Atmospheric pollution from wildfires

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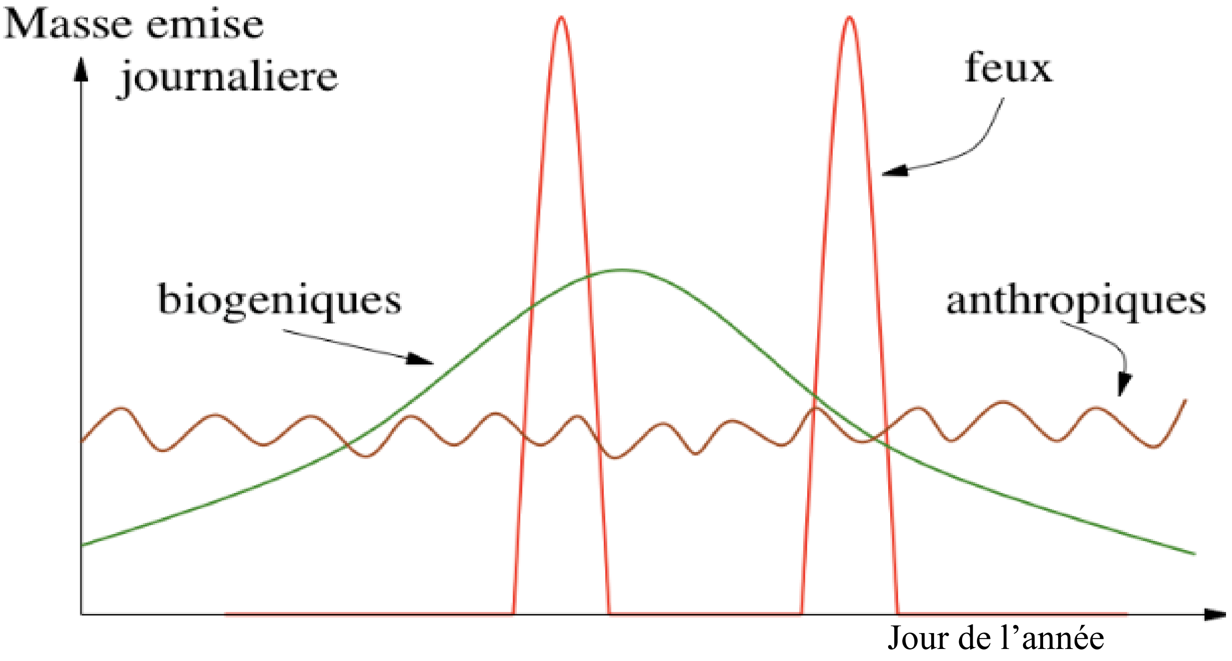
Wildfires and atmospheric pollution

Outdoor air pollution

- 4,2 – 6.5M premature death / year; exposure to fine particulate matter (PM) and ozone (O3)

  (Cohen et al., 2017; Lelieveld et al., 2019)
- 600 000 / year attributed to fires

  (Johnston et al., 2012)



Pollutant (µg/m3)	WHO recommandation	Exemples d'observations en surface – événements extrêmes
Particulate matter with diametre <10µm (PM10)	Mean 24h exposure 50 µg/m^3 (<3days/y)	Russia 2010[1]: 700-900µg/m^3 Indonesia 1997[3]: > 2000µg/m^3 Australia 2013[2]: PM10 > 500µg/m^3 (pic à 8000!!)
Particulate matter with diametre <2,5µm (PM2.5)	25 µg/m^3 (<3days/y)	Australia 2019-2020[4]: 100-500µg/m^3 à Sydney

1 (Konovalov et al., 2010)
2 (Heil and Goldammer, 2001)
3 (Rea et al., 2016)
4 (Yu et al., 2020)

Intense pollution worsen by the radiative impact of aerosols
e.g. on boundary layer dynamics
(Péré et al., LOA Lille, *Atmos. Chem. Phys.*, 2015)




Emissions


Australie, 12/2019 (Photo: Glen Morey/AP)

Flaming

- CO_2, H_2O, N_2, N_2O, NO_X, SO_2 + products of incomplete combustion (CO), PM
- Convection => plumes higher in altitude

