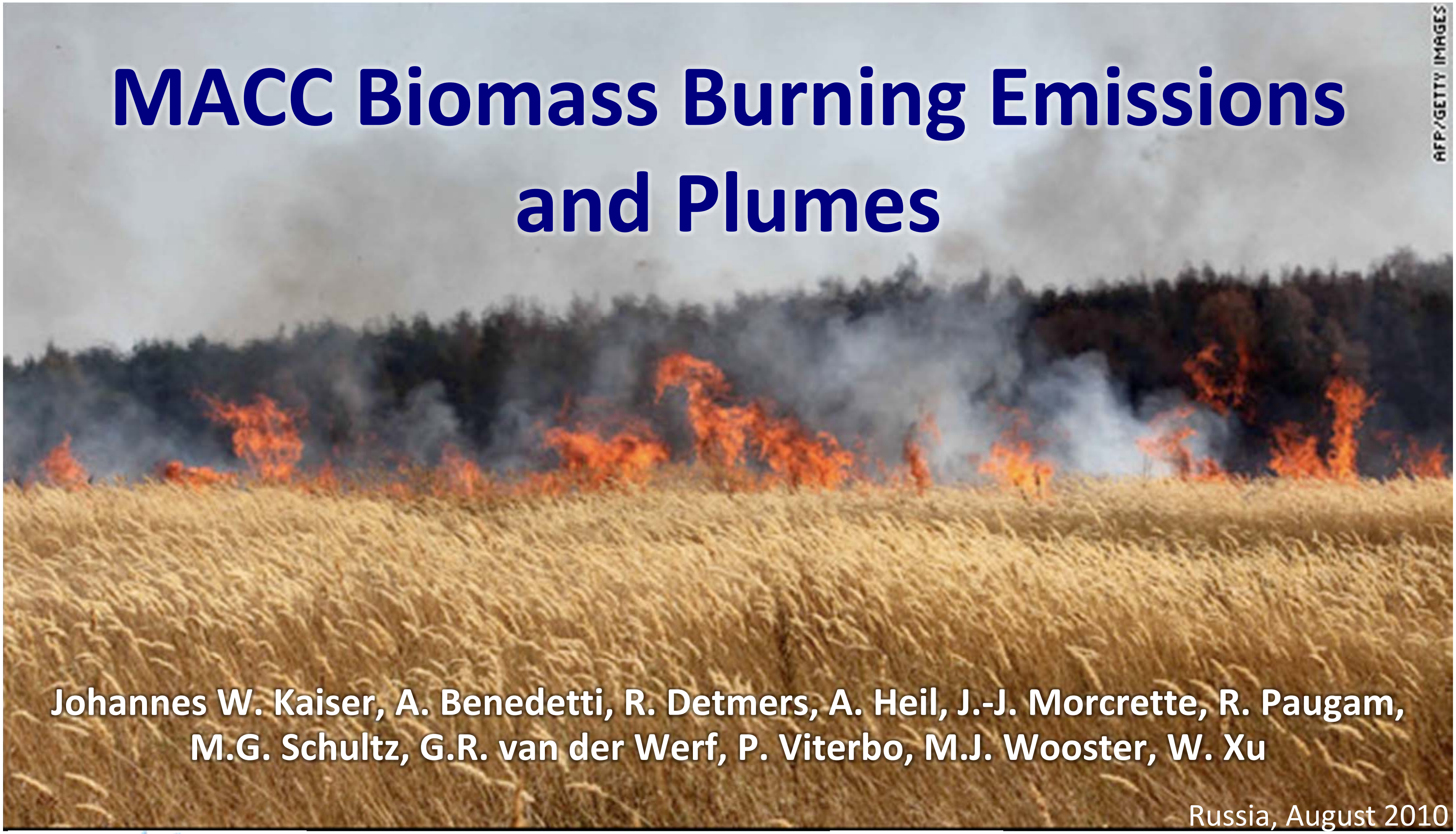
MACC Biomass Burning Emissions and Plumes

Johannes W. Kaiser, A. Benedetti, R. Detmers, A. Heil, J.-J. Morcrette, R. Paugam, M.G. Schultz, G.R. van der Werf, P. Viterbo, M.J. Wooster, W. Xu



Introduction

Bottom-Up Estimation of Fire Emissions

promising best accuracy: MACC real time

sat. obs. ~ const. **land cover map**

$E_i = FRE \times CF \times EF_i$ (Wooster et al. 2003/5)

$E_i = BA \times AFL \times CC \times EF_i$ *(Seiler & Crutzen 1980)*

burnt biomass

"key uncertainty"

(e.g. Reid et al. 2009)

(dynamic) vegetation model

most established, in particular GFED *(van der Werf et al. 2010)*: MACC retrospective

Ei = emission of species i [kg(species i)]

BA = burnt area [m2]

AFL = available fuel load [kg(biomass) / m2]

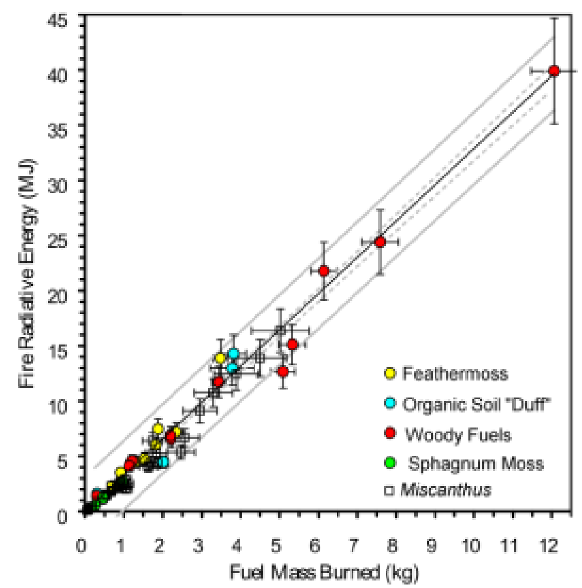
CC = combustion completeness [kg(burnt fuel) / kg (available fuel)]

EFi = emission factor for species i [kg(species i) / kg(biomass)]

FRP = fire radiative power [W]

FRE = fire radiative energy [J] = ∫ FRP(t) dt

CF = conversion factor [kg(biomass) / W(FRE)]



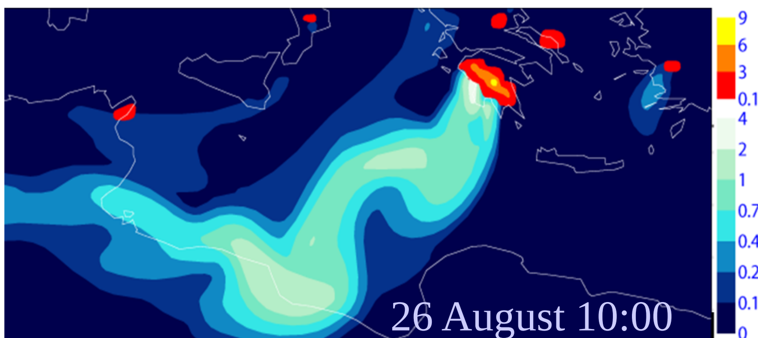
graphics by M. Wooster

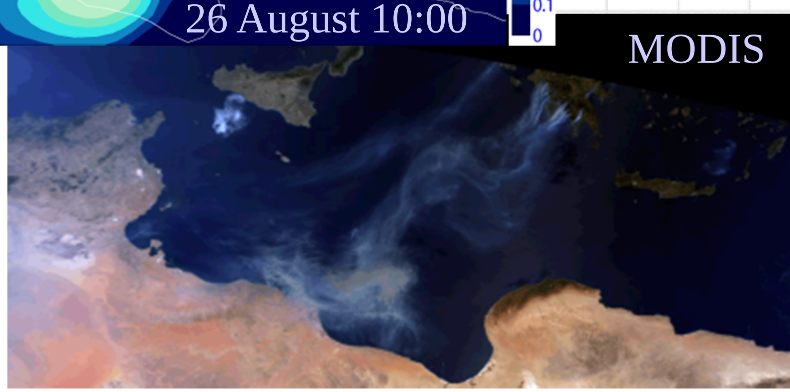
Modelled AOD of Greek Fire Plumes, August 2007

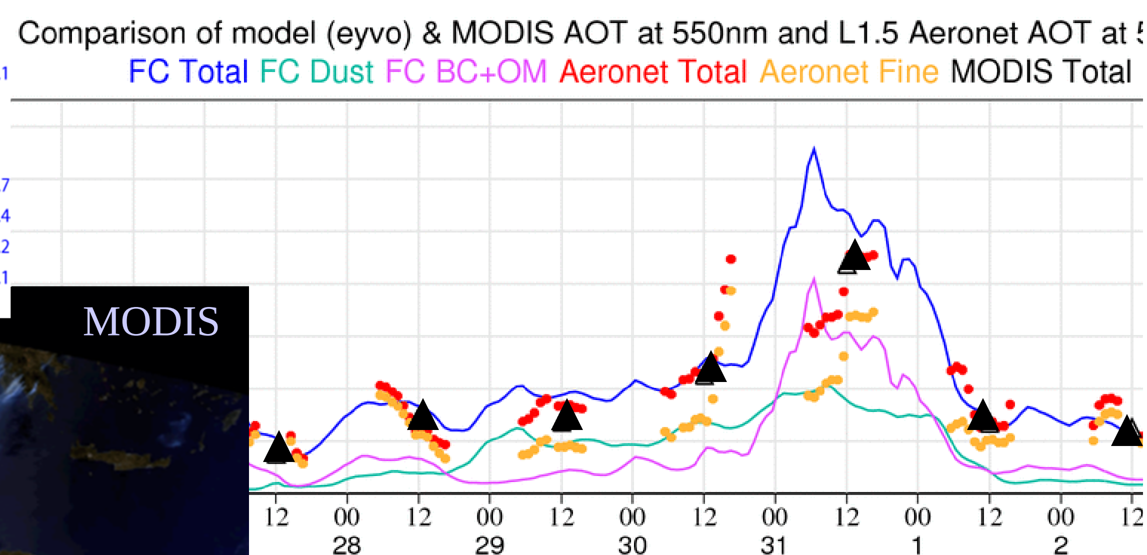
Emissions calculated from Fire Radiative Power observed by SEVIRI on Meteosat.

Emission factors from *Andreae & Merlet 2001* and *Ichoku & Kaufman 2005*.

Run at 25km global resolution, which is typical for regional models.

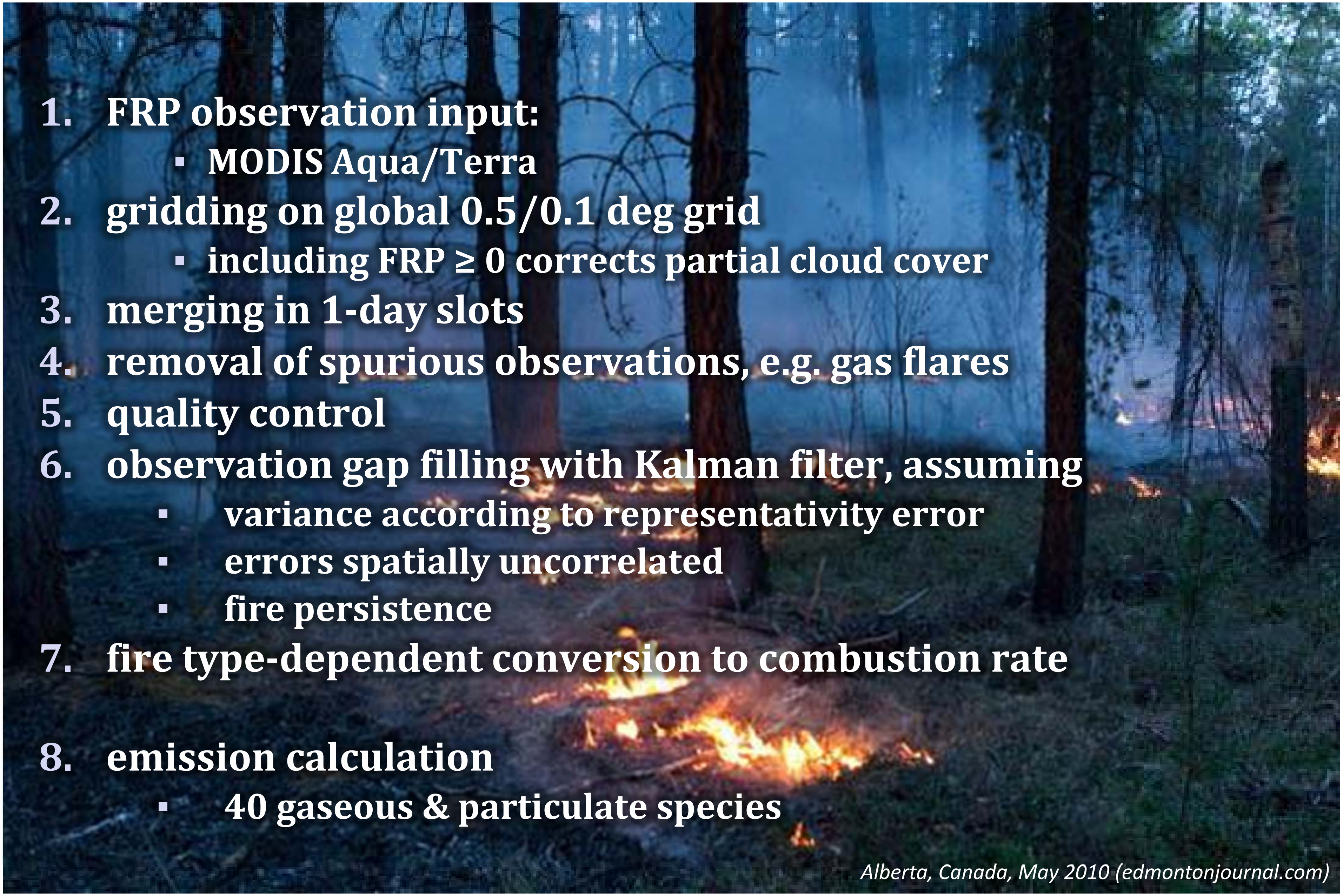






MACC's GFAS:
The Global Fire Assimilation System

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

Alberta, Canada, May 2010 (edmontonjournal.com)

Gridding of FRP Observations

FRP / unit area

$$\varrho_j = \frac{<F>_j}{<A>_j} = \frac{\sum_{i \in j} F_i \cos^2(\theta_i)}{\sum_{i \in j} A_i \cos^2(\theta_i)}$$

accuracy indicator

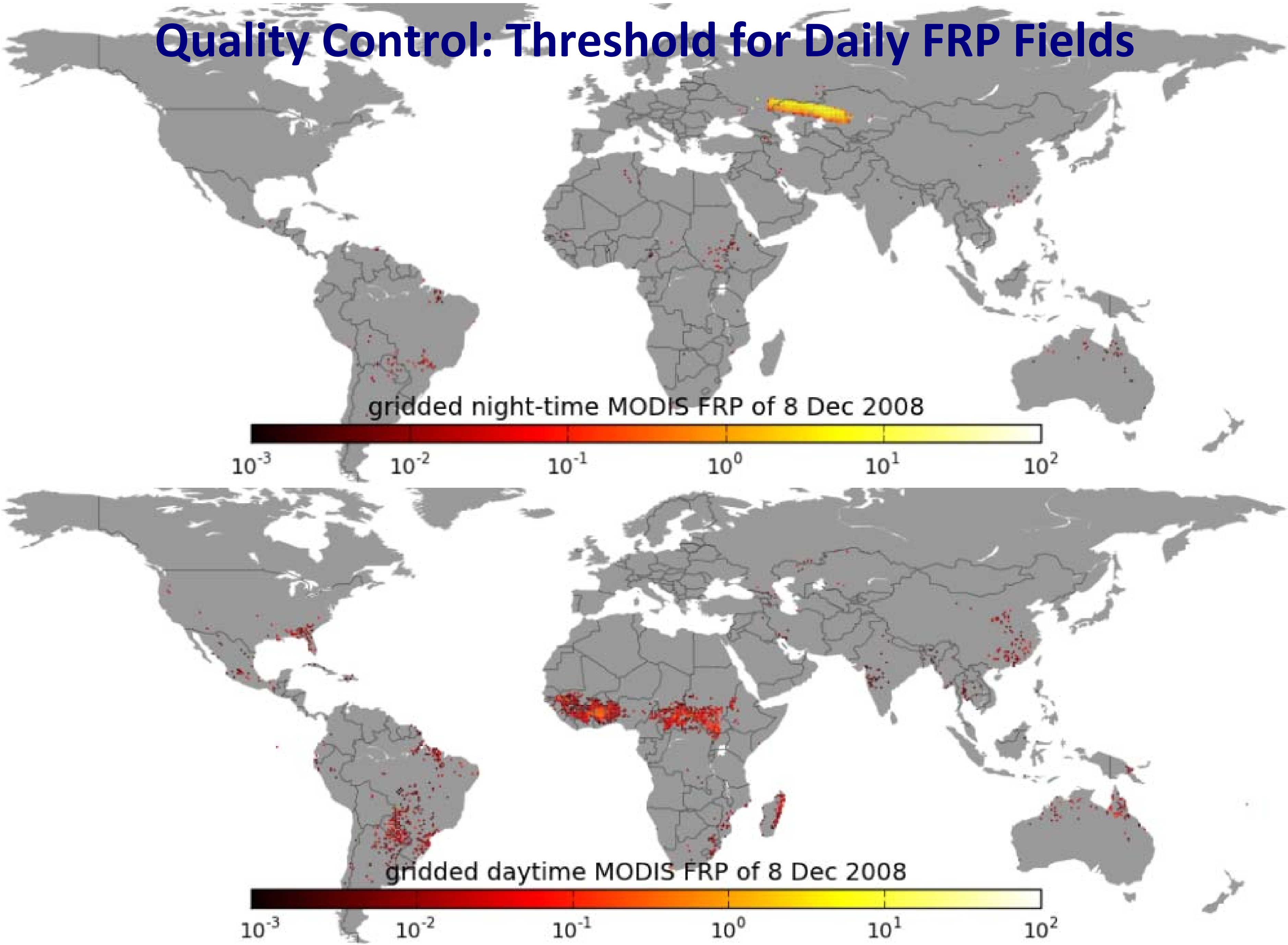
$$\gamma_j = \frac{\sum_{i \in j} A_i \cos^2(\theta_i)}{a_j}$$

