Perspectives for European scale services on Fires

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Thanks to
Mark Parrington & the BBURNED community
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SEEDS Assembly, Toulouse, 5-6 Dec 2023

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SEEDS

PROGRAMME OF THE EUROPEAN UNION

opernicus
Europe's eyes on Earth

IMPLEMENTED BY ECMWF

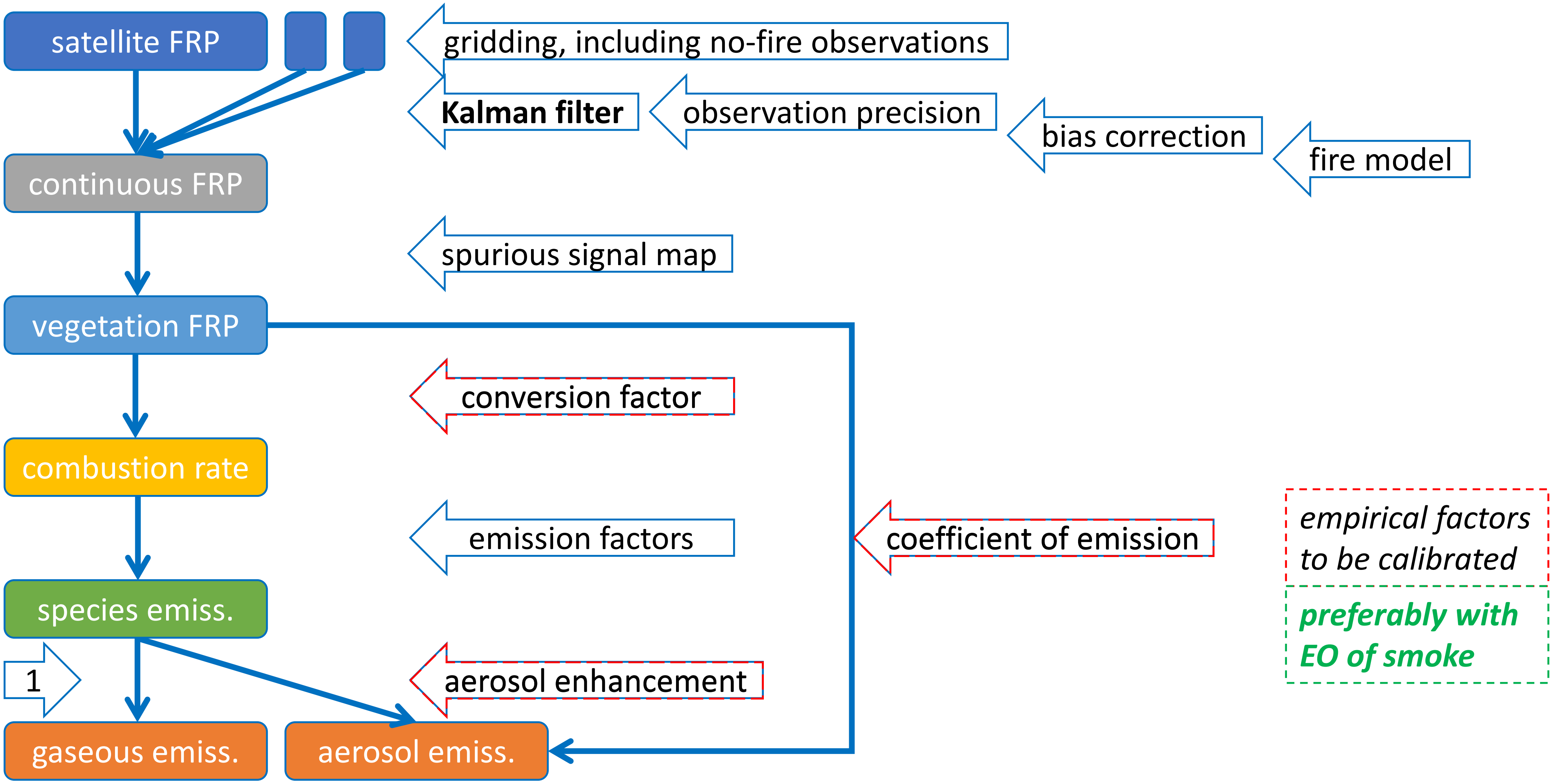
Atmosphere Monitoring Service
atmosphere.copernicus.eu

Outline

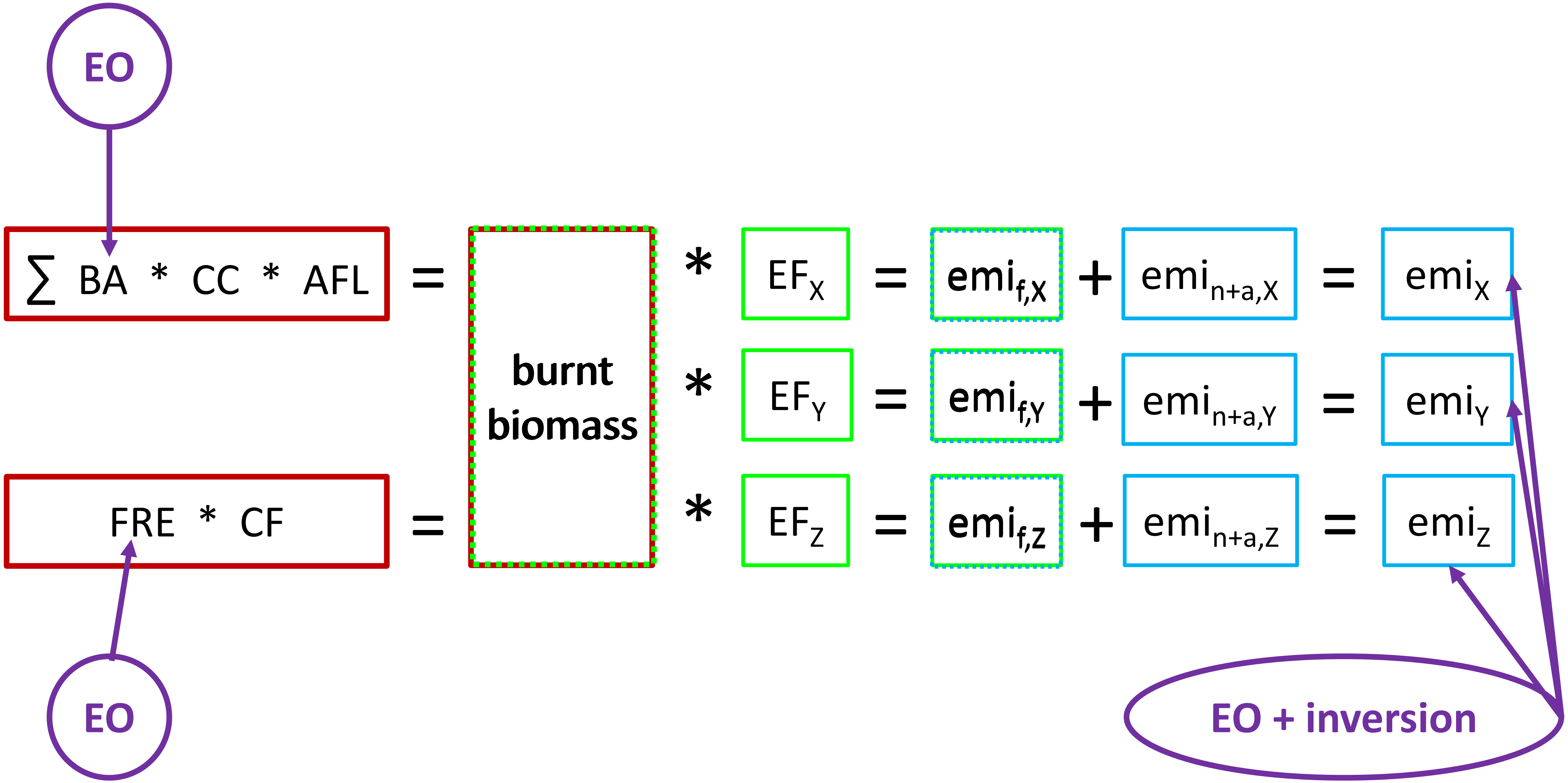
1. Perspective for integration of top-down and bottom-up

2. Perspective for using better fire observations

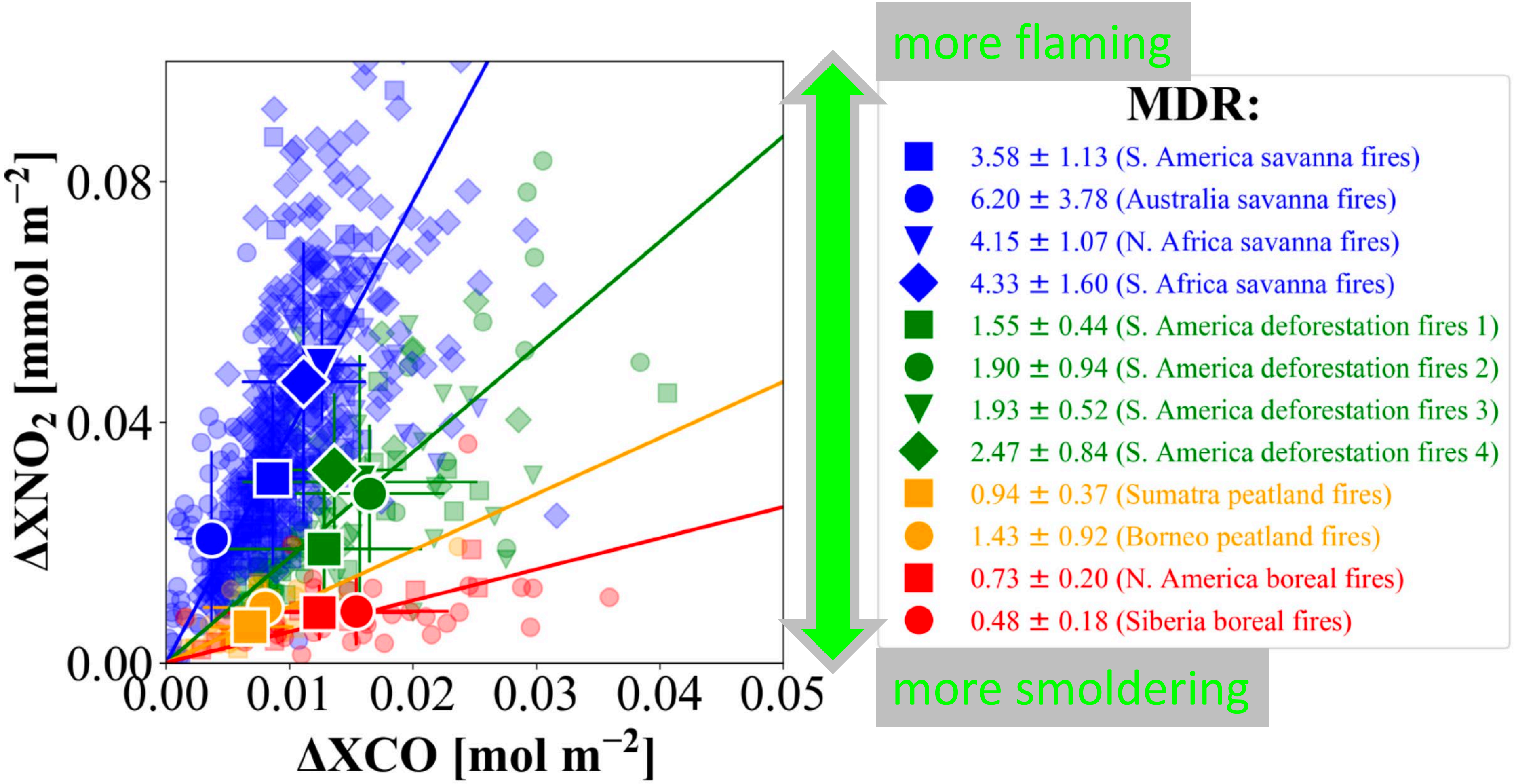
GFAS algorithm overview



The *pyrogenic emission network*



NO2/CO emission ratio differs systematically.



Atmos. Chem. Phys., 21, 597–616, 2021
https://doi.org/10.5194/acp-21-597-2021

Biomass burning combustion efficiency observed from space using measurements of CO and NO_2 by the TROPOspheric Monitoring Instrument (TROPOMI)

Ivar R. van der Velde[1,2], Guido R. van der Werf[1], Sander Houweling[1,2], Henk J. Eskes[3], J. Pepijn Veefkind[3,4], Tobias Borsdorff[2], and Ilse Aben[1,2]