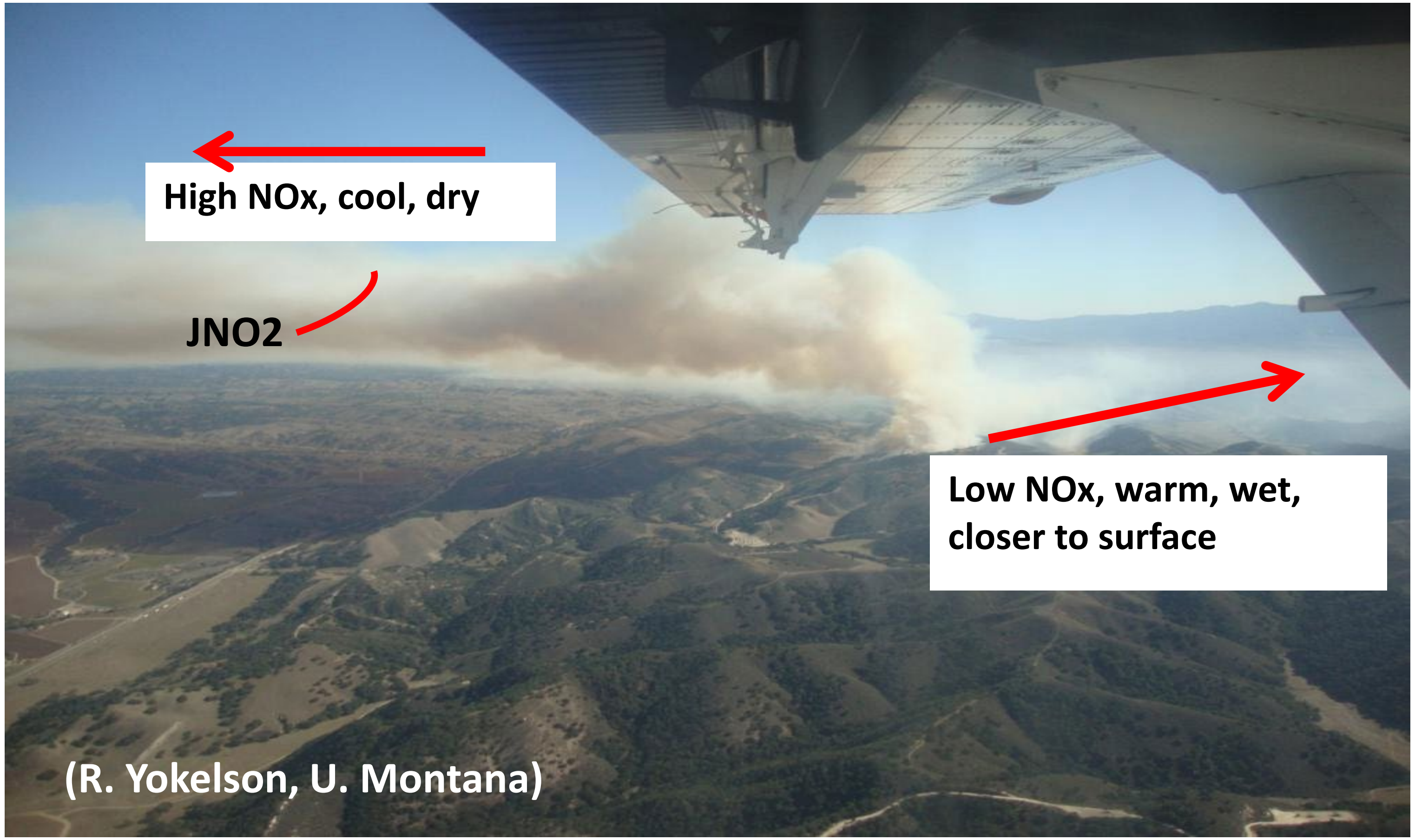
→ Dominant for bushfires

Smoldering

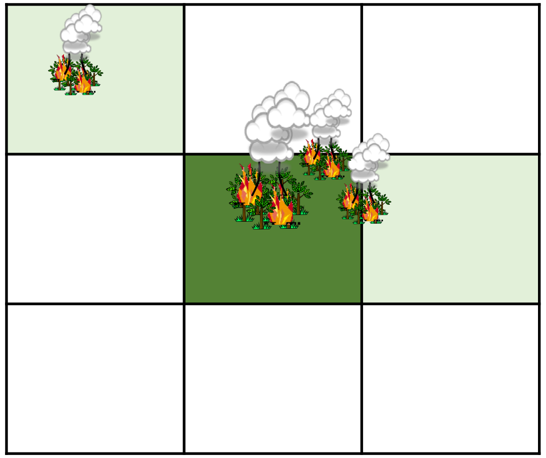
- Mainly incomplete combustion
- CO, CH_4, non methane organic compounds (NMOC), NH_3, black and organic carbon PM
- Emission closer to the surface

→ Peatlands, dense forests (tropical or boreal)


Alaska (Photo: Philip Higuera)



Regional modeling resolution ~ 5 – 50 km



What constrain from satellite observations?

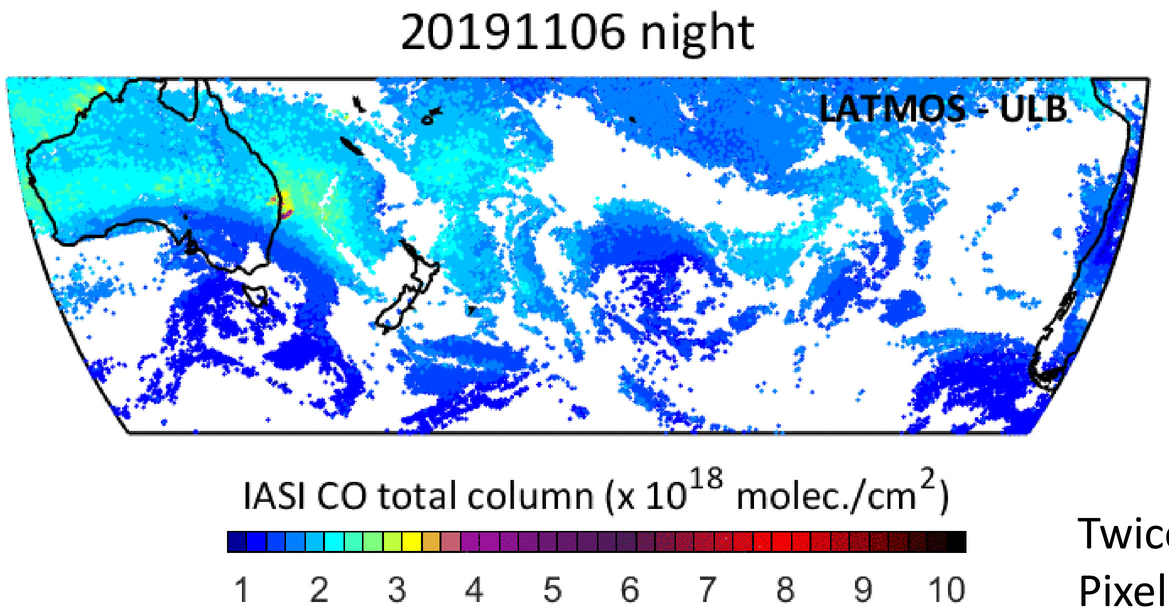
- Fire detection (active fires, burnt scars), intensity (FRP) : uncertainty 1-5 days, pb with diurnal cycle
- Trace gas concentrations (total columns), aerosol optical properties

e.g. IASI mission (LATMOS/IPSL, Laboratoire d'Aérologie), OMI/TROPOMI

CO, NO_2, NH3, but also in dense plumes

PAN, ethylene, methanol, formic acid

(Turquety et al., 2009; Coheur et al., 2009; R'honi et al., 2013; Whitburn et al., 2016)



Twice daily
Pixel ~12km

Observations of plume layer heights : CALIPSO Lidar, MISR, TROPOMI

Emissions : APIFLAME software

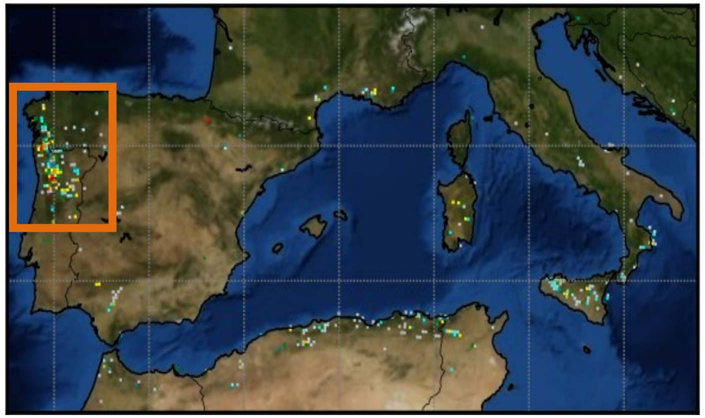
Emission for species i and burned area A

