MACC Biomass Burning Emissions and Plumes


Russia, August 2010
Introduction
Bottom-Up Estimation of Fire Emissions

Ei = emission of species i \([\text{kg(species i)}]\)

BA = burnt area \([\text{m}^2]\)

AFL = available fuel load \([\text{kg(biomass) / m}^2]\)

CC = combustion completeness \([\text{kg(burnt fuel) / kg (available fuel)}]\)

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

FRP = fire radiative power \([\text{W}]\)

FRE = fire radiative energy \([\text{J}] = \int \text{FRP(t)} \, dt\)

CF = conversion factor \([\text{kg(biomass) / W(FRE)}]\)
Emissions calculated from Fire Radiative Power observed by SEVIRI on Meteosat.


Run at 25km global resolution, which is typical for regional models.
MACC’s GFAS: The Global Fire Assimilation System
Global Fire Assimilation System (GFASv1.0)

1. FRP observation input:
   - MODIS Aqua/Terra
2. gridding on global 0.5/0.1 deg grid
   - including FRP ≥ 0 corrects partial cloud cover
3. merging in 1-day slots
4. removal of spurious observations, e.g. gas flares
5. quality control
6. observation gap filling with Kalman filter, assuming
   - variance according to representativity error
   - errors spatially uncorrelated
   - fire persistence
7. fire type-dependent conversion to combustion rate
8. emission calculation
   - 40 gaseous & particulate species
Gridding of FRP Observations

FRP / unit area

\[ Q_j = \frac{\langle F \rangle_j}{\langle A \rangle_j} \]

FRP / pixel

\[ = \frac{\sum_{i \in j} F_i \cos^2(\theta_i)}{\sum_{i \in j} A_i \cos^2(\theta_i)} \]

viewing angle

pixel area

accuracy indicator \( \gamma_j = \frac{\sum_{i \in j} A_i \cos^2(\theta_i)}{a_j} \)

grid cell area

- use FRP \( \geq 0 \) observations
  - assume same fire distribution throughout partially cloudy grid cell
  - tolerate double counting near MODIS swath edges
- flatten accuracy indicator across MODIS swath, using viewing angle
- interpretation of accuracy indicator as inverse variance allows subsequent consistent merging using optimal interpolation

(Kaiser et al. 2009, 2012)
Quality Control: Threshold for Daily FRP Fields
World’s Top 100 Grid Cells by FRE: ~1.3% of Total

Top 100 FRP: Source Categories
Contribution to total dry matter burned 2003-2009 equivalent (Sum Top100 FRP grid cells: 172 Tg)

- Volcano: 30%
- Gas Flare: 44%
- Industry: 13%
- Unclear: 5%
- Fires: 8%

MODIS-FRP [W m⁻²]
Frequency [N grids]

World’s Top 100 grid cells by FRE. Range: 0.01 to 1.48 W m⁻²

Masked in GFASv1.0

- Nyiragongo Volcano, Kongo
- Kilauea Volcano, Hawai
- Gas Flaring, Russia, Iraq, Kazakhstan
MODIS FRP Assimilation

accuracy indicator

night-time observations

FRP

daytime observations

24-hour analysis

night-time observational coverage of 20120110

observed night-time FRP [mW/m²] of 20120110

0.0 0.6 1.2 1.8 2.4 3.0 3.6 4.2 4.8 5.4

10 10 10

daytime observational coverage of 20120110

observed daytime FRP [mW/m²] of 20120110

0.0 0.6 1.2 1.8 2.4 3.0 3.6 4.2 4.8 5.4

10 10 10

analysis observational coverage of 20120110

analysis FRP [mW/m²] of 20120110

0.0 0.6 1.2 1.8 2.4 3.0 3.6 4.2 4.8 5.4

10 10 10
NRT production of daily FRP and Emissions

<table>
<thead>
<tr>
<th>GFASv0</th>
<th>GFASv1.0</th>
<th>GFASv1.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>since GEMS MODIS &amp; SEVIRI FRP observations</td>
<td>since 17 May 2011 MODIS FRP assimilation</td>
<td>since 9 November 2011 MODIS FRP assimilation</td>
</tr>
<tr>
<td>~125 km resolution</td>
<td>~50 km resolution</td>
<td>~10 km resolution</td>
</tr>
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</table>

FRP for Sep 2010 – Aug 2011

http://gmes-atmosphere.eu/fire
FRP conversion factor analysis against GFEDv3

Conversion factor depends on dominant fire type!