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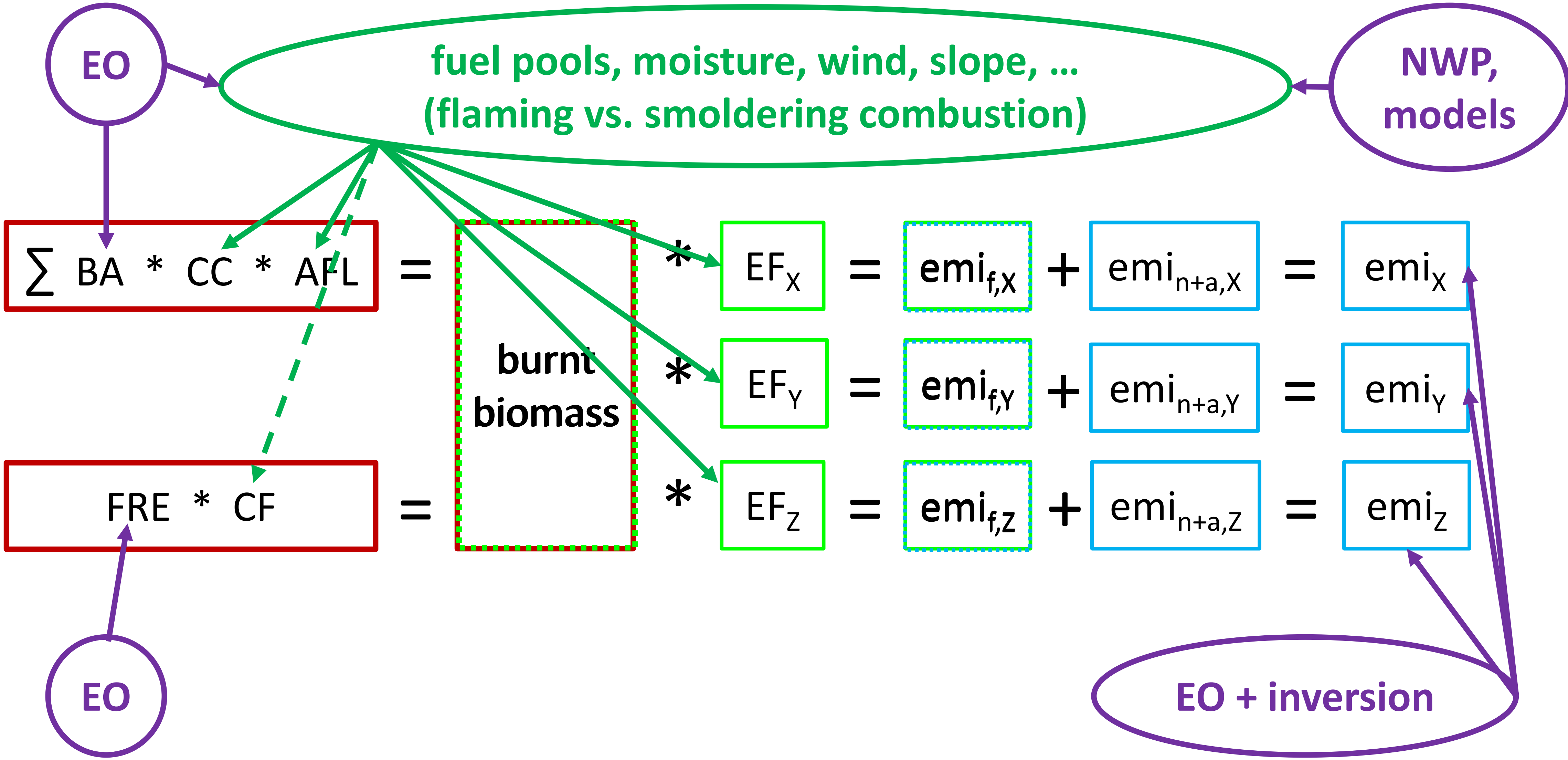
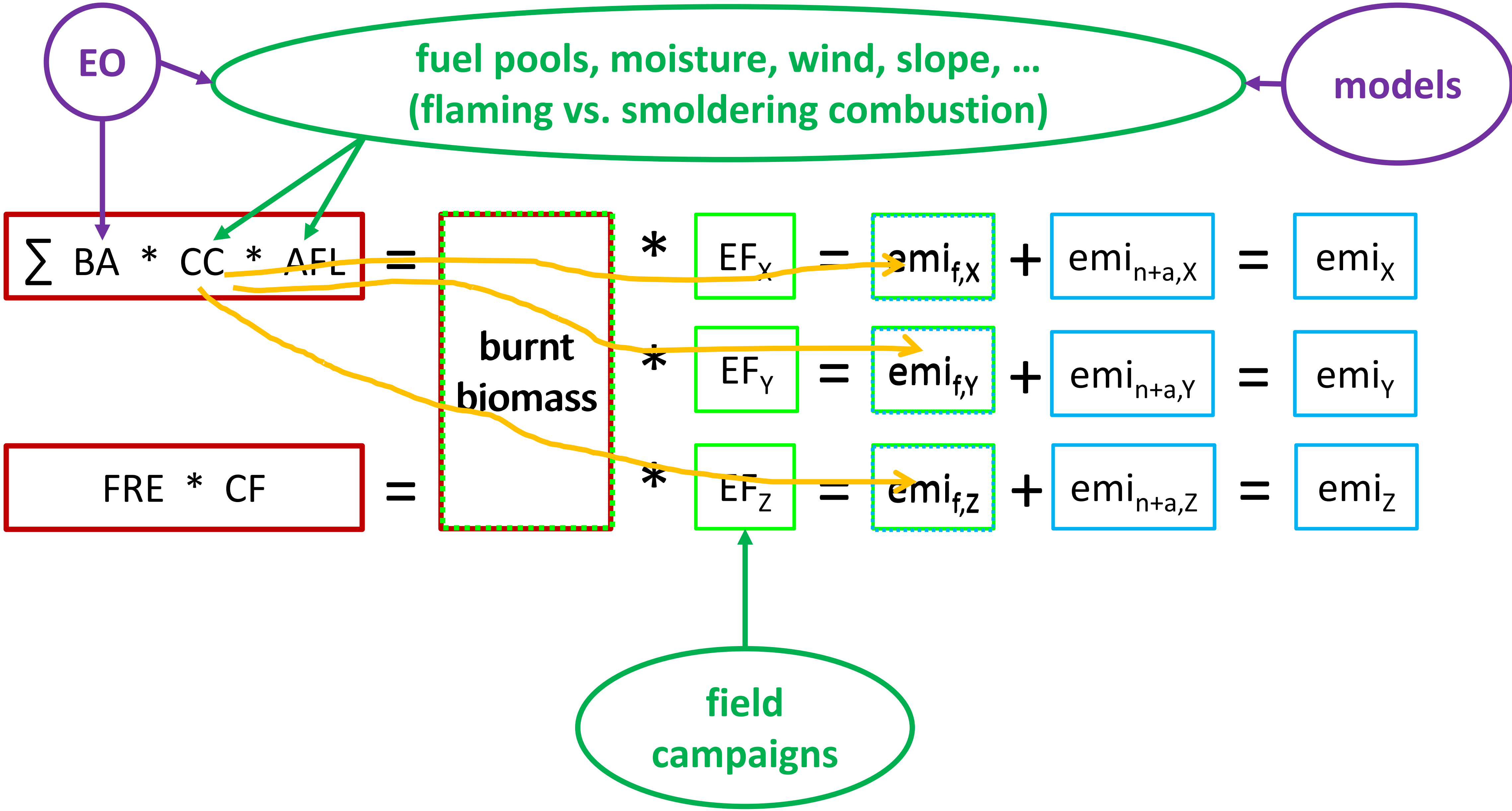
The *pyrogenic emission network*

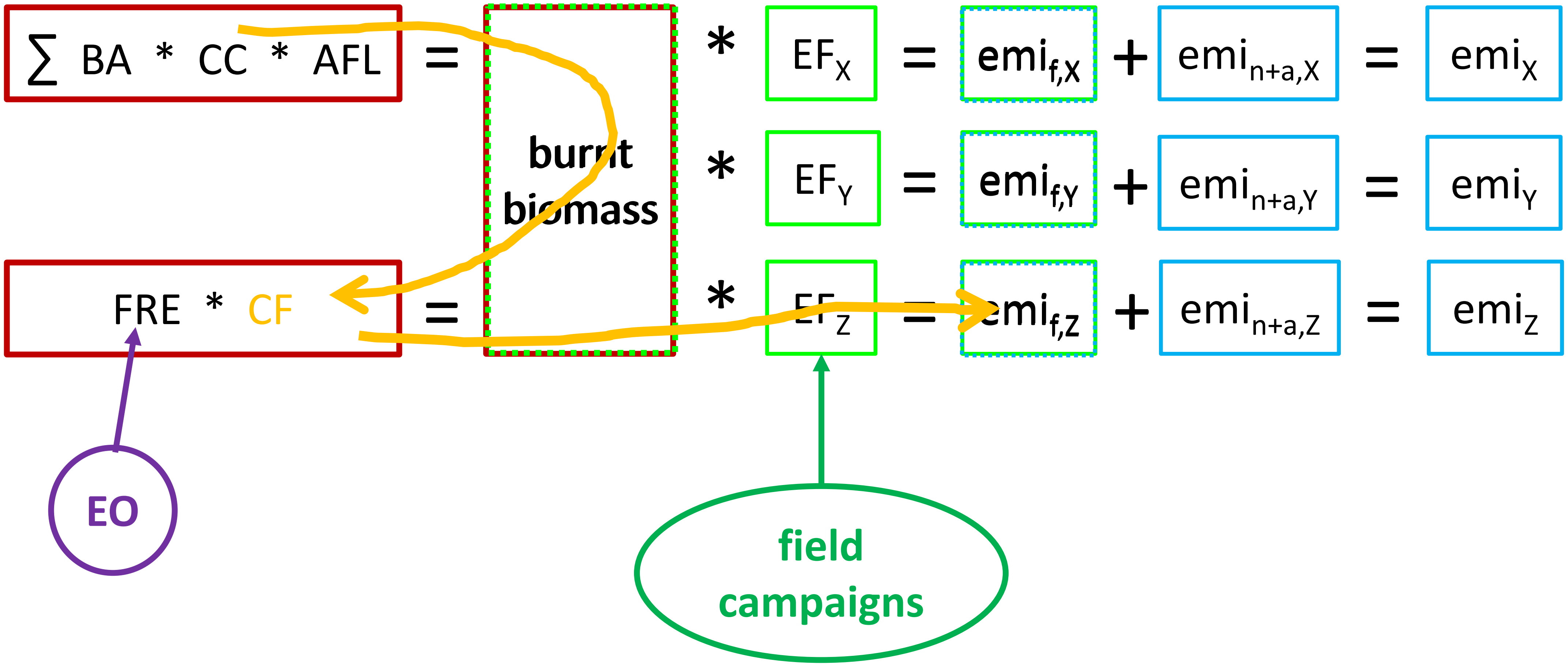


GFED4



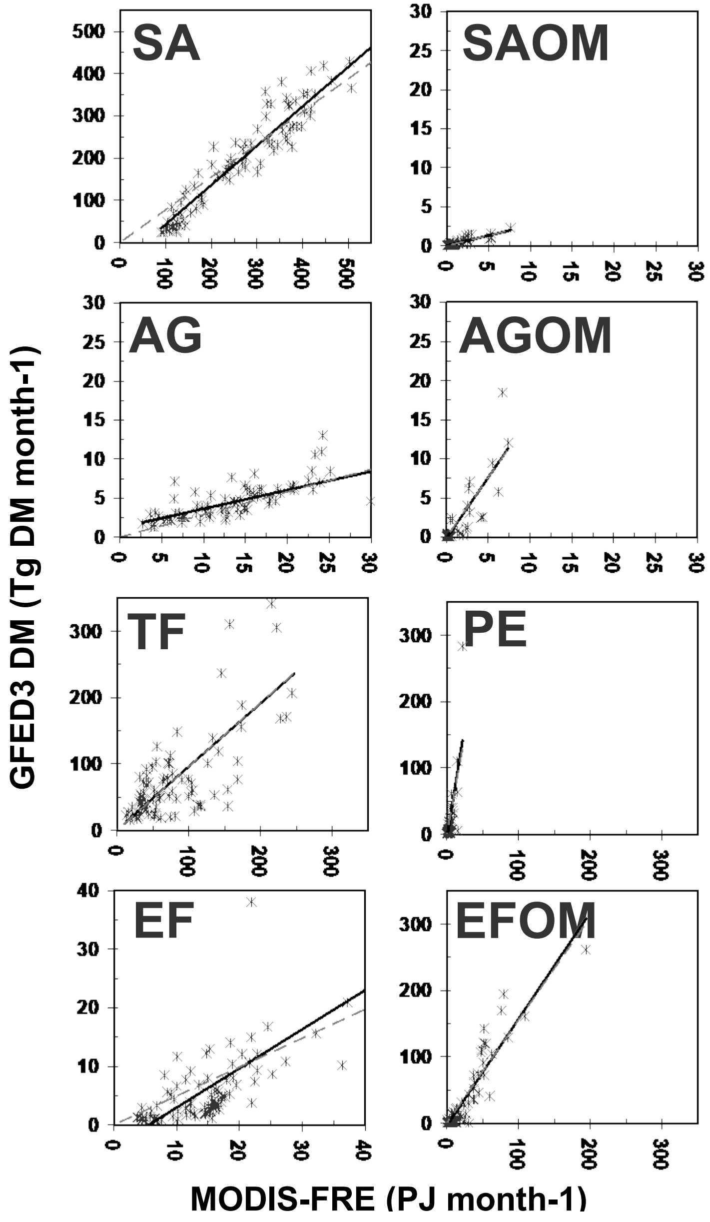
EO
fuel pools, moisture, wind, slope, …
(flaming vs. smoldering combustion)
models
∑ BA * CC * AFL
FRE * CF
=
=
burnt biomass
* EF_X = emi_f,X + emi_n+a,X = emi_X
* EF_Y = emi_f,Y + emi_n+a,Y = emi_Y
* EF_Z = emi_f,Z + emi_n+a,Z = emi_Z
field campaigns

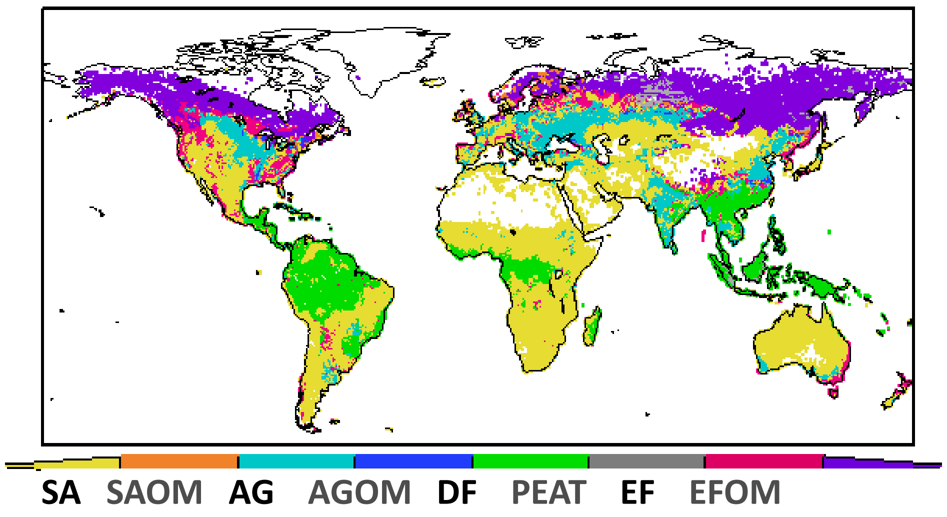
GFAS1



∑ BA * CC * AFL =
FRE * CF =
burnt biomass
* EF_X = emi_f,X + emi_n+a,X = emi_X
* EF_Y = emi_f,Y + emi_n+a,Y = emi_Y
* EF_Z = emi_f,Z + emi_n+a,Z = emi_Z
EO
field campaigns