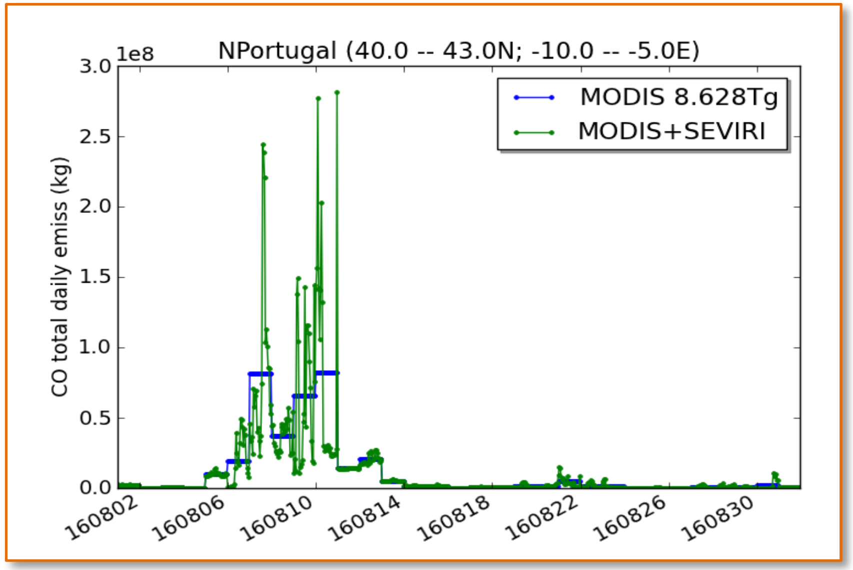
$$E_i = A \sum_{v=1}^{nv} f_v F_v \varepsilon_{v,i}$$

Fraction of **vegetation** type v
→ Landcover database

Fuel burnt (kgC/m^2)
(→ surface model ORCHIDEE)
x Fraction burnt

Emission Facteur for species i and vegetation v (g/kgC)
→ database/literature

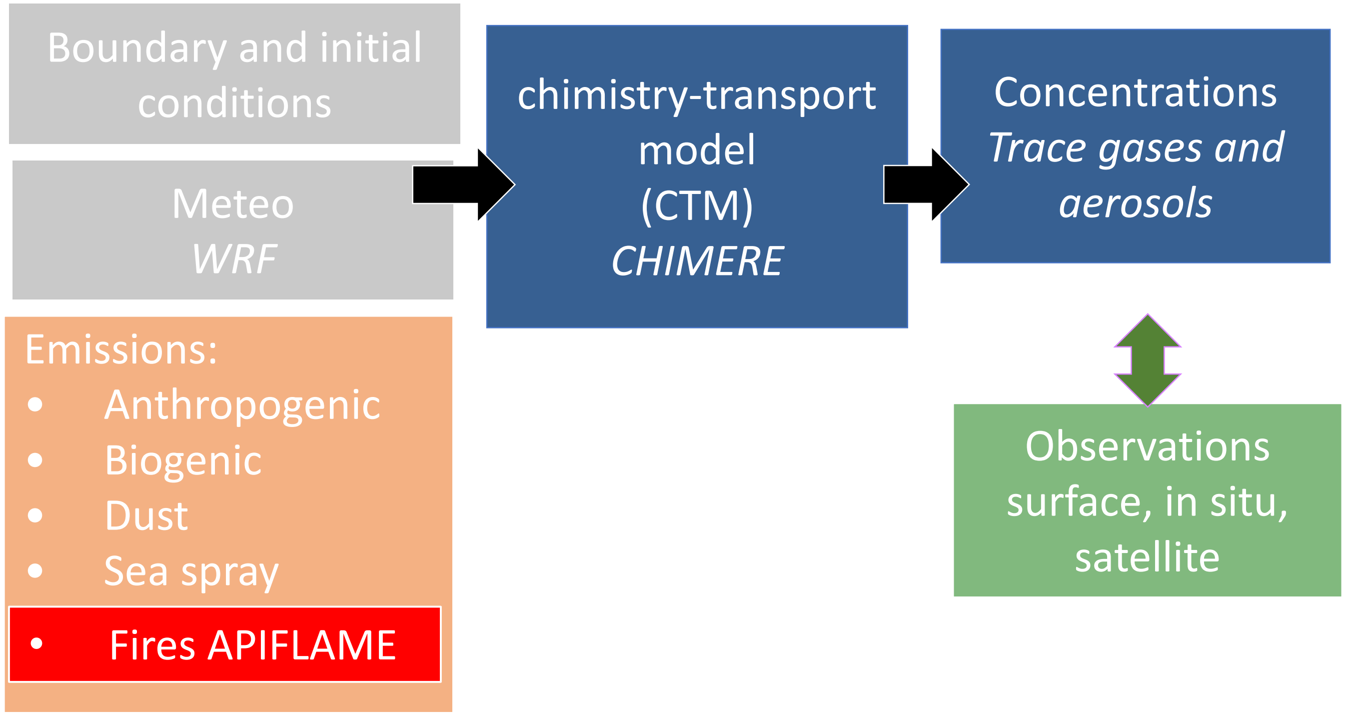


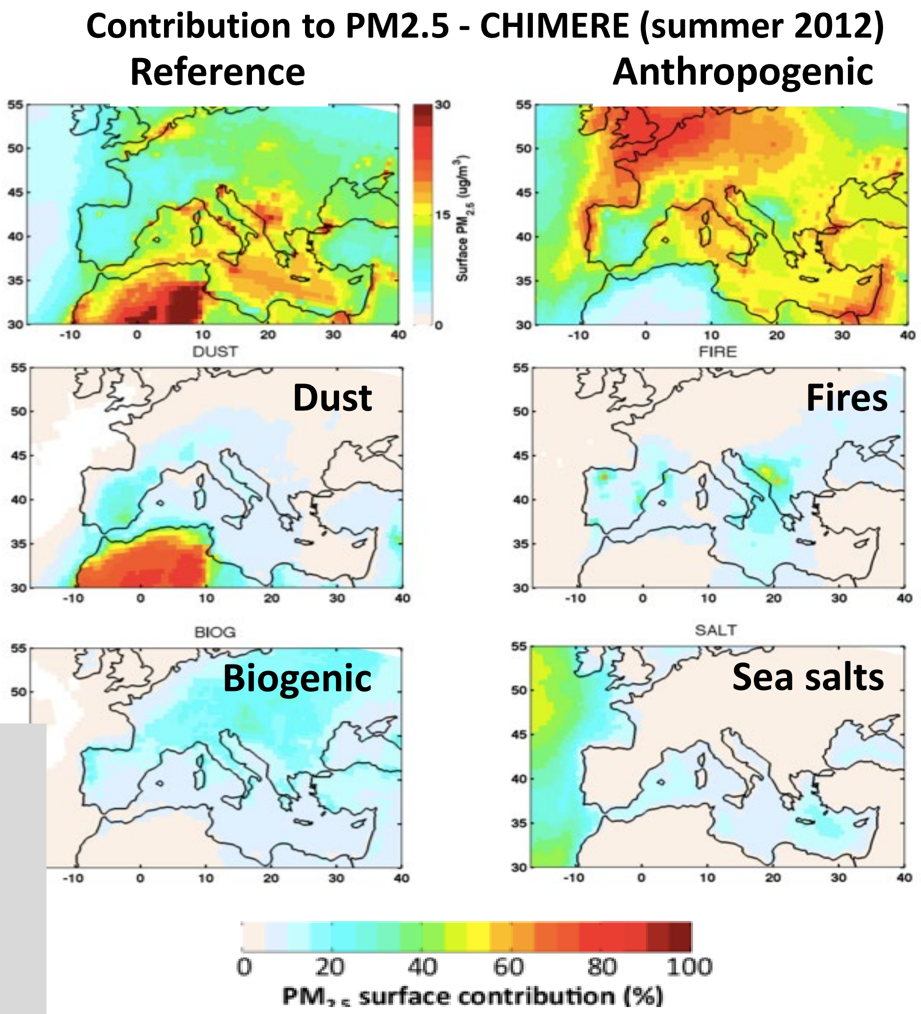


Résolution 1km, horaire

(Turquety et al., 2014, 2019)

