FOREST FIRES AND AGRICULTURAL BURNING: EMISSIONS AND EFFECTS

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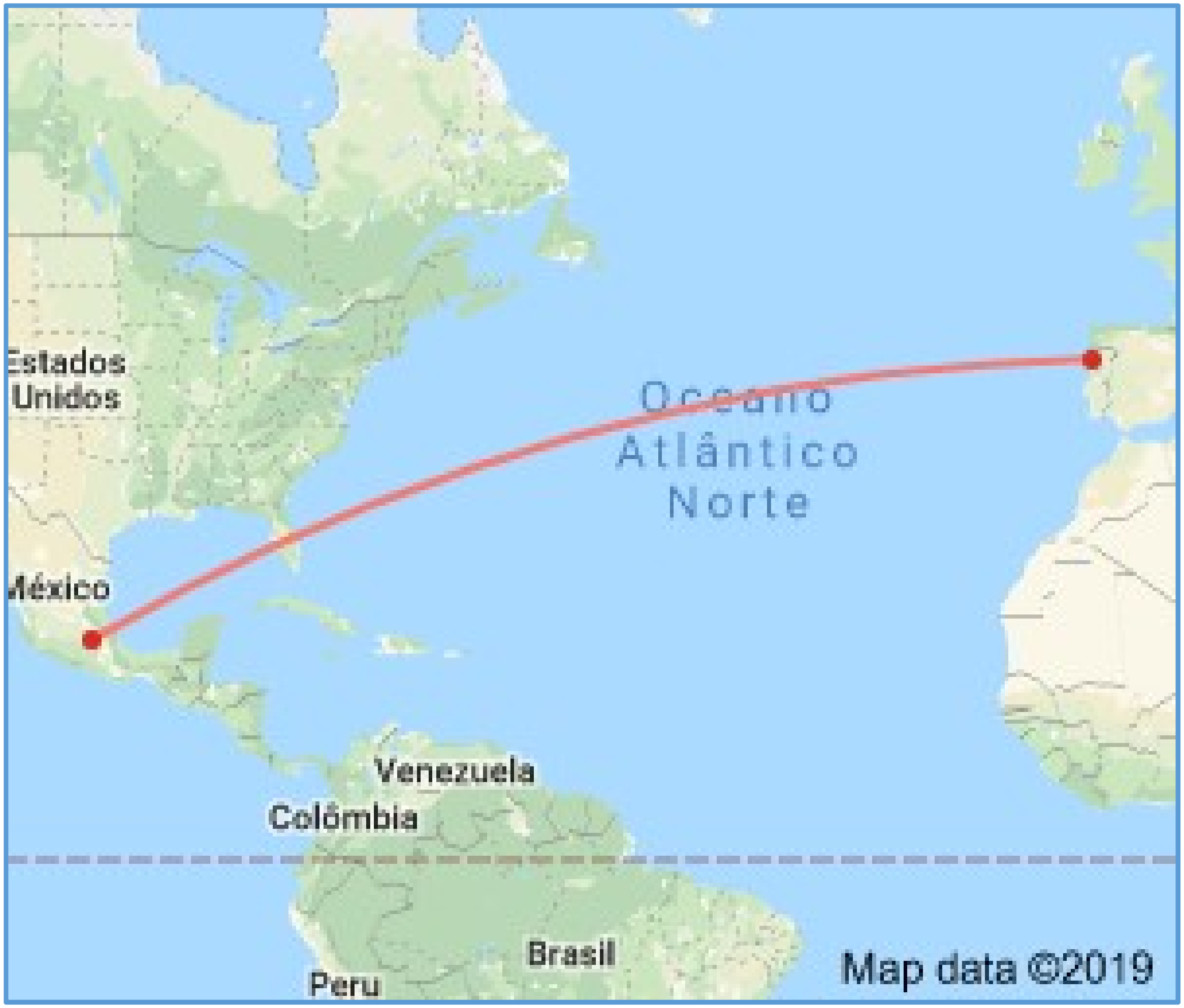
16 Aug. 2019

CESAM Centre for Environmental and Marine Studies
University of Aveiro


Estados
Unidos
México
Oceano
Atlântico
Norte
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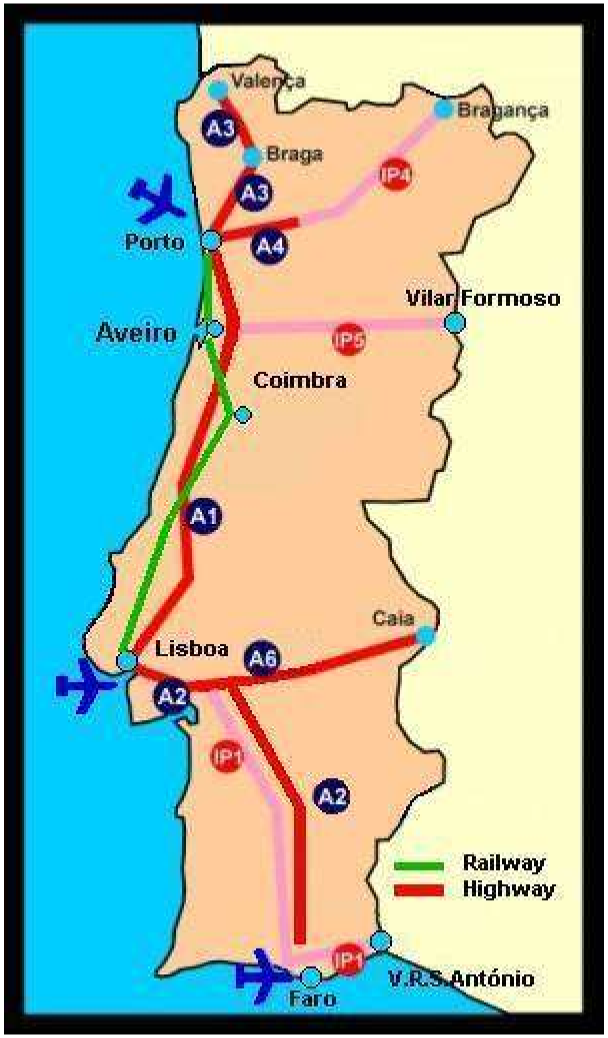
Colômbia
Brasil
Peru
Map data ©2019

