FRP Emissions

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Thanks to Niels Andela, Angelika Heil, Ronan Paugam, Martin G Schultz, Guido R. van der Werf, Martin J. Wooster and Samuel Remy!

MAX-PLANCK-INSTITUT FÜR CHEMIE
MAX-PLANCK-GESELLSCHAFT
KING'S College LONDON
ECMWF

GOFC-Gold Fire IT
Wageningen, April 2013

SEVENTH FRAMEWORK PROGRAMME
European Commission
GMES
macc
Monitoring atmospheric composition & climate – II
copernicus

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)

$E_i = \underbrace{BA \times AFL \times CC}_{\text{burnt biomass}} \times EF_i$ (Seiler & Crutzen 1980)

"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]

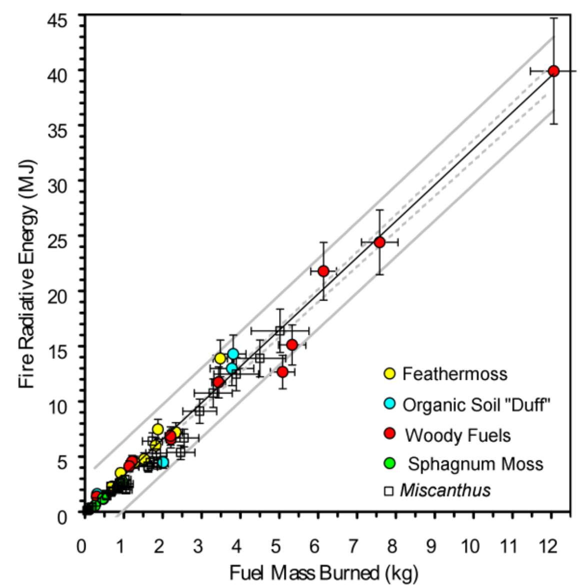
CC = combustion completeness [kg(burnt fuel) / kg (available fuel)]

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

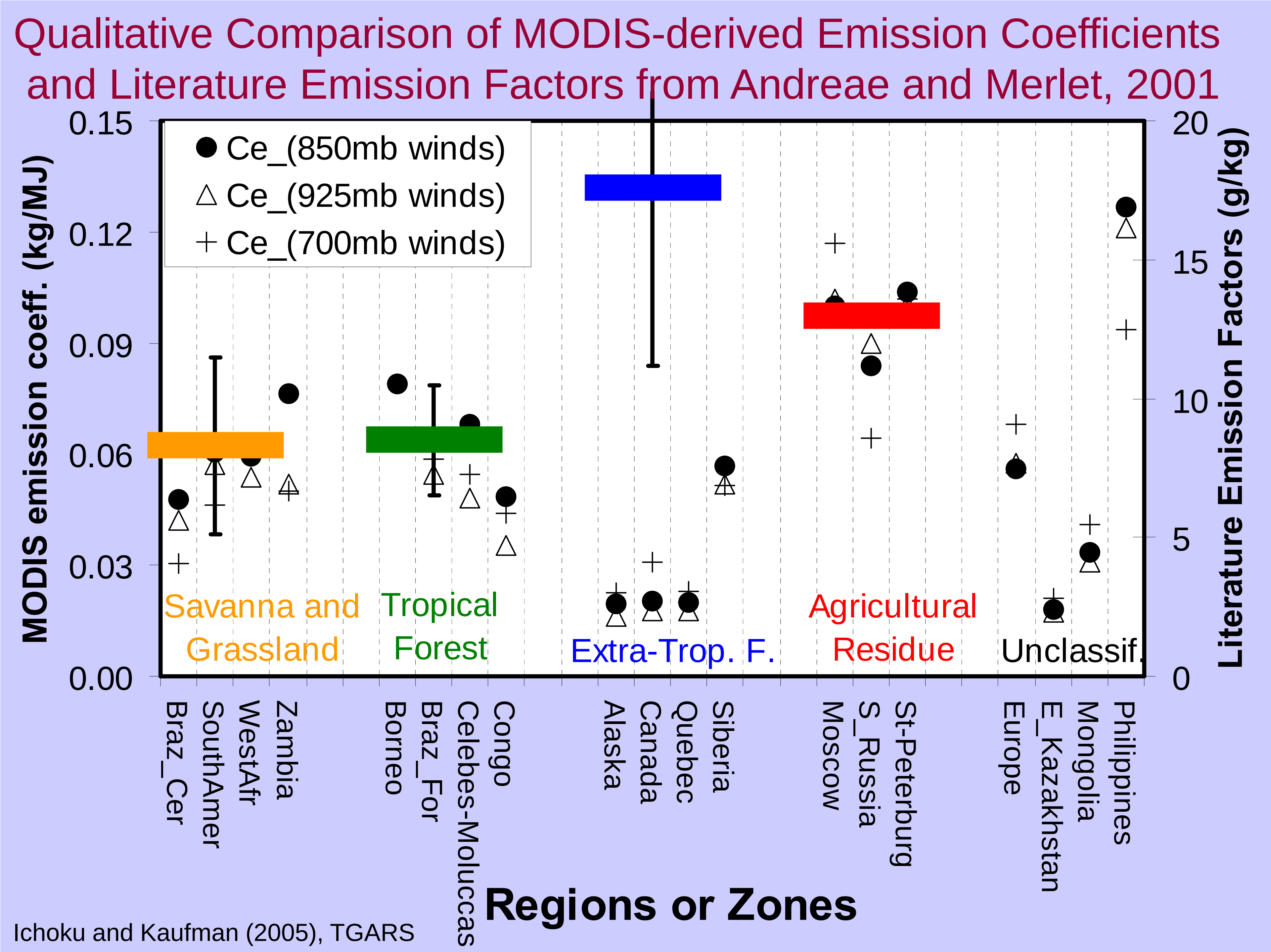
FRP = fire radiative power [W]

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

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



graphics by M. Wooster

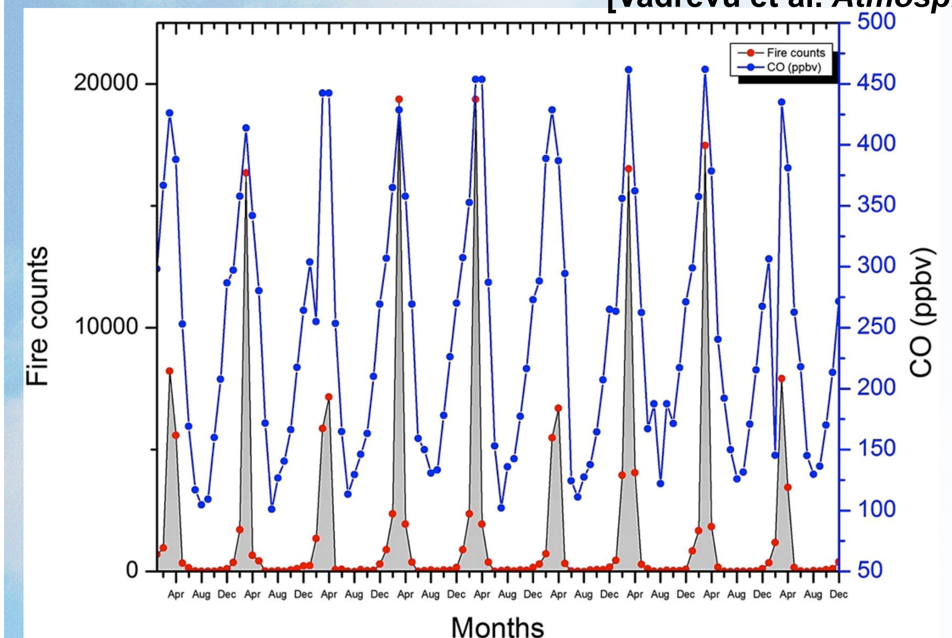


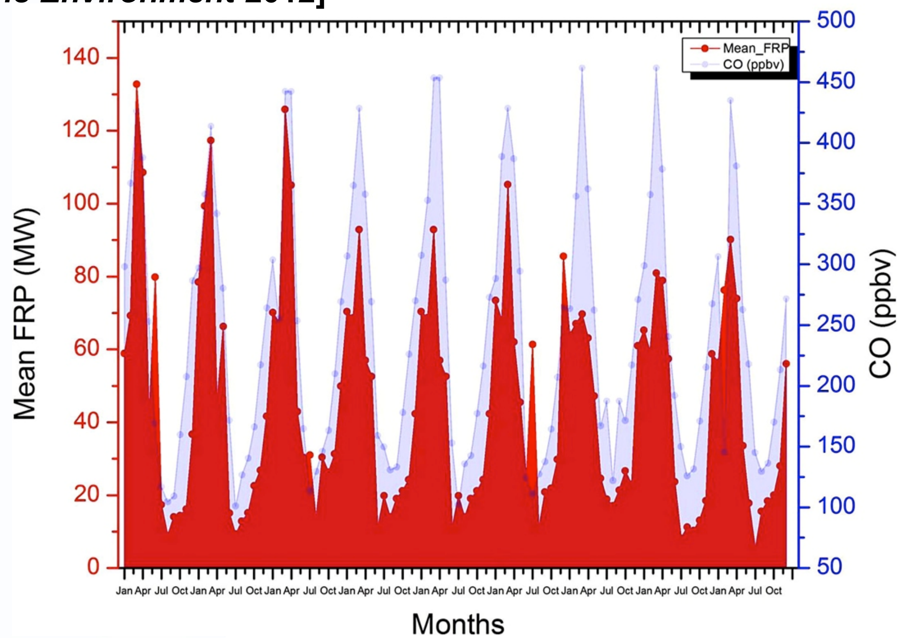
Qualitative Comparison of MODIS-derived Emission Coefficients
and Literature Emission Factors from Andreae and Merlet, 2001
Ce_(850mb winds)
Ce_(925mb winds)
Ce_(700mb winds)
MODIS emission coeff. (kg/MJ)
Literature Emission Factors (g/kg)
0.15
0.12
0.09
0.06
0.03
0.00
20
15
10
5
0
Savanna and Grassland
Tropical Forest
Extra-Trop. F.
Agricultural Residue
Unclassif.
Braz_Cer
SouthAmer
WestAfr
Zambia
Borneo
Braz_For
Celebes-Moluccas
Congo
Alaska
Canada
Quebec
Siberia
Moscow
S_Russia
St-Peterburg
Europe
E_Kazakhstan
Mongolia
Philippines
Regions or Zones
Ichoku and Kaufman (2005), TGARS

Why Fire Radiative Power (FRP)?

Atmospheric CO Concentration and Fire Observations in Northeast India

[Vadrevu et al. *Atmospheric Environment* 2012]





<u>Advantages of FRP</u>

– real time availability, low detection threshold (compared to burnt area)

– use quantitative observations, avoid assumptions on

- available fuel load
- combustion completeness (compared to fire counts)

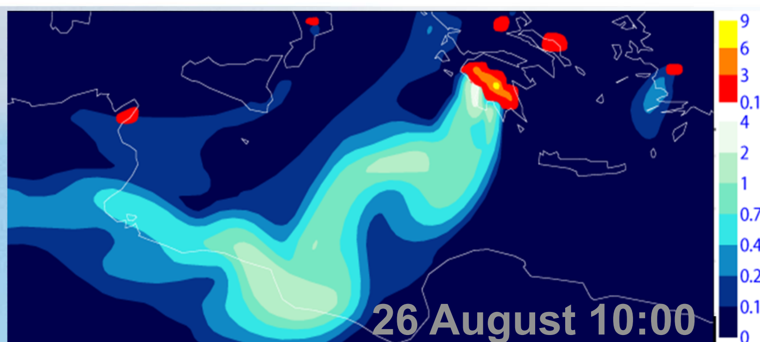
– proven suitability for Air Quality applications

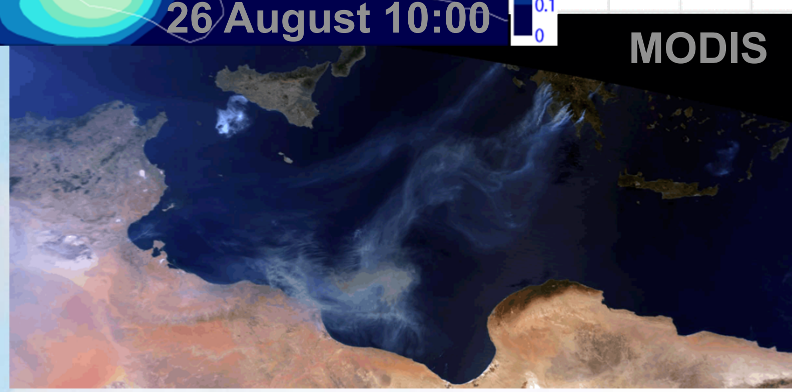
Modelled AOD of Greek Fire Plumes, August 2007

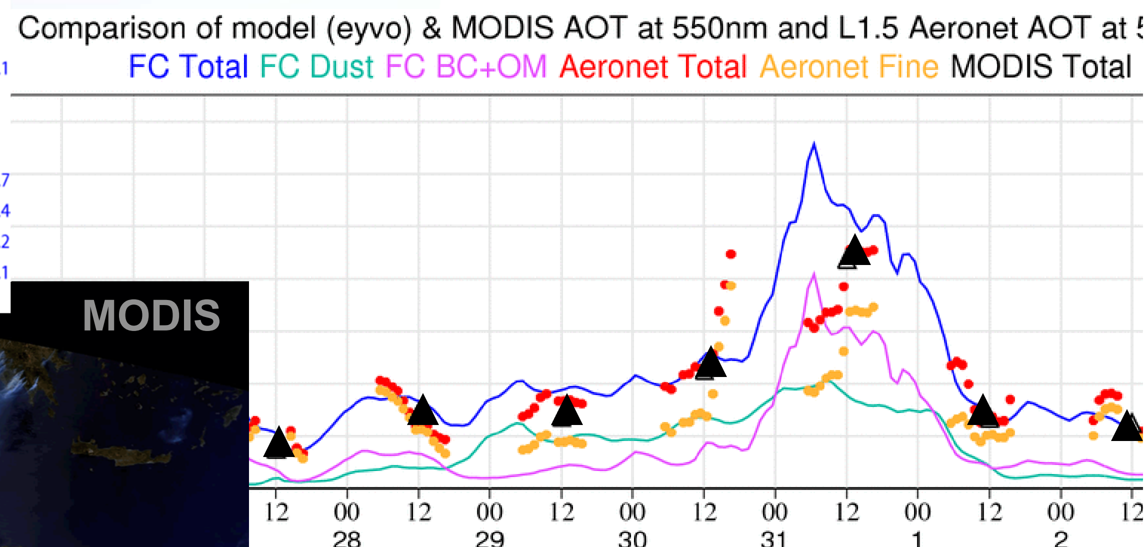
Emissions calculated from Fire Radiative Power observed by SEVIRI on Meteosat.

