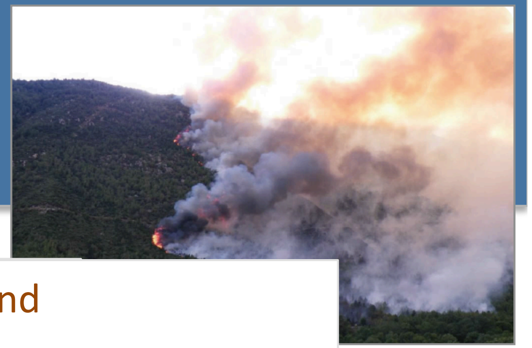
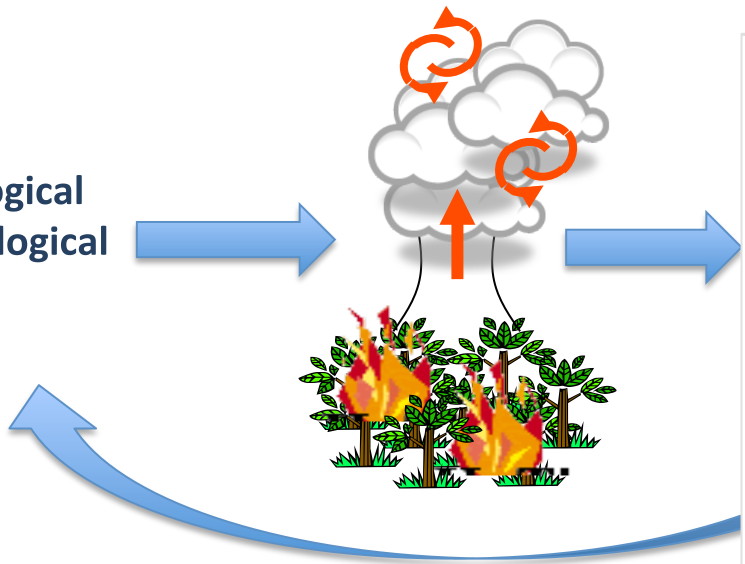
Regional Impact of Fires on Air Quality

Solène Turquety
Université Pierre et Marie Curie – Paris 6
Laboratoire de Météorologie Dynamique, IPSL

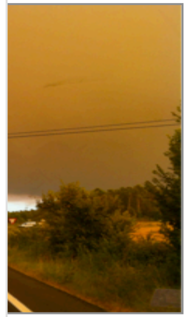
G.Rea, L. Menut, Y. Long, C. Rio (LMD, Paris, France)
C. Paton-Walsh (U. Wollongong, Australia)
S. Arnold, S. Monks (U. Leeds, UK), L. Emmons (NCAR, US)
B. Teufel, L. Sushama (UQAM, Canada)



Meteorological and hydrological conditions



- → Impact vegetation and carbon cycle
- → Modify meso-scale meteorology
- → Climate forcing
  - → **Emissions of GHG and aerosols**
  - → Impact **O3** => oxydizing capacity of the atmosphere
  - → Impact on surface albedo
- → **Air quality degradation**



Fires and air quality

Table 13.1 Pollution exposure standards in Europe and World Health Organization (WHO) recommendations for human health.

Pollutant (µg/m³)	European directives (hourly average)	WHO recommendations
Nitrogen dioxide (NO_2)	Limit: 200 µg/m³ Alert: 400 µg/m³ during 3 consecutive hours	1 h exposure: 200
Sulphur dioxide (SO_2)	Limit: 350 µg/m³ Alert: 500 µg/m³ during 3 consecutive hours	10 min exposure: 500 24 h exposure: 20
Carbon monoxide (CO)	8 h limit: 10 000 µg/m³	15 min exposure: 100 000 1 h exposure: 30 000
Ozone (O_3)	8 h limit: 120 µg/m³ Information: 180 µg/m³ Alert: 240 µg/m³	8 h exposure: 100
Particles with diameter <10 µm (PM10)	Limit: 40 µg/m³	24 h exposure: 50 (less than 3 days/year)
Particles with diameter <2.5 µm (PM2.5)	Limit: 25 µg/m³ Objectives: 20 µg/m³ in 2015	24 h exposure: 25 (less than 3 days/year)

Indonesian fires 1997: PM > 2000µg/m³ during several days (Heil and Goldammer, 2001)

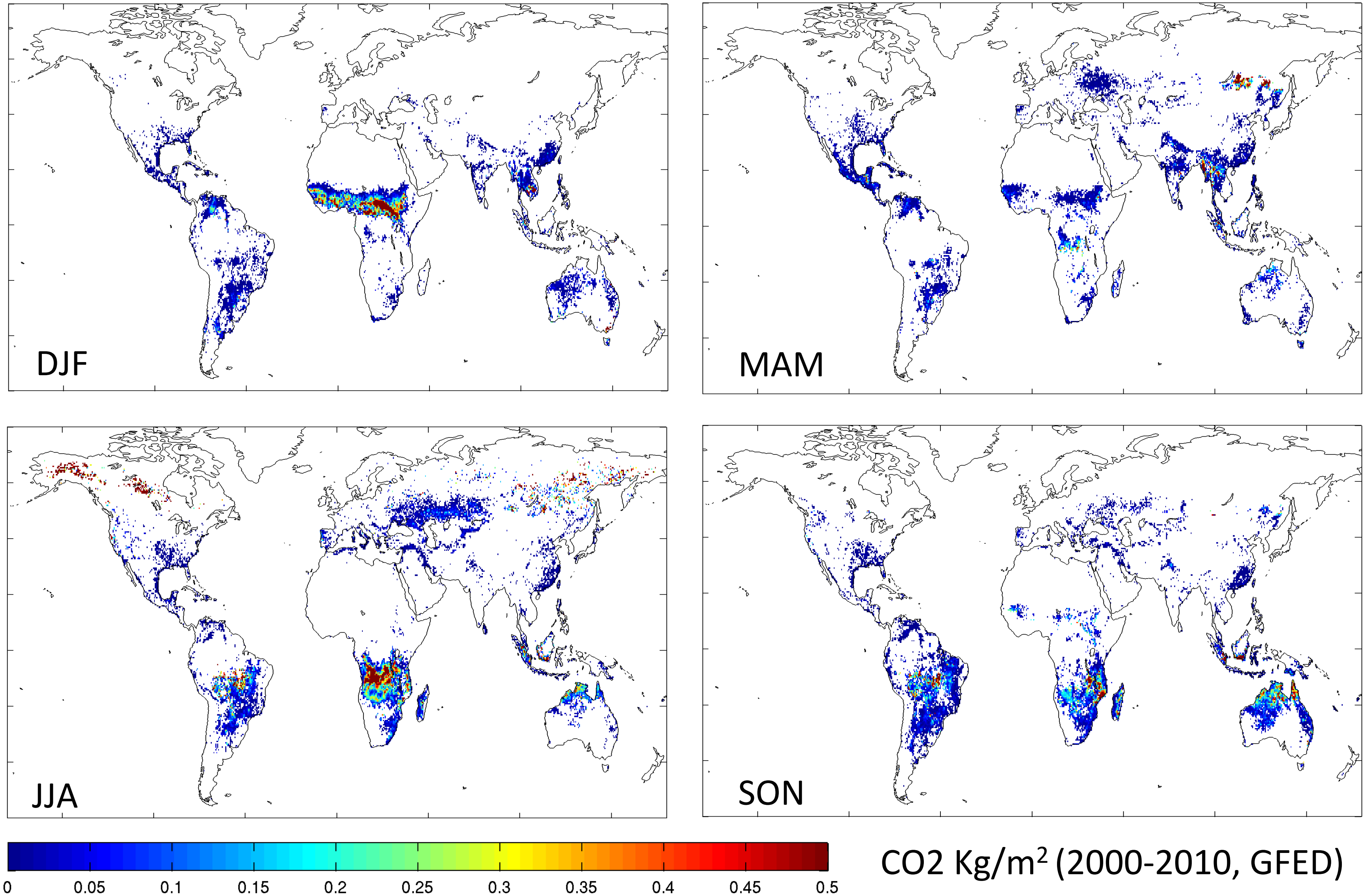
Californian fires in 2003: PM10 > 200µg/m³ (Wu et al., 2006)

Russian fires in 2010: PM10 ≈ 700-900µg/m³ (Konovalov et al., 2011)
CO ≈ 10mg/m³, up to 20mg/m³

Intense pollution; worsen by radiative impact of aerosols (more stable => lower PBL height => lower dillution)

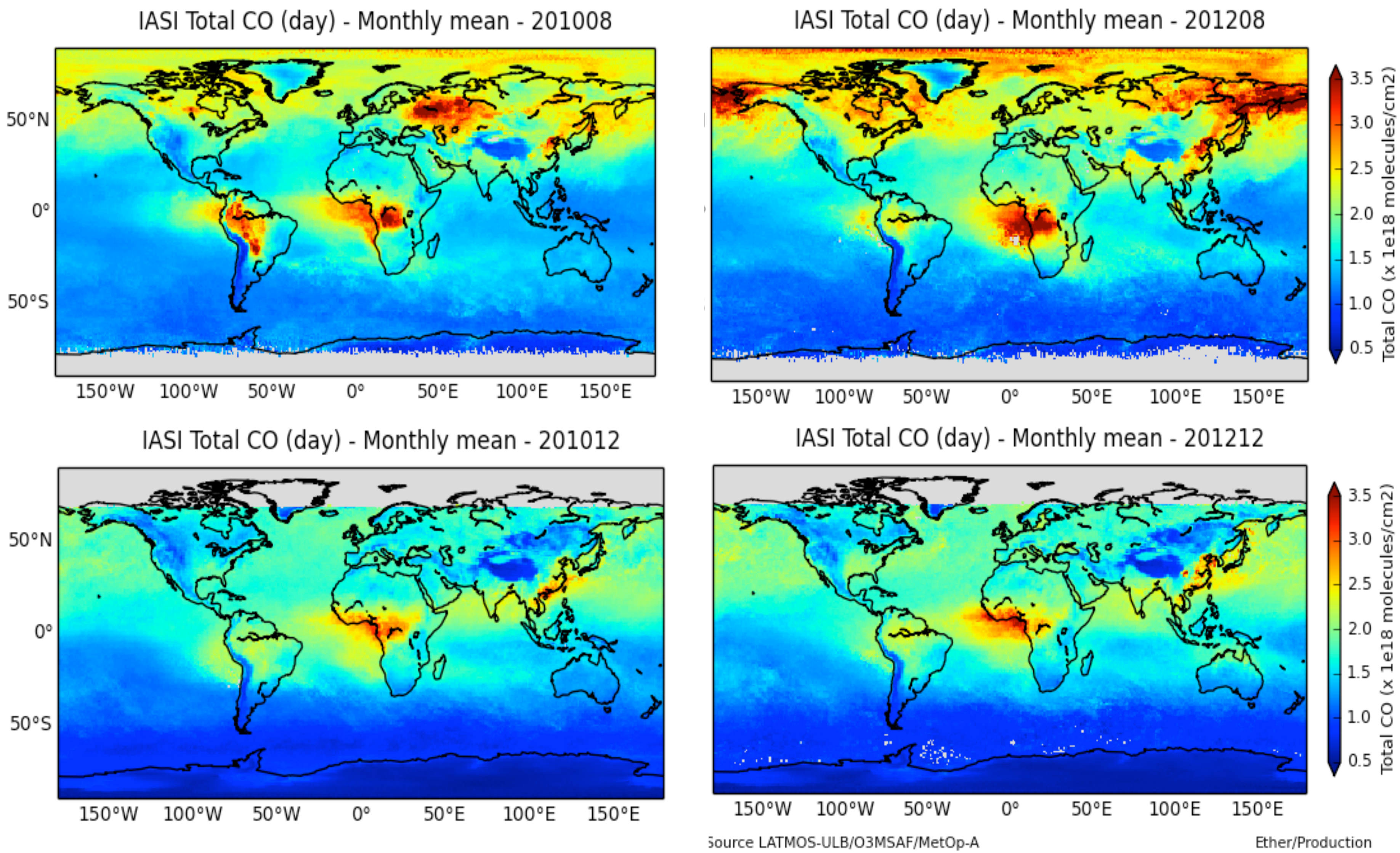
Fires: where and when?

Moyenne 2000-2010, inventaire GFED (van der Werf et al., 2012)



CO_2 Kg/m^2 (2000-2010, GFED)

Direct influence on atmospheric composition: example of CO

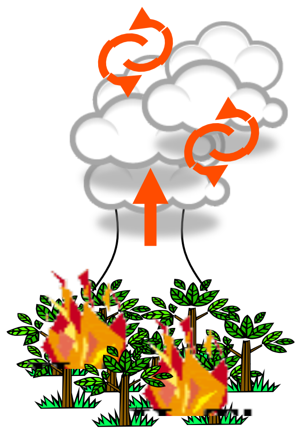


Evaluating the impact of wildfires on air quality

Observations

- Fire location
- Atmospheric chemical composition

Fire modeling



Chemical evolution

↑

Transport mechanisms

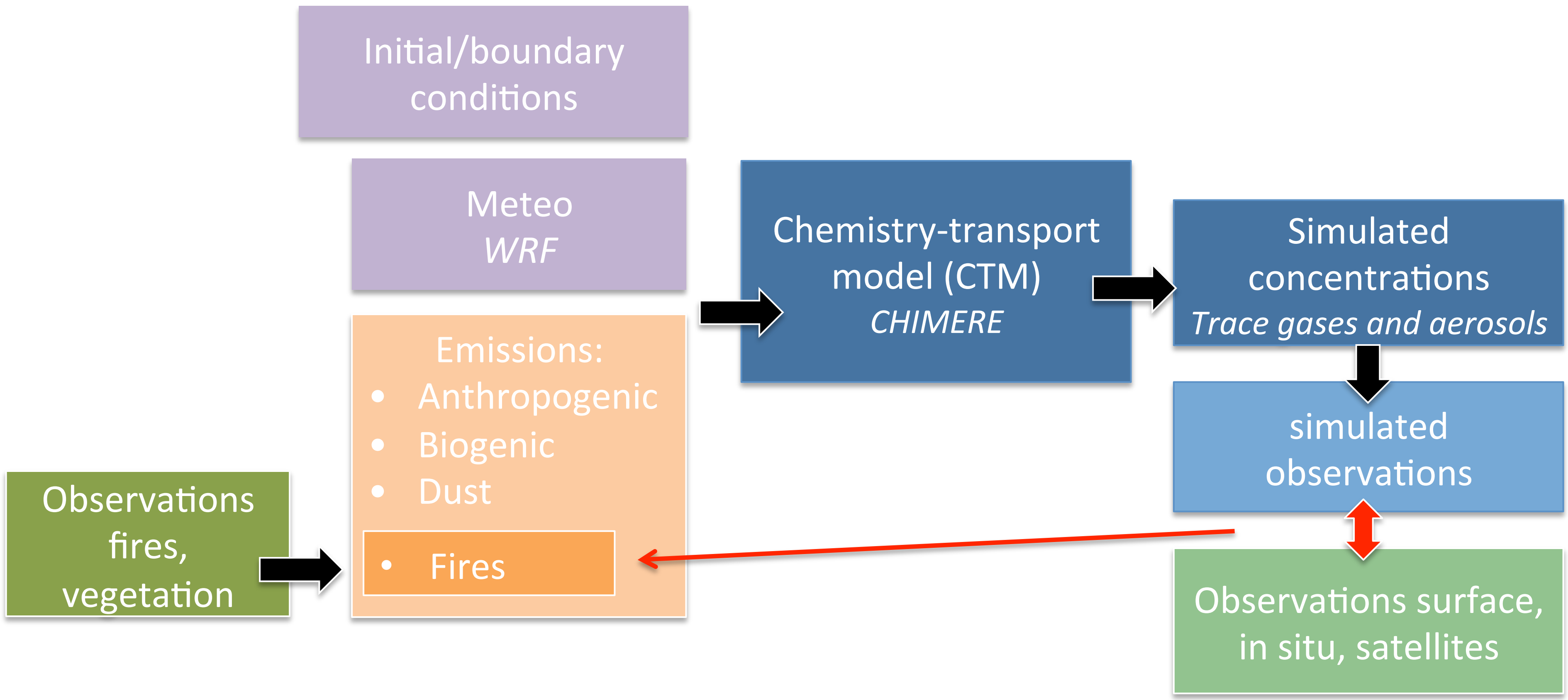
↑

Pollutant's emissions

Air quality impact

- Relative contribution to local pollution budgets
- Integration in forecasting plateforms

