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On contribution of wild-land fires to atmospheric composition

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- Fire Assimilation Systems of FMI
- Fire emission diurnal cycle
- Emission height from wild-land fires
- Summary

Information sources on fires

- In-situ observations and fire monitoring
  - pretty accurate when/where available
  - costly and incomprehensive in many areas with low population density
- Remote sensing products
  - burnt area inventories on e.g. monthly basis (registering the sharp and well-seen changes in the vegetation albedo due to fire)
  - hot-spot counts on e.g. daily basis (registering the temperature anomalies)
  - fire radiative power/energy and similar physical quantities on e.g. daily basis (registering the radiative energy flux)

- Impact on air quality is highly dynamic, thus temporal resolution play a key role

Fractionation of the fire energy

For moderate fires, the total energy release splits:

ε= *Radiation (*40%) + *Convection (*50%*)* + *Conduction (*10%*)*

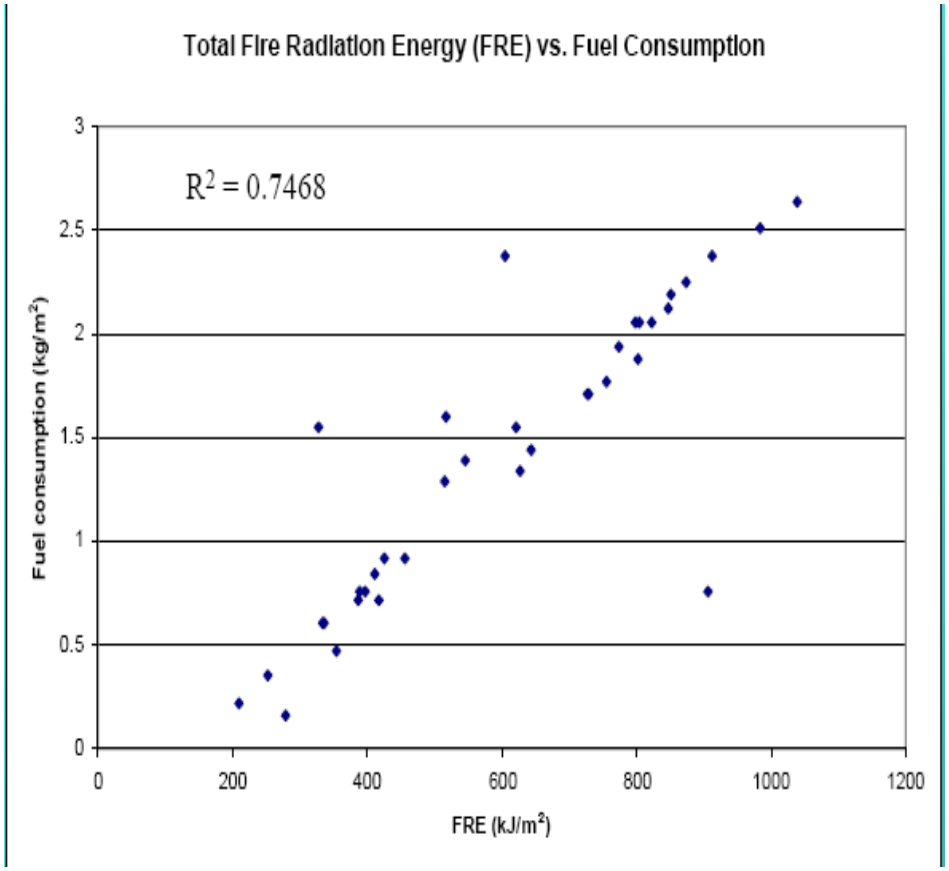
- The split is valid for a wide range of fire intensity and various land use types

(A.I.Sukhinin, Russian Academy of Sciences, V.N.Sukachev Forest Institute, Krasnoyarsk, Russia)

Empirical formula for total rate of emission of FRP:

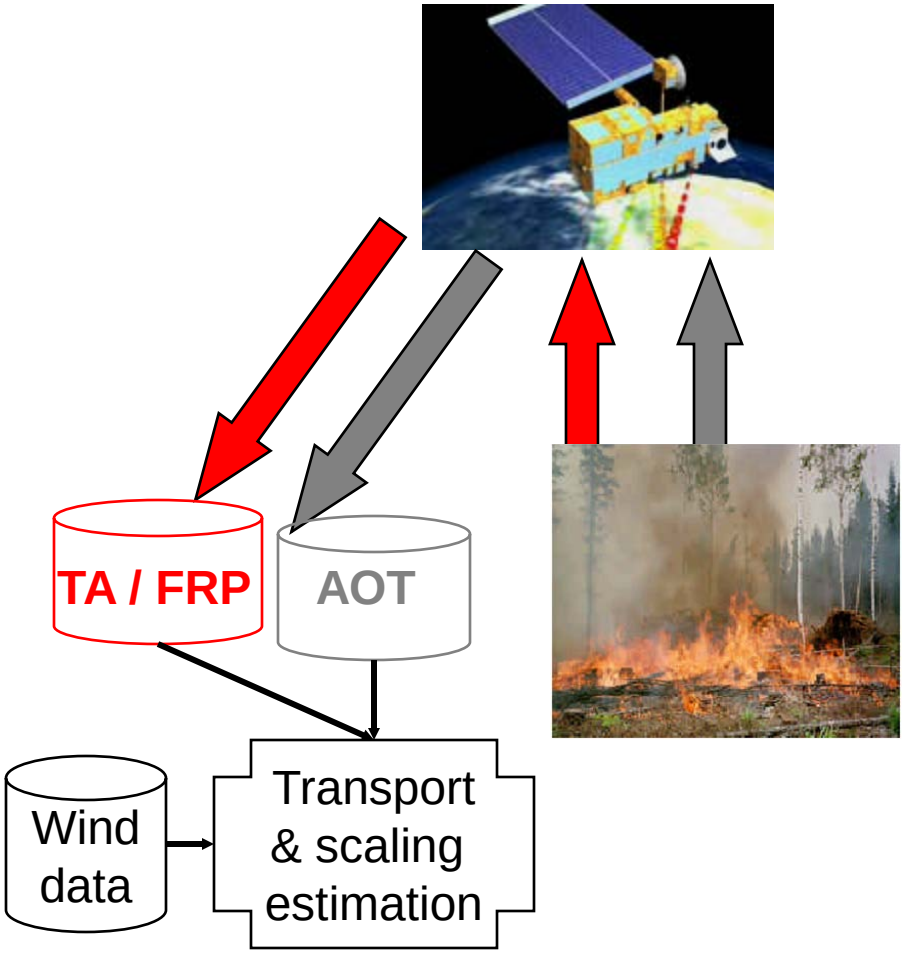
$$Ef = 4.34*10^{-19} (T_4^8 - T_{4b}^8) \quad \text{[MWatt per pixel]}$$