8636 km



Aveiro

Ovos moles

moliceiros

universidade de aveiro

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Medio Ambiente

Biología

Química

Geociencias

Física

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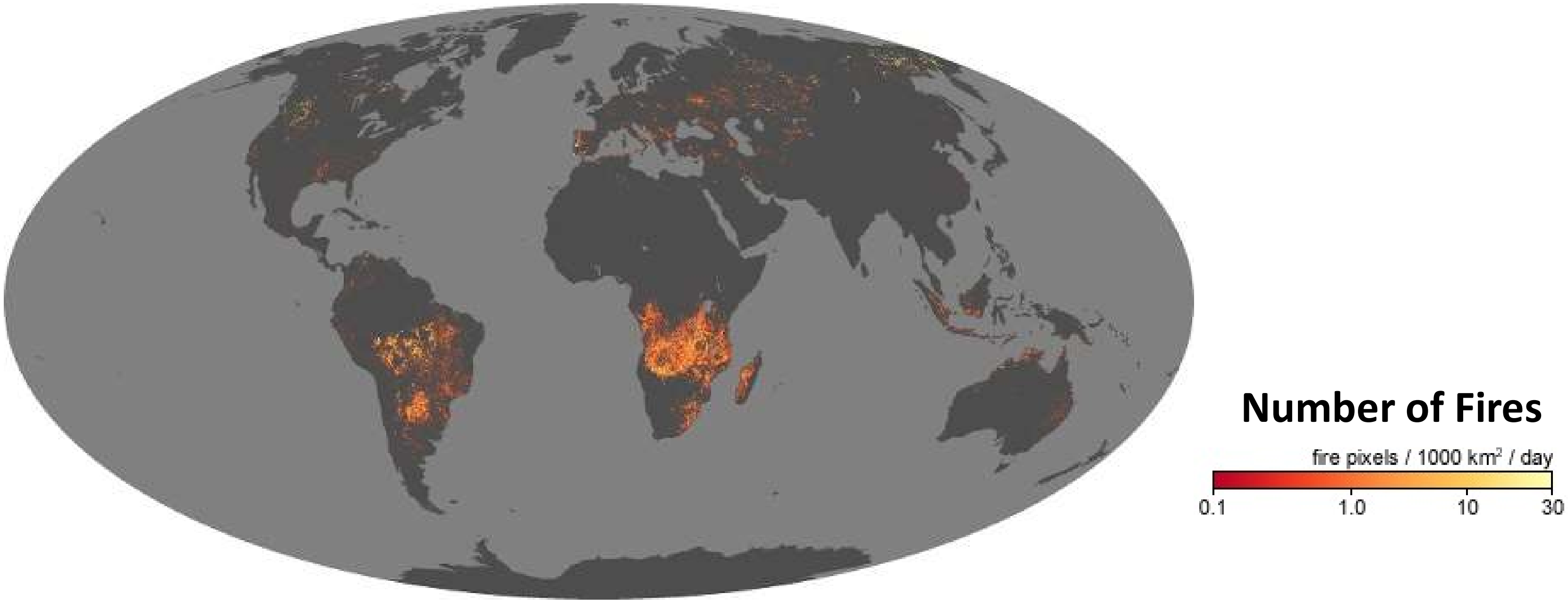
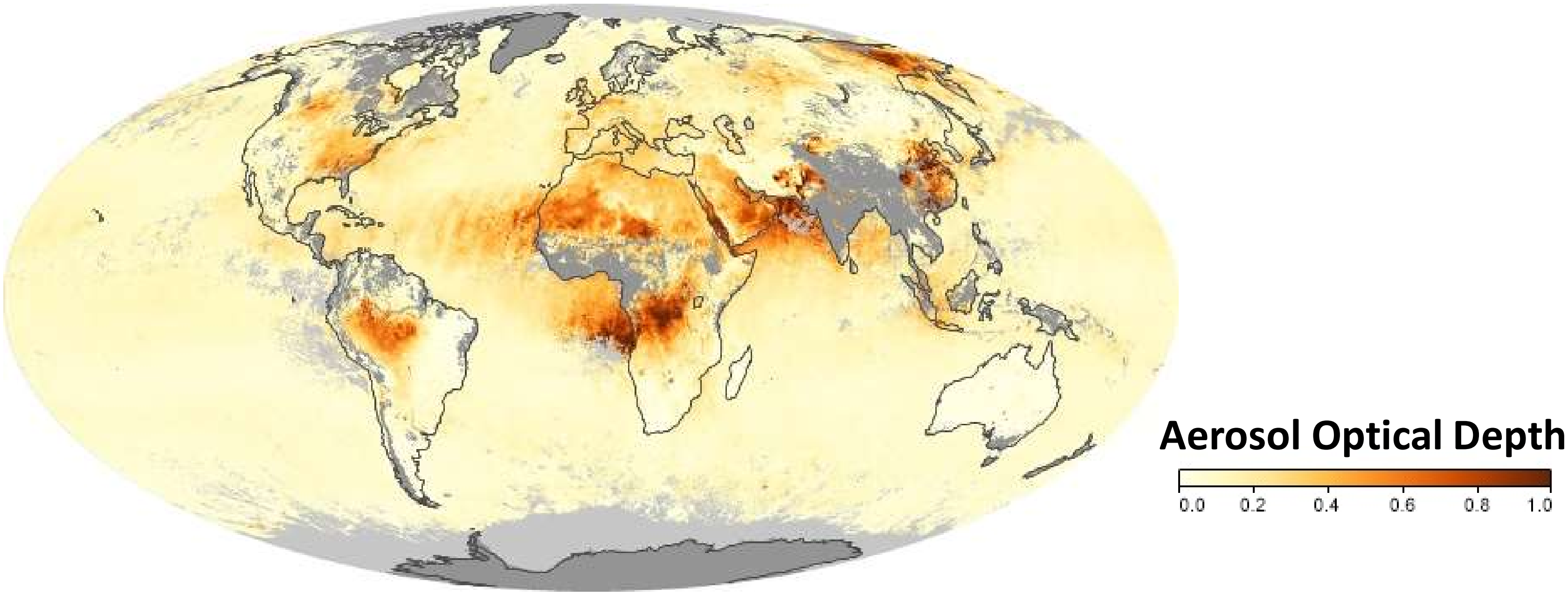
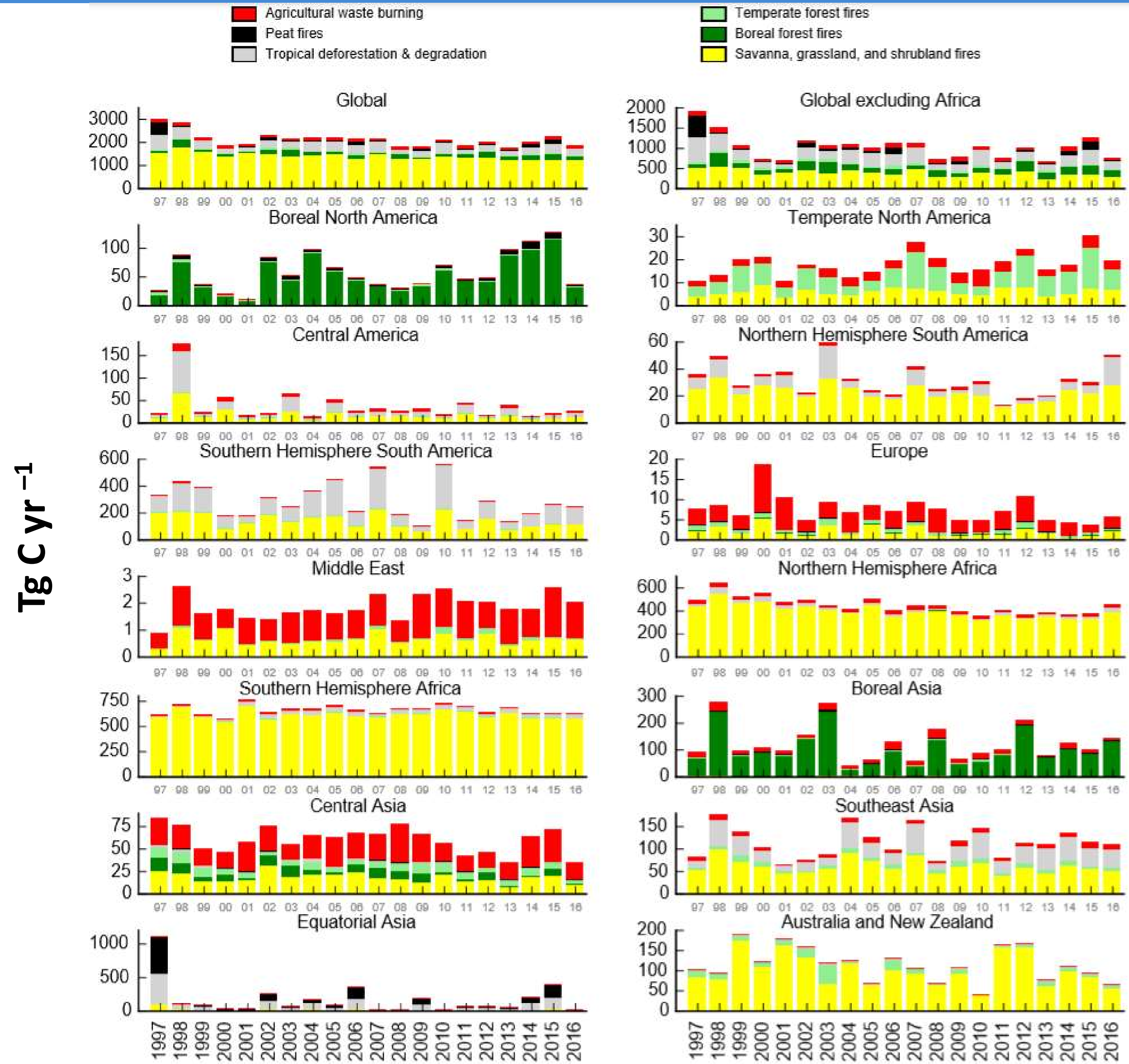
Wildfires: a GLOBAL issue





https://earthobservatory.nasa.gov/global-maps/MOD14A1_M_FIRE/MODAL2_M_AER_OD

Annual fire carbon emissions for various regions and sources



Global fire emission patterns for 1997–2016

(van der Werf et al., 2017. Earth Syst. Sci. Data)

Global mean carbon emissions

Carbon emissions from fires (Tg C yr^{-1})			Contribution of different fire categories to total carbon emissions (%)					
Mean	Min	Max	Savanna	Boreal forest	Temperate forest	Tropical forest	Peat	Agriculture
2160	**1773**	**3032**	65.3	7.4	2.3	15.1	3.7	6.3

van der Werf et al., 2017.
Earth Syst. Sci. Data

- Represent ~30-50% of the fossil fuel source
- Account for ~ 2/3 of the variability in CO_2 growth rate
- 20-60% of the global organic carbon aerosol (particulate) emission, 30% of the black carbon (soot) emission
- Potential for climate feedbacks
- Impacts on human health

Health Effects of Wildfire Smoke - Recent Reviews & Case Studies

Environmental Toxicology and Pharmacology 55 (2017) 186–195

Contents lists available at ScienceDirect

Environmental Toxicology and Pharmacology

journal homepage: www.elsevier.com/locate/etap

ELSEVIER

Review or Mini-review

Wildfire smoke exposure and human health: Significant gaps in research for a grow

Carolyı

a California
b Lovelace R
c Departmen

Environmental Research 136 (2015) 120–132

Contents lists available at ScienceDirect

Environmental Research

ELSEVIER

Review

A system non-occu

Jia C. Liu a,*,

a School of Forestry
b Center for Perinat

Science of the Total Environment 624 (2018) 586–595

Contents lists available at ScienceDirect

Science of the Total Environment

ELSEVIER

Wildland fire smc

Wayne E. Cascio *

National Health and Environmental Effe

Environmental Research 150 (2016) 227–235

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

ELSEVIER

Differential respirator California wildfires: A

Colleen E. Reid a,*,1, Michael John R. Balmes a,d

a Environmental Health Sciences Division, Schoo
b Epidemiology Division, School of Public Health,
c Biostatistics Division, School of Public Health, U
d Department of Medicine, University of Californ

Johnston et al. Environmental Health 2014, 13:105
http://www.ehjournal.net/content/13/1/105