FRP conversion factor analysis against GFED3

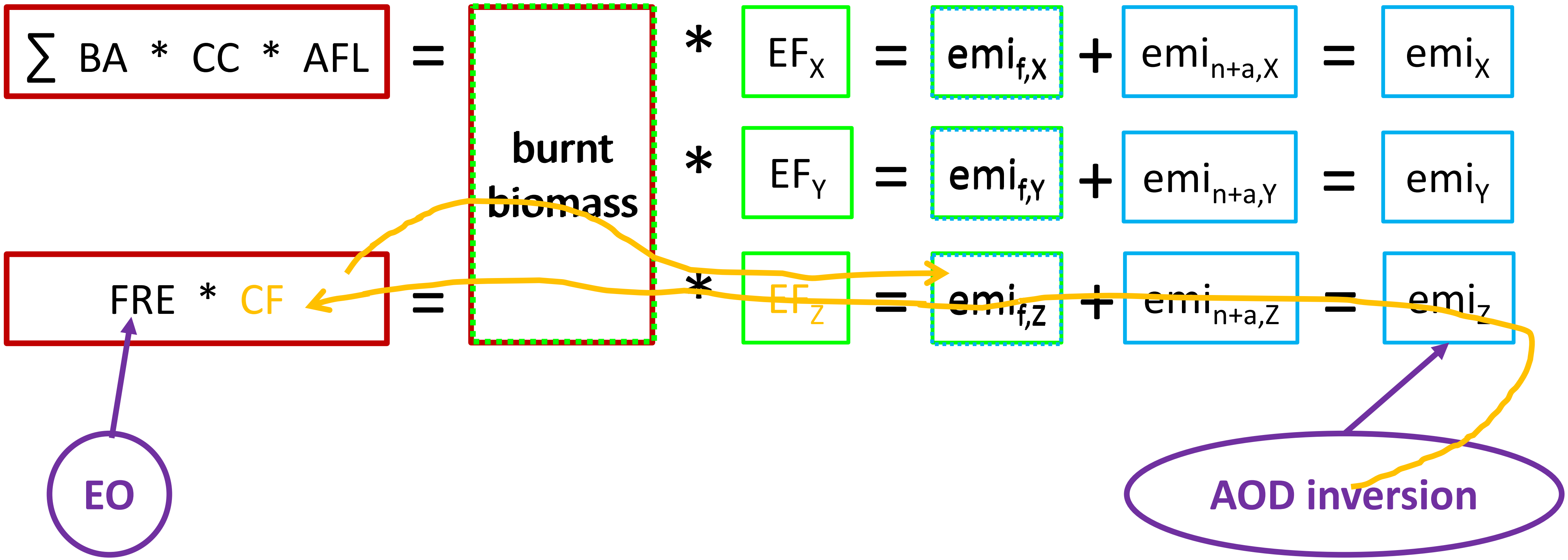




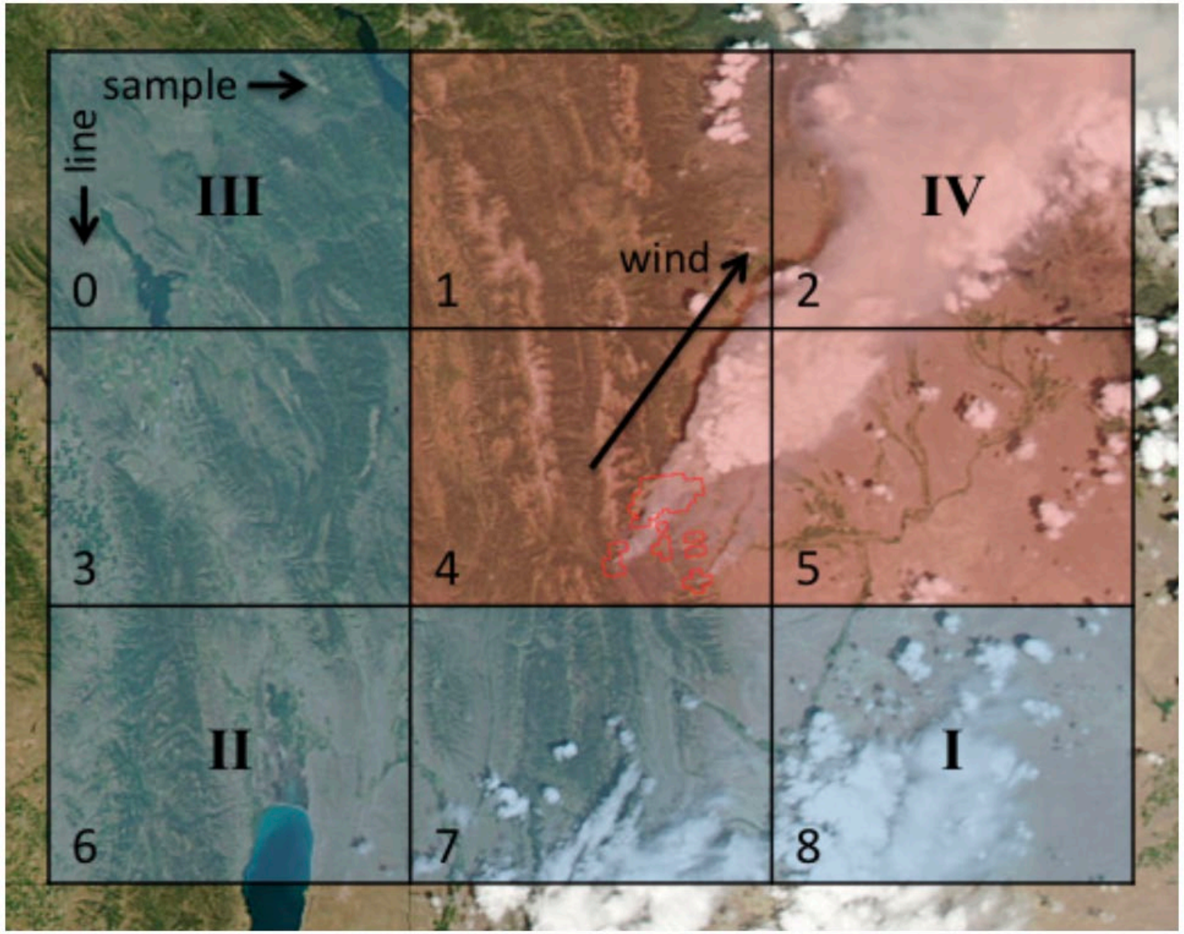
SA: savannah fires
SAOM: SA with potential OM burning
AG: agricultural fires
AGOM: AG with potential OM burning
DF: tropical fires
PEAT: peat burning
EF: extra-tropical fires
EFOM: EF with potential OM burning

[Heil et al., ECMWF TM628, 2010; Kaiser et al. BG 2012]

FEER / QFED constrained by plume analyses



Observe FRP and AOD in individual plumes (FEER)



Atmos. Chem. Phys., 14, 6643–6667, 2014
www.atmos-chem-phys.net/14/6643/2014/
doi:10.5194/acp-14-6643-2014

Global top-down smoke-aerosol emissions estimation using satellite fire radiative power measurements

C. Ichoku[1] and L. Ellison[1,2]

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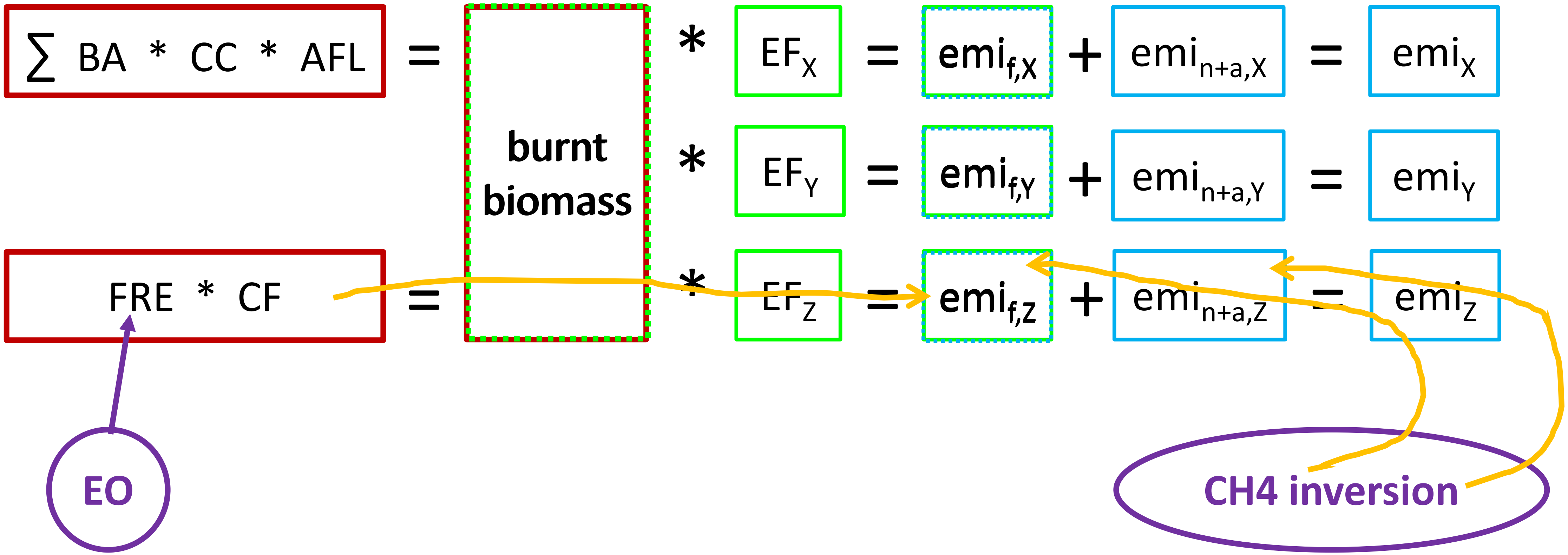
GHG inversions



Global 4D-Var CH4 inversion in GCM as "boundary condition" for other emissions

-

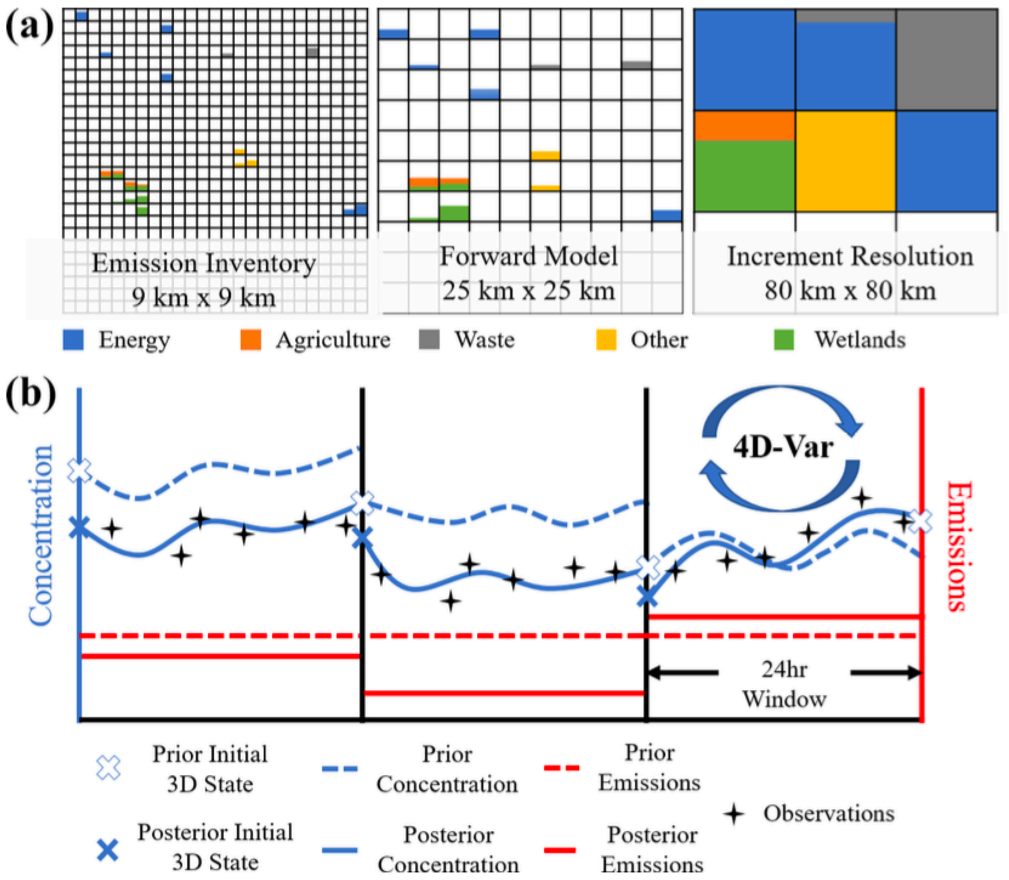
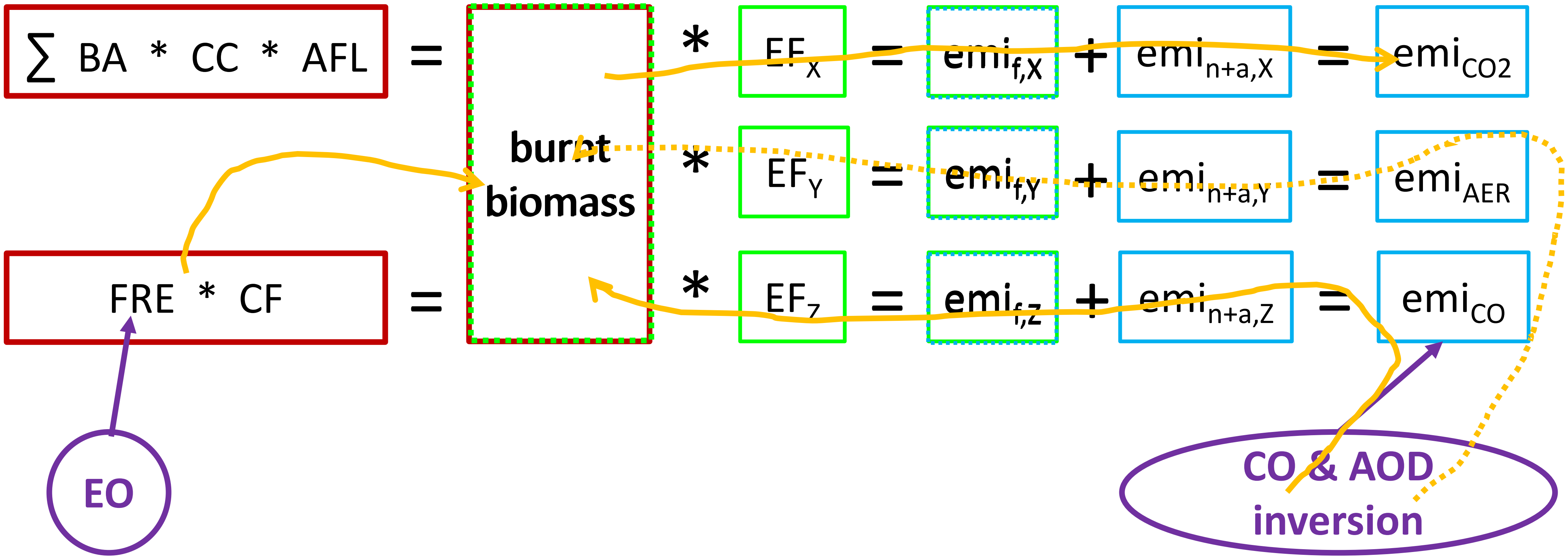


Figure 1. **(a)** Schematic of different resolutions used in the inversion shown by pseudo-data for five sectors. The magnitude of prior emissions at ~ 9 km (left panel) and those same emissions used as input to the forward model at ~ 25 km (middle panel). The inversion increment at ~ 80 km, resulting scaling factors are applied to all sectors within the grid cell, the boxes indicate relative contribution per sector (right panel). **(b)** Schematic of inversion setup using the 24-h window, correcting for the initial 3D state, emissions, and initial conditions in the prior of the subsequent window.