$T_{4,4b}$ is fire and background brightness temperatures at 3.96 μm (*Kaufman et al,1998*)

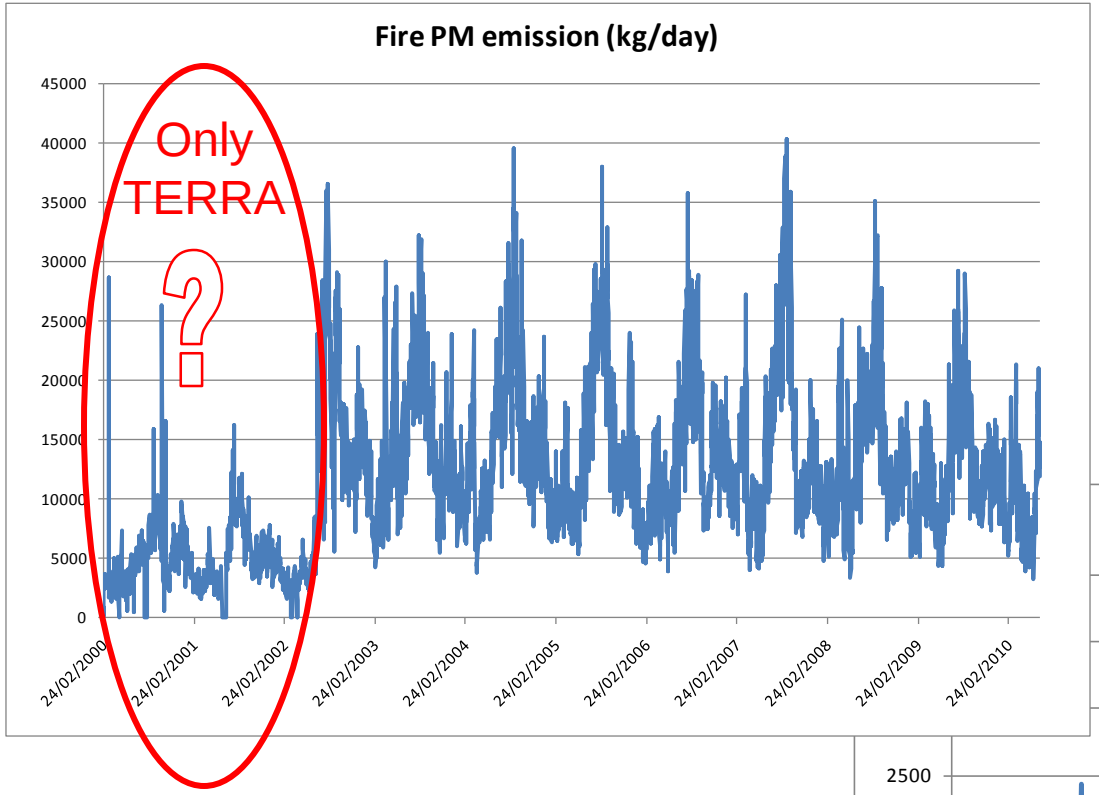


Emission scaling

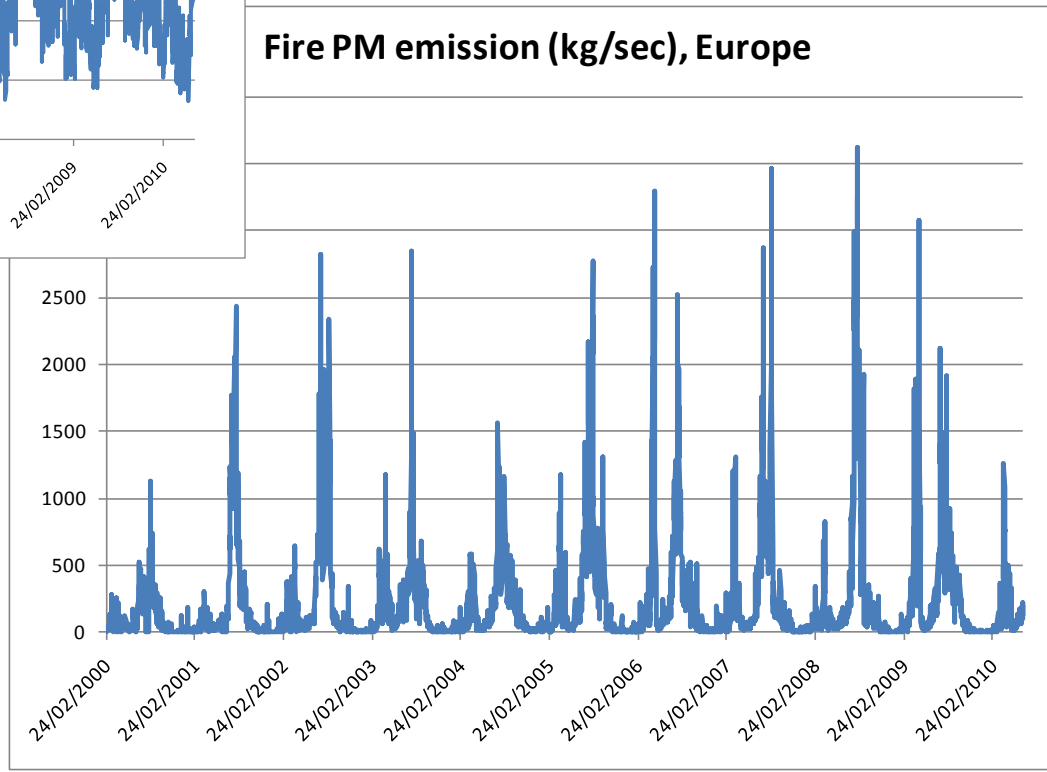
- Satellite(s) observe both fire itself and the resulting plume
- Horizontal dispersion is evaluated via transport simulations
- Empirical emission factors for TA/FRP-to-total PM based on land use type (Sofiev et al, 2009)
- Speciation is assumed mainly from laboratory studies (Andreae and Merlet, 2001)
- FAS output: gridded daily emission data