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

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

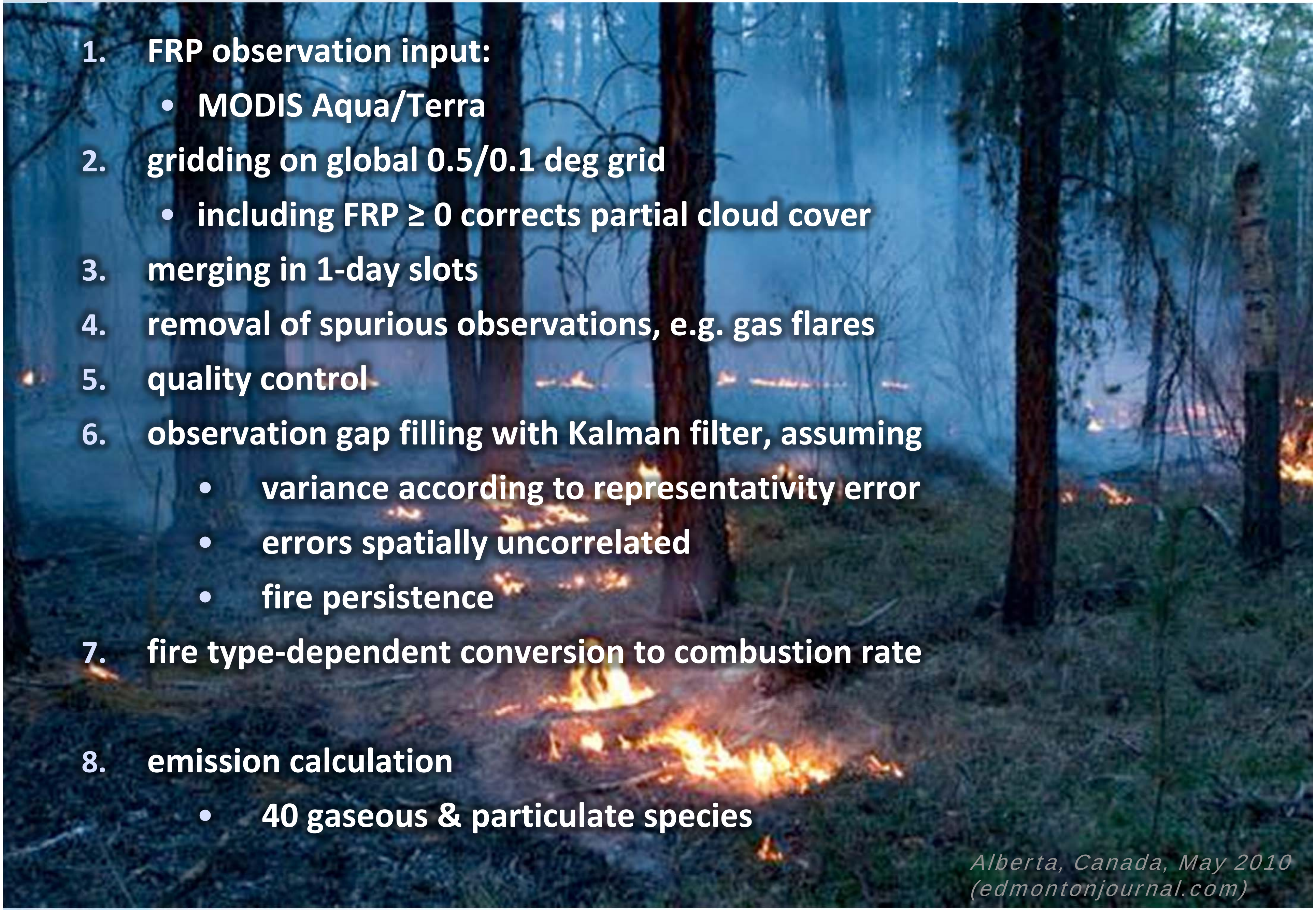






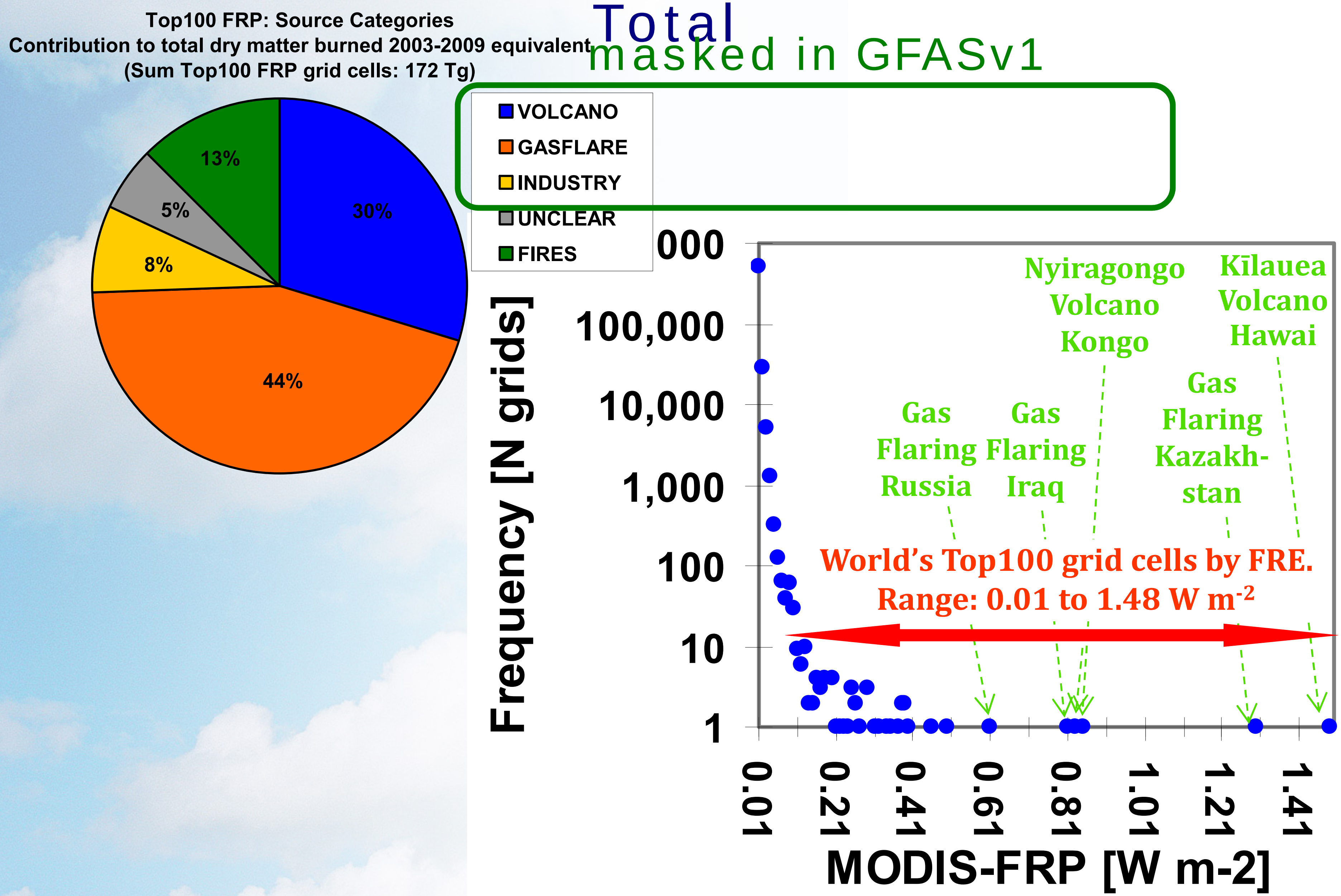
Global Fire Assimilation System (GFASv1.0)

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

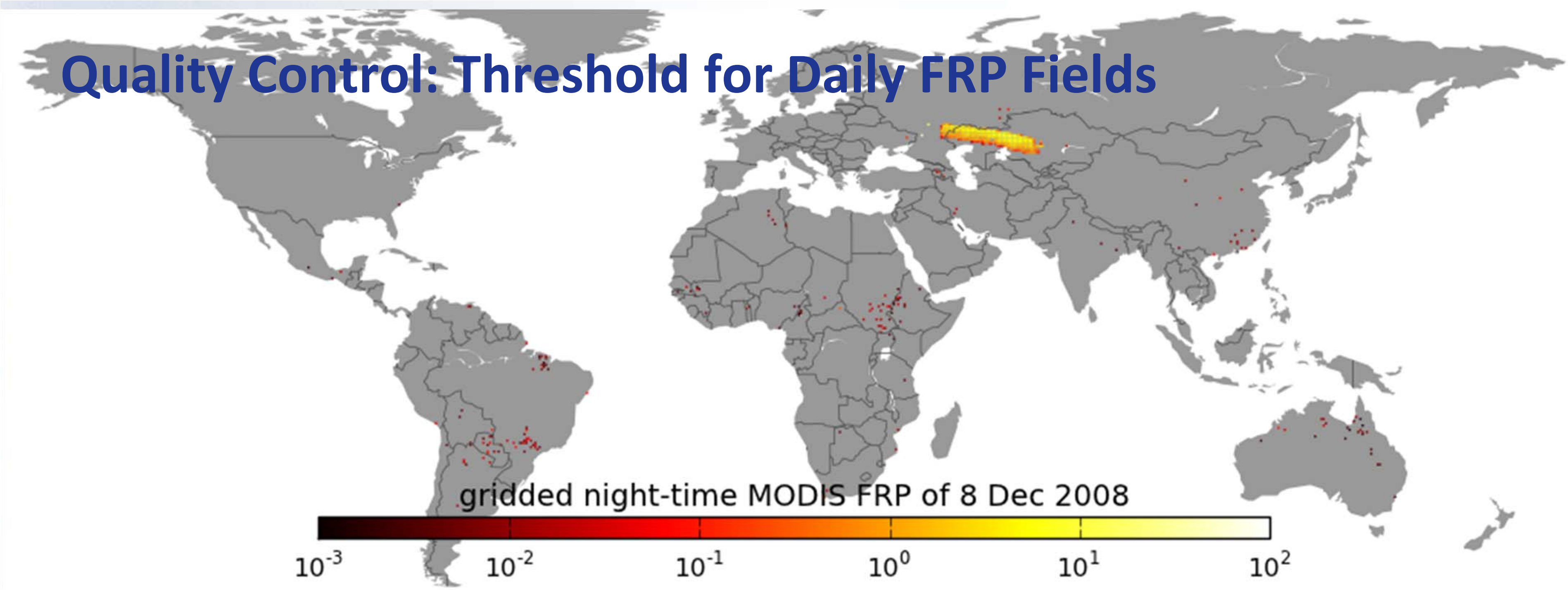


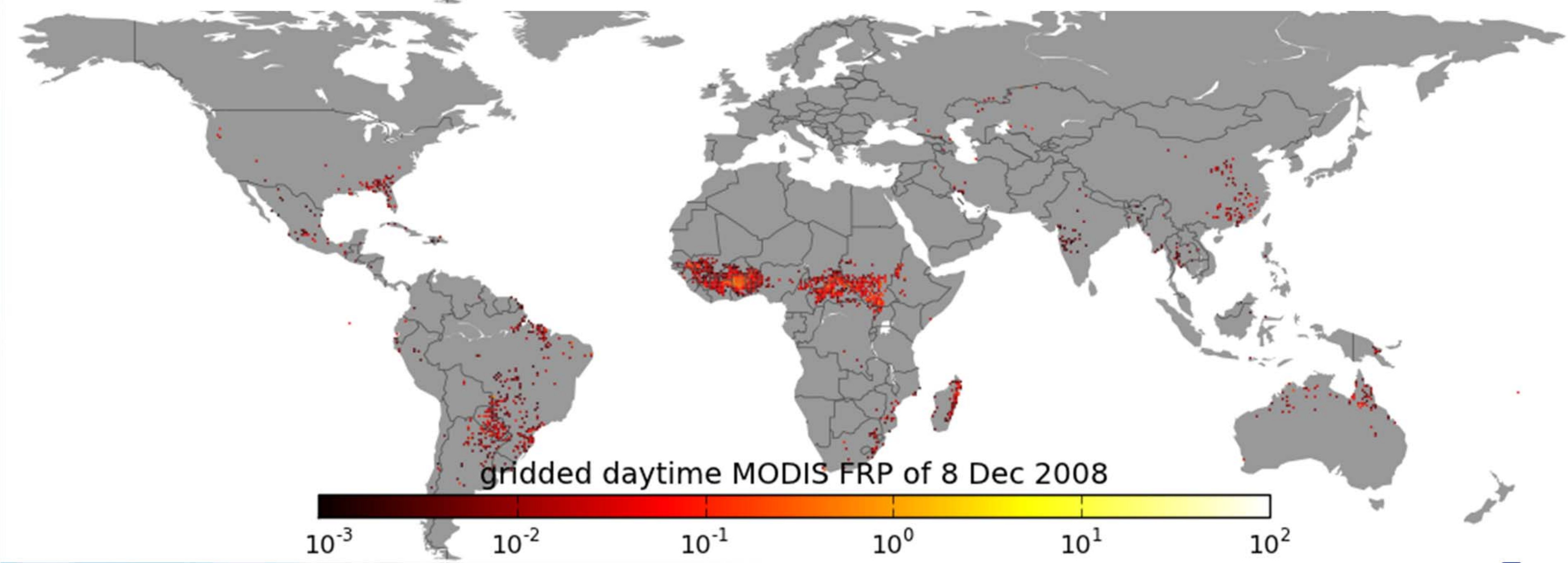
Alberta, Canada, May 2010 (edmontonjournal.com)