Atmos. Chem. Phys., 22, 5961–5981, 2022 https://doi.org/10.5194/acp-22-5961-2022

Probabilistic CO and AOD inversion



Regional inversion of CO and AOD with CTM

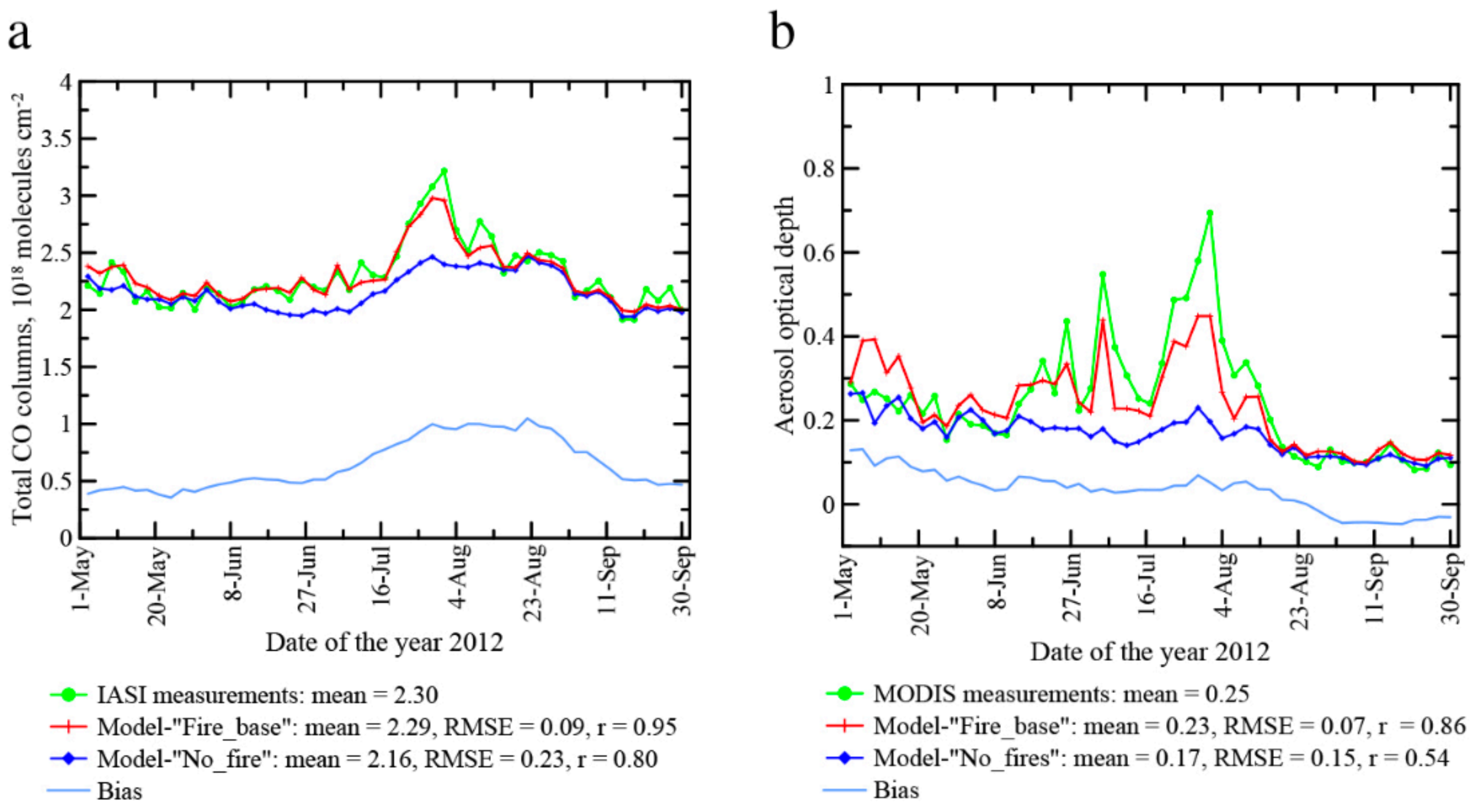
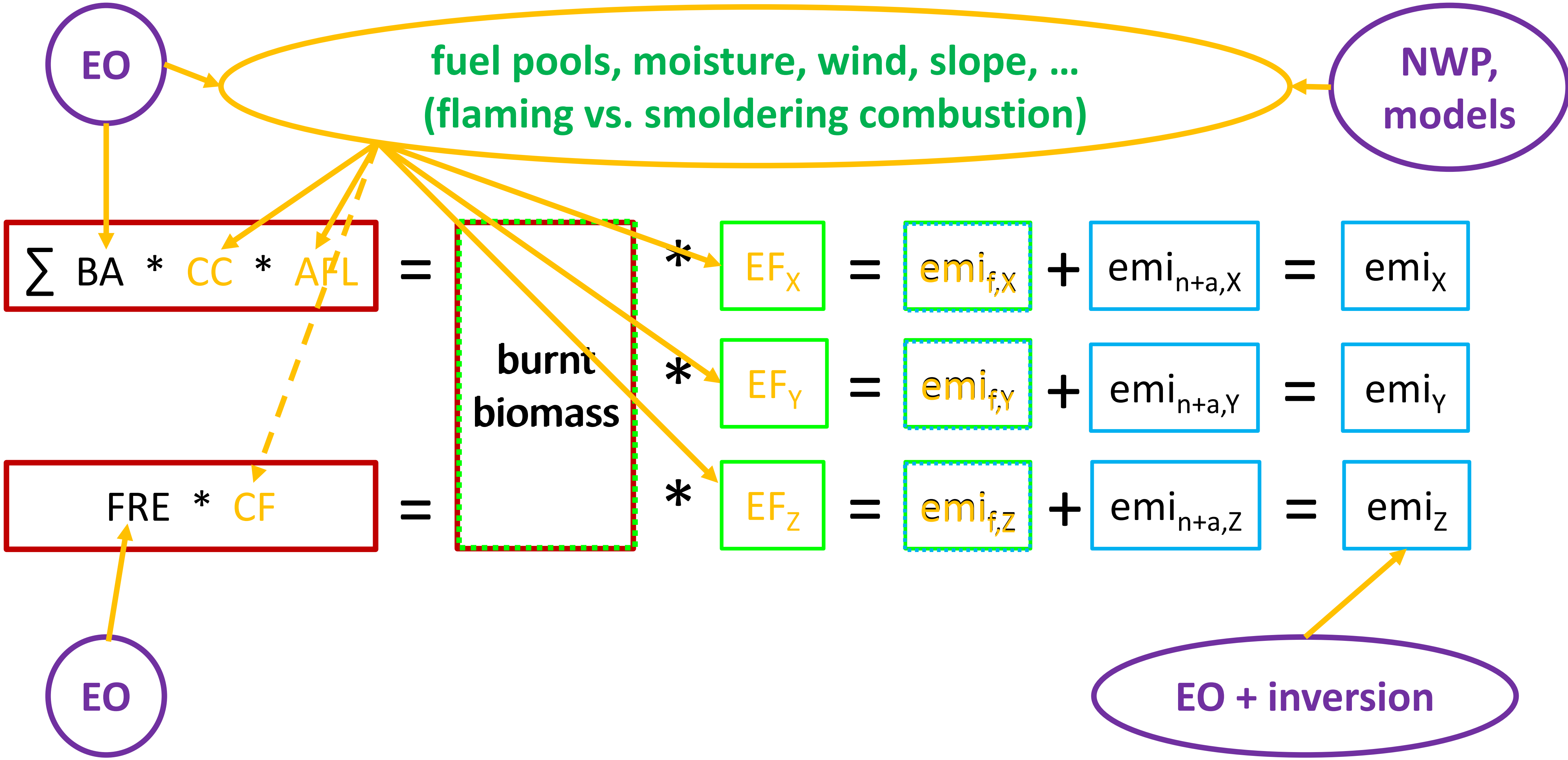
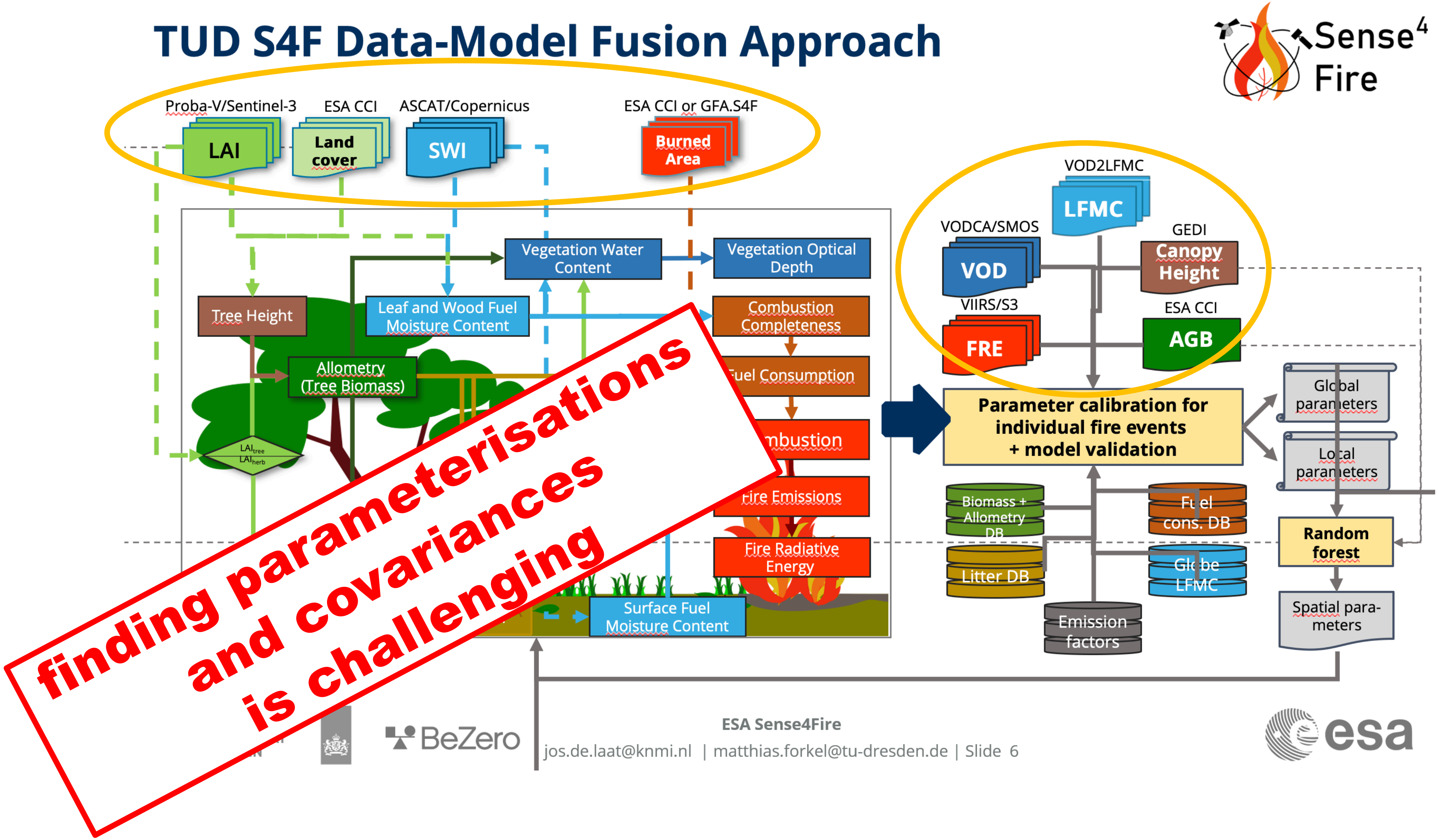


Figure 7. Time series of **(a)** daily total CO columns and **(b)** AOD simulated by CHIMERE with ("Fires_base") and without ("No_fires") fire emissions in comparison to the data from the corresponding IASI and MODIS measurements. The measurements and simulations for the days shown were withheld from the emission estimation procedure. The simulations are presented after debiasing. Note that the indicated bias represents the values of **Δ** (see Sect. 2.3) taken with the opposite sign. All values are the averages over the Siberian study region.

Goal: Constrain dynamic model for CC, AFL, EF



Example modelling of CC, AFL, CF & $EF_{X,Y,Z}$



Possible starting point

1. invert species with best observational constraint and knowledge on *emission factor (EF)* → carbon monoxide
   - CO emission flux inversion from S5P-TROPOMI, MetOp-IASI (SEEDS!)
   - EF_{CO} dependent on vegetation and fuel/soil moisture, possibly online
2. calculate *conversion factor (CF)*
   - dependent on vegetation and fuel/soil moisture
3. use *EF* for other species from literature
4. adjust *EF* well-observed species with dedicated regional inversions
   - S5P-TROPOMI: HCHO, NO_2, CH_4 (SEEDS!)
   - Metop, MODIS, VIIRS: aerosols
   - including dependence on vegetation and fuel/soil moisture