Fire emissions database: available, 2000 →



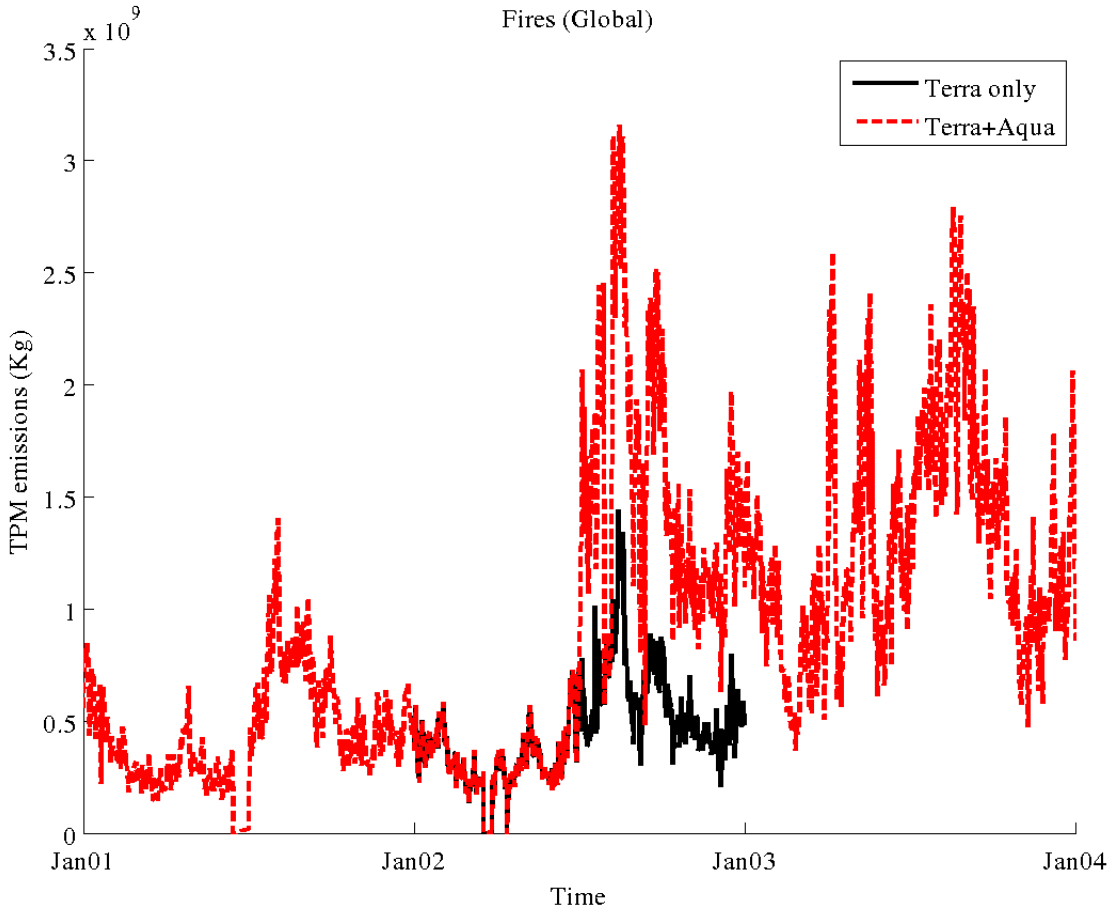
Global PM emission



European PM emission

Why the rise ?

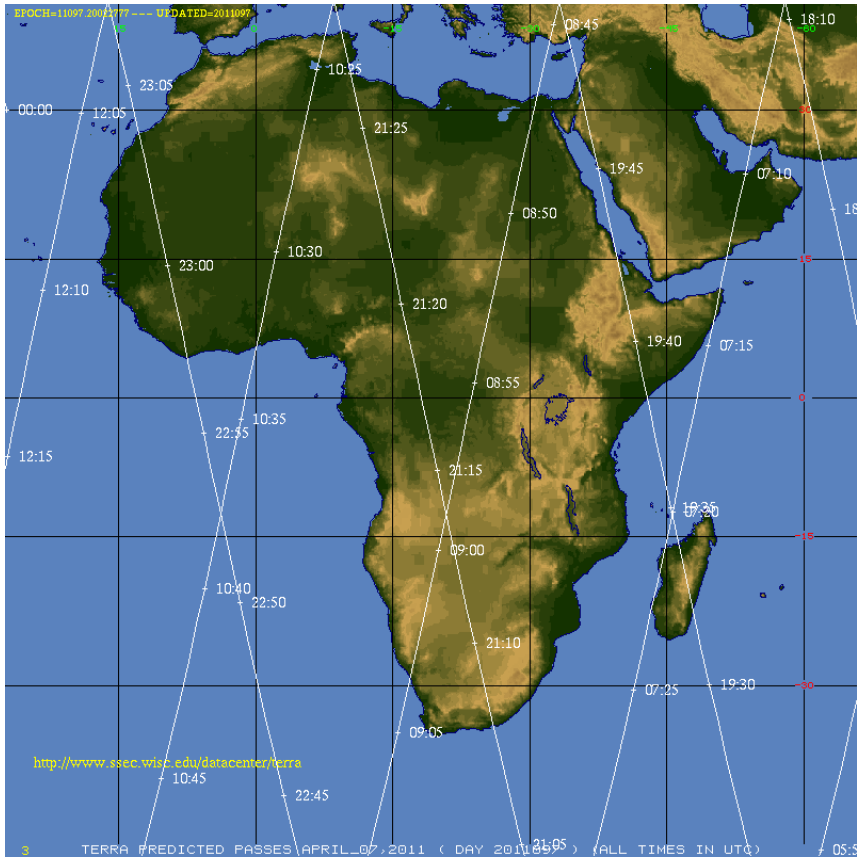
- Terra-only time series do not show jump…