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

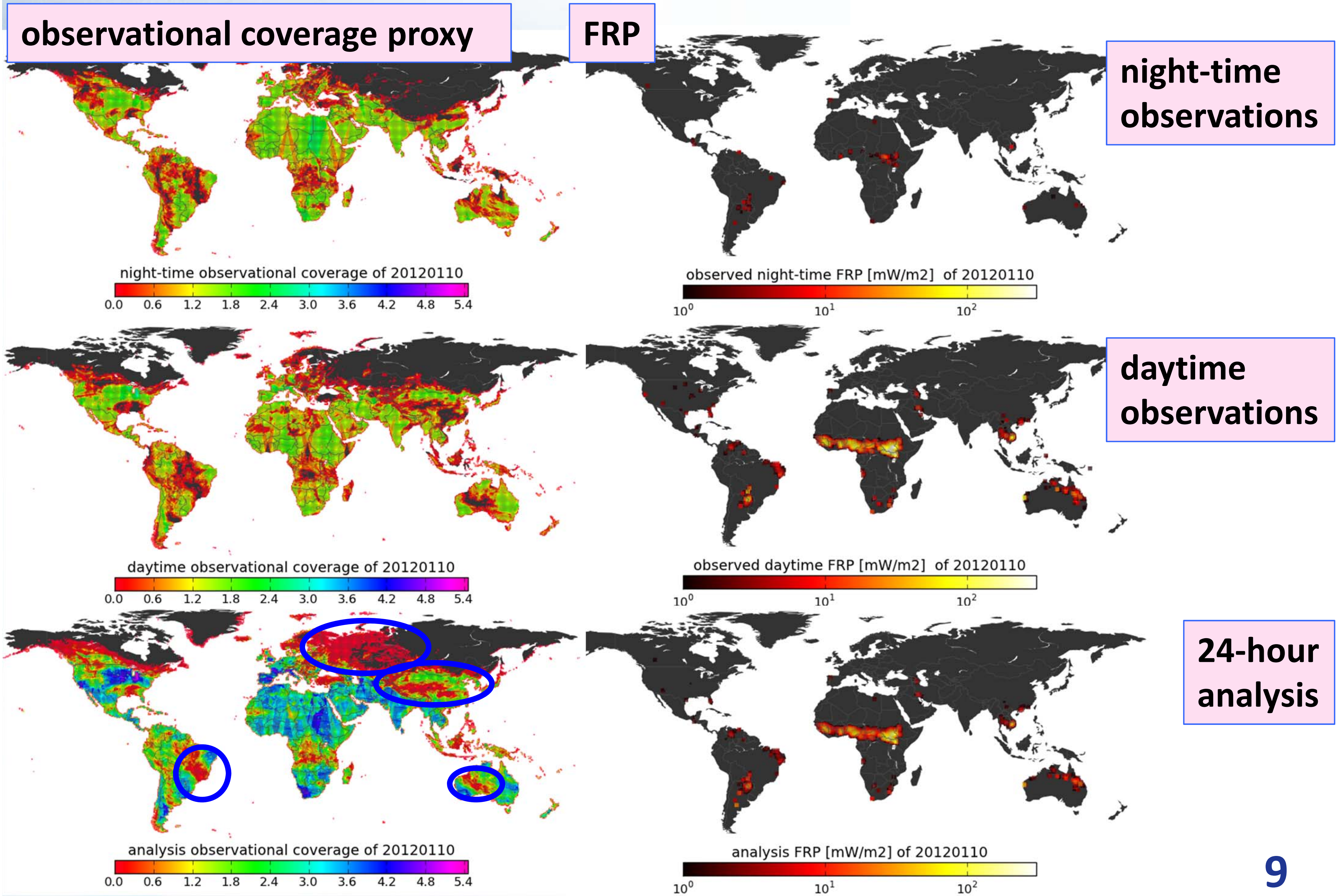


Quality Control: Threshold for Daily FRP Fields

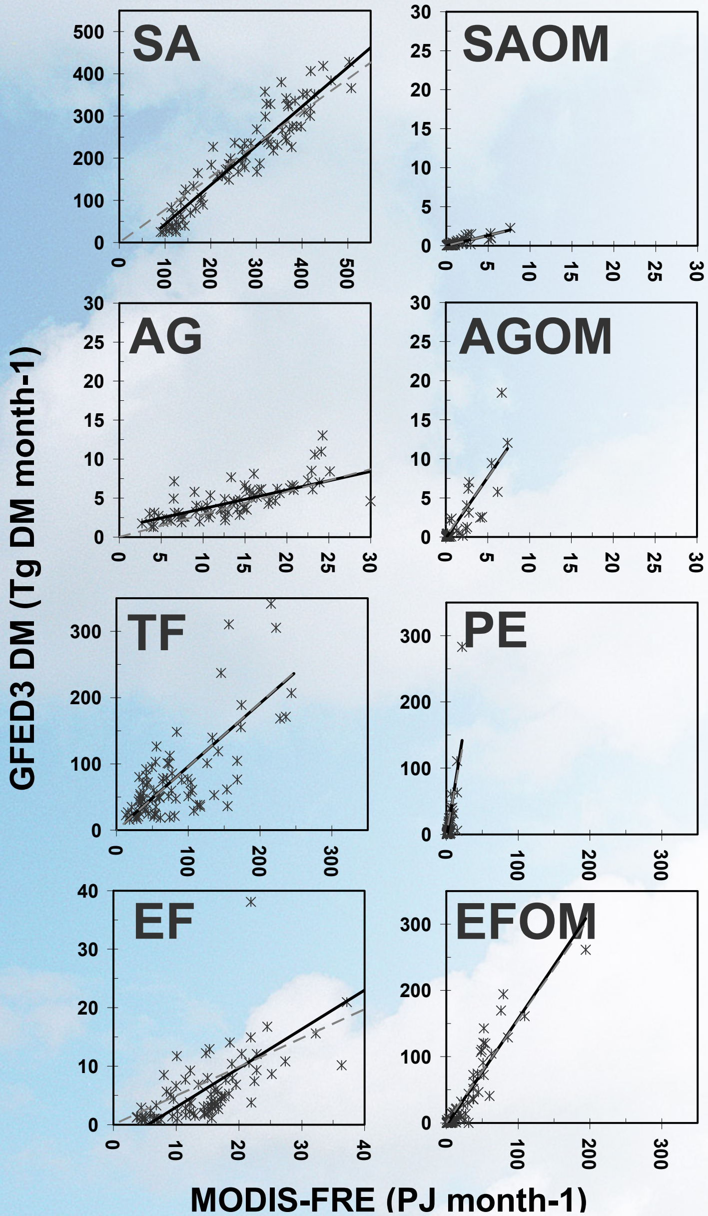


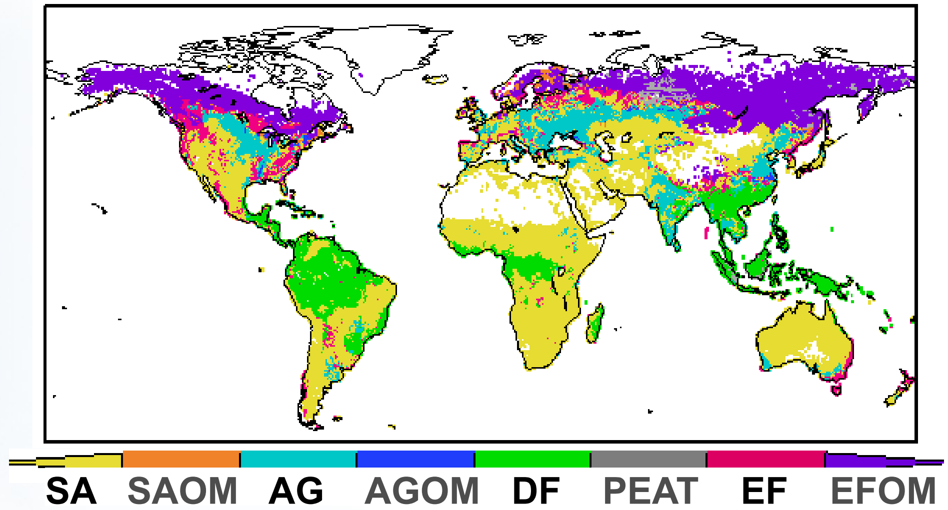


MODIS FRP Assimilation



FRP conversion factor analysis against GFEDv3





SA: savannah fires
SAOM: SA with potential OM burning
AG: agricultural fires
AGOM: AG with potential OM burning
DF: tropical fires
PEAT: peat burning
EF: extra-tropical fires
EFOM: EF with potential OM 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

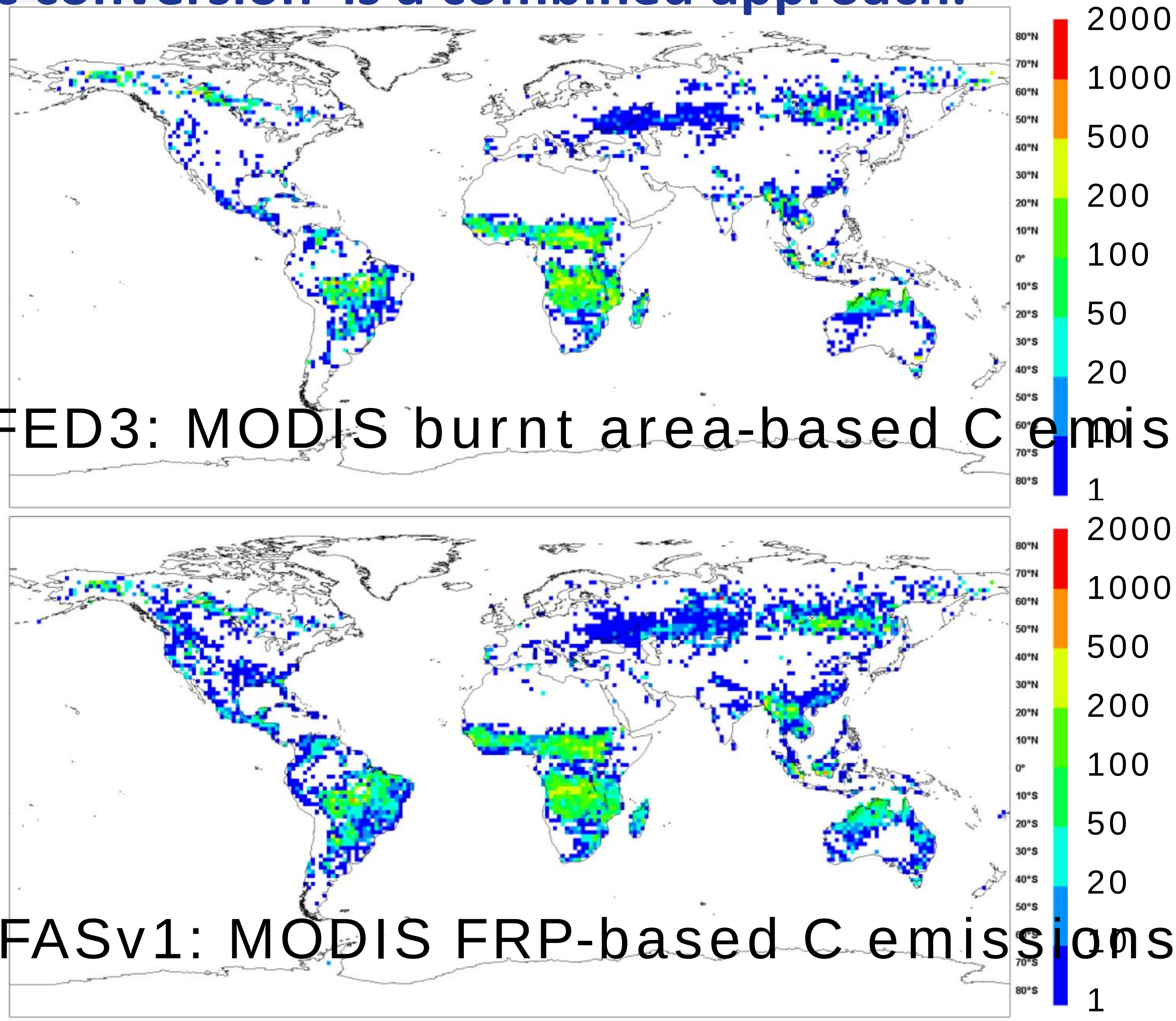
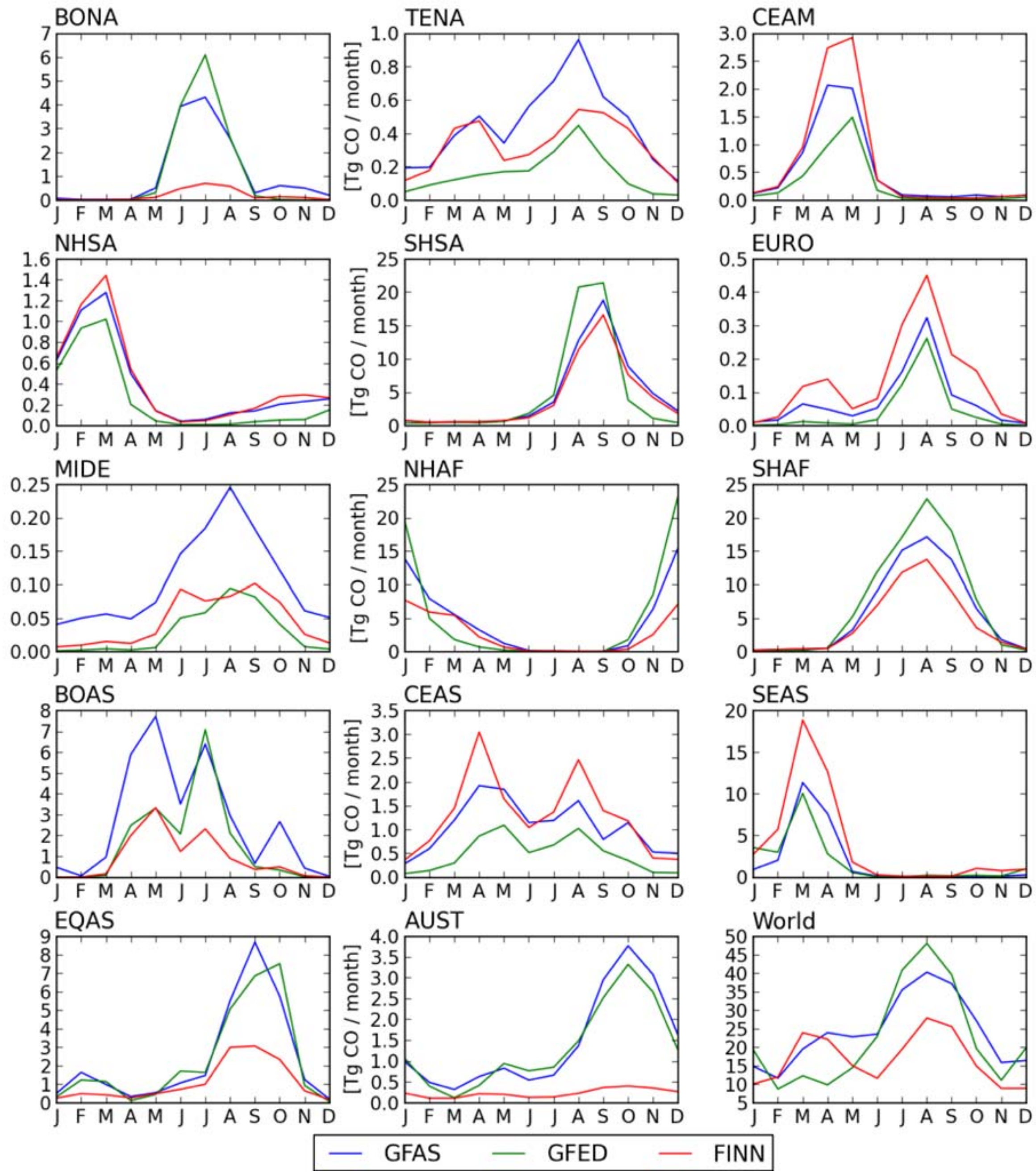