ENVIRONMENTAL HEALTH

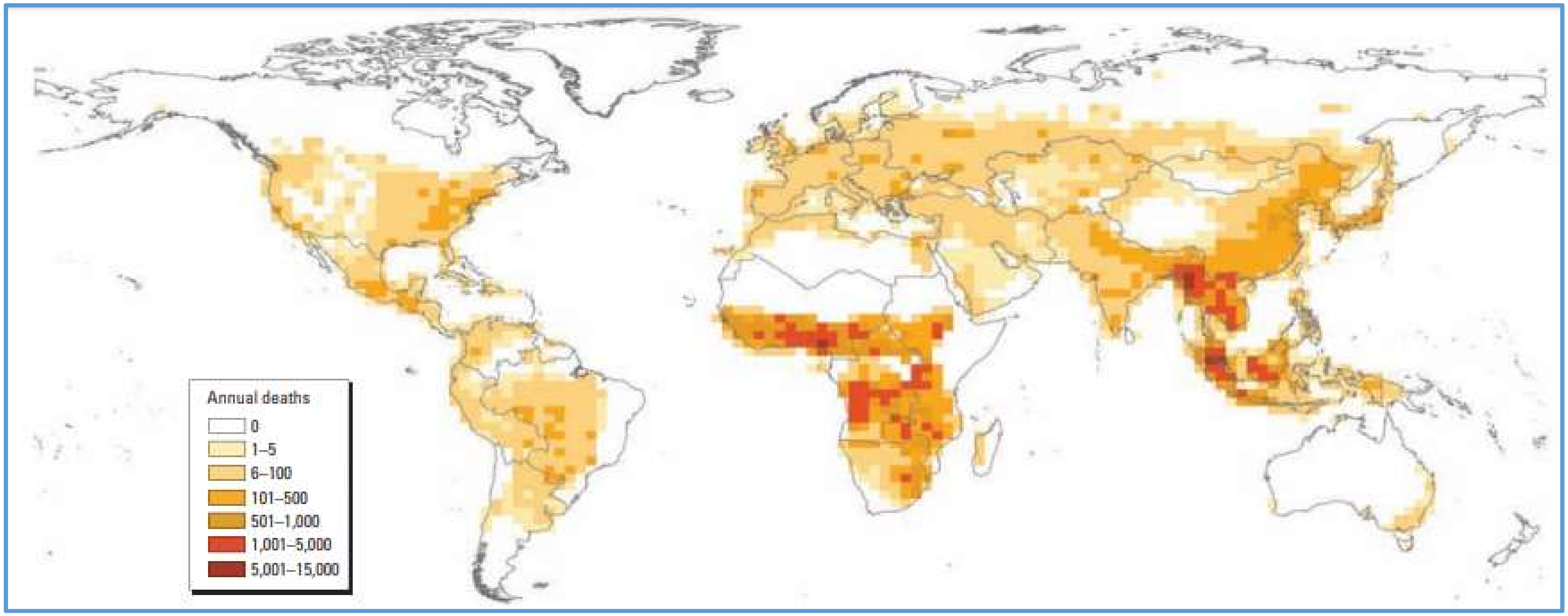
RESEARCH Open Access

Air pollution events from forest fires and emergency department attendances in Sydney, Australia 1996–2007: a case-crossover analysis

Fay H Johnston[1*], Stuart Purdie[2], Bin Jalaludin[3,4], Kara L Martin[5,6], Sarah B Henderson[7] and Geoffrey G Morgan[8,9]

Health Effects of Wildfire Smoke

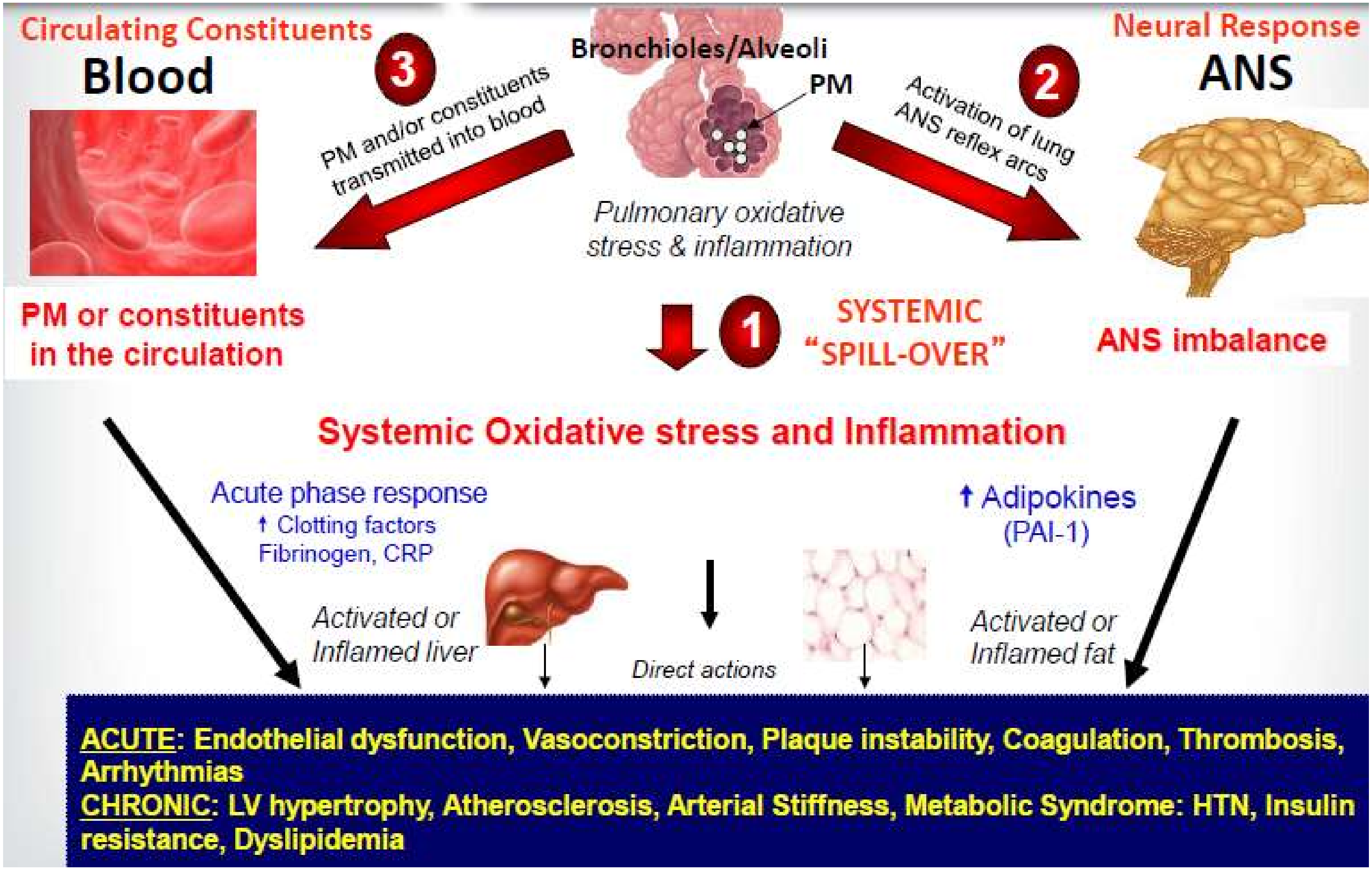
Global mortality attributable to landscape fires (forest, grass, and peat fires)



The average mortality attributable to landscape fires exposure was estimated to be 339,000 deaths annually

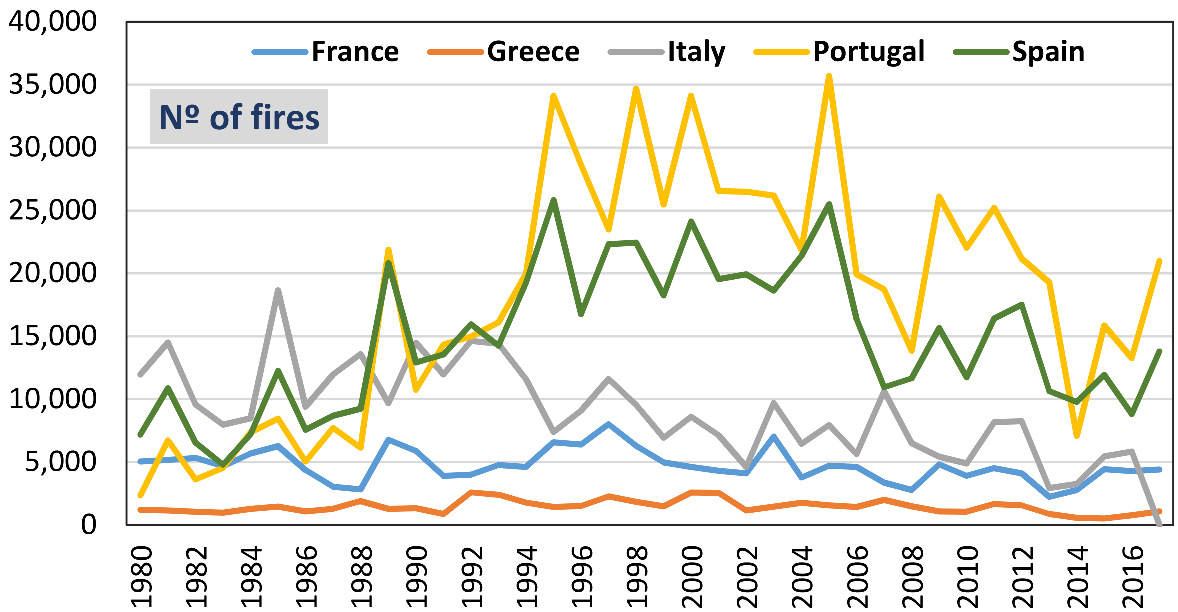
Johnston et al., 2012.
Environ. Health Persp.