Evaluating the impact of wildfires on air quality

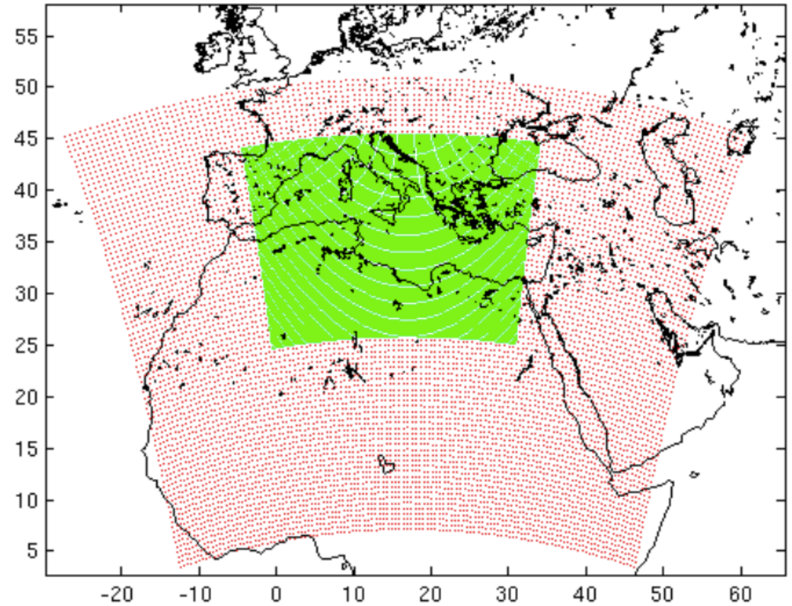


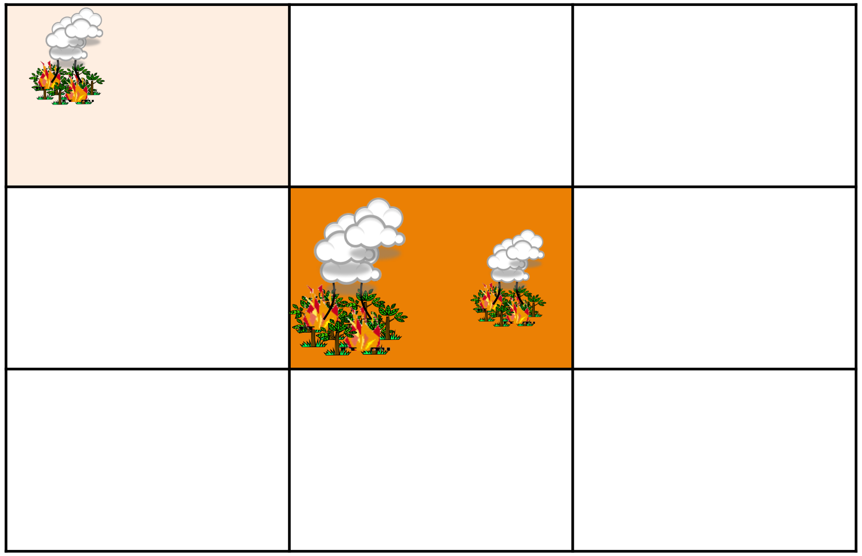
Evaluating the impact of wildfires on air quality

Example of regional domain:

- Chosen to include main sources, e.g. large enough for African dust, and transport pathways
- Zoom above regions of interest

Typically for regional CTMs: 60km large domain, down to 20km
Note: global simulations ~1° at best





⇒ Fire is a subgrid source
⇒ Same grid cell may include several fires
⇒ Often several simultaneous fires in domain

Emissions = averaged flux over grid cell (molecules/m²/s)
Injection heights = maximum height under which plume supposed well mixed ;
Or vertical profile

Fire emissions calculation

Emission for given species i and a detected fire of surface A

$$E_i = A \sum_{v=1}^{nv} f_v F_v \varepsilon_{v,i}$$

Fuel consumed

$$F_v = \sum_{p=1}^{np} C_v \beta_p B_{p,v}$$

Fraction of vegetation type v in area burned → Landcover database

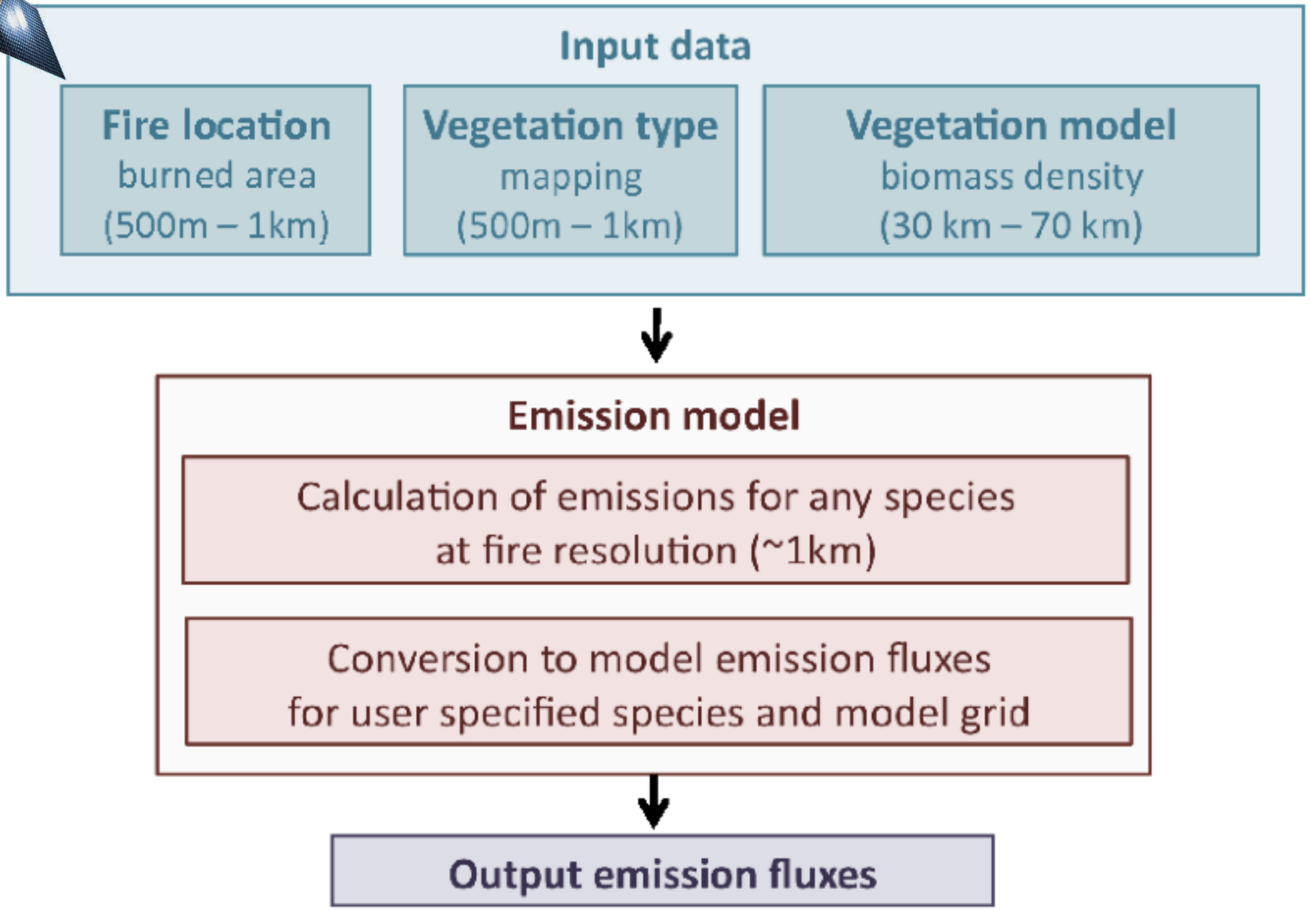
Emission factor for species i and vegetation type v → litterature

Combustion fraction

Burning fraction → Litterature

Biomass density (kgC/m^2) for carbon pool p and vegetation type v → Vegetation and carbon cycle mode ORCHIDEE

Fire emissions calculation: APIFLAME v1.0



(Turquety et al., GMD, 2014)

NRT:
http://www.lmd.polytechnique.fr/cosy/fires-modis-europe.php

Fire emissions calculation: APIFLAME v1.0

β_p

ORCHIDEE PFT	Litter	Leaf	Wood	Roots
Tropical broad-leaved evergreen	100	10 (5–20)	0	0
Tropical broad-leaved raingreen	100	10 (5–20)	0	0
Tropical needleleaf evergreen	100	30 (15–60)	10 (5–20)	0
Temperate broad-leaved evergreen	100	30 (15–60)	10 (5–20)	0
Temperate broad-leaved summergreen	100	20 (10–40)	10 (5–20)	0
Boreal needleleaf evergreen	70	20 (10–40)	20 (10–40)	5 (2.5–10)
Boreal broad-leaved summergreen	70	20 (10–40)	20 (10–40)	5 (2.5–10)
Boreal needleleaf summergreen	70	20 (10–40)	20 (10–40)	5 (2.5–10)
C3 grass	100	50 (25–100)	5 (2.5–10)	0
C4 grass	100	50 (25–100)	5 (2.5–10)	0
C3 agriculture	100	50 (25–100)	5 (2.5–10)	0
C4 agriculture	100	50 (25–100)	5 (2.5–10)	0

(Following Hoelzemann et al, 2004)

4 scenarios ('available fuel load'):

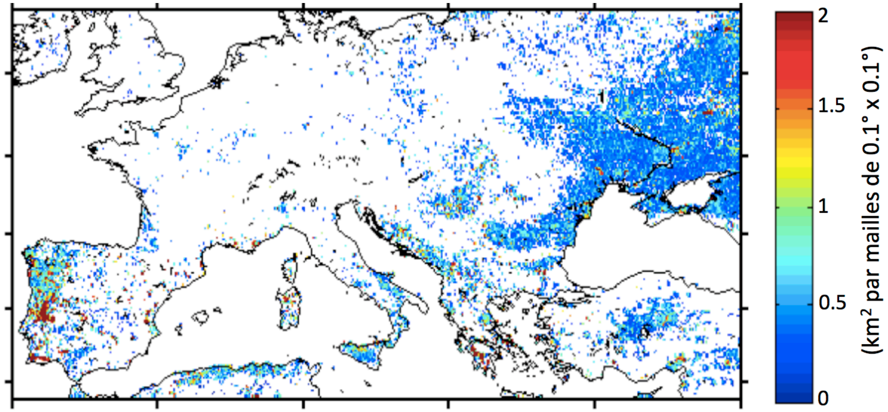
- Min
- Max
- Moyen
- Linear variation f(stress hydrique)

C_v

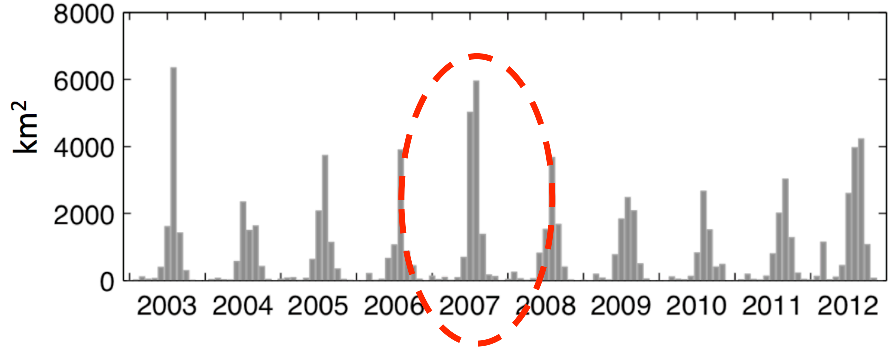
0.6 for forests
0.85 for grasslands and croplands
0.85 all PFTs in the Mediterranean during Summer

What about fires in Europe?

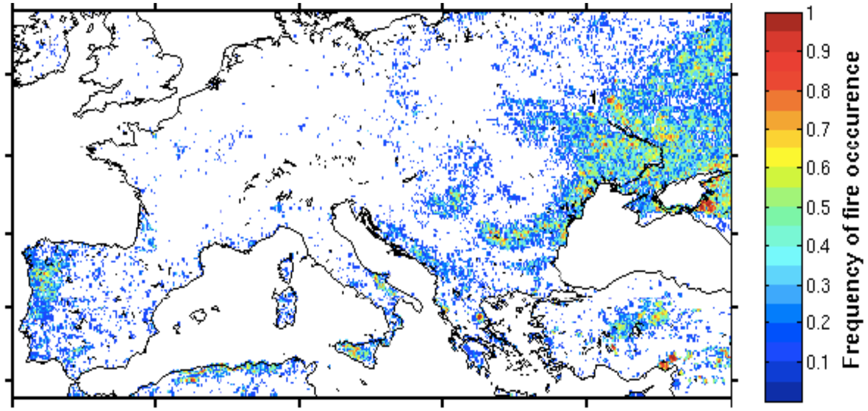
Average yearly area burned (MODIS MCD64, 2003-2012)