Regional modeling of wildfires' impact on pollution budgets





- Biomass burning emissions
  - APIFLAME (Turquety et al., 2014, 2020)
  - Uncertainty estimated to 70-100% on emissions, 30-50% on simulated plumes
  - Impact of plume height depending on event (e.g. Menut et al., 2018)

(Rea et al., 2015)

Project PRIMEQUAL 2011-2013; Chantier Méditerranée INSU (CHARMEX)
Collaboration INERIS, CEREA, LA, LATMOS, LOA, LISA

Example: Impact of the NSW fires in 2013 on air quality in eastern Australia

(Rea et al., Atmos. Env., 2016)
collab. University of Wollongong NSW (Clare Paton-Walsh)

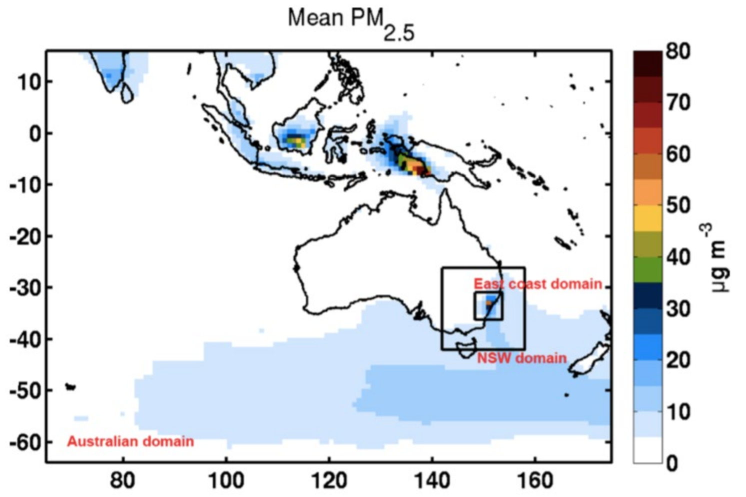
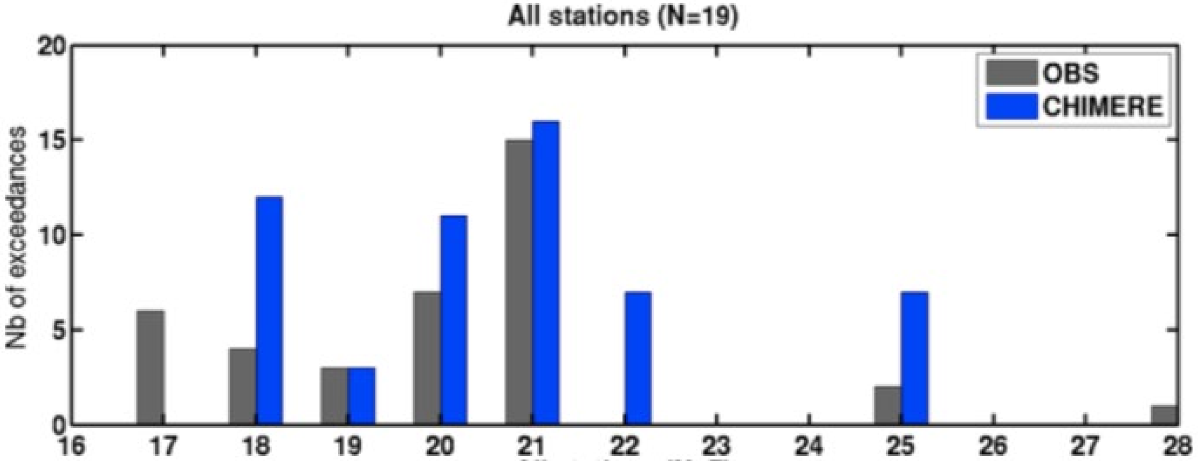


