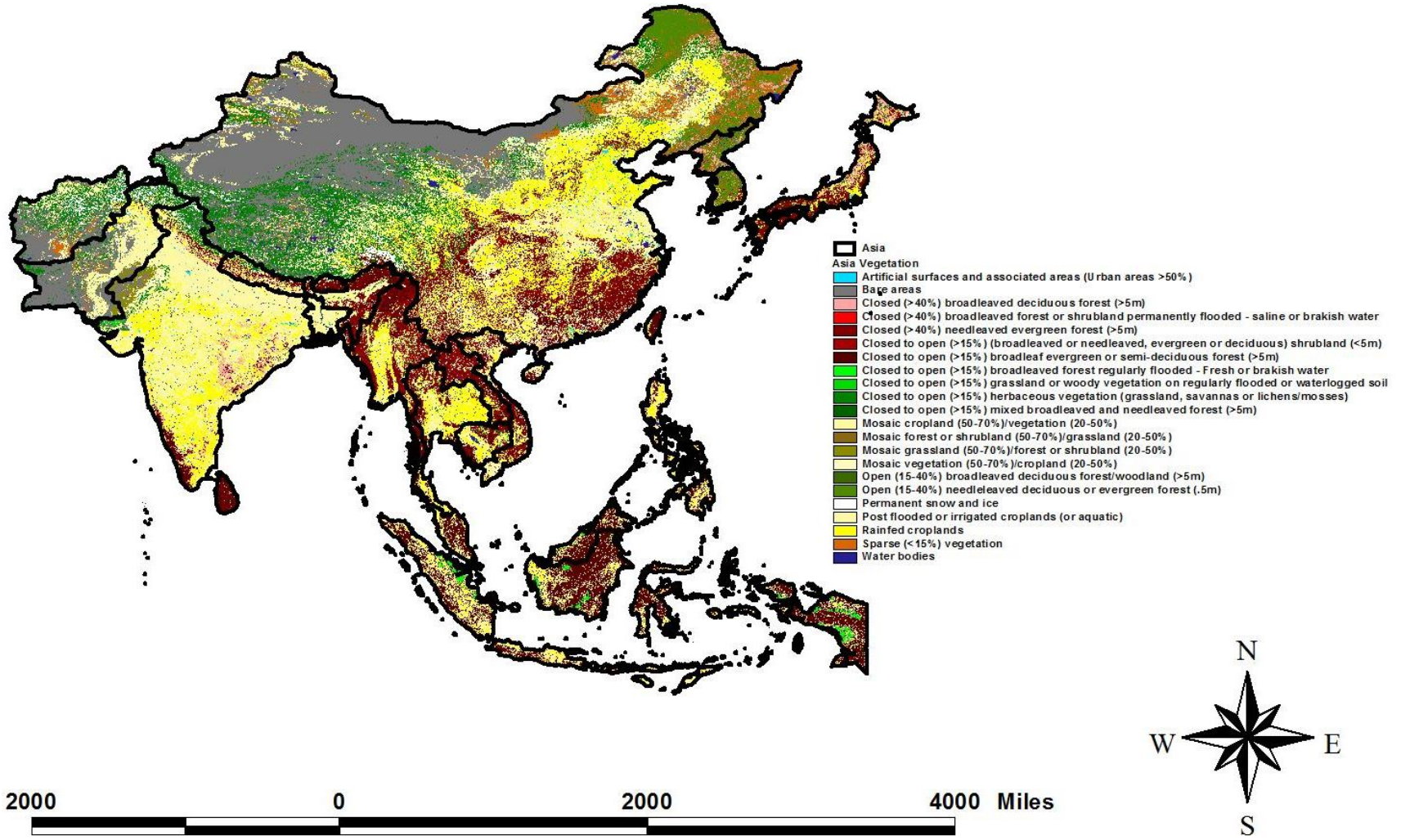






Fire Frequency Maps (2003-2011) with the highest fire frequency during March.

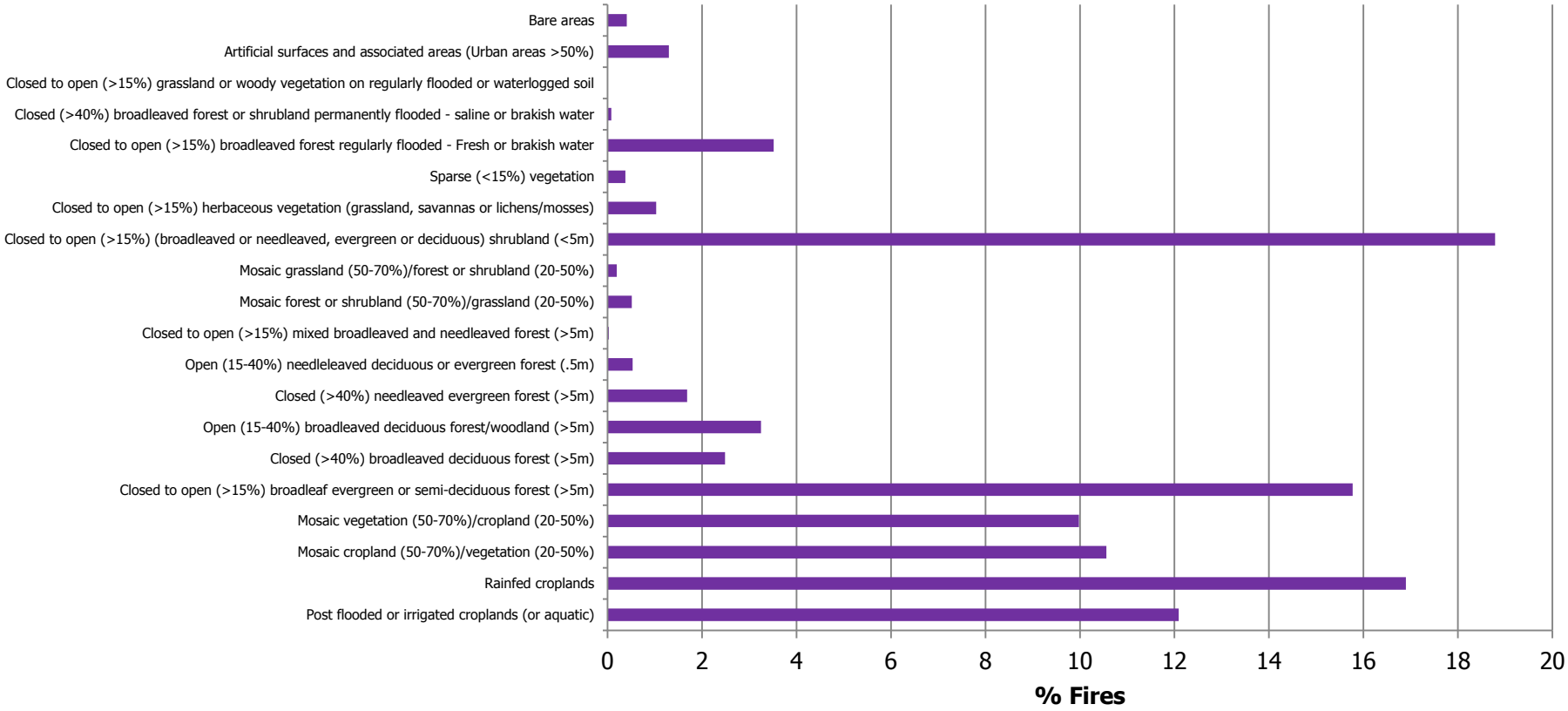
Fire-Vegetation Analysis – 300m MERIS data



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

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

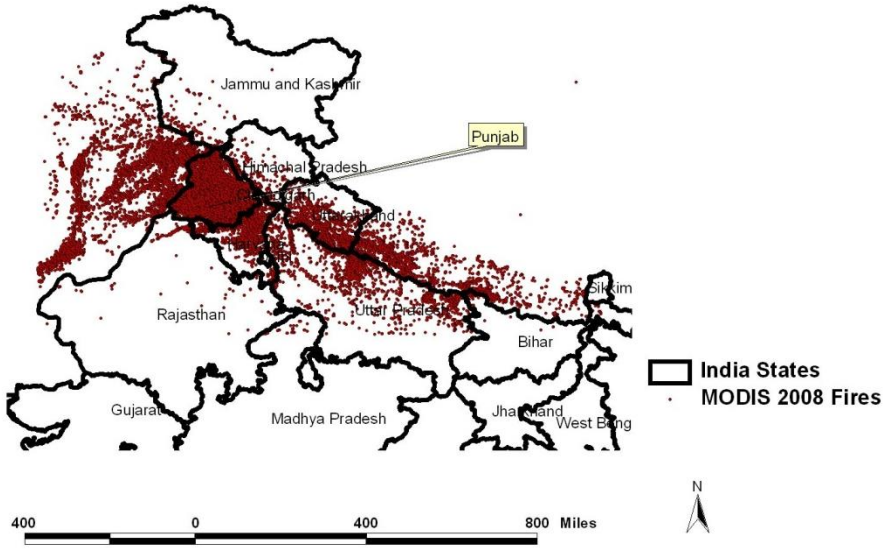
Fire-Vegetation Analysis – 300m MERIS data

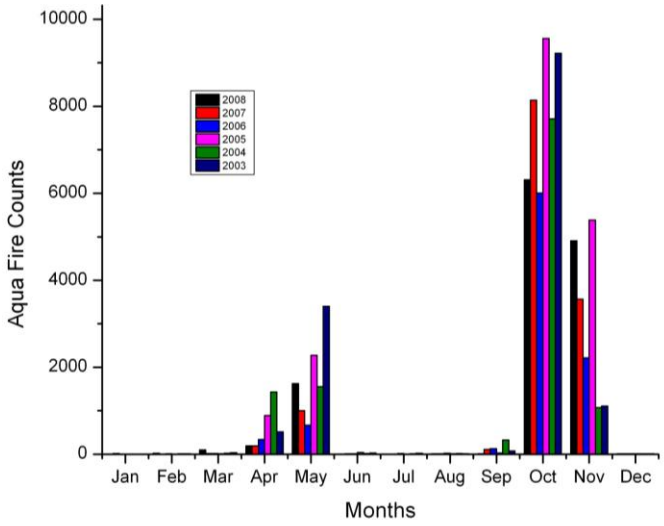


Percent fire occurrences in the diverse vegetation categories.

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

Fire Analysis





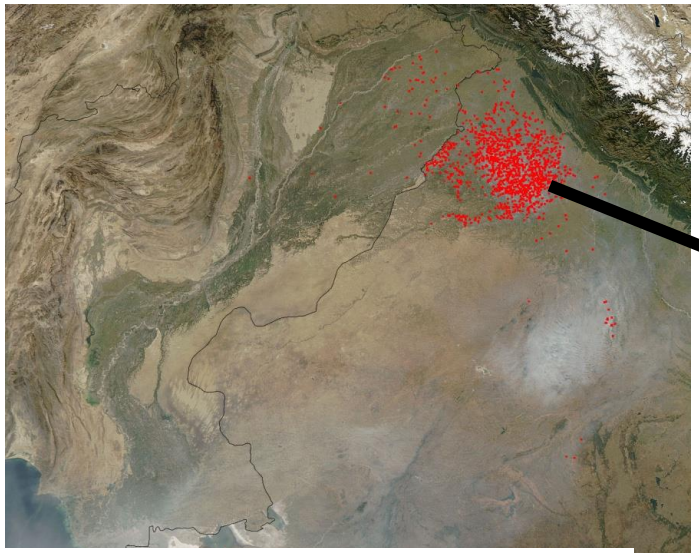
Punjab, India in the study area domain had the highest fire counts

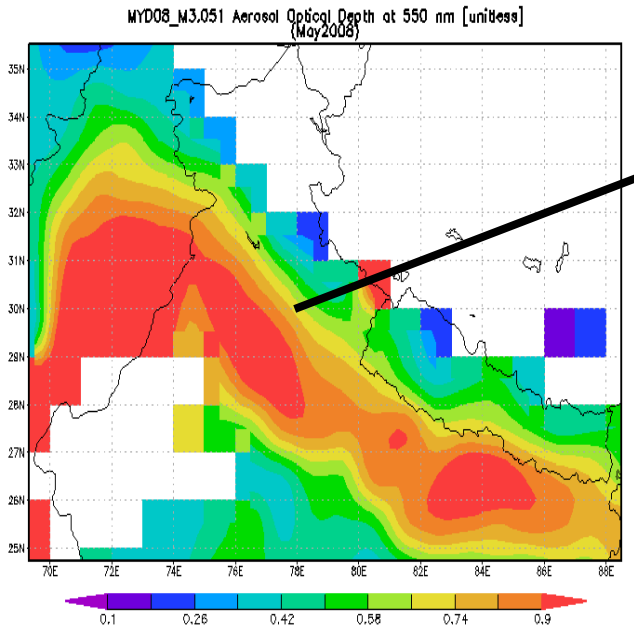
Bi-modal trend in Fire season April-May and Oct-Nov. Peaks correspond to Ag.residue burning.