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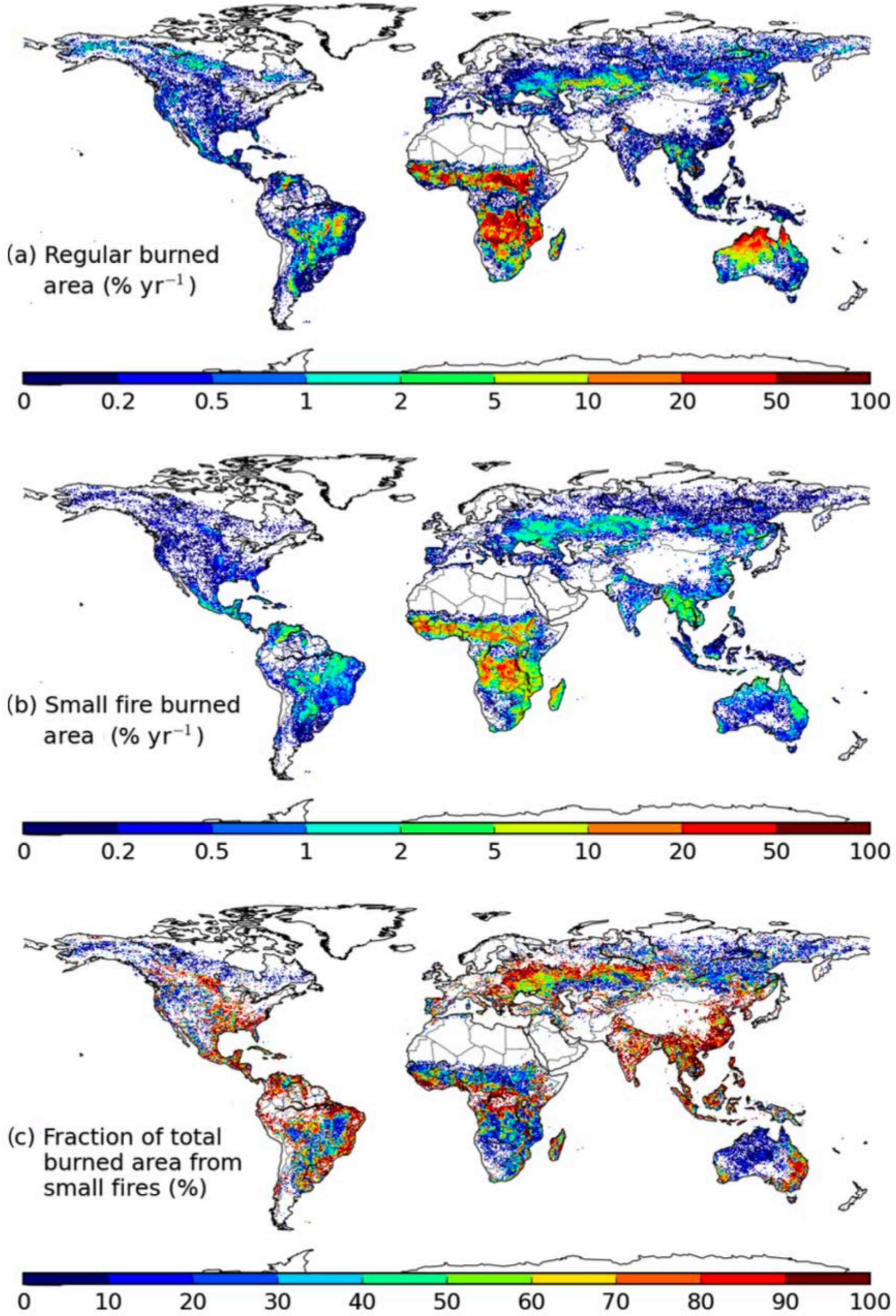
Outline

1. Perspective for integration of top-down and bottom-up

2. **Perspective for using better fire observations**

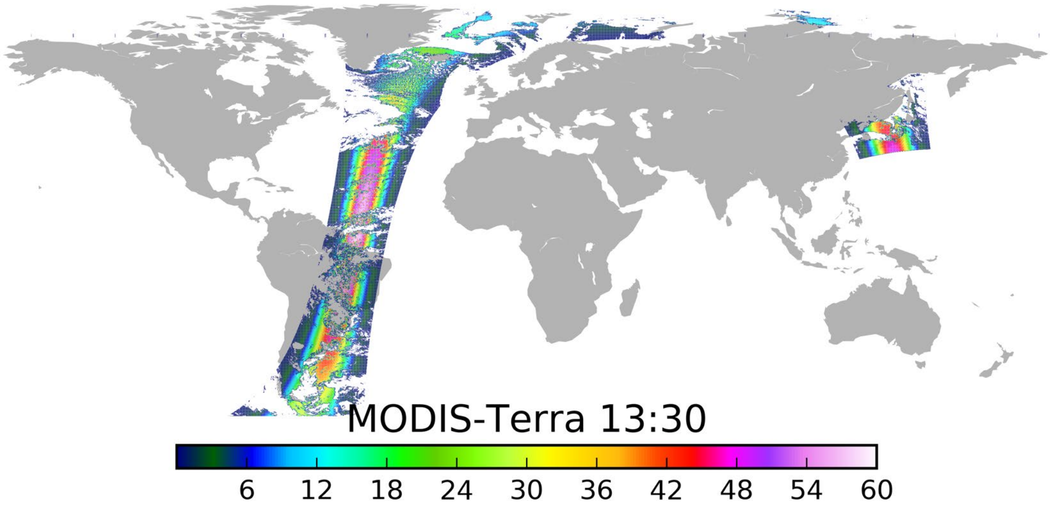
Some sources of error

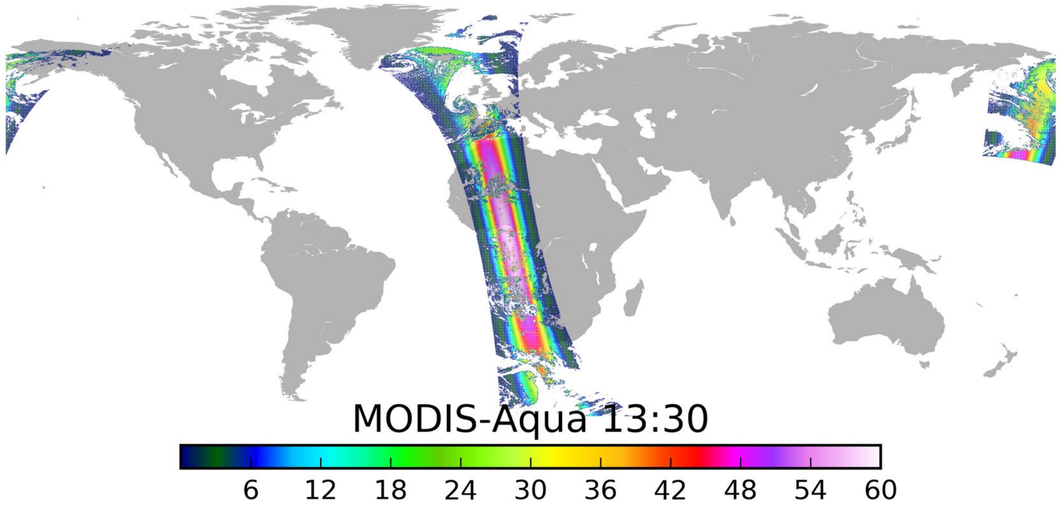
- Burnt Area: Small fires are often below detection threshold.
- Fire Radiative Power: Sampling of transient & stochastic phenomenon is incomplete due to orbits and clouds.
- Emissions: Fuel and fire modelling or empirical parameterisation is required.
  - But every fire is different, depending of fuel type, fuel condition, meteorology humans response etc.
- Little ground truth available.

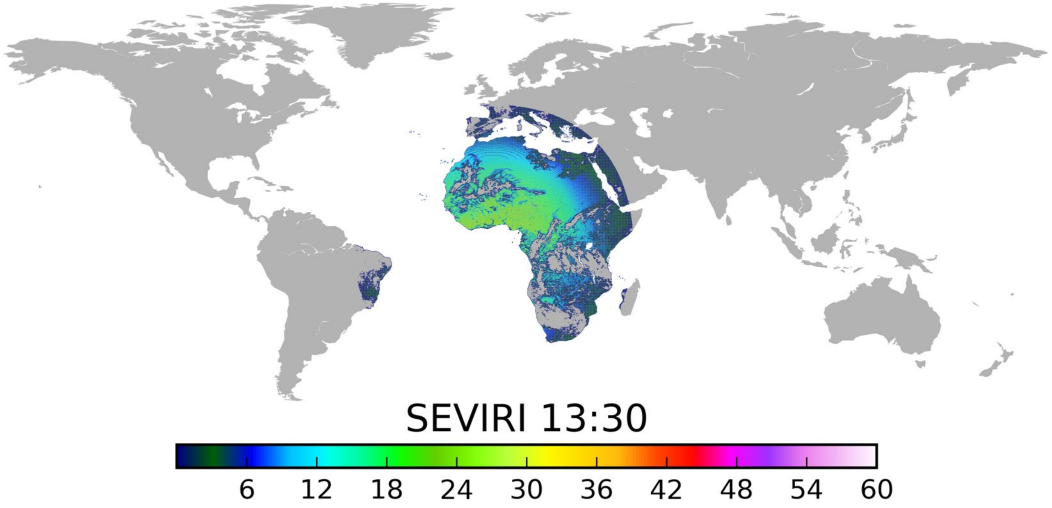


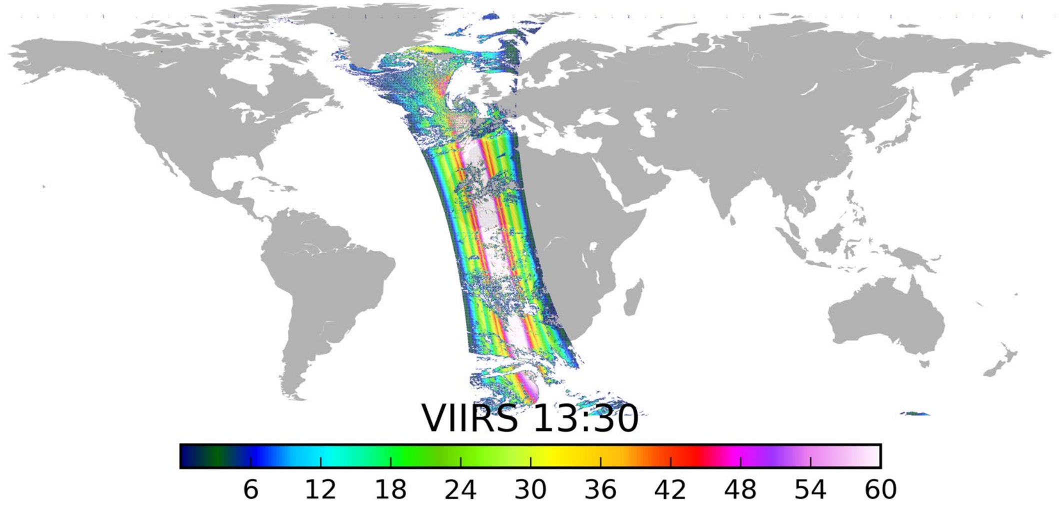
[van der Werf et al. 2017]

1-hour merged inverse variance for FRP observations in m^4W^{-2} 2016-01-01







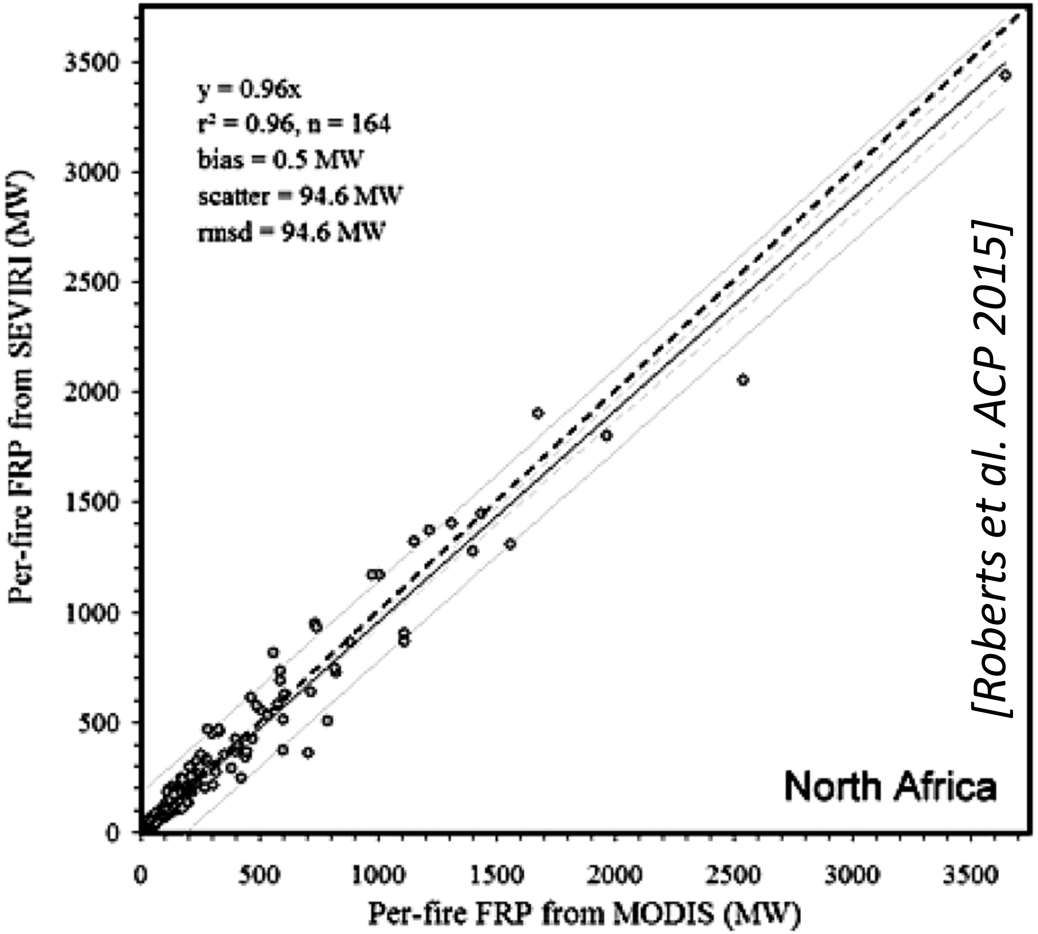


[Hüser et al. CAMS 2018]

FRP observation bias: SEVIRI w.r.t. MODIS

instantaneous fire clusters:

