Re-analysis of wild-land fires emission using remote-sensing observations of fire radiative power

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Fire information to emission: FAS v1.3

USGS Offline

MODIS

MISR

SEVIRI

USGS

AOD

FRP Offline calibration
(Sofiev et al, 2009)

AOD

FRP

TA Offline

Emission factors

Land use

Emission flux

Injection height profile

Plume top

Offline

(Sofiev et al, 2012)

Offline

Plume rise param.

Diurnal variation

CTM (SILAM)

ECMWF Meteo parameters

Offline

FRP

Offline

FRP
The Fire Assimilation System v.1.3 re-analysis

- Domains: global, European
- Resolution: 10km (0.5° for GEIA)
- Primary scaling: FRP / TA to PM$_{10}$ (Sofiev et al., 2009)
- Secondary scaling (Andreae & Merlet, 2001): PM$_{2.5}$, SO$_2$, NO$_2$, CO, NH$_3$, HCHO
- Temporal resolution: daily, diurnal variation suggested
- Injection height: $\sim$(1÷1.5) $H_{ABL}$ is suggested
FAS emission database (2000 - 2011)

Fire PM emission (kg/sec), global

Global PM$_{10}$ emission

Fire PM emission (kg/sec), Europe

European PM$_{10}$ emission
FAS emission database (2000 - 2011)

- Fire PM emission (kg/sec), global
- Terra only
- Global PM$_{10}$ emission
- European PM$_{10}$ emission
• actual-fire observations and empirical calibration gets 3-5 times the total emission of the GFED-like approaches.
• numerous small fires, which are visible when active but whose burnt scars are probably too small to be distinguished.
Plume rise in FAS: a new approach

- Plume rise: Briggs and others
  - Hot plume rises until is bented out:
    horizontal motion $>>$ vertical motion
  - Empirical parameterizations, rise is limited for all stratification types

- CAPE
  - Overheated parcel rises until in equilibrium with surrounding air: energy excess=0.
  - Rising through unstably stratified layer increases energy

$U(z)$

$w(T_p, T_a, w_0, ...)$
Plume-rise formula (Sofiev et al, 2012)

\[ H_p = \alpha H_{abl} + \beta \text{FRP}^\gamma e^{-\delta N_{FT}^2} \]

Data
- MODIS active-fires: FRP
- ECMWF NWP fields: \( H_{abl} \) (atmospheric boundary layer height), \( N_{FT} \) (Brunt-Vaisala frequency for free troposphere)
- MISR: plume height (Kahn et al., 2008; Mazzoni et al., 2007) to obtain \( \alpha, \beta, \gamma, \delta \)
  - coefficients: \( \alpha \) - ABL passed freely
  - \( \beta \) - weights the contribution of the fire intensity
  - \( \gamma \) - determines the power-law dependence on FRP
  - \( \delta \) - defines the dependence on stability in the FT

Processing
- two years processed: 2001, 2008 (US and Siberian fires)
- sum-up the fire plumes (>1 mln fires), then normalize
- fill-in gaps (no-fires grid cells with burns nearby)

Evaluation
- ranking sum fitting criterion with accuracy of 500 m
Evaluation against MISR plume height database

\[ \alpha = 0.24; \quad \beta = 170 \, \text{m}; \quad \gamma = 0.35; \quad \delta = 0.6 \]

- Outcome is independent from fire location, continent, land use, learning/control dataset:
- ~70% of cases are within 500m from observations (~MISR uncertainty)
a) Learning dataset

b) Control dataset

Coefficients obtained from fitting into MISR learning subset (above-ABL 204 fire cases):

$$\alpha = 0.93; \quad \beta = 298 \text{ m}; \quad \gamma = 0.13; \quad \delta = 0.7$$
Comparison with other methods

Briggs’69

1-D model
BUOYANT

Briggs’84

New formula
Comparison with other methods

Briggs’69

Briggs’84

1-D model

BUOYANT

New formula

Hit rate (within 500m) for full MISR set (~2000 fires)

Observed height

Calculated height

High: 14%

Good: 42%

Low: 36%

High: 12%

Good: 37%

Low: 43%

High: 14%

Good: 65%

Low: 18%

Hit rate (within 500m) for full MISR set (~2000 fires)

Briggs’69

Briggs’84

OND-86

BUOYANT

Const = 1289m

New formula

Observed height

Calculated height

Observed height

Const = 1289m

New formula
Fire emission vertical profile: climatology

- Goal: 3-D mean global distribution of fire emission
  - supplement for existing fire emission databases
- Input
  - MODIS active-fires: FRP
  - ECMWF NWP fields: $H_{ab}^l$, $N_{FT}$
  - estimated diurnal variation using SEVIRI FRP
- Processing
  - two years processed: 2001, 2008
  - sum-up the fire plumes (>1 mln fires), then normalize
  - fill-in gaps (no-fires grid cells with burns nearby)
- Evaluation (on-going)
  - CALIOP new L3 fire profiles
Height of 50% and 90% of emission injection
Height of 50% and 90% of emission injection

Height of 90% mass injection, day, August mean, [m]
Vertical injection profile: daily variation

Zonal-mean fraction of injected mass, gap_fill, August

Daytime

Night time
Conclusions

• IS4FIRES data- and knowledge-base: http://is4fires.fmi.fi
  - Emission database, 2000-c.m. (daily, 10km, global)
  - GEIA database: 2000-2011 (daily, 0.5°, global)

• New semi-empirical method for injection height estimation was developed for wild-land fires
  - outperforms existing generic methods by 15-30% (fraction of good predictions) and constant height approach
  - can be recommended for 3-D models that possess fire intensity information

• Complementing the existing emission databases, the global map of “climatologic” injection profile from wild-land fires is being calculated
  - targets all fire-related applications
Thank you!
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FAS v.1.3

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Meteo parameters
From approximation to real life

\[
\frac{de}{dz} = -\frac{c_p \rho \theta}{g} N^2 - \frac{6\pi K_{\text{hor}} / w}{(S_f + 6\pi z K_{\text{hor}} / w)^2} P_f
\]

buoyancy \hspace{5cm} \text{plume widening, entrainment of surrounding air}

If all parameters constant:

\[
H_p \sim \left( \frac{P_f}{N^2} \right)^\alpha, \quad \alpha < 1
\]

\(N^2\) – Brunt-Vaisala frequency, 1/s²;
\(P_f\) – fire power released into air as sensible

- \(P_f \to \text{FRP} \to \text{FRP}'\) (normalized)
- \(N \to N'\) (normalized)
- Detach \(\text{FRP}'\) from \(N'\) since \(N'\) is \(z\)-dependent
- Allow \(N'\) to approach zero
- ABL has less stable stratification than the FT