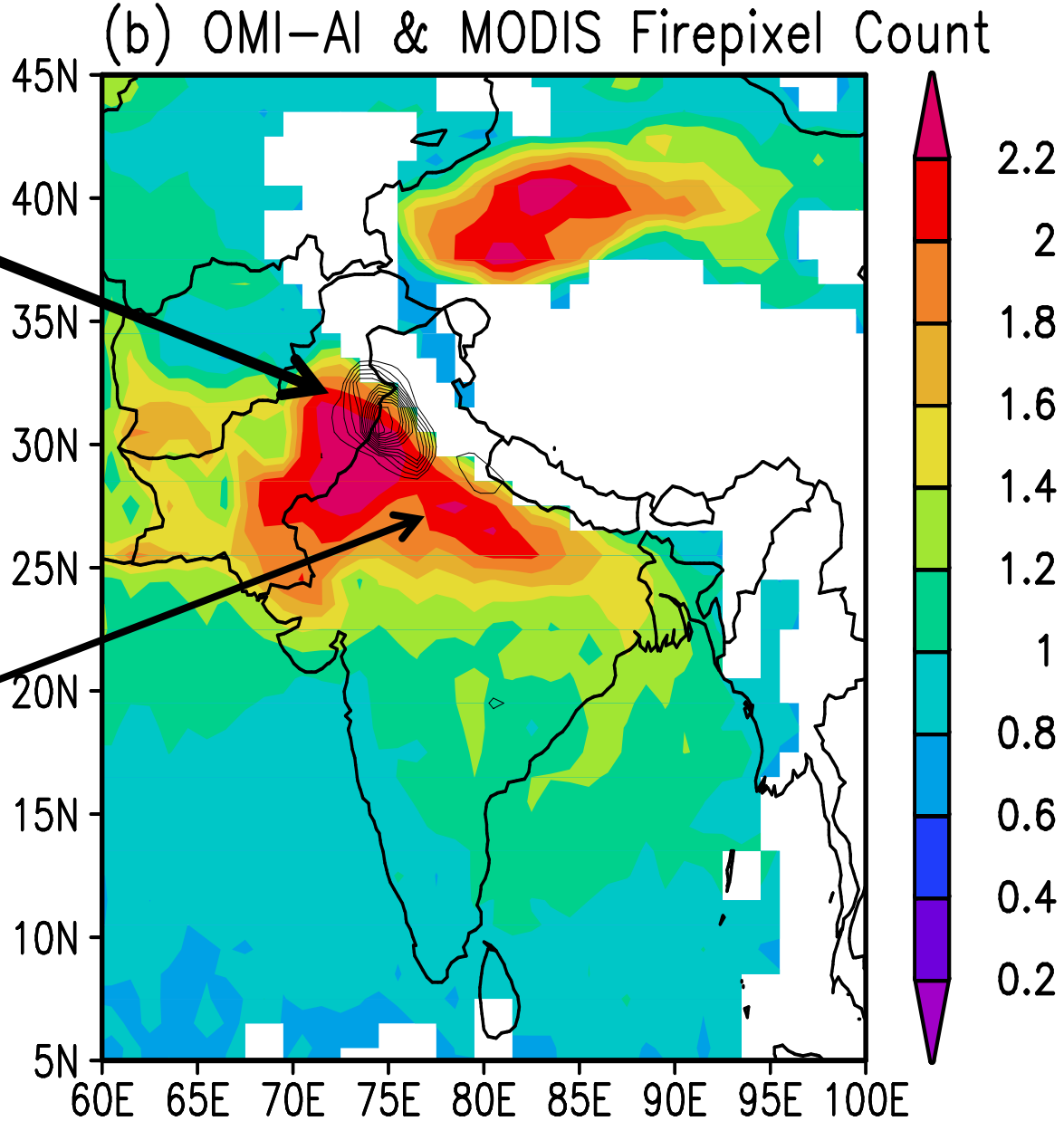
2010 Total Fire counts – 35318

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

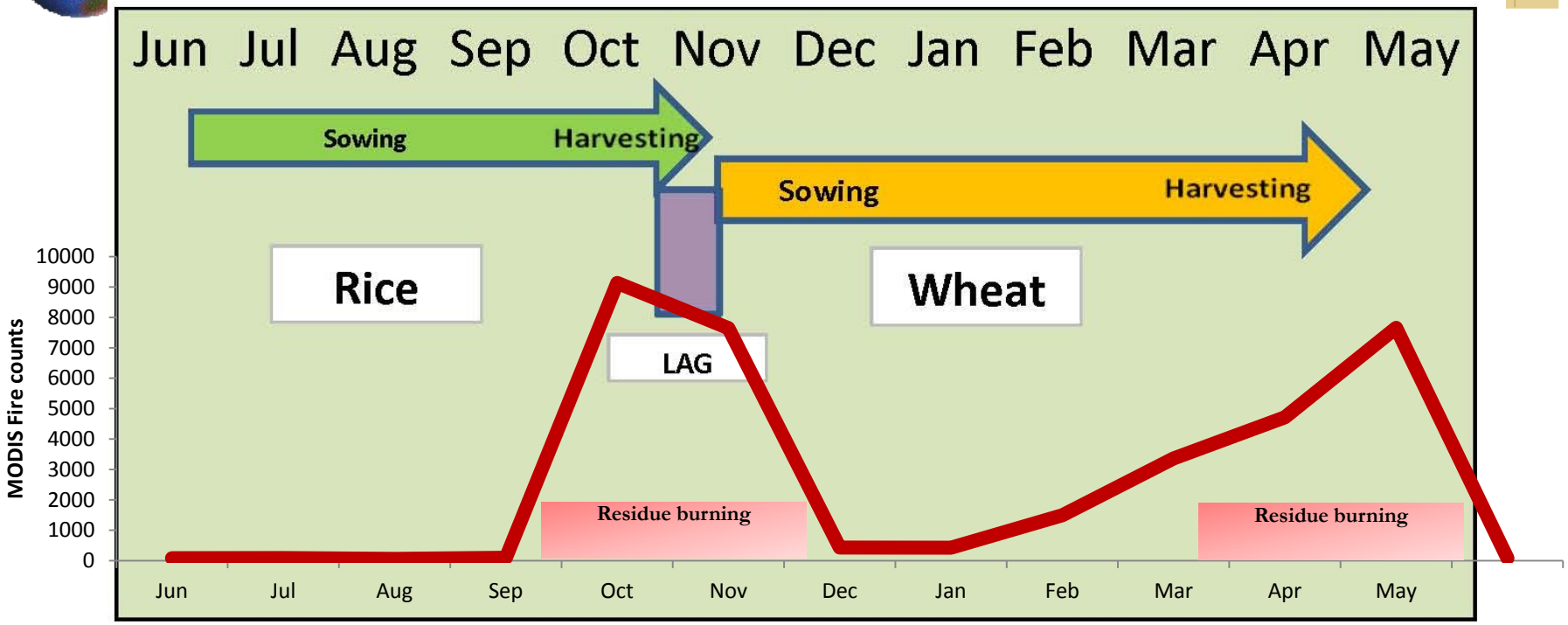
Intense Aerosol Optical Depth during Summer - IGP







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., Environmental Pollution, 2012

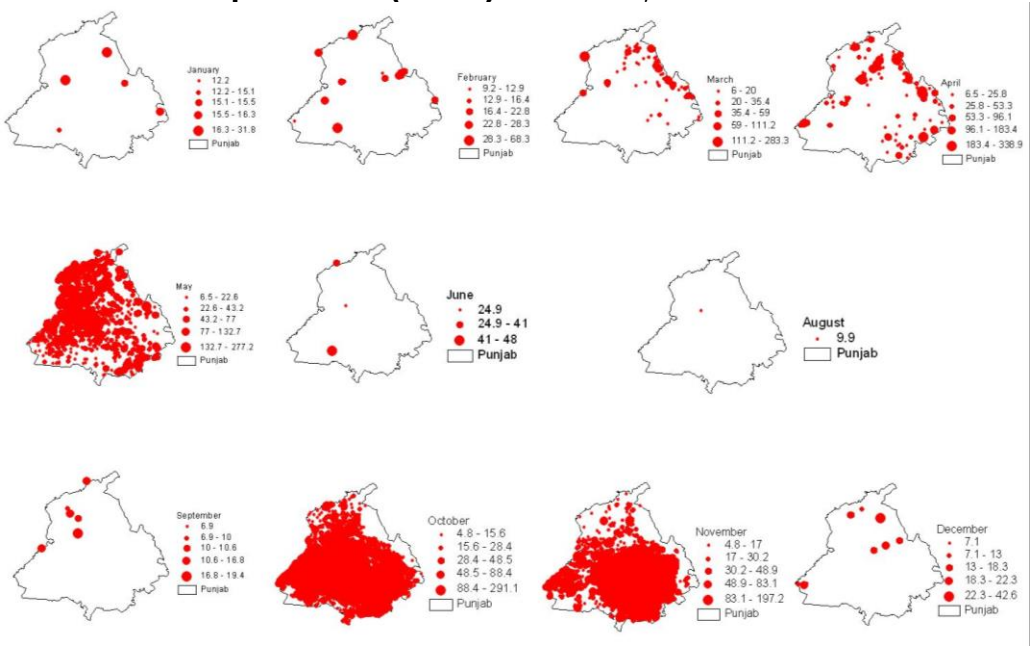
Does Agricultural Residue Burning Episodes in Punjab corresponds to variations in AOD seasonality?

How does Fire Counts and FRP vary with AOD?

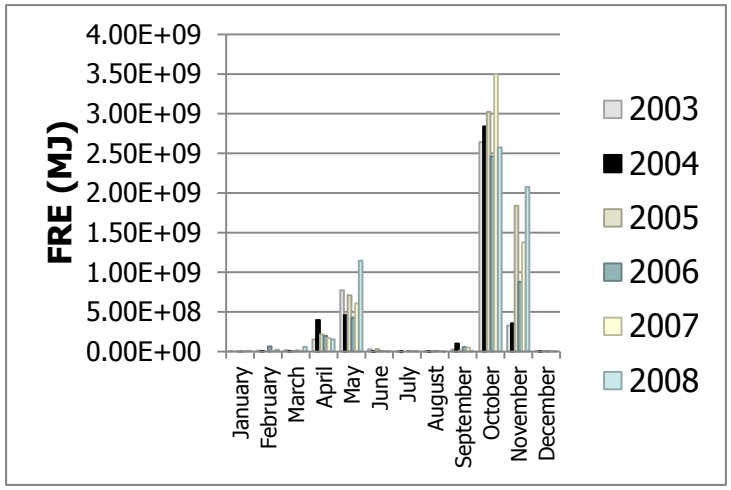
Does increase in FRP corresponds to increase in AOD?

What about temperature and precipitation seasonality?

Aqua FRP (MW) monthly variations



FRE (MJ/sec) monthly variations

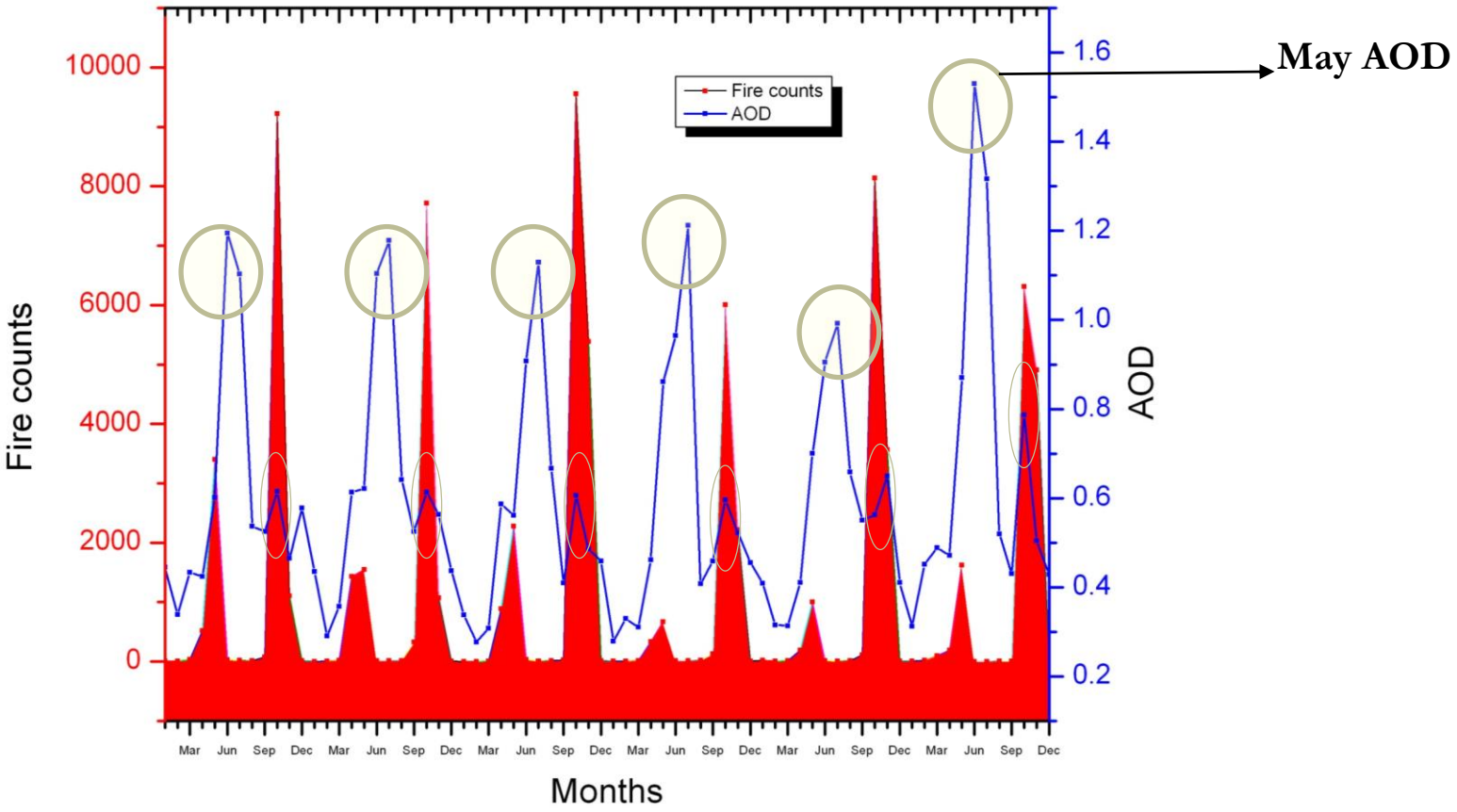


Fire Radiative Energy (FRE) was highest during the October and November months (Rice residue burning) compared to March and April (Wheat residue burning season).

On an average (2003-2008), FRE based estimates of biomass burnt (4.87 Tg) closely matched with the amount of residues burnt estimated empirically (4.74 Tg) (Vadrevu et al., 2010, submitted).

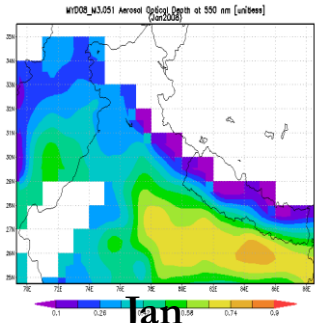
Earlier estimates from Gupta et al., (2004) for 1994 – 7.8Tg residues burnt from Punjab

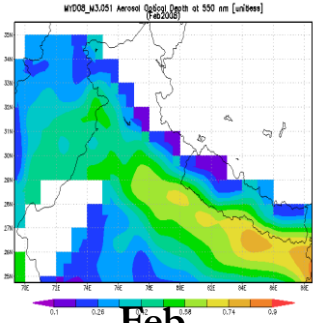
AQUA MODIS AOD (550nm) and MODIS Fire Counts

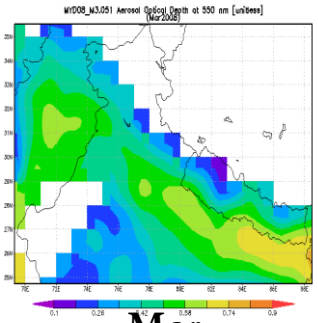


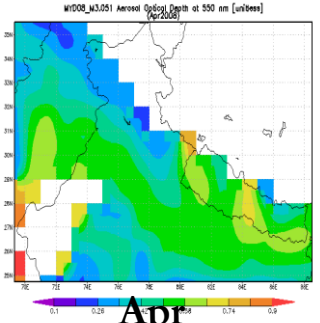
High FRP during October/November should correspond to high AOD-however more AOD in May (low FRP)

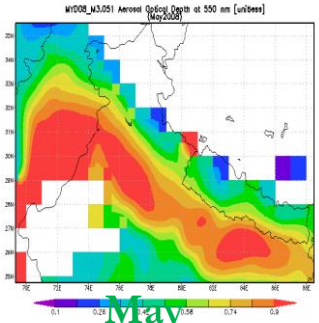
Aqua MODIS AOD (550nm) Seasonality

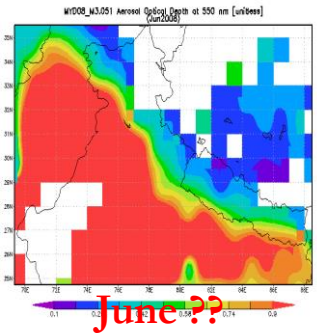

Jan

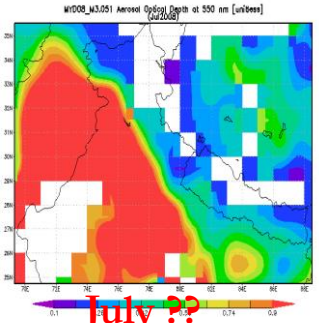

Feb

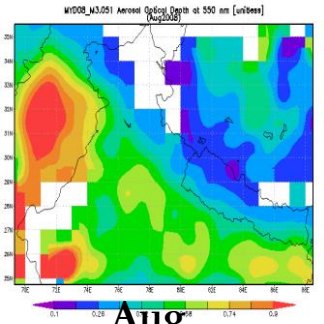

Mar

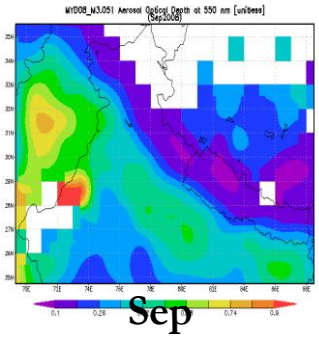

Apr

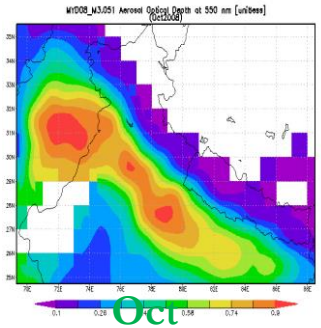

May

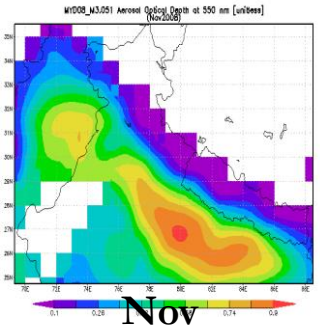

June ??