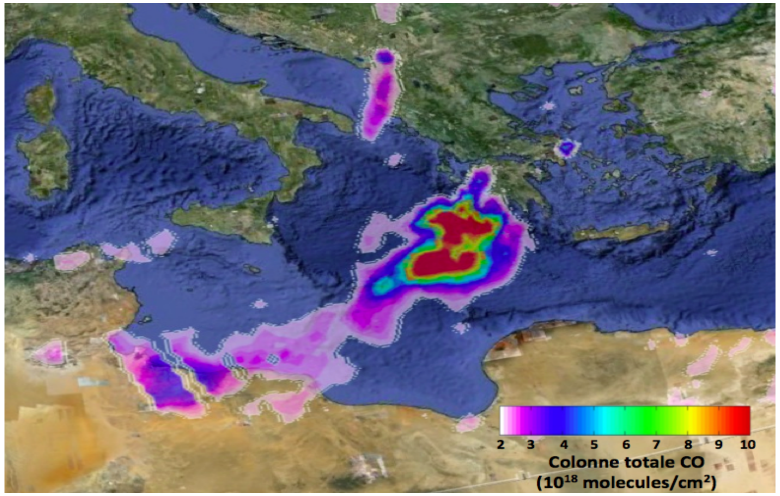


Surface brûlée mensuelle



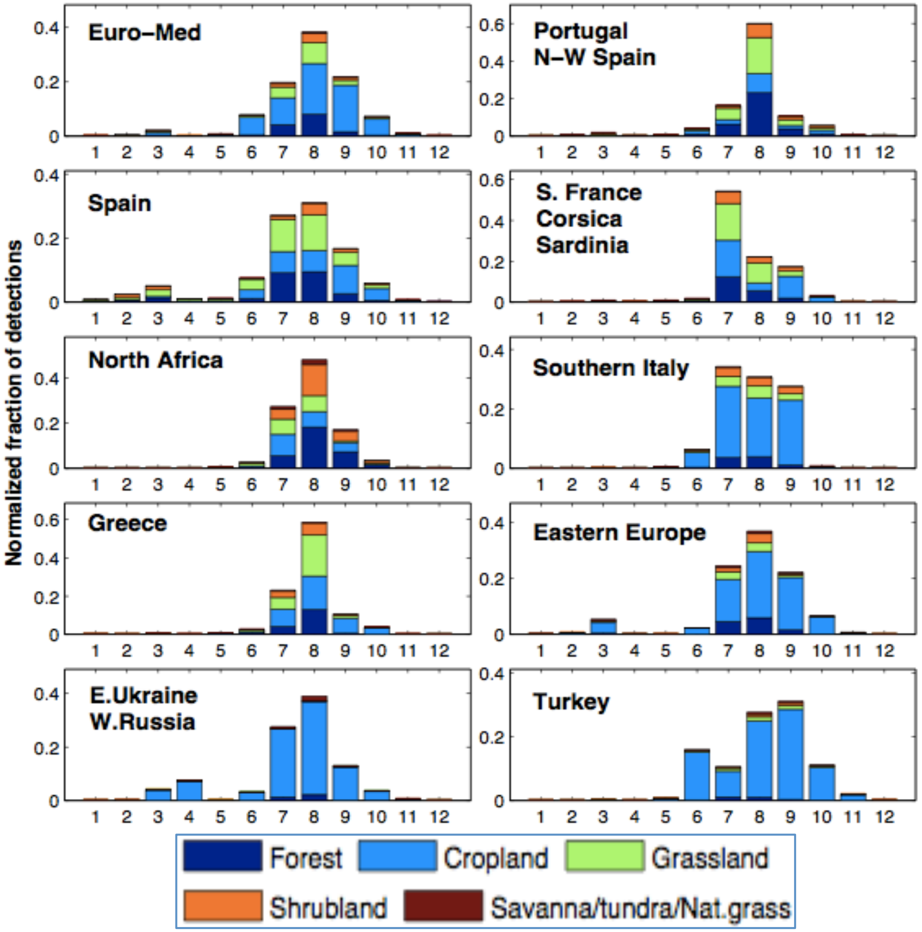
Fire frequency

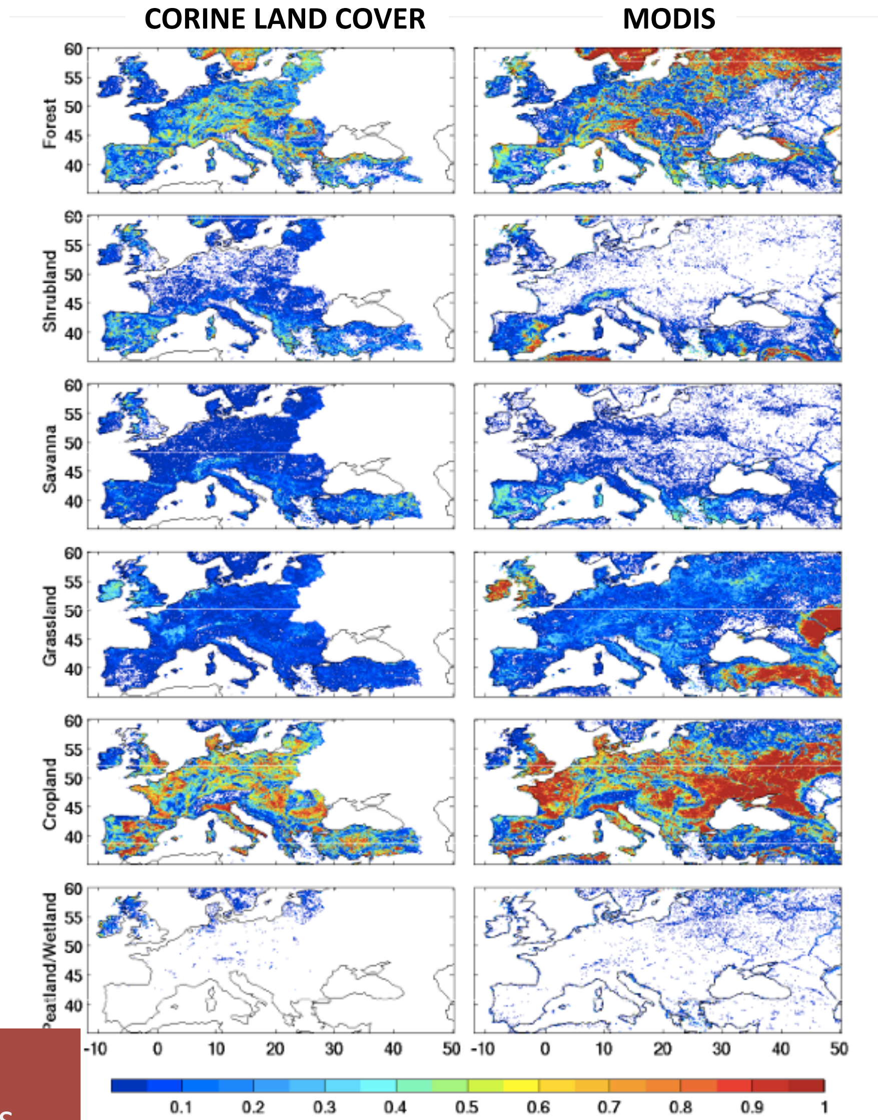




- Eastern Europe, Ukraine – Russia : smaller fires, recurrent;
- Southern Europe, Mediterranean area: Large events, more sporadic.

What about fires in Europe?



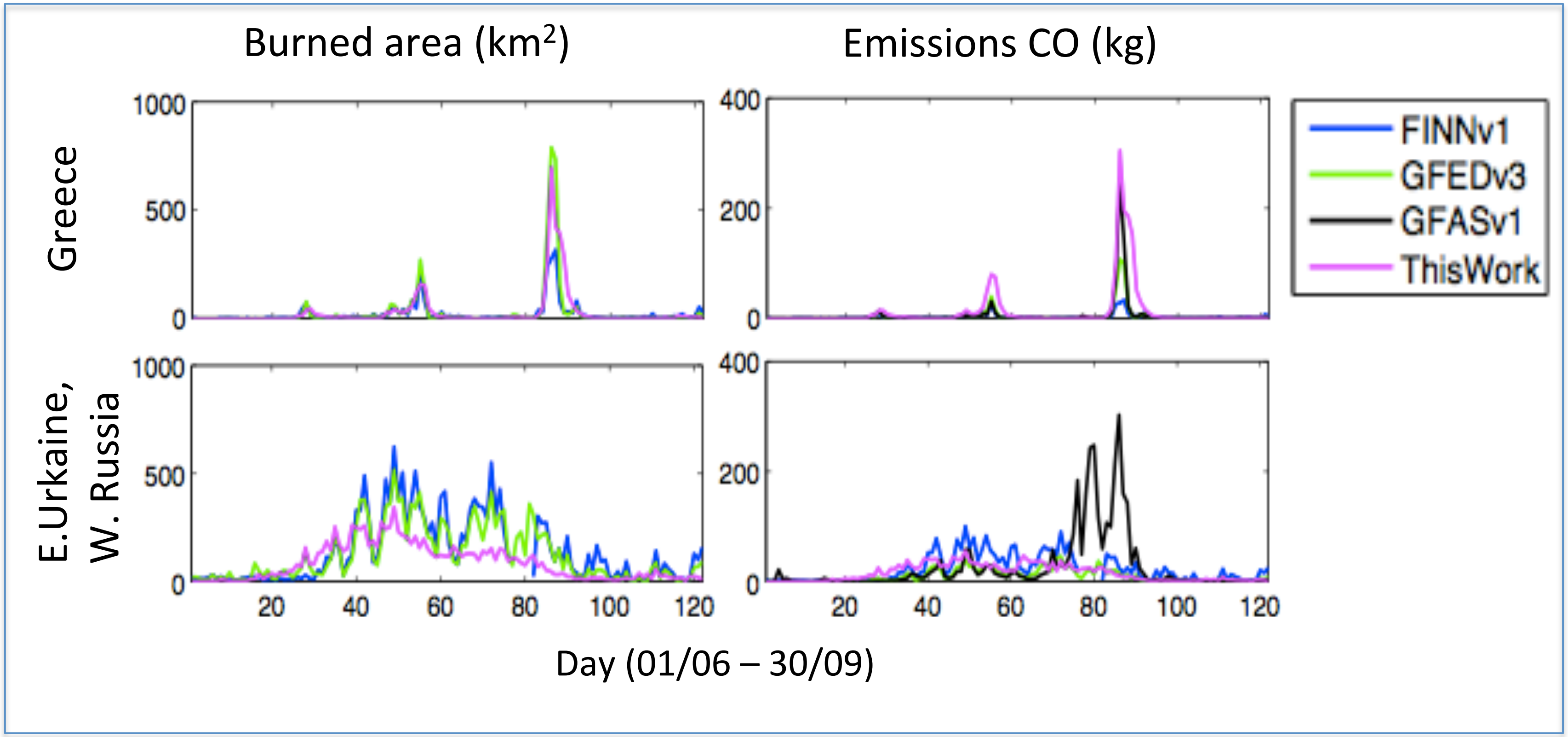


- Eastern Europe, Ukraine, W. Russia: croplands;
- Mediterranean area: Forests, shrublands, grasslands.

BUT: strongly depends on the landuse database used.

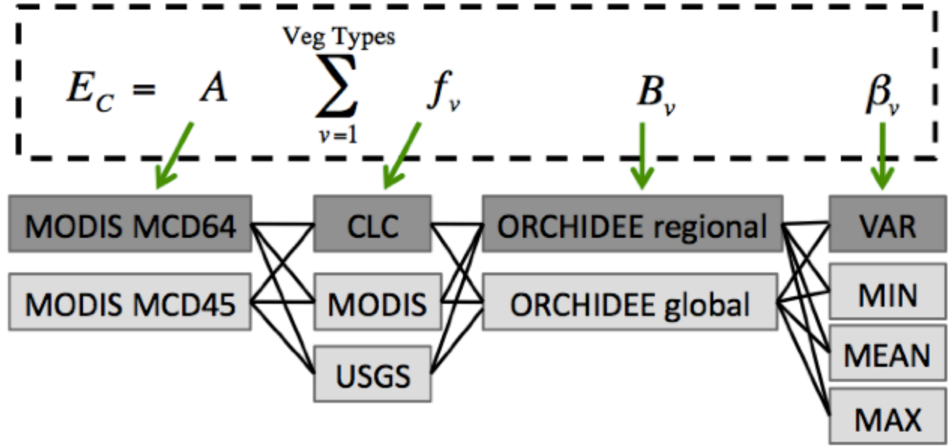
Uncertainty evaluation
Case of the summer of 2007

Comparison of daily regional emissions from APIFLAME v1.0 with other widely used inventories



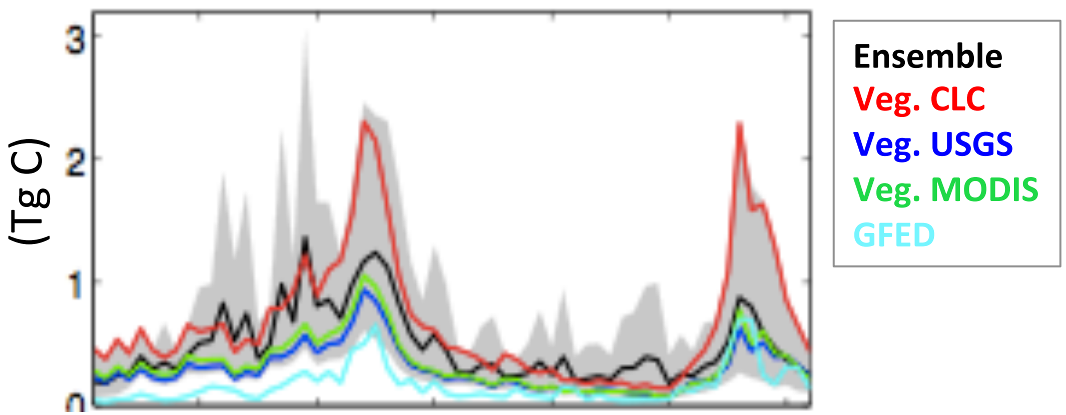
Uncertainty evaluation
Case of the summer of 2007

Uncertainty estimated using an ensemble approach, incl. different "reasonable" choices of databases / parameters.



Uncertainty estimated to ~ 100%:
1) Burned area (σ>100%);
2) Vegetation (σ≈44%);
3) Biomass density (σ≈14%)
+ NON-LINEAR

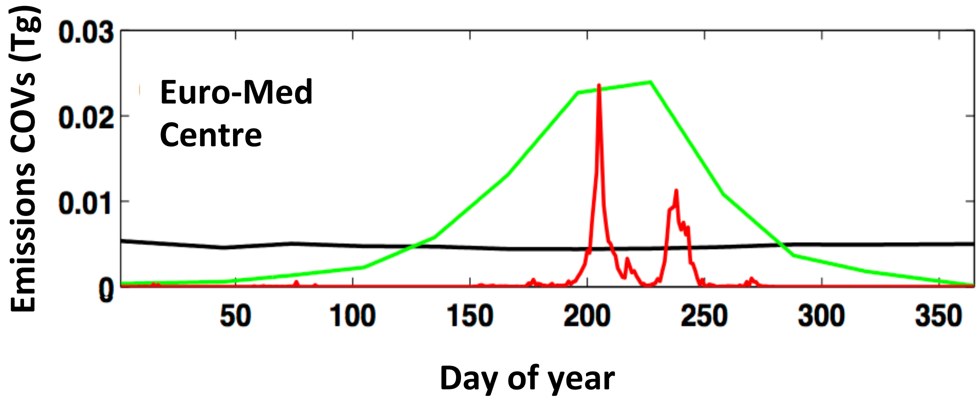
Euro-Med region, summer of 2007 daily emissions

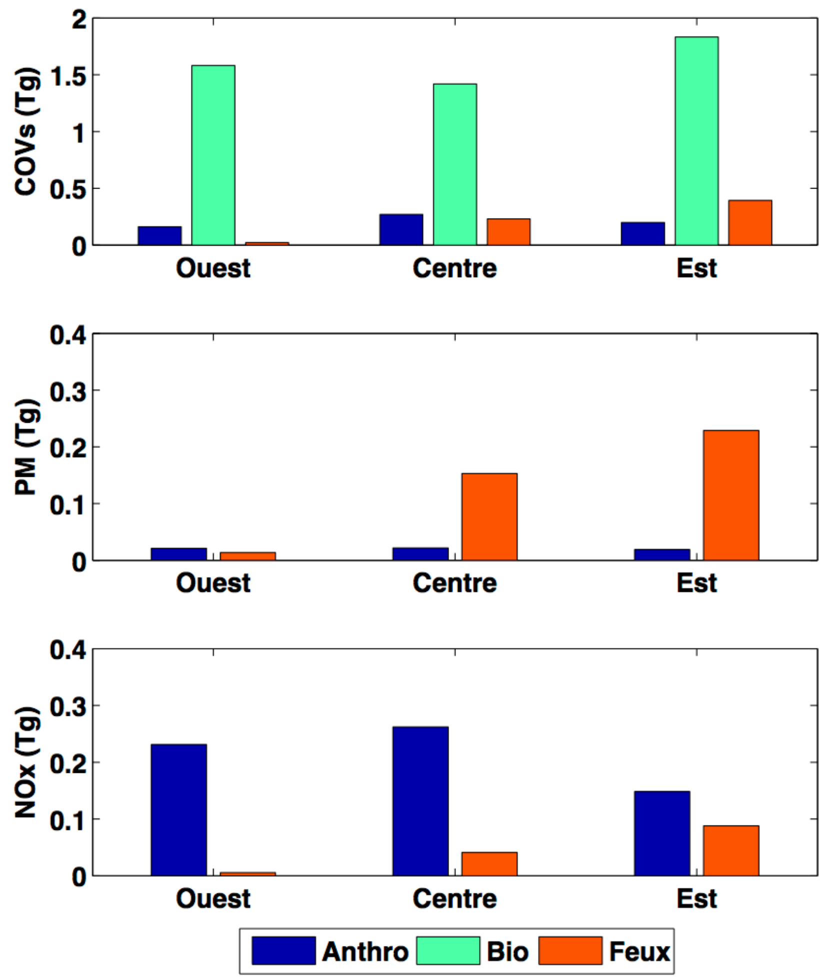


Jour (01/06 – 30/09)

Emissions in Europe

Relative importance of fire emissions for a few key pollutants



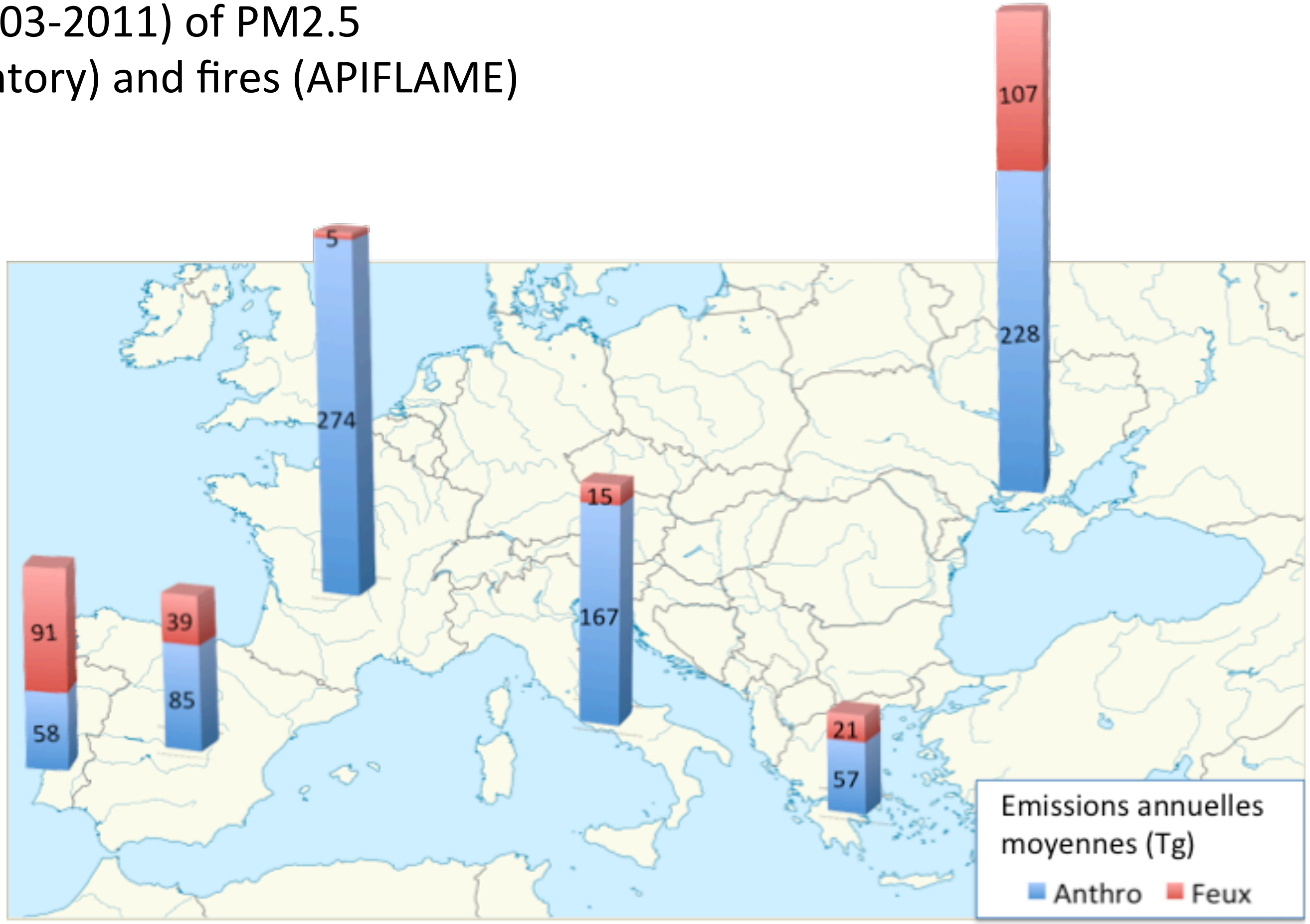


Fires: an intense, sporadic source, concentrated on short time periods, often regionally dominant during severe events.