- F_i: FRP / pixel
- θ_i: viewing angle
- A_i: pixel area
- a_j: grid cell area

(Kaiser et al. 2009, 2012)

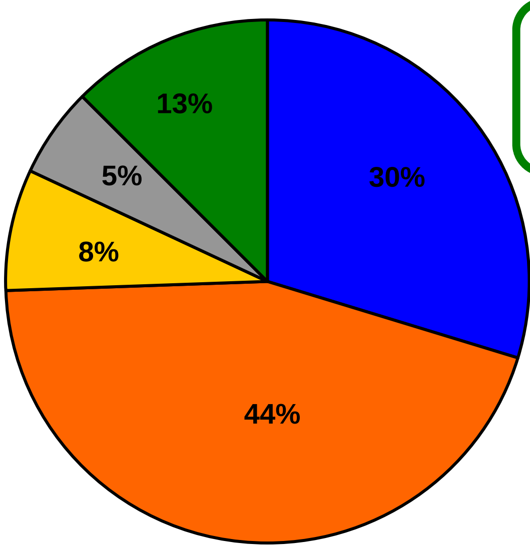
- use FRP ≥ 0 observations
  - assume same fire distribution throughout partially cloudy grid cell
  - tolerate double counting near MODIS swath edges
- flatten accuracy indicator across MODIS swath, using viewing angle
- interpretation of accuracy indicator as inverse variance allows subsequent consistent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

Quality Control: Threshold for Daily FRP Fields



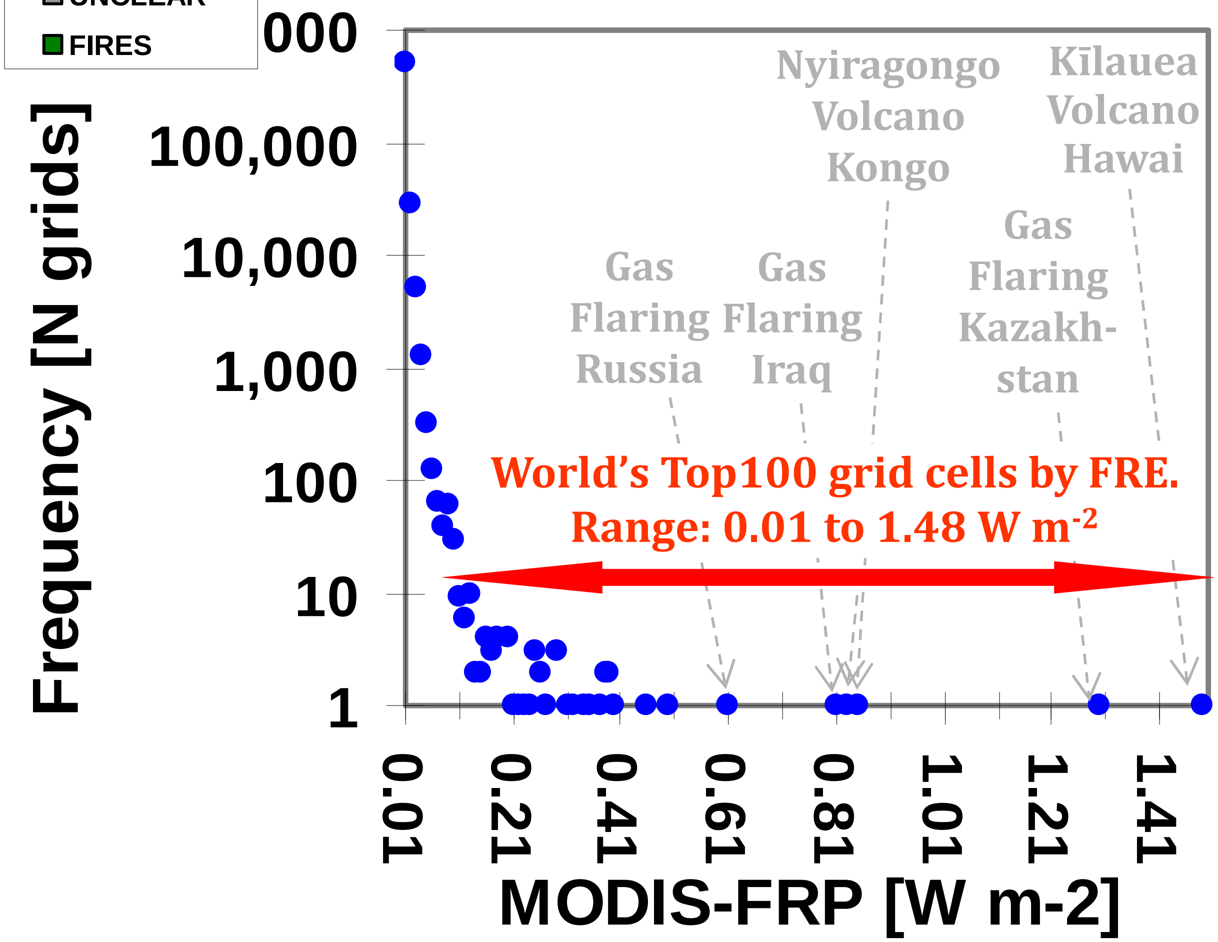
World's Top 100 Grid Cells by FRE: ~1.3% of Total

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

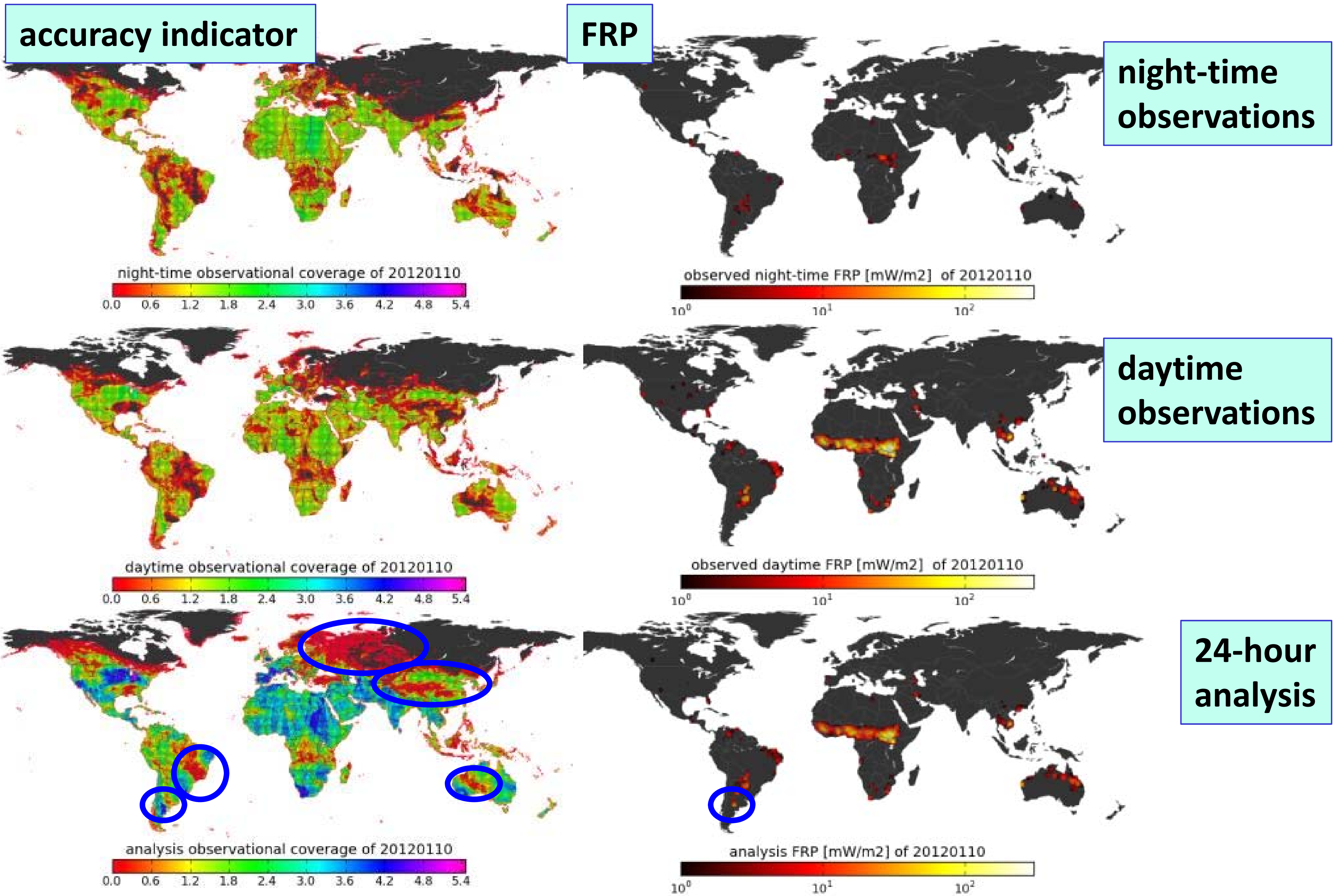


masked in GFASv1.0

- VOLCANO
- GASFLARE
- INDUSTRY
- UNCLEAR
- FIRES



MODIS FRP Assimilation

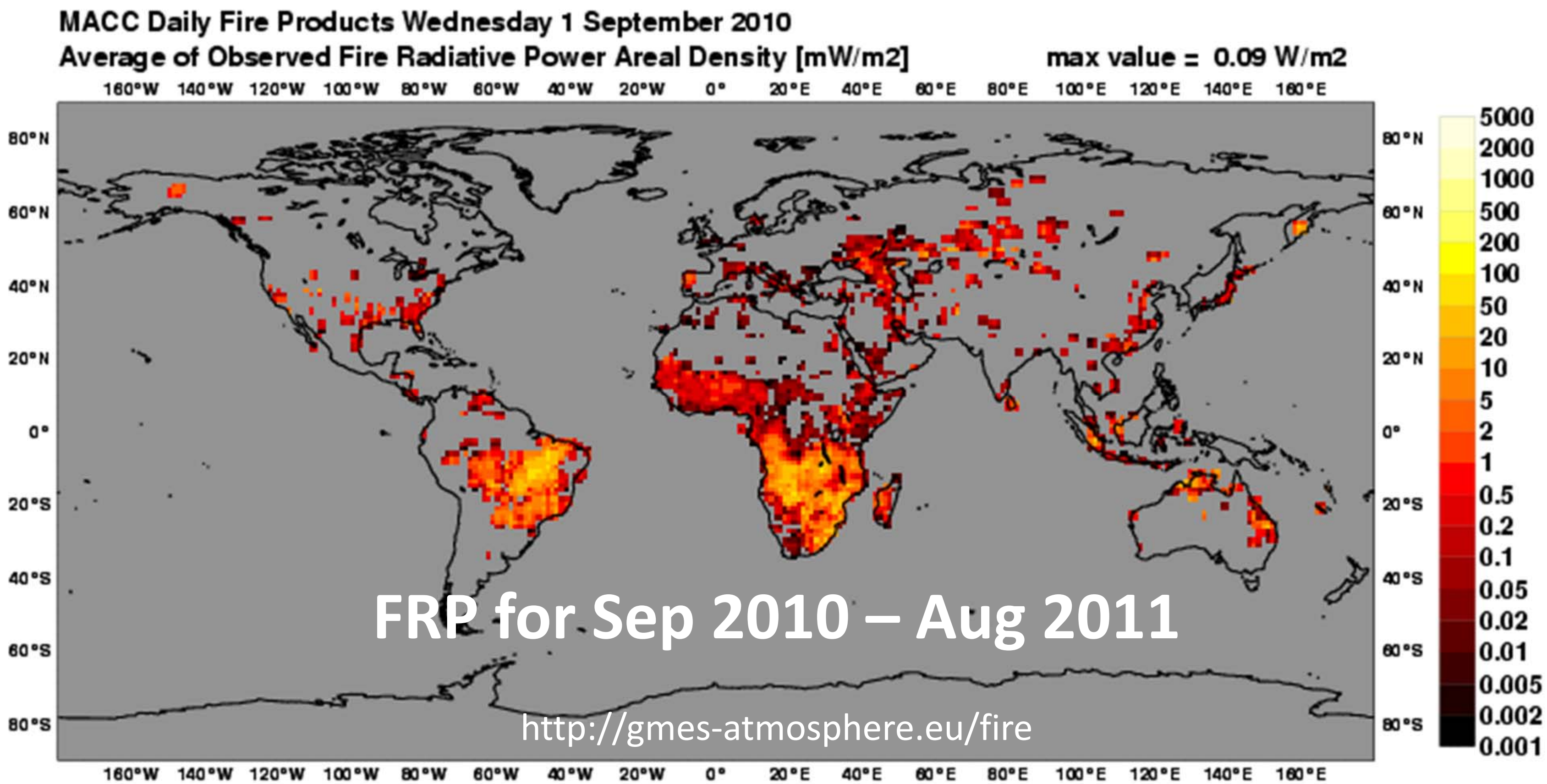


NRT production of daily FRP and Emissions

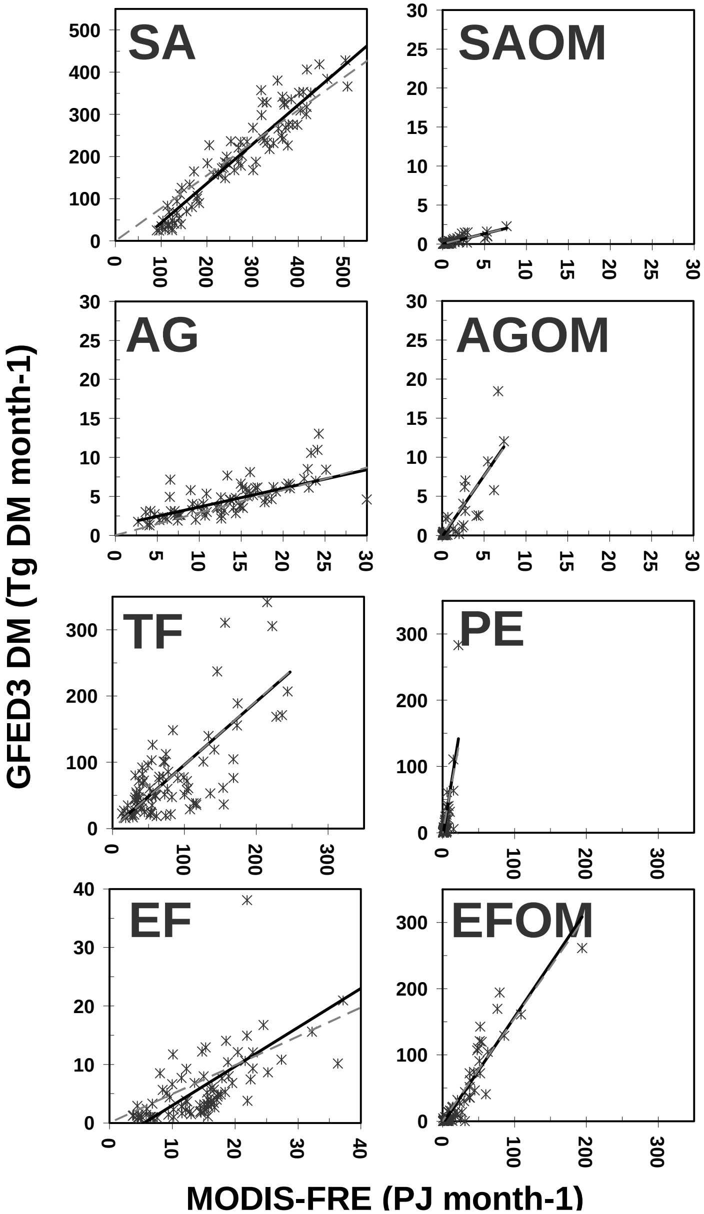
<u>GFASv0</u>
- since GEMS
- MODIS & SEVIRI FRP observations
- ~125 km resolution