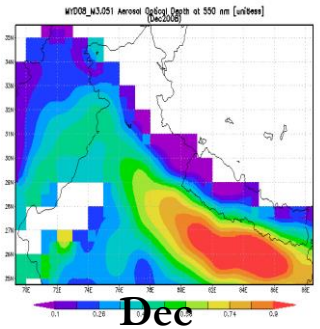

July ??


Aug


Sep

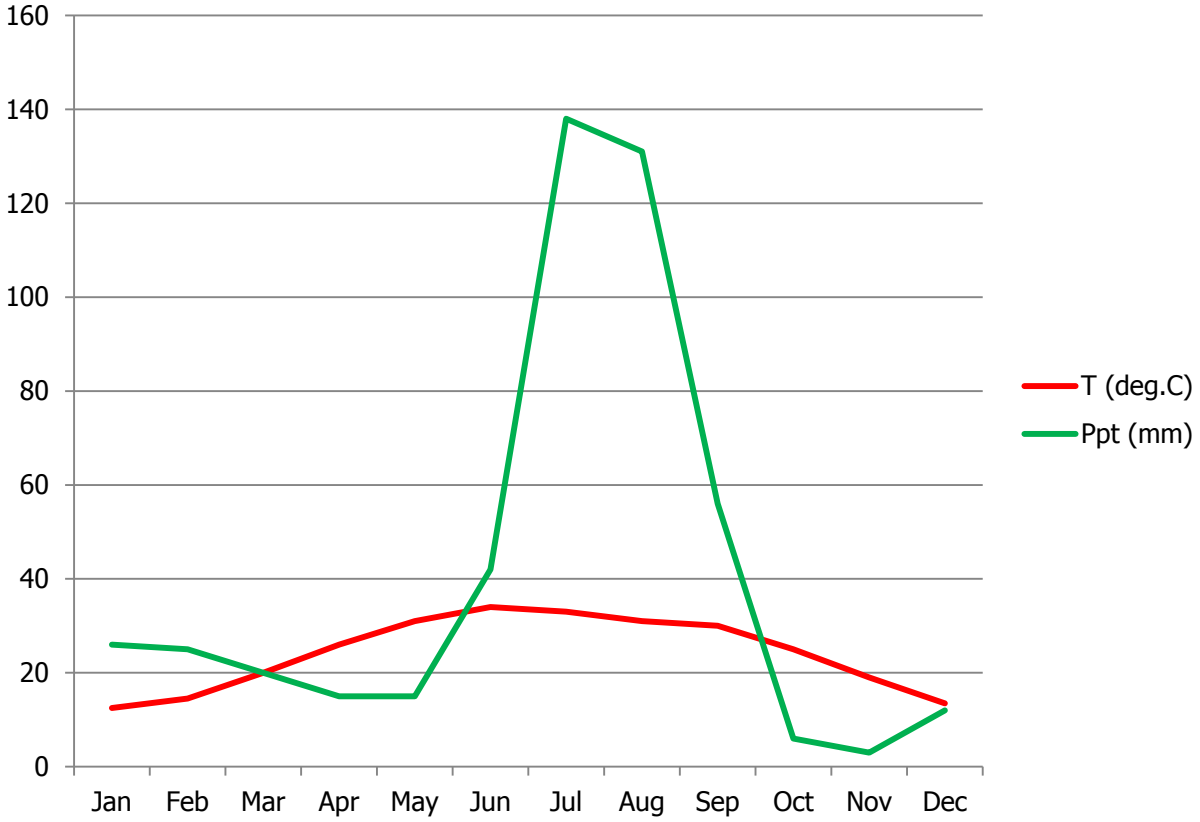

Oct


Nov


Dec

High AOD during May, October and November can be well explained by Agricultural residue burning as well as fire counts. In contrast, fire events during June and July are less than 1% and high AOD loads does not clearly coincide with the Agricultural Residue burning events(!)

Temperature and Precipitation Seasonality



SUMMER – MID APRIL to End of June

Rainy season - July to end of September

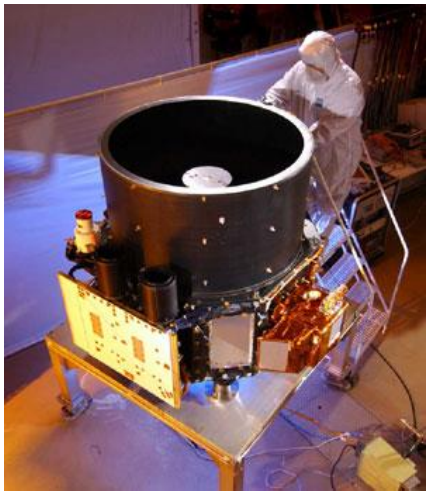
Winter – December to February

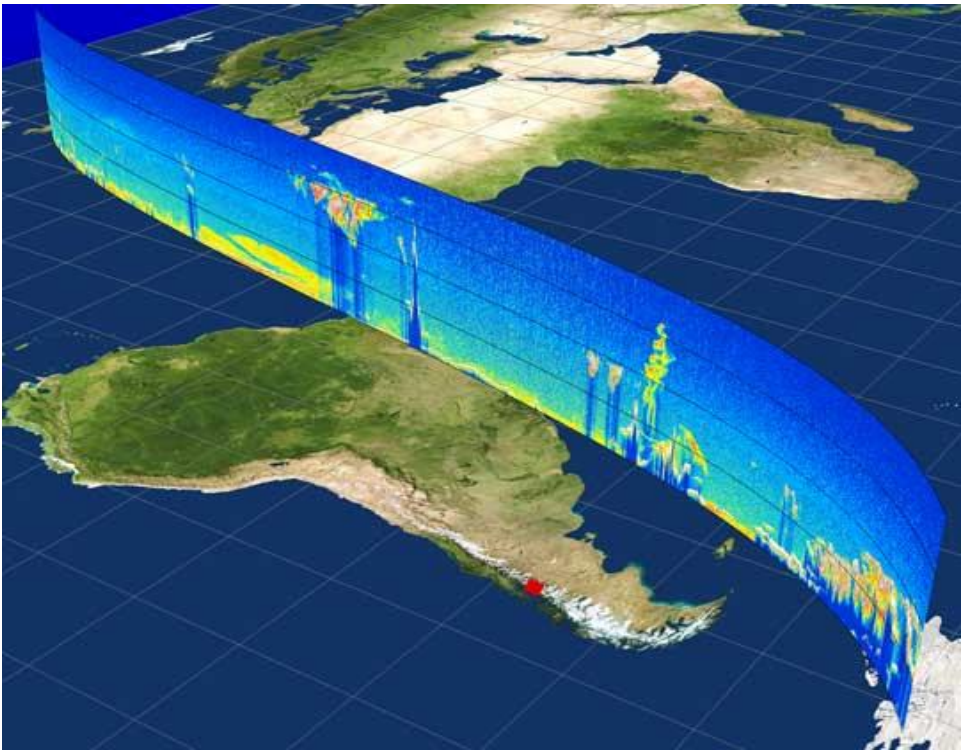
Smoke Plume Heights of Agriculture and Forest Fires from CALIOP

CALIPSO-CALIOP LIDAR Data

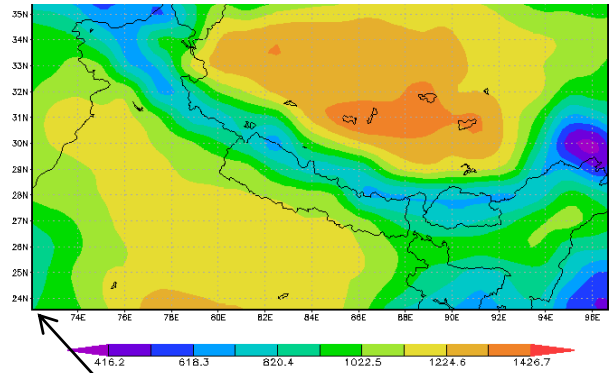
- Contains CALIOP, IIR, and WFC sensors

- 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.

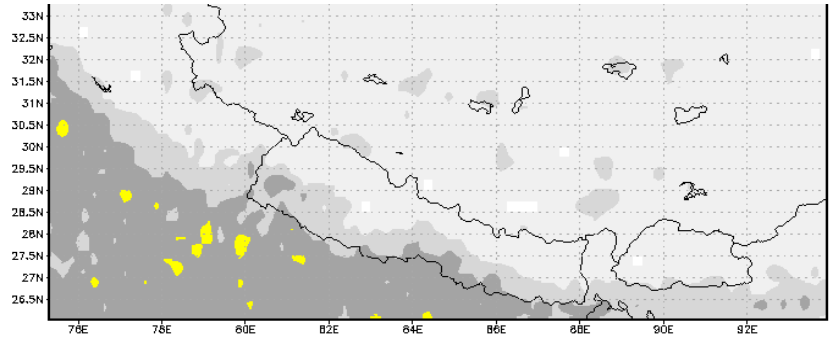




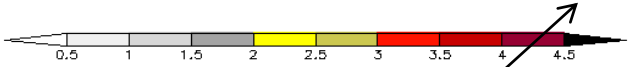
CALIOP	
laser:	Nd: YAG, diode-pumped, Q-switched, frequency doubled
wavelengths:	532 nm, 1064 nm
pulse energy:	110 mJoule/channel
repetition rate:	20.25 Hz
receiver telescope:	1.0 m diameter
polarization:	532 nm
footprint/FOV:	100 m/ 130 µrad
vertical resolution:	30-60 m
horizontal resolution:	333 m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



MERRA PBL

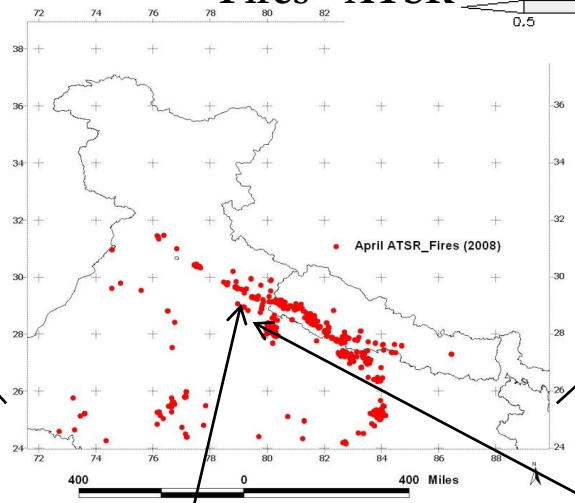


Fires - ATSR

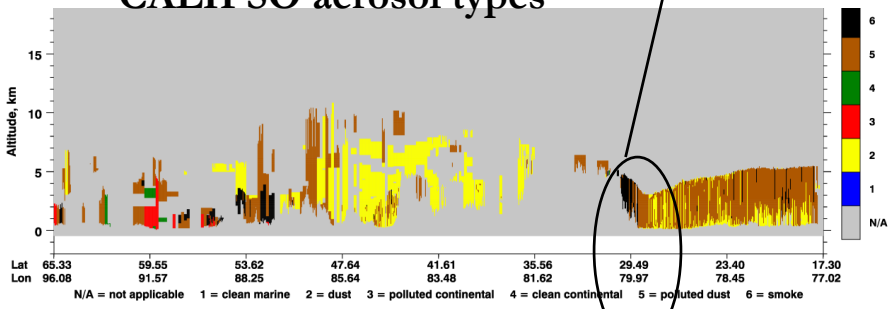


OMI-Aerosol Index

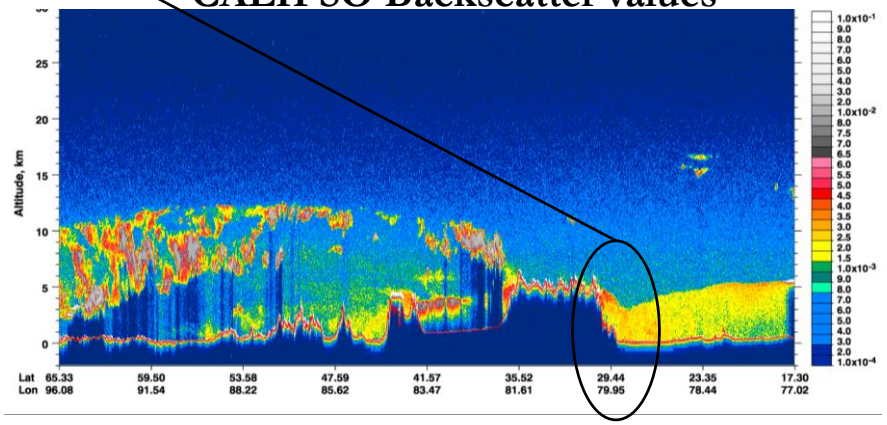
AI sensitive to UV Absorbing aerosols such as smoke, mineral dust, volcanic ash.



CALIPSO aerosol types



CALIPSO Backscatter values



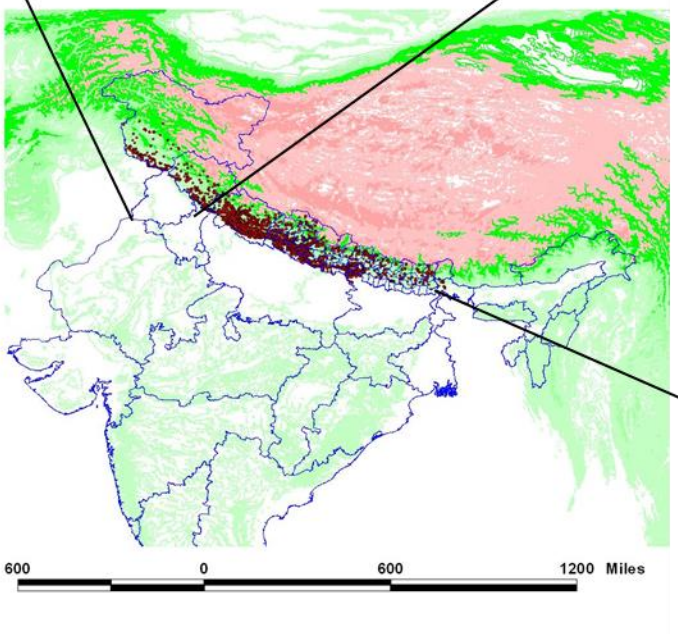
CALIPSO data shows biomass burning plumes reaching more than 5-km ht beyond the Planetary Boundary Layer.