SA: Savanna fires
SAOM: SA with potential OM burning
AG: Agricultural fires
AGOM: AG with potential OM burning
DF: Tropical fires
PEAT: peat burning
EF: Extratropical fires
EFOM: EF with potential burning

(adapted from Heil et al., ECMWF TM628, 2010)
Land-cover specific conversion is a combined approach.

- consistent with GFED3 inventory (within its accuracy)

- advantages
  - quantitative information
  - low detection threshold
  - real-time availability

![Graph showing carbon combustion distribution](image)

**GFED3: MODIS burnt area-based C emissions**

**GFASv1: MODIS FRP-based C emissions**

Fig. 5. Average distribution of carbon combustion $[g(C) \text{ a}^{-1} \text{ m}^{-2}]$ during 2003–2008 in GFED3.1 (top) and GFASv1.0 (bottom).

(Kaiser et al. 2012)
Monthly C emission up to September 2011
Black Carbon Cross-validation

**GFASv1.0** (with aerosol enhancement) compares well with NASA’s **QFEDv2.2**.

(courtesy A. da Silva)
Applications & Validation
- MACC GFASv0/1.0:
  - global NRT AER
  - delayed-mode GHG, AER
  - reanalysis (2009-10)
  - CO-tracer forecasts
  - MOZART/TM5 offline runs
- GFEDv3.1:
  - GRG production
- GFEDv3.0 redistributed:
  - reanalysis (2003-9)
Validation of Fire Emissions: AOD(OM) + AOD(BC)

assimilation of MODIS AOD
active: “analyses”
passive: “model”
average of 15 Jul – 31 Dec 2010

AOD (OM+BC) low by factor 3.4

similar to other top-down estimates:
- NASA (GFED2.2)
- NRL (Reid et al. 2009)
- LSCE (N. Huneeus et al. 2012)
- FMI (Sofiev et al. 2009)

inconsistent with bottom-up estimates:
- GFED2/3 (van der Werf et al. 2006/10)
- published emission factors (e.g. Andreae & Merlet 2001)
- INPE/CPTEC (Freitas et al. 2005)

recommendations:
correct emissions by factor 3.4
do multi-parameter analysis

[Kaiser et al. 2012]
Russian Fires of Summer 2010

- Assimilation of MODS FRP
  - in GFASv1.0

- Assimilation of MODIS AOD
  - using enhanced GFASv1.0

[16 July 2010] [Kaiser et al. 2012]
AOD Simulations with IFS

- Assimilation adapts total AOD.
- Speciation is determined by emissions.
- Forecasts near sources strongly depend on emissions.

[Huijnen et al. 2012]
CO Simulations with IFS-TM5

Much of the signal in CO column is captured by either emissions or assimilation.

Accurate column forecasts require both.

Surface concentrations are dominated by emissions.

Forcasts suffer from poor fire predictions.

[Huijnen et al. 2012]
IASI-CO based Inversion in ESA ALANIS Smoke Plumes

- confirms GFASv1.0 emission estimates for Russian fires of 2010

**Optimized from GFAS prior**
Derived Products
2003-8 Fire Emissions for MACC Reanalysis

- redistribute GFED3.0 according to reprocessed MODIS FRP to achieve
  - consistency with GFED3.0 (1 month, 0.5 deg resolution)
  - improved resolution of 1 day, 0.1 deg
Daily CO Emissions [Tg] of GFASv1.0(0.5deg) and GFASv1.1(0.1deg) in 2011
Ongoing Developments
Observational FRP Coverage