Figure 3: *Localization of OEH air quality monitoring stations in inner Sydney.*



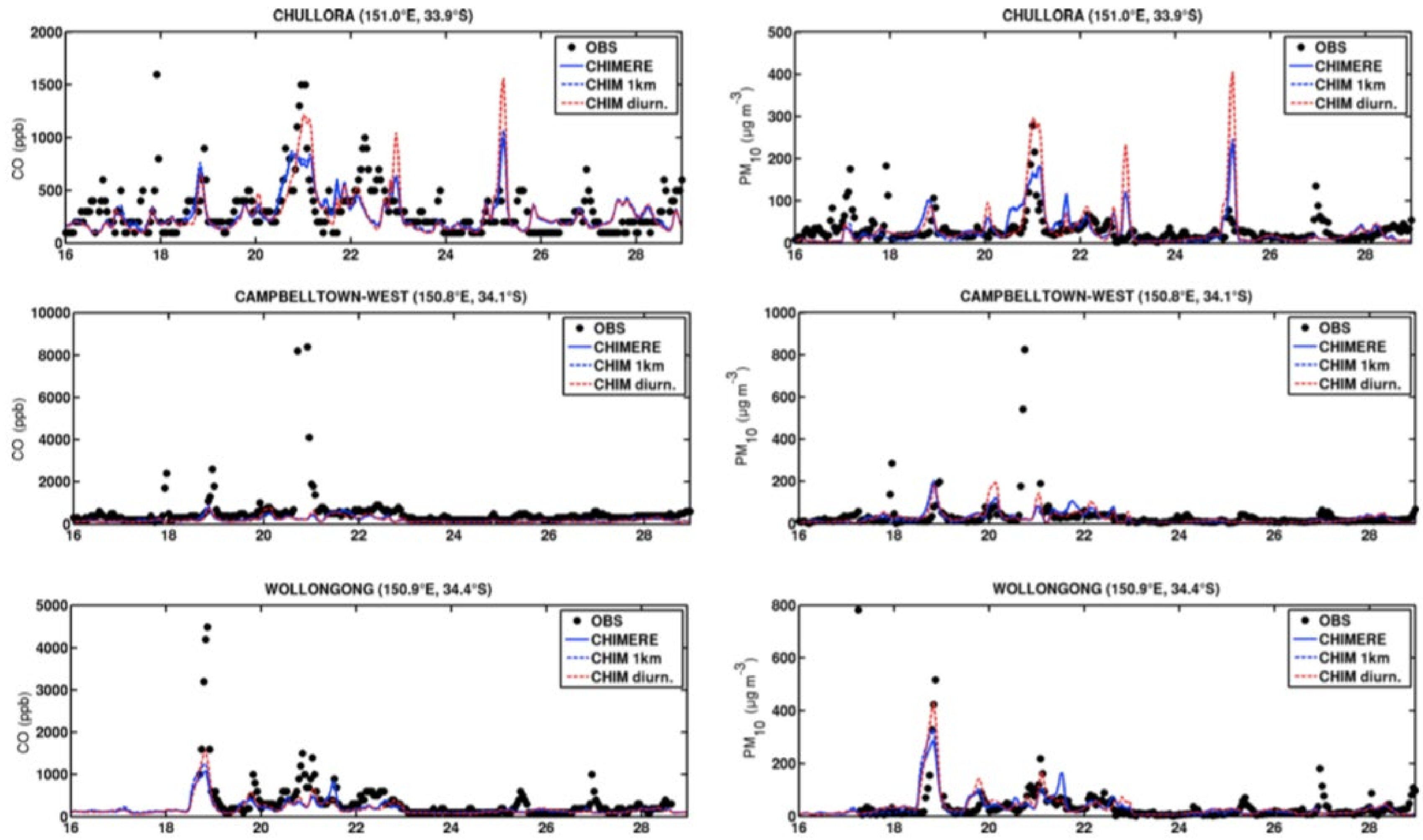
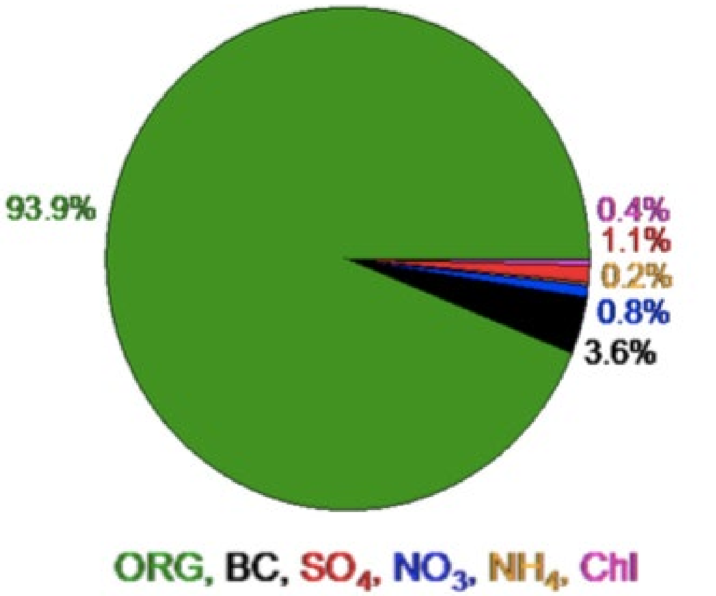


Figure 4: *Time series of CO and PM_{10} surface concentrations for Chullora (Sydney east), Campbelltown-West and Wollongong stations, for observations (black dots) and the CHIMERE model co-located (blue line). Results for two other CHIMERE simulations are also shown: in dashed blue, with all the fire emissions injected homogeneously under 1 km, and in dashed red with a diurnal profile for the amount of fire emissions.*

- Satellite observations of vertical distribution
  - most < 1km;
  - Low impact on results in this case
- Strong diurnal cycle
- Difficulty simulating strongest peaks at this resolution
- Transport error + BL dynamics

Chemical production of secondary organic aerosols (SOA)

Aerosols in biomass burning plumes



LI Kleinman and AJ Sedlacek, January 2016,
BBOP Final Campaign Report

Organic aerosols = primary OA (POA) + SOA

↑ Oxydation

- Volatile Organic Compounds
- Semi-volatile + intermediate volatility

- Large fraction of non-identified VOCs in emissions inventory

⇒ gas-particle partitioning and oxidation of S-IVOCs (e.g. in CHIMERE @ LISA/IPSL for Russian fires 2010 Konovalov et al., Atm. Chem. Phys., 2015)

Chemical production of secondary organic aerosols (SOA)

Extension of the SOA scheme of Couvidat et al. (2012)

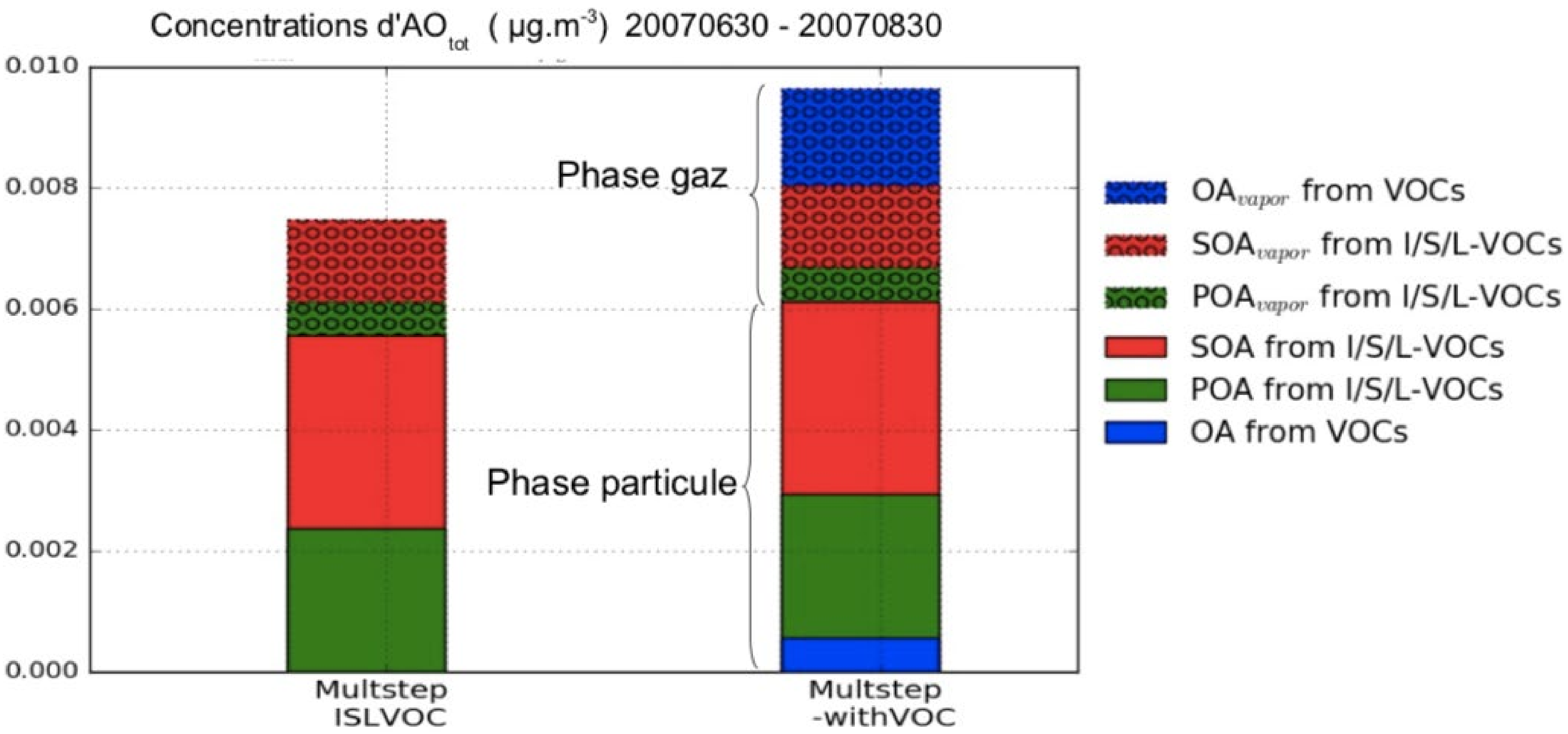
→ **H²Oaro** *(Majdi et al., ACP, 2019)*