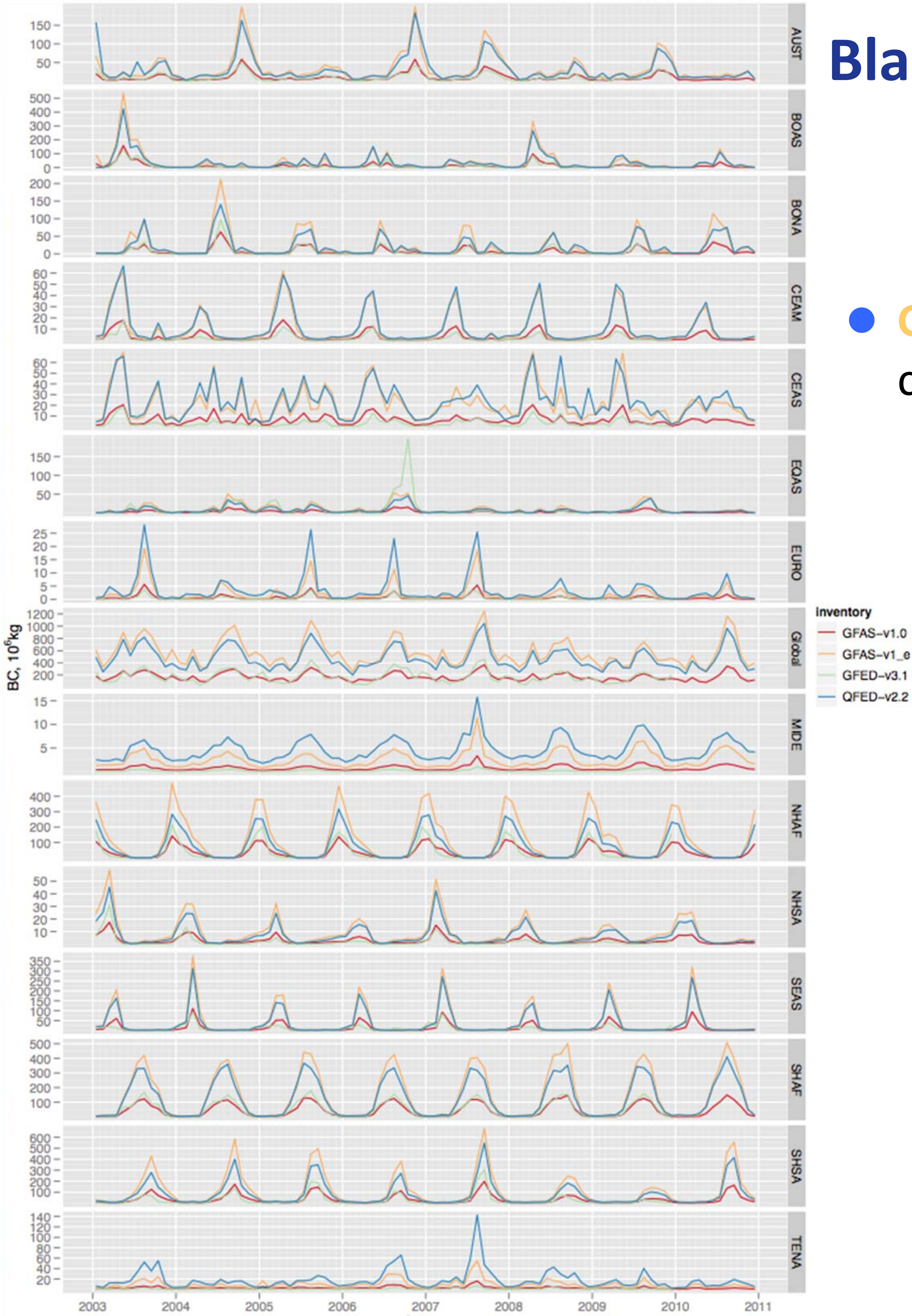
Fig. 5. Average distribution of carbon combustion [g(C) a^{-1} m^{-2}] during 2003–2008 in GFED3.1 (top) and GFASv1.0 (bottom).

(Kaiser et al. 2

Comparison to other inventories: Monthly CO emissions

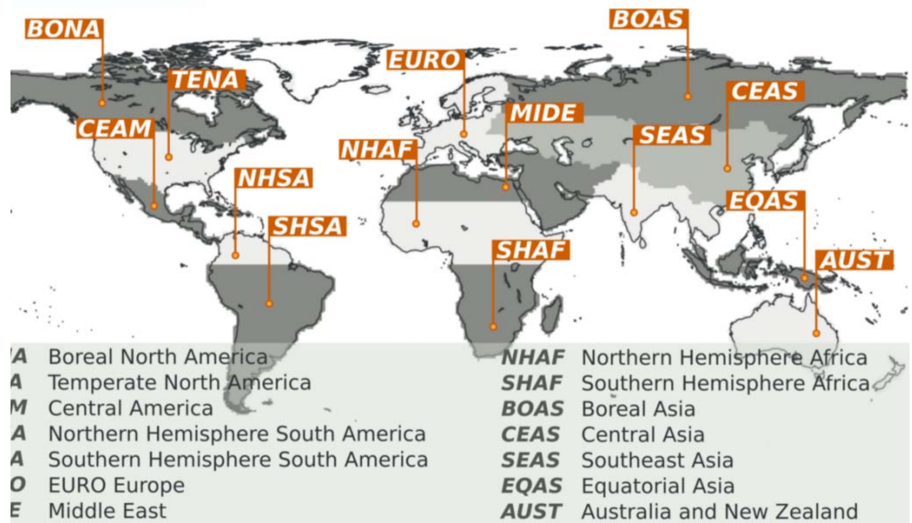


by Niels Andela



Black Carbon Cross-validation

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



(courtesy A. da Silva)

Two approaches, with consistent results:

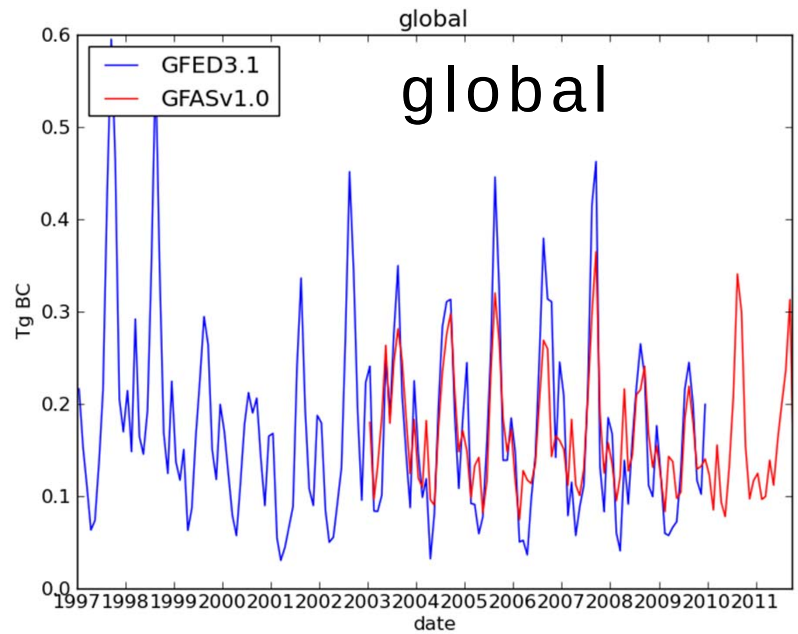
<u>Ichoku, da Silva, Sofiev</u>

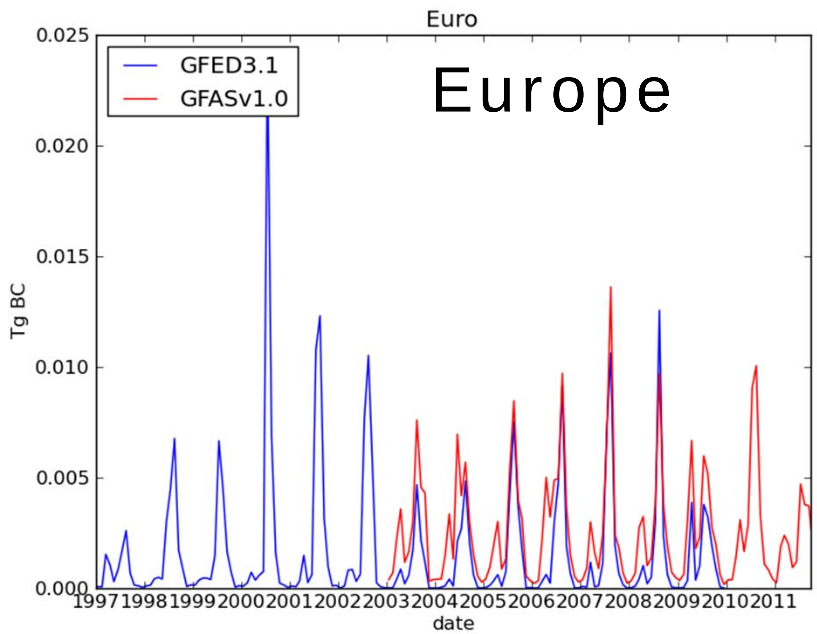
- scale FRP empirically to emissions as observed in plumes
- geographical dependence
- possibly extend to other species with relative emission factors

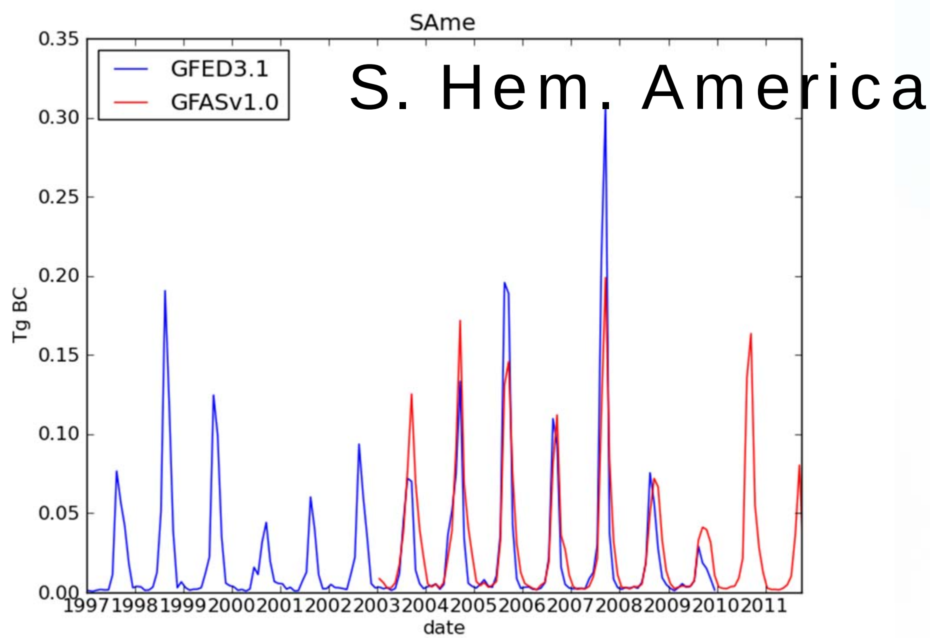
<u>Wooster, Kaiser</u>

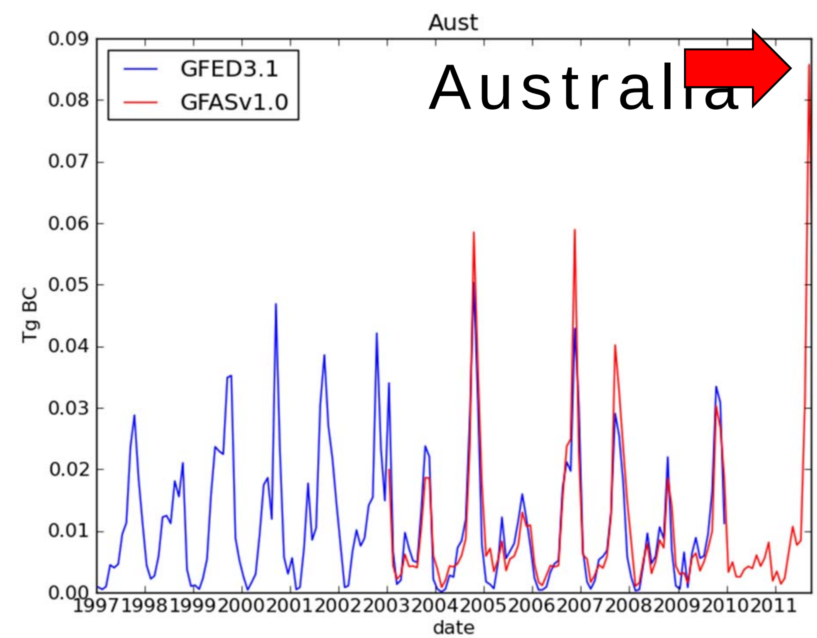
- scale FRP to DM as prescribed in GFED
- fire type dependence
- adjust single species emission factors to atmospheric observations
- Without CO2 observations, the parameters remain underdetermined ☹