Emissions in Europe

Mean annual emissions (2003-2011) of PM2.5 anthropogenic (EMEP inventory) and fires (APIFLAME)

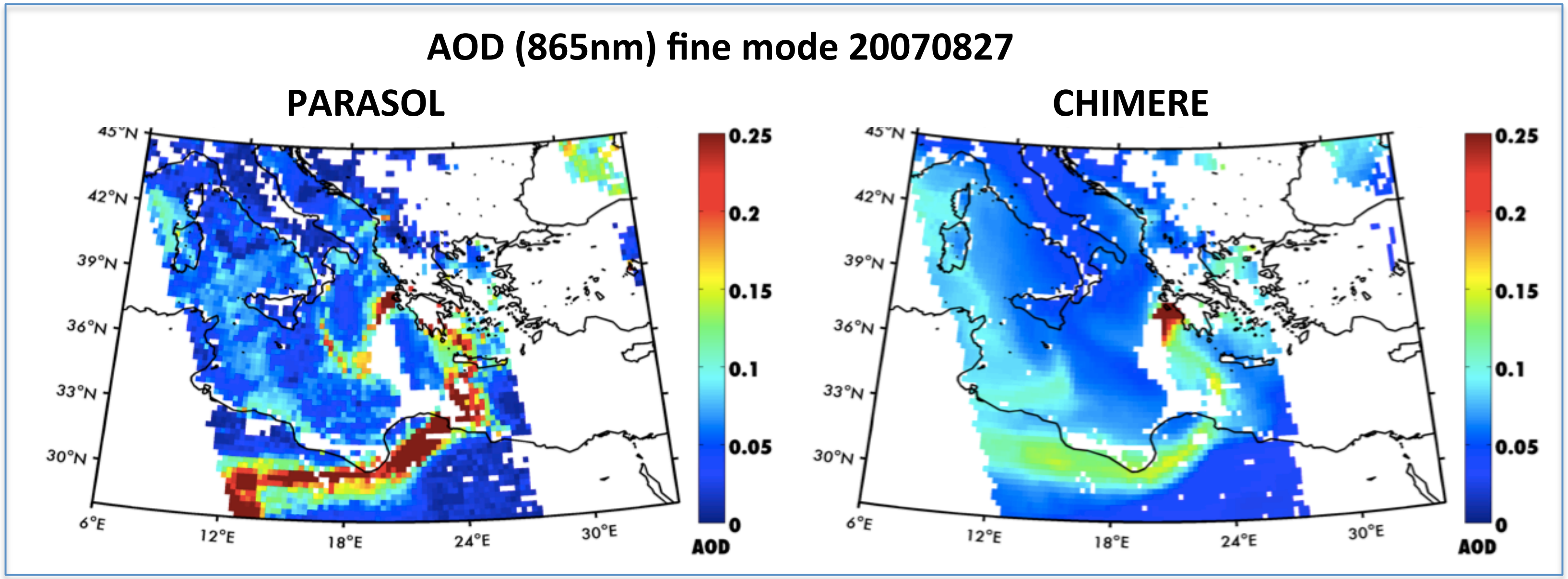
$$\frac{\text{Fires}}{\text{Anthropogenic}} = 28\%$$



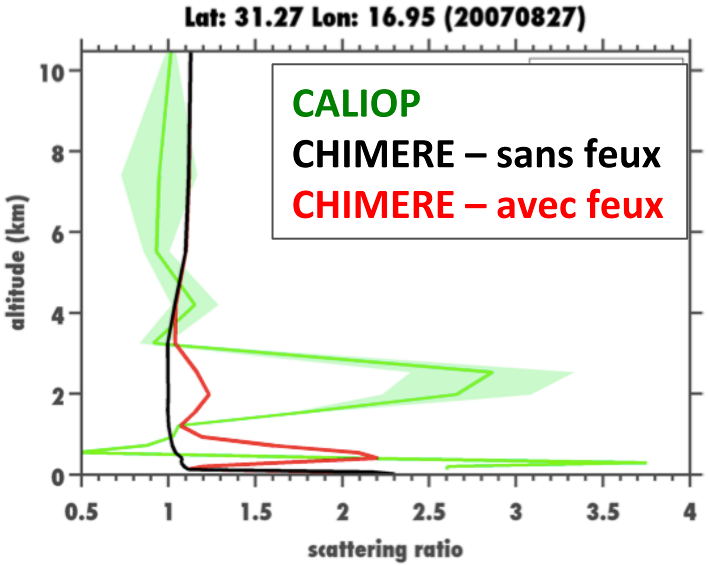
Very significant importance for recurrent episodes.

(Turquety et al., GMD, 2014)

Modeling the impact of fires: case of the summer 2007

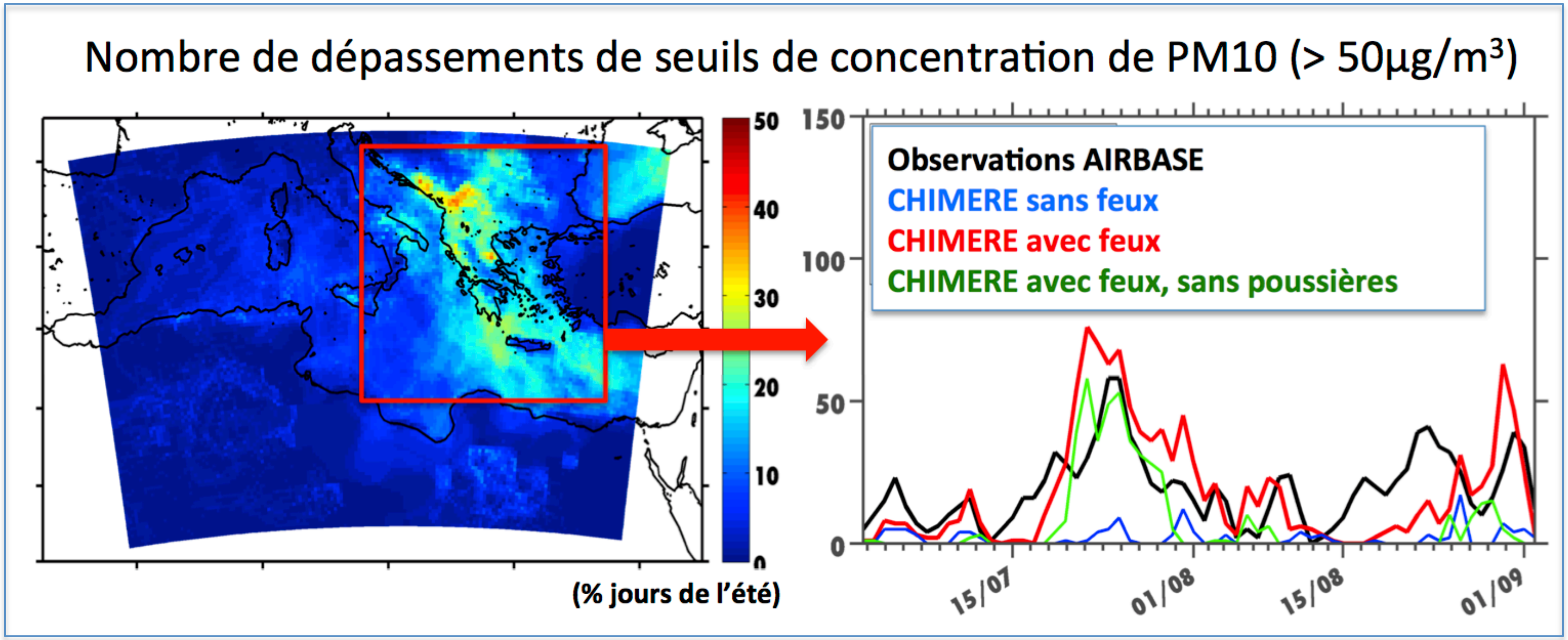


- Good consistency in plume transport;
- Strong underestimate of AOD for this LRT event;
- Uncertainties on emissions and vertical transport.



(Stavros Stromatas, 2013)

Modeling the impact of fires: case of the summer 2007



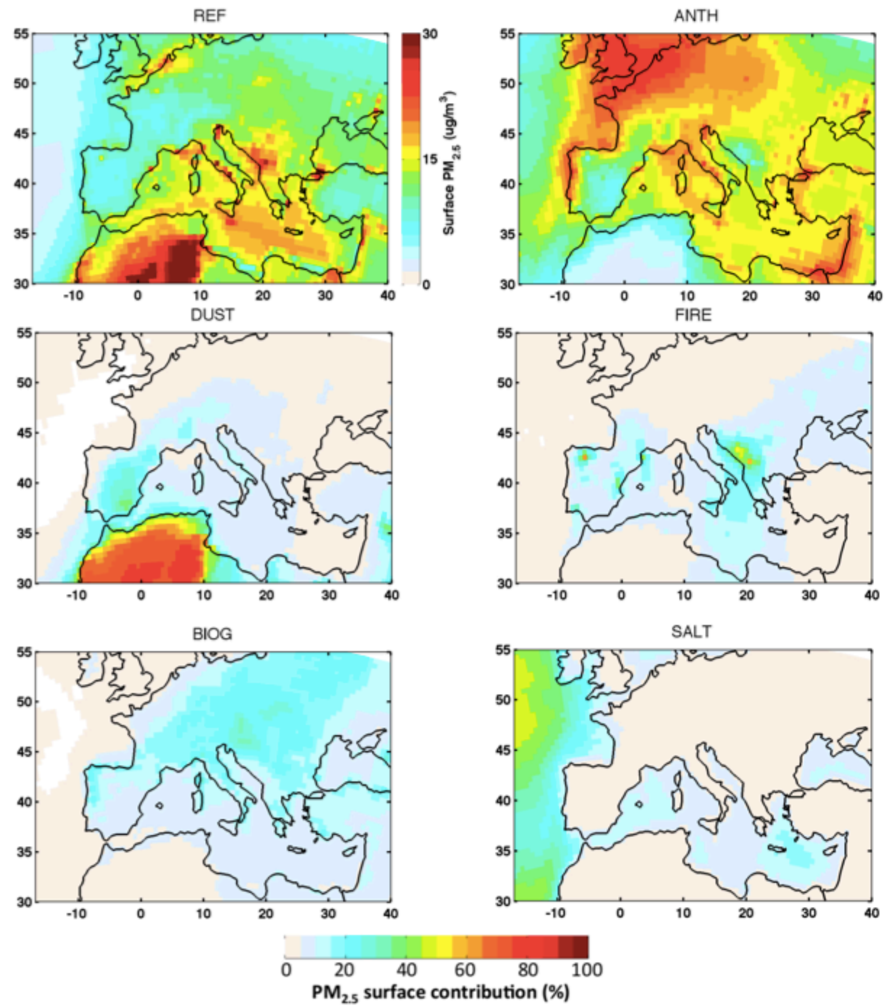
- Extended zone of influence;
- Observed threshold exceedances only reproduced including fire emissions;
- 40-55% of exceedances during the summer of 2007 attributed to fires

(Stavros Stromatas, 2013)

Modeling the impact of fires: case of the summer 2012

Source contributions according to CHIMERE

Sensitivity analysis using the CHIMERE CTM

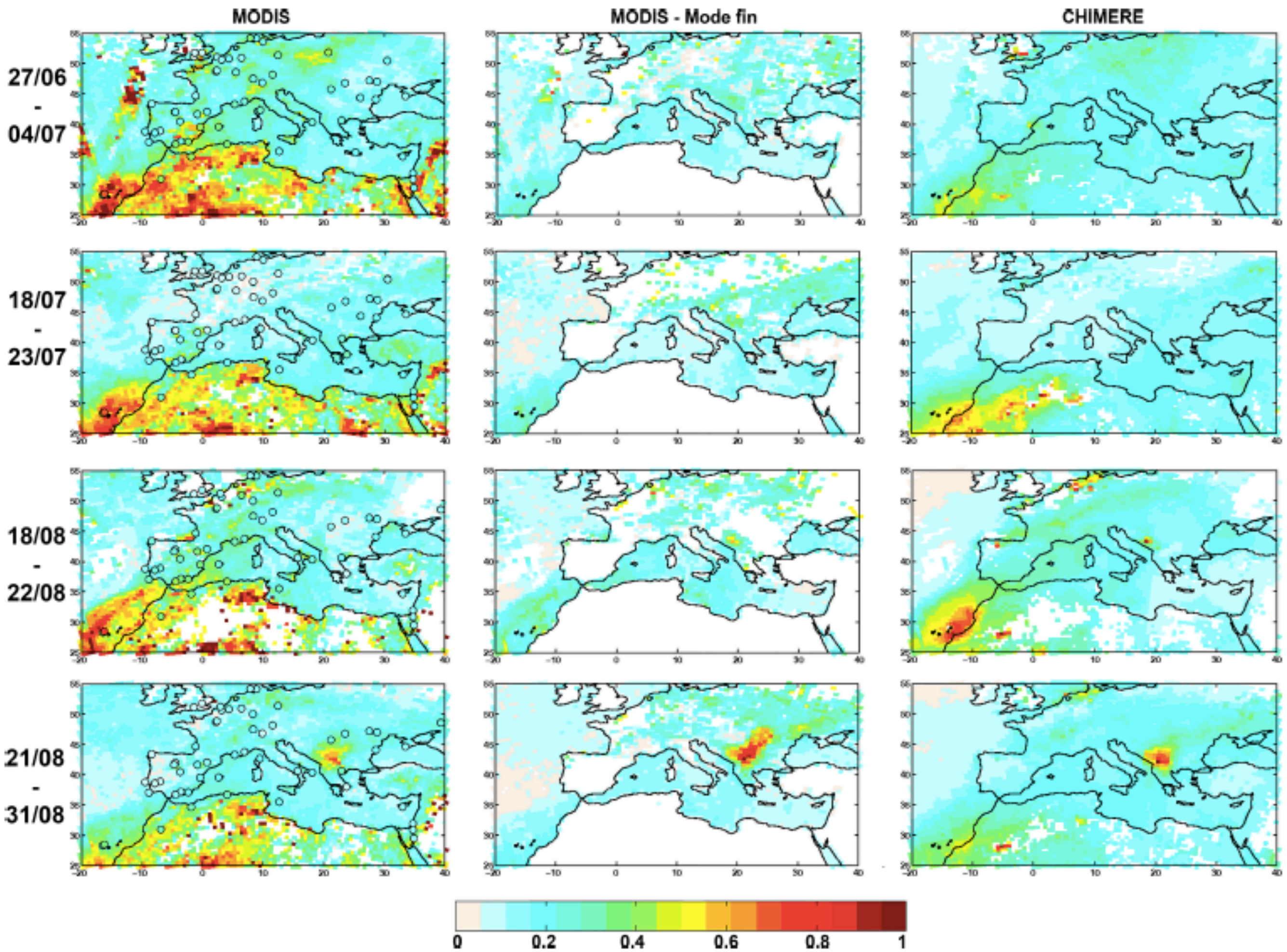


- Dust: 36% of PM10 50µg/m^3 AQ std exceedances
- Fires: up to 20% of avg surface PM2.5
- Anthropogenic: 21% of PM2.5 25µg/m^3 recommendation threshold exceedances

