Sentinel Convoy Mission

Fire Sensing: Current Status & Future Needs

Martin Wooster (Kings College London, UK)

Slide contributions from many others...
Presentation Structure

- Why knowledge of biomass burning emissions is important to:
  - Carbon cycle studies.
  - Atmospheric composition monitoring and modelling.

- EO data used to quantify BB emissions – and its inconsistencies.
  - Burned Area, Fire Radiative Power [FRP] and Fire Radiative Energy [FRE].

- Use of FRP and FRE data in GMES Atmospheric Service.

- Current FRP datasets and their advantages and limitations.

- Future European Missions (MTG, METOP 2nd Gen, Sentinel-3).

- Potential Sentinel Convoy Capability
- Fires burn across 3-4.5 million km² of Earth annually, affecting on average 3 - 4% of the global vegetated land area (Giglio et al., 2009).
- GBB is 2nd largest source of atmospheric trace gases and largest for fine C-particles to troposphere (Bowman et al., 2009; Akagi et al., 2011).
- BB shows very large variability's on all spatio-temporal scales \(\Rightarrow\) satellite remote sensing is key (van der Werf et al., 2010).
Understanding of carbon cycle and the atmospheric CO$_2$ record requires information on fire emissions (Simmonds et al., 2005).

Dr. Pieter Tans, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/) and Dr. Ralph Keeling, Scripps Institution of Oceanography (scrippsc2.ucsd.edu/).

Jones and Cox (2005) Geophysical Research Letters
Biomass Burning [BB] & Carbon Cycle

- Understanding of carbon cycle and the atmospheric CO₂ record requires information on fire emissions (Simmonds et al., 2005).

Atmospheric Trace Gas Concentration Growth Rates

Simmonds et al. (2005) Atmospheric Environment
Balzter et al. (2005) Geophysical Research Letters

2003 is largest single fire year

Page et al. (2002) Nature

Siberian Burned Area

Fig. 1. Normalised Growth Rates of CO₂, CO, CH₄, H₂, O₃, and CH₃Cl (1995–2003).

No Data

Source: Scorned earth: Impact of 2021 Siberian forest fires on Earth's climate.
Atmospheric monitoring requires BRT BB emissions (Reid et al., 2009).

Active Fire “Hotspot” Detections

Biomass Burning Product Inconsistency

- Large biases, uncertainties & differences between EO products \(\Rightarrow\) great variability in emissions estimates (Al-Saadi et al., 2008).

*Burned Area Product comparison*

*Tansey et al. (2007) GRL*

*Roy et al. (2008) Remote Sensing Environment*
Biomass Burning Emission Estimation

Calculate $E_x$ [emission of species $x$ (kg)]

$E_x = BA \times FL \times CC \times EF_x$

$BA = $ burnt area [m$^2$]

$FL = $ fuel load [kg(biomass) / m$^2$]

$CC = $ combustion completeness [kg(burnt fuel) / kg (available fuel)]

$EF_x = $ emission factor for species $x$ [kg(species $x$) / kg(biomass)]

van der Werf et al. (2010)

Atmospheric Chemistry and Physics

“key uncertainties” (Reid et al. 2005)
Biomass Burning Emission Estimation

\[ E_x = \text{emission of species } x \ [\text{kg}] \]

\[ E_x = BA \times FL \times CC \times EF_x \]

burnt biomass

\[ E_i = FRE \times CF \times EF_x \]

Total “Fire-Emitted”

Thermal Energy

[ EO Product & GCOS ECV]

\[ FRE = \text{Fire Radiative Energy [MJ]} \ldots \text{temporal integral of Fire Radiative Power (FRP)} \]

\[ CF = \text{combustion factor } [\text{kg(biomass)} / \text{MJ (FRE)}] \]

\[ EF_x = \text{emission factor for species } x \ [\text{kg(species i)} / \text{kg(biomass)}] \]

Kaiser et al. (2011)