- average number of observations
  - damped for large VA
- of any area in 0.5 deg grid cell
- during 1 day

[1 Oct 2010]

FRP production in MACC

GOES-West Imager

GOES-East Imager

Meteosat-9 SEVIRI

FRP production by EUMETSAT LSA SAF

Terra MODIS

Aqua MODIS

FRP production by NASA

[Kaiser et al. 2011]
Fires Diurnal Cycle in Americas from GOES-W

[Xu et al. 2010]
GOES-East/-West FRP Product Generation in MACC-II

- real time
- processing to be moved from KCL to IM Lisbon

- input:
  - GOES radiances from UCAR (www.ucar.edu)
  - water vapour from operational forecast of ECMWF

- based on SEVIRI processing algorithm

- validation against MODIS:
  - relatively low false alarm rate
    (compared to SEVIRI FRP)
  - strong correlation: $R^2 = 0.86$
  - biased low

[Xu et al. 2010]
Linear Regression: SEVIRI over MODIS areal FRP in 2010

0.5 deg resolution, 5 deg smoothing

+ gap filling with viewing angle dependence
Corrected SEVIRI FRP over MODIS FRP

- strong regional variations
- strong temporal variations
- static bias correction impossible
- dynamic, “on the fly” approach needed
Ratio of GFED3 to GFASM
Ratio for Savannah Fuel (SA) of Australia

Increasing GFED3/GFASM ratio with increasing fractional tree cover
Indication of attenuation of FRP signal by tree canopy
■ according to FRP, probably smouldering sub-surface fires
■ Conversion and emission factors need to be adapted dynamically.

[Kaiser et al. 2011]
Are NO2 emission estimates too high?

■ [Inness et al. 2012, almost submitted]
Injection Heights: Plume Rise Model

- Convective zone
  - Atmospheric interaction
- Wind Drag
- Pyroconvection
- PBL
- Convective Flux
- Entrainment
- Plume Rise Model
  - Freitas et al. 2007
- Active Fire Area
- Fire Radiative Power
- Combustion Zone
- Vegetation
Conclusion and Perspective on Plume Rise

Conclusions so far:

- Literature shows a need for more robust parameterization
- So far, the plume rise model approach seems the most adequate
- Current Work:
  - comprehensive MISR validation / training data set
  - new assumption in the model
  - Optimization and Validation are still undergoing

Perspective:

- Use of more MISR Observation: other vegetation type and geographical location
- Possible collection of more detailed data (SAMBBA) usable for validation
- Use of high resolution model? [Trentmann 2002]
- Validation at both fire event and regional scale
Plume Rise Model: Result

Single fire:

\[ y = 0.7x + 0.7 \]
\[ r^2 = 0.7 \]

29 fires:

detainment zone and time dependence?
Summary
### FIRE Product Overview

- **GFASv1.0** products also publicly available in NetCDF format from:
  - [http://geiacenter.org](http://geiacenter.org)