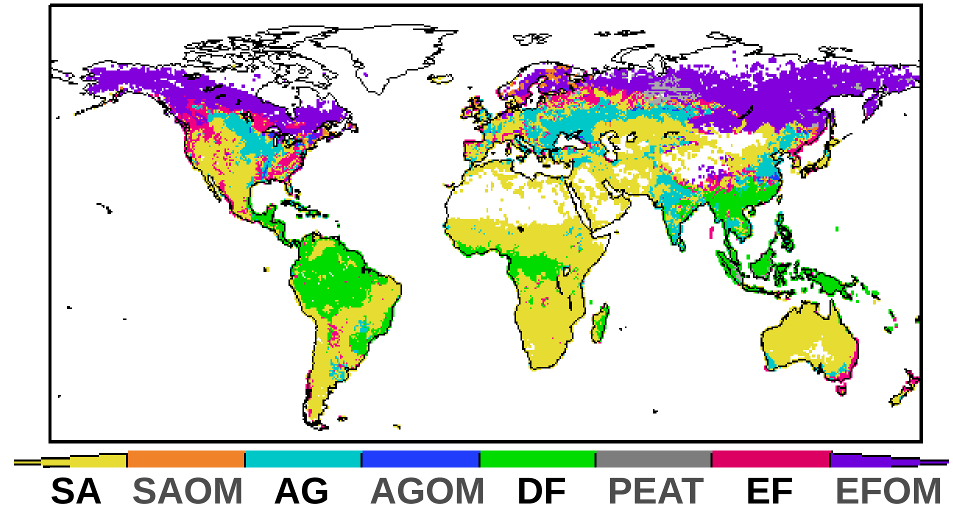
<u>GFASv1.0</u>
- since 17 May 2011
- MODIS FRP assimilation
- ~50 km resolution

<u>GFASv1.1</u>
- since 9 November 2011
- MODIS FRP assimilation
- ~10 km resolution



FRP conversion factor analysis against GFEDv3





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]

Conversion factor depends on dominant fire type!

(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

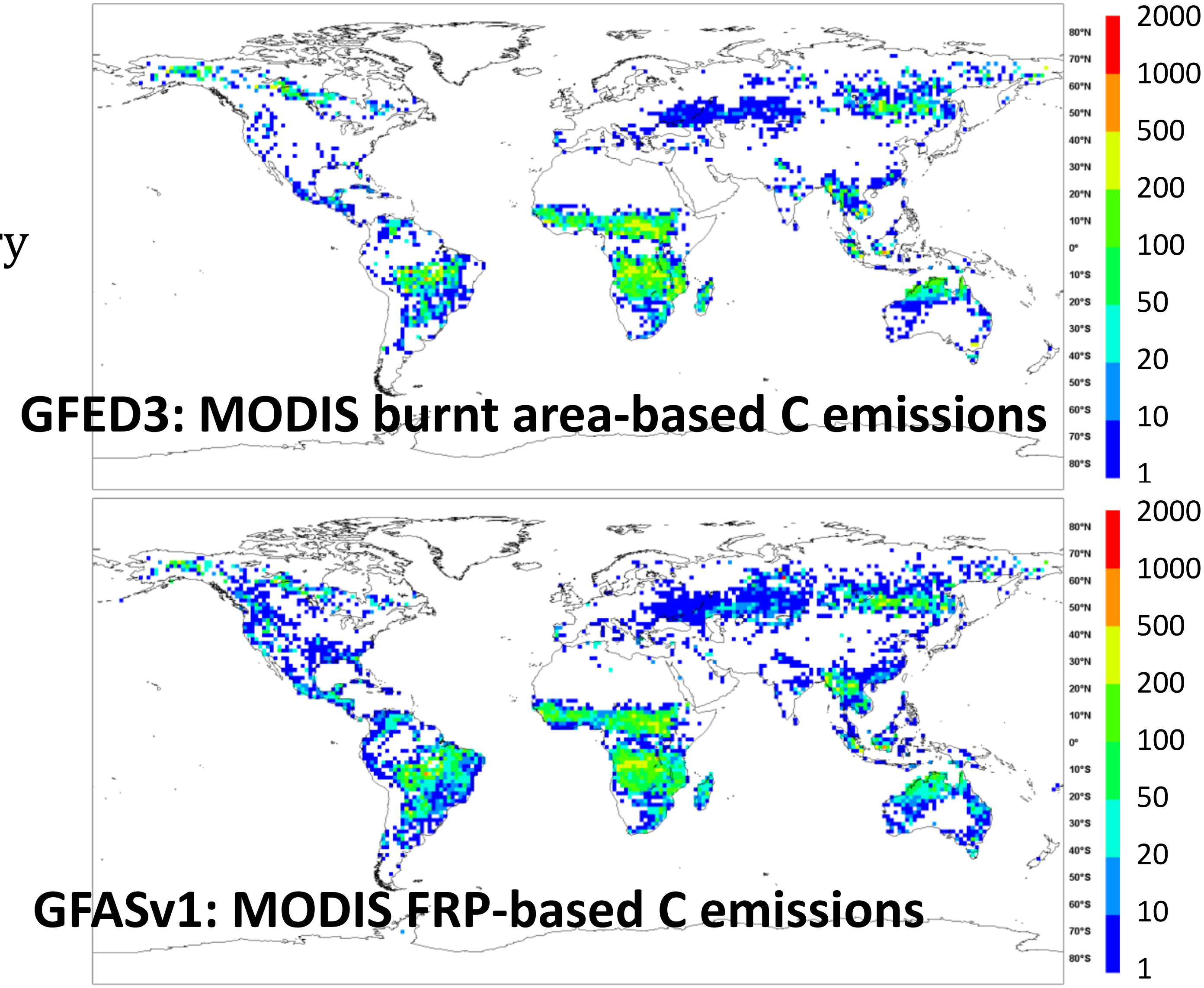
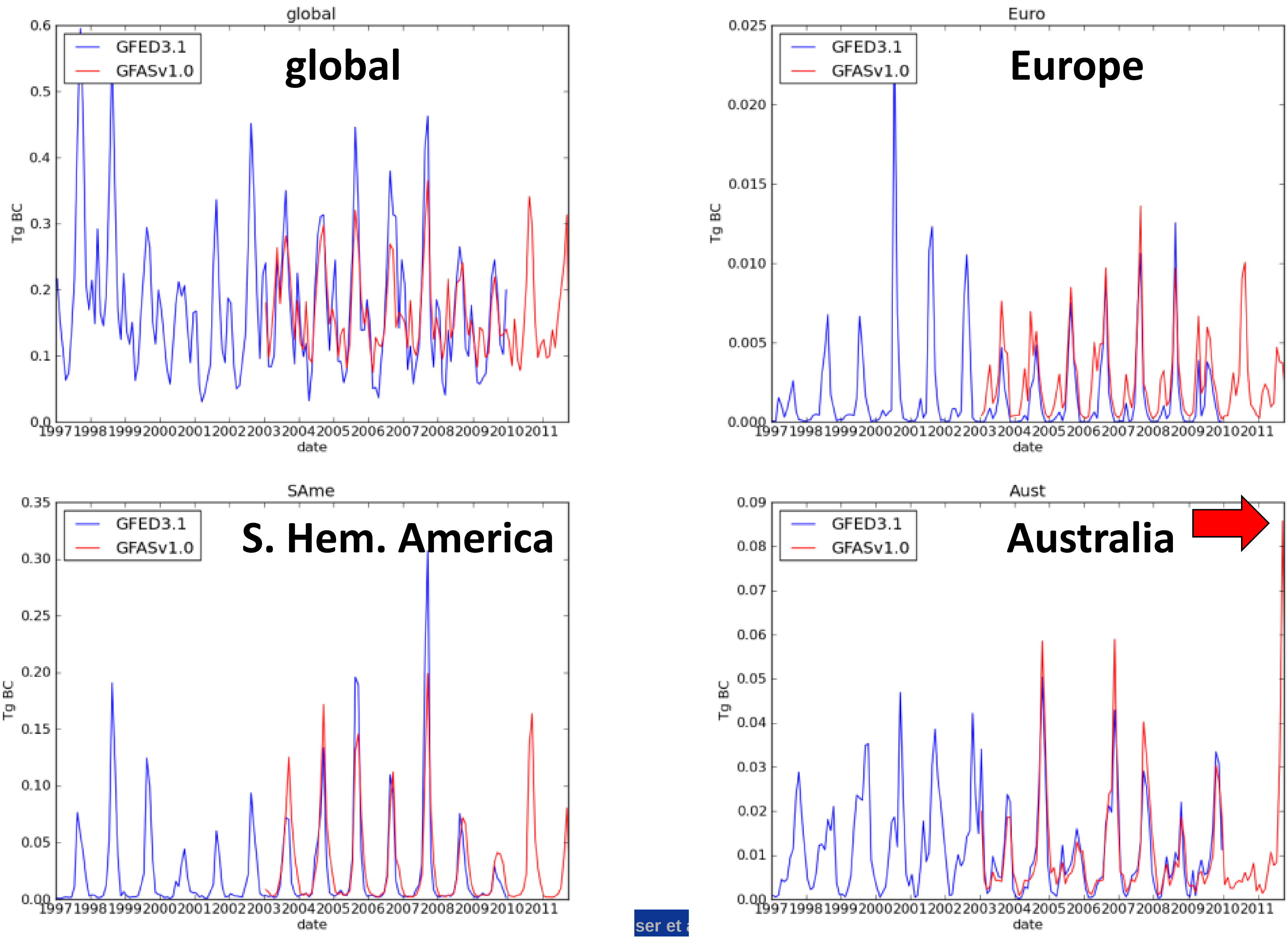
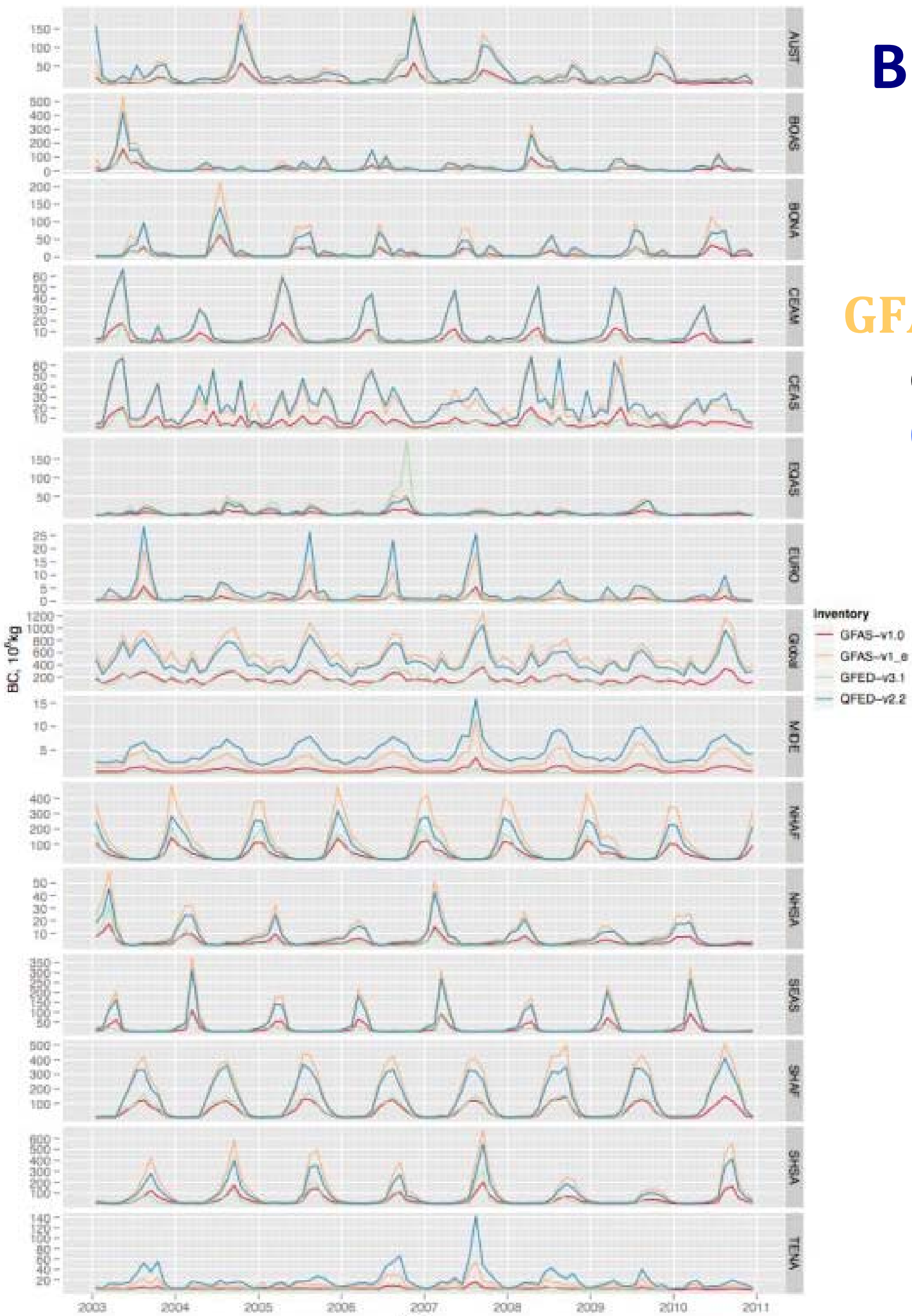


Fig. 5. Average distribution of carbon combustion [g(C) a^{-1} m^{-2}] during 2003–2008 in GFED3.1 (top) and GFASv1.0 (bottom).