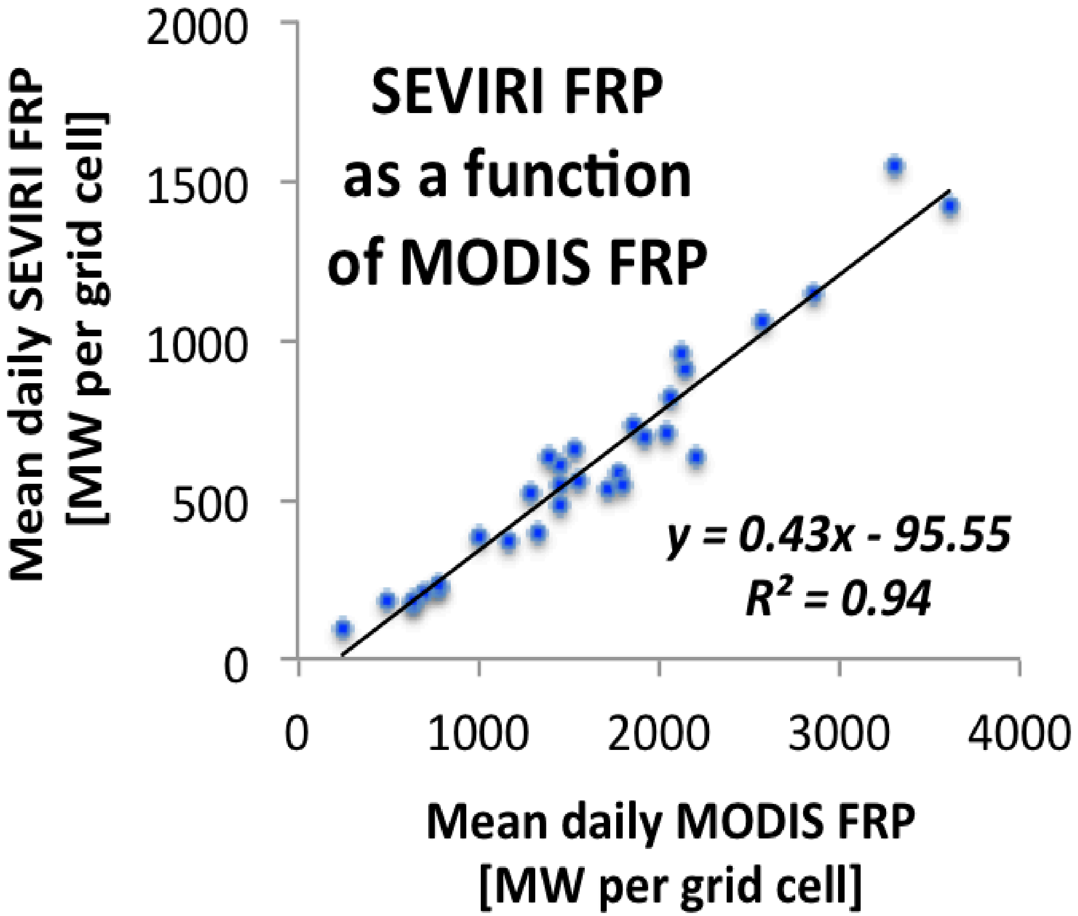
- **4% underestimation**



[Roberts et al. ACP 2015]

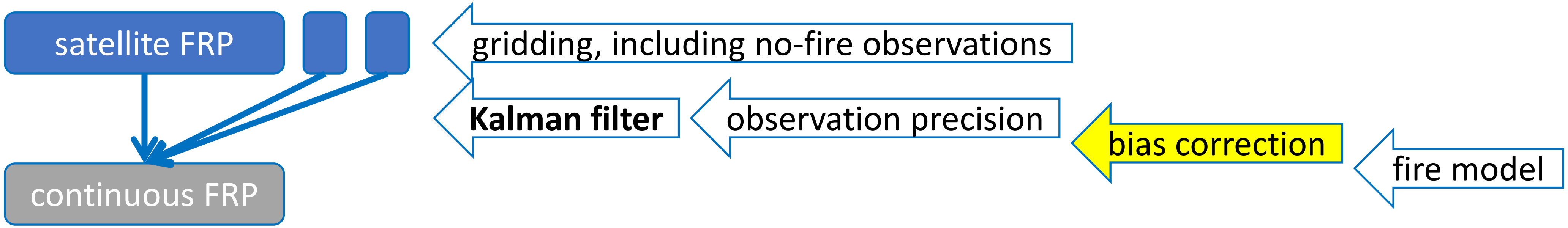
monthly 2°x2° grid cells:

- **57% underestimation**



[Heil et al. CAMS 2016]

GFAS algorithm overview

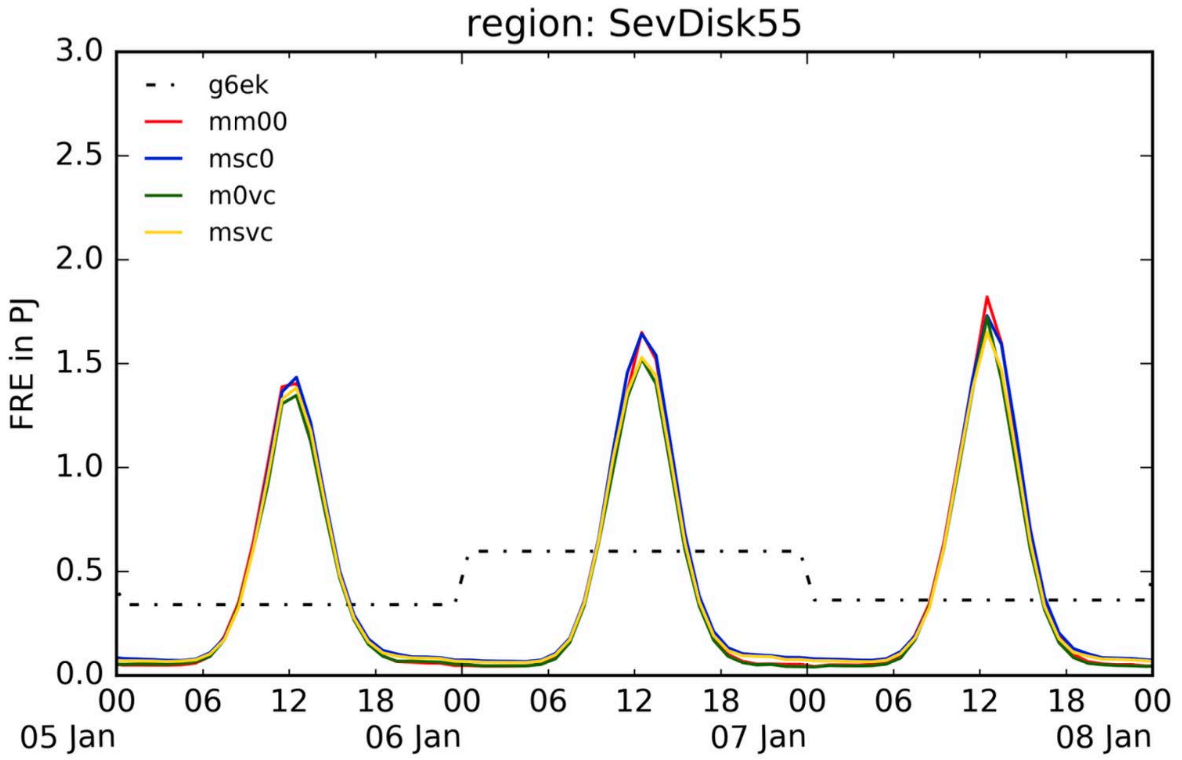


Basic bias correction works on continental scale.

Bias correction factors calculated to keep the global annual assimilated FRP budgets from different instruments un-biased:

Instrument	Bias correction factors	
	Daytime	Night-time
MODIS-Terra	1.87	1.20
MODIS-Aqua	0.73	1.67
VIIRS-NPP	0.79	6.27
SEVIRI	1.8	1.8
GOES-E	3.2	3.8
GOES-W	2.7	2.4
Himawari-8	3.1	4.1
SLSTR	TBD	TBD

Hourly GFAS FRP over SEVIRI disc using different combinations of bias-corrected **MODIS-, VIIRS- and SEVIRI-FRP**:



[Hüser et al. CAMS 2018, Zhang et al. CAMS 2021, Kaiser et al. 2023]

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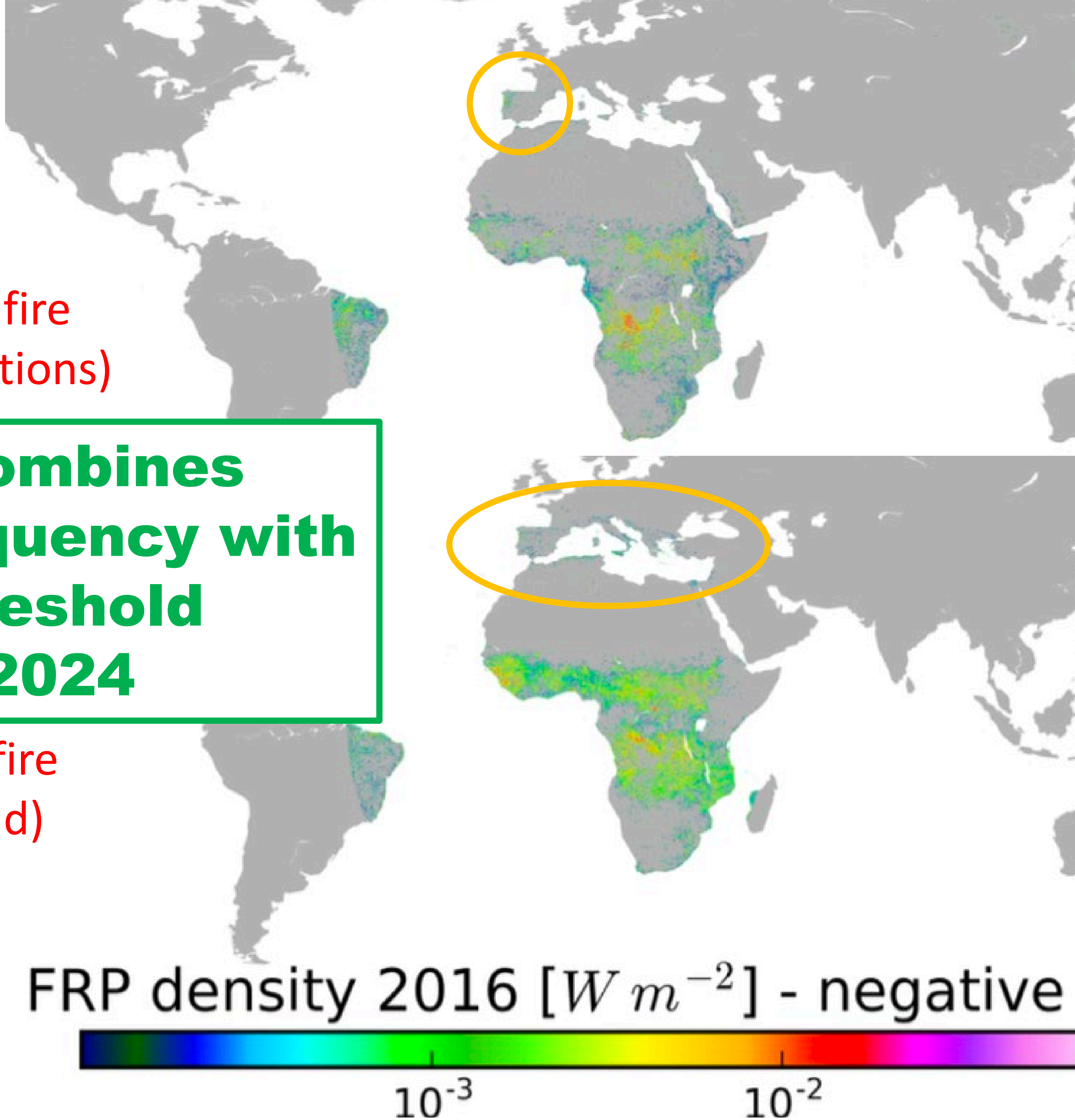
SEVIRI w.r.t. MODIS on finer scale

where SEVIRI saw more fire
(more frequent observations)

FCI aboard MTG combines high observations frequency with low detection threshold -> available in 2024

where MODIS saw more fire
(lower detection threshold)



Summary

1. Fire Radiative Power observations from Meteosat Third Generation provide a unique opportunity to significantly reduce the major error sources in fire observations over Europe

2. Bottom-up and top-down emission estimates
   - integration paths can be identified

3. key elements of initial improved European service:
   - **FRP** from **MTG**
   - **calibrated** with atmospheric CO observations -> S5P, S5, S4, Metop
   - HCHO, CH4, NO2, aerosols, … optimised individually -> S5P, S5, S4, Metop
   - track flaming / smoldering
   - compatibility with CAMS-GFAS and integrated assimilation

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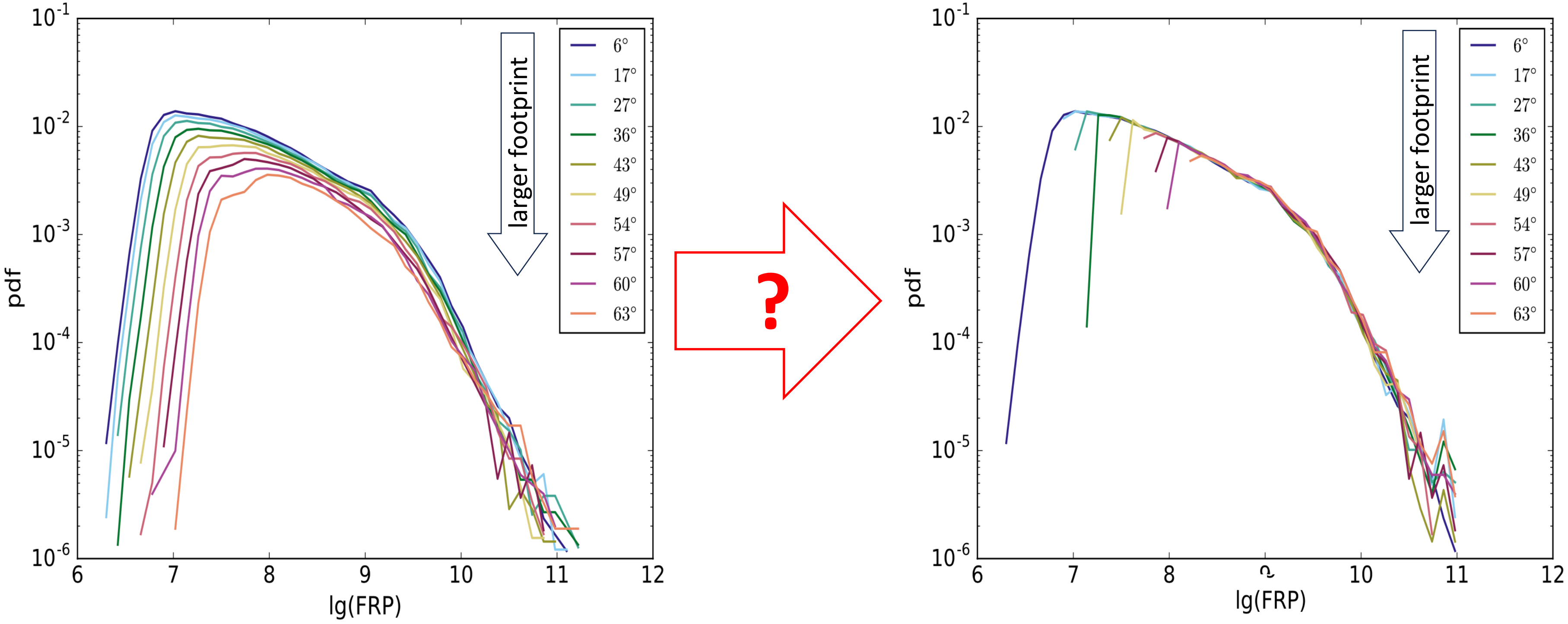
Outline, extended