Monthly C emission up to September 2011

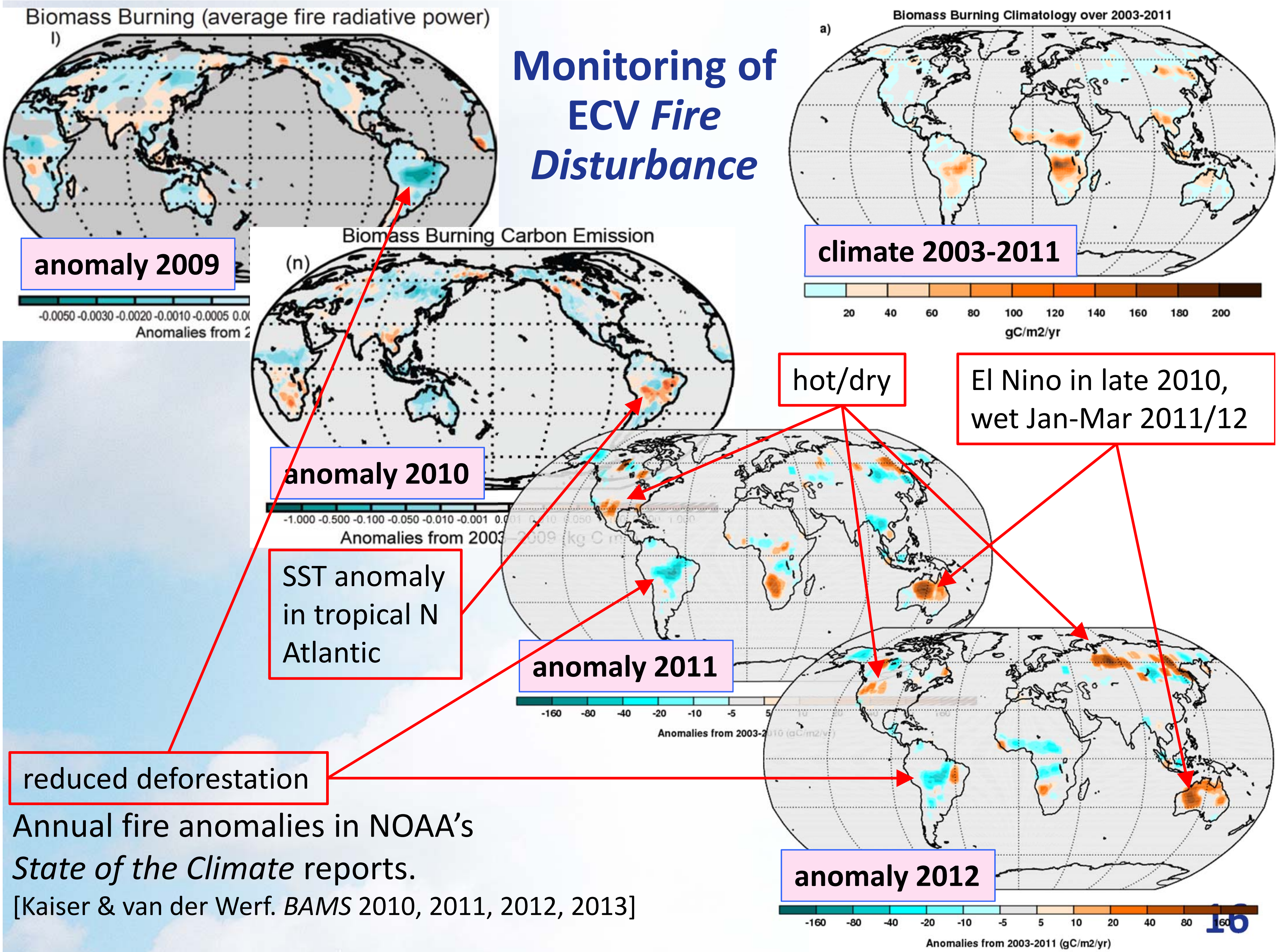








Monitoring of ECV *Fire Disturbance*



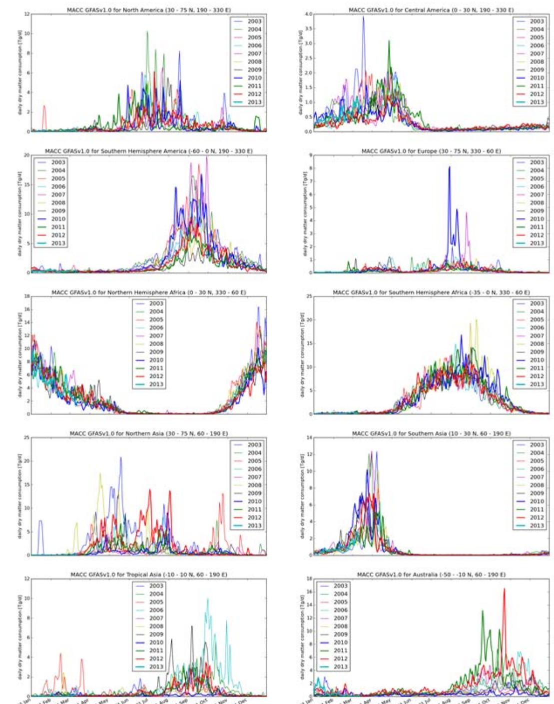
Annual fire anomalies in NOAA's *State of the Climate* reports.

[Kaiser & van der Werf. *BAMS* 2010, 2011, 2012, 2013]

Key Features

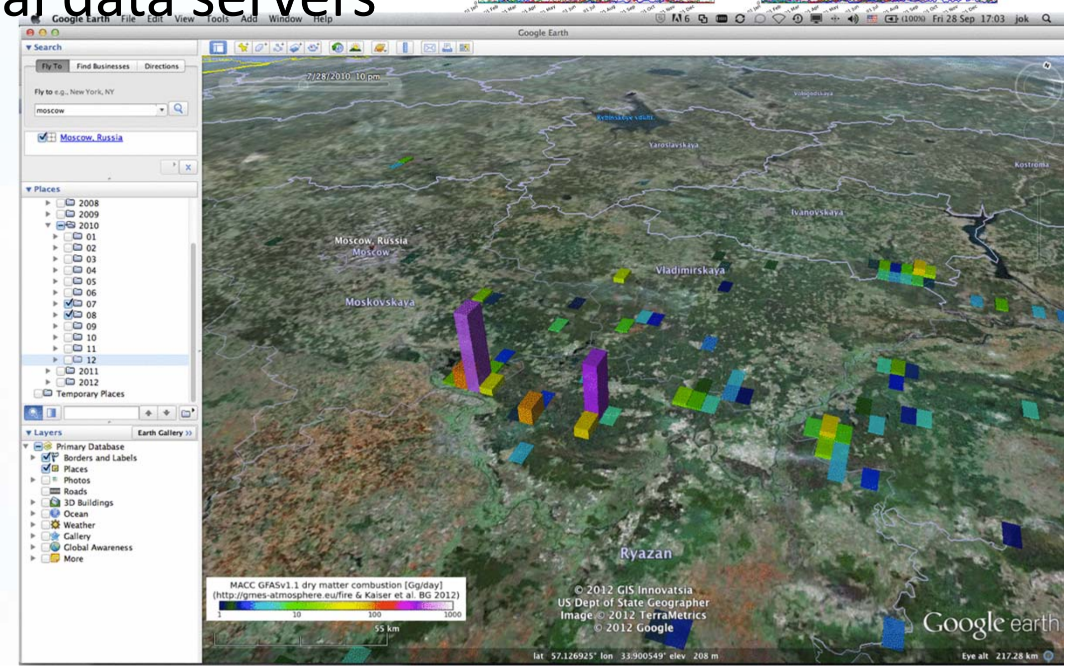
satellite-based FRP assimilation :

- global coverage
- NRT availability
- daily resolution (tests: hourly)
- similar maturity as BA approach



MACC-GFAS:

- publicly available in several data servers
- various product formats:
  - GRIB
  - NetCDF
  - GIF map
  - PNG spaghetti plot
  - KML



http://gmes-atmosphere.eu/fire

Real-time Supply Chain

Data providers: (acquired by OBS)

- NASA: MODIS FRP
- EUMETSAT LSASAF: SEVIRI FRP
  - UCAR: GOES-E/-W rad.
  - ECMWF: met. forecasts

MACC FRP processing:

- KCL (IM): GOES-E/-W FRP

MACC GFAS processing:

- GFAS @ ECMWF
  - assimilated FRP
  - combustion rate
  - emissions
  - (injection heights)

archives @ ECMWF:

- ECFS
- MARS

archive @ FZJ:

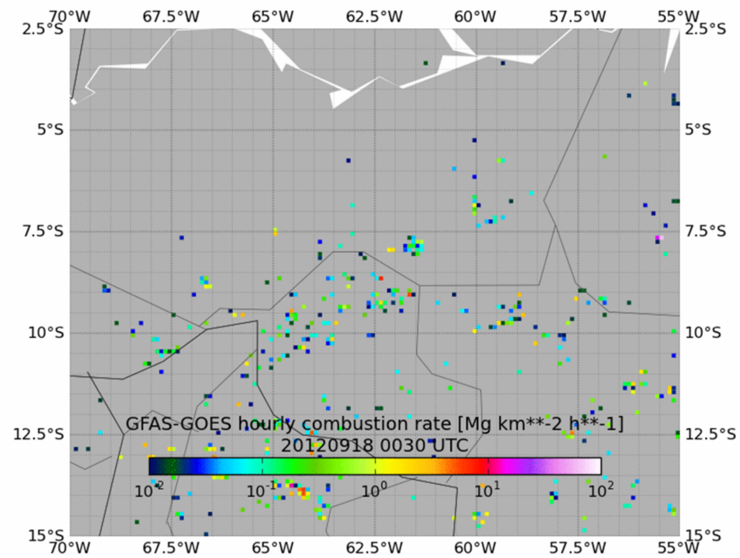
- OGC web server

GEIA **archive**:

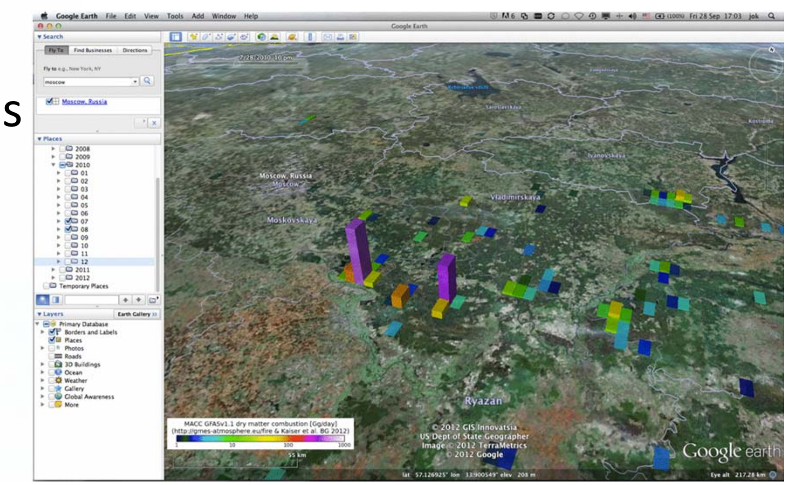
- OGC web server

USERS

Conclusions



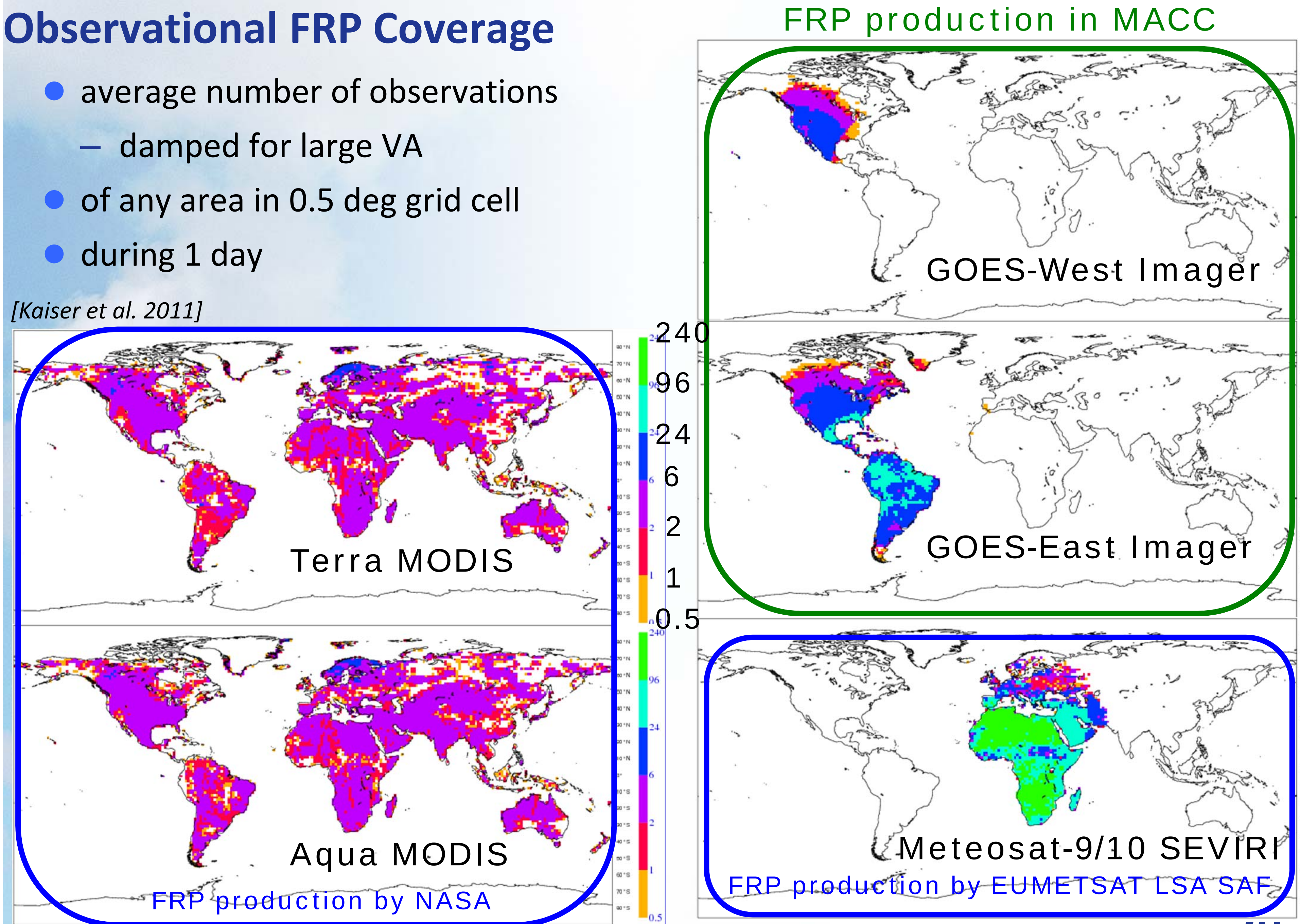
- MACC GFAS is producing daily biomass burning estimates
  - for 40 smoke constituents
  - in real time
  - publicly available
- All global MACC systems consistently use GFAS emissions.
- More and more regional air quality systems use GFAS.
- GFAS compares well with other inventories.
- Feedback from atmospheric validation is becoming more widely available.
- Many uncertainties remain. Current developments focus on
  - plume rise model
  - merging of geostationary FRP observations
  - 5-day fire evolution prediction
  - improved emission factor formulation
- http://gmes-atmosphere.eu/fire