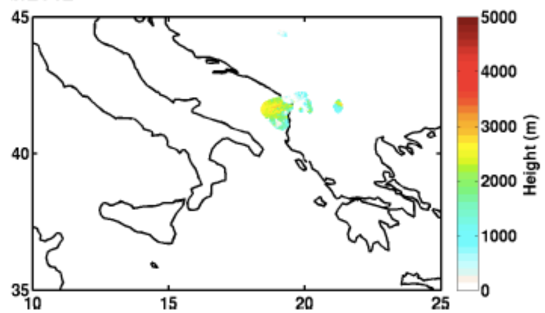
(G.Rea et al., ACPD, 2015)

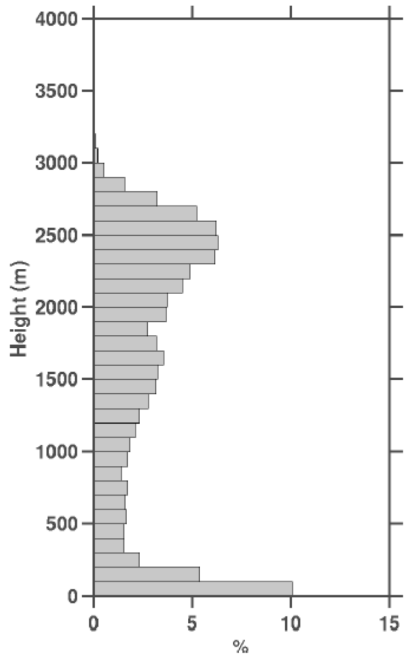
Modeling the impact of fires: case of the summer 2012

Several fires events during the summer of 2012



MISR plume height





Modeling the impact of fires: case of the summer 2012

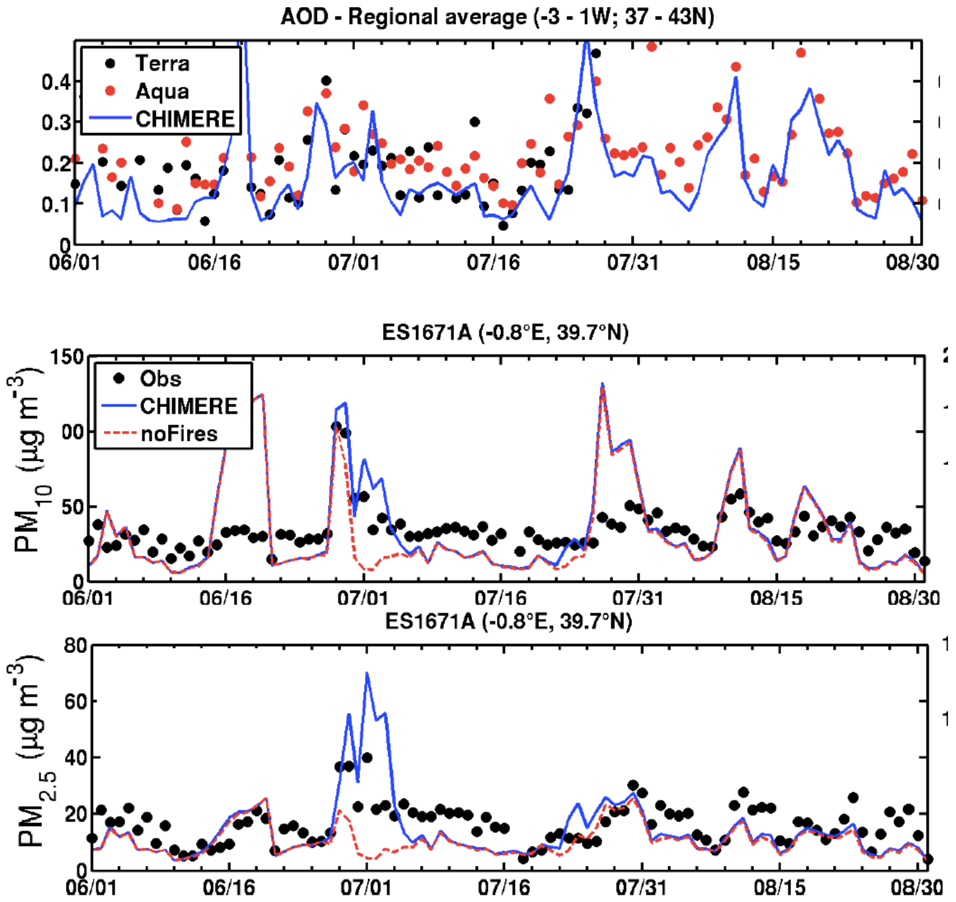
Air quality impact: comparisons to surface PM observations

Episodes	Nombre stations/points	Moyenne Mod.	Moyenne Obs.	R	RMSE	MNB	Dépassements Mod.	Dépassements noF	Dépassements Obs.
Espagne									
27 juin-4 juillet									
PM_{10}	20/159	38.8	40.5	0.84	22.9	1.0%	42	32	36
$PM_{10}{}^{a}$	11/87	46.0	43.2	0.78	27.5	19.4%	26	18	21
$PM_{2.5}$	11/87	22.0	17.8	0.48	14.4	33.9%	23	0	17
19-22 août									
PM_{10}	32/126	28.2	22.5	0.47	14.8	51.1%	19	5	11
$PM_{10}{}^{a}$	13/42	29.7	19.6	0.35	16.0	66.6%	10	3	7
$PM_{2.5}$	13/49	18.7	9.4	0.36	15.0	160.8%	10	0	2
Portugal									
18-23 juillet									
PM_{10}	8/48	33.7	23.7	0.69	20.4	48.8%	9	0	2
$PM_{10}{}^{a}$	6/36	26.3	24.7	0.81	14.1	10.6%	2	0	2
$PM_{2.5}$	6/36	18.8	10.7	0.80	13.6	111.4%	4	0	1
Balkans									
21-31 août									
PM_{10}	5/55	34.5	46.4	0.85	18.4	-30.1%	10	0	19
$PM_{10}{}^{a}$	1/11	60.9	79.6	0.79	26.5	-25.9%	7	0	10
$PM_{2.5}$	1/11	49.5	37.9	0.76	23.9	22.6%	8	0	10

[a] aux stations mesurant aussi la concentration en $PM_{2.5}$

Overestimate by CHIMERE, especially in the Iberic Peninsula.

Modeling the impact of fires: case of the summer 2012



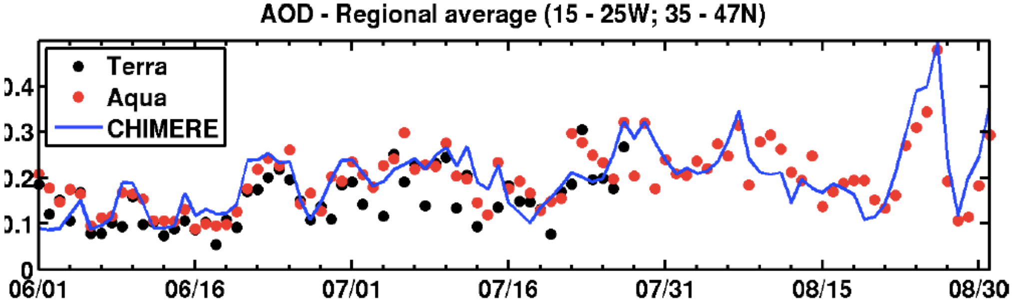
Spanish fires 27-06 – 04/07

Mixed influence of fires and dust; Evaluation of fire emissions difficult due to large uncertainties on both dust and fire sources…

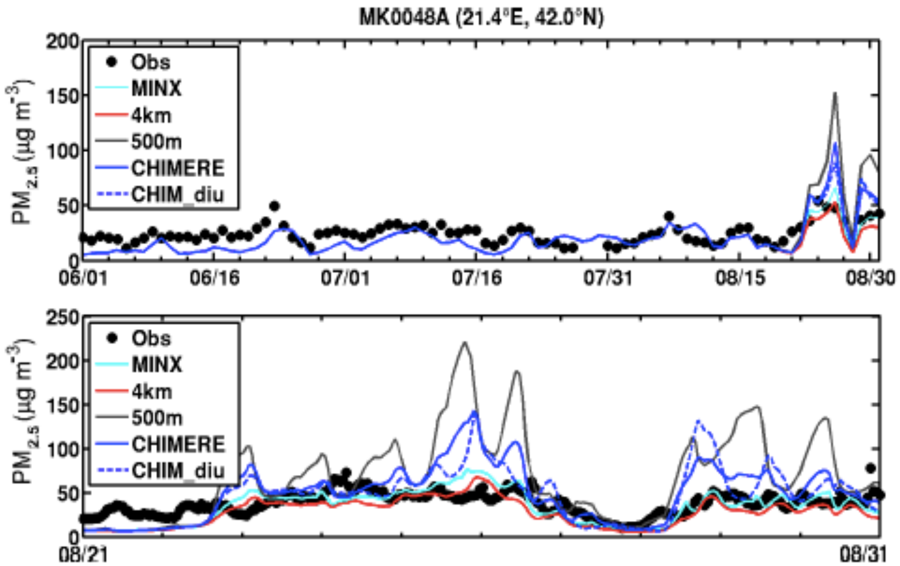
Surface PM from fires seems over-estimated; and event seems to last longer.

Modeling the impact of fires: case of the summer 2012

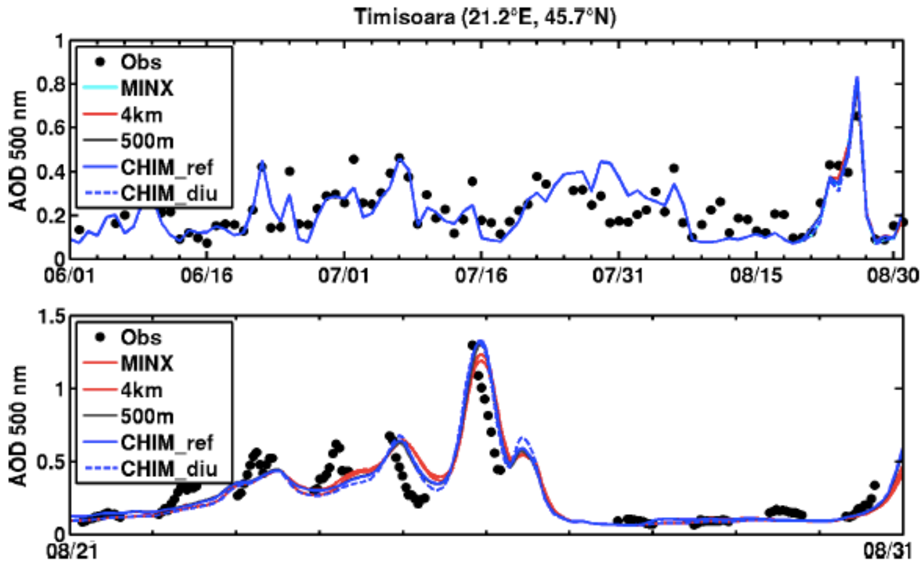
Sensitivity to diurnal cycle and injection height for fire episode in the Balkans



Surface PM observations in Macedonia

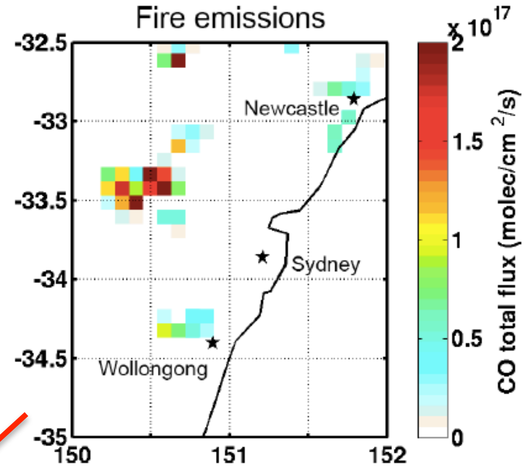


AOD at AERONET station in Romania

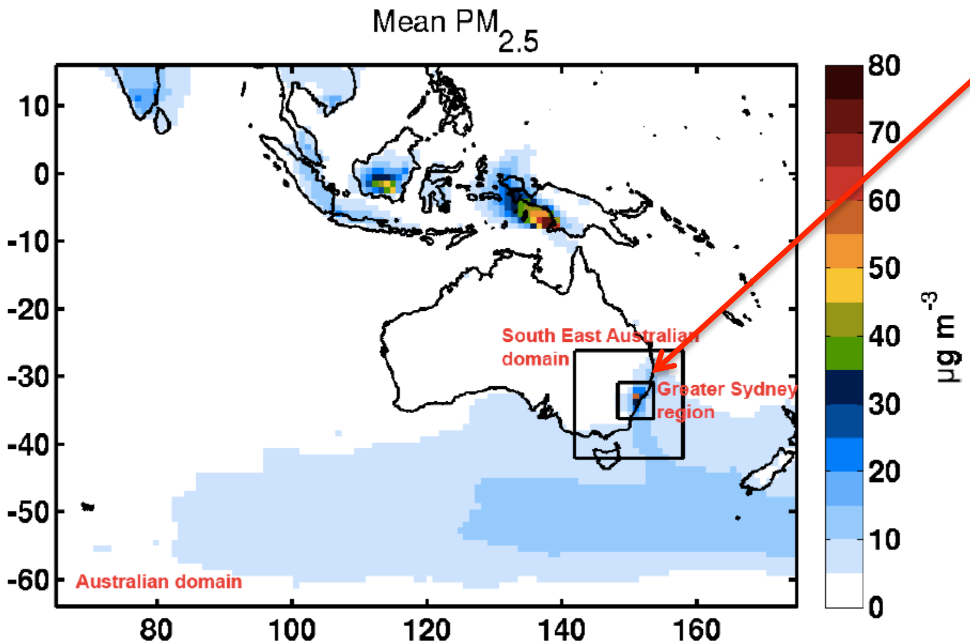


In this case, injection height is critical for local impact; not so much for AOD downwind; Lack colocated PM and AOD observations for stronger conclusion on emissions.