Biogeochemistry Discussions
Fire Detection & FRP Assessment

- Fires 100x more emissive than the ambient background in TIR.
- Fires 1000x more emissive than the ambient background in MIR.
- Can detect fires @ $10^{-3}$ to $10^{-4}$ of pixel area.
- Detect and estimate FRP using data from only a few spectral bands.
Fire Detection & FRP Assessment

MIR Rapid Scan (5 mins)

Meteosat SEVIRI

$B_\lambda(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$
FRP and Smoke Plume Modelling

Geostationary FRP $\Rightarrow$ Fuel Consumption Rate
$\Rightarrow$ Emissions Production Rate $\Rightarrow$ Atmospheric Model

Modelled Plume AOD

23 August 2007 01:00

Modelling using prototype GMES Atmospheric Service, EU MACC Project - Johannes Kaiser (ECMWF)
Global Fire Assimilation System (GFAS) GMES Atmospheric Service

Global FRP, BB Emissions and Atmospheric Composition

[NRT Operational and Reanalysis]
GMES Atmospheric Service (EU MACC)

Operational deployment of FRP product via EUMETSAT LSA SAF: [http://landsaf.meteo.pt/](http://landsaf.meteo.pt/)

Combined with MODIS FRP - then used to model fire chemical emissions in prototype GMES Atmospheric Core Service @ ECMWF [http://www.gmes-atmosphere.eu/](http://www.gmes-atmosphere.eu/)

**Observed Global FRP Areal Density**

**Modelled CO Biomass Burning Tracer**
Global Fire Assimilation System (GFAS v1)

DAILY MODIS FRP OBSERVATIONS

TERRA

Fuel Consumption Rate \((g[C] m^{-2} d^{-1})\)

Atmospheric Composition [here AOD]

Part of the EU FP7 Monitoring Atmospheric Chemistry and Climate (MACC) Project: Products @ www.gmes-atmosphere.eu
Satellite EO Fire Radiative Power & Fire Radiative Energy Datasets

[NRT Operational & Science Products]
Operational Meteosat SEVIRI FRP Product

SEVIRI FRP Pixel Product (3 km spatial/ 15 min temporal resolution) – available in 30 mins
Available via EUMETSAT Land Surface Analysis Satellite Application Facility (http://landsaf.meteo.pt/)

Meteosat SEVIRI

MTG Flexible Combined Imager has improved temporal & spatial resolution (0.5 - 2 km)
- Better spectral coverage (more channels)
- Improved spectral and radiometric accuracy
- Specific design for ‘active fire’ observations (3.7 µm and 10.8 µm channels)
Operational Aqua/Terra MODIS FRP Product

- Tens thousands of users worldwide: NRT production and upcoming 6th archive reprocessing.
- 4 observations per day in many areas....but MODIS will not last and VIIRS less capable.

Vermote et al. (2009)

Freeborn et al. (2010)

http://modis-fire.umd.edu/index.html

http://feer.gsfc.nasa.gov/tools/
MODIS vs. SEVIRI FRP Datasets

- Temporal disadvantage of MODIS-type data
- Detection disadvantage of Geostationary-type data

Freeborn et al. (2009)
Australian Bush fires: 5 Jan 2002
Hot clusters projected on NIR band 

Wooster et al. (2003) 
Remote Sensing Environment
Varying relationship between FRE and GFEDv3.1 fuel consumption.
- Caused in part by undetected low FRP fires.
- Caused in part by poor diurnal sampling.

Derivation of conversion factors (CF) from linearly regressing monthly GFED3.1 DM with GFAS1.0 FRE

Kaiser et al. (2011) www.biogeosciences-discuss.net
Future “Fire Capable” European EO Missions

Meteosat 3rd Generation
METOP 2nd Generation
Sentinel-3 SLSTR
### Sentinel-3 SLSTR