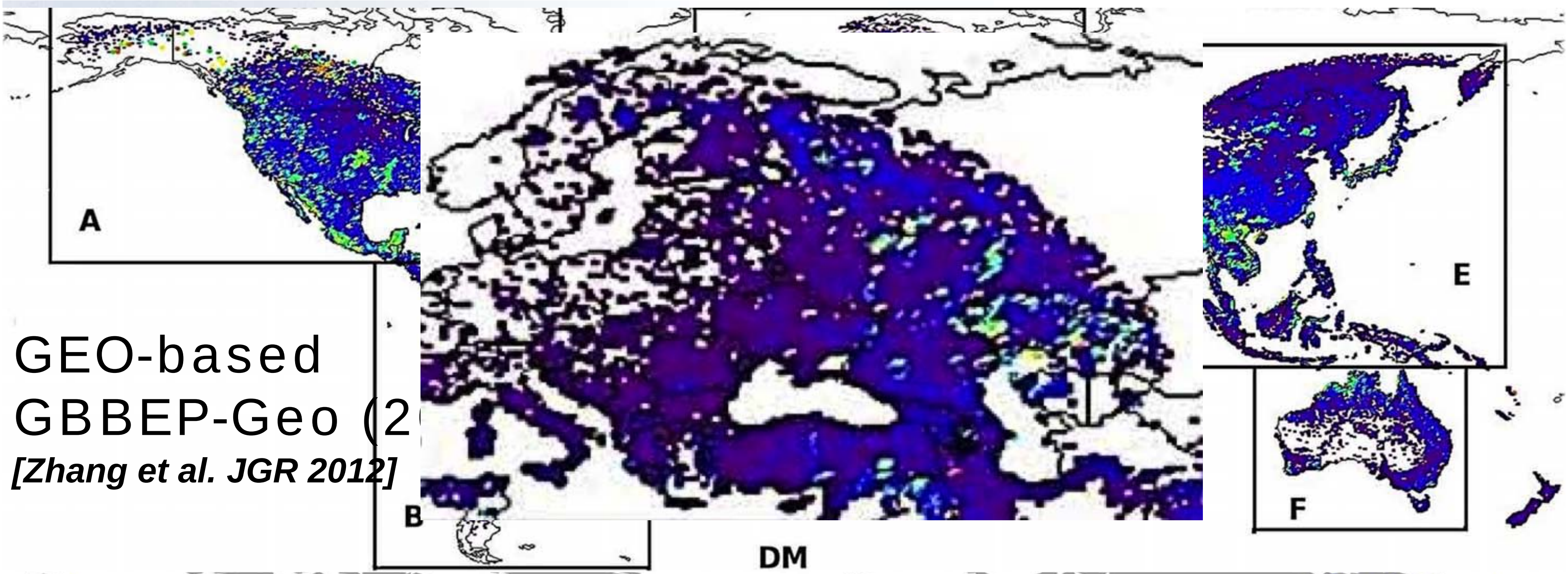
Observational FRP Coverage

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

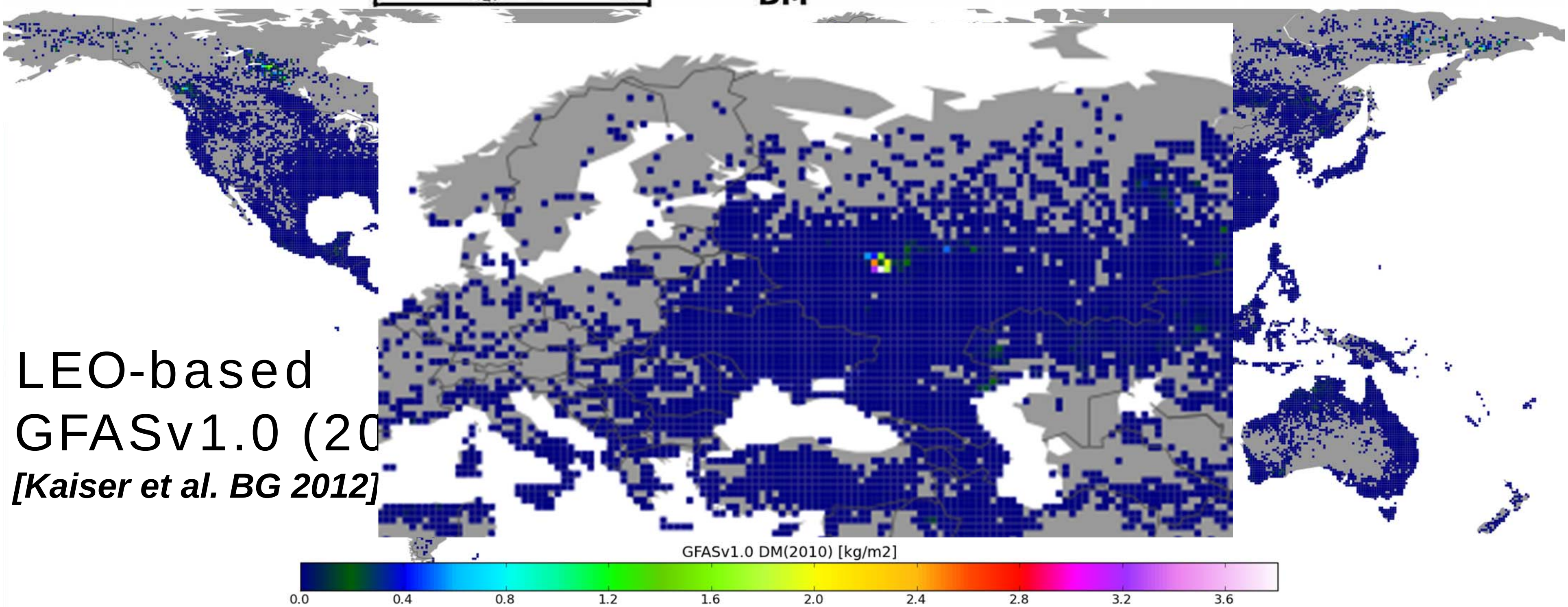
[Kaiser et al. 2011]



GEO-based
GBBEP-Geo (2
[Zhang et al. JGR 2012]



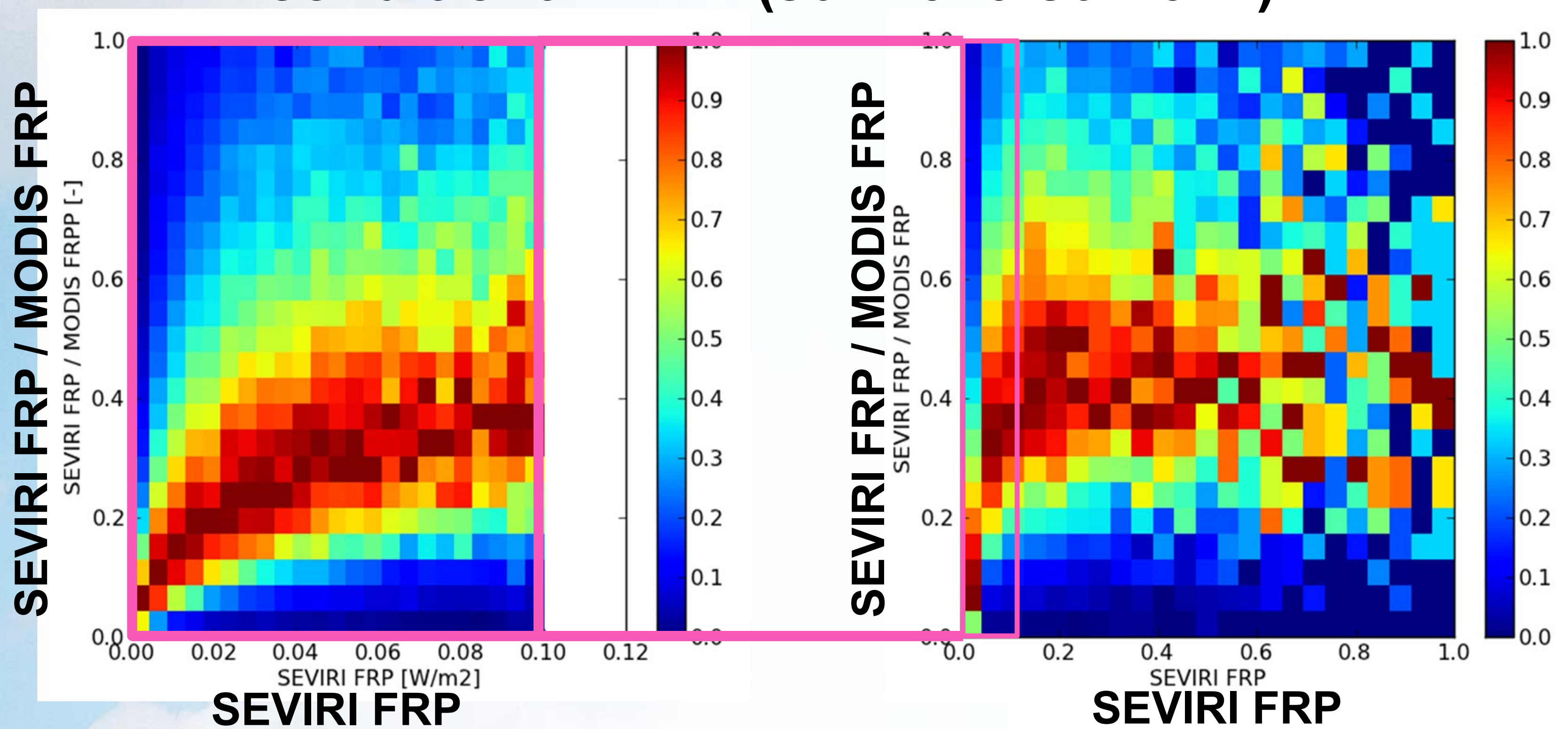
LEO-based
GFASv1.0 (20
[Kaiser et al. BG 2012]



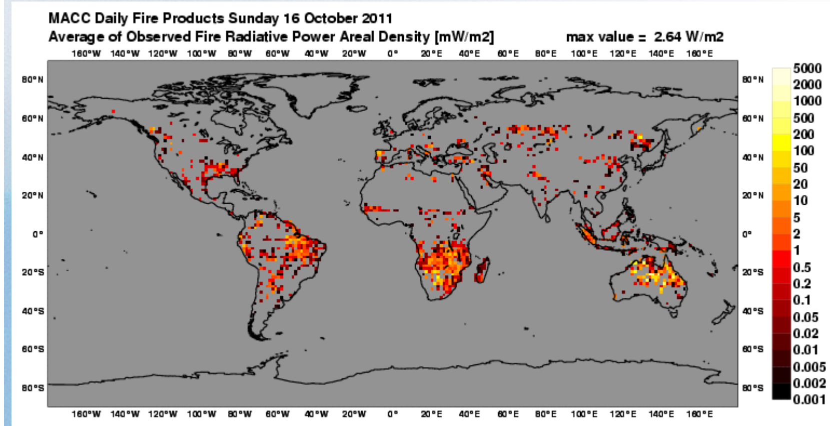
FIR Developments: FRP merging of GEO and LEO observations

- scientifically not solved anywhere
- We follow two approaches
  - based on GFAS-gridded observations
  - characterisation of bias (GEO FRP, view angle, local time)
  - prediction of bias from previous co-located observations

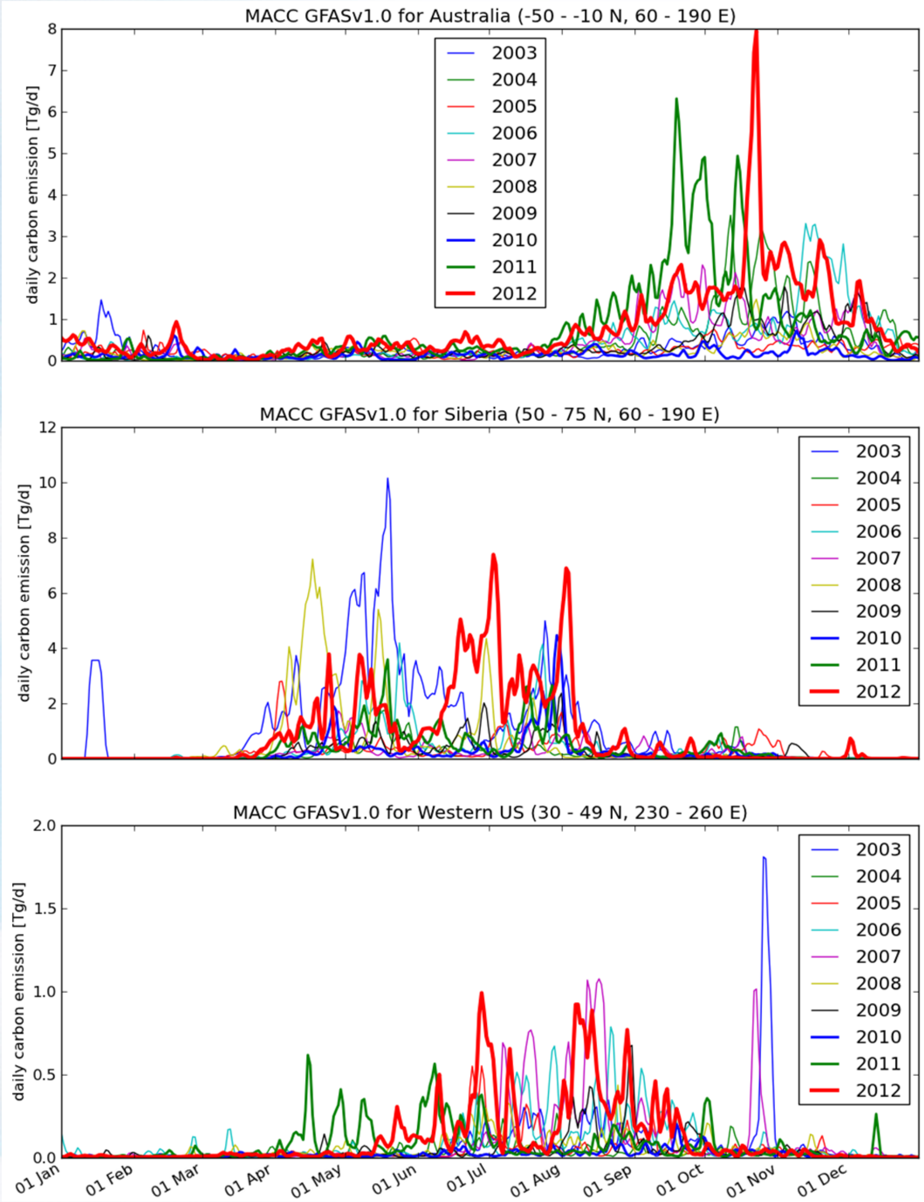
conditional PDF (Jun2010-Jul2012)



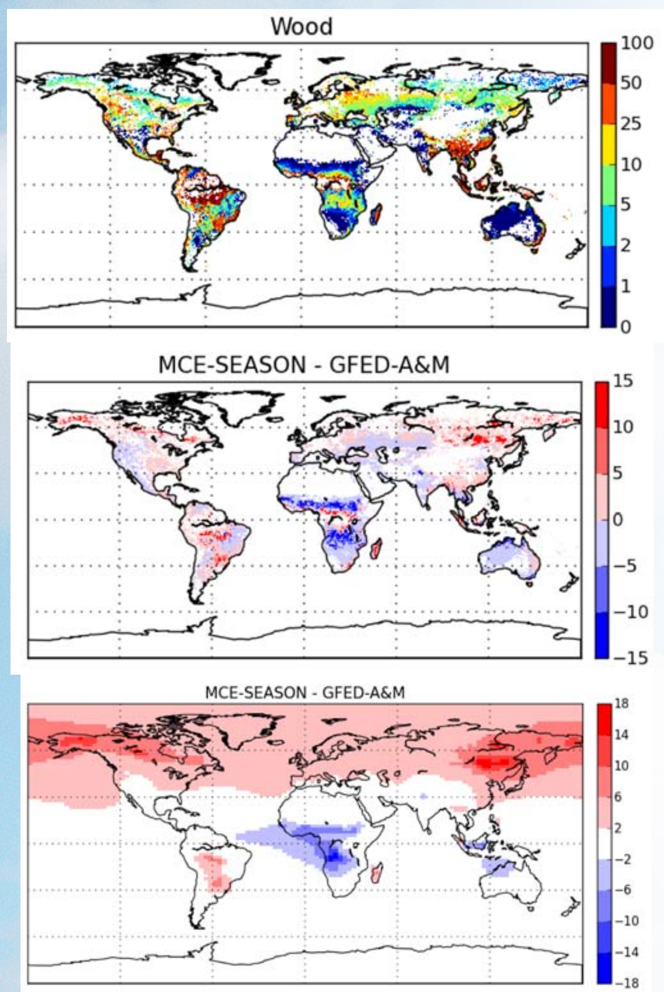
GFAS Emissions in MACC Systems



- global production
  - aerosols
  - reactive gases
  - greenhouse gases
- reanalysis (2009-10)
- CO-tracer forecasts
- EURAD regional forecasts