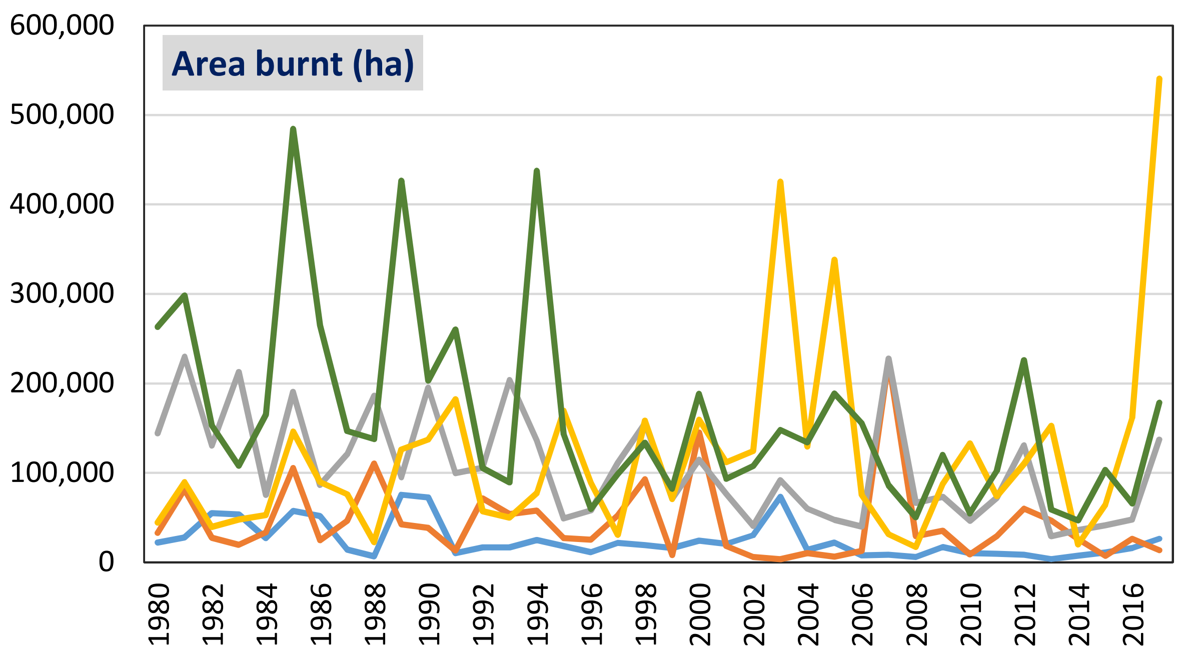
Health Effects of Inhaled PM



Cascio, 2016. ORD Tools & Resources Webinar, USEPA

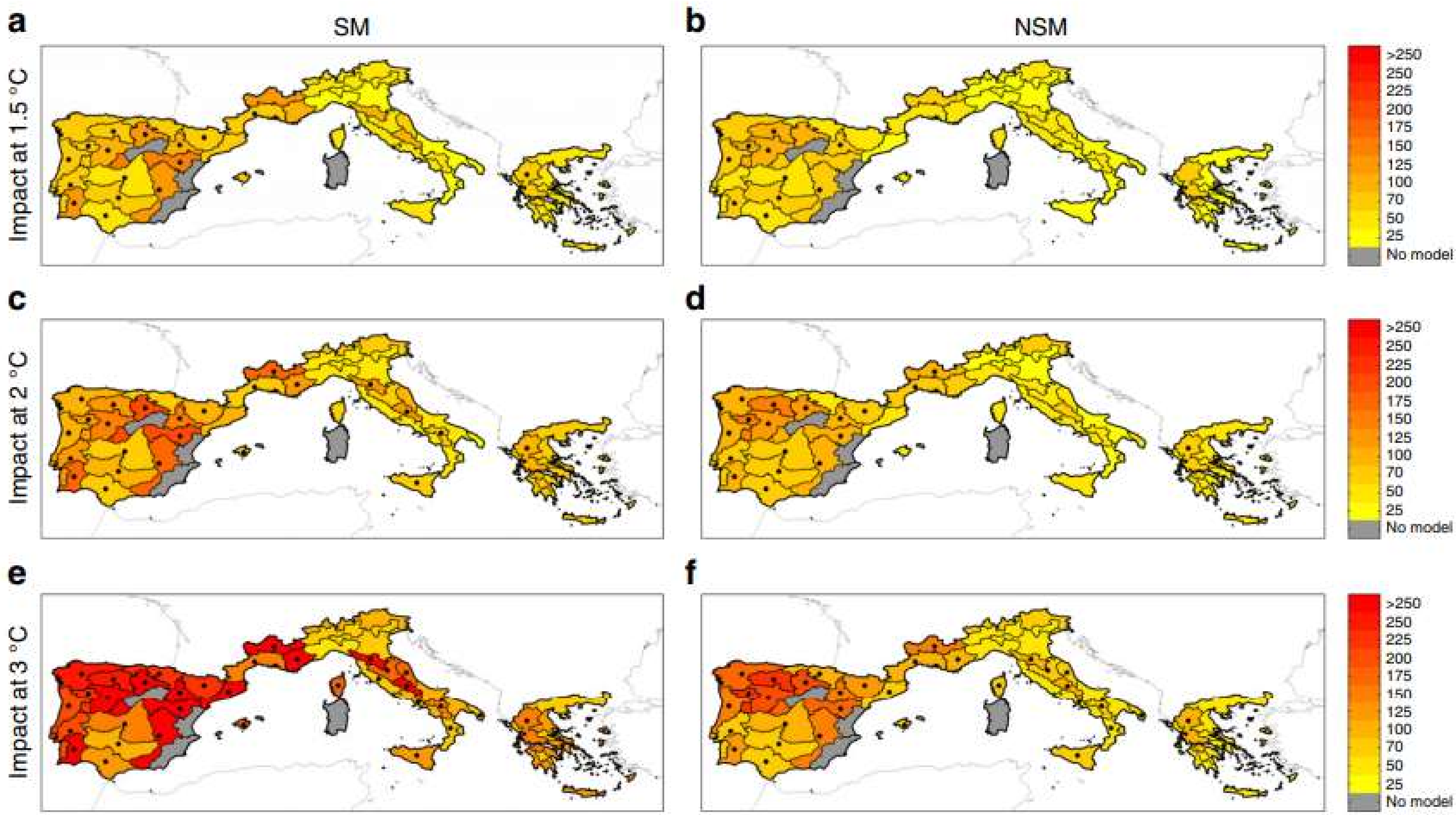
Wildfires in Southern Europe





Data Sources: Eurostat | UNECE | ITTO | FAO | National Entities - Joint Forest Sector Questionnaire (JFSQ)
Source: PORDATA

Wildfires under climate change scenarios



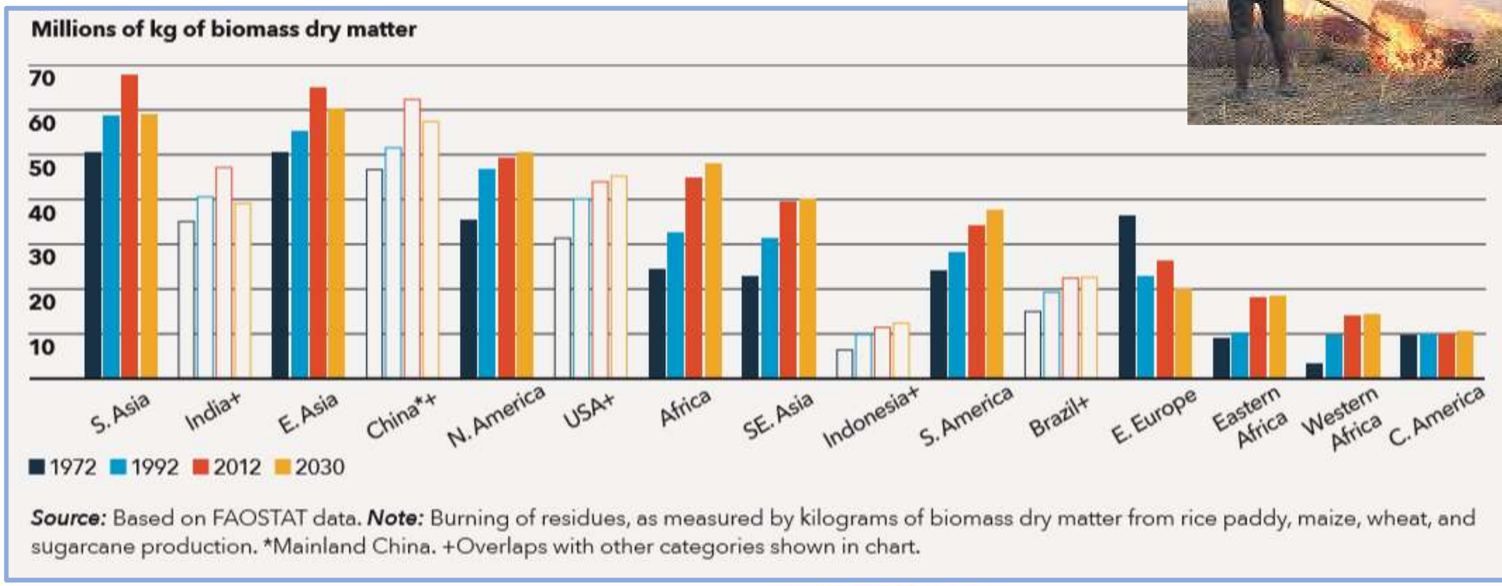
(Turco et al., 2018. Nature Communications)

Burned area changes (%) due to anthropogenic warming projected with (non)stationary climate-fire models

Agricultural burning

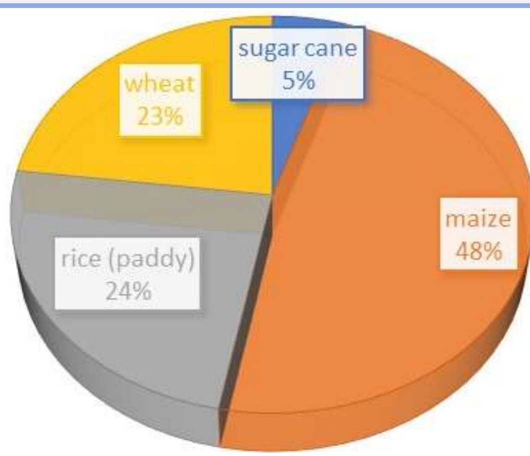
Crop burning is a widespread global practice

China and India are the top burners of crop residues



Source: Based on FAOSTAT data. ***Note:*** Burning of residues, as measured by kilograms of biomass dry matter from rice paddy, maize, wheat, and sugarcane production. *Mainland China. +Overlaps with other categories shown in chart.