<table>
<thead>
<tr>
<th>Products Archived in MARS</th>
<th>EXPV</th>
<th>Time Range</th>
<th>Temporal Resolution</th>
<th>Spatial Resolution</th>
<th>Type</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>f711</td>
<td>10/2008- present</td>
<td>1 day / 1 hour</td>
<td>T159</td>
<td>FRP-NRT</td>
<td>a (since 17Jun10 also NOx, NMHC)</td>
<td></td>
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<tr>
<td>f712</td>
<td>10/2008- present</td>
<td>1 day / 1 hour</td>
<td>T159, archived as 0.1 deg</td>
<td>FRP-NRT (GFASv0)</td>
<td>a (since 17Jun10 also NOx, NMHC) FRP (W/m2)</td>
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<tr>
<td>f922</td>
<td>1/2003-1/2009</td>
<td>1 day / 1 hour</td>
<td>T159</td>
<td>MODIS FRP</td>
<td>a,b</td>
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<tr>
<td>f98v</td>
<td>1997-2000,2008*</td>
<td>1 month</td>
<td>1.0 deg</td>
<td>GFED2</td>
<td>a,b</td>
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<tr>
<td>f98v</td>
<td>2001-2007</td>
<td>8 days</td>
<td>1.0 deg</td>
<td>GFED2</td>
<td>a,b</td>
<td></td>
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<tr>
<td>fa5z</td>
<td>1997-2008*</td>
<td>1 month</td>
<td>0.5 deg</td>
<td>GFED2</td>
<td>a,b,c</td>
<td></td>
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<tr>
<td>fa5q</td>
<td>2003-2008</td>
<td>1 day</td>
<td>0.1 deg</td>
<td>GFED3.1</td>
<td>a,b</td>
<td></td>
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<tr>
<td>fh1i</td>
<td>1997-2009*</td>
<td>1 month</td>
<td>0.5 deg</td>
<td>MODIS FRP-NRT (GFASv1.0)</td>
<td>a,b,c,d</td>
<td></td>
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<tr>
<td>ff9r</td>
<td>2003-present</td>
<td>1 day</td>
<td>0.5 deg</td>
<td>MODIS FRP-NRT (GFASv1.1)</td>
<td>a,b,c,d</td>
<td></td>
</tr>
<tr>
<td>ff6z</td>
<td>7 Feb 2011-present</td>
<td>1 day</td>
<td>0.1 deg</td>
<td>MODIS FRP-NRT (GFASv1.0)</td>
<td>a,b,c,d</td>
<td></td>
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- * also multi-year averages with time stamps of year 1904
- a = BC, CO2, CO, CH4, OC, PM2.5, SO2, TPM, C
- b = H, NOx, N2O, NMHC
- c = dry matter combustion rate, total carbon emission, C2H4, C2H4O, C2H5OH, C2H6, C2H6S, C3H6, C3H6O, C3H8, C5H8, CH2O, C3OH, Higher_Akanes, Higher_Akanes, NH3, Terpenes, Toluene lump
- d = C7H8, C6H6, C8H10, C4H8, C5H10, C6H12, C8H16, C4H10, C5H12, C6H14, C7H16

The NOx emissions refer to NOx (as NO) as we use the NOx (as NO) emission factors from Andreae&Merlet (2001, last updated 2009) for the calculation.

The GRIB identification codes and units for all species are listed in the GRIB Parameter Database. They cover the paramId range 210080-210118,210231-210241. You may want to start off by modifying our example MARS retrieval script, which can be executed on egcage. We also recommend the web-based MARS catalogue for checking data availability and example batch requests. If the previous sentences do not make sense to you, please contact our [user support](http://geiacenter.org).
Summary

- Global FRP observations allow fire emission estimation
  - consistently with burnt area-based estimates of GFED3
  - with additional quantitative information
    - day-to-day variability
    - small fires

- Accurate emission estimates are essential for accurate air quality monitoring and forecasting.

- MACC-II publicly provides for 2003 – yesterday: (amongst others)
  - daily global FRP-based emission data
  - global smoke plume analyses and forecasts

- Bottom-up and top-down smoke aerosol estimates disagree by a factor of 2-4.

- Emission validation with atmospheric plume observations
Outlook: Lots of Potential for Improvements

- Plume rise models will give realistic injection heights.
- Merging GEOs and LEOs will improve sampling and diurnal cycle estimation.
  - LEOs can serve as transfer standards between GEOs.
  - A dynamic bias correction will be needed.
- Weather forecasts carry information for 5-day fire forecasting.
- FRP-conversion factors and emission factors might be
  - based on physical model
  - fire observations like maximal FRP and diurnal cycle

- FRP products above ocean would help to monitor emissions from gas flares.
- SEVIRI above Indian ocean would help.
- BIRD-like sensors could provide a standard for comprehensive FRP error characterisation.
- FRP products from VIIRS and Sentinel-3 SLSTR are urgently needed!
This topics remains interesting!
MOZART CO Column Simulations of July 2008

- good pattern
- good consistency between GFED and GFAS
- possibly overestimation in Africa, too be analysed in detail