Modeling the impact of fires:
case of the NSW Australian fires in October 2013



(9km resolution)

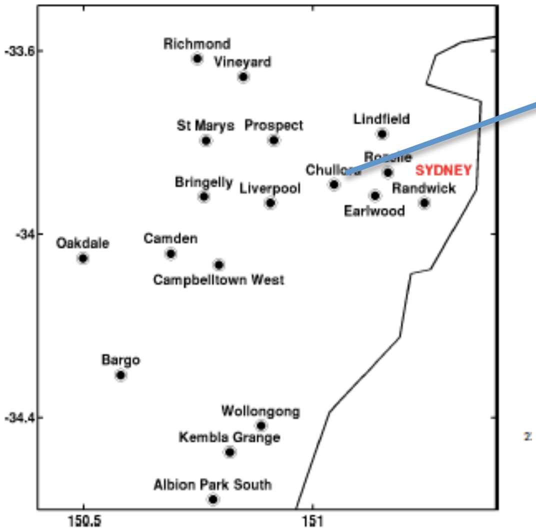


- WRF-CHIMERE simulation
- APIFLAME fire emissions
- Australian emission factors (derived from field measurements)

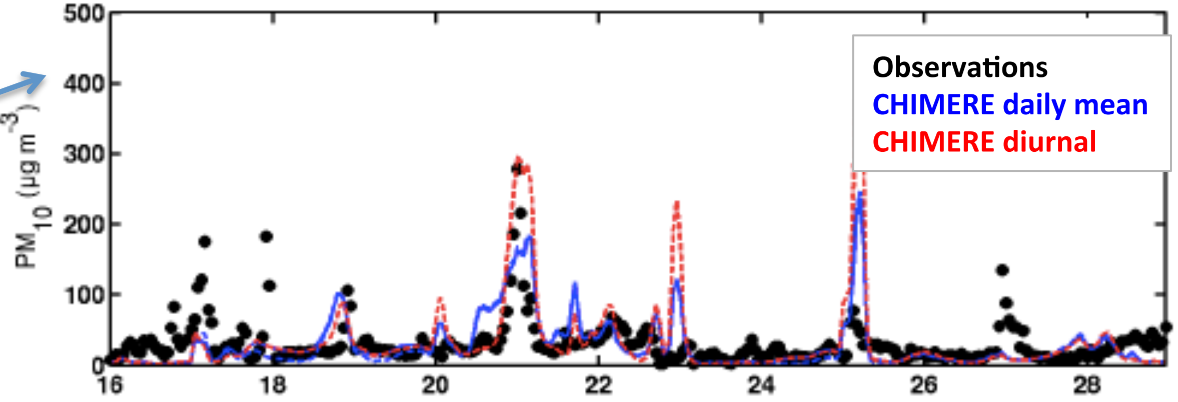
(G.Rea et al., submitted, 2015)

Modeling the impact of fires: case of the NSW Australian fires in October 2013

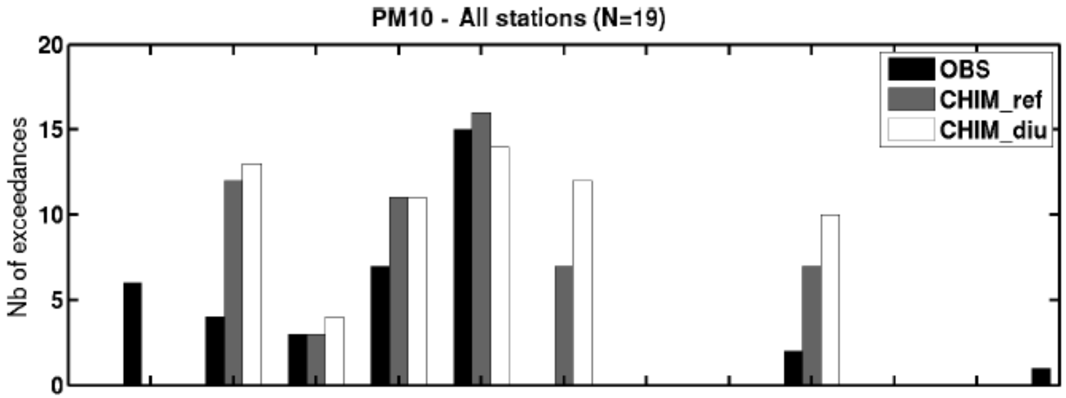
NSW air quality network



Chullora (151°E, 33.9°S)



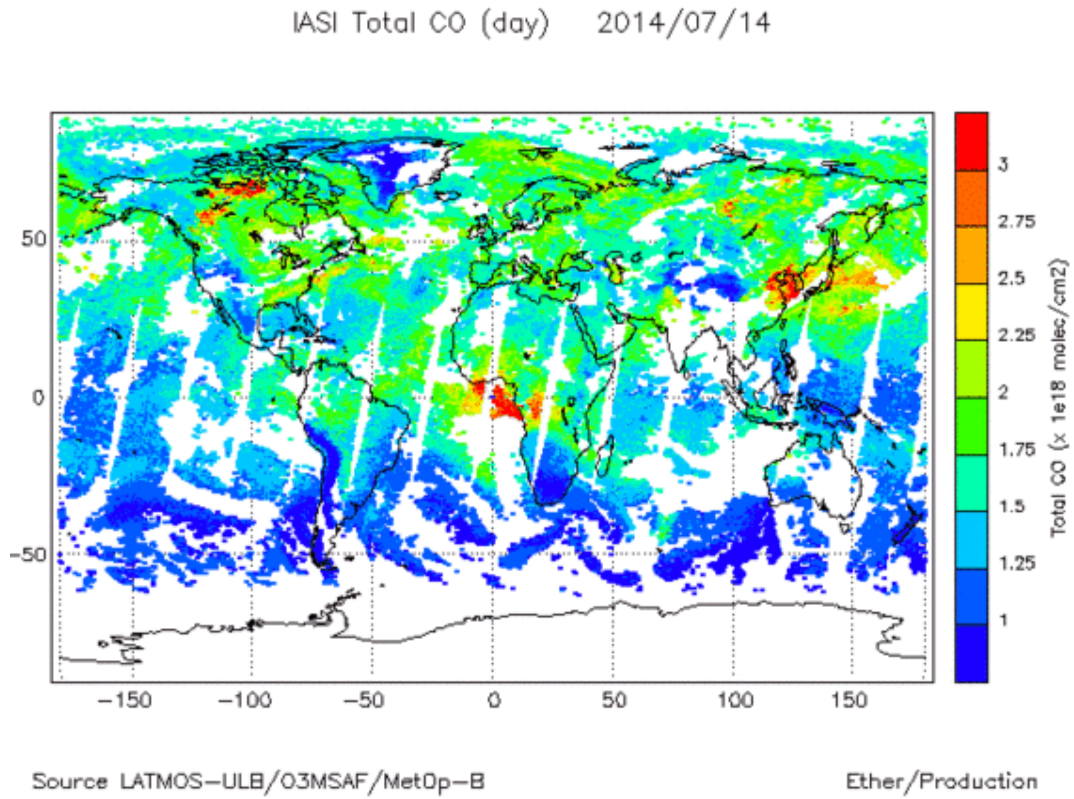
Air quality threshold exceedances (PM10 > 50 µg/m³)

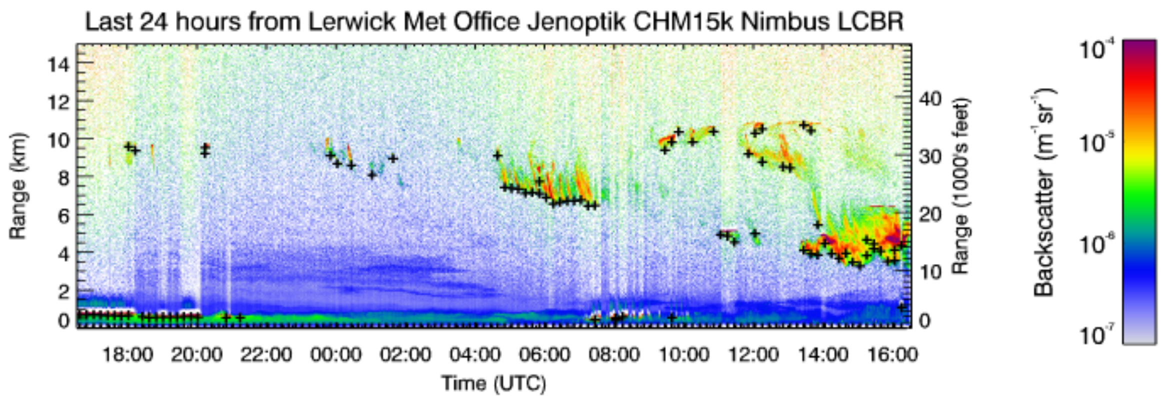


In this case, emissions' diurnal cycle is essential to capture surface PM, and exceedances.

(G.Rea et al., submitted, 2015)

Hemispheric impact of boreal fires





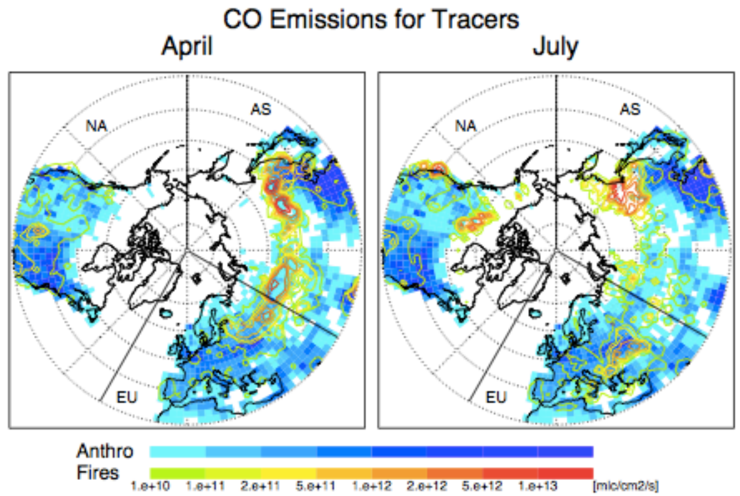
Inflow of pollution in Europe from boreal wildfires

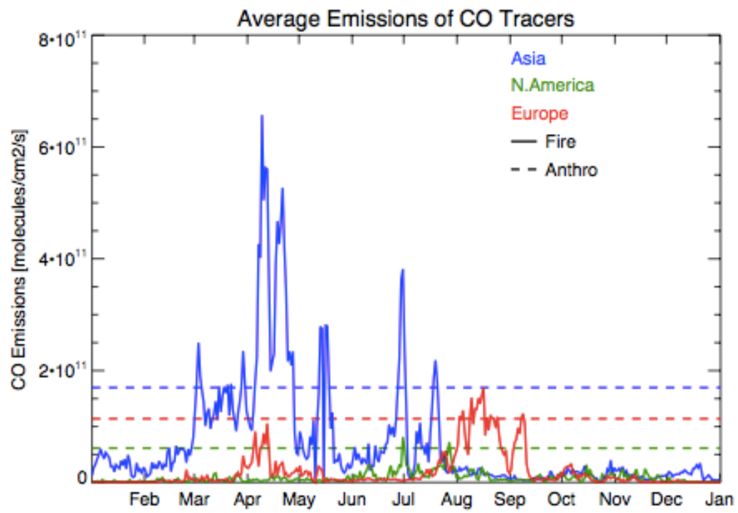
Multi-model analysis of composition in the Arctic (POLMIP Experiment)

- Global models intercomparison
- Evaluation of transport towards the Arctic
- 2008: international campaigns (ARCTAS, YAK, POLARCAT)
- Several fire plumes sampled by aircrafts

Table 3. Summary of POLMIP models.

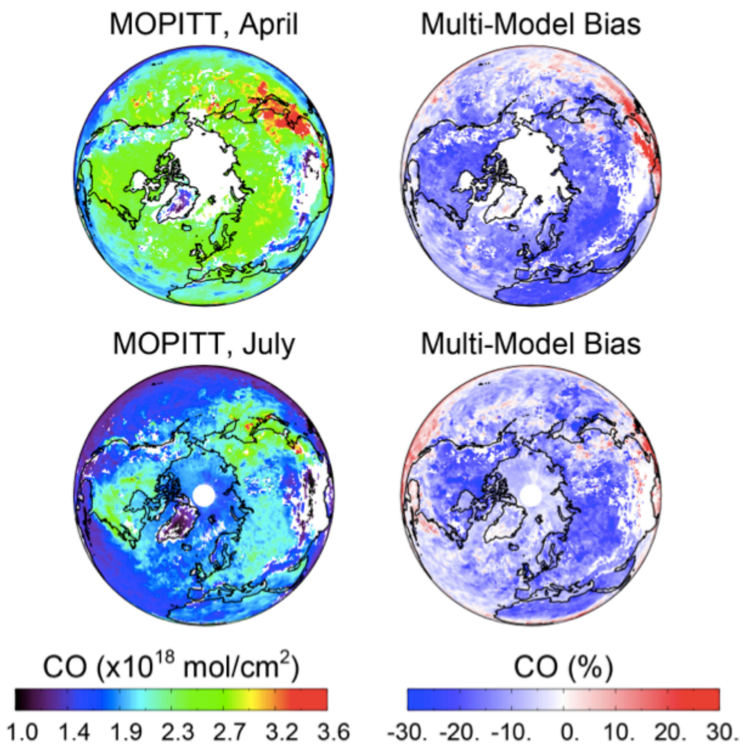
Model	Resolution	Meteorology	Chemistry
CAM4-chem	1.9°x2.5°, 56 levels	GEOS-5	MOZART-4, bulk aerosols
CAM5-chem	1.9°x2.5°, 56 levels	GEOS-5	MOZART-4, modal aerosols
C-IFS	1.125°x1.125°, 60 levels	ECMWF	tropospheric, CB05
GEOS-Chem	2°x2.5°, 47 levels	GEOS-5	tropospheric, 100 species
GMI-GEOS5	2°x2.5°, 72 levels	GEOS-5	stratospheric and tropospheric, 154 species, GOCART aerosols
LMDZ-INCA	1.9°x3.75°, 39 levels	ERA-interim	tropospheric, 85 species, aerosols
MOZART-4	1.9°x2.5°, 56 levels	GEOS-5	tropospheric, 103 species, bulk aerosols
TM5	2°x3°, 60 levels	ECMWF	tropospheric, CB05
TOMCAT	2.8°x2.8°, 31 levels	ERA-interim	tropospheric, 82 species
SMHI-MATCH	hemispheric		
WRF-Chem	100 & 50km, Canada	WRF/NCEP FNL	MOZART, GOCART aerosols



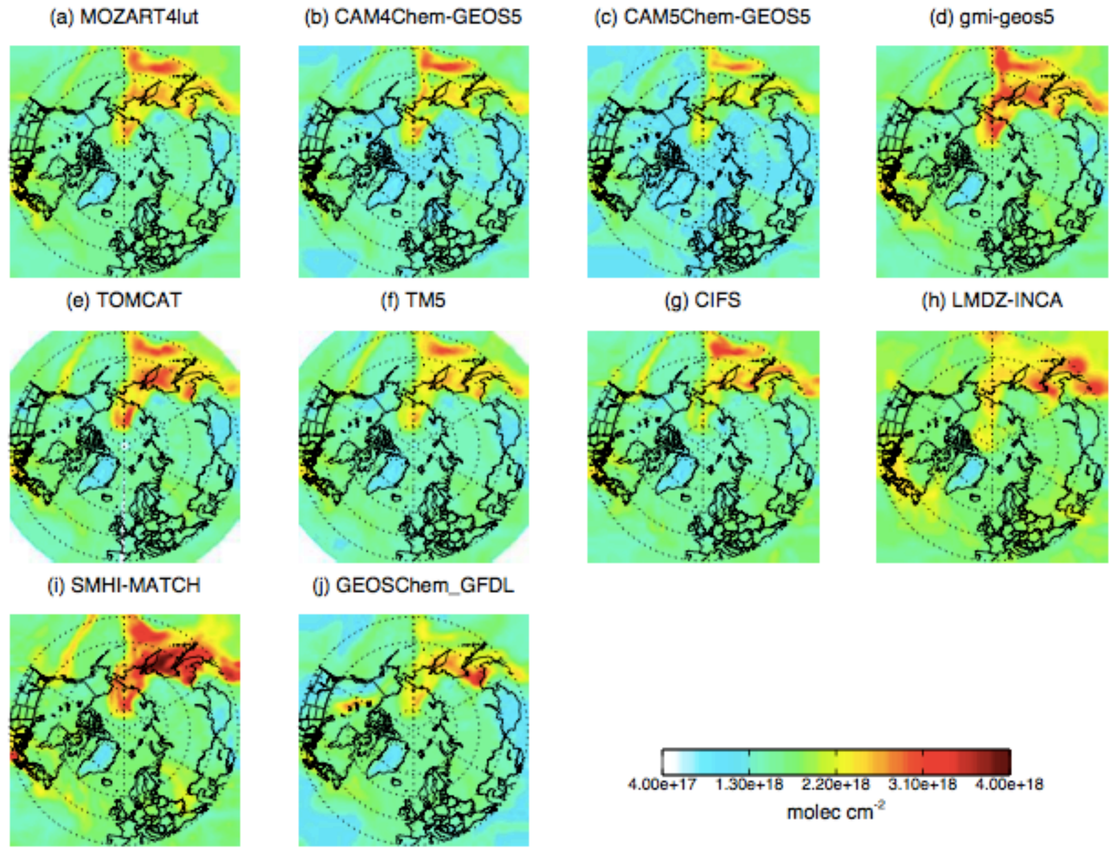


(Emmons et al., ACP, 2015)

Multi-model analysis of composition in the Arctic (POLMIP Experiment)