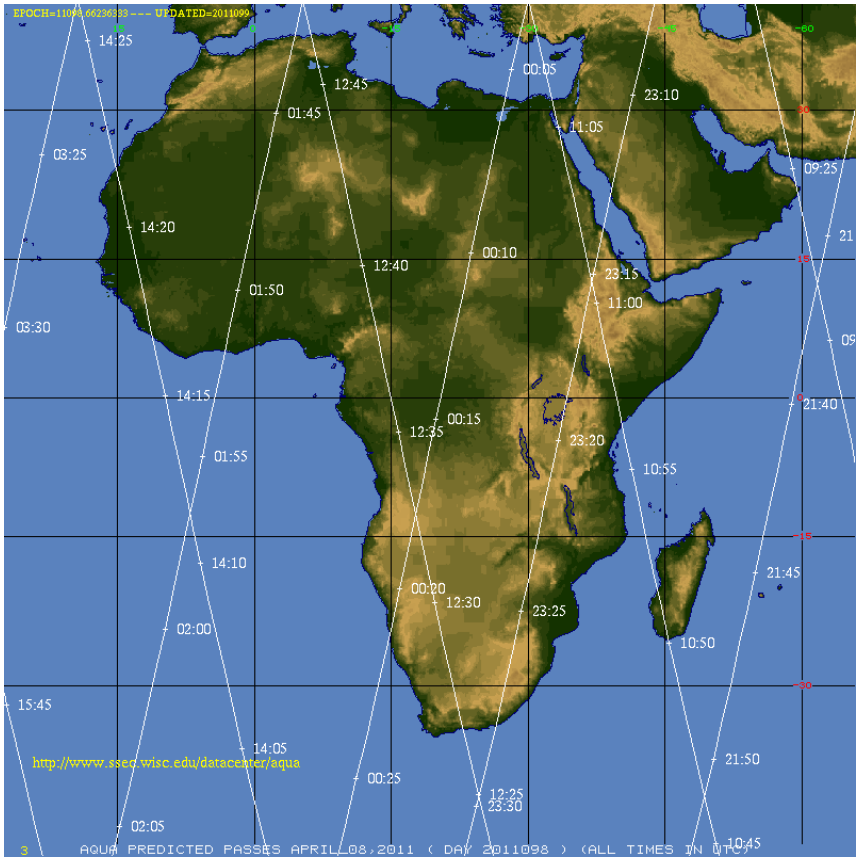
Reason for jump: overpass timing over Africa

- Diurnal variations in both fire intensity and number of fires
  - correlate with satellite overpass times
- More overpasses will still see more fires

TERRA: 8:50 and 21:20

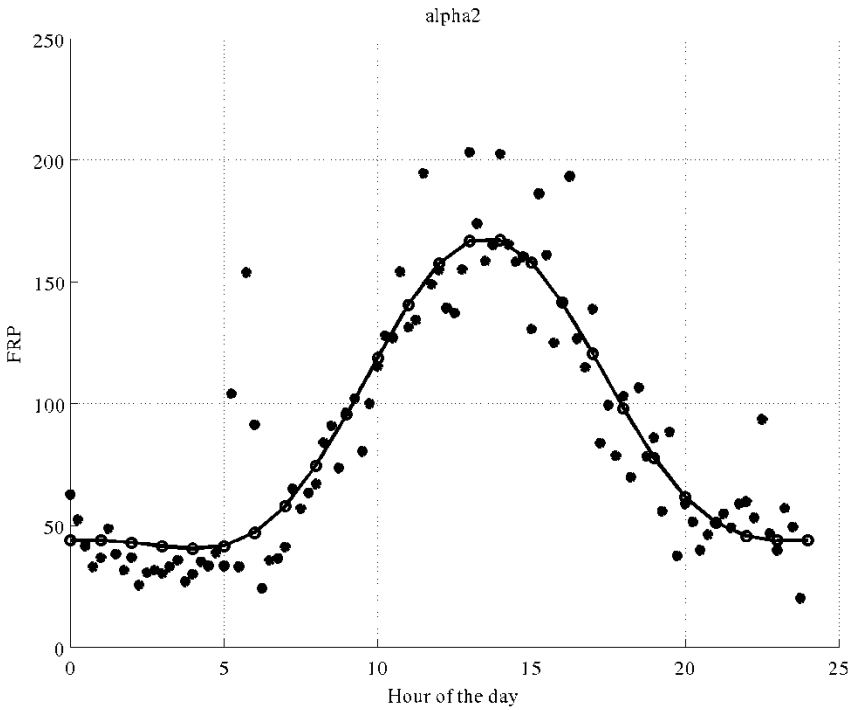


AQUA: 00:10 and 12:40



SEVIRI: source of diurnal variation data

- Geostationary satellite
  - 15 minutes temporal resolution
  - ~20km pixel size in Southern Europe >> ~1.5km of MODIS
- Example: diurnal variation of FRP
  - Italy, July 2007
- Depends on both fire intensity and number of fires in SEVIRI gridcell



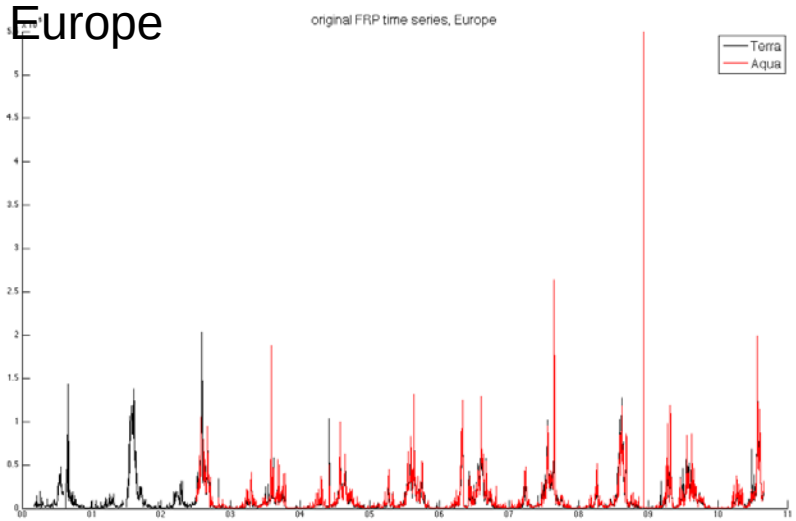
Adjustment of African FRP observations

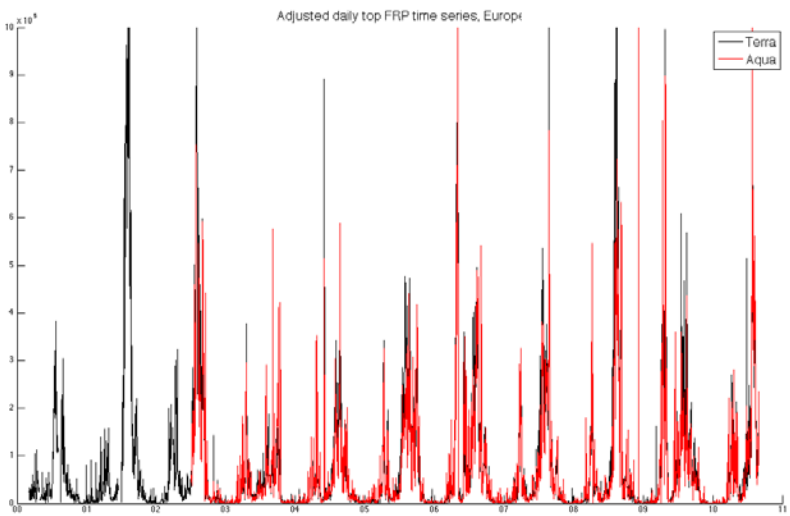
- Diurnal variation of fires applied to the MODIS observed FRP to obtain the daily-total radiative energy release