Thesis Marwa Majdi (2018);

Collab. CEREA, INERIS, LMD

Additional gaseous precursors
(Majdi et al., 2019a, Majdi et al., 2019b)

Contributions of precursors to SOA formation – Fires in Greece 2007

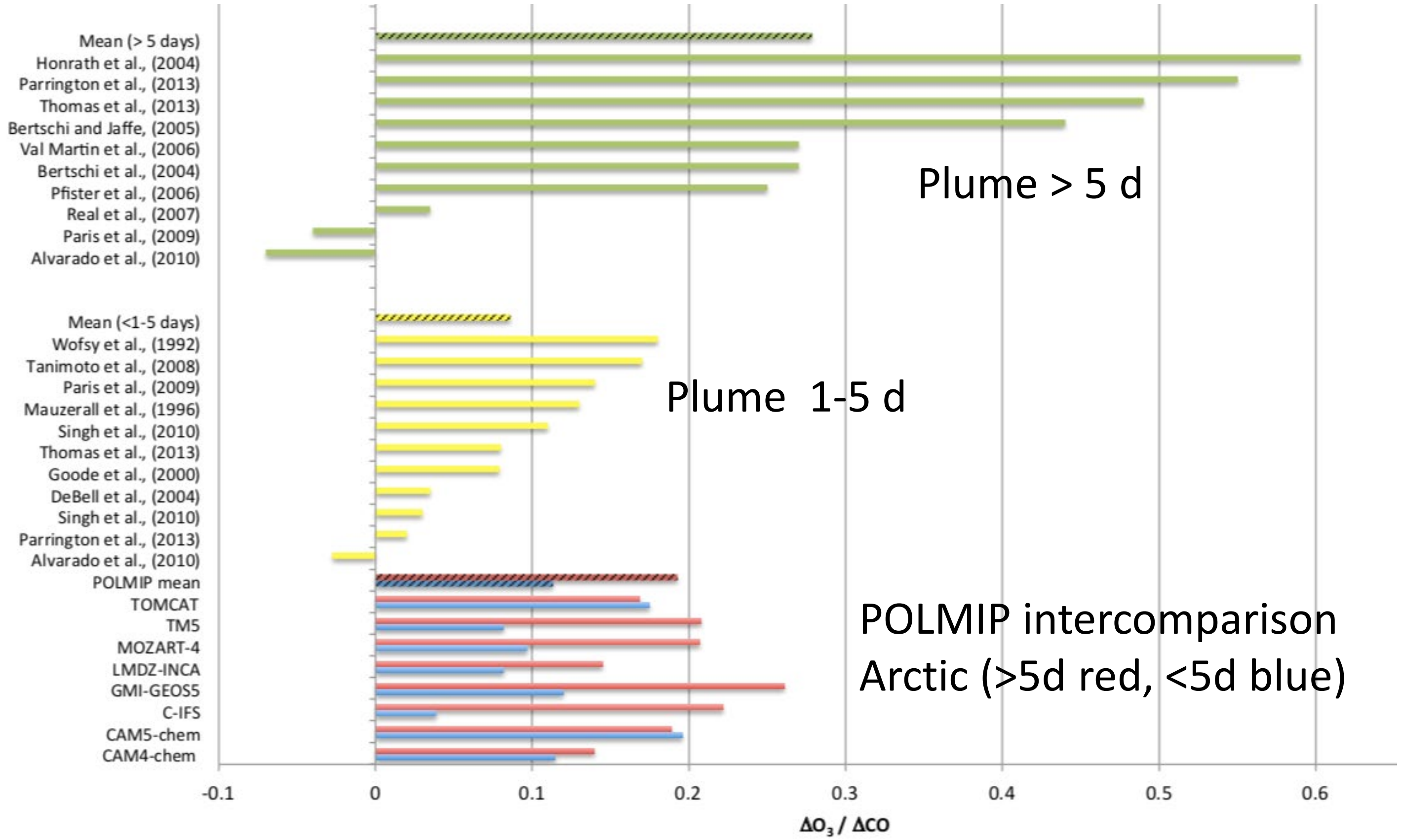


- Concentrations of OA formed from VOCs = 10 x lower than from S-IVOCs
- 70% of OA from VOCs are in gas phase

Chemical production of ozone – O3

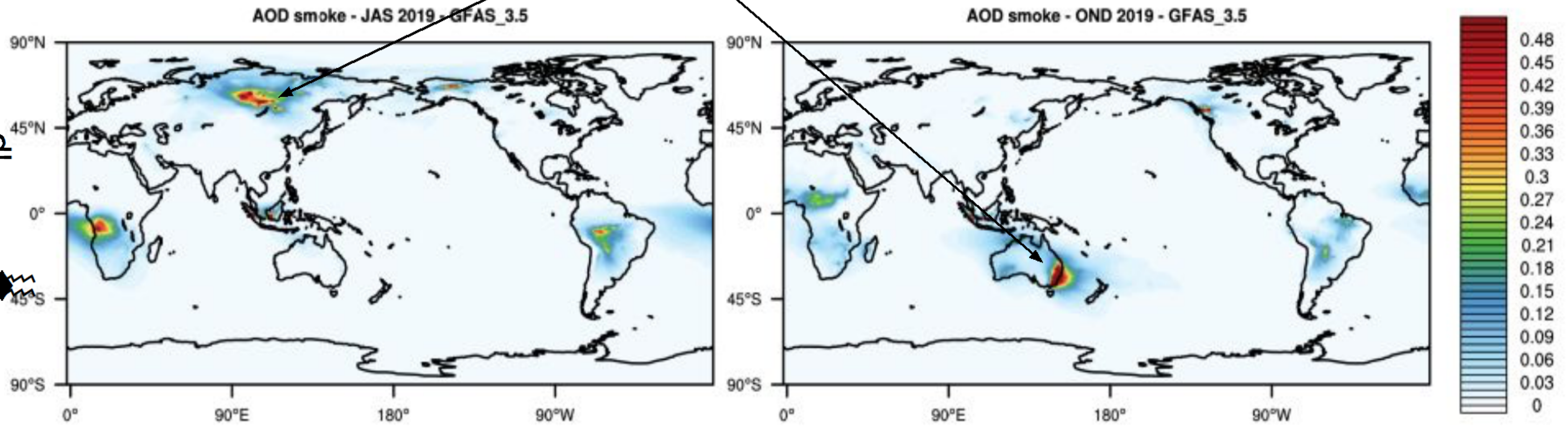
- VOCs, CO, NO_X : precursors of ozone formation
- Strong non-linearity depending on NOX, VOCs (chemical regime) and radiation

