Satellite Remote Sensing of Biomass Burning Pollution in Asia

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Questions Addressed

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?

-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?
South South East Asia
(Evergreen forest fires-
MODIS Aqua –April 8th, 2013)

Punjab, India (Agriculture fires-
MODIS Aqua October 31st, 2012)

Nepal Himalayamas (Pine Forest
Burning, Aqua, April 24th, 2012)
Fire Frequencies (2003-2011) – 10-minute (18km) grid

Fire Frequency Maps (2003-2011) with the highest fire frequency during March.
<table>
<thead>
<tr>
<th>Country</th>
<th>Annual Fire counts</th>
<th>% contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afghanistan</td>
<td>248</td>
<td>0.065</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>3113</td>
<td>0.814</td>
</tr>
<tr>
<td>Bhutan</td>
<td>209</td>
<td>0.055</td>
</tr>
<tr>
<td>Brunei</td>
<td>35</td>
<td>0.009</td>
</tr>
<tr>
<td>Cambodia</td>
<td>25360</td>
<td>6.631</td>
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<tr>
<td>China</td>
<td>56668</td>
<td>14.817</td>
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<tr>
<td>East Timor</td>
<td>1128</td>
<td>0.295</td>
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<tr>
<td>Hong Kong</td>
<td>69</td>
<td>0.018</td>
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<tr>
<td>India</td>
<td>63696</td>
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<td>Indonesia</td>
<td>60224</td>
<td>15.747</td>
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<tr>
<td>Japan</td>
<td>1771</td>
<td>0.463</td>
</tr>
<tr>
<td>Laos</td>
<td>32601</td>
<td>8.524</td>
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<td>Malaysia</td>
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<td>Myanmar</td>
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<td>1.764</td>
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<td>Singapore</td>
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<td>South Korea</td>
<td>578</td>
<td>0.151</td>
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<td>Sri Lanka</td>
<td>1277</td>
<td>0.334</td>
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<td>Taiwan</td>
<td>307</td>
<td>0.080</td>
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<td>Thailand</td>
<td>31643</td>
<td>8.274</td>
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<tr>
<td>Vietnam</td>
<td>15051</td>
<td>3.935</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>382455</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

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

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.
Intense Aerosol Optical Depth during Summer - IGP
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
Smoke Plume Heights of Agriculture and Forest Fires from CALIOP
• 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

CALIPSO aerosol types

CALIPSO Backscatter values

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

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

<table>
<thead>
<tr>
<th>Punjab</th>
<th>Date</th>
<th>Lat</th>
<th>Long</th>
<th>Altitude</th>
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<tbody>
<tr>
<td>1</td>
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<td>76.88</td>
<td>29.35</td>
<td>1.8</td>
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<tr>
<td>2</td>
<td>11-Oct-10</td>
<td>76.09</td>
<td>32.29</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>18-Oct-10</td>
<td>74.0</td>
<td>30</td>
<td>2.8</td>
</tr>
<tr>
<td>4</td>
<td>20-Oct-10</td>
<td>77.0</td>
<td>30</td>
<td>2</td>
</tr>
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2.28 km

Himalayan Forest Fires

<table>
<thead>
<tr>
<th>Date</th>
<th>Lat</th>
<th>Long</th>
<th>Smoke altitude (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/2/2008</td>
<td>28</td>
<td>84.02</td>
<td>4.3</td>
</tr>
<tr>
<td>4/5/2008</td>
<td>32.5</td>
<td>78</td>
<td>9.3</td>
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<td>4/7/2008</td>
<td>29.59</td>
<td>80.01</td>
<td>2.5</td>
</tr>
<tr>
<td>4/9/2008</td>
<td>28.78</td>
<td>82.88</td>
<td>3.7</td>
</tr>
<tr>
<td>4/11/2008</td>
<td>28.4</td>
<td>86.2</td>
<td>7.2</td>
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<tr>
<td>4/12/2008</td>
<td>31.62</td>
<td>76.32</td>
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<tr>
<td>4/18/2008</td>
<td>28.4</td>
<td>84</td>
<td>4.2</td>
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<tr>
<td>4/21/2008</td>
<td>31</td>
<td>77</td>
<td>4.2</td>
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<td>4/23/2008</td>
<td>29.47</td>
<td>79.97</td>
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<tr>
<td>4/30/2008</td>
<td>30</td>
<td>78</td>
<td>5</td>
</tr>
</tbody>
</table>

Mean smoke altitude

5.35 km

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

Vadrevu et al., AE, 2012.
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
MOPITT CO Variations within Agriculture and Forests

Vadrevu et al., AE. 2013.
Fire Radiative Power (FRP) versus CO Variations – Forest Fires
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\textsubscript{3}, NO\textsubscript{2}, SO\textsubscript{2} and aerosols

**SCIAMACHY Instrument**

- Onboard ENVISAT, operational from 2002- April 2012
- 0.24 – 2.38\textmu m 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
OMI NO2 better correlates with Active Fires than SCIAMACHY NO2.
GOSAT CO2
MODIS fires and GOSAT CO2 Data (2010-2013)

GOSAT TANSO-CAI-SWIR-L2. v2.10, 2.11
GOSAT CO2 (2010-2013) versus MODIS Active Fires - Asia

$R^2 = 0.39$
GOSAT CO2 (2010-2013) versus MODIS FRP - Asia

\[ R^2 = 0.14 \]
Fire counts/FRP vs GOSAT CO2 Data (2010-2013)
Agricultural Fires, Punjab, Northwest India
MODIS fires within 20-km radius of GOSAT CO2 Data – March

Forest Fires, Northeast India and Myanmar
CO2 highest in broadleaf forest fires (> 397.88ppmv) compared to Agriculture (<394.74ppmv)
GOSAT CO2 Variations within Fire affected vegetation
(20-km Radius of GOSAT and MODIS Fire co-locations)

March-April, 2013
CO2 (PPM)

Evergreen forests: 397.88

Croplands: 394.74

393 394 395 396 397 398 399
- Aerosol Optical Depth;
- UV Aerosol Index;
- Aerosol Small Mode Fraction;
- Aerosol Absorbing Optical Depth
Indonesia Biomass Burning season – August to September.

The fire season in this region coincides with the dry weather season and the southwest monsoon.

Earlier researchers reported several biomass burning-related haze episodes from the region during August to September 1982.

Another major episode occurred during 2013, June that impacted more than 10-countries in SEA.
Indonesia Biomass Burning – June, 2013

**Fig. 2a**

**Indonesia**

- Fire counts vs Year

**Fig. 2b**

- Fire Count vs Months
- Months: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec

**Fig. 2c**

**Pelalawan**

- Fire counts vs Years

**Fig. 2d**

- Fire counts vs Dates
NDVI Change
AAOD and UVAI

AAOD

UVAI

AAOD

UVAI
Aerosol Optical Depth and Small (Fine) Mode Fraction

AOD

SMAF

AOD

SMAF
Correlations

Fire counts vs. AOD

Fire counts vs. SMF

Fire counts vs. AAOD

Fire counts vs. UVAI
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.