Original

After correction

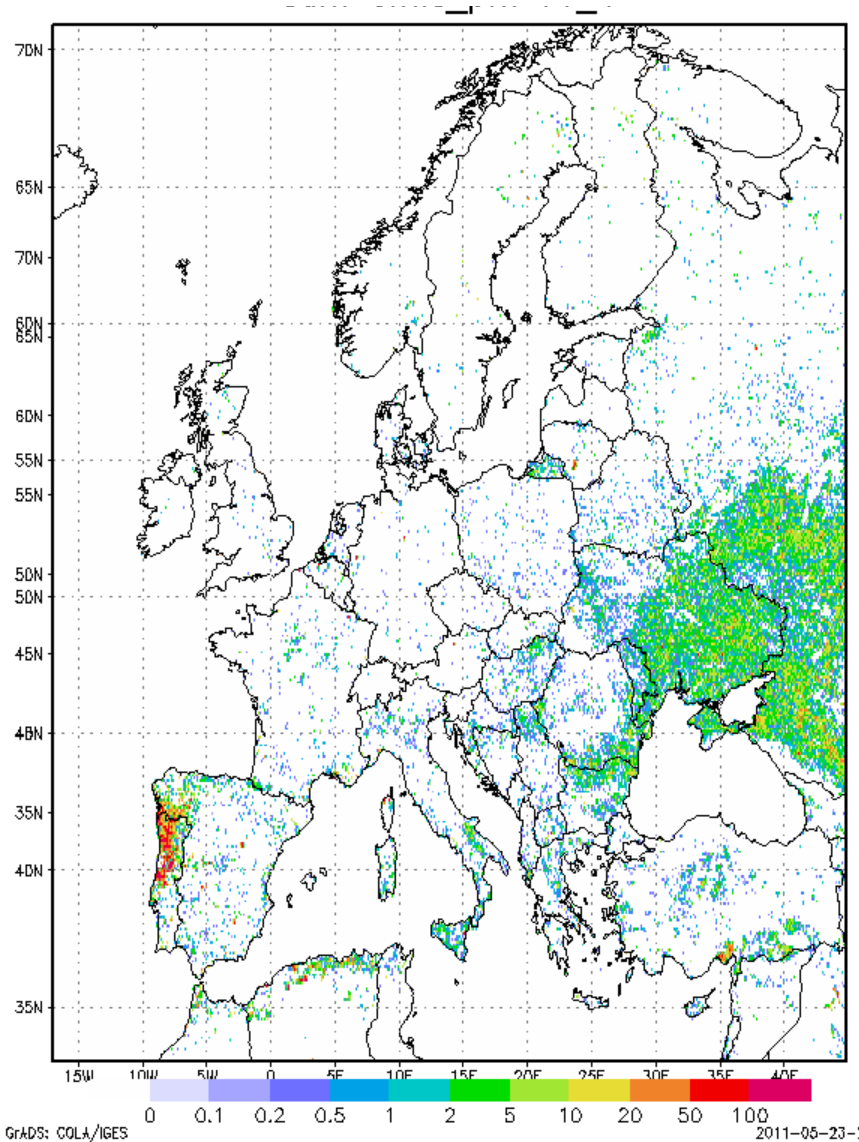
Europe



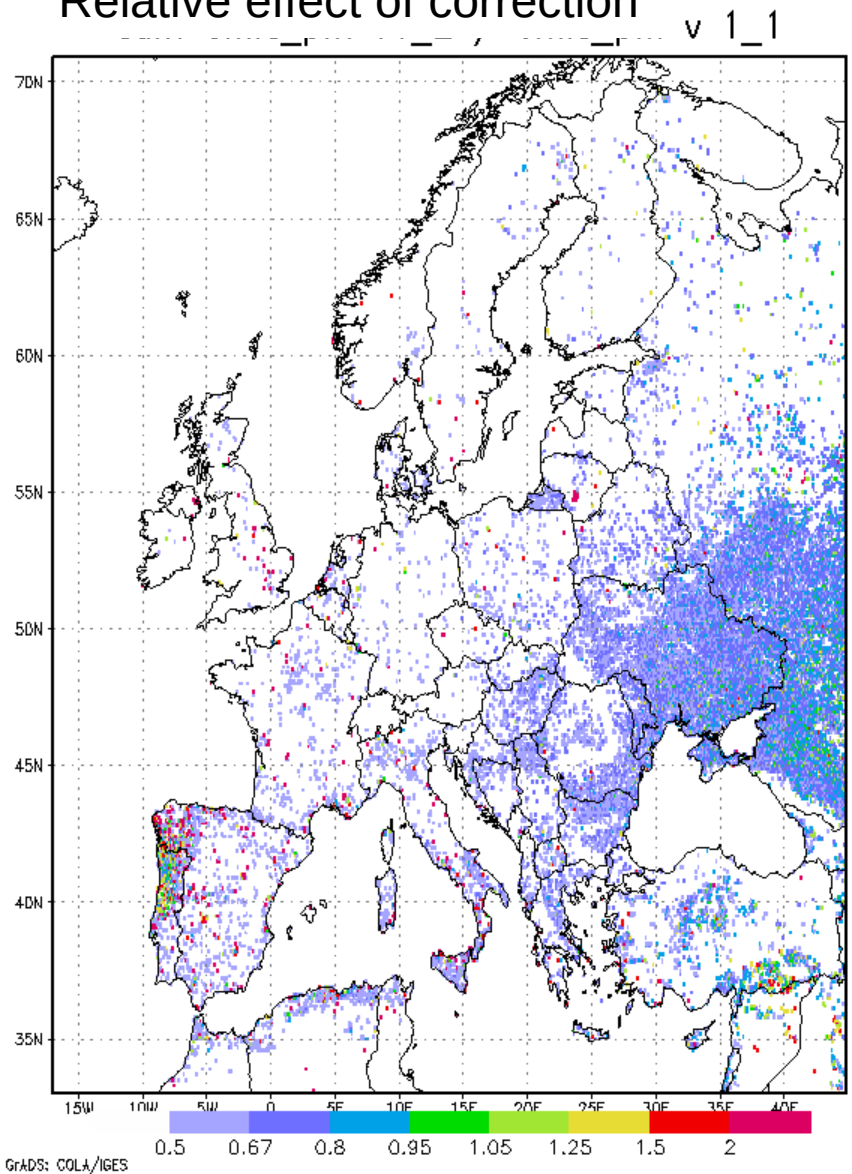


Impact on European totals

Total PM, 2005, before correction



Relative effect of correction



Plume rise from fires: motivation

- Strong dependence of injection height on:
  - fire features (size, intensity)
  - meteorological parameters (ABL height, stratification)
- Doubtful applicability of existing plume-rise algorithms
  - empirical formulas and 1D models were not developed and evaluated for very wide plumes
- Most of AQ models simply assume constant injection height
  - Wide range of guesses from 0.5km up to 5km