<table>
<thead>
<tr>
<th>Band #</th>
<th>Centre $\lambda_{centre}$ µm</th>
<th>Spectral Width $\Delta\lambda$ µm</th>
<th>Lmin/Tmin</th>
<th>Lref/Tref</th>
<th>Lmax/Tmax</th>
<th>SNR/NEDT</th>
<th>Radiometric Accuracy</th>
<th>Ref SSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.555</td>
<td>0.02</td>
<td>2.92</td>
<td>2.92</td>
<td>585</td>
<td>20</td>
<td>2%</td>
<td>0.5km</td>
</tr>
<tr>
<td>S2</td>
<td>0.659</td>
<td>0.02</td>
<td>2.43</td>
<td>2.43</td>
<td>475</td>
<td>20</td>
<td>2%</td>
<td>0.5km</td>
</tr>
<tr>
<td>S3</td>
<td>0.865</td>
<td>0.02</td>
<td>1.53</td>
<td>1.53</td>
<td>295</td>
<td>20</td>
<td>2%</td>
<td>0.5km</td>
</tr>
<tr>
<td>S4</td>
<td>1.375</td>
<td>0.15</td>
<td>0.58</td>
<td>0.58</td>
<td>113.1</td>
<td>20</td>
<td>2%</td>
<td>0.5km</td>
</tr>
<tr>
<td>S5</td>
<td>1.61</td>
<td>0.06</td>
<td>0.39</td>
<td>0.39</td>
<td>74.0</td>
<td>20</td>
<td>2%</td>
<td>0.5km</td>
</tr>
<tr>
<td>S6</td>
<td>2.25</td>
<td>0.05</td>
<td>0.13</td>
<td>0.13</td>
<td>24.3</td>
<td>20</td>
<td>2%</td>
<td>0.5km</td>
</tr>
<tr>
<td>S7</td>
<td>3.74</td>
<td>0.38</td>
<td>200K</td>
<td>270K</td>
<td>323K</td>
<td>0.08K</td>
<td>0.2K (0.1K goal)</td>
<td>1km</td>
</tr>
<tr>
<td>S8</td>
<td>10.85</td>
<td>0.9</td>
<td>200K</td>
<td>270K</td>
<td>321K</td>
<td>0.05K</td>
<td>0.2K (0.1K goal)</td>
<td>1km</td>
</tr>
<tr>
<td>S9</td>
<td>12.0</td>
<td>1.0</td>
<td>200K</td>
<td>270K</td>
<td>318K</td>
<td>0.05K</td>
<td>0.2K (0.1K goal)</td>
<td>1km</td>
</tr>
<tr>
<td>F1</td>
<td>3.74</td>
<td>0.38</td>
<td>350K</td>
<td>500K (634K Goal)</td>
<td>1K</td>
<td>3K</td>
<td></td>
<td>1km</td>
</tr>
<tr>
<td>F2</td>
<td>10.85</td>
<td>0.9</td>
<td>330K</td>
<td>400K</td>
<td>0.5K</td>
<td>3K</td>
<td></td>
<td>1km</td>
</tr>
</tbody>
</table>

~ 10 am & 10 pm local time equator crossing

[ also fire channels on MTG (& METOP-2?) ]
Fire FRP Frequency Distribution

- Current “Fire Capable” sensors have limits
- under estimated carbon and trace gas emissions
- Sentinel-3 far from ideal diurnal sampling
Potential Secondary Applications

- FRP and active fire area $\Rightarrow$ plume rise (and thus transport)

- “Fire Capable” instrument is inherently capable of providing:
  - Heat fluxes at active volcanoes $\Rightarrow$ volcano monitoring.
  - Quantification of natural gas flaring $\Rightarrow$ CO$_2$ emissions.
Potential Convoy Mission Requirements

- At least MIR, TIR & NIR spectral channels (avoiding atm. abs band).
- Higher spatial resolution than SLSTR to detect low FRP fires.
  - Desired spatial resolution 250 m or perhaps better.
  - Channel saturation temperatures linked to spatial resolution (> 500 K)
- Would provide sampling of unknown low FRP fire component of BB regimes → FRP correction factors for emissions estimation.
  - Fly in formation with Sentinel-3 SLSTR to provide correction factors.
- Flying at alternative overpass time (~ 1:30 pm local time) would provide much better sampling of fire diurnal cycle.
- Ideal maybe “Dual Imager” mission [?] – low resolution, wide swath and high resolution steerable “zoom” ?