Geography and Evolution of Crop Residue Burning

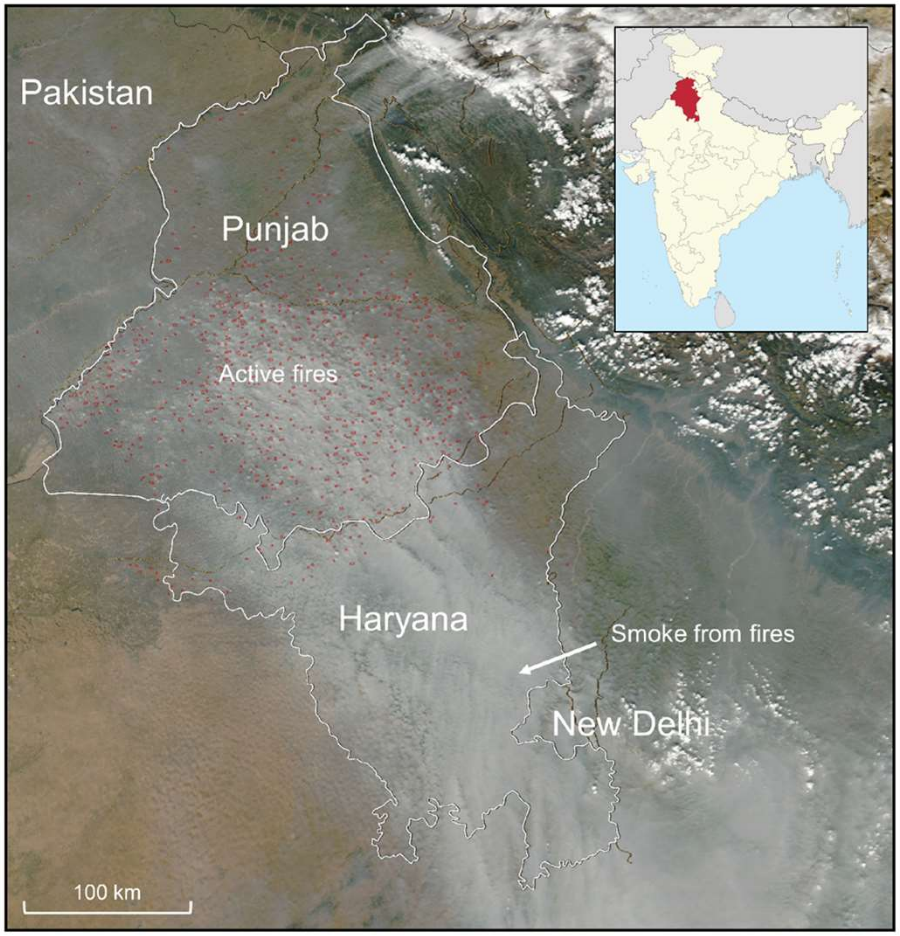


Burning Residues by Major Crop

Crop waste open burning in India

- Crop burning in India is concentrated in the northwest region
- When rice farmers burn their fields $PM_{2.5}$ concentrations in Delhi, the highly populated capital city located downwind of burning areas, spike to about 20 times beyond the WHO guideline
- Living in districts with air pollution from intense crop residue burning is associated with a 3-fold higher risk of acute respiratory infection
- The economic cost of exposure to air pollution from crop residue burning was estimated to be US$30 billion

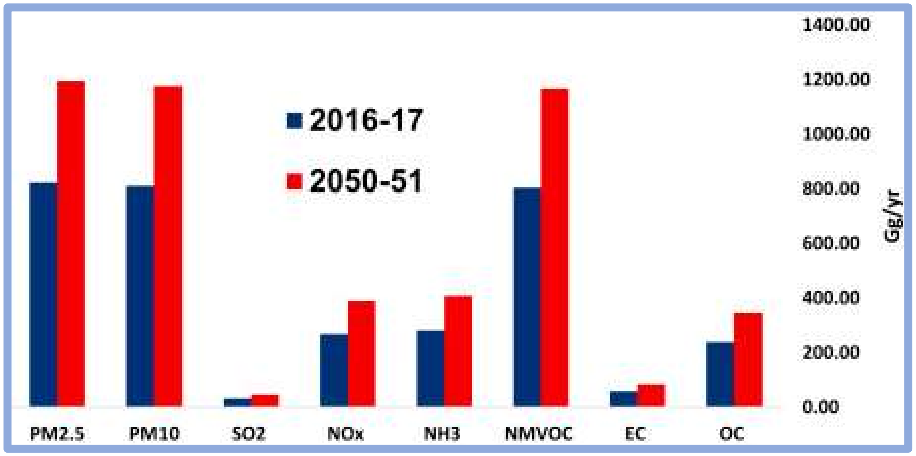
Typical crop residue burning episode

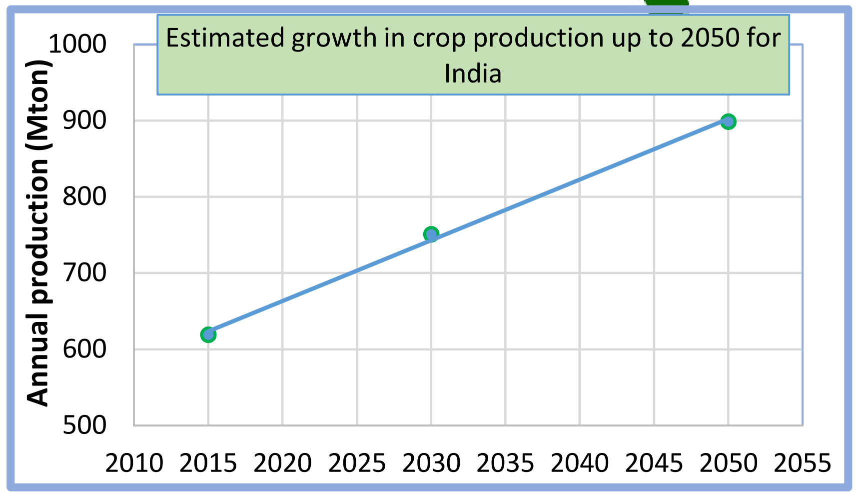


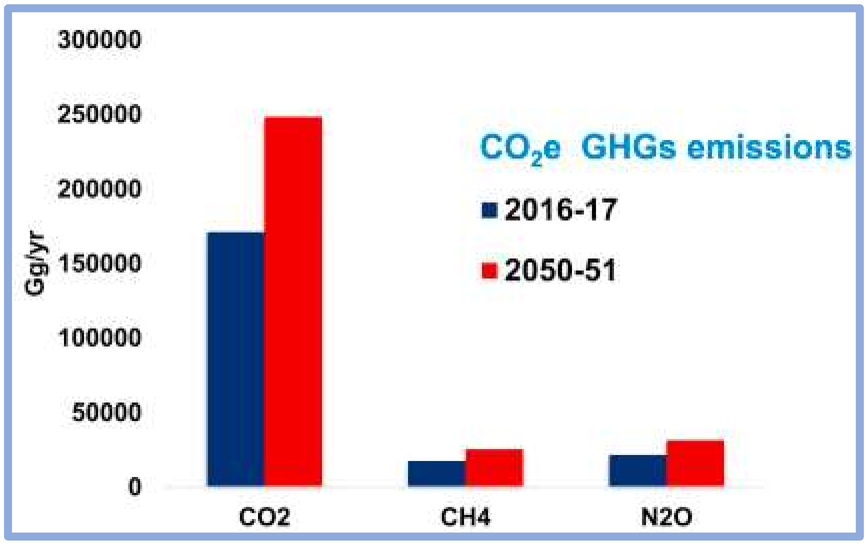
(Chakrabarti et al., 2019. Int. J. Epidem.)