MACC GFASv1.0 for Australia (-50 - -10 N, 60 - 190 E)
daily carbon emission [Tg/d]
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
MACC GFASv1.0 for Siberia (50 - 75 N, 60 - 190 E)
daily carbon emission [Tg/d]
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
MACC GFASv1.0 for Western US (30 - 49 N, 230 - 260 E)
daily carbon emission [Tg/d]
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
01 Jan
01 Feb
01 Mar
01 Apr
01 May
01 Jun
01 Jul
01 Aug
01 Sep
01 Oct
01 Nov
01 Dec

FIR Developments: Dynamic Emission factors



Top: partition fuel sources contributing to emissions (shown here the fraction wood)

Each fuel source gets a MCE range based on literature (MCE = Modified Combustion Efficiency = $CO_2 / (CO+CO_2)$)

Meteorology used to scale within the range

MCE relates (reasonably) well with EFs of other trace gases and aerosols

Middle: emissions difference between MCE run and standard GFED run (Gg CO / year)

Bottom: atmospheric concentration (ppb / month) for lower atmosphere (up to 800 hPa)

Next step: build into GFAS

van Leeuwen, VUA

Plume Rise Model Development

Objective: Improvement and Validation of a new PRM based on the Freitas Model

Improve Physics

mass conservation
new entrainment scheme

⇨

Validation and optimization on well characterised fire event

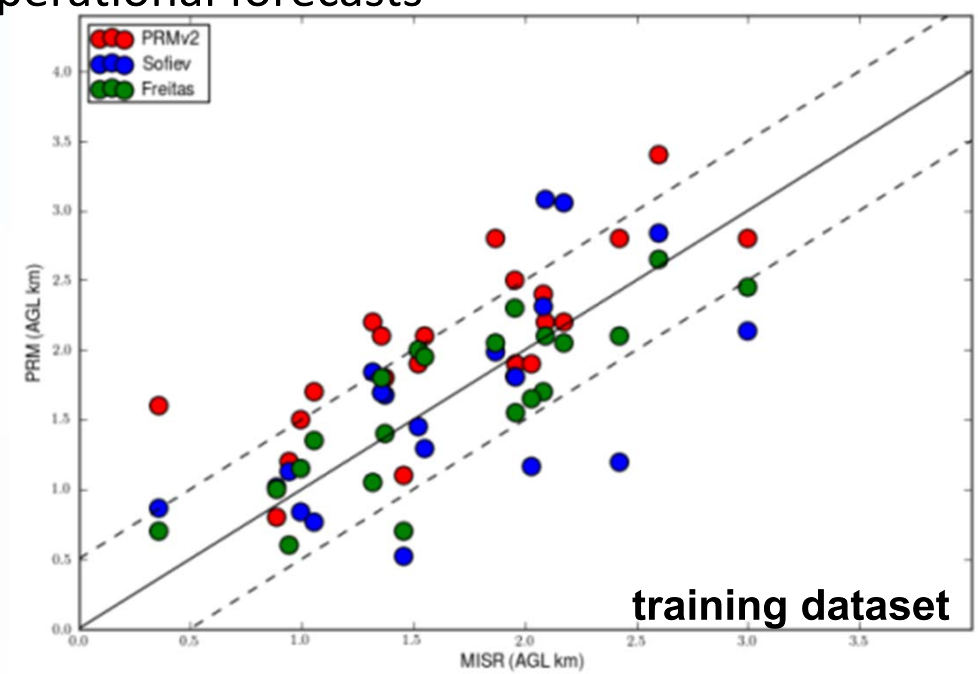
MISR + MODIS FRP
+ Atmospheric Profile

⇨

Introduce more time dependence with an Implementation on-line

validation on large regional scale simulation with CALIOP product

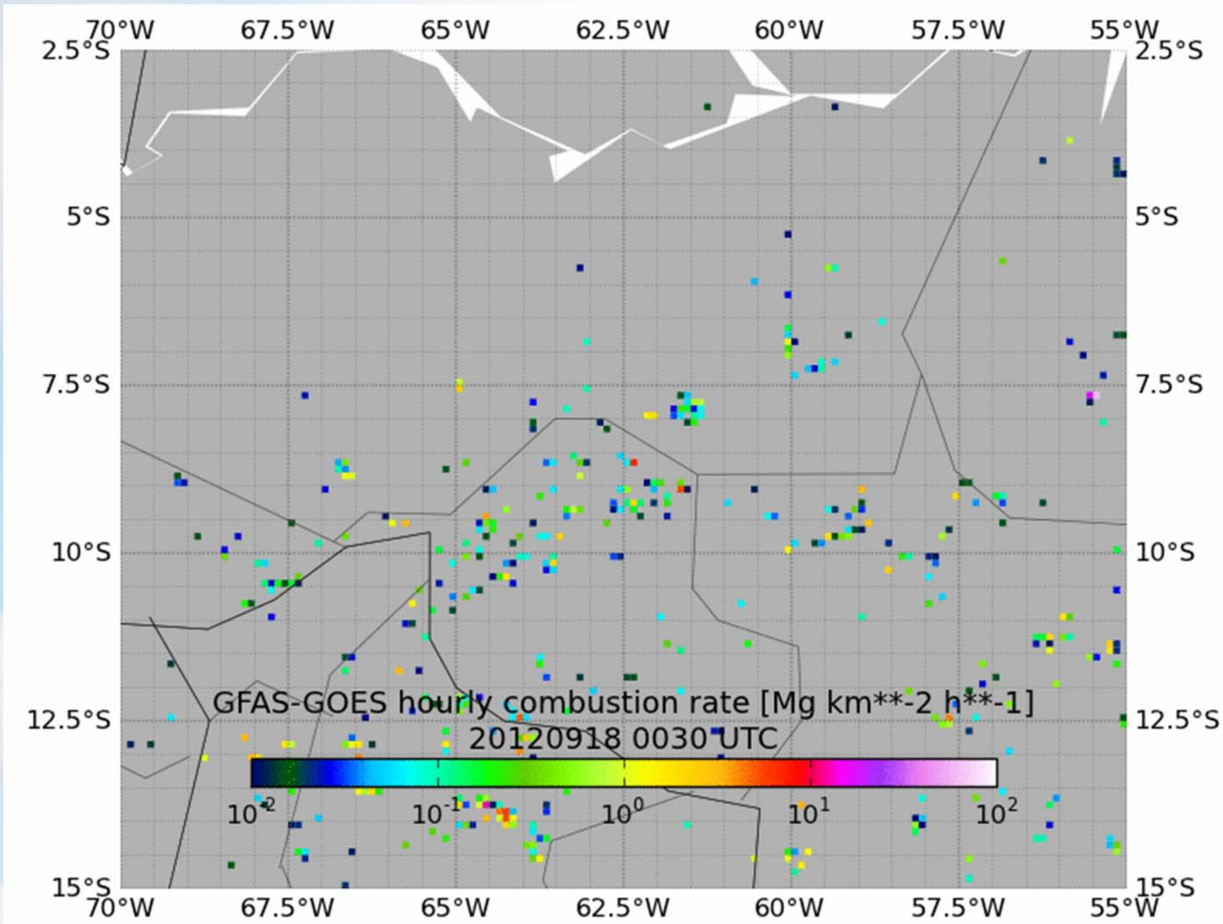
- MISR reference dataset of observed FRP and plume top height created (N America)
- PRM by Freitas et al. 2007 implemented and optimised
    - input data stream from ECMWF operational forecasts
- Sofiev et al. 2012 implemented
- PRMv1 delivered to ECMWF
    - for implementation in GFAS



Ronan Paugam, KCL

GFAS test version with 1 hour time resolution implemented

- assimilation of GOES FRP products
- 1-hour forecast based on corresponding 5 hour window of past 24 hours
- provided for SAMBBA campaign in real time
- evaluation to follow



Key Features

satellite-based FRP assimilation :

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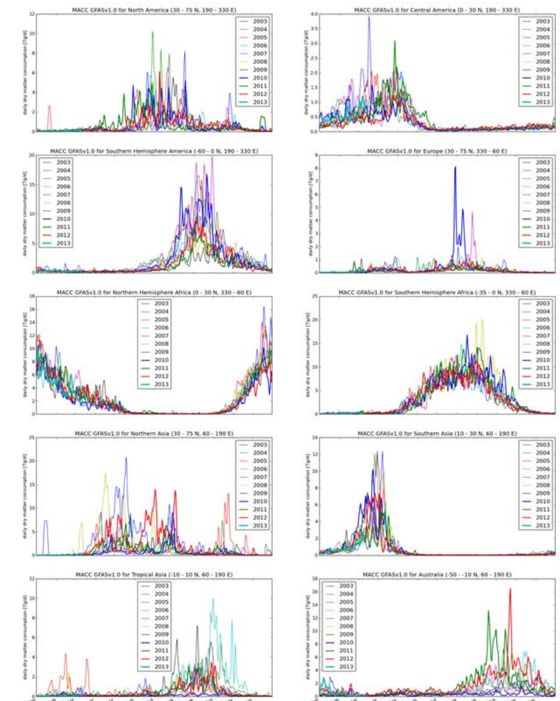
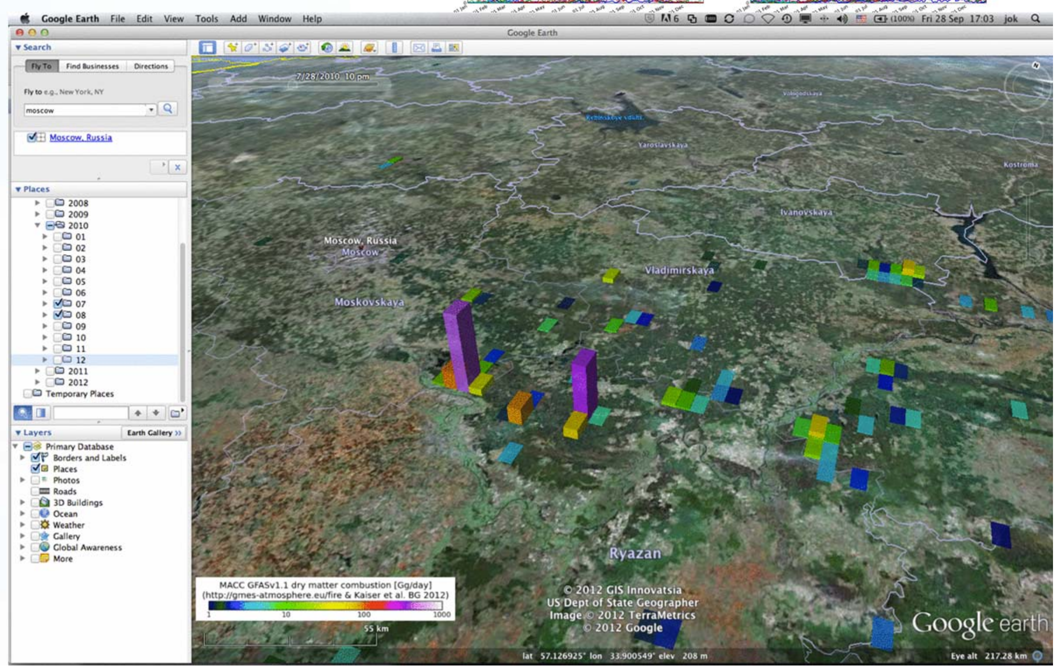
- NRT availability
- daily resolution (tests: hourly)

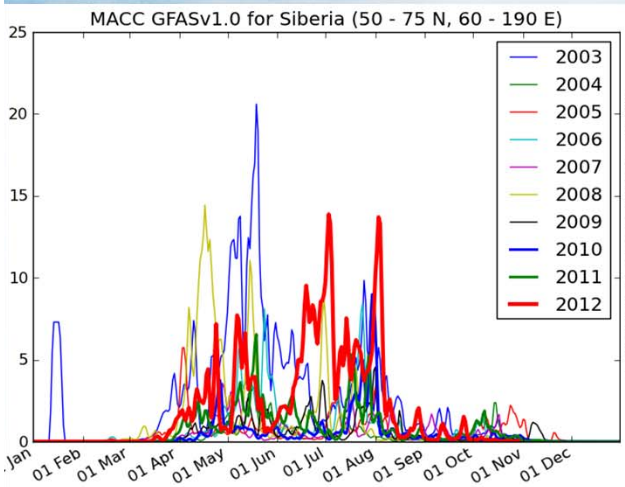
- well documented
- publicly available in several data servers
- various product formats:
  - GRIB
  - NetCDF
  - GIF map
  - PNG spaghetti plot
  - KML

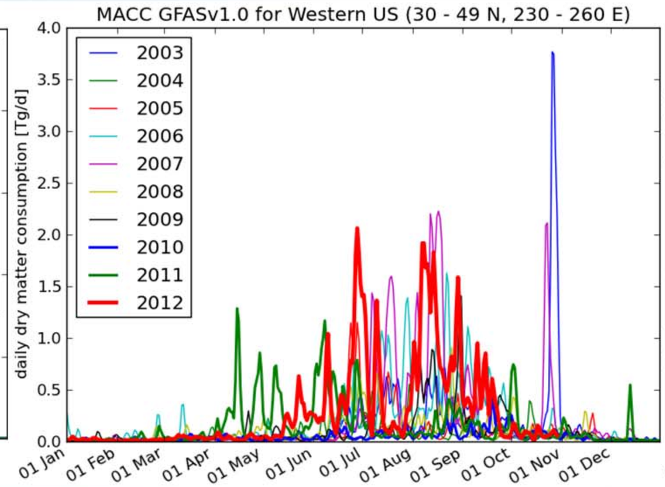
http://gmes-atmosphere.eu/fire

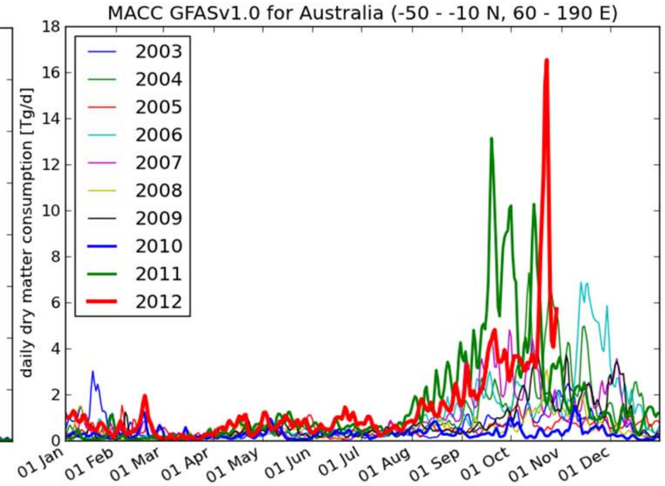


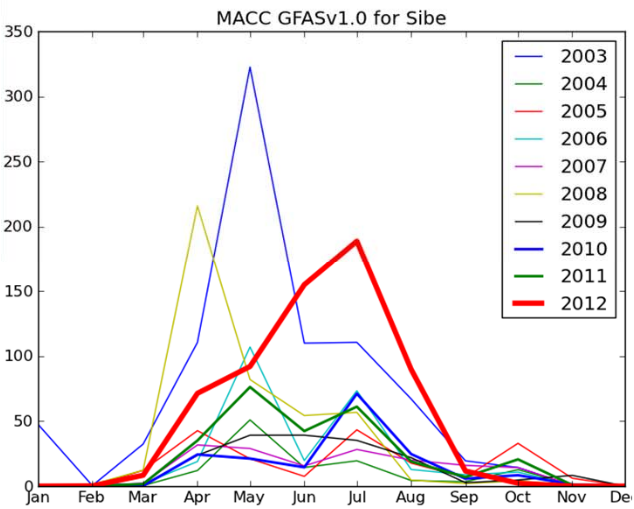


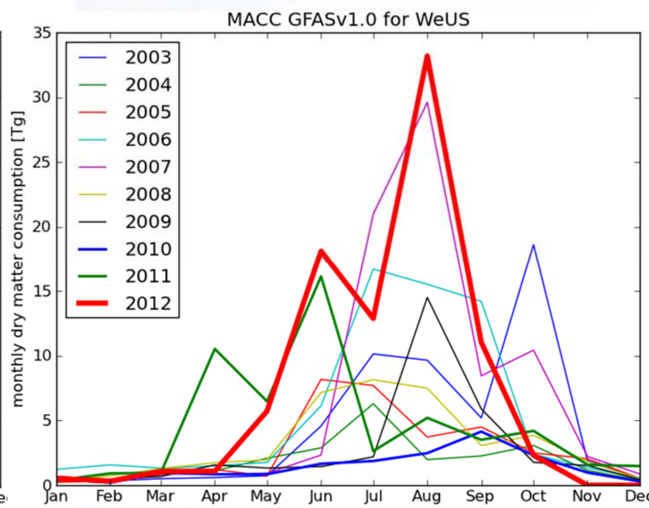
2012 is most interesting: Siberia, Western US & Australia!

