[Some] Updates on Research into Fire Radiative Power & Energy

Presented by Martin Wooster
(Kings College London, UK)

Slide contributions from many others...

Environmental Monitoring and Modelling Research Group,
Dept. of Geography, King’s College London, UK.
MODIS FRP to FRE

[problem is MODIS only provides a few observations per day]
Vermote (2009): MODIS FRP to FRE

Estimated Total FRE: 2003

Figure 6. Estimated 2003 FRE (MJ/m²) from Aqua MODIS. Integrated energy was calculated from FRP (MW) values derived from a Gaussian function using modeled parameters.

MODIS FRE – 8 day 0.5° resolution [but apparently underestimated compared to geostationary]
Freeborn et al. (2011) Addressing the spatiotemporal sampling design of MODIS to provide estimates of the fire radiative energy emitted from Africa, RSE.
MODIS FRP to FRE (compared to Vermote [2009])

The graph shows a linear relationship between predicted FRE_{MODIS} using the original Vermote method (MJ) and predicted FRE_{MODIS} using SEVIRI. The equation of the line is $y = 0.99x$ with $R^2 = 0.99$. This indicates a strong correlation with a good fit of the data points to the line.
1. Retrieve FRP in centre of MODIS swath
2. Retrieve area in centre of MODIS swath
3. Calculate the FRP per unit area in centre of MODIS swath:

\[
\phi_{\pm 40^\circ} = \frac{FRP_{\pm 40^\circ}}{A_{\pm 40^\circ}}
\]

4. Multiply FRP per unit area in centre of swath by the total area of the swath:

\[
FRP_{Full} = FRP_{\pm 40^\circ} \times \frac{A_{Full}}{A_{\pm 40^\circ}}
\]

\[
A_{Full} = 1.897 \times A_{\pm 40^\circ}
\]

\[
FRP_{Full} = 1.897 \times FRP_{\pm 40^\circ}
\]

Freeborn et al (2011)

Recommend that the sum of FRP measured within \(\pm 40^\circ\) of nadir is made available in MODIS Collection 6 CMG fire product (to aid bow tie adjustment).
Geostationary FRP
Zhang et al. (2012) GEOSTATIONARY FRP

- Uses all current FRP capable geostationary sats except FY (China)
- WFABBA based fire detection algorithm.
- FRP calculated using MIR radiance method (linear fn).
- Applied to network of geostationary (GOES E/ W, Meteosat, MTSAT)
- Many fire pixel records have non-detections or saturation – and gaps due to cloud cover. Reconstruction of full diurnal cycle using defaults.

Zhang et al. (2012) GEOSTATIONARY FRP

Fuel Mass Combusted (0.25 deg grid cells)

Comparison to GFEDv3.1 (Africa)
Effect of Errors of Omission

On “per fire” basis Geosat FRP close to MODIS FRP

MODIS (1 x 1 km)  
GOES (2.4 x 4 km)

Red = fire pixel detects  
MODIS California Fires 20:55 UTC  
GOES California Fires 20:45 UTC

On “per region” basis Geosat FRP underestimates polar-orbiting (MODIS) FRP

Non-detection of low FRP Fires

MODIS Geostationary

10 MW  
30 MW
GEO to LEO
Merging
Merging GEO and LEO Datasets

Temporal disadvantage of MODIS-type data

Detection disadvantage of Geostationary-type data

Varying SEVIRI to MODIS FRP Ratio

Freeborn et al. (2009)
Temporal disadvantage of “Polar Orbiting” data [MODIS]

Spatial disadvantage of “Geostationary” data [SEVIRI]

Merging GEO and LEO Datasets

MODIS

Daily Mean

FRP density (Wm⁻²)

SEVIRI

Daily Mean

FRP Density (Wm⁻²)

Merged FRP Density (Wm⁻²)

transfer fn.

Merged & Bias-Corrected
FRP merging of GEO & LEO

- Scientifically not yet solved
  - based on GFAS-gridded observations
  - characterisation of bias (GEO FRP, view angle, local time)
  - prediction of bias from previous co-located observations

Also new paper by Heyer et al (2013)
Atmospheric Res. Usig MODIS & MTSAT

Conditional PDF (Jun2010-Jul2012)
Potential to “Merge” with Burned Area Products
Large discrepancies between GFED and “raw” FRE-derived emissions....
Solution: Combine FRE & Burned Area

**Active Fire Detects & FRP Measure**

- Advantages
  - Well observed fires → measure of energy/total fuel consumption

- Disadvantages:
  - Missing fires occurring between views.
  - Missing data due to cloud cover.
  - Missing data due to low FRP” fires below active fire detection limit.