(Kaiser et al. 2012)

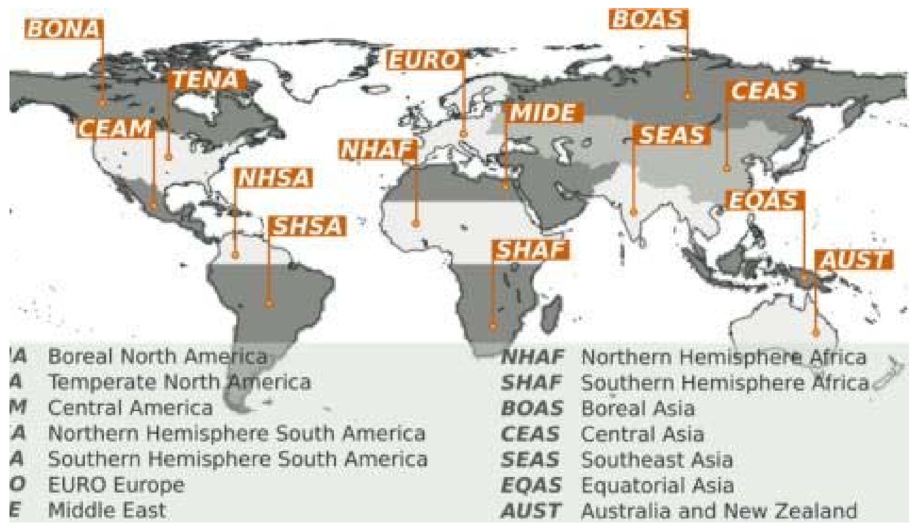
Monthly C emission up to September 2011





Black Carbon Cross-validation

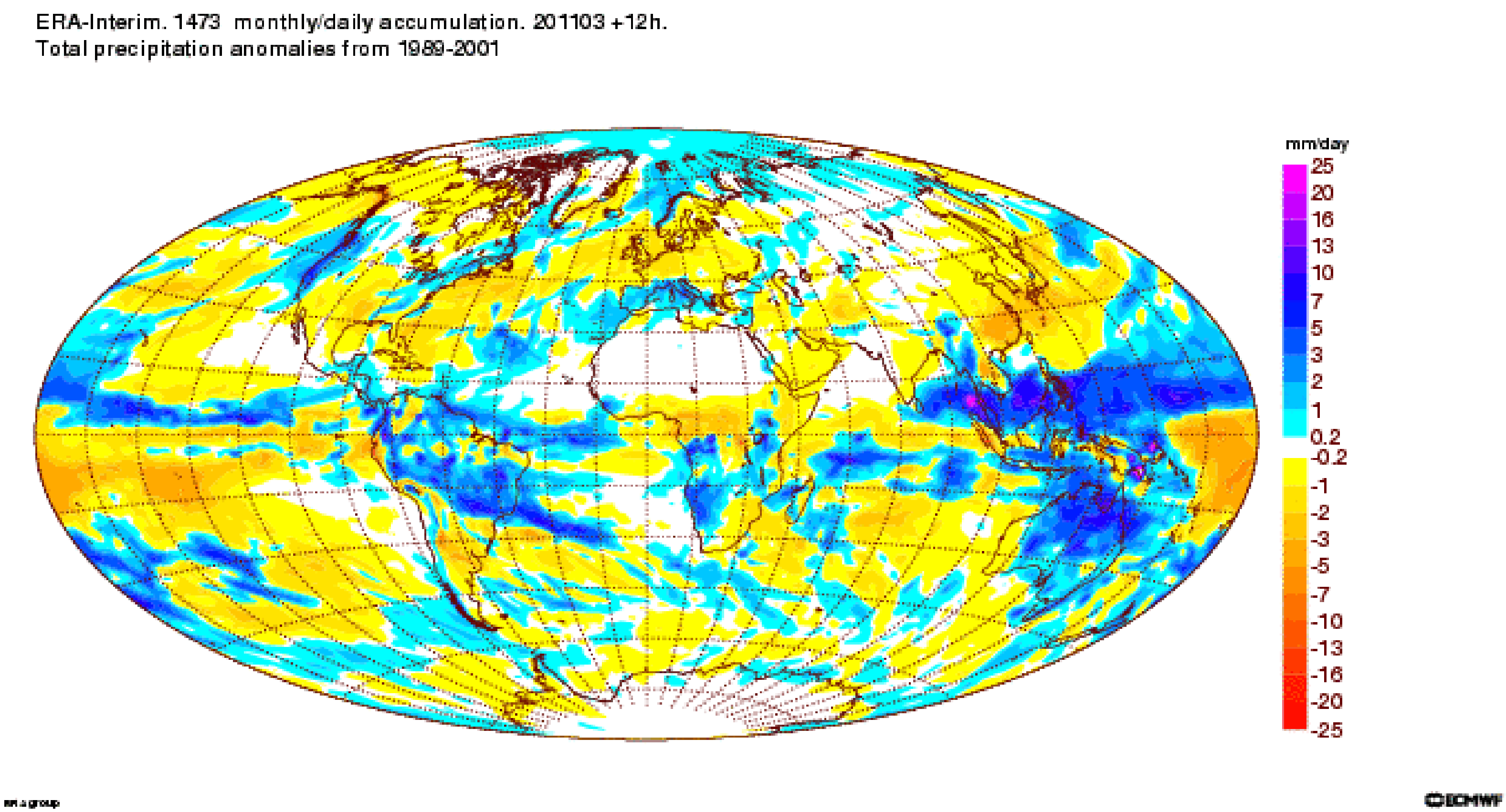
GFASv1.0 (with aerosol enhancement) compares well with NASA's **QFEDv2.2**.

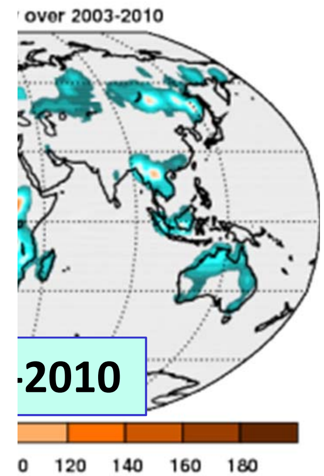


(courtesy A. da Silva)

Applications & Validation

photo: M. Andreae

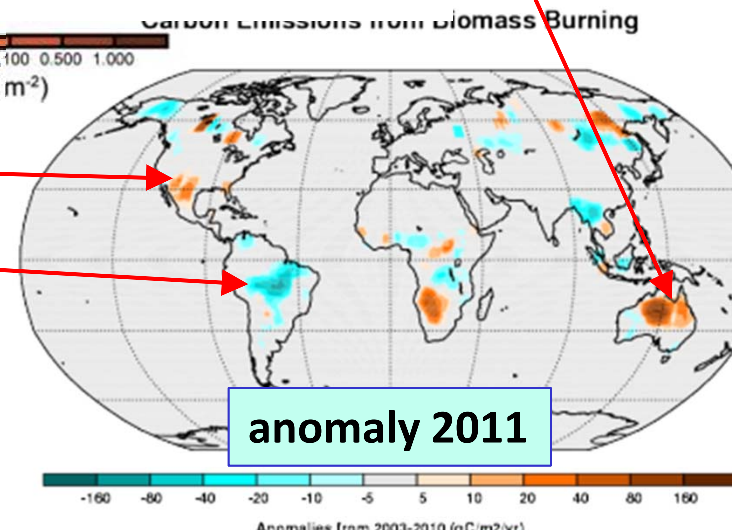




-2010

y in
tlantic

n late 2010,
Mar 2011



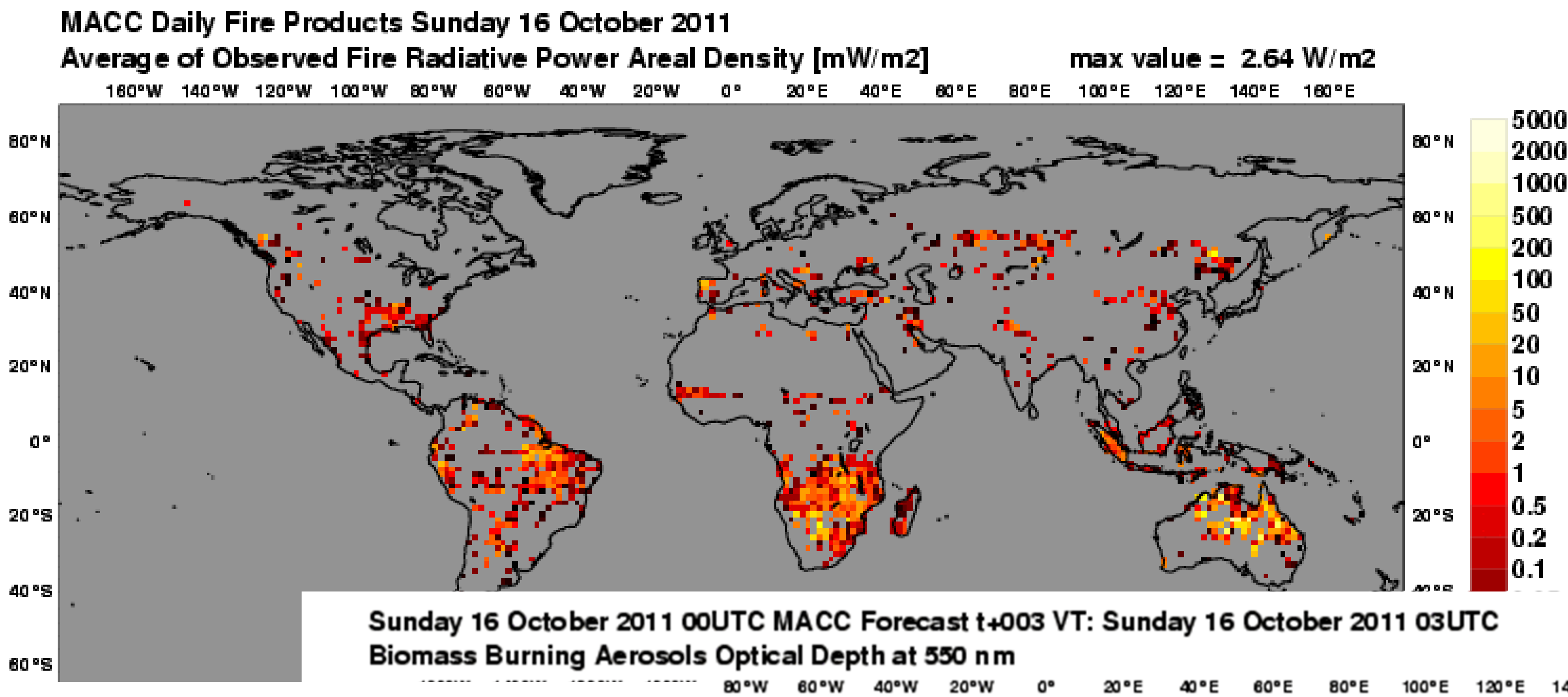
hot and dry

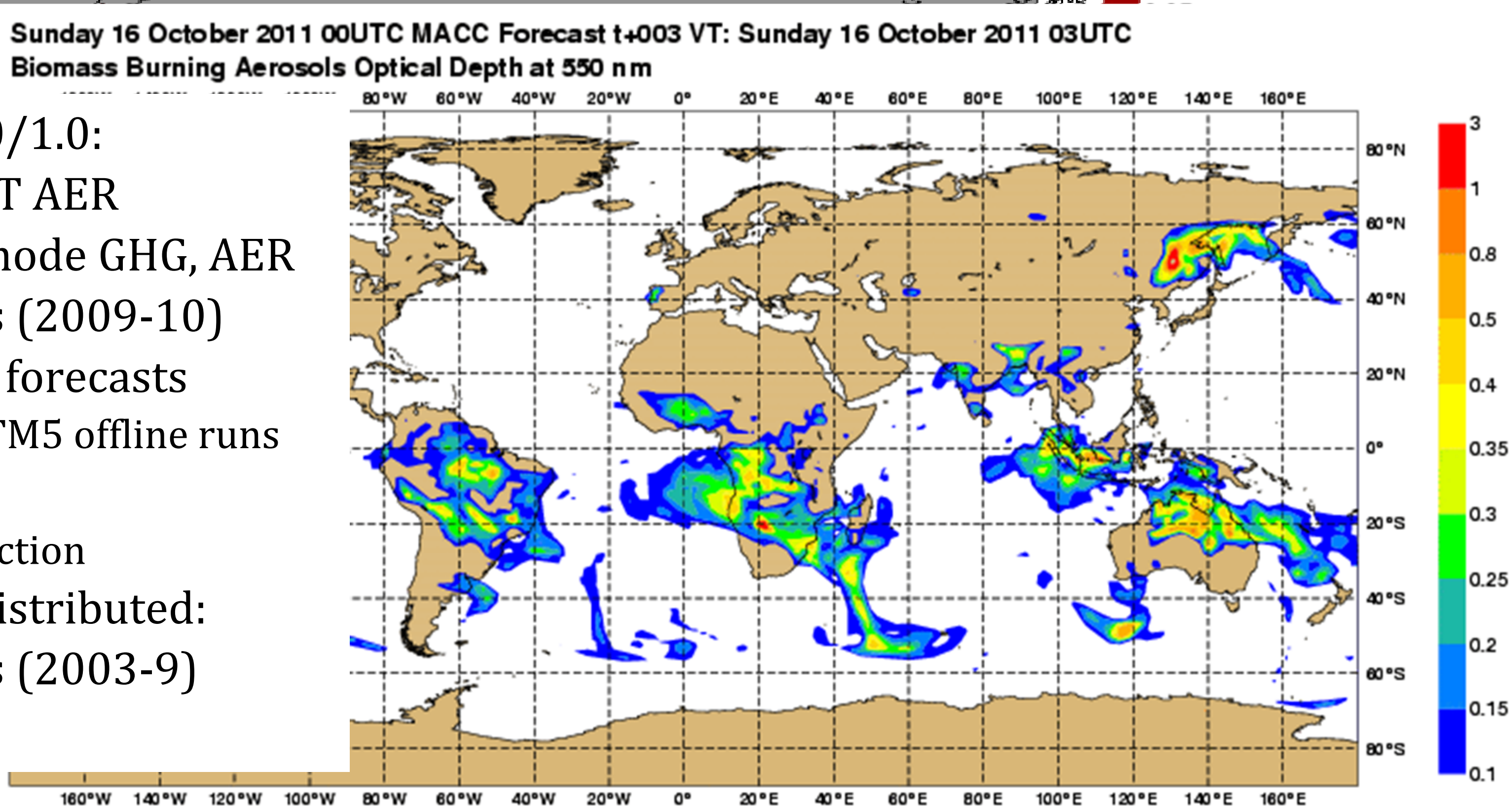
reduced deforestation

anomaly 2011

Annual fire anomalies in NOAA's *State of the Climate* reports. [Kaiser et al. *BAMS* 2010,2011,2012]

D-FIRE Emissions in MACC Systems

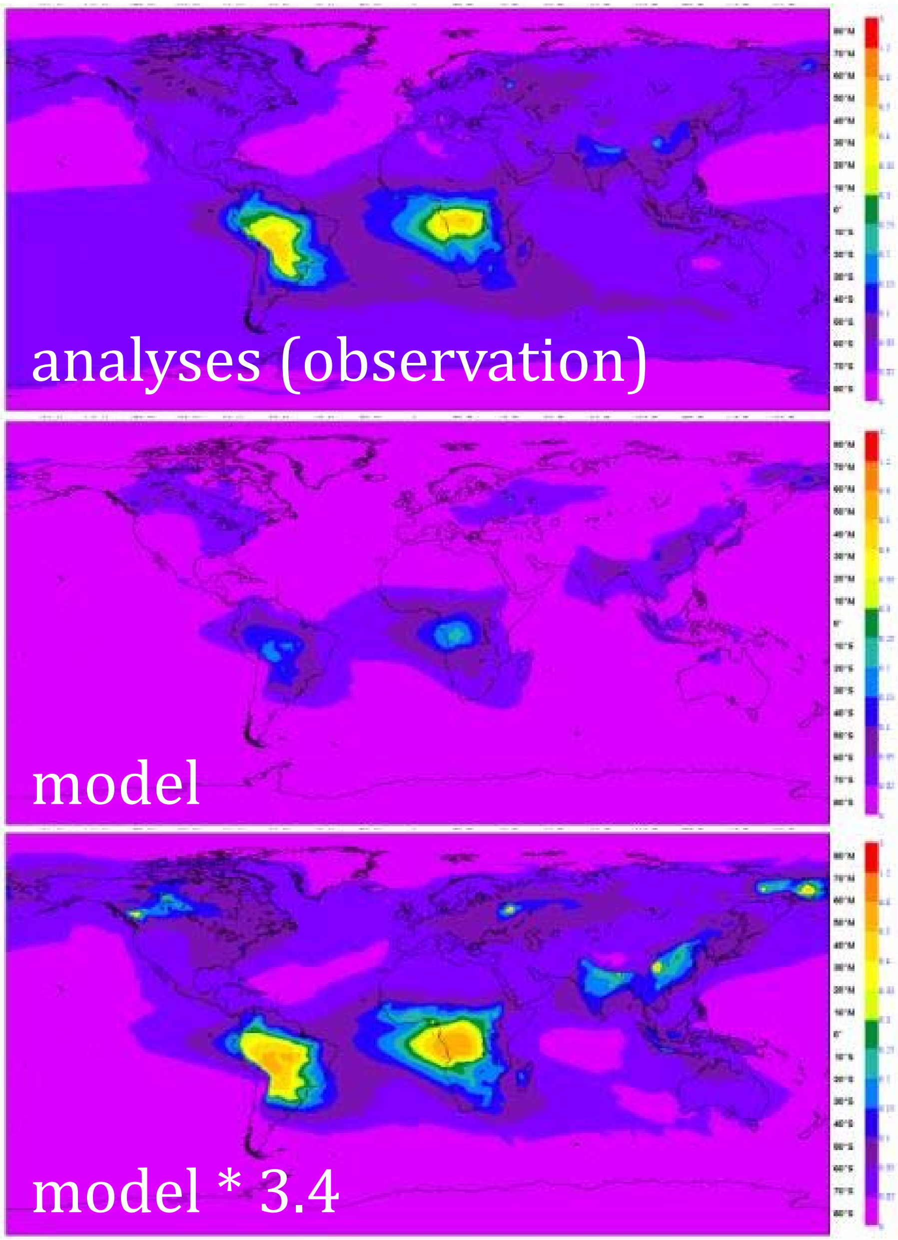




- MACC GFASv0/1.0:
  - global NRT AER
  - delayed-mode GHG, AER
  - reanalysis (2009-10)
  - CO-tracer forecasts
  - MOZART/TM5 offline runs
- GFEDv3.1:
  - GRG production
- GFEDv3.0 redistributed:
  - reanalysis (2003-9)

macc

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:

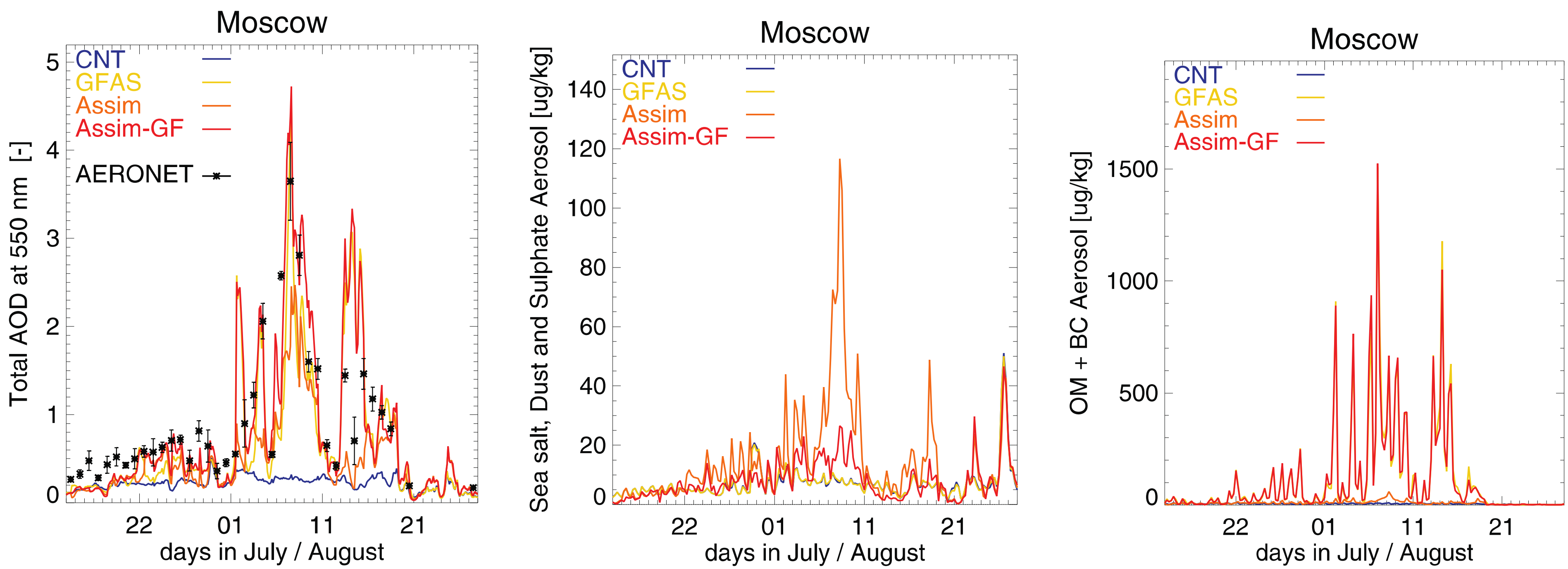
- correct emissions by factor 3.4
- do multi-parameter analysis

[Kaiser et al. 2012]

Russian Fires of Summer 2010

- Assimilation of MODS FRP
  - in GFASv1.0
- Assimilation of MODIS AOD
  - using enhanced GFASv1.0

AOD Simulations with IFS



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

Model, with climatological emissions

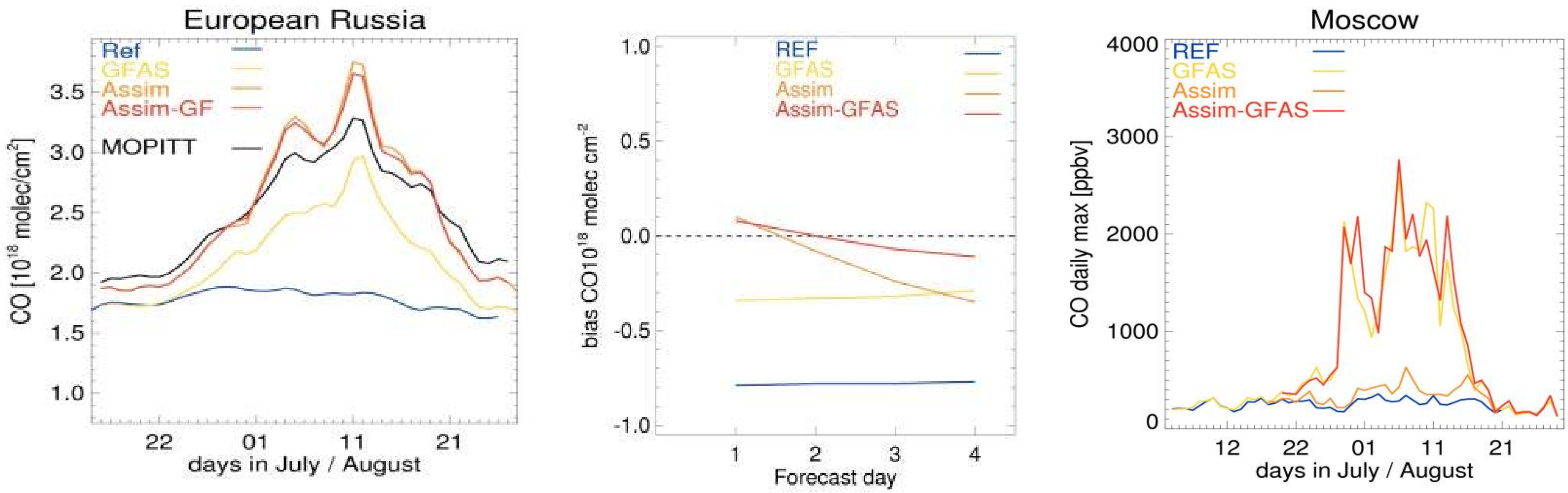
Model, with analysed emissions

Assimilation of AOD, with climatological emissions

Assimilation of AOD, with analysed 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.

Model, with climatological emissions

Model, with analysed emissions

Assimilation of IASI CO, with climatological emissions

Assimilation of IASI CO, with analysed emissions

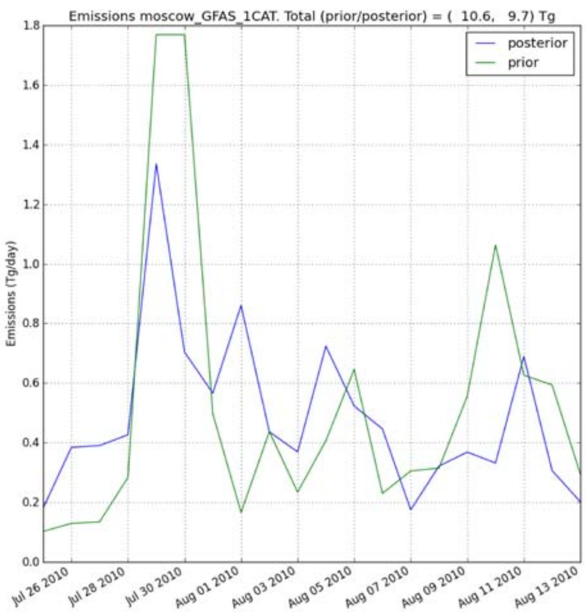
[Huijnen et al. 2012]

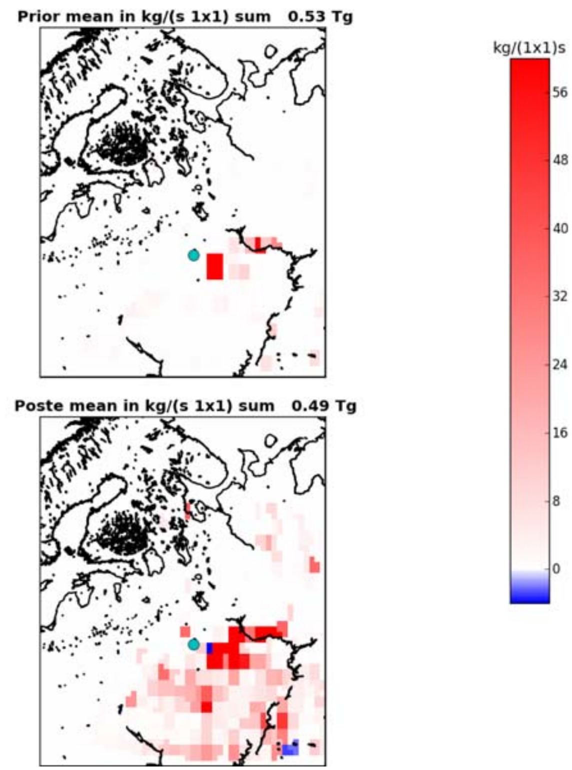
IASI-CO based Inversion in ESA ALANIS *Smoke Plumes*

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

NOVELTIS UCL JRC EUROPEAN COMMISSION WAGENINGEN UR LATMOS

Optimized from GFAS prior

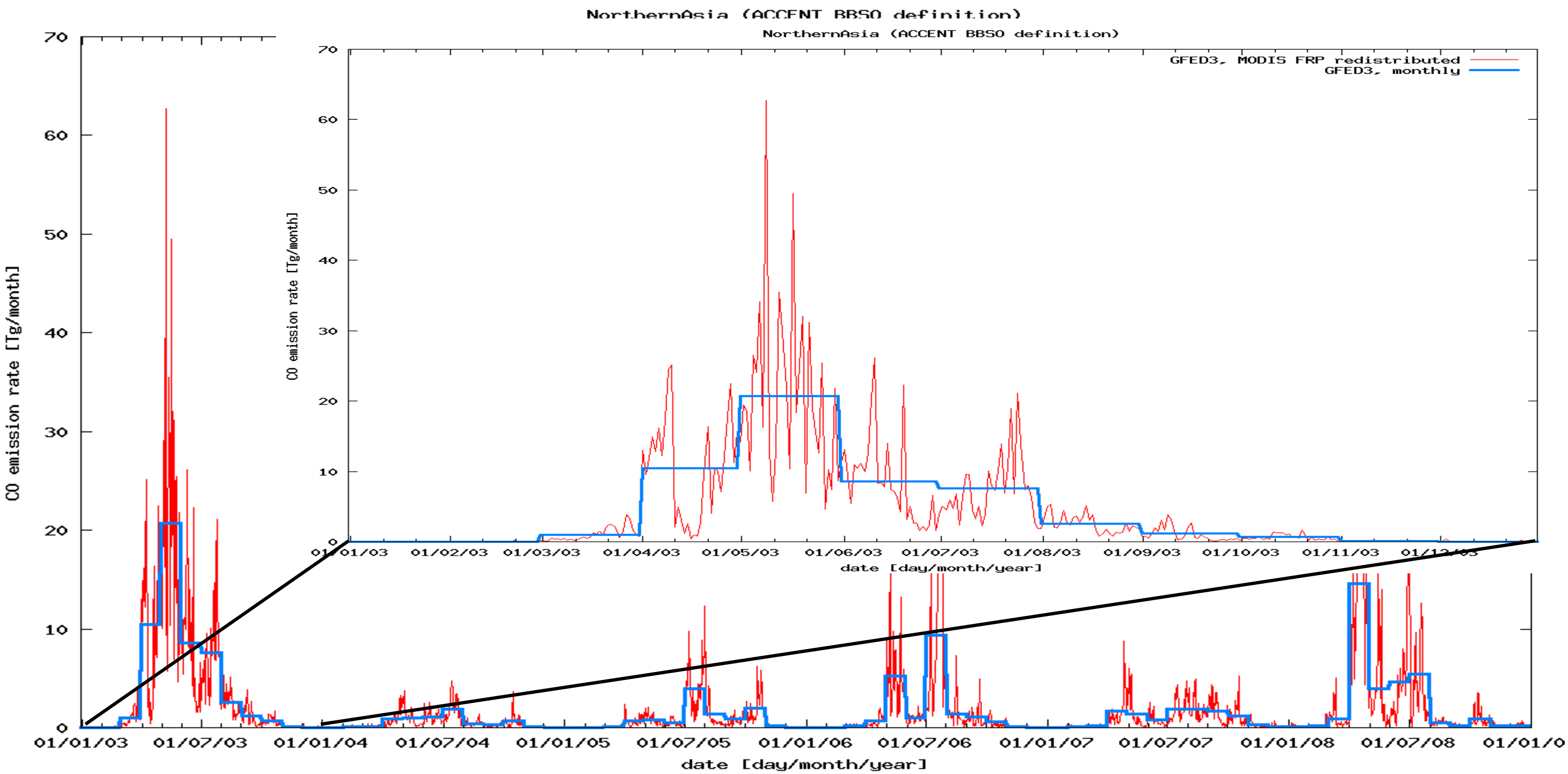


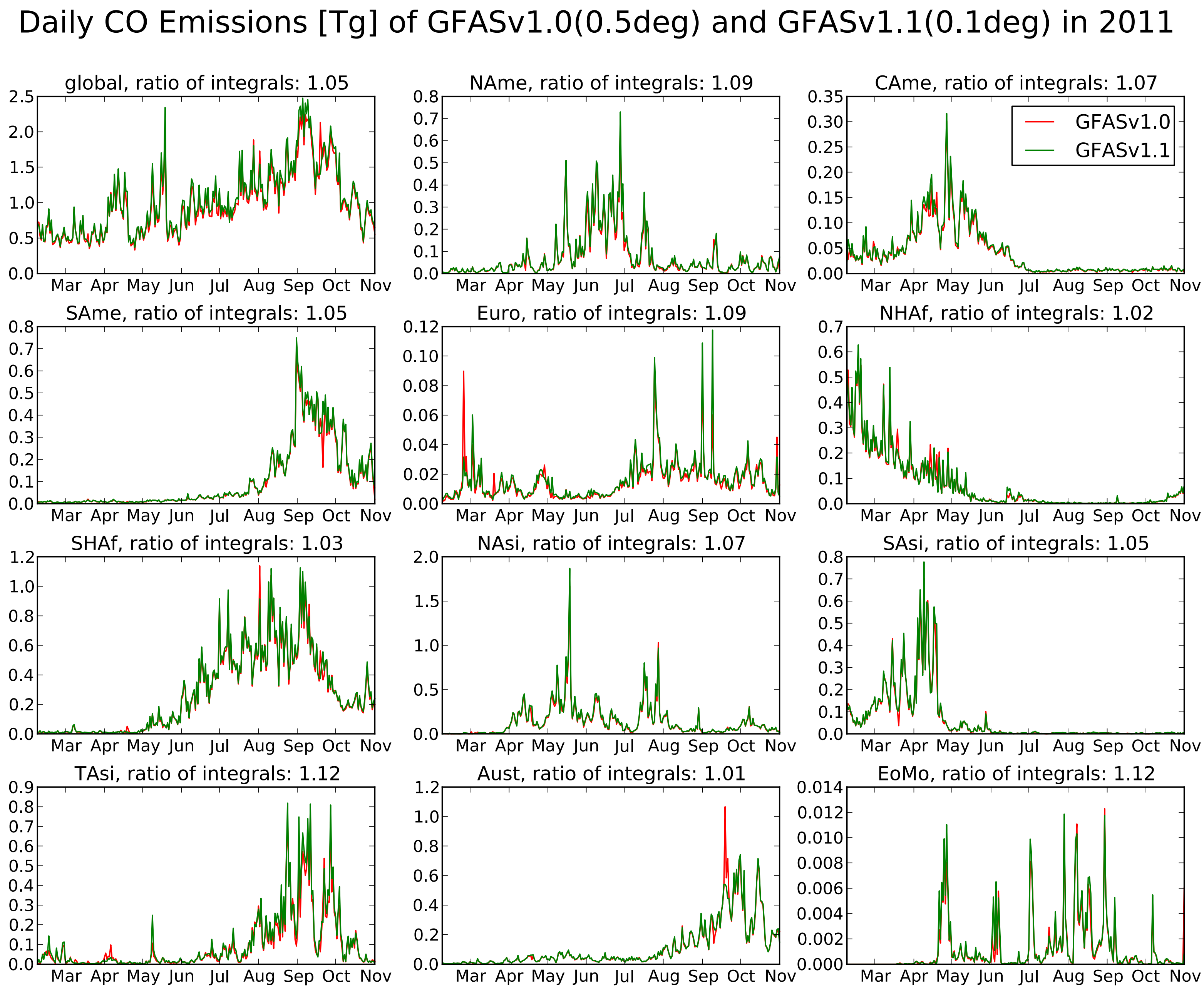


Derived Products

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 of resolution of 1 day, 0.1 deg