Vadrevu et al., 2012,2013. AE

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

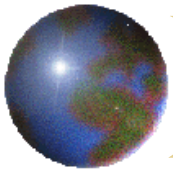


Himalayan Forest Fires

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**

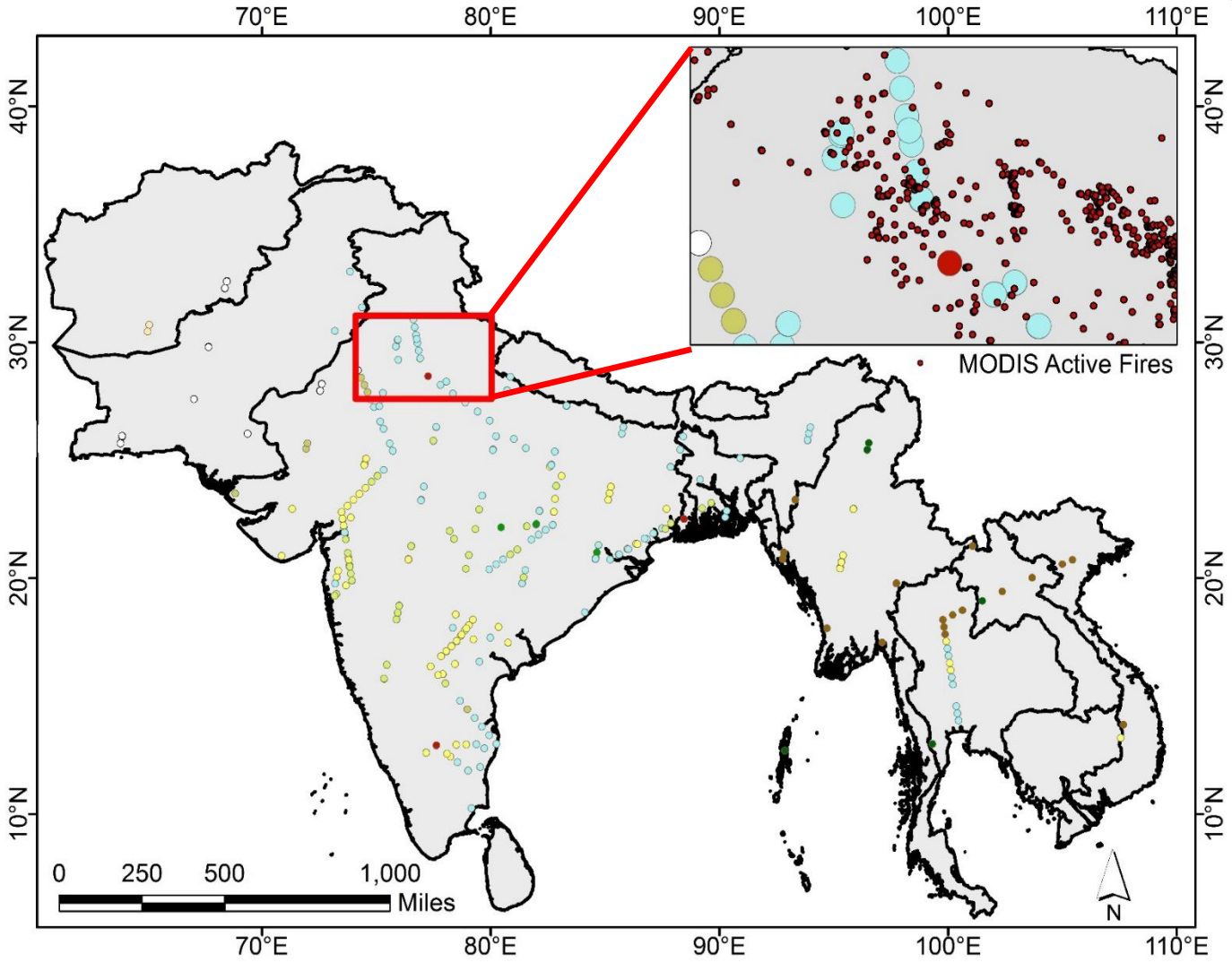
Sub-Himalayas (500-1900m); Lower Himalayas (1901-4000m); Greater Himalayas (4001-8700m).

Vadrevu et al., AE, 2012.



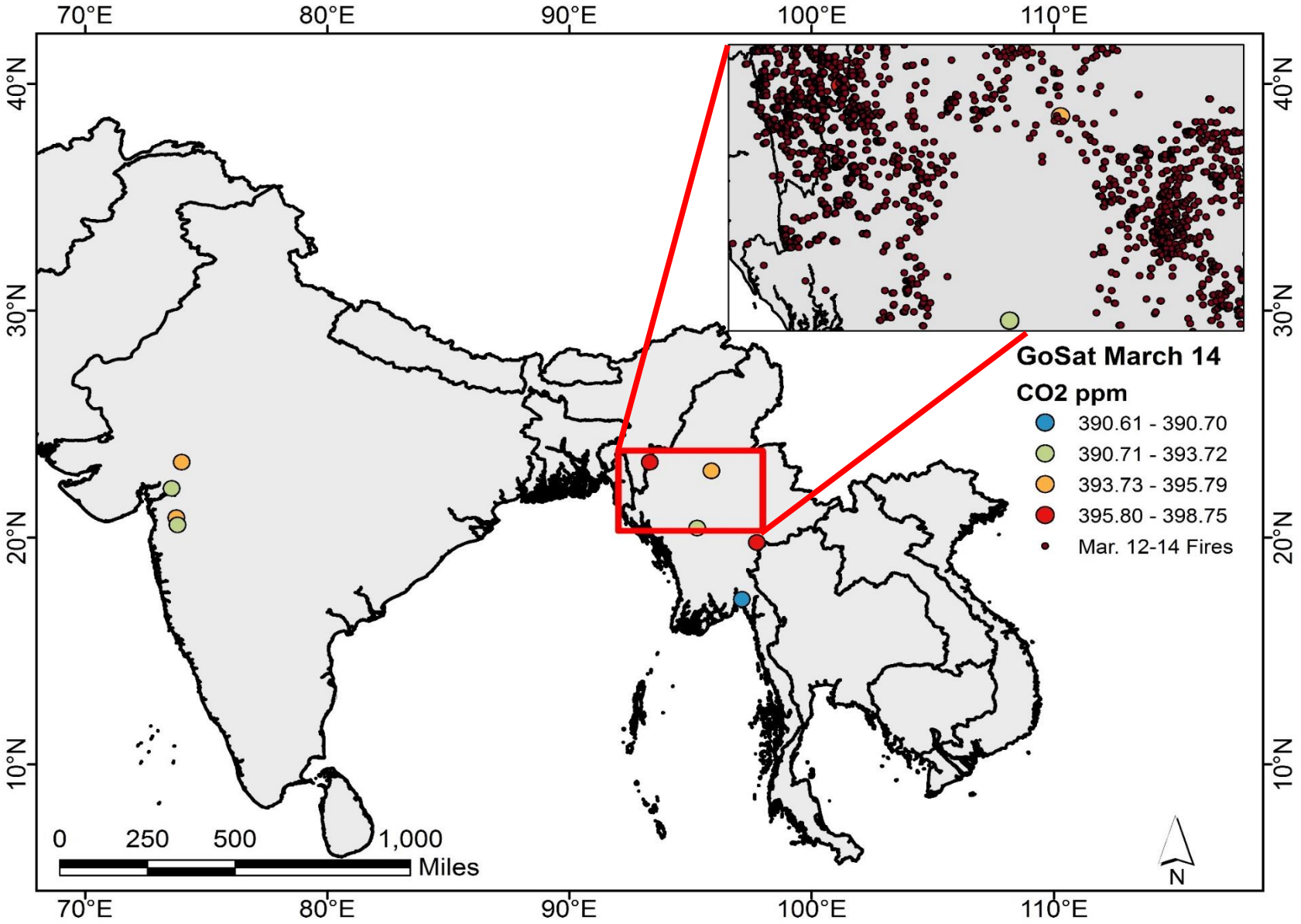
GOSAT CO2

MODIS fires within 20-km radius of GOSAT CO2 Data – March

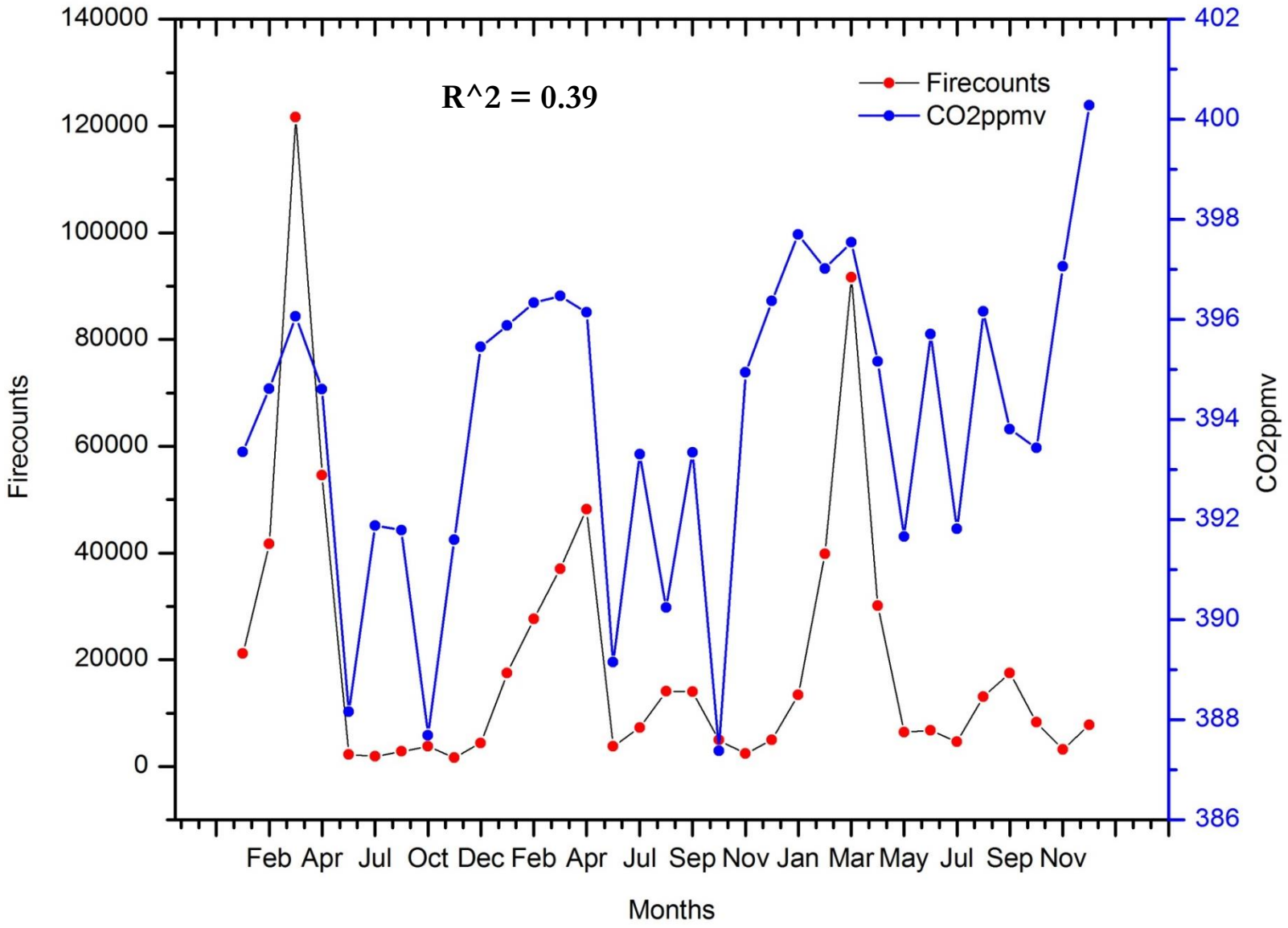


Agricultural Fires, Punjab, Northwest India

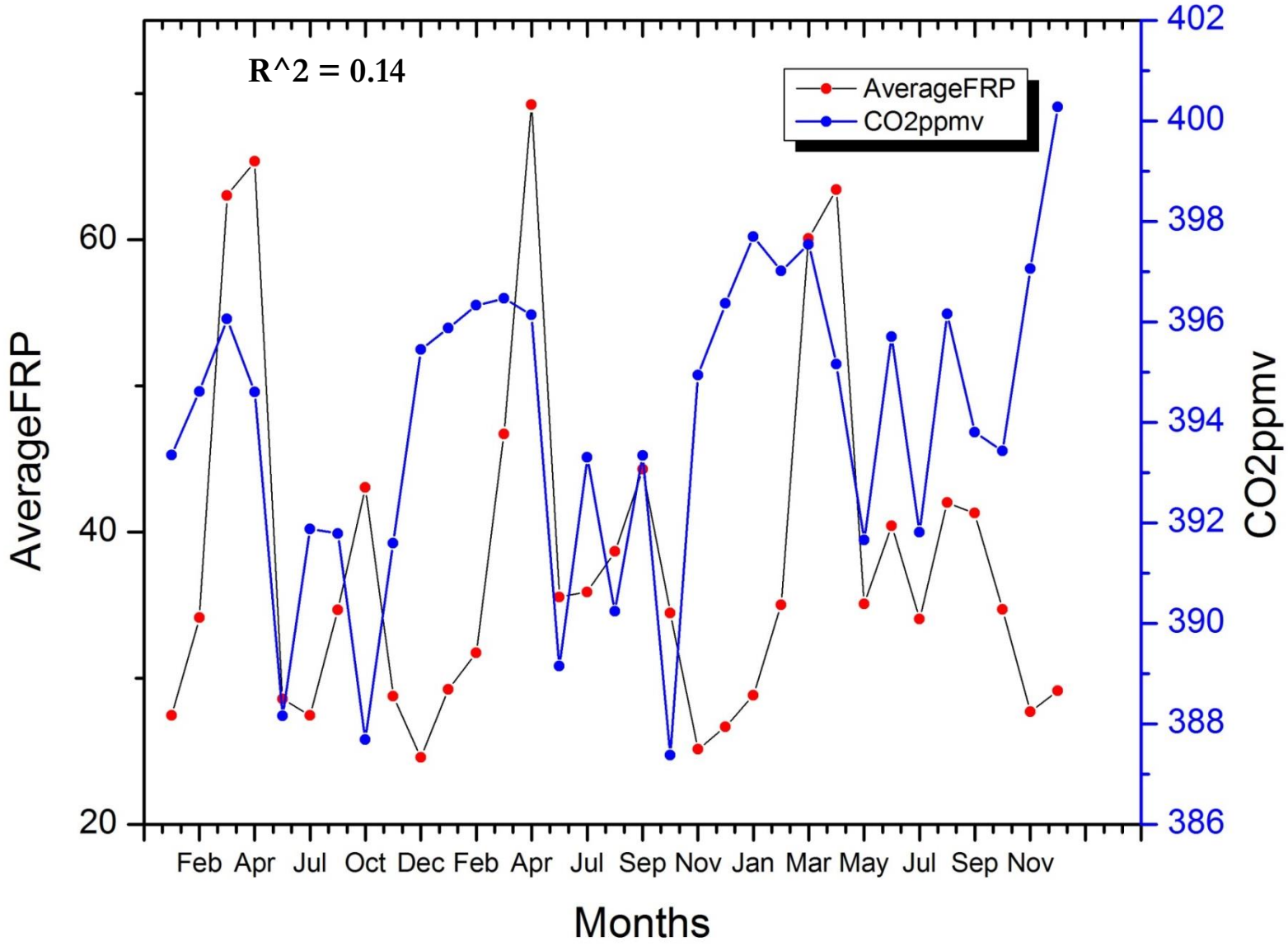
MODIS fires within 20-km radius of GOSAT CO2 Data – March



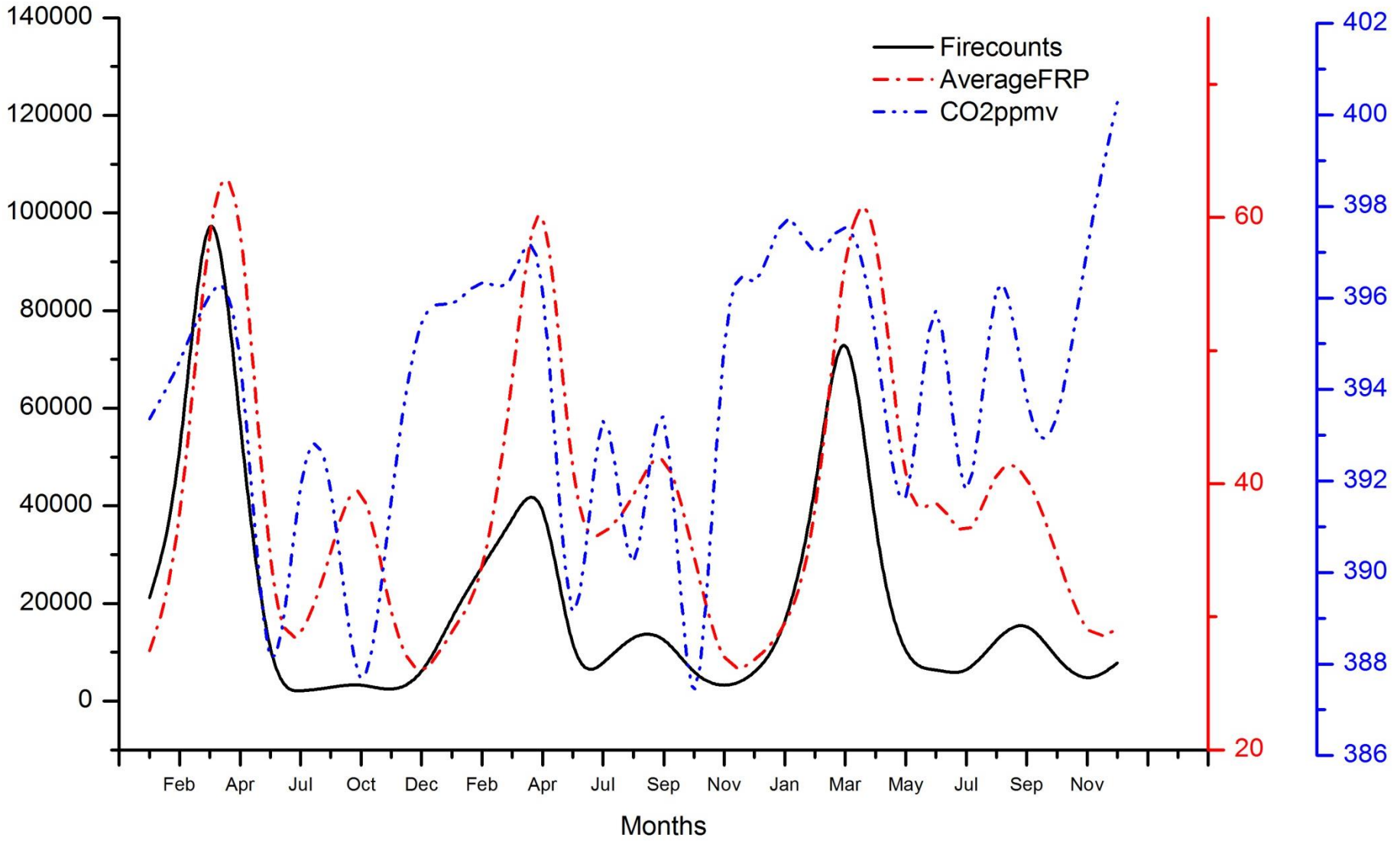
GOSAT CO2 (2010-2013) versus MODIS Active Fires - Asia