**Burned Area Map**

- Advantages
  - More “complete” coverage (wait for cloud to clear and for overpass)

- Disadvantages:
  - Requires additional “hard to obtain” information on fuel load in order to estimate fuel consumption.
Fuel Consumption (g/m²)

PATHWAY 1
- Integrate the diurnal FRP (MW)
  - FRE (MJ) = ∫ FRP(t) dt
- Calculate the total fuel consumed (kg)
  - FC_T = FRE × CF

PATHWAY 2
- Integrate the diurnal FRP (MW)
  - FRE (MJ) = ∫ FRP(t) dt
- Calculate fuel consumption (FC_A) (g/m²)
- Extrapolate to burned area pixels with no FRP obs.
- Extrapolate fuel consumption to unobserved fires

PATHWAY 3
- FRP observations (MW)
- Missing FRP obs. due to cloud obscuration or low intensity
- Extrapolate fuel consumption to unobserved fires

Burned Area (m²)

Continental daily biomass combustion estimates (Tg)
Fuel Consumption (g /m²)

• FRE = 1.1x10⁸ MJ
• Total Fuel Burned = 39 ktonnes
• Burned area = 40.8 km²
⇒ Fuel Consumption ~ 1.0 kg.m⁻²

500 m MODIS burned area data (white is day of interest)

• Repeat for all “well observed” fires detected by SEVIRI
• Extrapolate using burned area for “poorly observed” fires
Fire Radiative Energy vs. Global Fire Emissions Database (v3)

Feb 2004 – Jan 2005 Fuel Consumption Totals (0.5° cells)
Fire Radiative Energy vs. Global Fire Emissions Database (v3)

Feb 2004 – Jan 2005 Fuel Consumption Totals (Southern and Northern Hemisphere Africa)

Roberts et al. (2011) Integration of geostationary FRP and polar-orbiter burned area datasets for enhanced biomass burning inventory, Remote Sensing Environ., 115.
Direct Relationship to Trace Gas Emission
Mebust et al. (2011) FRP and NO$_2$

- Derive emissions factors (grammes of NO$_2$ emitted per kg of fuel burned) from combination of MODIS FRP and GOME NO$_2$ columns.


EFs vary in the expected way, but are lower than previous measures. Underestimated contribution from smouldering previously?
Field Based FRP Studies
Remote Determination of Emissions Factors (EF$_x$)

Field Portable Open Path FTIR Spectrometry

Gas Concentration Time Series

- Wooster et al. (2011) Field determination of biomass burning emission ratios and factors via open-path FTIR spectroscopy, Atmos. Chem. Physics, 11, 11591-11615.
Remote Determination of Emissions Factors ($\text{EF}_x$)

- Used to provide environment & time specific $\text{EF}_x$ parameters
- FRE recorded simultaneously from aircraft used to weight the components to calculate weighted mean EFs
Controls on MODIS FRP in Alaska

- Used MODIS FRP observations of Alaskan forests to determine the controls of FRP (forest type, “large fire year”, fire front or residual burning etc)

- Periods of high fire activity in the Alaskan boreal forest are characterized by a higher proportion of residual burning...which may ultimately impact tree mortality and species makeup.

Barrett and Kasischke (2012) Controls on variations in MODIS FRP in Alaskan boreal forests: Implications for fire severity conditions
New FRP Products

- NPP VIIRS
- SENTINEL3 SLSTR
Sentinel-3 Satellite Overview

- **Payload**
  - Colour Instrument: OLCI
  - **Surface Temperature Instrument**: SLSTR
  - Radar Altimeter: SRAL
  - Micro Wave Radiometer: MWR
  - GPS receiver: GNSS
  - Laser Retro Reflector: LRR
  - Doris instrument

Sentinel-3 SLSTR ~ 2013/14
## SLSTR Spectral Bands

<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>1km</td>
<td></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>1km</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
- New spectral bands at 1.375µm and 2.25µm
- VIS/SWIR Spatial Resolution at Nadir of 0.5km
- Fire channels at 3.74 and 10.85µm
- Radiometric accuracy requirement of 0.2K with goal of 0.1K

Algorithm for active fire detection and FRP assessment should be in ESA ground station