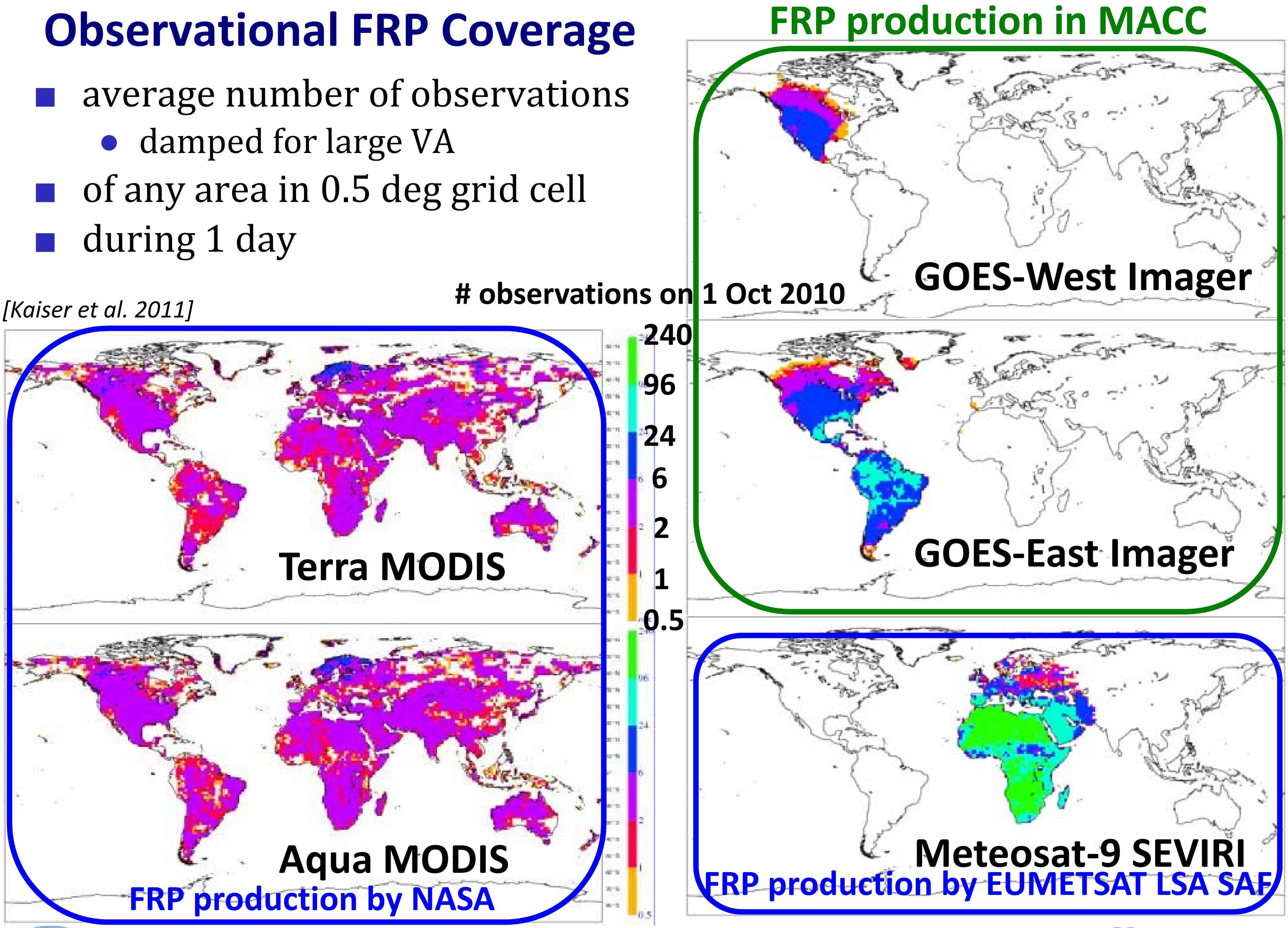

Daily CO Emissions [Tg] of GFASv1.0(0.5deg) and GFASv1.1(0.1deg) in 2011
global, ratio of integrals: 1.05
NAme, ratio of integrals: 1.09
CAme, ratio of integrals: 1.07
GFASv1.0
GFASv1.1
SAme, ratio of integrals: 1.05
Euro, ratio of integrals: 1.09
NHAf, ratio of integrals: 1.02
SHAf, ratio of integrals: 1.03
NAsi, ratio of integrals: 1.07
SAsi, ratio of integrals: 1.05
TAsi, ratio of integrals: 1.12
Aust, ratio of integrals: 1.01
EoMo, ratio of integrals: 1.12
Mar Apr May Jun Jul Aug Sep Oct Nov

Ongoing Developments

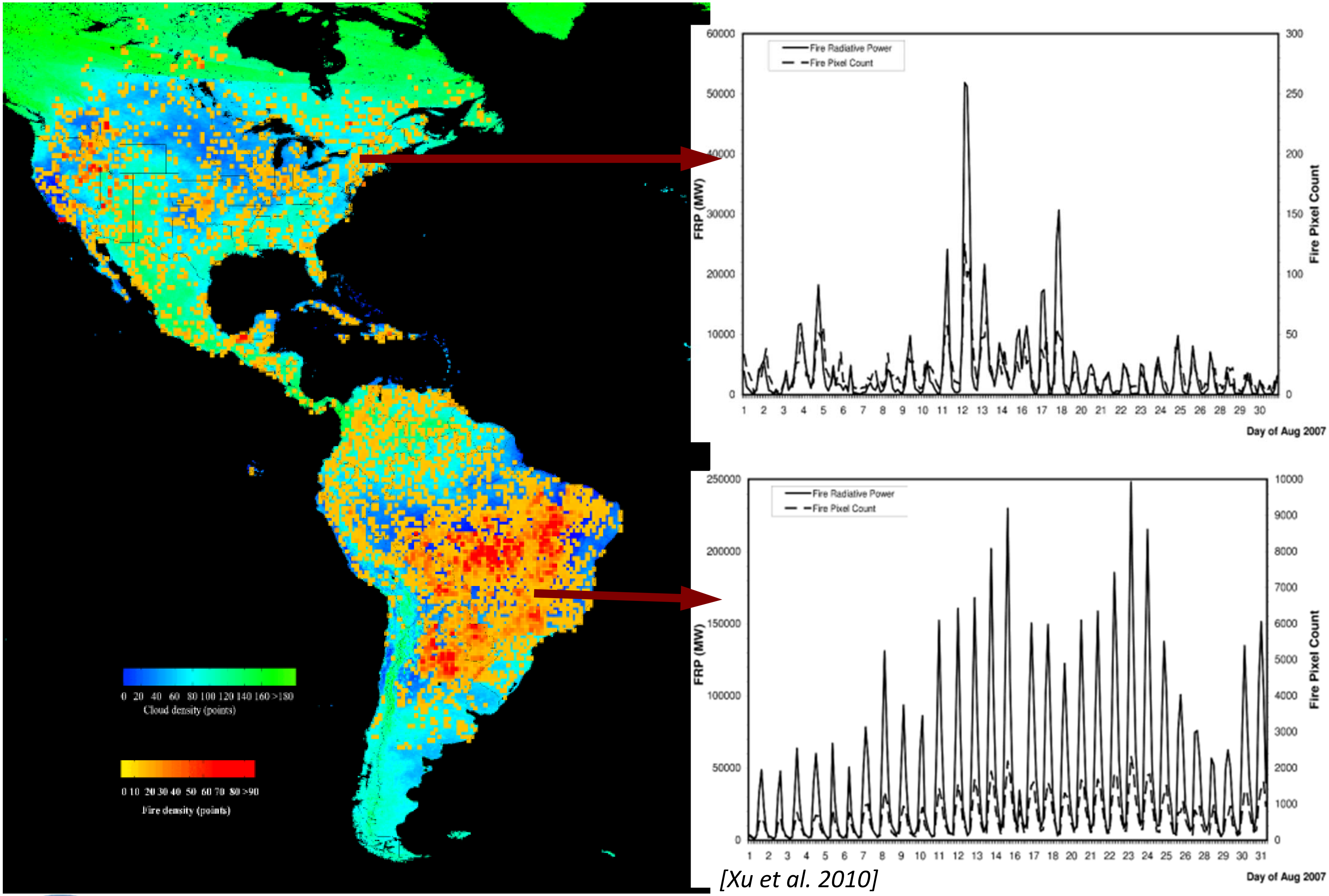
Observational FRP Coverage

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

[Kaiser et al. 2011]



Fires Diurnal Cycle in Americas from GOES-W



[Xu et al. 2010]

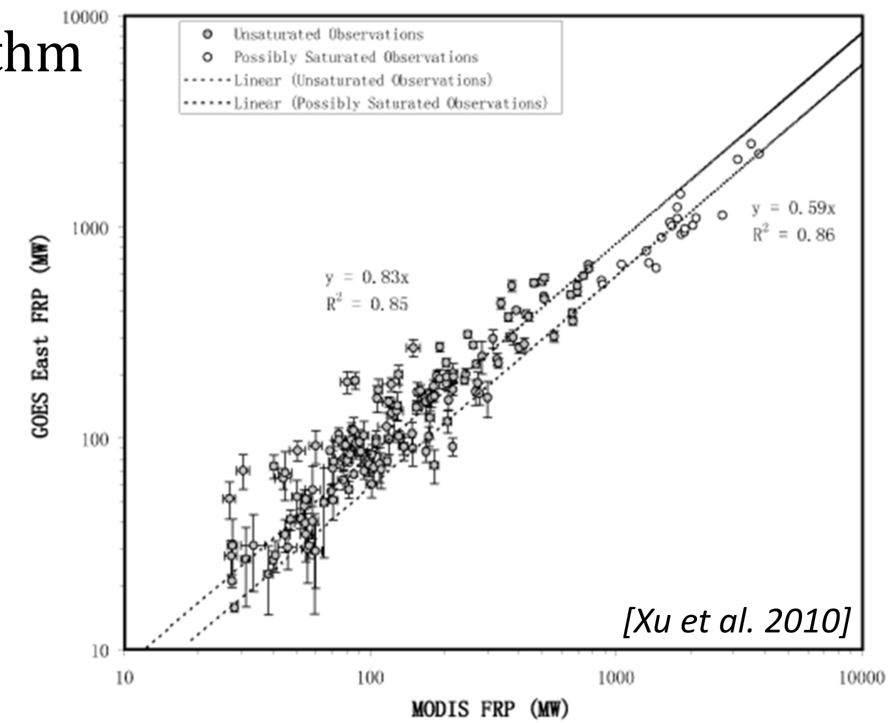
GOES-East/-West FRP Product Generation in MACC-II