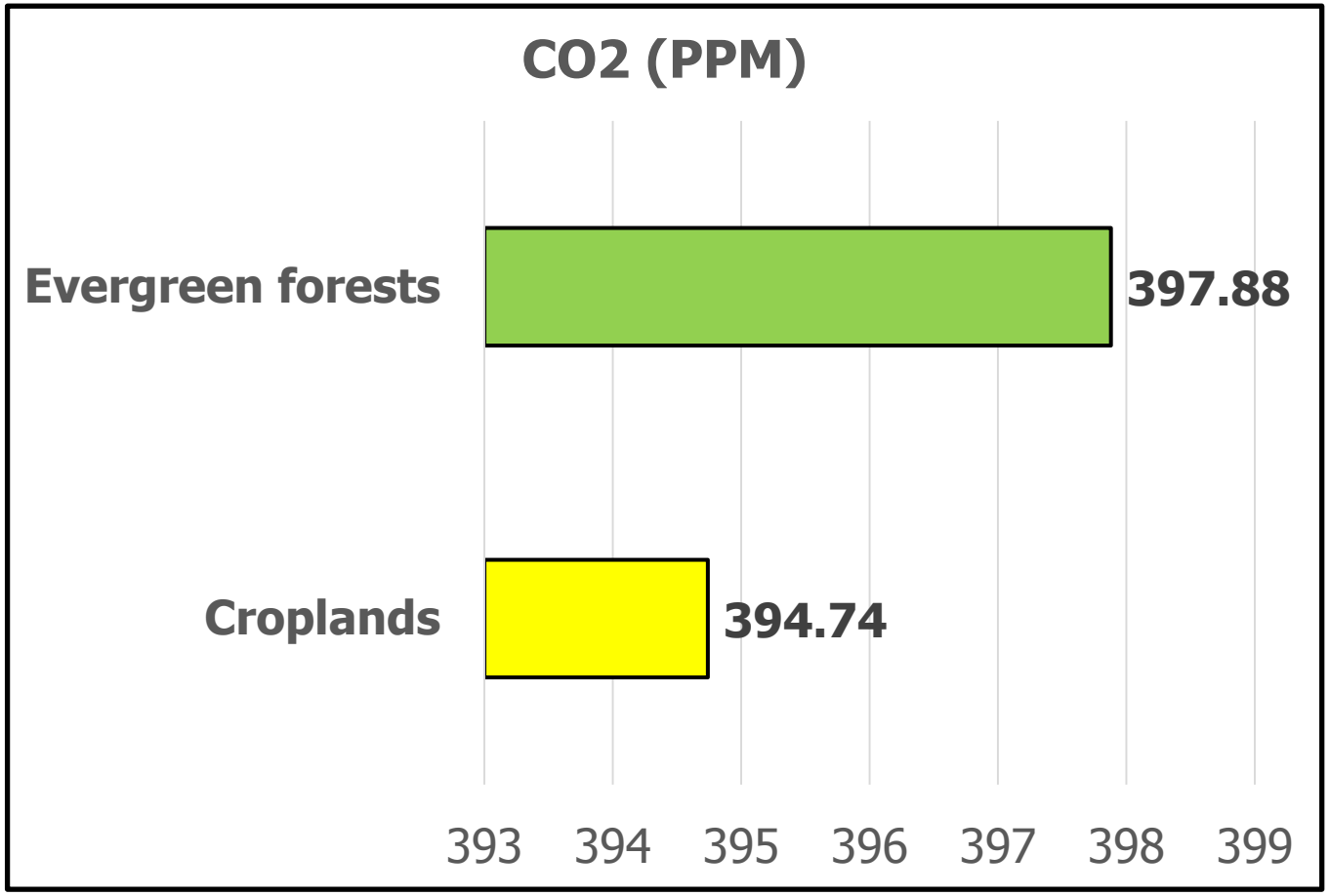
GOSAT CO2 (2010-2013) versus MODIS FRP - Asia



Fire counts/FRP vs GOSAT CO2 Data (2010-2013)



GOSAT CO2 Variations within Fire affected vegetation (20-km Radius of GOSAT and MODIS Fire co-locations)

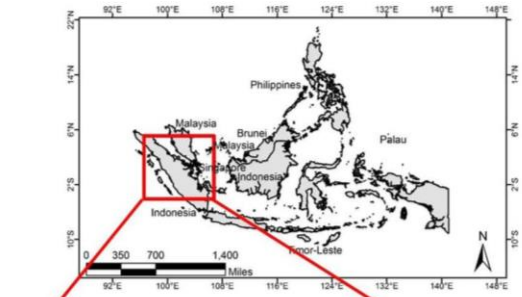


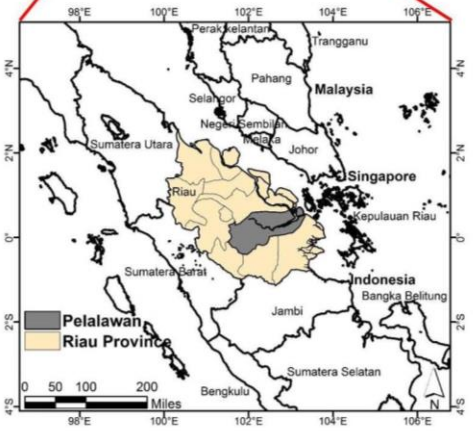
- MODIS Aerosol Optical Depth;
- MODIS Aerosol Small Mode Fraction;
- OMI - UV Aerosol Index;
- OMI Aerosol Absorbing Optical Depth

Indonesia Biomass Burning - 2013

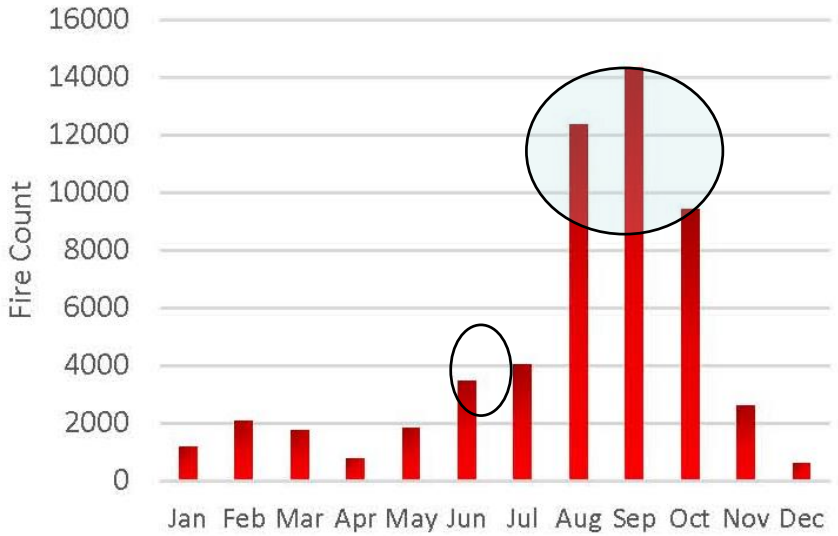
Indonesia Biomass Burning season – August to September.

Unusual Fire episode occurred during 2013, June that impacted more than 10-countries in SEA.