Suggested methodology

- Semi-empirical approach (Sofiev et al, 2011, ACPD)
  - Analytical derivation of form of the dependencies considering:
    - rise against stratification
    - widening due to outside air involvement
  - Modification of the analytical solution keeping main dependencies but involving a series of empirical constants
  - MODIS fire FRP + MISR plume top datasets for calibration and evaluation of the constants
- Final formulation:

$$H_{top} = \alpha H_{ABL} + \beta \left(\frac{FRP}{FRP_0} \right)^{\gamma} \exp\left(\delta \frac{N^2}{N_0^2} \right)$$

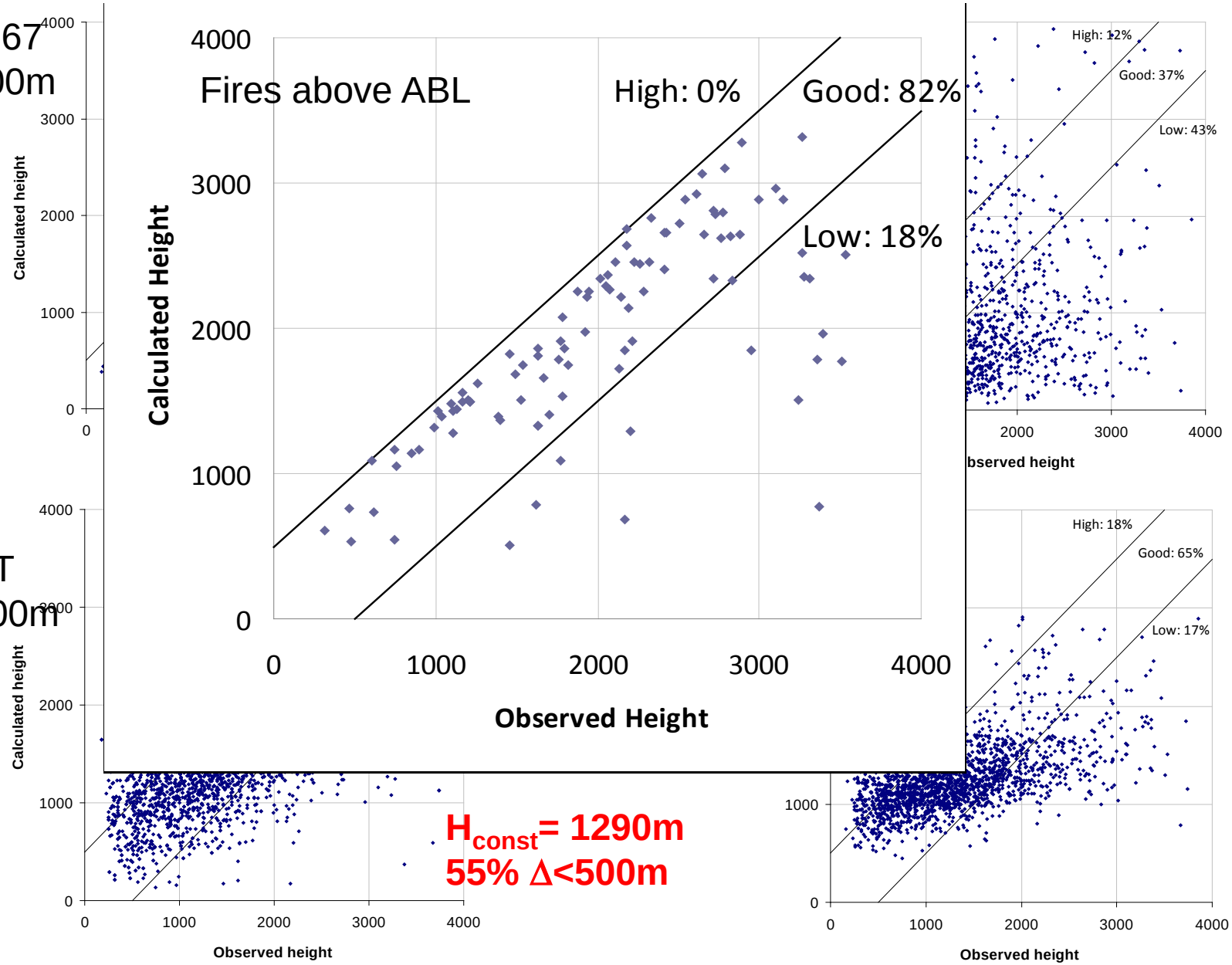
$$\alpha = 0.22; \;\; \beta = 260m; \;\; \gamma = 0.27; \;\; \delta = 0.15;$$