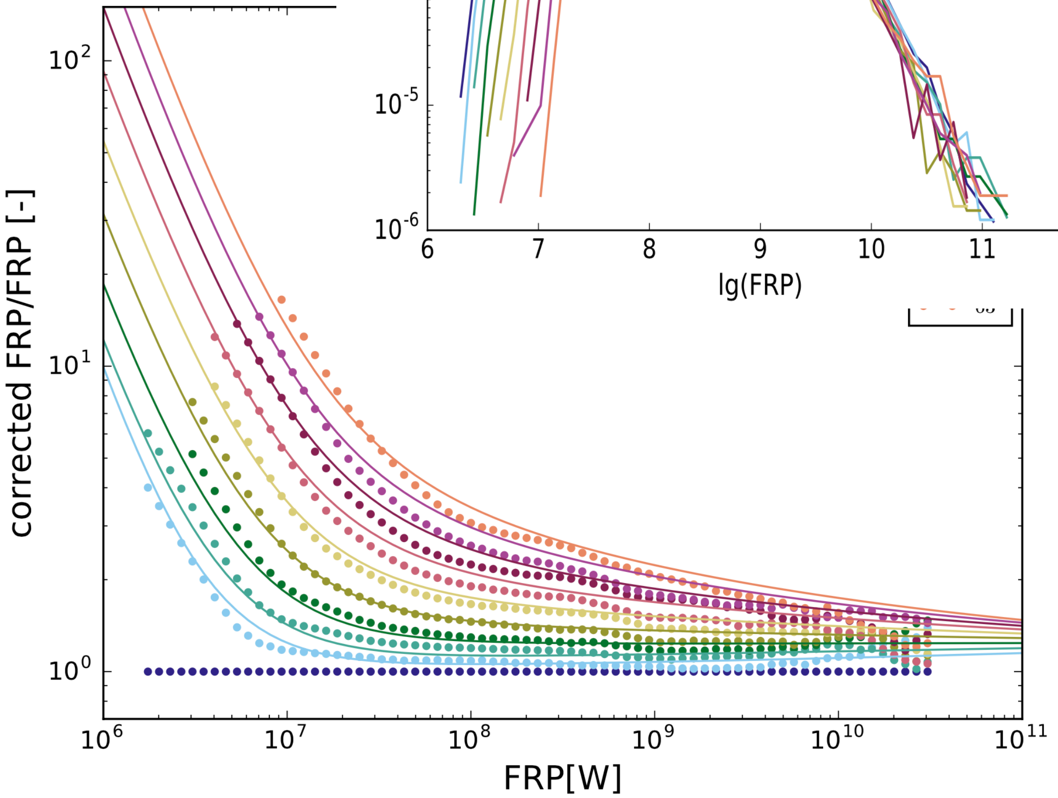
1. Perspective for better fire observation

2. Perspectives for integration of top-down and bottom-up

3. **Other aspects**

Bias correction for individual FRP products feasible at 1 deg resolution, using PDF matching.





Larger MODIS viewing angles have large footprints and thus higher detection thresholds and negative biases.

<u>Task:</u> Find map of each PDF onto rightmost part of 6-deg one.

<u>Solution:</u>

$$\varrho(\rho,\theta) = 1 + \exp(a - b\log\rho) + \exp(c - d\log\rho).$$

$$a = 72.76 - 0.677\theta + 0.00963\theta^2$$

$$b = 26.83 - 0.248\theta + 0.00317\theta^2$$

$$c = -19.43 + 0.54\theta$$

$$d = -5.34 + 0.16\theta$$

[Kaur et al. RSE 2019]

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FRP modelling using NWP input

Machine learning provides better forecasting and gap filling than persistence.

	Mean Average Error [W/m^2]	Root Mean Squared Error [W/m^2]	Correlation
Persistence	0.1660	0.2491	0.6374
Linear regr.	0.1939	0.2054	0.7383
Regr. Tree	0.2220	0.2356	0.6274
NN ensemble	0.0991	0.1795	0.8156

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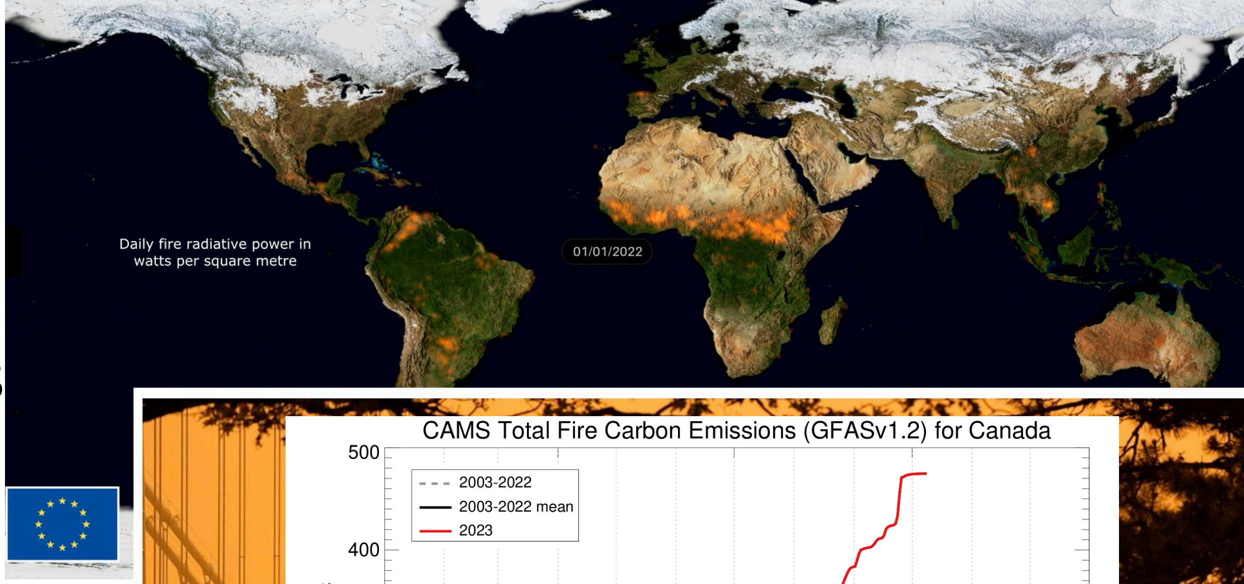
Collaborate with

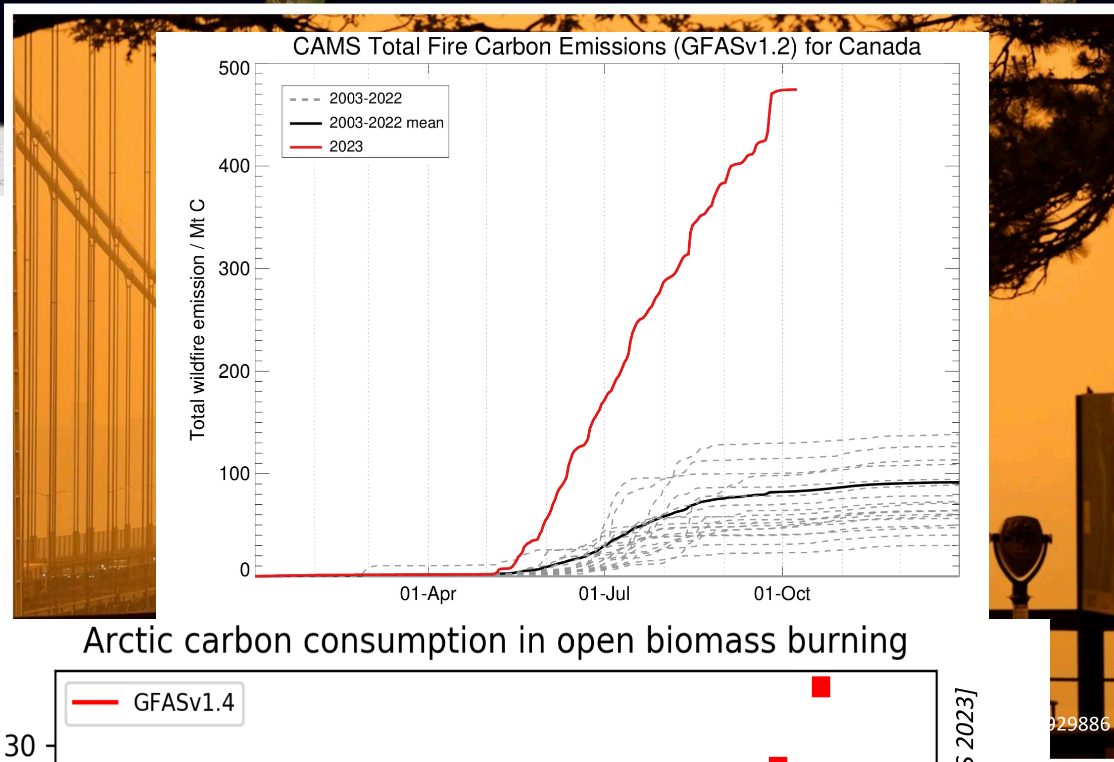
- Copernicus Emergency Service
  - fire weather
- Copernicus Land Service
  - vegetation state, burnt area
- ESA Sense4Fires for variability in emission and conversion factors
- ECMWF for land and fire modelling
- U Wageningen for GFED modelling

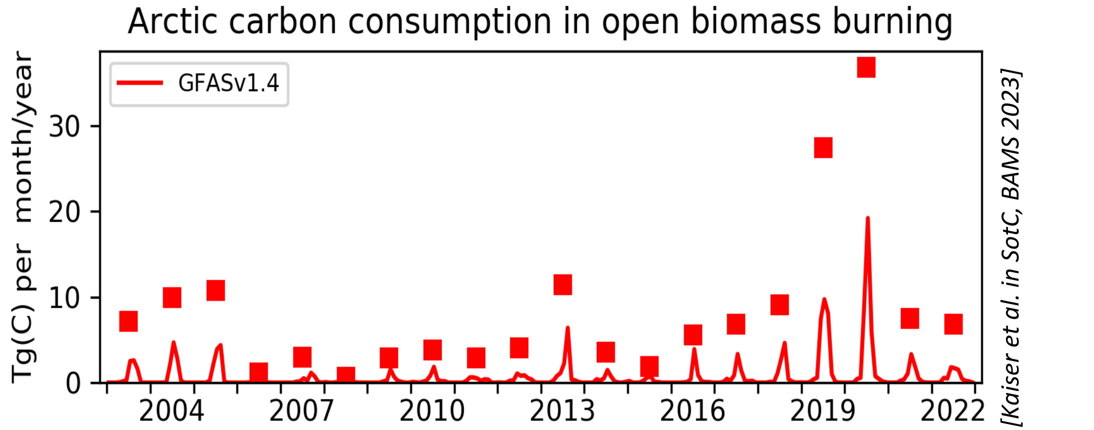
Thank you for your attention!

Vegetation fires

- natural part of many ecosystems
- peat, soils and deforestation fires are net sources of CO_2
- affect atmosphere & air quality
- global trend negative
  - savanna -> agriculture
- increase in high latitudes
- increased intensity and frequency change land cover