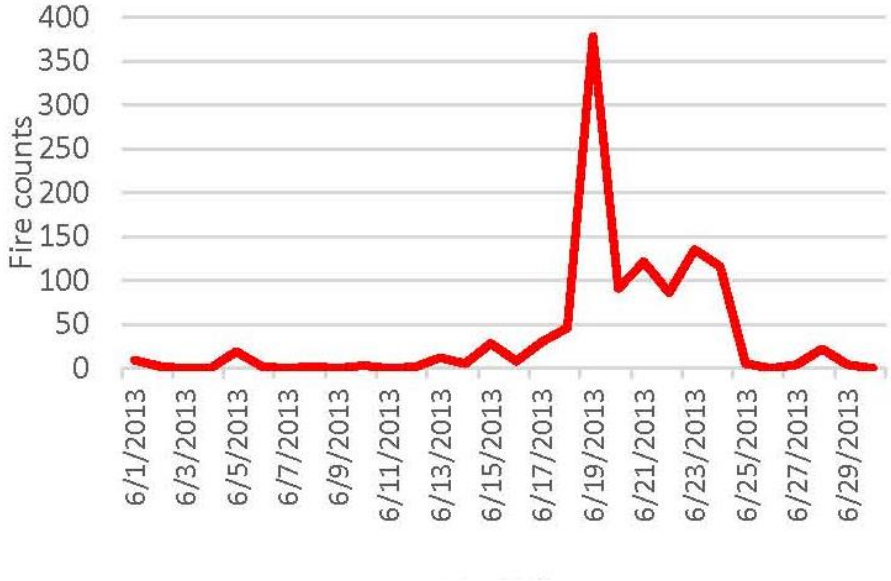




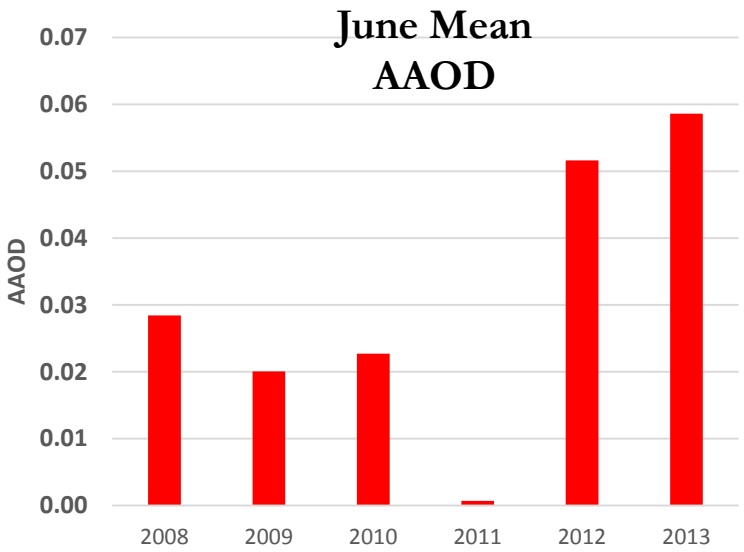
Indonesia Biomass Burning – June, 2013

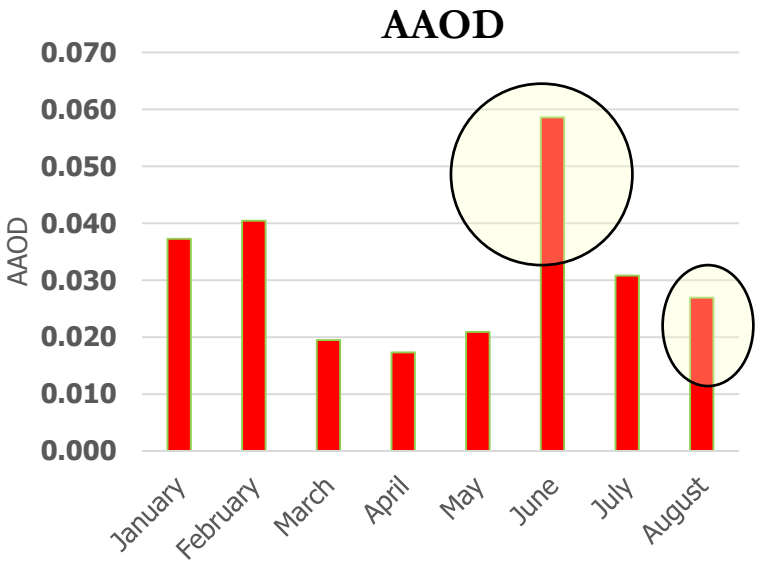


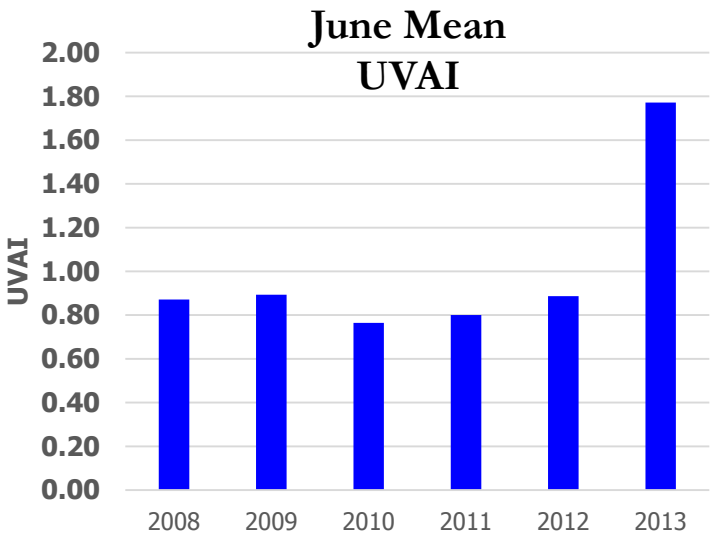
June 2013

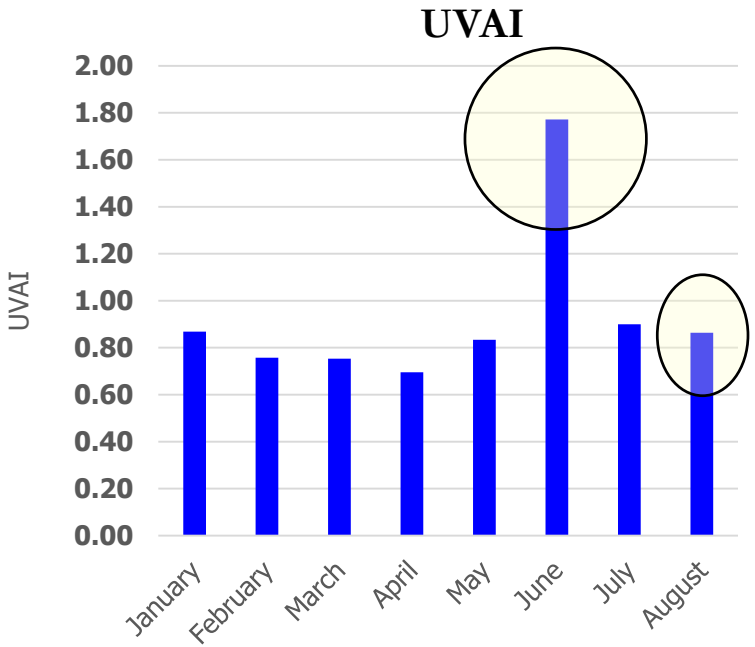


AAOD and UVAI

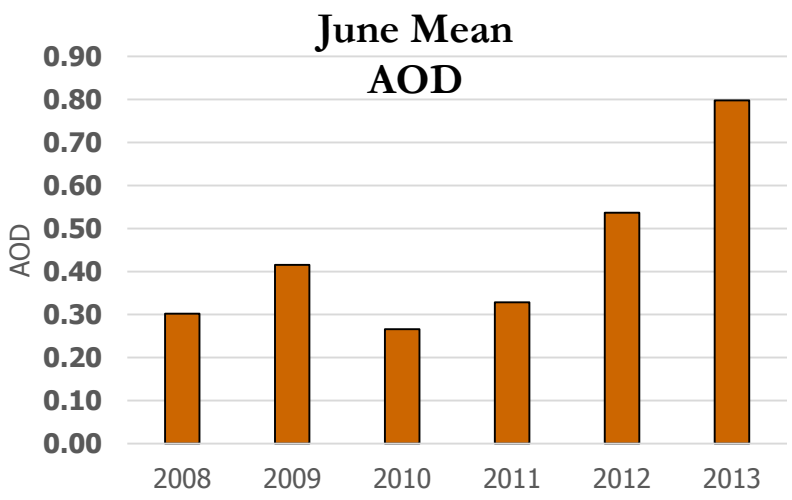


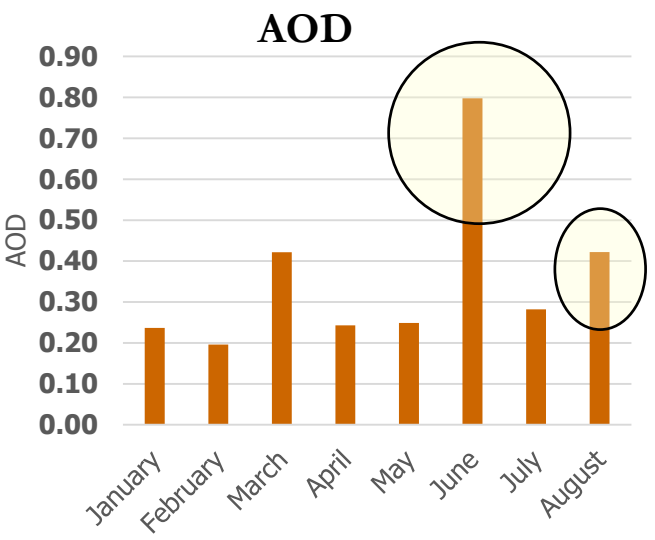


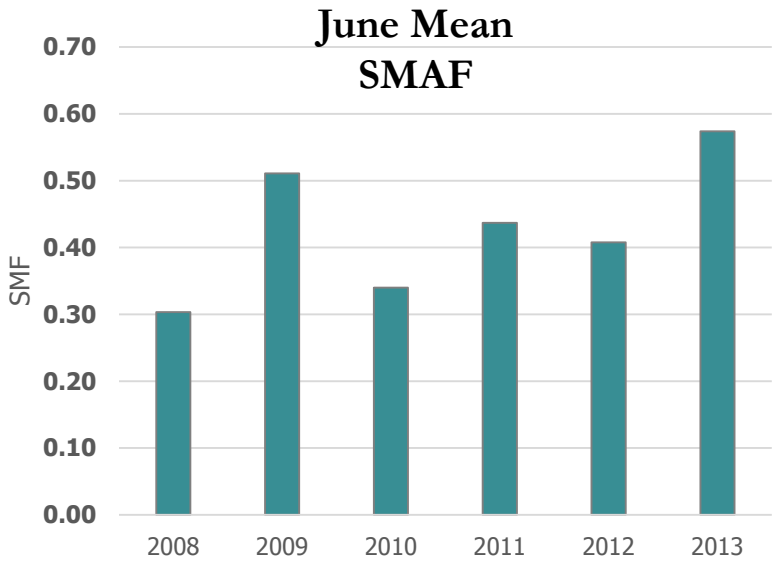


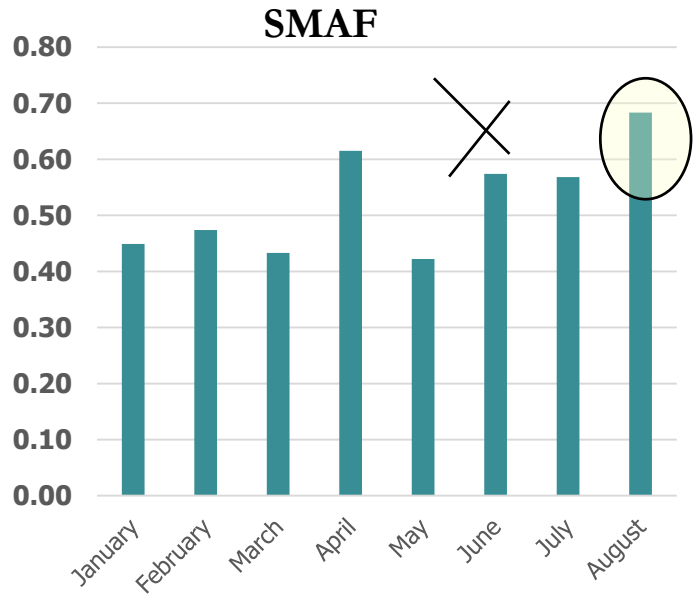


Aerosol Optical Depth and Small (Fine) Mode Fraction

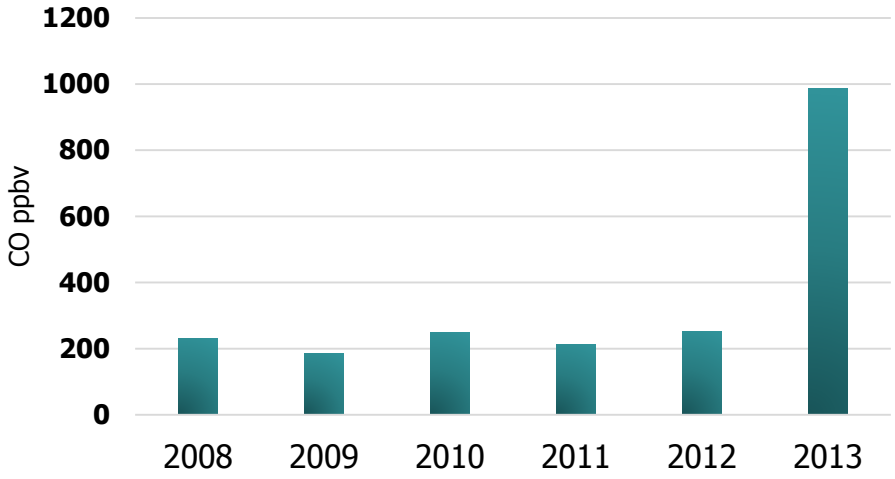


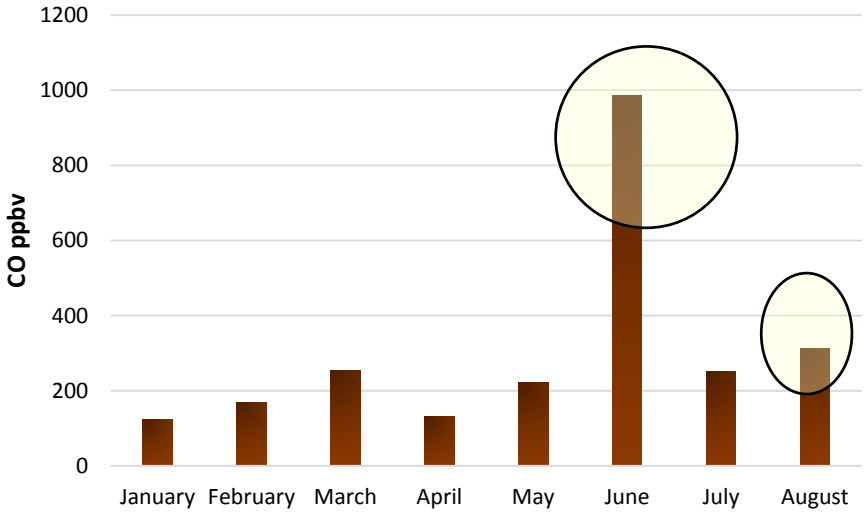






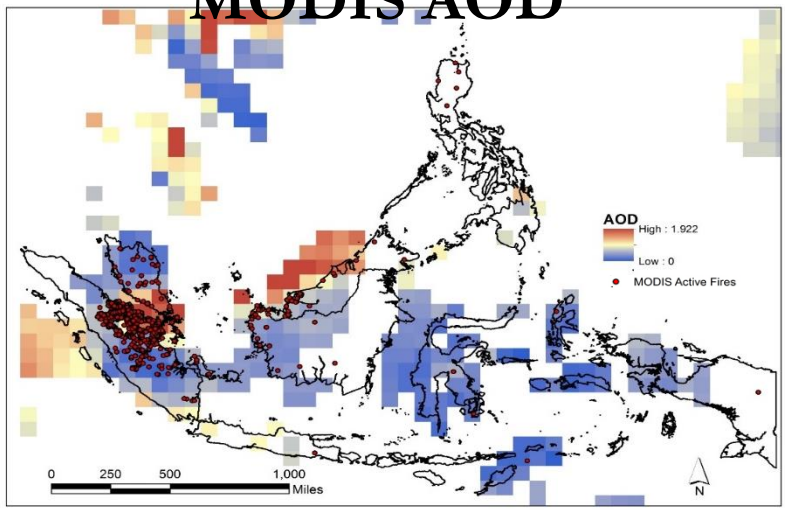
MOPITT CO


1200
1000
800
600
400
200
0
CO ppbv
2008
2009
2010
2011
2012
2013

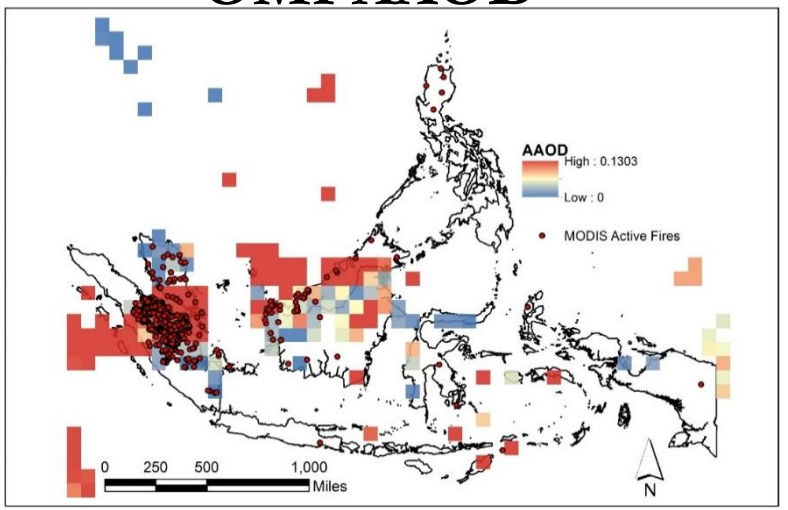

1200
1000
800
600
400
200
0
CO ppbv
January
February
March
April
May
June
July
August