Crop waste open burning in India

488 million tonnes of total crop residues were generated in India during 2017, and about 24% of which were burnt in agricultural fields





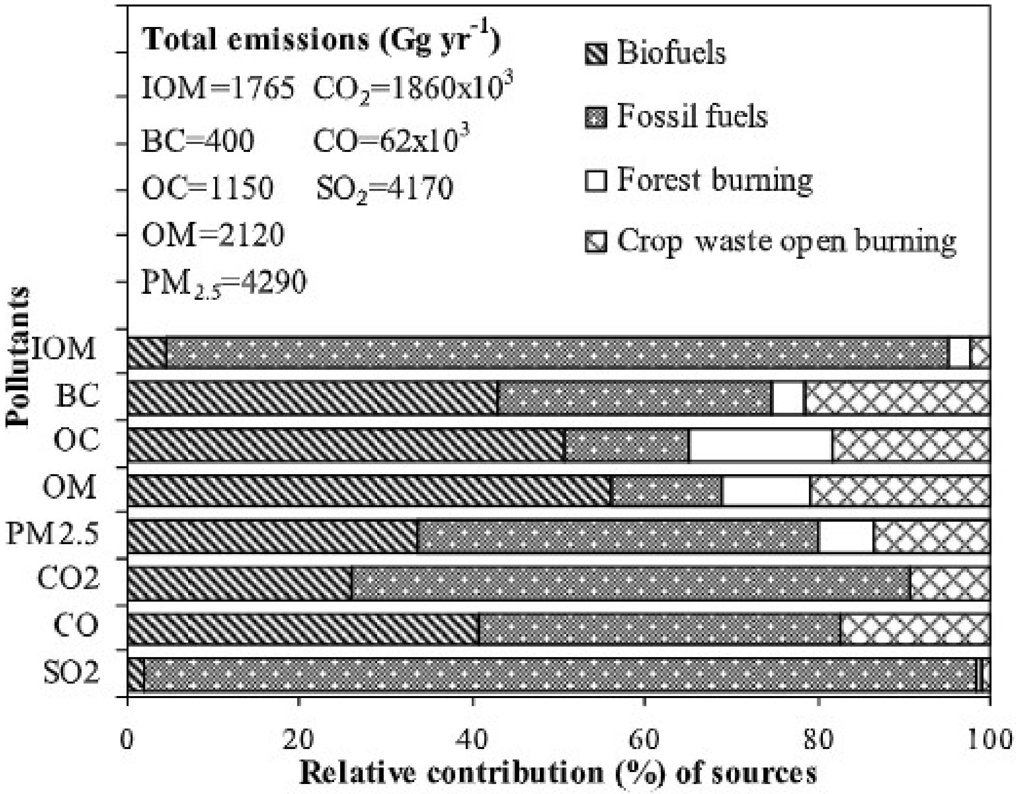


Ravindra et al., 2019. J. Clean. Prod.

- Population growth will lead to an increase in food demand, which will exert pressure on crop production and likely increase the agricultural crop residue
- In India, stubble burning emissions will almost double by 2050

Crop waste open burning in India

Source contributions to pollutant emissions



(Venkataraman et al., 2006. Global Biogeochem. Cycles)

Open burning accounts for:

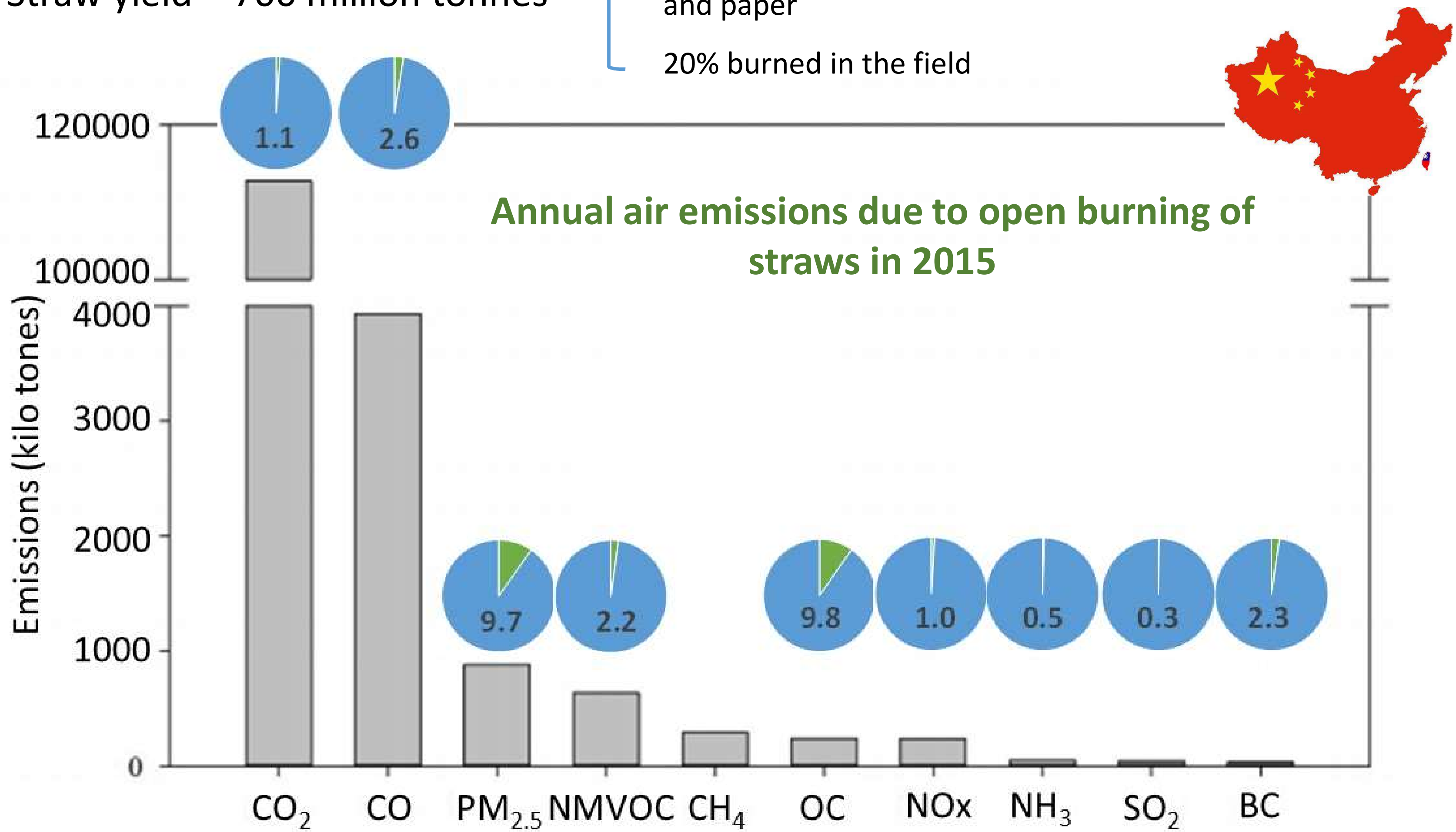
- about 25% of BC, organic matter, and CO emissions
- 9-13% of $PM_{2.5}$ and CO_2 emissions

Estimated uncertainty on BC and OC emissions ~ 300%

Crop burning in China

Straw yield ~ 700 million tonnes

- 80% returned to the soil, production of roughage, biomass fuels, biogas, straw-fired power/heat generation, straw board, and paper
- 20% burned in the field



(Ren et al., 2019. Sustainability)

$PM_{2.5}$ and OC emissions were equivalent to 10% each of the 2015 annual national anthropogenic emissions

Crop burning in China

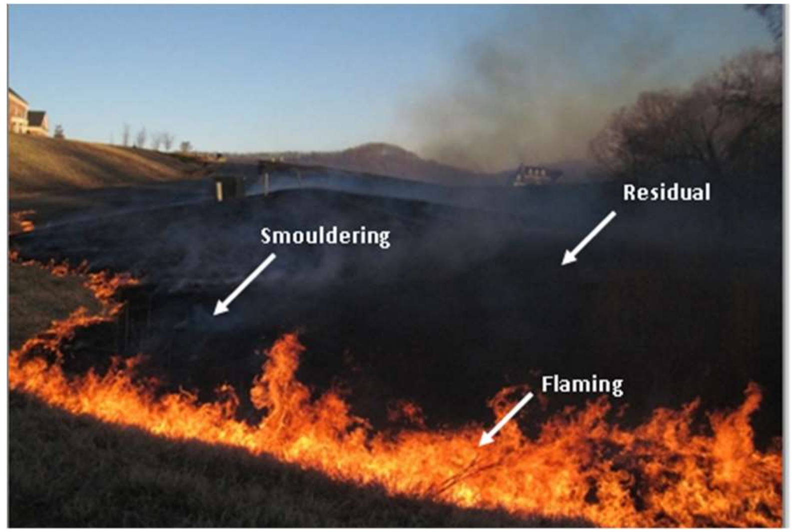
Comparison of annual average CO_2 emissions from crop burning

Reference	Tg/year
Yin et al. (2019)	35.3
Huang et al. (2012)	68.0
Yan et al. (2006)	185.0
Li et al. (2015)	2.5
van Der Werf et al. (2017)	38.2
Wiedinmyer et al. (2011)	38.1

- Estimates with uncertainties up to 700 %
- Large discrepancies between emission inventories

Estimating emissions: sources of UNCERTAINTIES

- **Area** consumed by wildfires or **proportion of crop residues** burned in fields



- **Combustion efficiency**
(depends on the stage of the fire)