$$FRP_0 = 1MW; \;\; N_0^2 = 2.4 \cdot 10^{-4} \sec^{-2}$$

Plume rise evaluation, inter-comparison

Briggs, 1967
42% Δ<500m

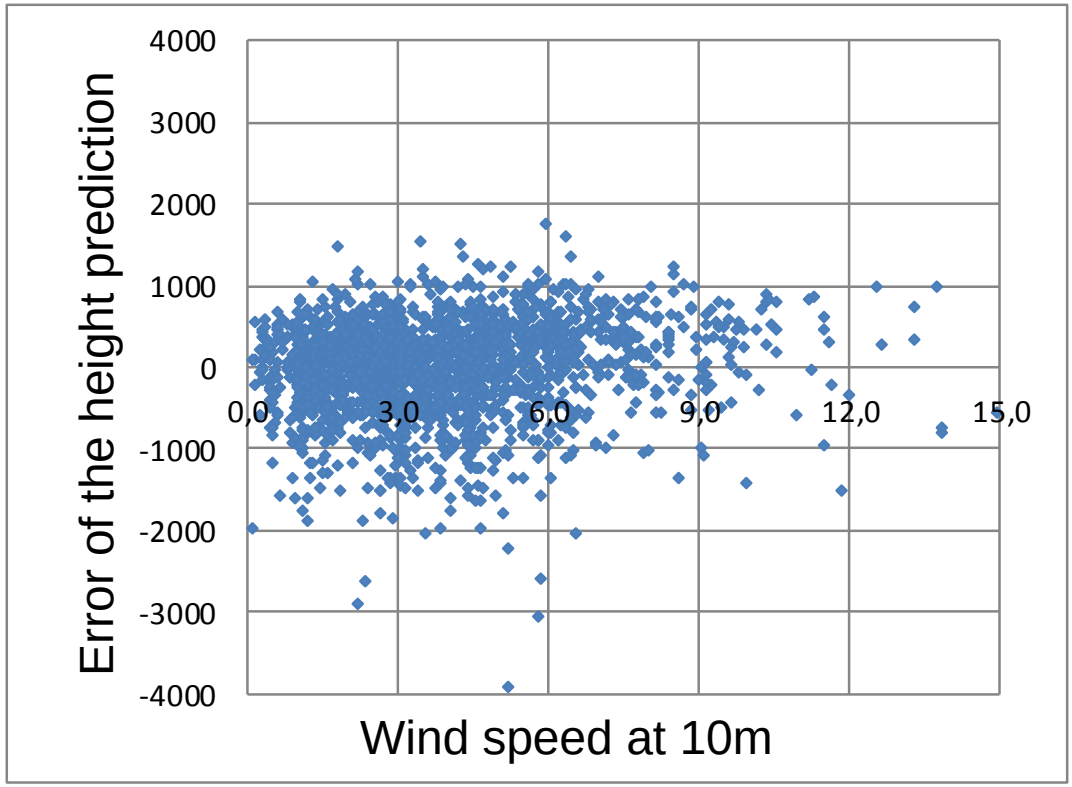
1D model
BUOYANT
51% Δ<500m



H_{const}= 1290m
55% Δ<500m

Is wind speed important?

- The error of the method does not correlate with the wind speed

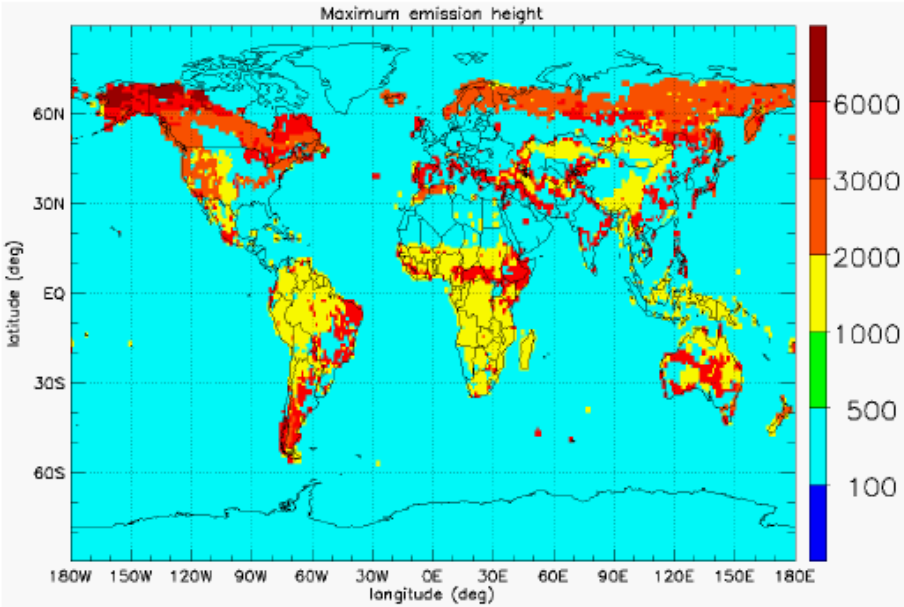


Application: global injection height distribution

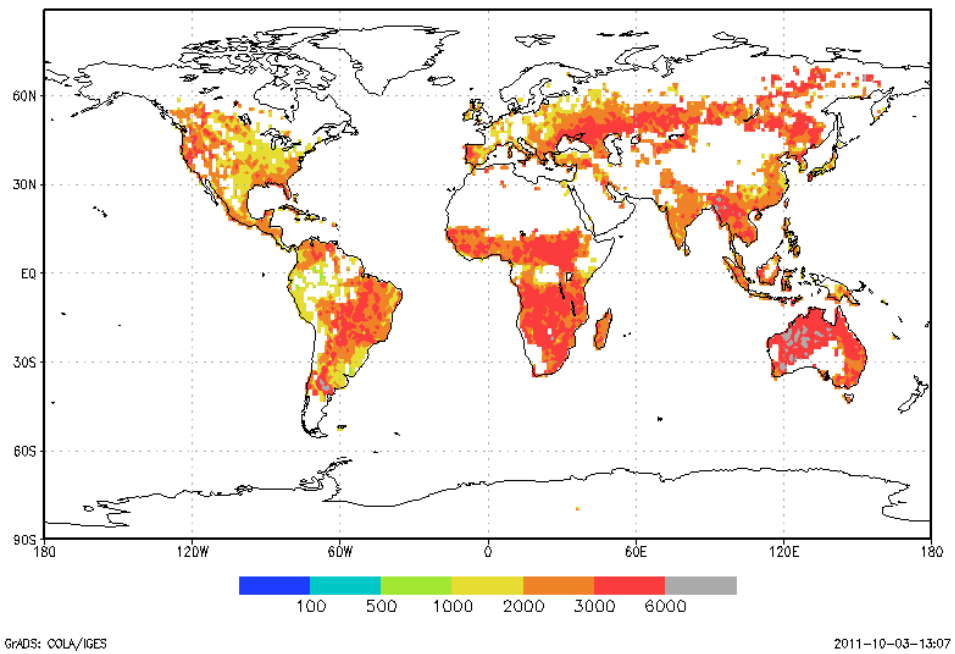
- Motivation:
  - request from AEROCOM community
  - necessity to accompany the FAS emission database with injection height information
- Brute-force approach:
  - MODIS active fires
  - ECMWF archived meteorological data
  - injection height computed and averaged-up
  - result: space- and time- resolving vertical injection profile