Spatial Patterns

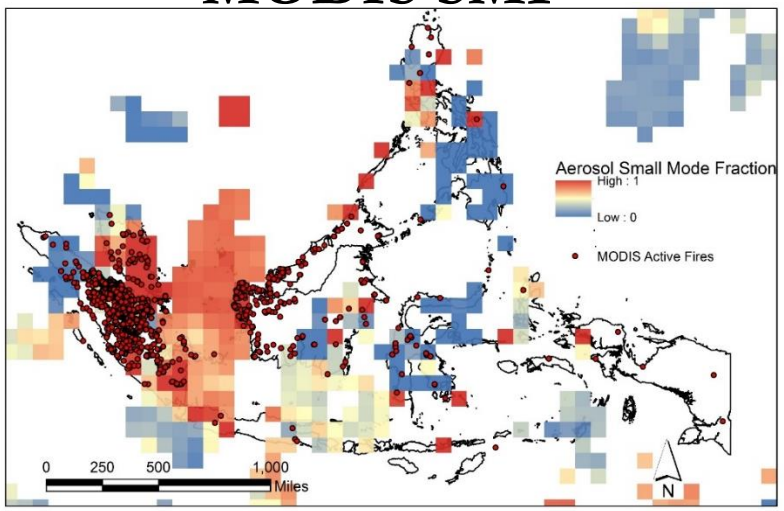
MODIS AOD



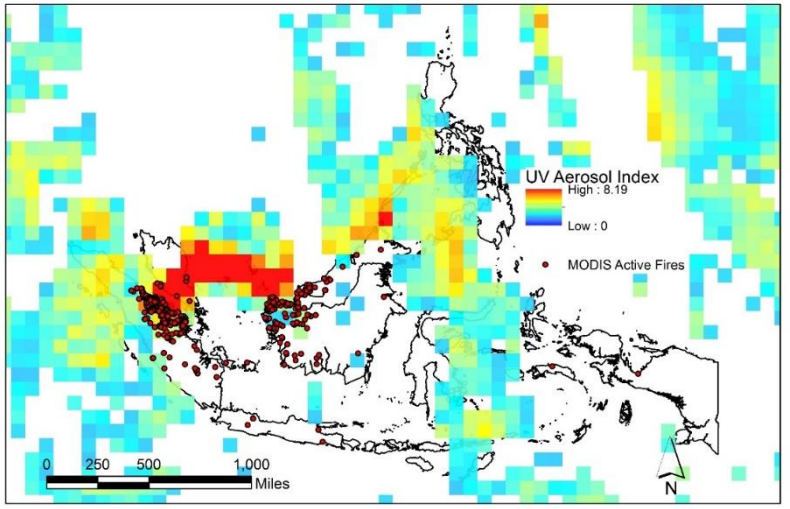
OMI AAOD



MODIS SMF

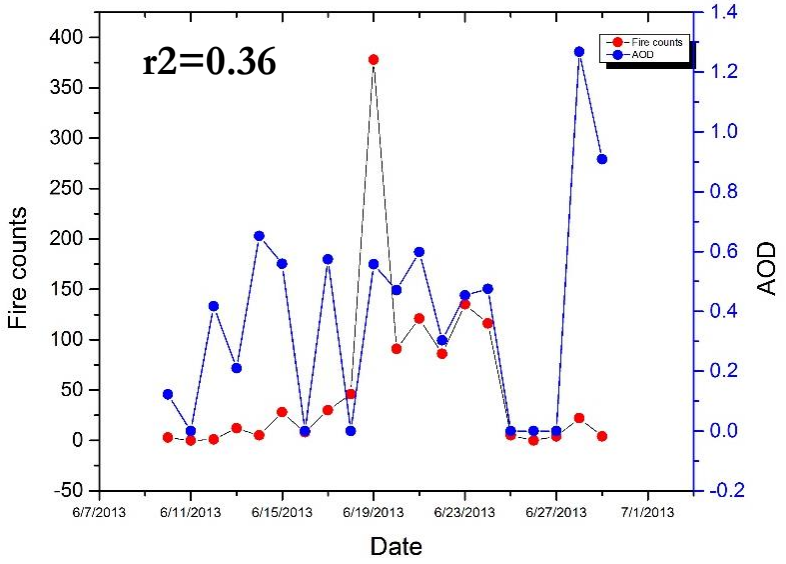


OMI UVAI

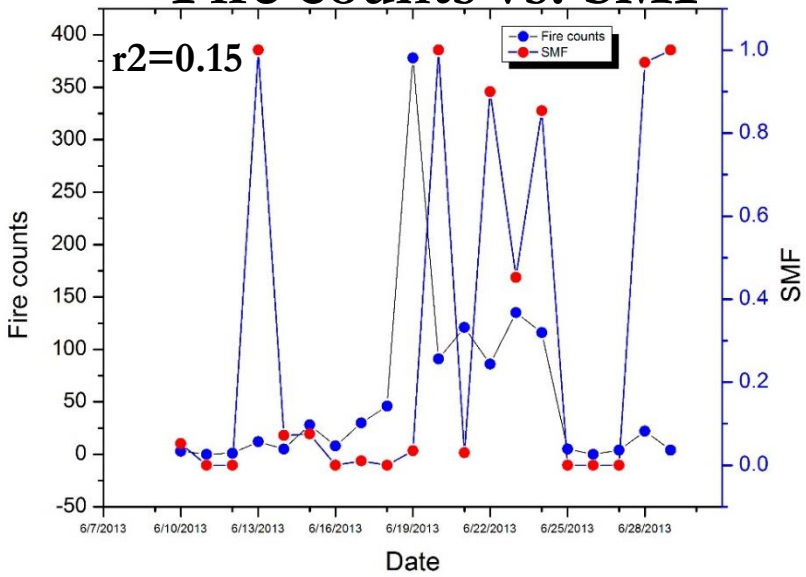


Correlations

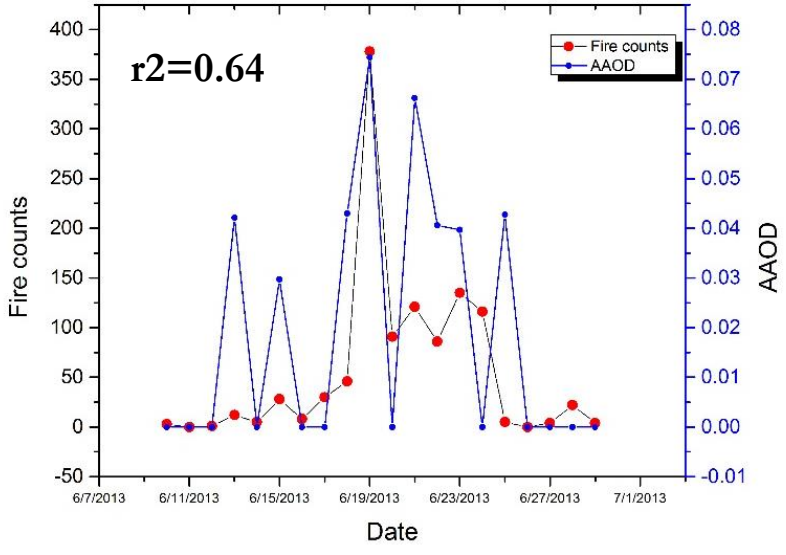
Fire counts vs. AOD



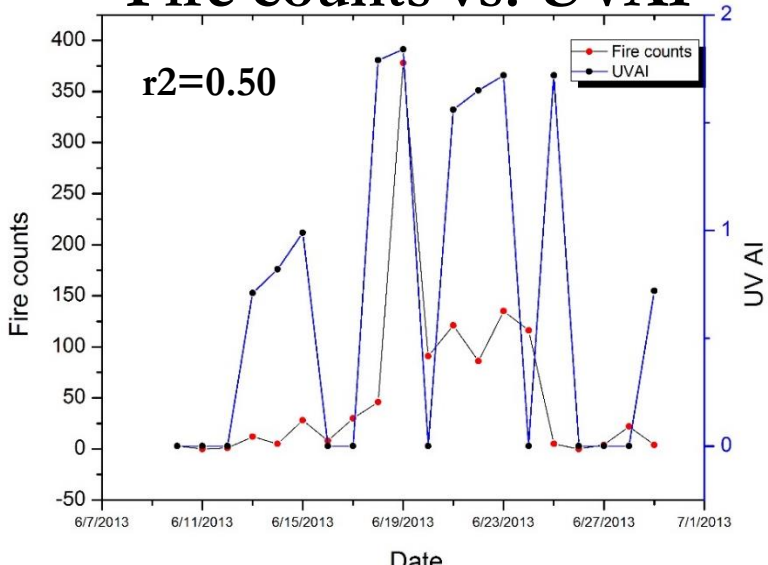
Fire counts vs. SMF



Fire counts vs. AAOD



Fire counts vs. UVAI



Summary

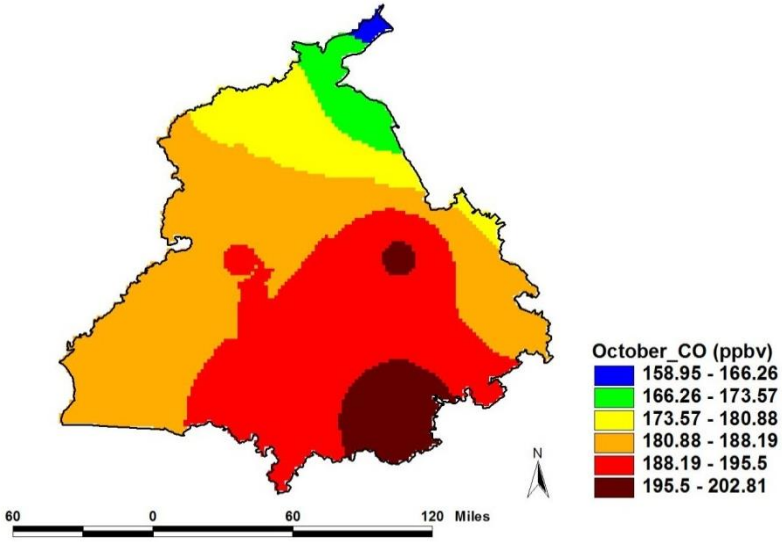
Specific to Biomass burning studies:

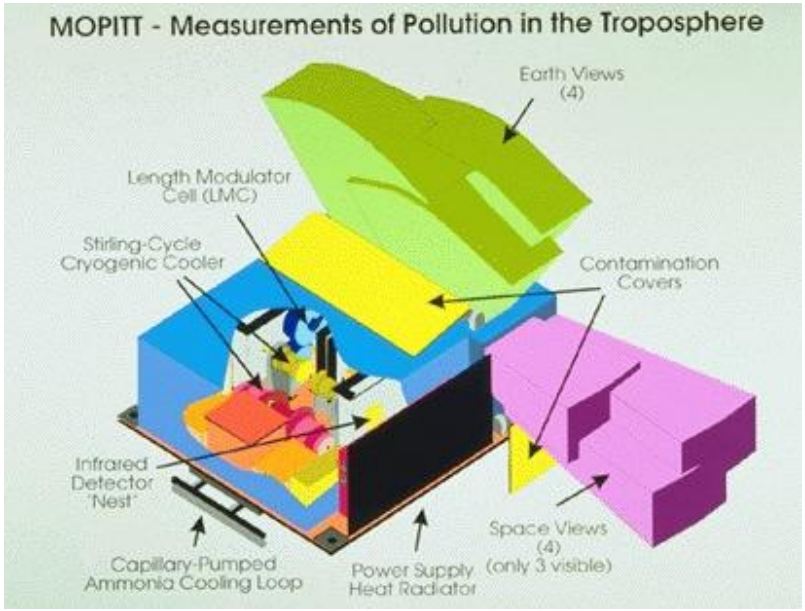
- **Strong correlations with AOD, MOPITT CO, UVAI, AAOD with Active Fire Products at spatial and temporal scales.**
- **More work needs to be done in case of NO2, Small mode fraction, CO2.**
- **Relationship between Fire radiative power products (indicator of fire intensity) and atmospheric products needs more exploration.**

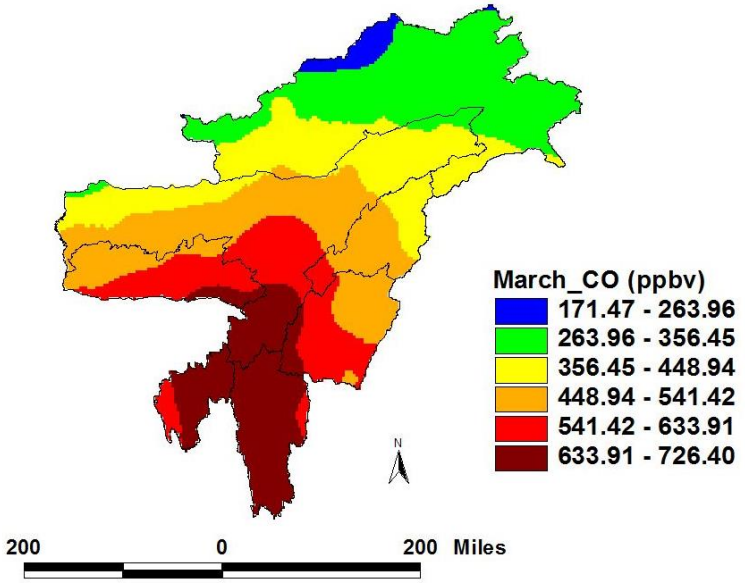
MOPITT – Carbon Monoxide

MOPITT Carbon Monoxide

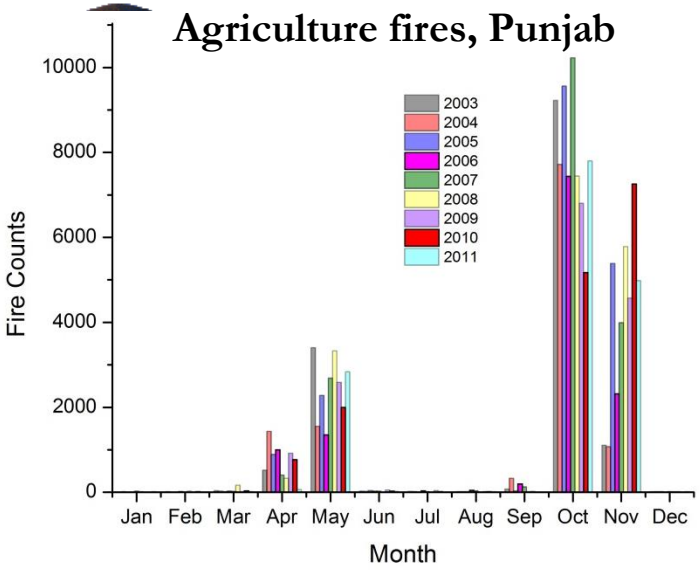
- Mounted on EOS Terra with a daily equatorial pass (10:30 a.m.)
- Measures global columnar CO and CO volume mixing ratio profiles with near-IR (2.3um) and Thermal-IR (4.7um) bands