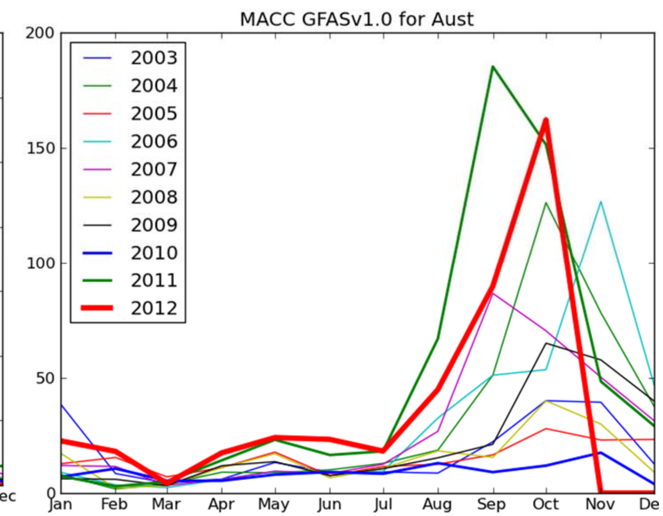




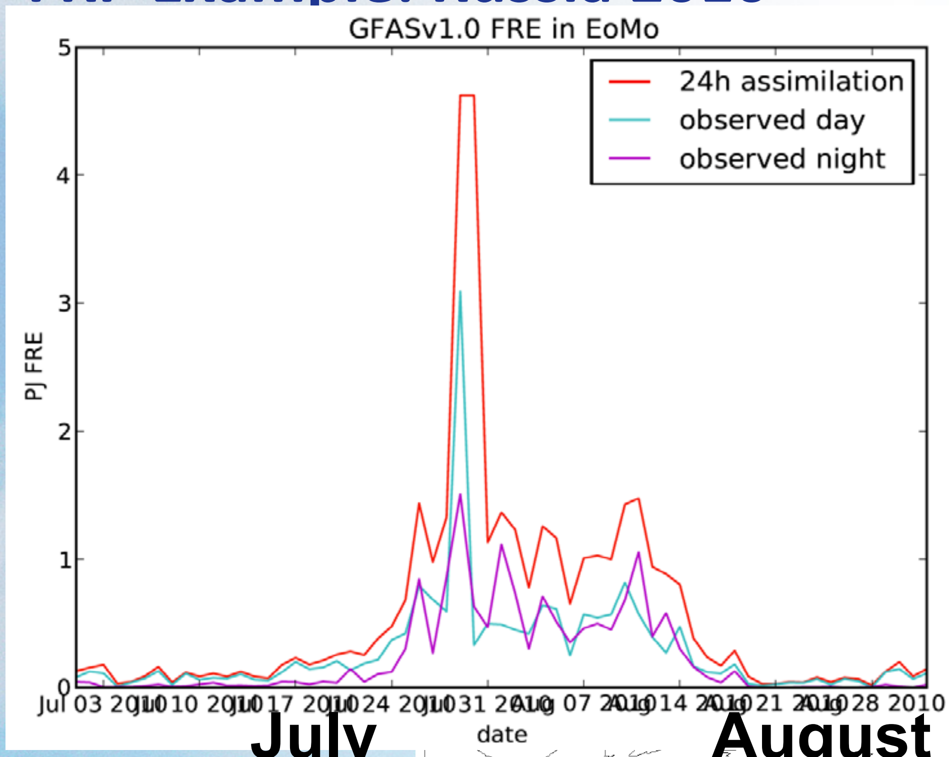


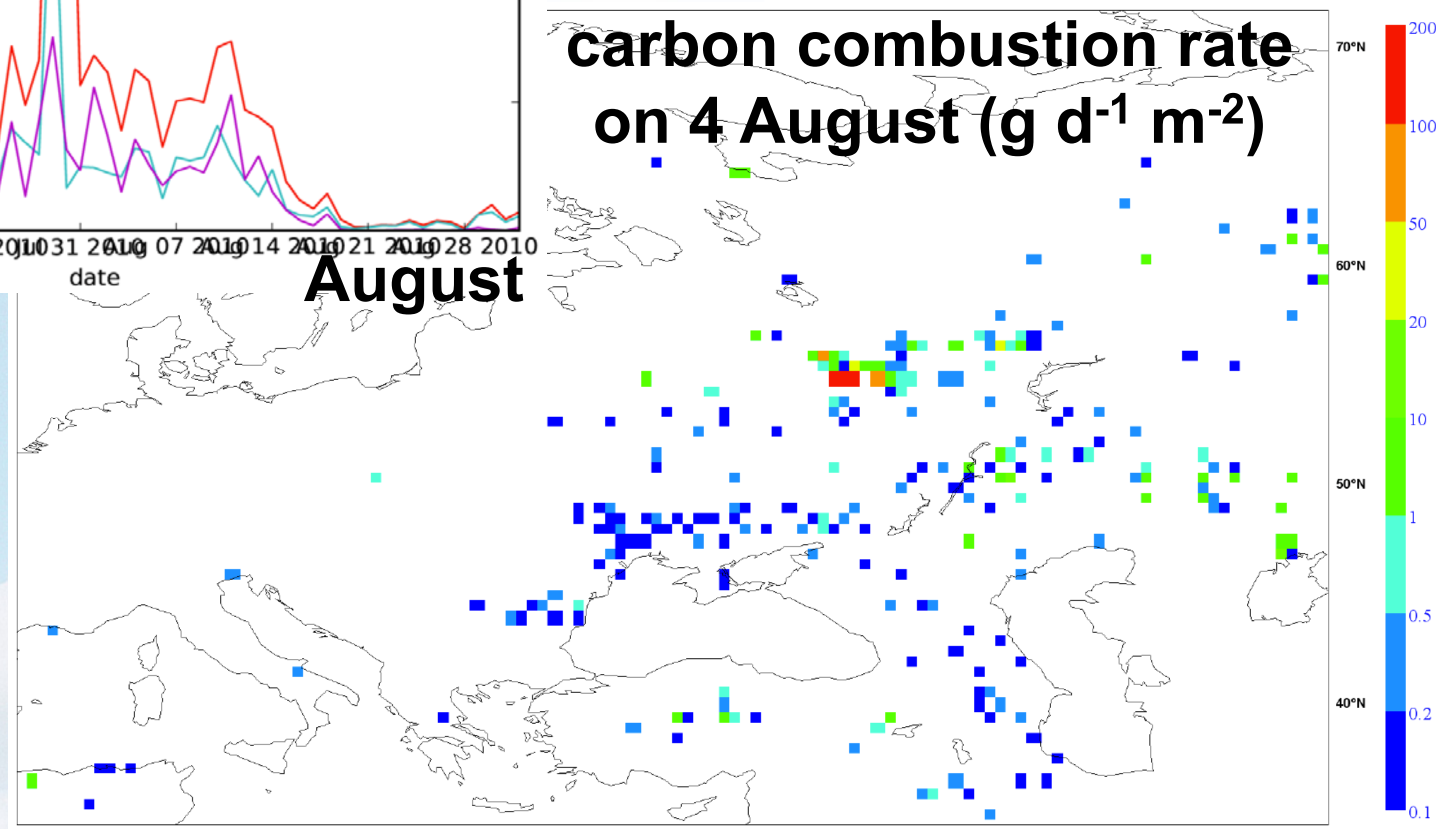






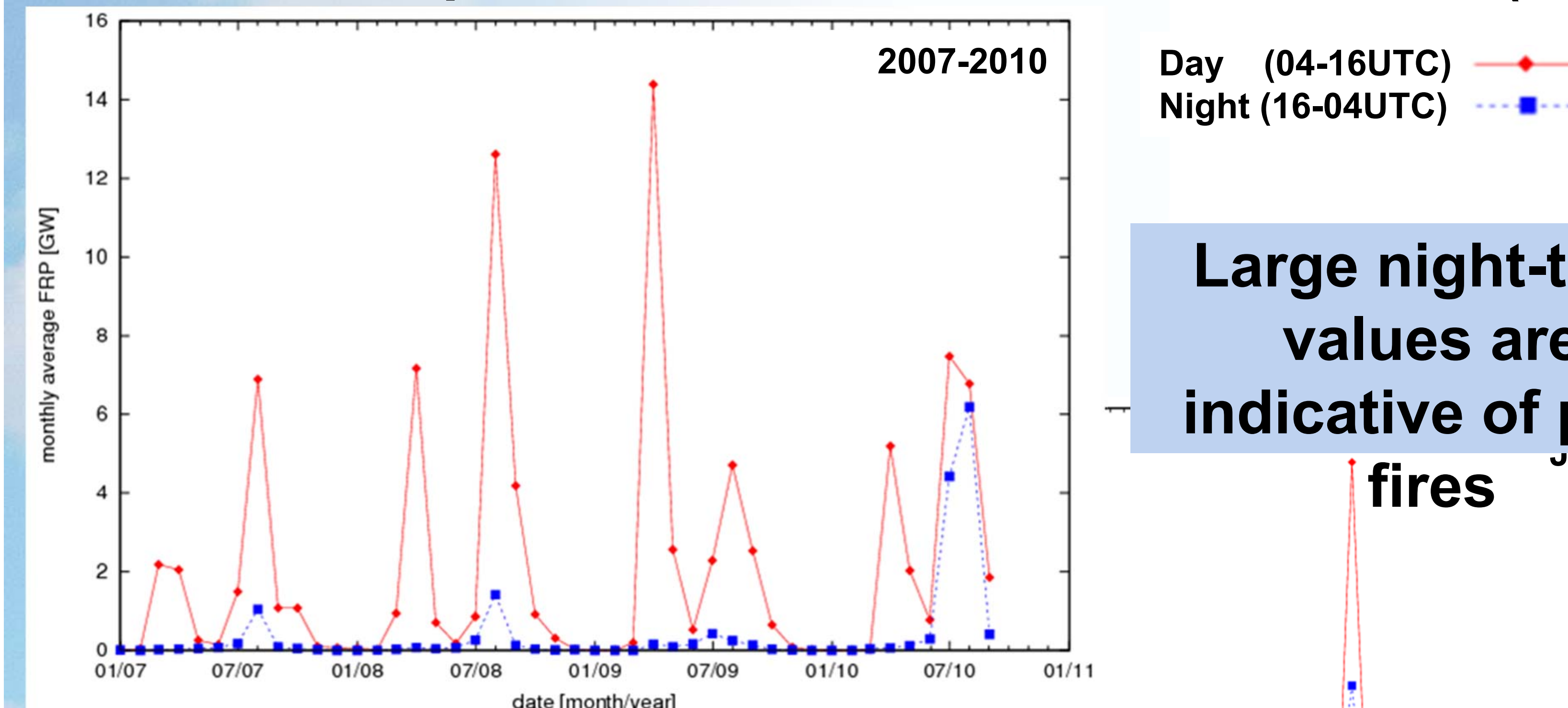
FRP Example: Russia 2010



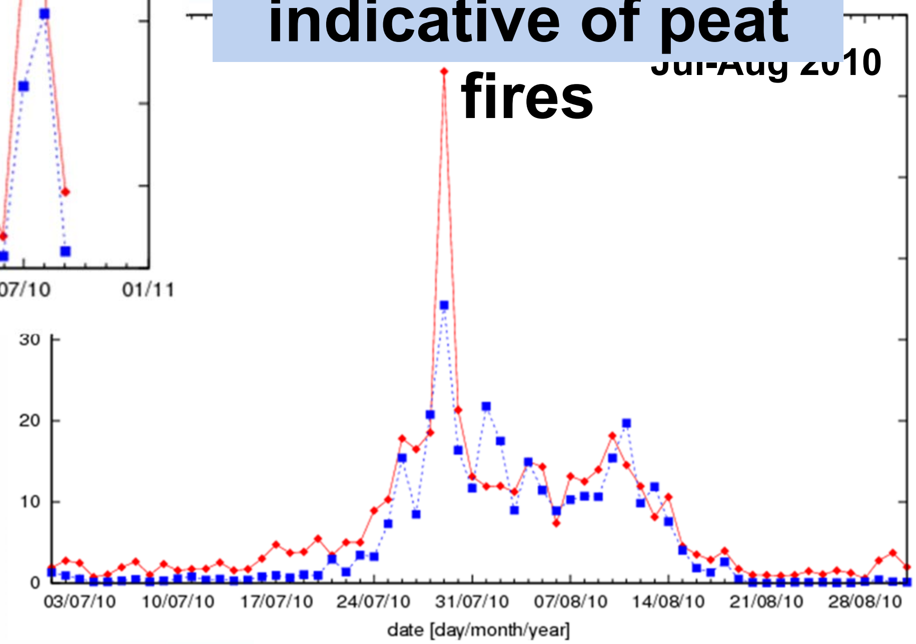


2010 fires over Russia

Fire radiative power from MODIS, east of Moscow (50-60N, 35-



Large night-time values are indicative of peat fires



Modelled emissions were those appropriate to woodland fires

User statistics: GEIA ECCAD

1. Patricia Oliva, Universidad de Alcala, Spain
2. Giuseppe Baldassarre, Istanbul Technical University, Turkey
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