- Large O3 production during transport
- Depends on combustion efficiency (NOX)
- Photolysis rate vary with aerosol loading
- Strong sensitivity to PAN concentrations, vertical transport

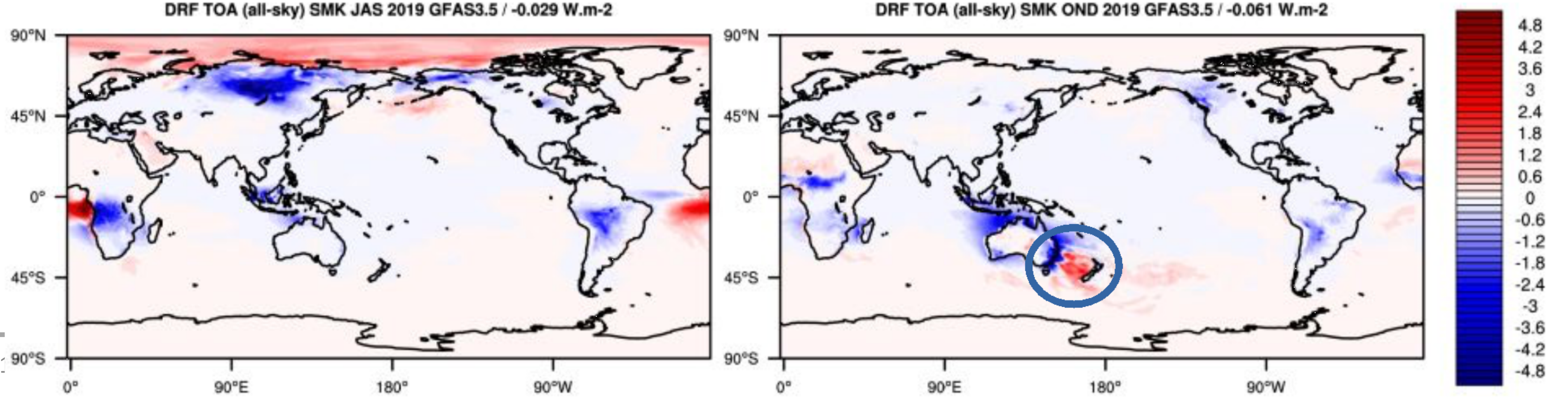


ΔO3/ΔCO

(Arnold et al., 2015)



AOD smoke - JAS 2019 - GFAS_3.5
AOD smoke - OND 2019 - GFAS_3.5
90°N
45°N
0°
45°S
90°S
0°
90°E
180°
90°W
0.48
0.45
0.42
0.39
0.36
0.33
0.3
0.27
0.24
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0



DRF TOA (all-sky) SMK JAS 2019 GFAS3.5 / -0.029 W.m-2
DRF TOA (all-sky) SMK OND 2019 GFAS3.5 / -0.061 W.m-2
90°N
45°N
0°
45°S
90°S
0°
90°E
180°
90°W
4.8
4.2
3.6
3
2.4
1.8
1.2
0.6
0
-0.6
-1.2
-1.8
-2.4
-3
-3.6
-4.2
-4.8

Conclusions

- **Near-real time observation available by satellite**
- **Emission factors**: invetories include more and more chemical species (> 120)

  BUT strong variability, under-representation of intense fires, representativity for regional models?

- **Calculation of emissions of trace gases and aerosols**

uncertainties ~ 100% : strong variability, lack of observation, characterisitcs of fuel often missing, etc.

- **Long range transport** tracked by satellite missions
- **Simulation of peaks at** +/- 40% for AOD, +/- 20% for CO et +/- 1 day

- **Chemical evolution**: models include more processes, e.g. for SOA but many approximations

- Radiative impact significant at regional and global scales (Péré et al., 2015; Mallet et al., 2019)
- Uncertainty related to the mixing of aerosols *(Péré et al., 2010; Majdi et al., Atm. Env., 2019)*

Many other questions

- Small scale (sub-grid scale): strong consequences for chemical regimes => for the formation of O3 and SOA (Mari et al., 2013)

- Pyroconvection
  Thermal plume schemes but missing surface constrain on the intensity of the fires

→ Towards a better constrain from satellite?

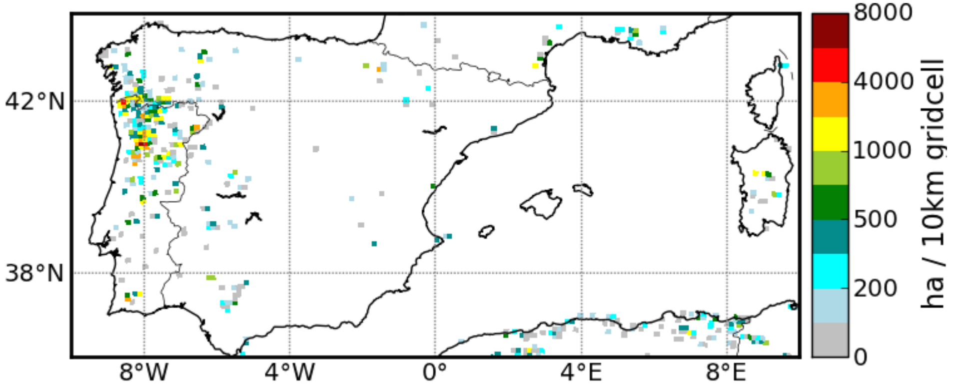
- Long-range transport & transport schemes in CTMs (often too diffusive)

- Need to better account for surface – atmosphere interactions in regional modeling
  In the IPSL climate model: fire scheme in ORCHIDEE (Yue et al. GMD, 2014)