- **Emission factors**

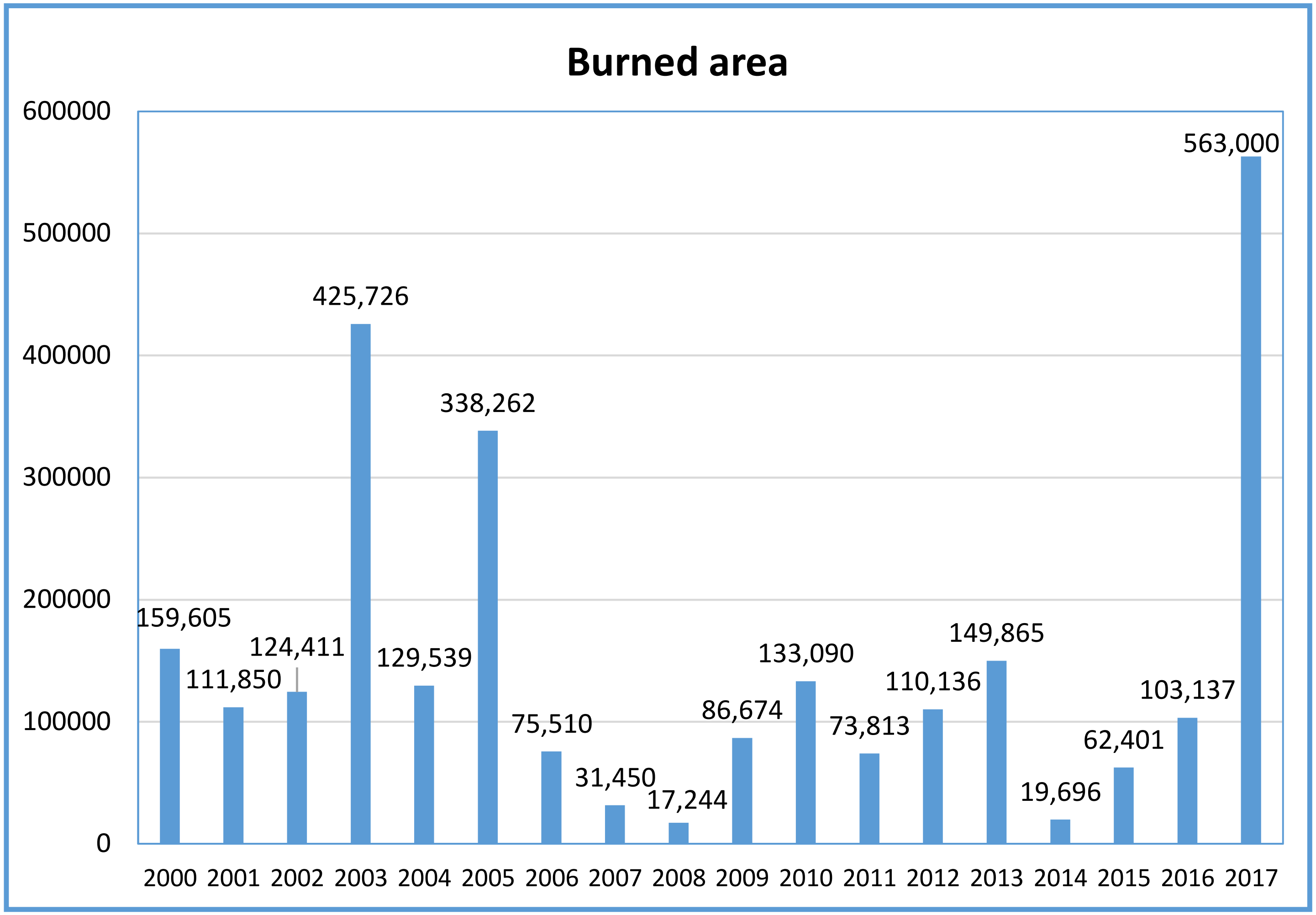
Laboratory sampling

(Missoula Fire Sciences Laboratory)

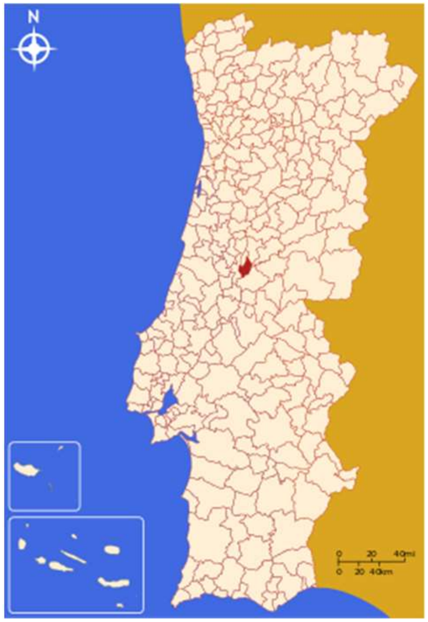
Field sampling

(especially prescribed and crop burning)

Wildfires in Portugal: a recurring tragedy



Wildfires in Portugal: a recurring tragedy



Pedrógão Grande, 17/06/2017

- 66 dead
- 253 injured
- 500 houses and 50 companies destroyed
- 53,000 ha burned
- estimated loss of EUR 500 million

Wildfires in Portugal: a recurring tragedy

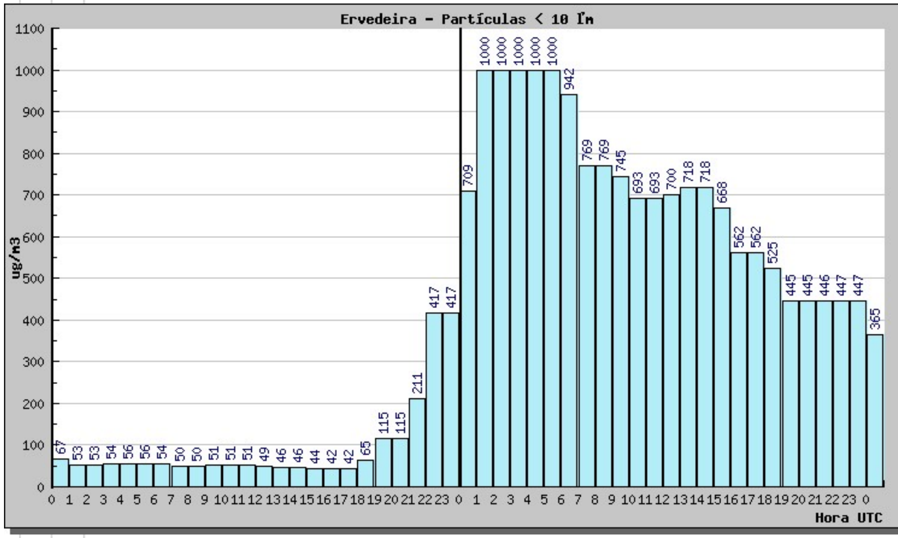
Vieira de Leiria, 15/10/2017

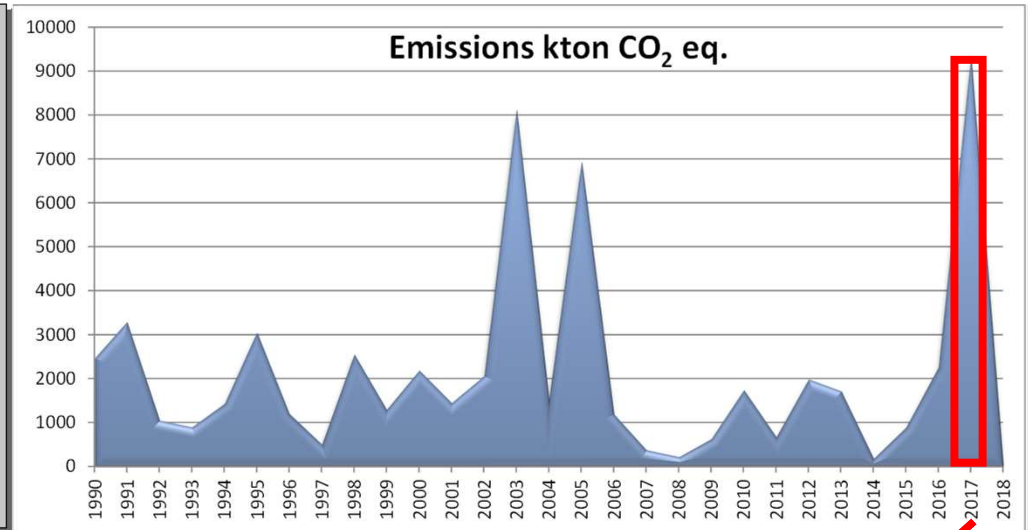
Braga, 16/10/2017

- 495 fires in a single day
- 49 dead
- 70 injured
- 1483 houses and 516 companies destroyed

Wildfires in Portugal: emissions and air quality

CO_2 eq. emissions from wildfires in Portugal





15-16/10/2017

15% of total annual GHG emissions

However….

- Emissions are probably underestimated and the associated uncertainties are very high

Wildfires in Portugal: a recurring tragedy

GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 15, NO. 4, PAGES 955-966, DECEMBER 2001

Emission of trace gases and aerosols from biomass burning

M. O. Andreae and P. Merlet
Biogeochemistry Department, Max Planck Institute for Chemistry, Mainz, Germany

Table 1. Emission Factors for Pyrogenic Species Emitted From Various Types of Biomass Burning[a]