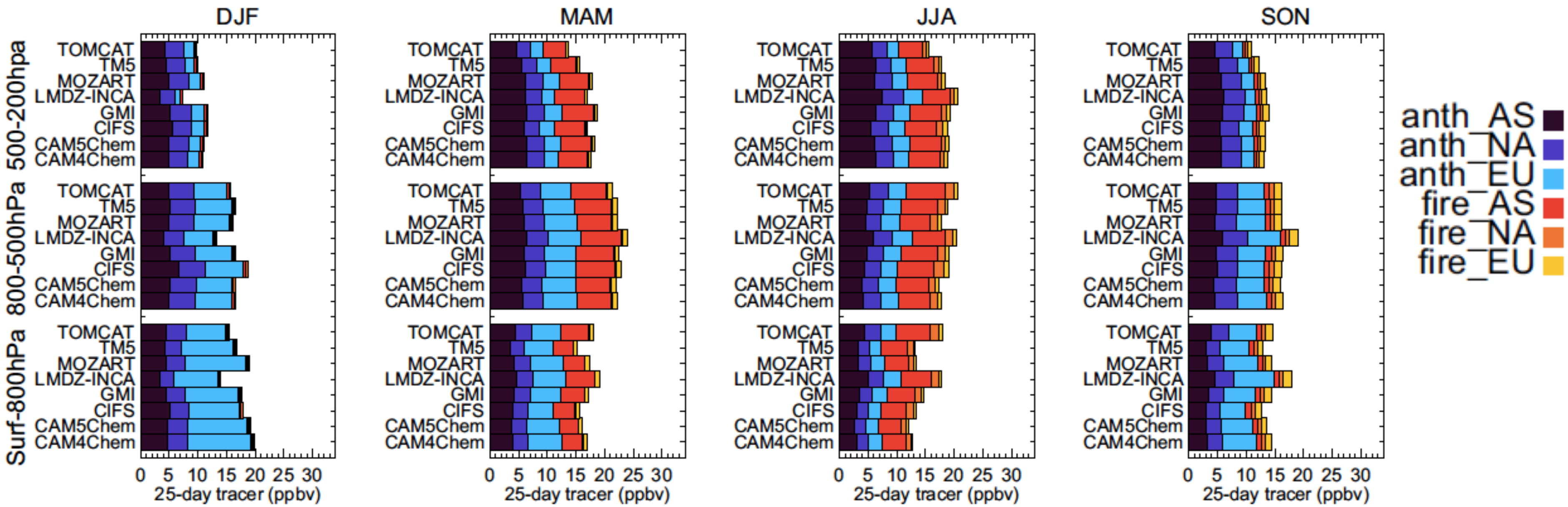
06:00UT, 7 July 2008



Monks et al., ACP, 2015
Arnold et al., ACP, 2015

Multi-model analysis of composition in the Arctic (POLMIP Experiment)

Transport of fixed lifetime tracers = 25 days



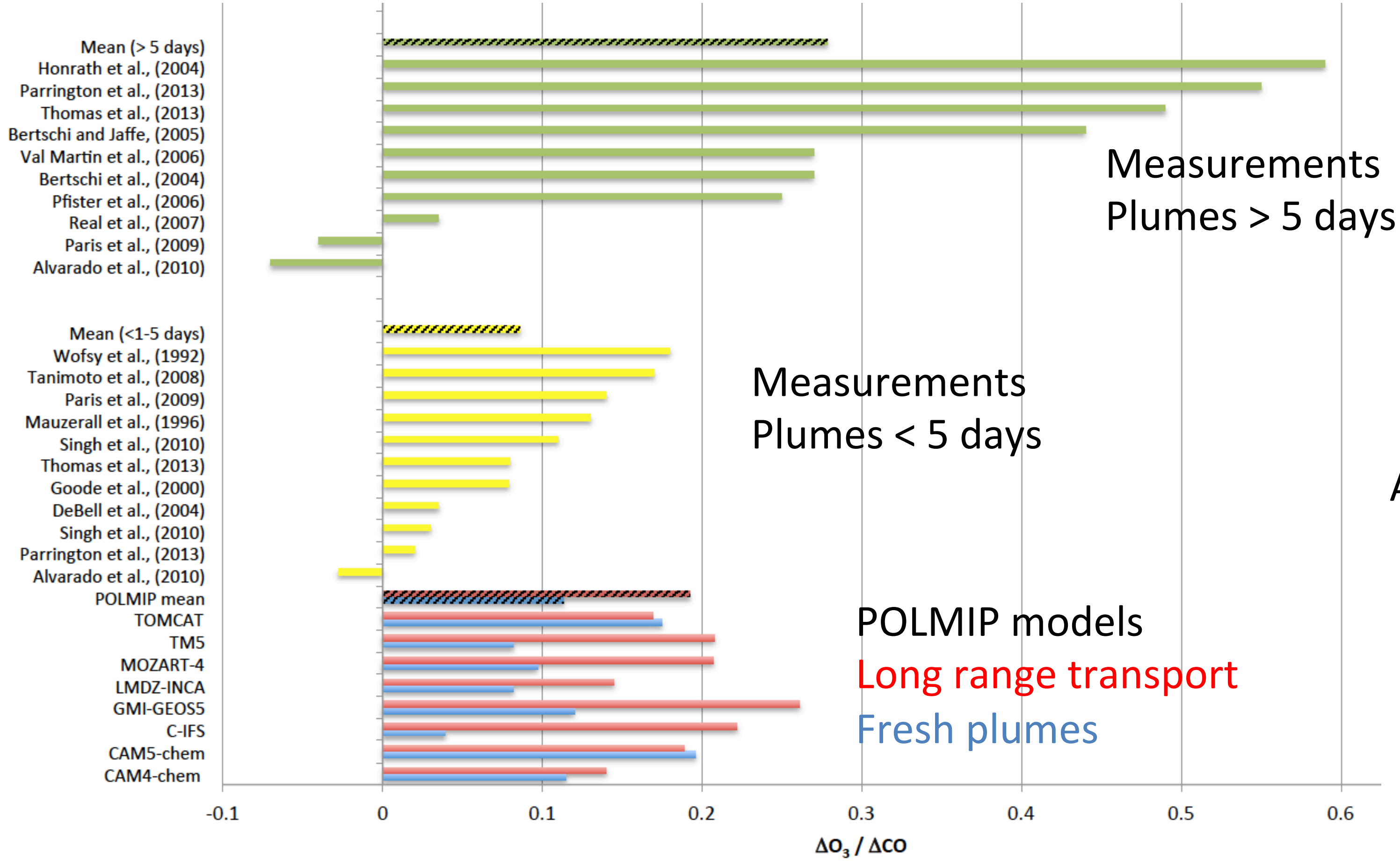
- Strong influence of fires in spring and summer; Good consistency btw models;
- BUT results very different if lifetime controlled by reactivity with OH (real life)…

  => different chemical evolution btw models

Monks et al., ACPD

Multi-model analysis of composition in the Arctic (POLMIP Experiment)

Ozone production wrt CO within fire plumes



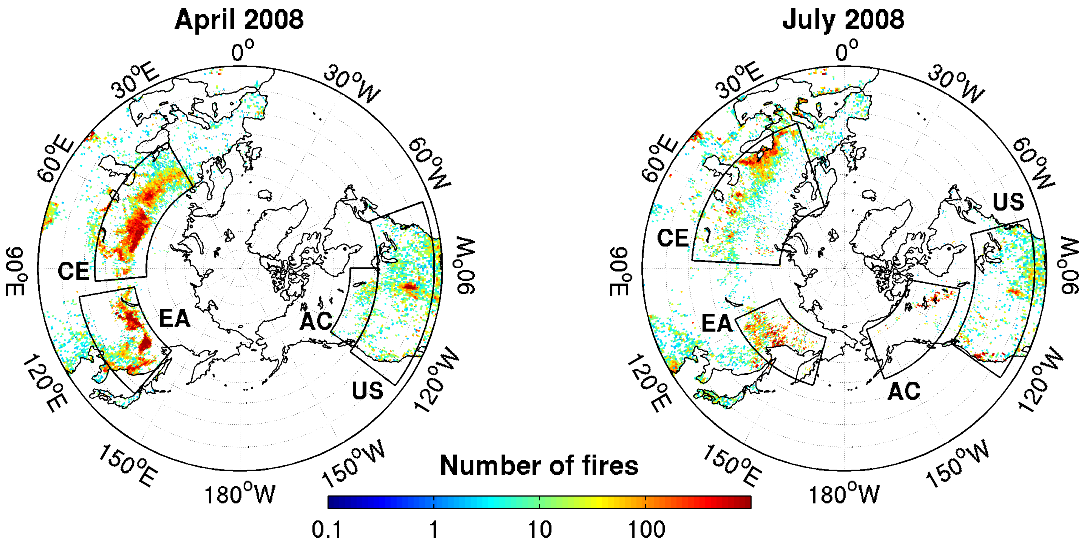
Arnold et al., ACP, 2015

- Strong ozone production in plumes transported towards the Arctic
- ↗ during transport
- Strong sensitivity to PAN; themselves dependent on vertical transport simulated by models

Global modeling including pyroconvection

LMDZORINCA

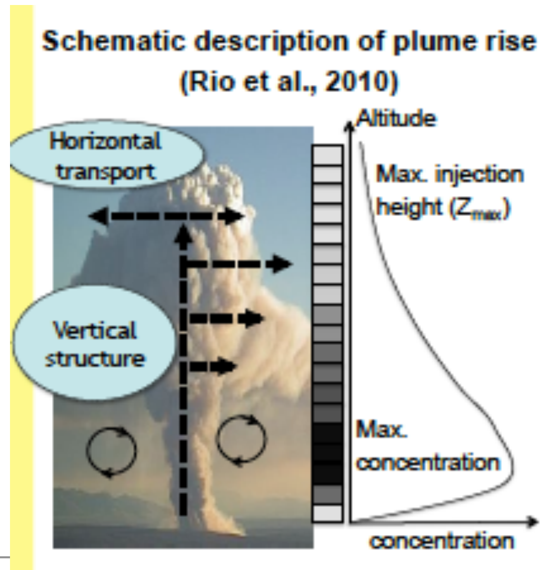
- Daily fire emissions from POLMIP
- Resolution 96x96, 3.75°x1.9°, 39 vertical levels
- Driven by ECMWF reanalyses (6hrs)



Pyroconvection implementation (Rio et al., 2010)

- Surface forcing ==> fire characteristics :
  Fire power / heatflux (MODIS FRP in W/m2), burned area (AB), number of fires within grid cell
- ~ 10% of fire energy detected from space
- ~ 50% available for convection

$$P(i,j) = n\frac{10\ FRP_{mean}(i,j)}{2\ AB_{mean}(i,j)}$$



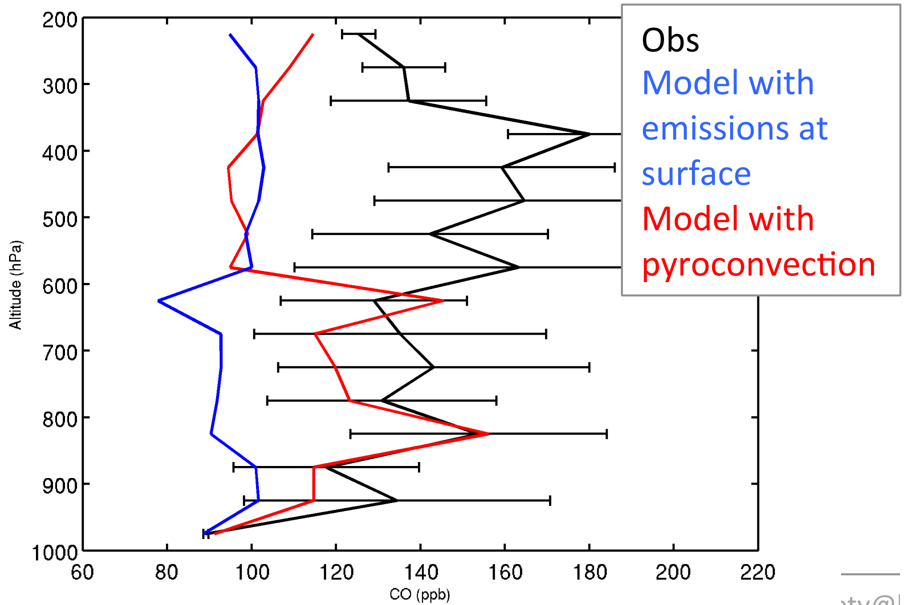
Evaluating pyroconvection: impact on plume modeling

Comparison to aircraft observations for 2008

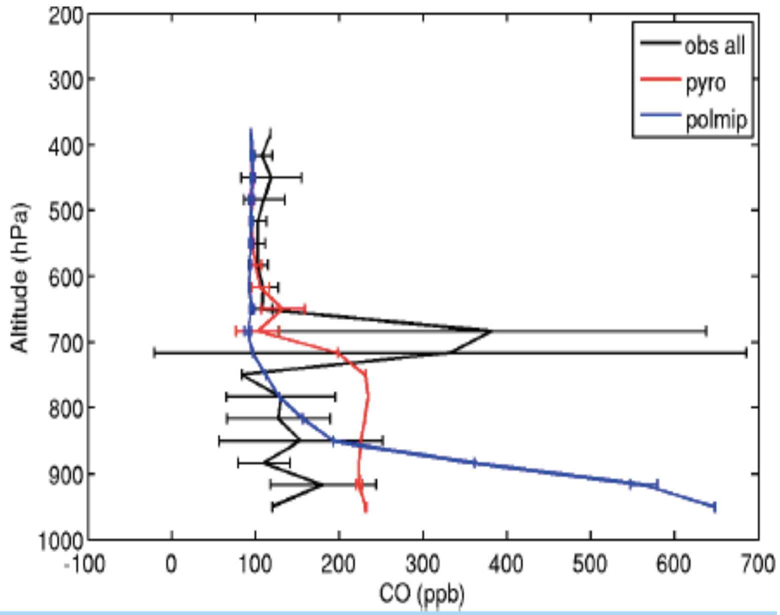
	WP3		NP3		YAK		DLR		ATR-42	
	Base	Pyro.	Base	Pyro.	Base	Pyro.	Base	Pyro.	Base	Pyro.
R	0.6	0.65	0.45	0.57	0.29	0.45	0.62	0.64	0.7	0.7
RMSE ($ppbv^2$)	24.32	23.48	97.35	95.51	37.45	24.3	30.11	30.04	14.99	15.01
MB (ppbv)	-10.43	-10.07	-28.35	-32.85	-4.5	-6.51	-5.48	-6.06	-8.38	-8.54
NMB	-0.06	-0.06	-0.2	-0.23	-0.04	-0.06	-0.05	-0.06	-0.08	-0.06

- Improves correlations (NP3, YAK)
- Biais also often increases…

Example: DC8 flight above Canadian fires

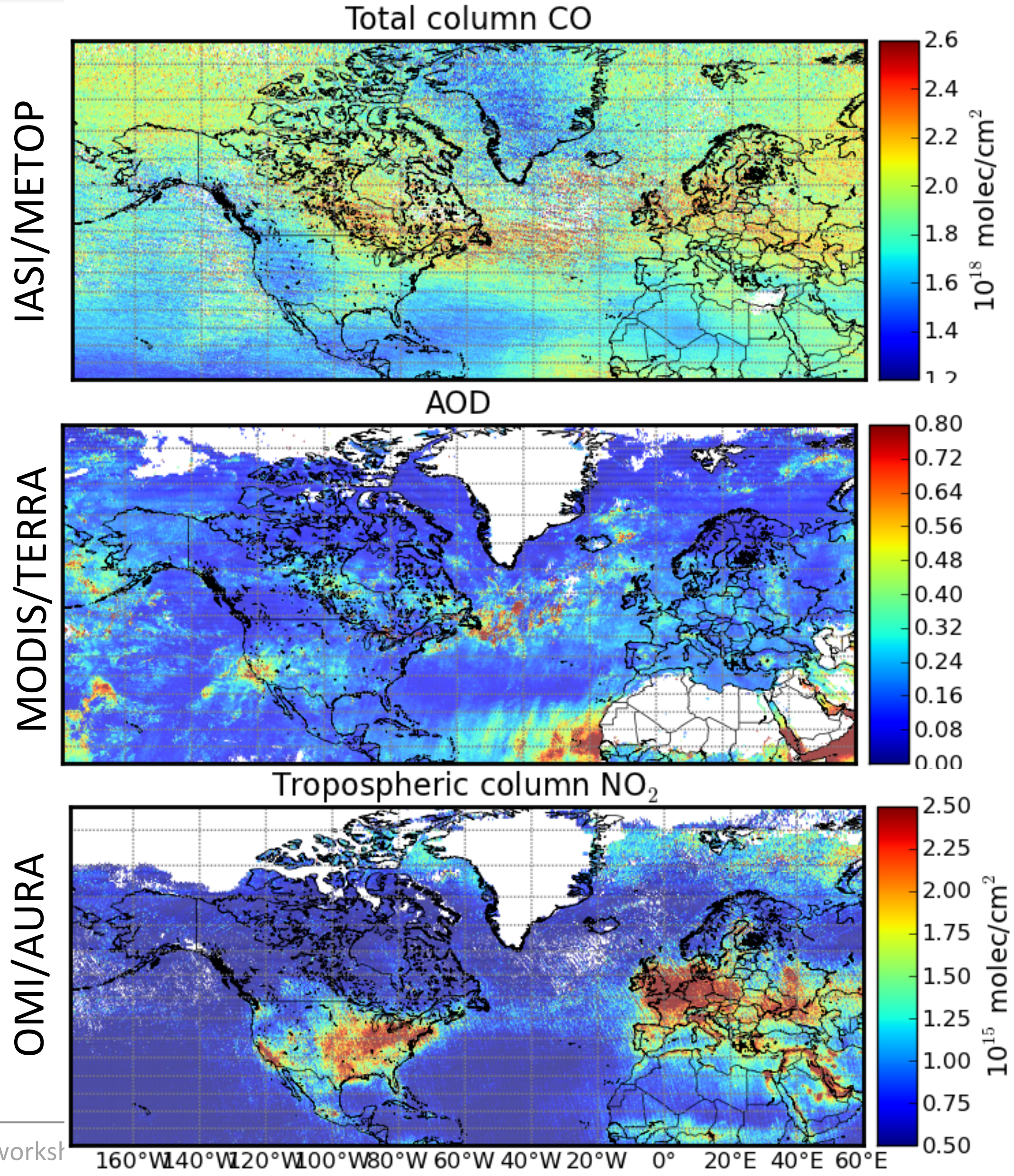


Siberian fire (11/07; YAK)