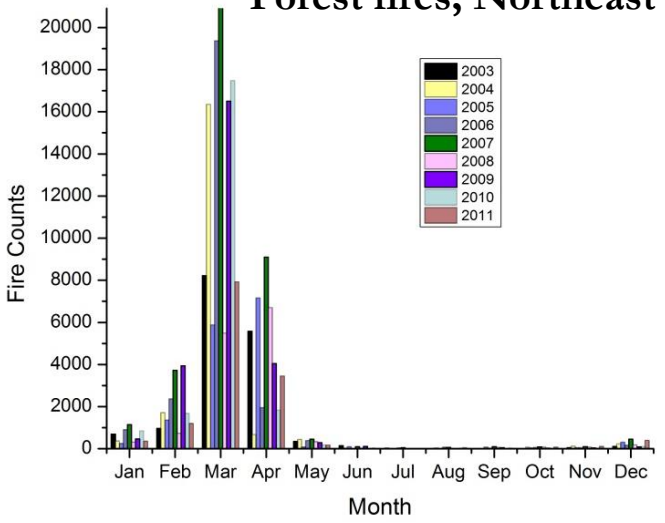




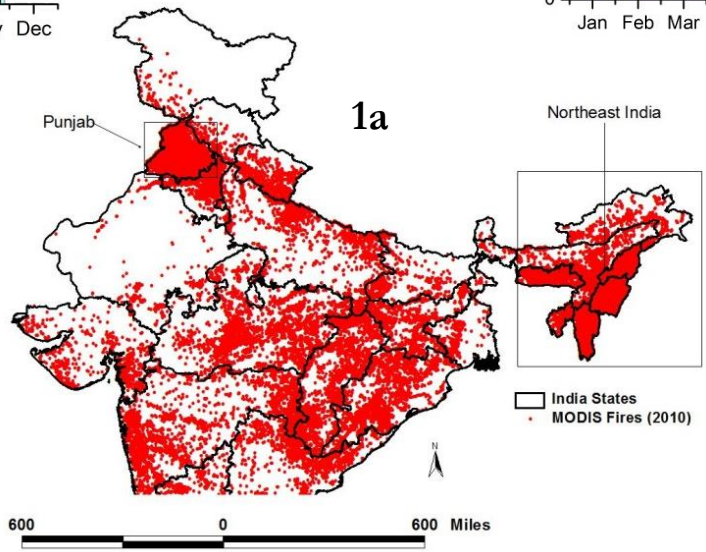
Agriculture fires, Punjab



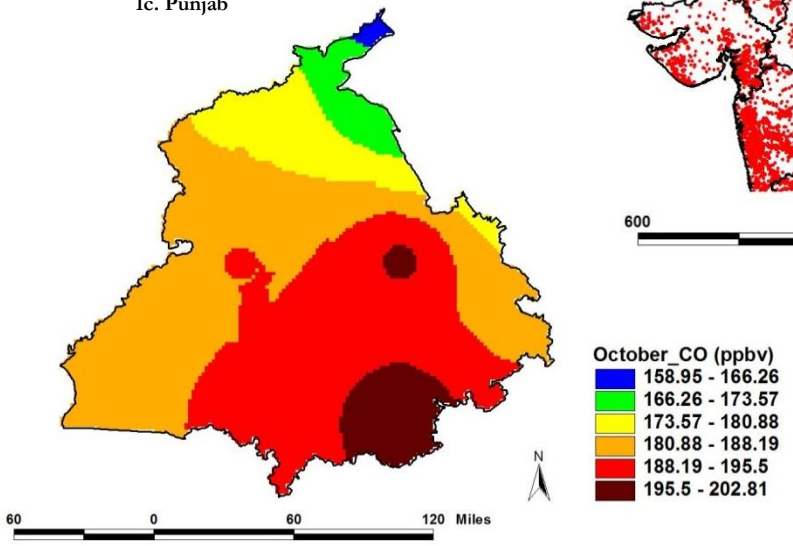
Forest fires, Northeast



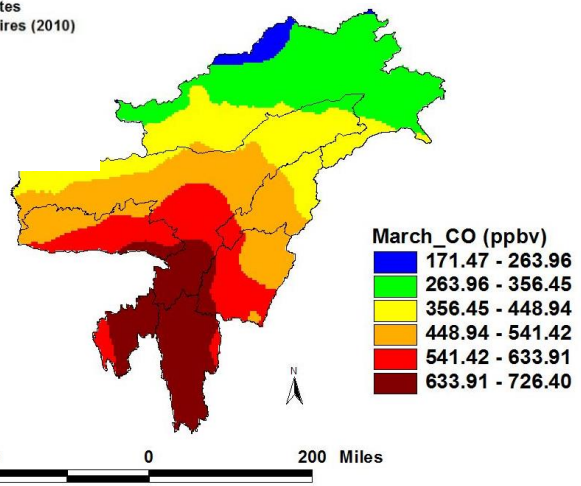
1a



1c. Punjab

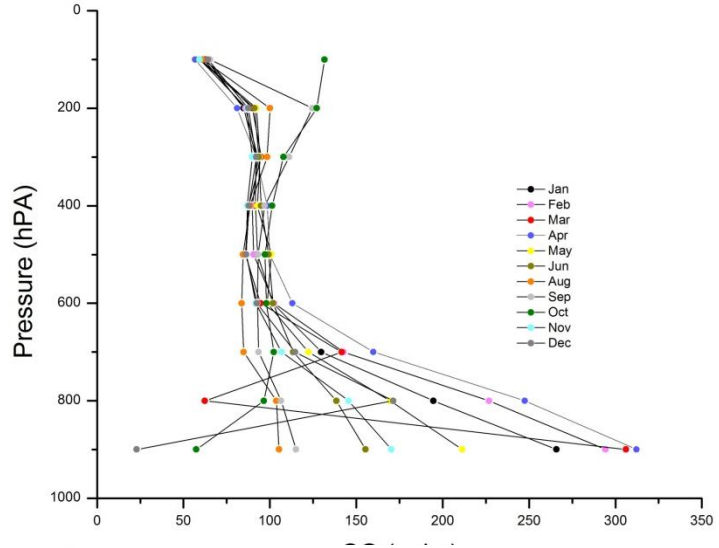


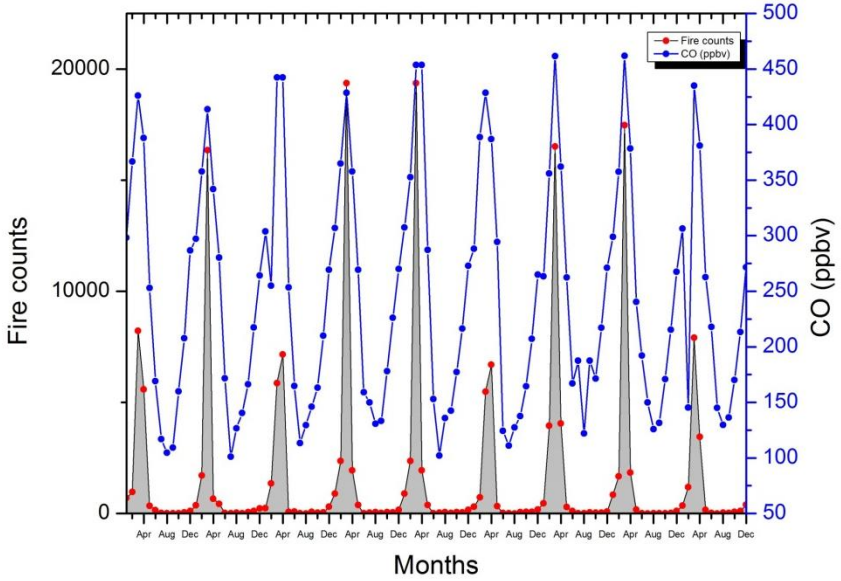
1e. Northeast

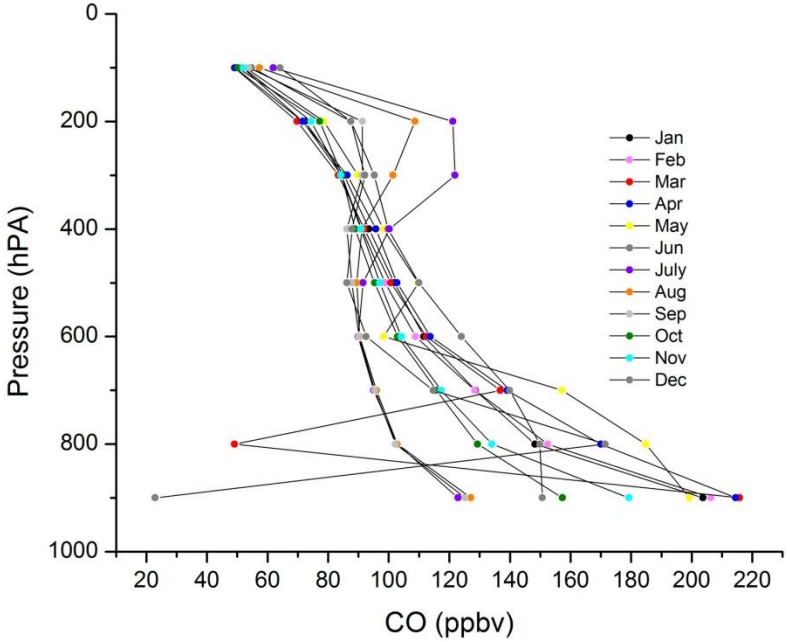


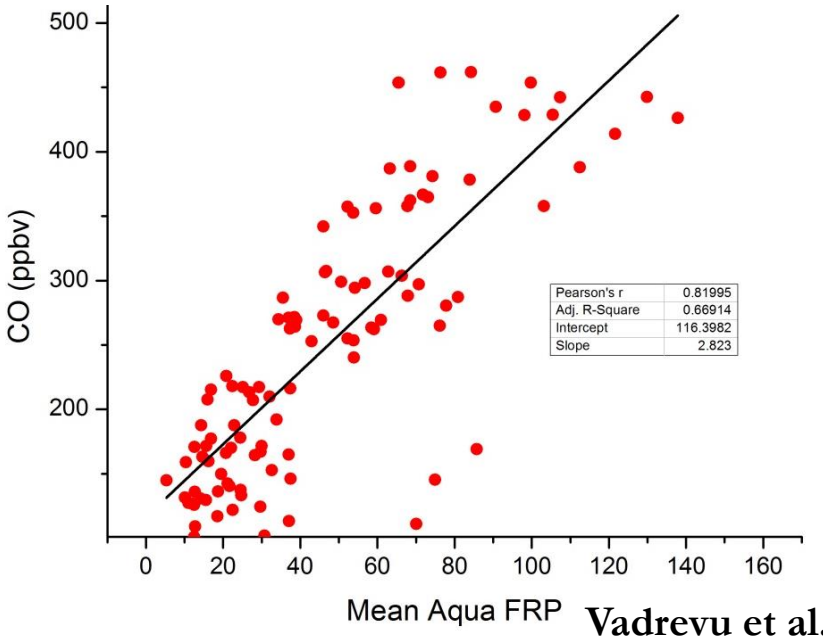
Vadrevu et al., 2013. AE

MOPITT CO Variations within Agriculture and Forests



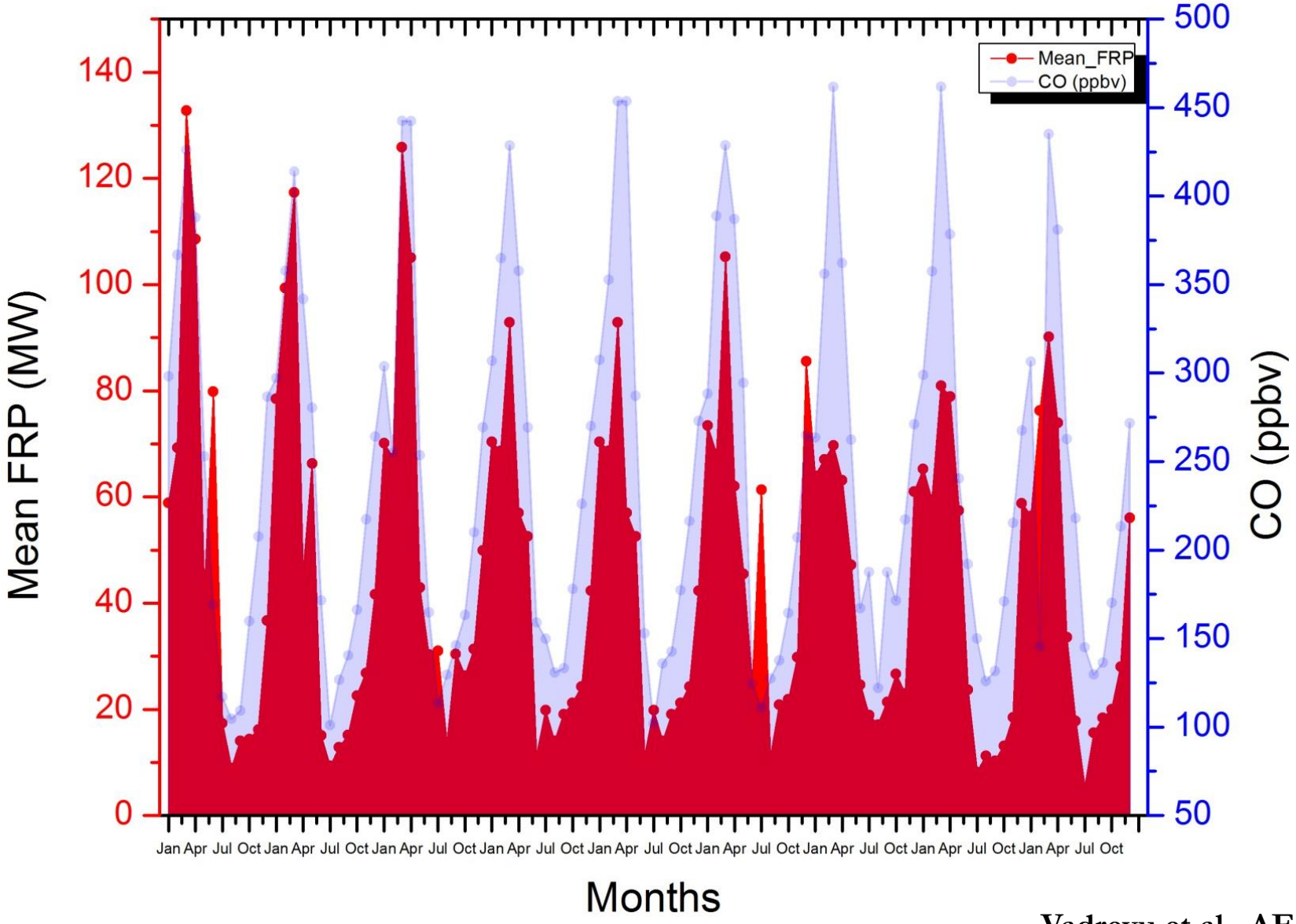






Vadrevu et al., AE. 2013.

Fire Radiative Power (FRP) versus CO Variations – Forest Fires



Vadrevu et al., AE. 2013.

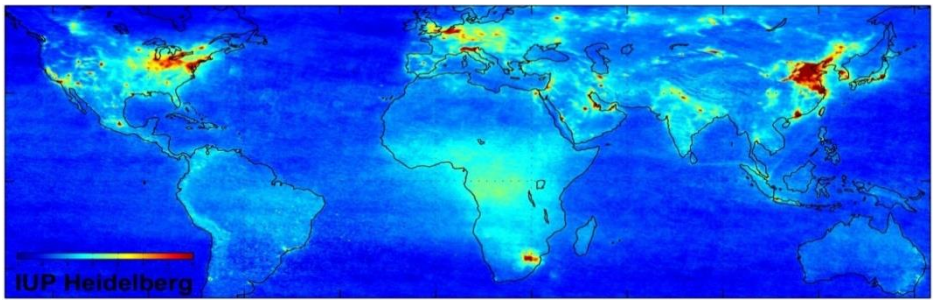
OMI and SCIAMACHY NO2

Ozone Monitoring Instrument

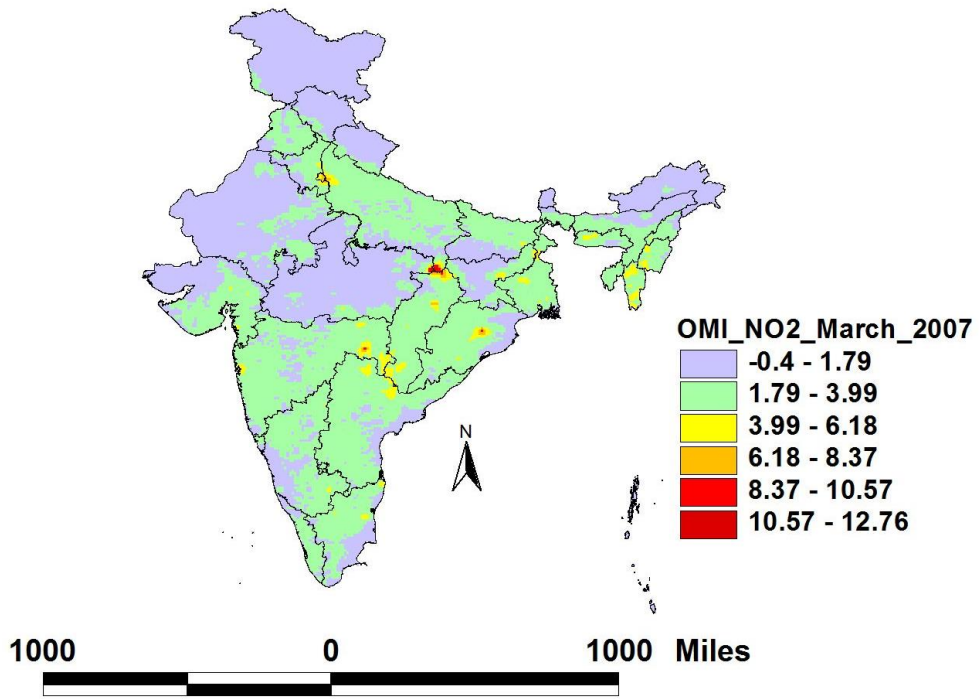
- Mounted on the EOS Aura Platform
- Observes back-scattered radiation with a Hyperspectral (UV-Visible), nadir-viewing, with daily global coverage.
- Measures total column amount of O_3, NO_2, SO_2 and aerosols

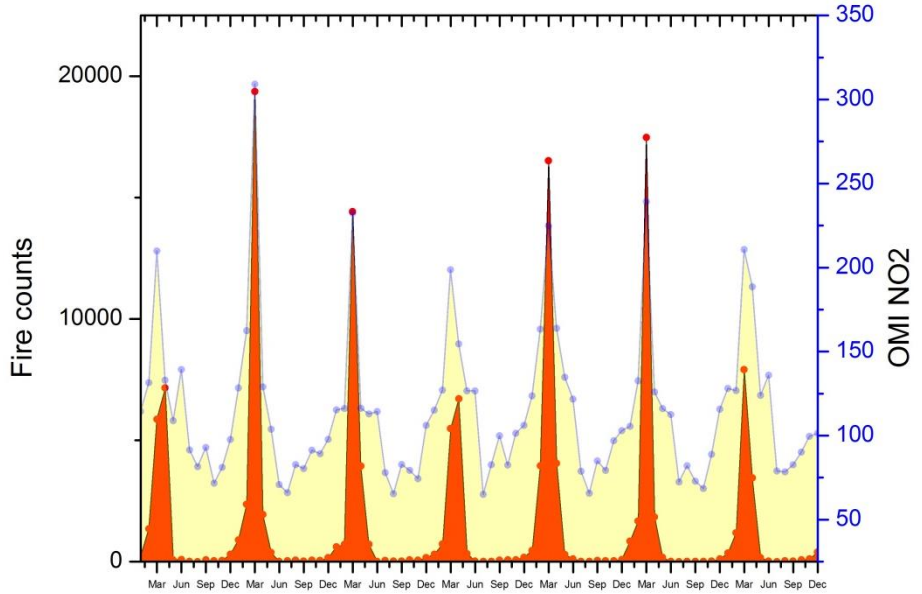
SCIAMACHY Instrument

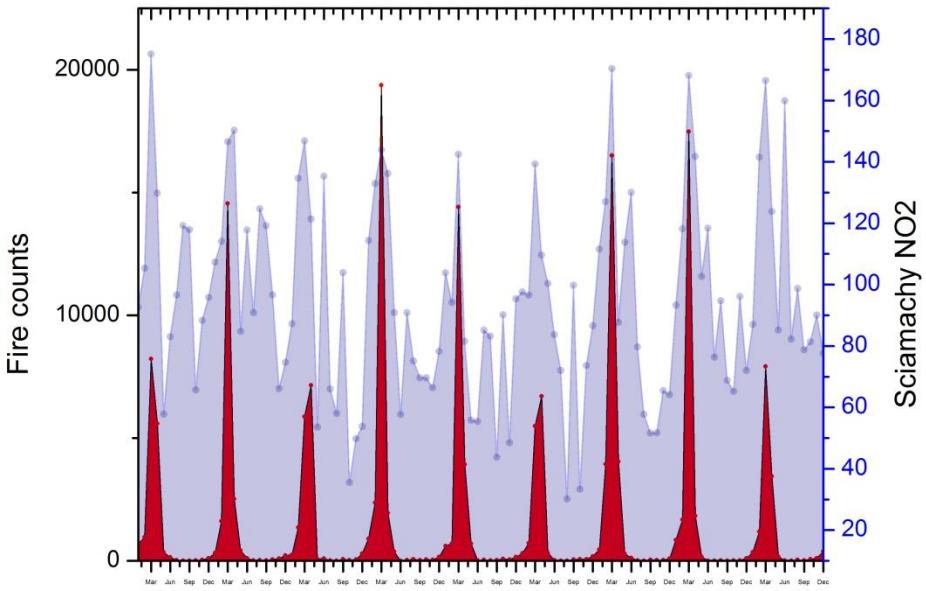
- Onboard ENVISAT, operational from 2002- April 2012
- 0.24 – 2.38um spectral range, Polar Orbit, 35 day repeat cycle, 10:00 a.m. mean local solar time descending node.
- Measures trace gases, aerosols, and clouds through backscattered, reflected, and transmitted solar radiation



Fires and OMI versus SCIAMACHY NO2







OMI NO2 better correlates with Active Fires than SCIAMACHY