Top of the plume

AEROCOM recommended plume top



This study plume top



-Eurasia and North America are more reasonable

-fire regions are realistic

-eliminated spots of extremely high plumes

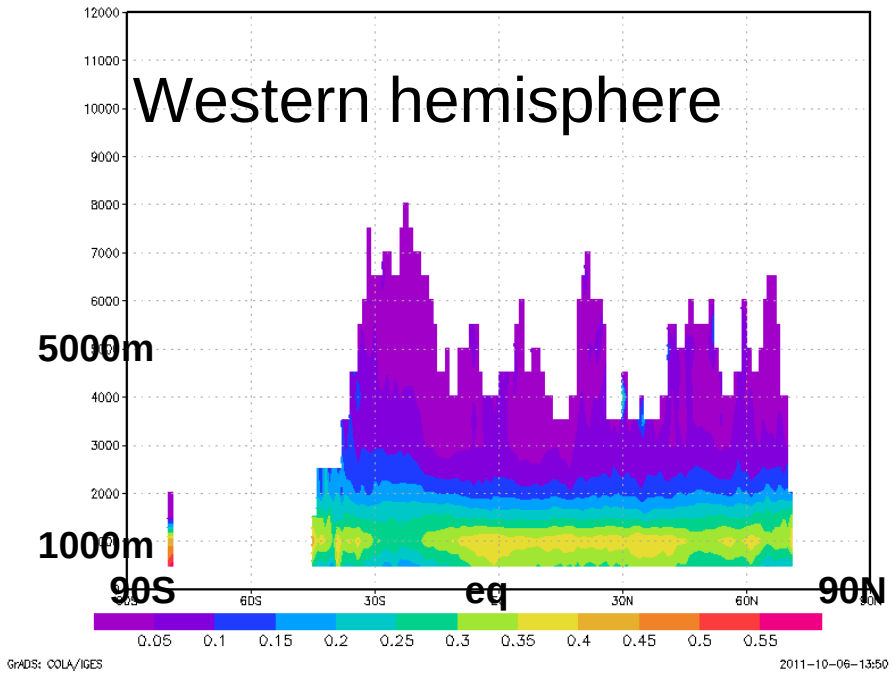
-but:

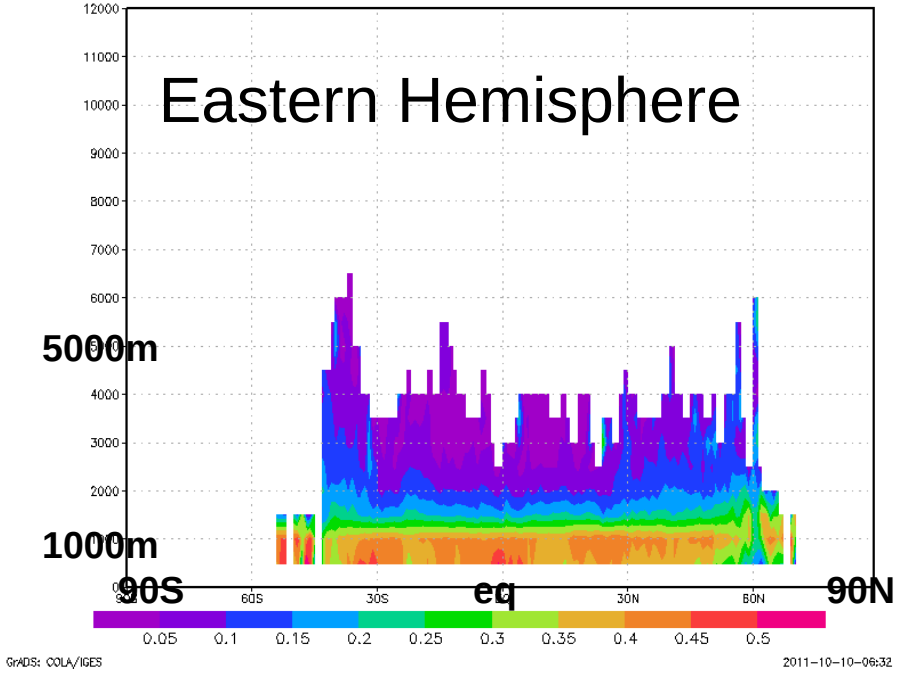
-Alaska is missing (too few fires in 2001, 2008)

-Africa is noticeably higher – and no MISR verification available

Injection profile, zonal average

- Assumption:
  - 80% is emitted from $0.5H_{top}$ till H_{top}
  - 20% below $0.5H_{top}$





Summary

- Fire Assimilation System (FAS) v.1.2: scaling MODIS Collection 5 Temperature Anomaly (TA) and Fire Radiative Power (FRP)
- Diurnal variation of both fire intensity and the number of fires correlate with Terra and Aqua overpasses
- FRP diurnal variation curve extracted from SEVIRI was applied to MODIS-Aqua and Terra FRP
  - Significant impact in Africa, where previously MODIS-Terra and Aqua estimates differed noticeably
- A methodology for estimating the plume injection height from wild-land fires has been developed and validated against MISR dataset
- The plume-rise method was used to obtain global space- and time-resolving injection profiles for wild-land fires

Thank you for your attention !

Acknowledgements:

- IS4FIRES, MACC, PASODOBLE, MEGAPOLI, TRANSPHORM, KASTU

SILAM fire plume forecasts: http://silam.fmi.fi

Modification of Briggs' formulas

$$H_C = \begin{cases} 1.6F^{1/3}(3.5x^*)^{2/3}U^{-1} \\ 2.4\left(F/Us\right)^{1/3} \\ 5F^{1/4}s^{-3/8} \end{cases} = \begin{cases} 21.4F^{3/4}U^{-1}, & neutral,\ unstable,\ F < 55\,m^4\,\sec^{-3} \\ 38.7F^{3/5}U^{-1}, & neutral,\ unstable,\ F \geq 55\,m^4\,\sec^{-3} \\ 2.4\left(F/Us\right)^{1/3}, & stable,\ U > 0.5\ \ m\sec^{-1} \\ 5F^{1/4}s^{-3/8}, & stable,\ U \leq 0.5\ \ m\sec^{-1} \end{cases}$$

- Switch from internal "stack" parameters to the fire power P_f, then to FRP

$$F = gv_s r^2 \frac{1/T_a - 1/T_p}{1/T_a} = \frac{g}{T_p} v_s r^2 (T_p - T_a) = \frac{g}{\pi T_p} \frac{P_f}{c_p \rho_a} = \frac{g}{\pi T_p} \frac{FRP}{c_p \rho_a}$$

$$H_p = \begin{cases} 5.7\left(\dfrac{g\,FRP}{N^3 T_p c_p \rho}\right)^{1/4}, & stable,\ U \leq 0.5\ \ m\sec^{-1} \\ 2.4\left(\dfrac{g\,FRP}{N^2 U T_p c_p \rho}\right)^{1/3}, & stable,\ U > 0.5\ \ m\sec^{-1} \\ 29\left(\dfrac{g\,FRP}{T_p c_p \rho}\right)^{3/5} U^{-1}, & neutral,\ unstable \end{cases}$$