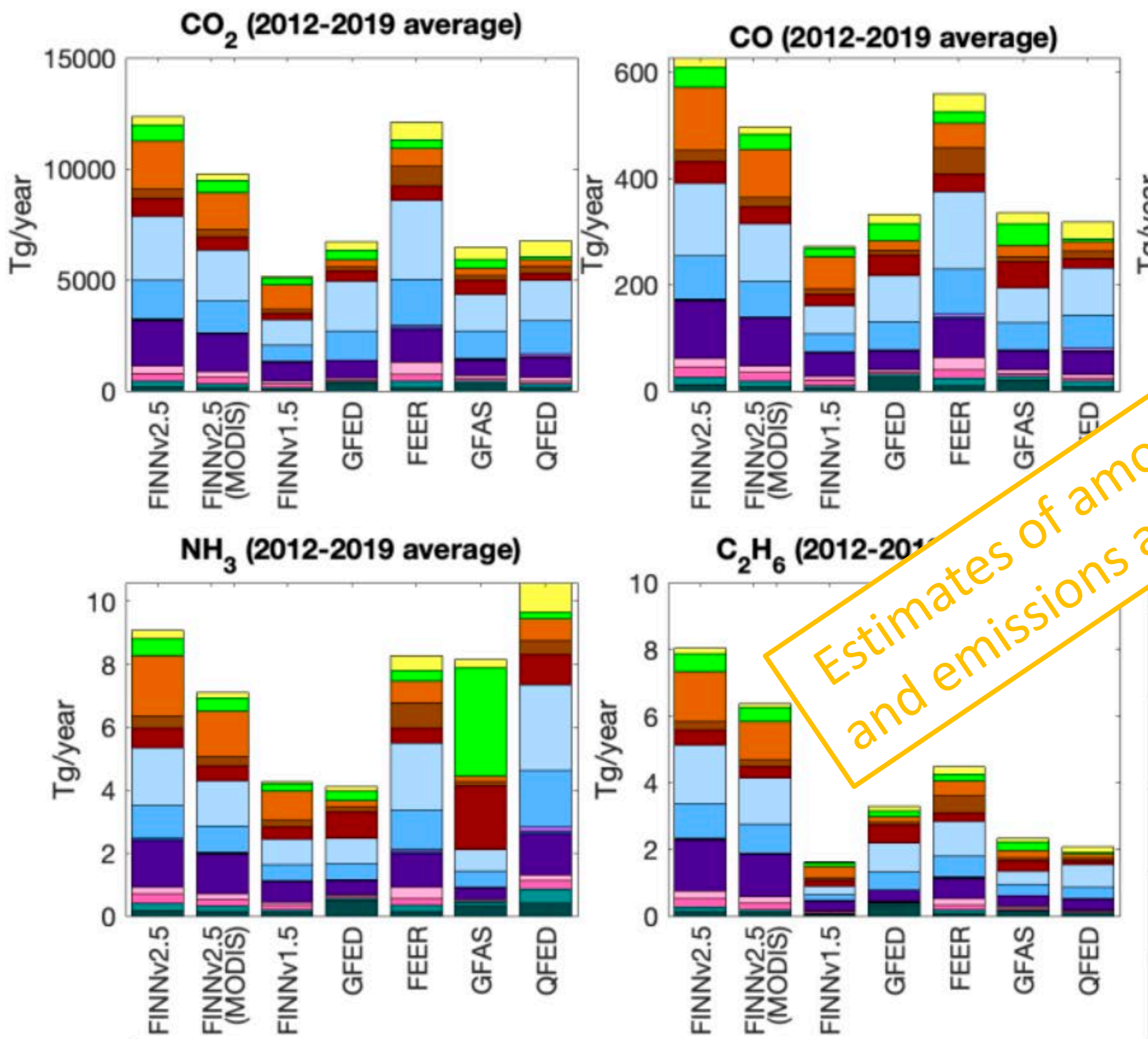




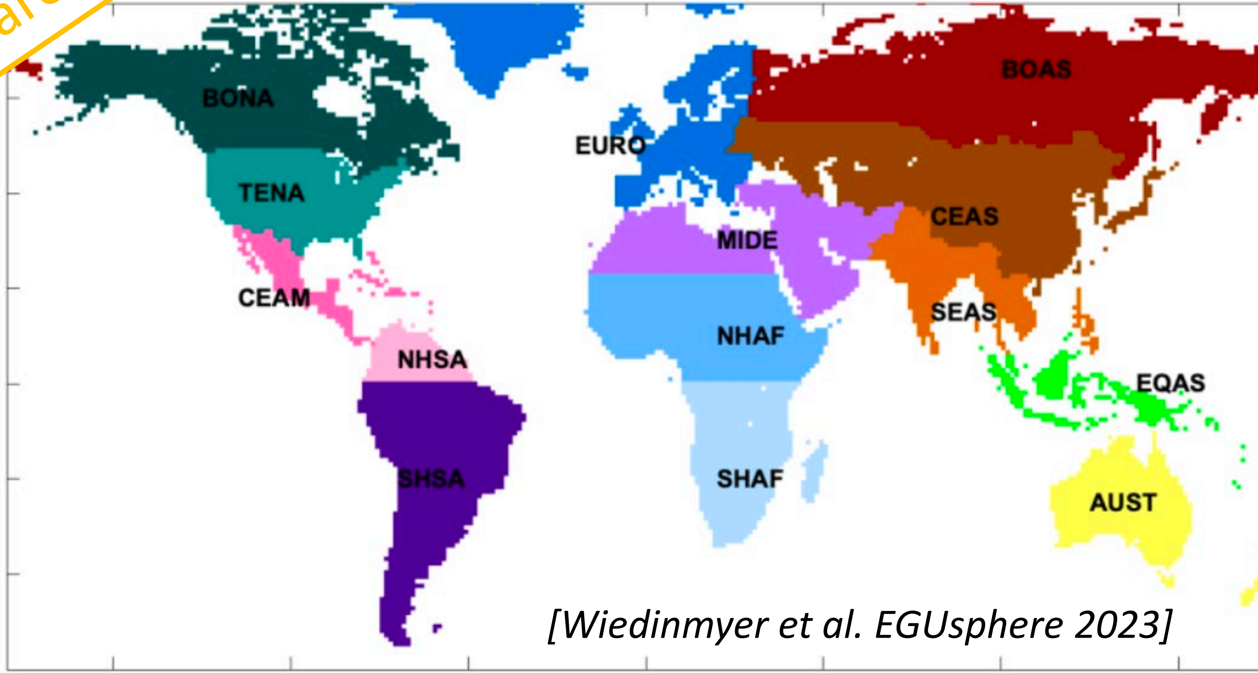


[Kaiser et al. in SotC, BAMS 2023]

Comparison of inventories



Estimates of amount of biomass burnt and emissions are still highly uncertain.



[Wiedinmyer et al. EGUsphere 2023]

Copernicus atmosphere Monitoring Service (CAMS)

CAMS is one of six thematic information services provided by the Copernicus Earth Observation Programme of the European Union.

User driven with free and unrestricted access.

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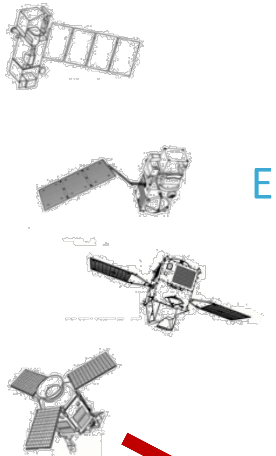
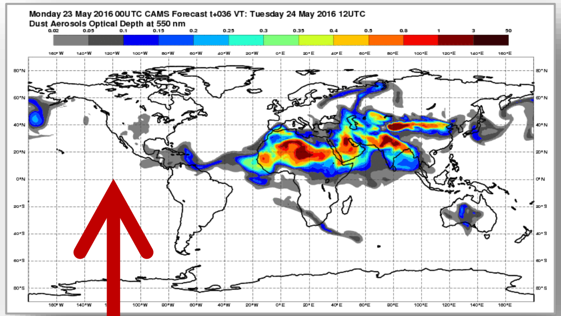
CAMS workflow: Combining observations with models



Earth Observation from satellite (>80 instruments) and in-situ (regulatory and research)

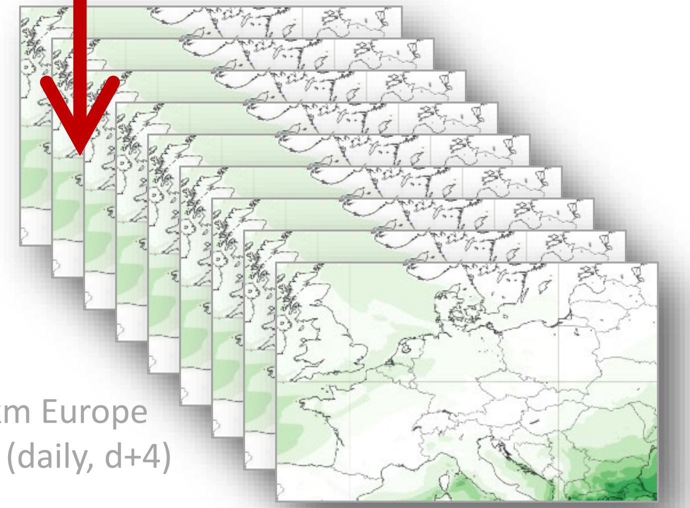
Emissions

CAMS main operational **data assimilation and modelling systems**

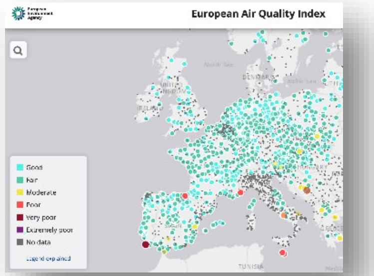


GFAS

(twice daily, d+5)

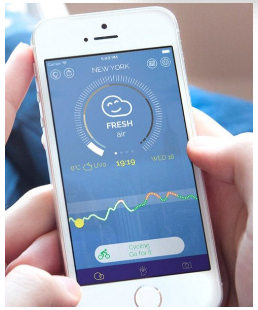


10km Europe
(daily, d+4)



Routine validation and EQC of products

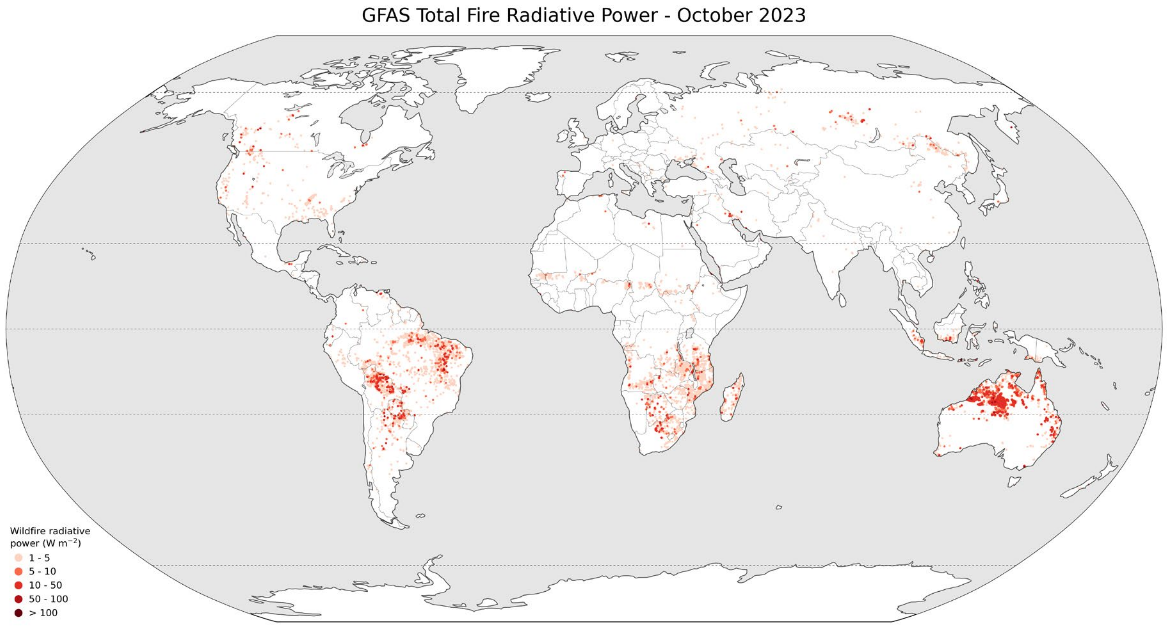
CAMS users
>23500
(>3050 routine)



Major multiplication factor
(100Mil+)

Windy.com

CAMS Global Fire Assimilation System v1.4 (GFAS1.4)



PROGRAMME OF THE EUROPEAN UNION

- <u>Main uses:</u>
  - Input for CAMS global and regional operational systems
  - Applied to many other models across the atmospheric chemistry modelling community
  - Communication activities (e.g., CAMS communication & press; BAMS & C3S state of the climate reports; presented at workshops for various wildfire-related activities)

- Global Fire Assimilation System (**GFAS**); see https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-fire-emissions-gfas?tab=overview
- Uses satellite observations of Fire Radiative Power (FRP)
  - Currently Aqua and Terra MODIS FRP observations
- Global Coverage at ~10km Resolution
  - Hourly Output (+24-h means): 7-hours behind NRT
- Emissions of aerosols and gases are estimated using factors dependent on vegetation type.
- Injection heights calculated with Plume Rise Model and IS4FIRES

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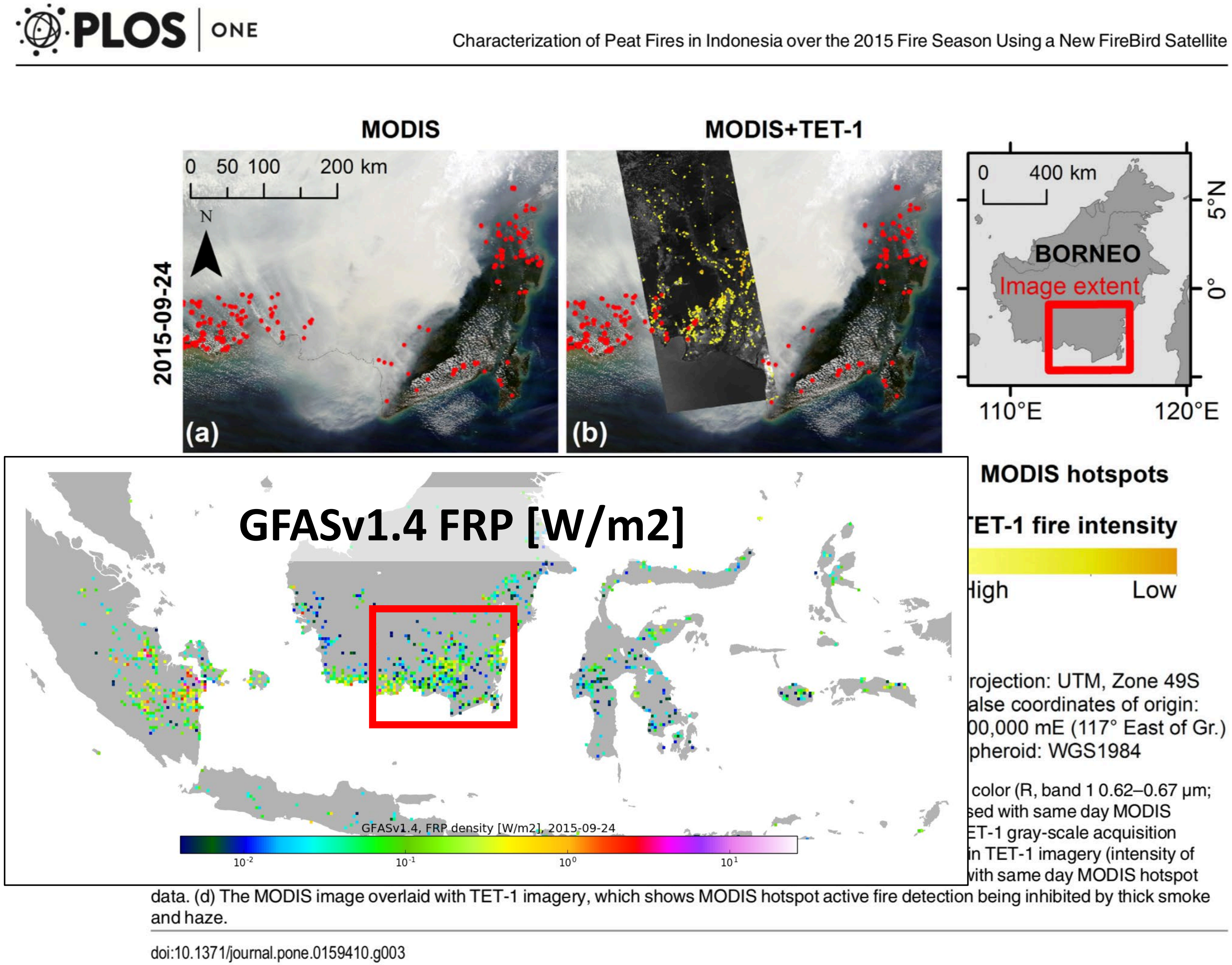
GFAS observation gap filling

- Kalman filter with **persistence** model
- **FRP>0** observations ignite fires.
- **FRP=0** observations extinguish fires.



Challenges 1/3: Some major scientific interests

- increase in **intensity** of wildfires
- increase in wildfire activity in **boreal and arctic** regions
- 2-way interaction with **land cover change**
  - associated net release of CO_2 into atmosphere
- impact on **air quality & atmospheric composition**

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Challenges 2/3: satellite-based Earth observation

- Fill FRP observation gaps by **merging all available FRP observations & fire modelling** with ML**!**

- distinguish **flaming vs. smoldering** and above- vs. below-ground fires
  - ➢ use diurnal cycle and peak FRP from EO

- calibrate **empirical conversion of FRP to burnt biomass and emissions**
  - ➢ use top-down constraints from plume EO
  - ➢ dependence on **meteorology & vegetation** **-> "Fire4Sense" by Jos de Laat**

- combined analysis of **FRP and burnt area** observations

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Challenges 3/3: CAMS-GFAS

- continuity **beyond MODIS** era
  - assimilate FRP from VIIRS and SLSTR
  - basic bias correction and spurious signal map, to be improved

- also assimilate **geostationary** observations of FRP
  - SEVIRI, GOES-E/-W, Himawari-8, MTG-FCI

- operationalisation of new developments
  - **bias correction** and **FRP modelling**

- re-calibrate **empirical parameters:** FRP -> burnt biomass -> species
  - against upcoming **GFED5** or
  - **inversion** of CO & AOD plume observations (and others)