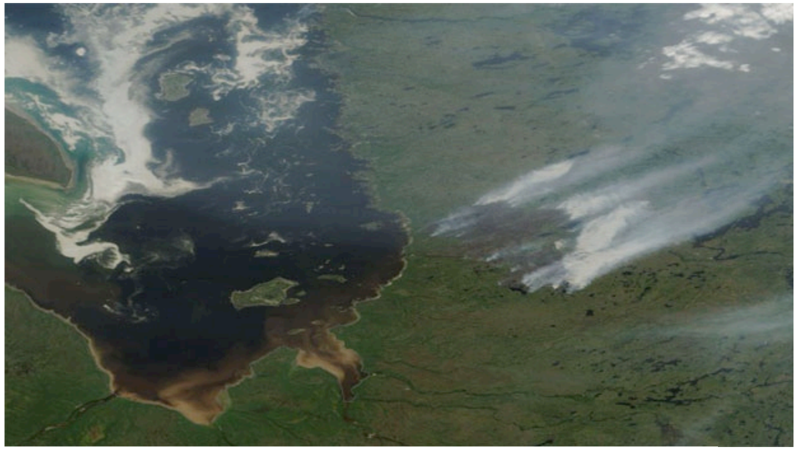


LONG RANGE TRANSPORT FROM BOREAL FIRES
EXAMPLE OF THE 2013 FIRE SEASON

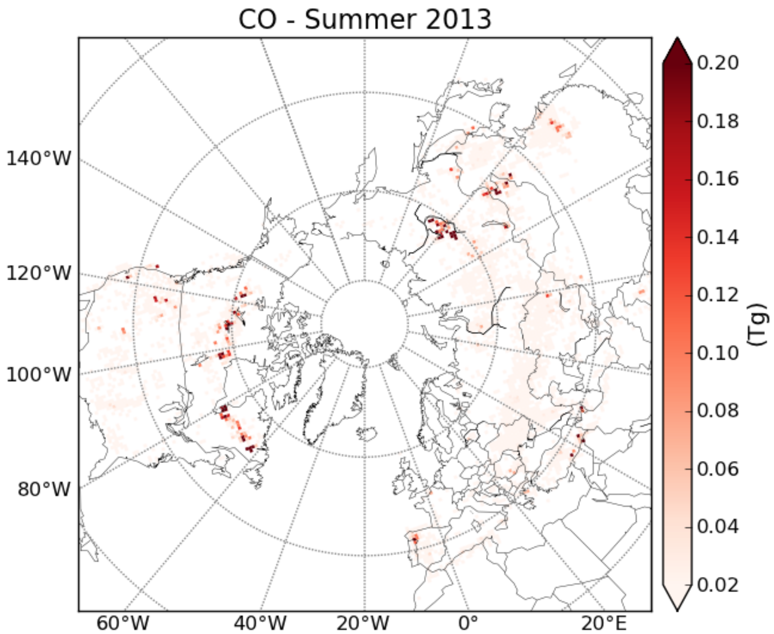
July 2013

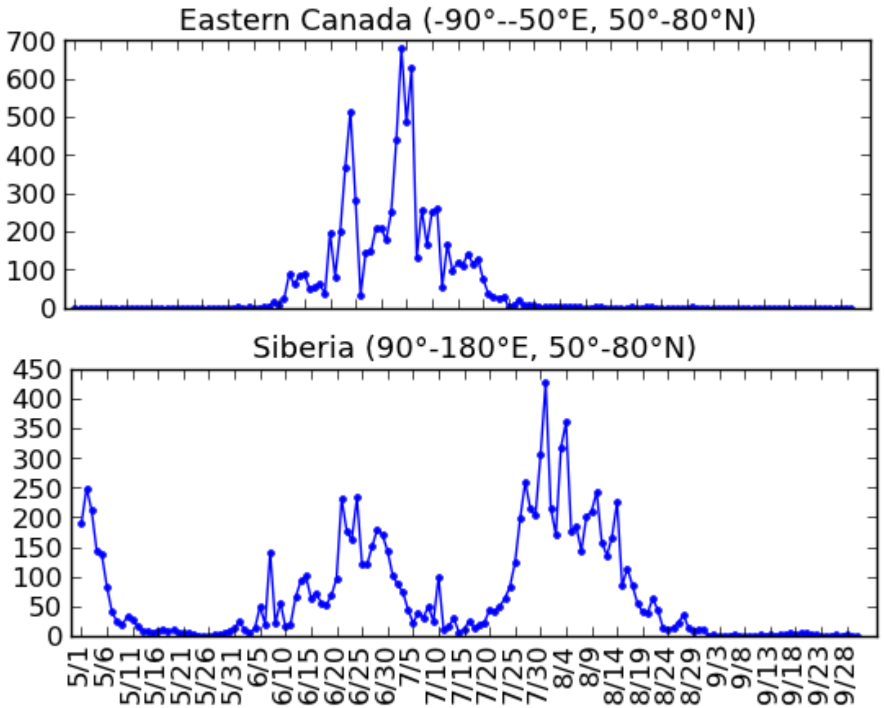


Long range transport from boreal fires
Example of the 2013 fire season



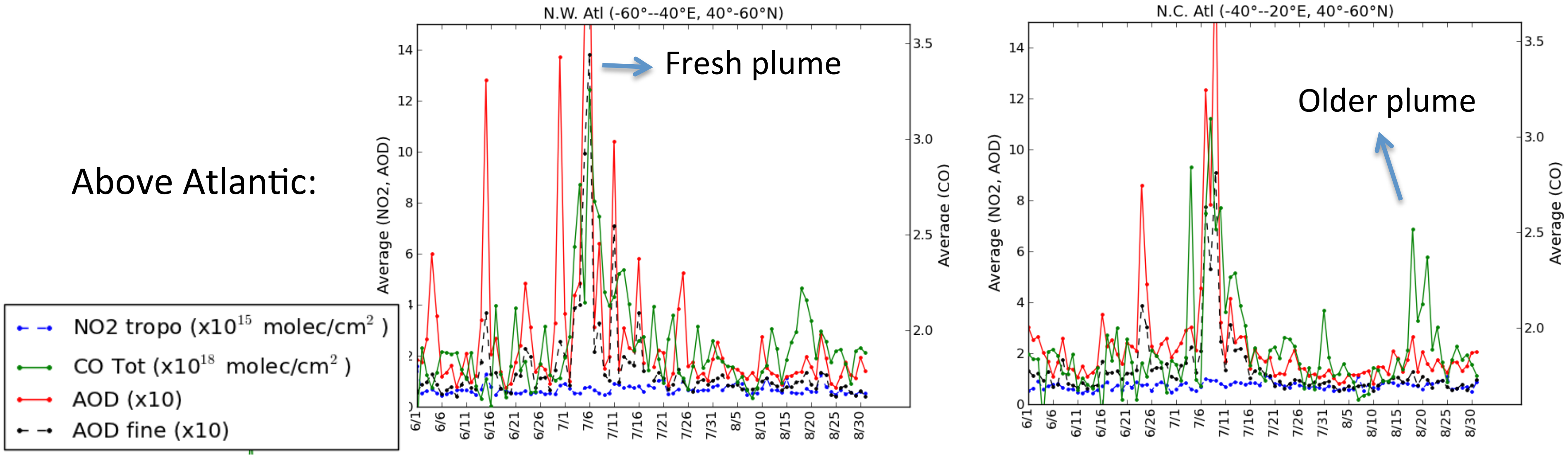
Daily emissions of CO (10^6 kg)



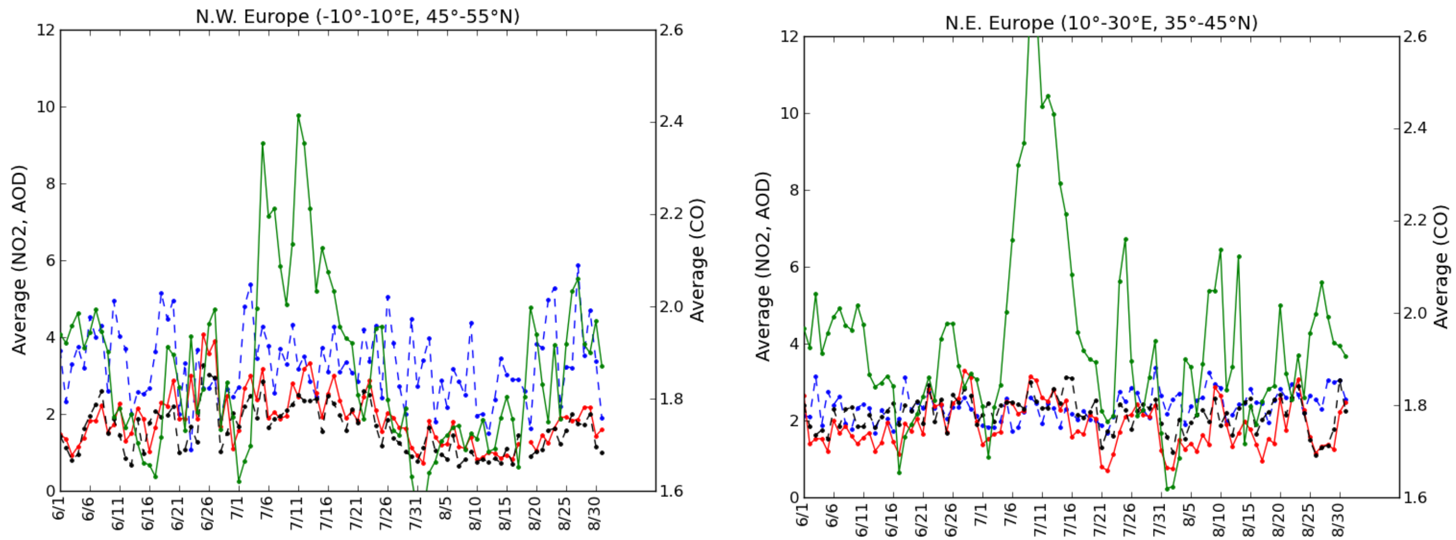


Long range transport from boreal fires
Example of the 2013 fire season

Above Atlantic:



Above Europe:

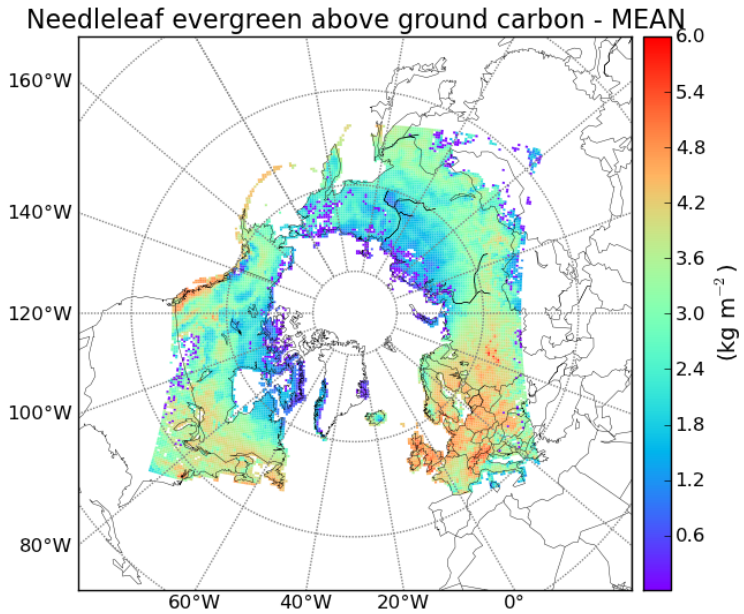


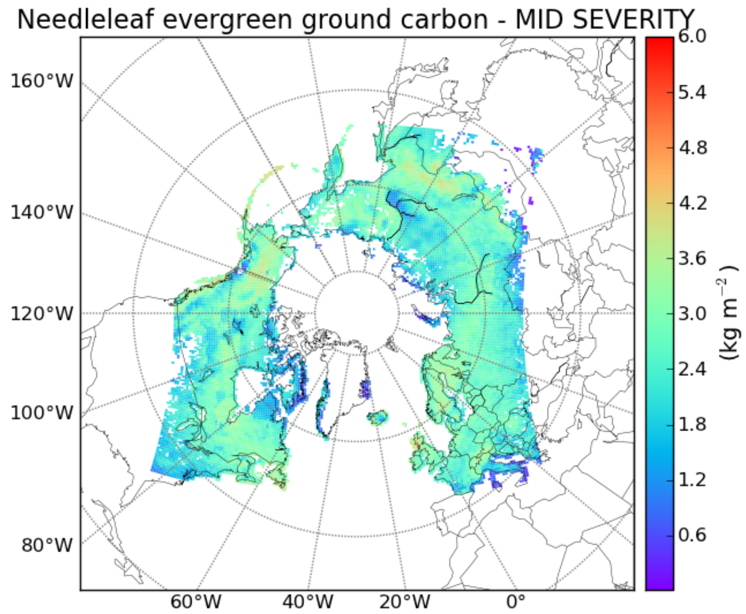
Adapting APIFLAME fire emissions for boreal regions
Ongoing work!

Intense wildfires in boreal regions can burn a significant fraction of the ground organic layer
⇒ Estimate emissions from the burning of both above-ground and ground fuels.

- Use CLASS-CTEM model simulations outputs (Teufel et al., UQAM);
- For above ground burning: burned fraction depending on soil moisture
- 1st test: assume medium severity burning (Soja et al., 2004): 2cm depth for forests, 5cm for peatlands

Estimates for August:





Conclusions

- **Strong impact on air quality – but still difficult to quantify and forecast**
- Fires in Europe are lower than in the tropics or boreal regions but still have significant impact on regional pollution budgets during intense episodes
- Boreal fires impact atmospheric composition at local to hemispheric scales; with strong impact in the Arctic
- Large uncertainties on emissions (>100%) but also on transport processes and chemical evolution

⇒ **Need more in situ observations of fire characteristics and plume composition**

⇒ **Need to merge scales, develop new parameterizations to improve regional modeling**

Thank you for your attention!

Collaborateurs projet APIFLAME:
LMD: L. Menut, S. Mailler, C. Rio, H. Chepfer, A.Anav, P.Messina, S.Stromatas, G.Réa
INERIS: F. Meleux, B. Bessagnet, JC Péré ; LOA: D. Tanré, F. Ducos, J-L Deuzé, O. Dubovik
LA: C. Liousse; CEREA: K. Sartelet; LATMOS: M. George, C. Clerbaux

POLMIP: NCAR: L. Emmons, U. Leeds: S. Arnold, S. Monks, LATMOS: K. Law, J. Thomas, LMD: Y. Long