- Urban-wildland interfaces

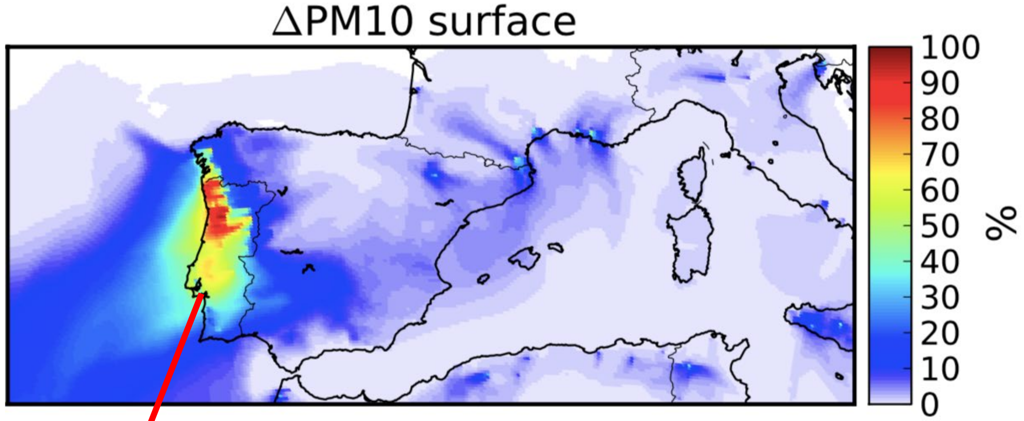
Exemple: feux au Portugal - Août 2016

Surface brulée observée par satellite (MODIS) – juin-juillet-aout 2016



Détection à 500m, grille de 10km

Contribution relative des feux aux PM en surface (moyenne sur l'été)



Observations en surface à Lisbonne:
PM10 > 200 µg/m^3 pendant 5 jours; jusqu'à 500 µg/m3
(le seuil alerte réglementaire est à 80 µg/m^3)

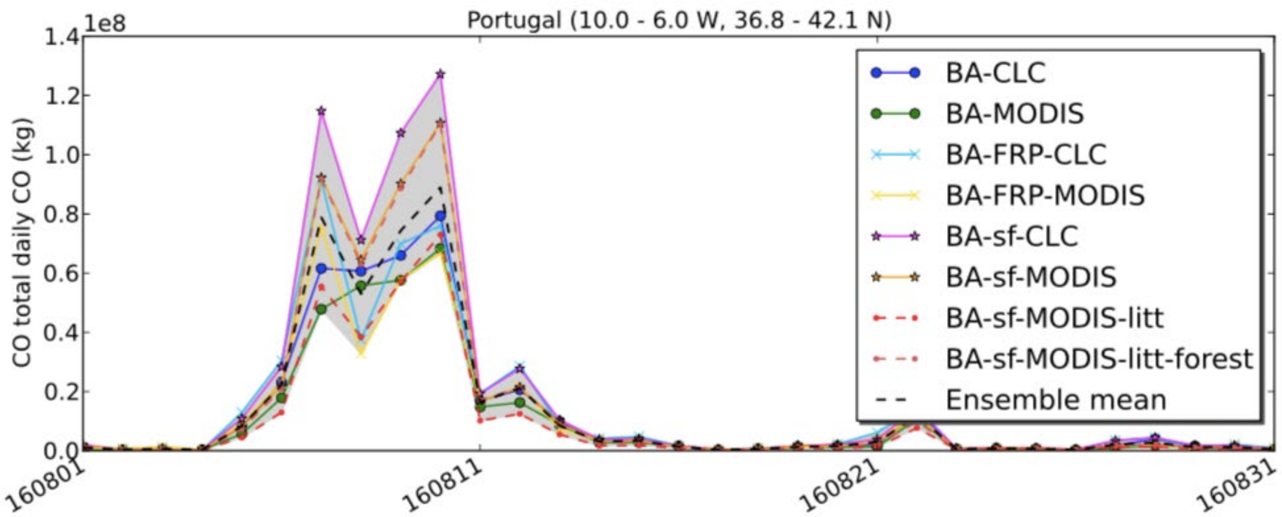
A multi-scale chemistry-transport model for atmospheric composition analysis and forecast

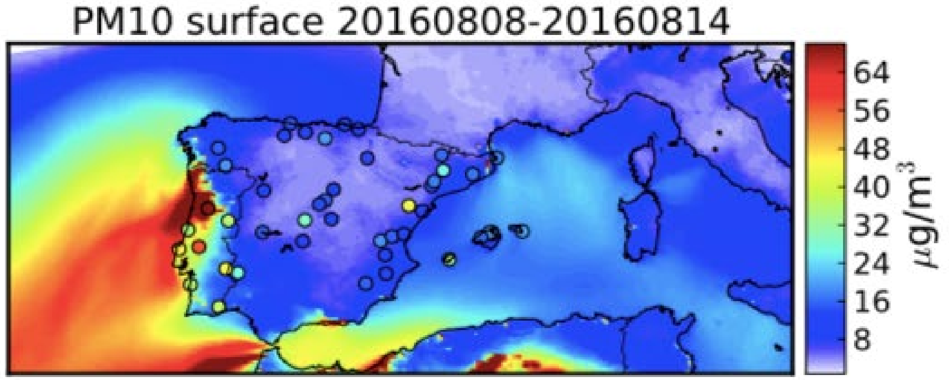
(Turquety et al., Geosc. Model Devel., 2020)

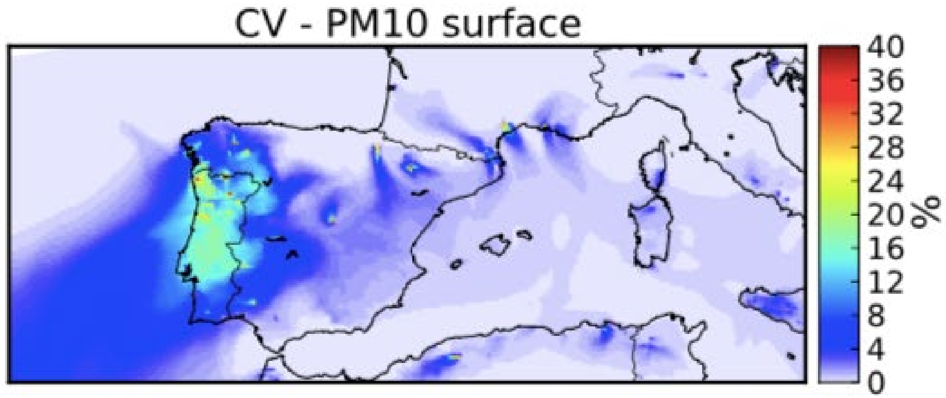
Exemple: feux au Portugal - Août 2016

Dispersion des émissions en fonction des choix de modélisation : ~ 75%

Dispersion des concentration de PM10 simulées en surface : ~30% au-dessus des zones de feux, ~10% dans le vent







Incertitude:

- Surface brûlée
- Type de végétation

Et aussi:

- Densité de biomasse
- Efficacité combustion
- Facteur d'émission

(Turquety et al., Geosc. Model Devel., 2020)