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

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

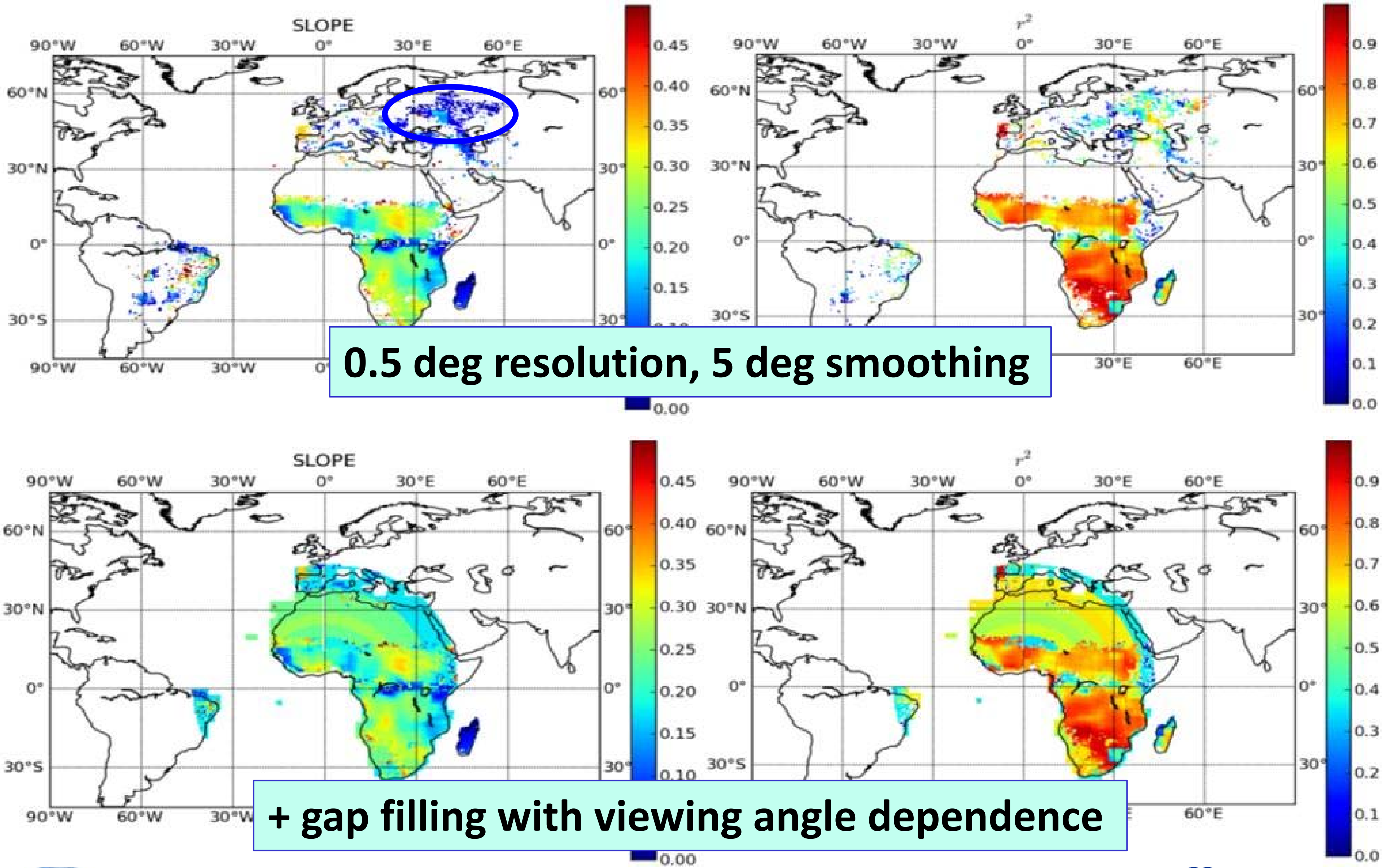
- based on SEVIRI processing algorithm

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

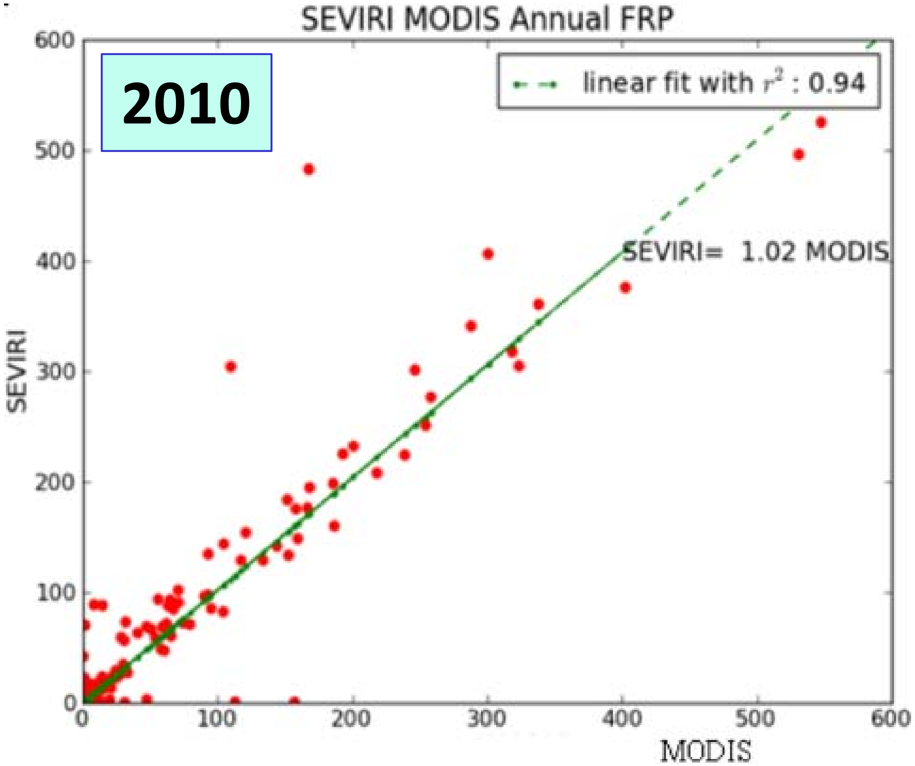


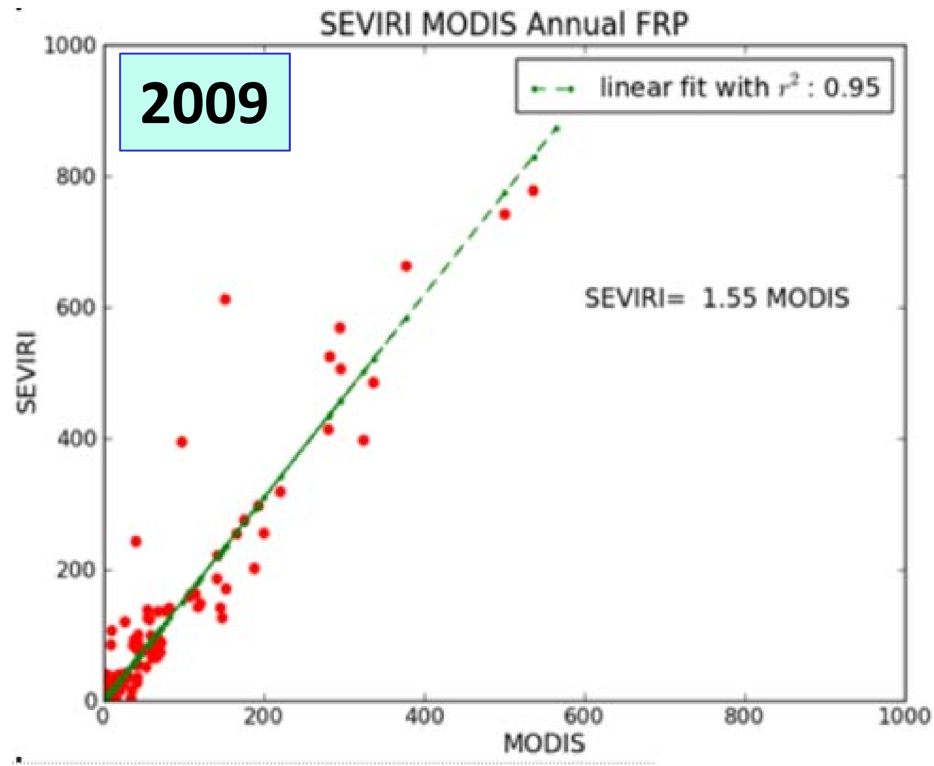
[Xu et al. 2010]

Linear Regression: SEVIRI over MODIS areal FRP in 2010



Corrected SEVIRI FRP over MODIS FRP



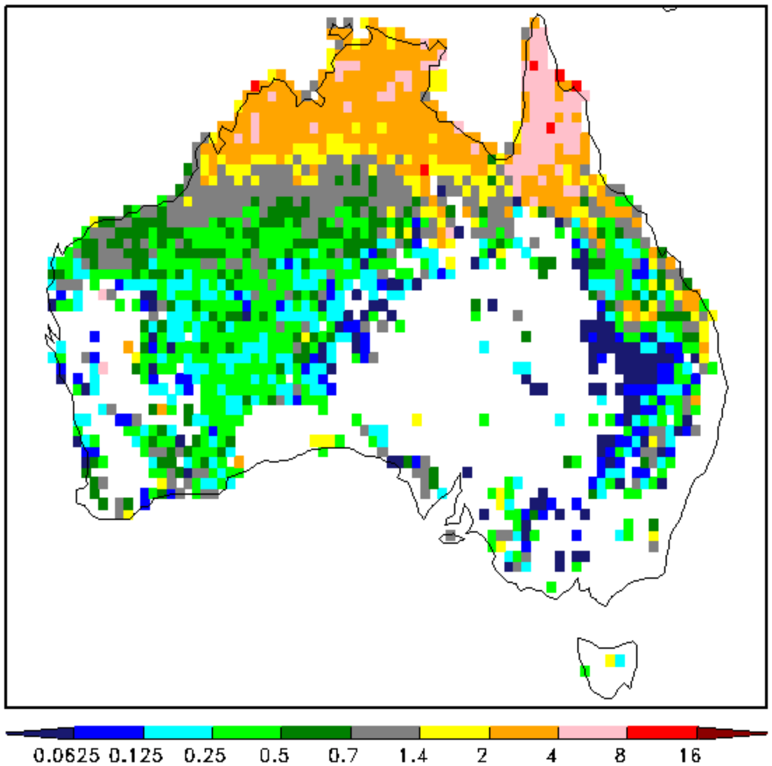


- strong regional variations
- strong temporal variations

- static bias correction impossible
- dynamic, "on the fly" approach needed

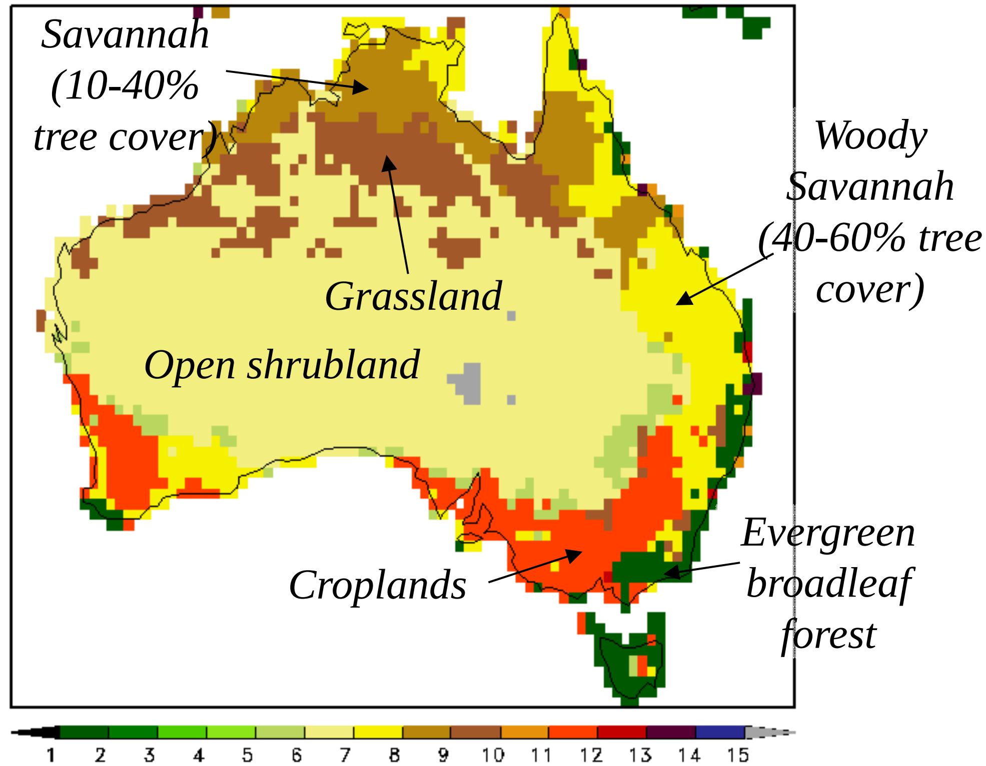
Ratio of GFED3 to GFASM

Ratio for Savannah Fuel (SA) of Australia



Ratio GFED3/GFASM DM burned

MCD12C1 Predominant MODIS/Terra+ Aqua Land Cover Type Year 2005

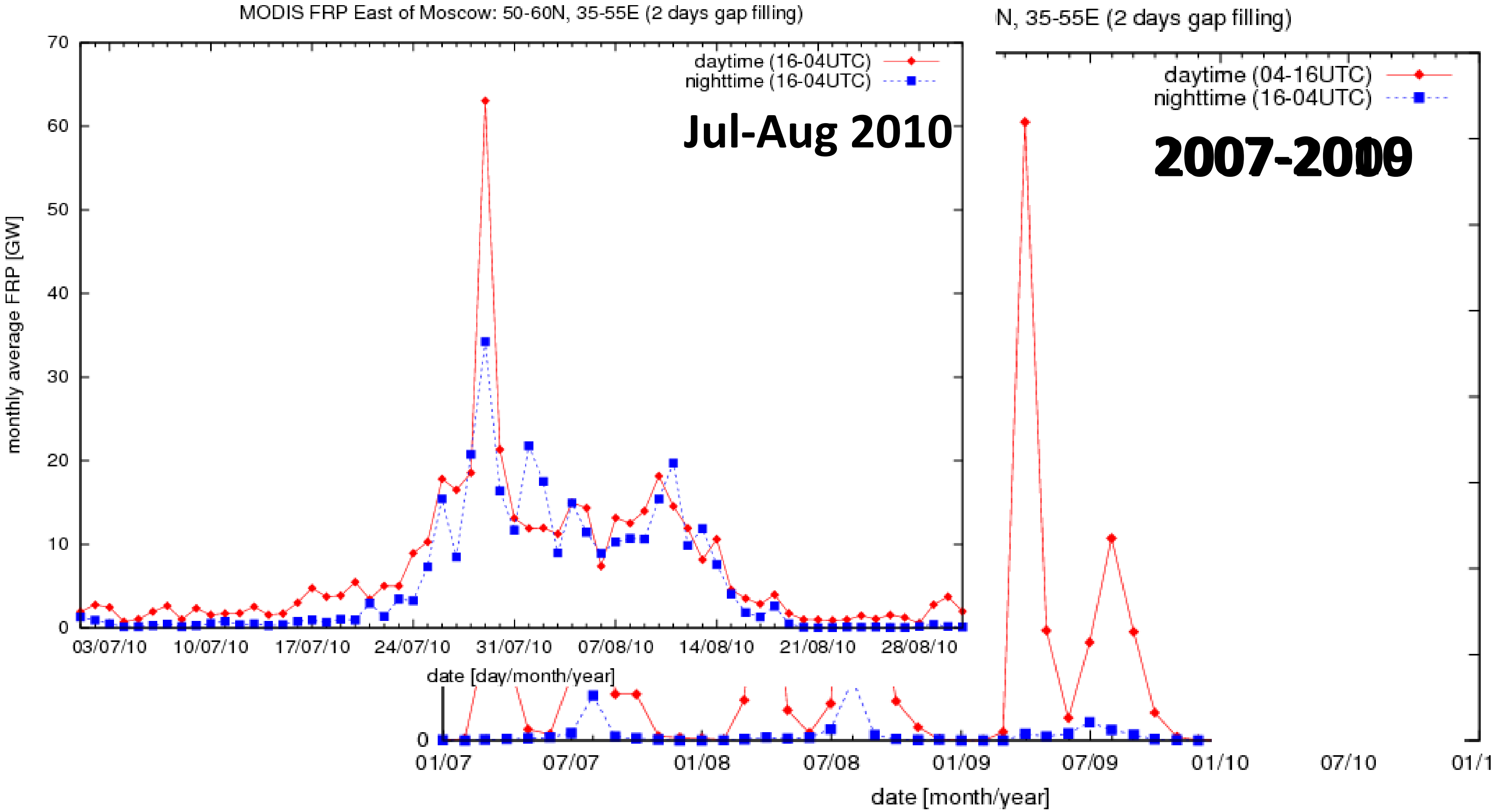


IGBP Land Cover Classification Type

→ Increasing GFED3/GFASM ratio with increasing fractional tree cover

→ Indication of attenuation of FRP signal by tree canopy

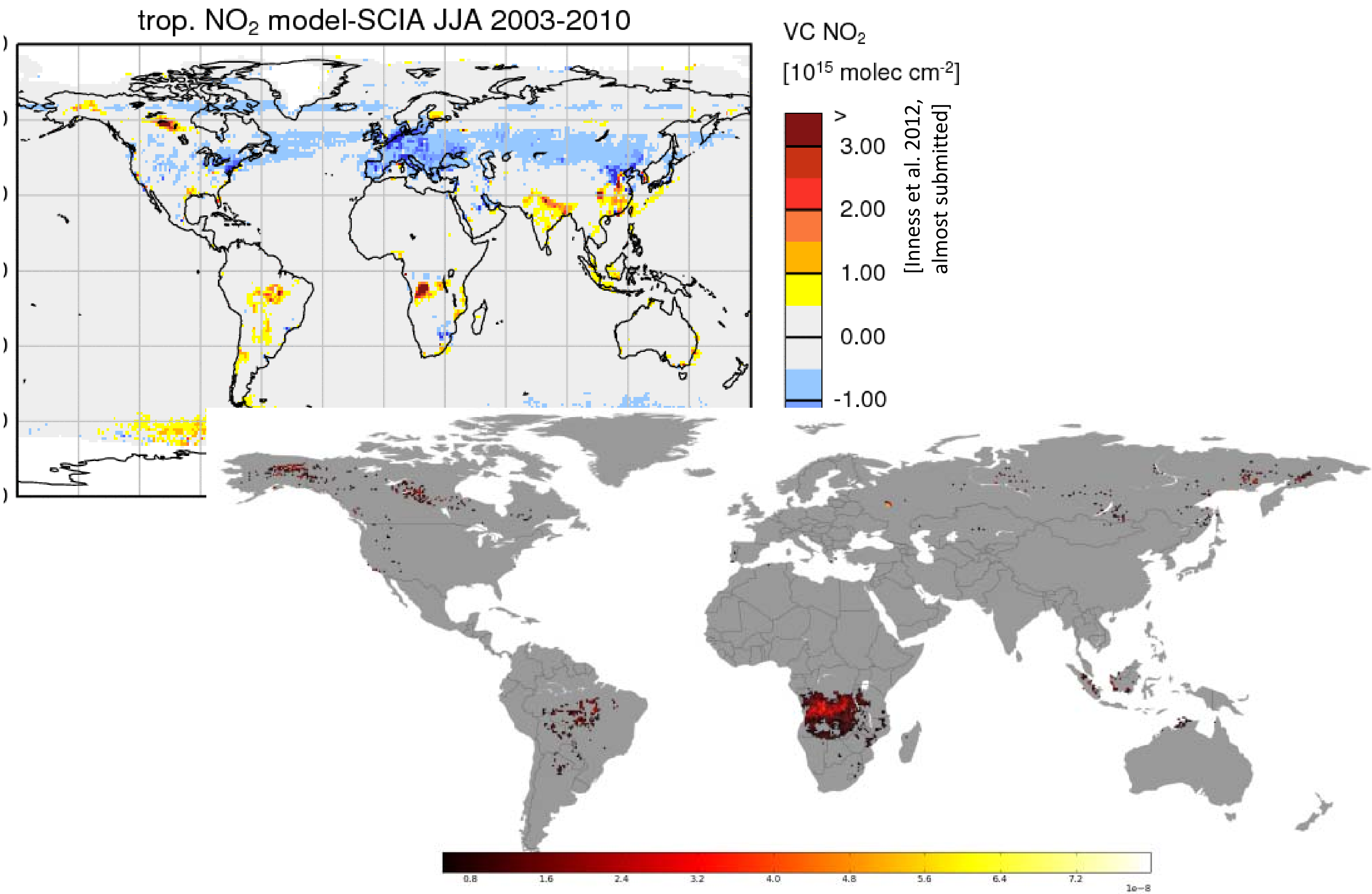
2010 Fires in Russia: Burning throughout the Night!



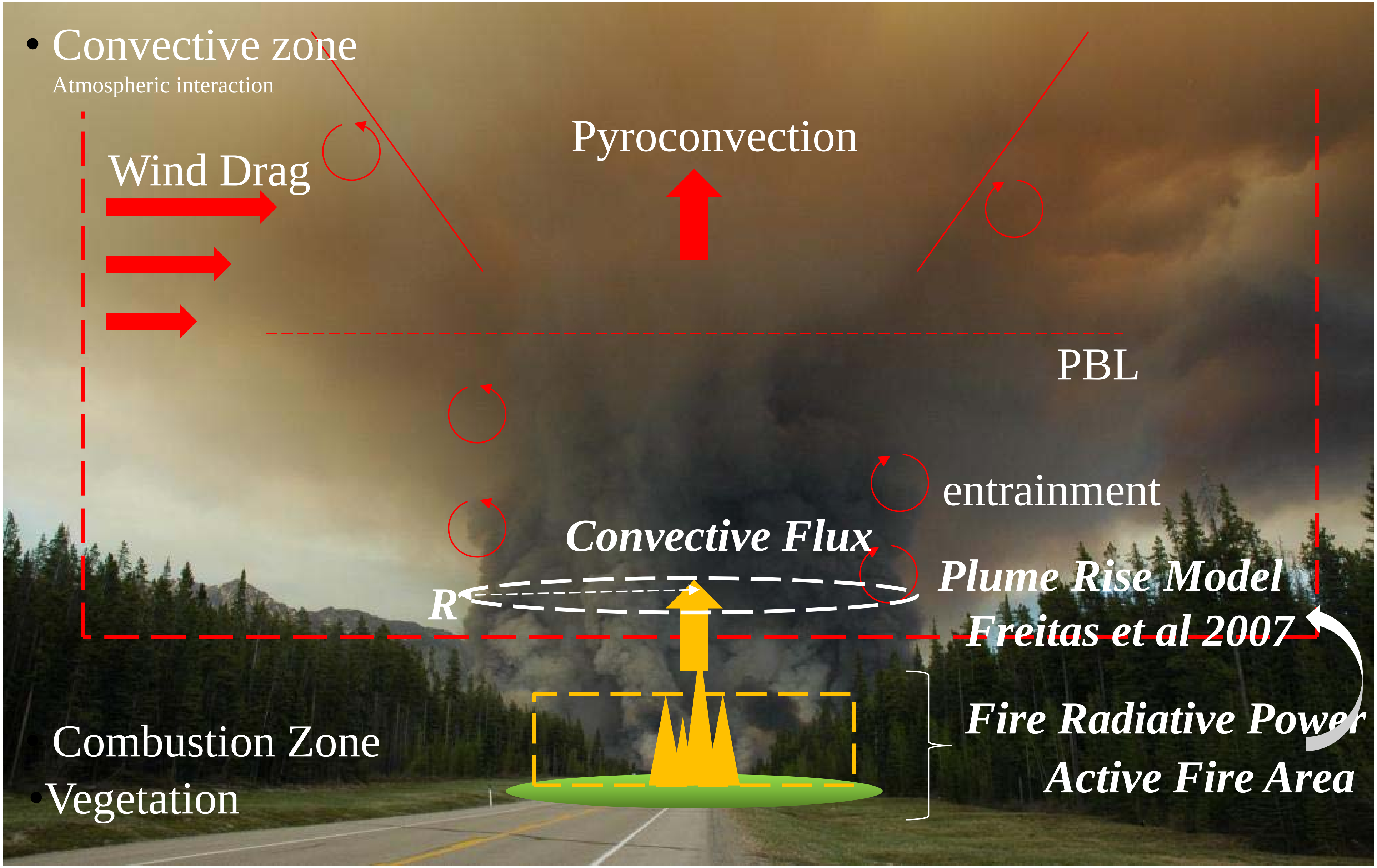
- according to FRP, probably smouldering sub-surface fires
- Conversion and emission factors need to be adapted dynamically.

[Kaiser et al. 2011]

Are NO2 emission estimates too high?



Injection Heights: Plume Rise Model



Conclusion and Perspective on Plume Rise

Conclusions so far:

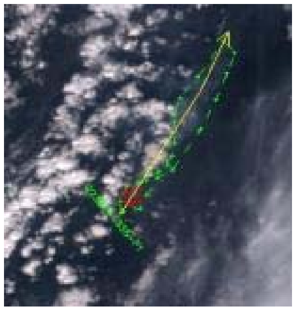
- Literature shows a need for more robust parameterization
- So far, the plume rise model approach seems the most adequate
- Current Work:
  - comprehensive MISR validation / training data set
  - new assumption in the model
  - Optimization and Validation are still undergoing

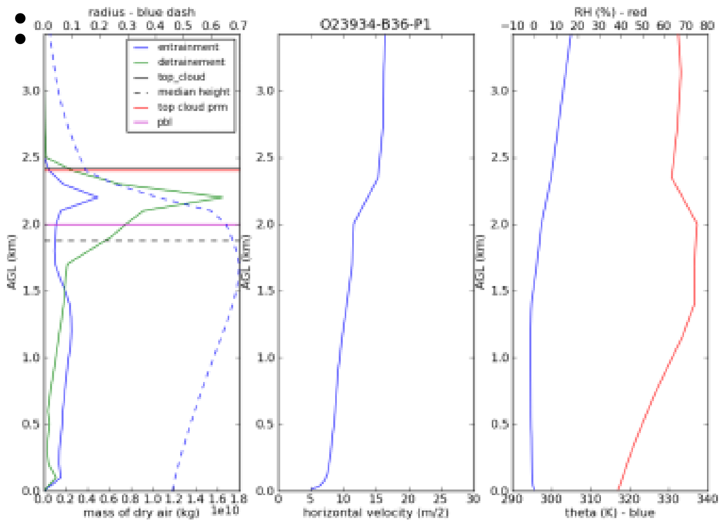
Perspective:

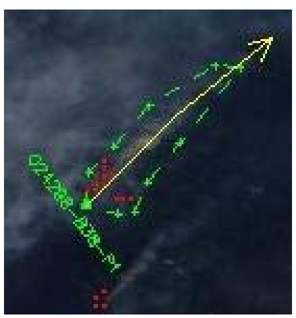
- Use of more MISR Observation: other vegetation type and geographical location
- Possible collection of more detailed data (SAMBBA) usable for validation
- Use of high resolution model? [Trentmann 2002]
- Validation at both fire event and regional scale

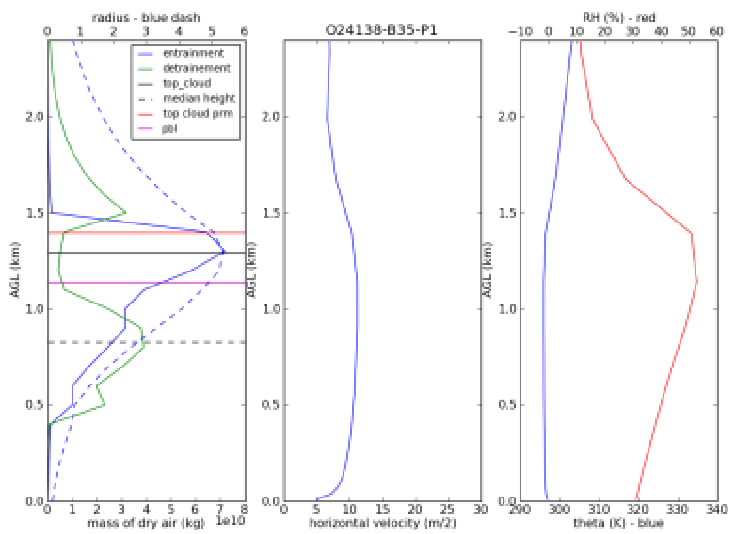
Plume Rise Model: Result

Single fire :

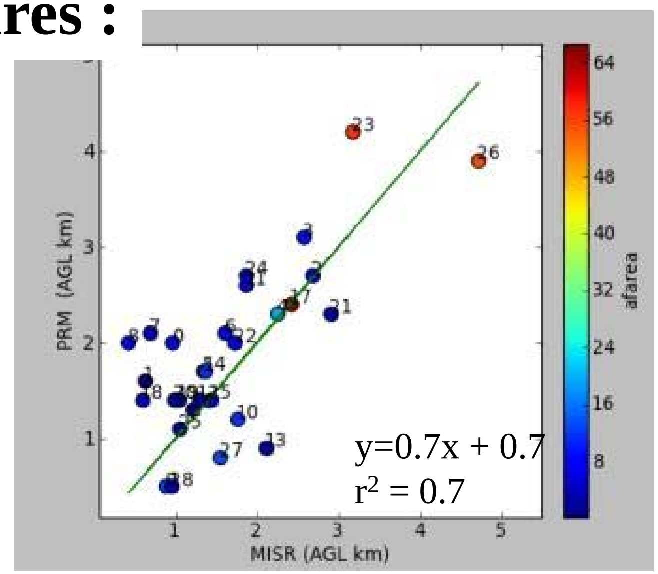


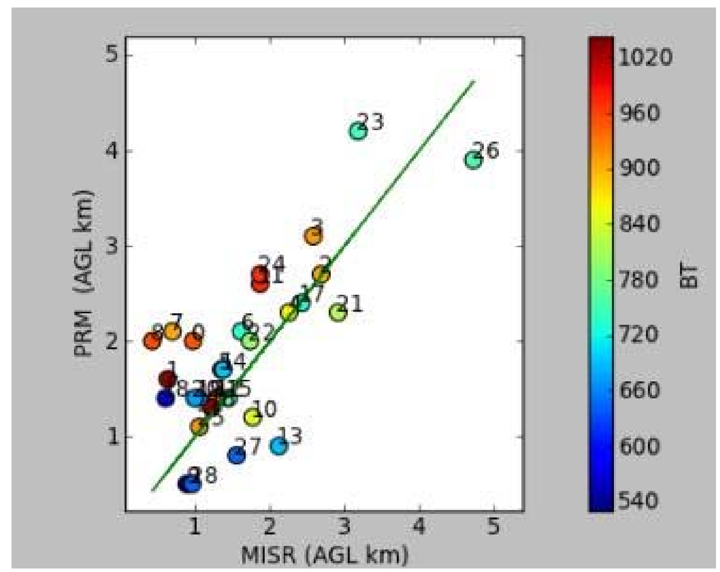






29 fires :





detrainment zone and time dependence?

Summary


www.wildlandfire.com

FIRE Product Overview

- GFASv1.0 products also publicly available in NetCDF format from
  - http://macc.icg.kfa-juelich.de:50080
  - http://geiacenter.org

Monitoring atmospheric composition & climate — Logout

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- Reactive Gases
- Aerosols
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Products Archived in MARS

EXPV	Time Range	Temporal Resolution	Spatial Resolution	Type	Species
f7i1	10/2008-present	1 day / 1 hour	T159	FRP-NRT	a (since 17Jun10 also NOx, NMHC)
f7i2	10/2008-present	1 day / 1 hour	T159, archived as 0.1 deg	FRP-NRT (GFASv0)	a (since 17Jun10 also NOx, NMHC)
f922	1/2003-1/2009	1 day / 1 hour	0.1 deg	MODIS FRP	FRP (W/m2)
f98v	1997-2000,2008*	1 month	1.0 deg	GFED2	a,b
f98v	2001-2007	8 days	1.0 deg	GFED2	a,b
fa5z	1997-2008*	1 month	0.5 deg	GFED3.0	a,b,c
fagg	2003-2008	1 day	0.1 deg	redistributed GFED3.0	a,b,c
fhhi	1997-2009*	1 month	0.5 deg	GFED3.1	a,b, DM
ffxr	2003-present	1 day	0.5 deg	MODIS FRP-NRT (GFASv1.0)	a,b,c,d
fl6z	7 Feb 2011 - present	1 day	0.1 deg	MODIS FRP-NRT (GFASv1.1)	a,b,c,d

* 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, CH3OH, Higher_Alkanes, Higher_Alkenes, 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 ecgate. 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.

Edit P… | Add | Edit | Delet… | Copy… | Versi… | My Dr…

Servi… | Europ… | Globa… | Comp… | Clima… | UV, S… | Strato…

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Quick… | GEMS | PROM… | GMES

MACC-II is a Collaborative Project (2011-2014) funded by the European Union under the 7th Framework Programme. It is coordinated by the European Centre for Medium-Range Weather Forecasts and operated by a 36-member consortium.

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

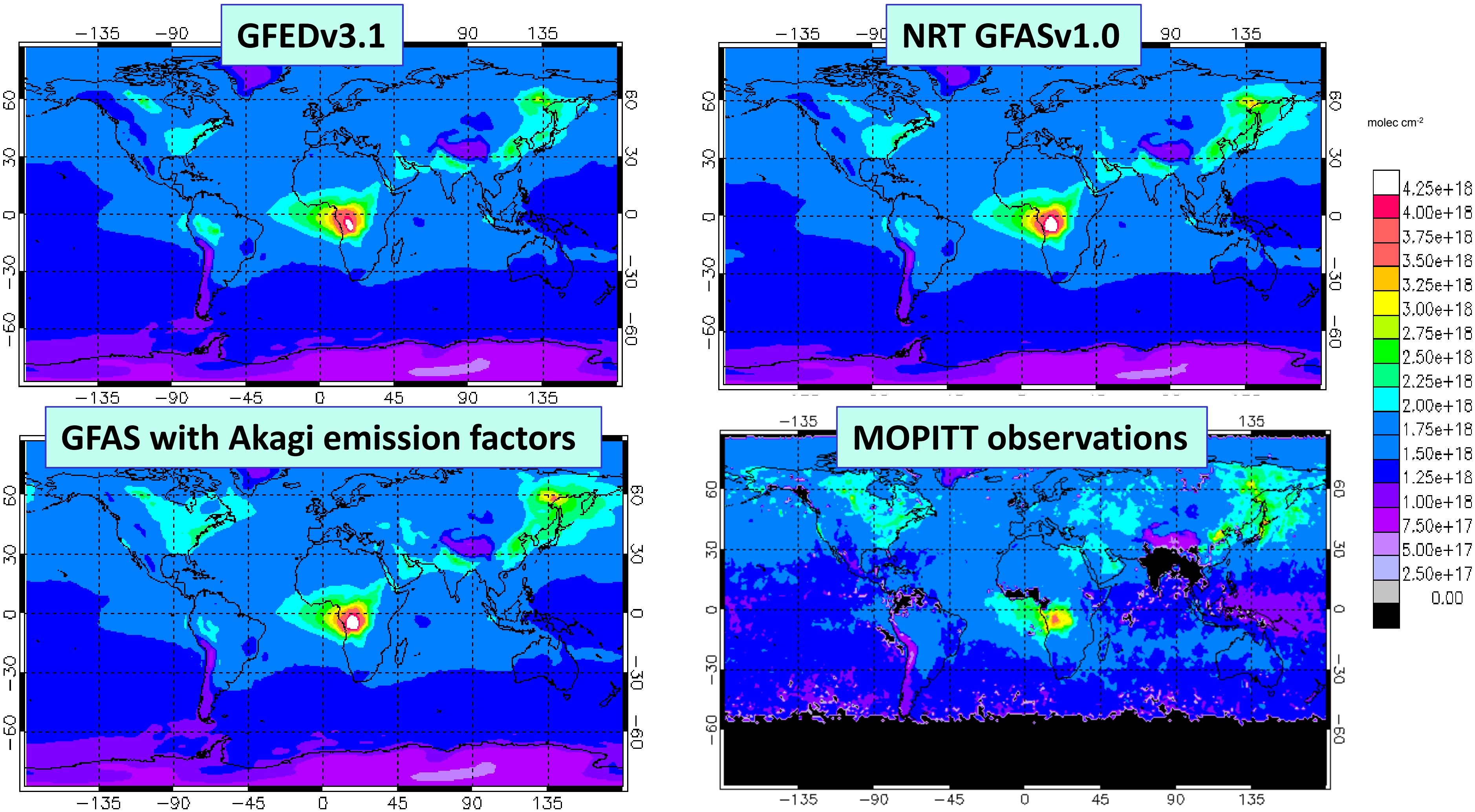
Outlook: Lots of Potential for Improvements

- 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!
www.wildlandfire.com

MOZART CO Column Simulations of July 2008



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