Species	Savanna and Grassland[b]	Tropical Forest[c]	Extratropical Forest[d]	Biofuel Burning[e]	Charcoal Making[f]	Charcoal Burning[f]	Agricultural Residues[i]
CO_2	1613 ± 95	1580 ± 90	1569 ± 131	1550 ± 95	440	2611 ± 241	1515 ± 177
CO	65 ± 20	104 ± 20	107 ± 37	78 ± 31	70	200 ± 38	92 ± 84
CH_4	2.3 ± 0.9	6.8 ± 2.0	4.7 ± 1.9	6.1 ± 2.2	10.7	6.2 ± 3.3	2.7
Total nonmethane hydrocarbons	3.4 ± 1.0	8.1 ± 3.0	5.7 ± 4.6	7.3 ± 4.7	2.0	2.7 ± 1.9	(7.0)[h]
C_2H_2	0.29 ± 0.27	0.21–0.59	0.27 ± 0.09	0.51–0.90	0.04	0.05–0.13	(0.36)[h]
C_2H_4	0.79 ± 0.56	1.0–2.9	1.12 ± 0.55	1.8 ± 0.6	0.10	0.46 ± 0.33	(1.4)[h]
C_2H_6	0.32 ± 0.16	0.5–1.9	0.60 ± 0.15	1.2 ± 0.6	0.10	0.53 ± 0.48	(0.97)[h]
C_3H_4	0.022 ± 0.014	0.013	0.04–0.06	(0.024)[h]	–	(0.06)[h]	(0.032)[h]
C_3H_6	0.26 ± 0.14	0.55	0.59 ± 0.16	0.5–1.9	0.06	0.13–0.56	(1.0)[h]
C_3H_8	0.09 ± 0.03	0.15	0.25 ± 0.11	0.2–0.8	0.04	0.07–0.30	(0.52)[h]
1-butene	0.09 ± 0.06	0.13	0.09–0.16	0.1–0.5	–	0.02–0.20	(0.13)[h]
i-butene	0.030 ± 0.012	0.11	0.05–0.11	0.1–0.5	–	0.01–0.16	(0.08)[h]
trans-2-butene	0.024 ± 0.014	0.05	0.01–0.05	0.05–0.3	–	0.01–0.06	(0.04)[h]
cis-2-butene	0.021 ± 0.011	0.042	0.008–0.13	0.05–0.18	–	0.01–0.03	(0.05)[h]
Butadiene	0.07 ± 0.05		0.06–0.08	0.11–0.36	–	0.01–0.10	(0.09)[h]
n-butane	0.019 ± 0.09	0.041	0.069 ± 0.038	0.03–0.13	–	0.02–0.10	(0.06)[h]
i-butane	0.006 ± 0.003	0.015	0.022 ± 0.009	0.01–0.05	–	0.006–0.01	(0.015)[h]
1-pentene	0.022 ± 0.010	0.056	0.04–0.07	0.5	–	0.028	0.008
n-pentane	0.005 ± 0.004	0.014	0.05–0.06	0.07	–	0.10	(0.025)[h]
2-methyl-butenes	0.008 ± 0.004	0.074	0.033	0.16	–	0.015	0.007
2-methyl-butane	0.011 ± 0.012	0.008	0.026–0.029	0.08	–	0.07	(0.018)[h]
Isoprene	0.020 ± 0.012	0.016	0.10	0.15–0.42	–	0.017	(0.05)[h]
Cyclopentene	0.012 ± 0.008	(0.02)[h]	0.019	0.61	–	0.035	(0.02)[h]
4-methyl-1-pentene	0.048	0.048	(0.05)[h]	0.015	–	(0.09)[h]	0.016
1-hexene	0.037 ± 0.016	0.063	0.07–0.11	(0.05)[h]	–	(0.13)[h]	0.013
n-hexane	0.039 ± 0.045	(0.05)[h]	0.03–0.06	(0.04)[h]	–	0.063	(0.05)[h]
Isohexanes	0.05	(0.08)[h]	(0.08)[h]	(0.06)[h]	–	(0.15)[h]	(0.08)[h]
Heptane	0.05	(0.08)[h]	(0.08)[h]	(0.06)[h]	–	(0.15)[h]	(0.08)[h]
Octenes	0.003–0.008	0.012	0.005	(0.007)[h]	–	(0.017)[h]	0.004
Terpenes	0.015	(0.15)[i]	0.22	(0.15)[i]	–	0.0	(0.015)[h]
Benzene	0.23 ± 0.11	0.39–0.41	0.49 ± 0.08	1.9 ± 1.0	–	0.3–1.7	0.14
Toluene	0.13 ± 0.06	0.21–0.29	0.40 ± 0.10	1.1 ± 0.7	–	0.08–0.61	0.026
Xylenes	0.045 ± 0.025	0.04–0.08	0.20	0.55 ± 0.44	–	0.04–0.22	0.01

Wildfires in Portugal: a recurring tragedy

Atmos. Chem. Phys., 11, 4039–4072, 2011
www.atmos-chem-phys.net/11/4039/2011/
doi:10.5194/acp-11-4039-2011

Atmospheric Chemistry and Physics

Emission factors for open and domestic biomass burning for use in atmospheric models

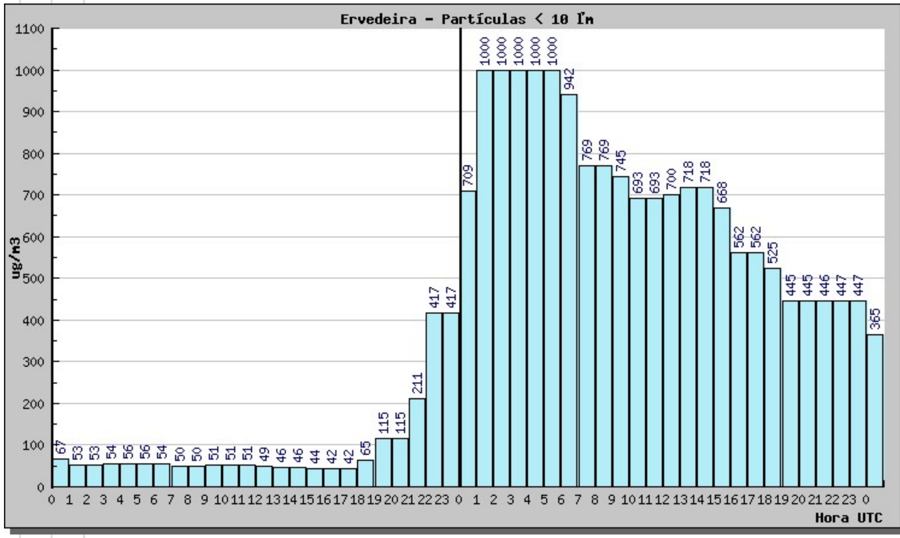
S. K. Akagi[1], R. J. Yokelson[1], C. Wiedinmyer[2], M. J. Alvarado[3], J. S. Reid[4], T. Karl[2], J. D. Crounse[5], and P. O. Wennberg[6]

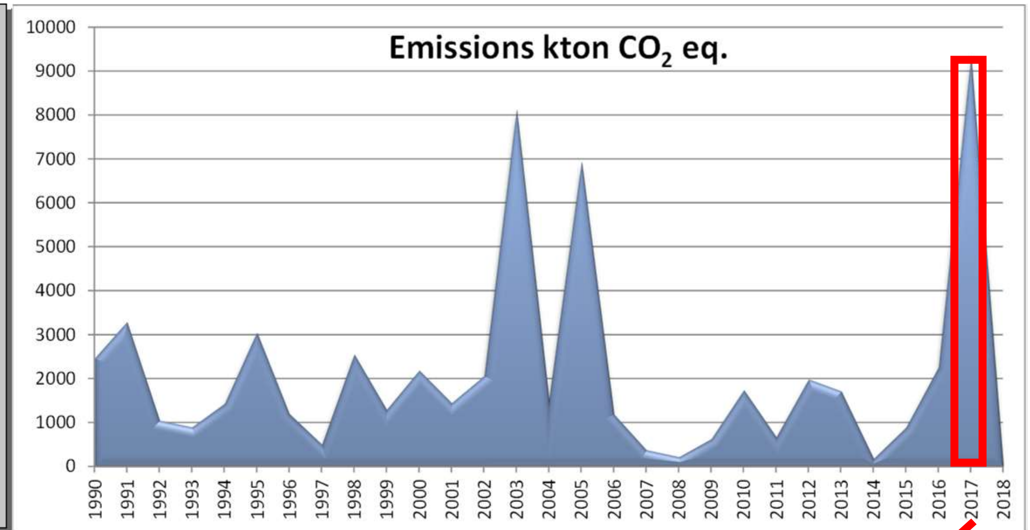
Table 1. Emission factors ($g\,kg^{-1}$) for species emitted from different types of biomass burning[a].

	Tropical Forest	Savanna	Crop Residue	Pasture Maintenance	Boreal Forest	Temperate Forest	Extratropical Forest[b]
Carbon Dioxide (CO_2)	1643 (58)	1686 (38)	1585 (100)	1548 (142)	1489 (121)	1637 (71)	1509 (98)
Carbon Monoxide (CO)	93 (27)	63 (17)	102 (33)	135 (38)	127 (45)	89 (32)	122 (44)
Methane (CH_4)	5.07 (1.98)	1.94 (0.85)	5.82 (3.56)	8.71 (4.97)	5.96 (3.14)	3.92 (2.39)	5.68 (3.24)
Acetylene (C_2H_2)	0.44 (0.35)	0.24 (0.10)	0.27 (0.08)	0.21 (0.29)	0.18 (0.10)	0.29 (0.10)	0.19 (0.090)
Ethylene (C_2H_4)	1.06 (0.37)	0.82 (0.35)	1.46 (0.59)	1.28 (0.71)	1.42 (0.43)	1.12 (0.35)	1.38 (0.42)
Ethane (C_2H_6)	0.71 (0.28)	0.66 (0.41)	0.91 (0.49)	0.95 (0.43)	1.79 (1.14)	1.12 (0.67)	1.70 (1.05)
Propadiene (C_3H_4)	0.016 (0.0066)	0.012 (0.005)	–	0.020 (0.009)	–	–	–
Propylene (C_3H_6)	0.64 (0.43)	0.79 (0.56)	0.68 (0.37)	0.85 (0.66)	1.13 (0.60)	0.95 (0.54)	1.11 (0.61)
Propyne (C_3H_4)	–	–	–	–	0.059	–	0.059
Propane (C_3H_8)	0.126 (0.060)	0.10 (0.067)	0.28 (0.15)	0.22 (0.10)	0.44	0.26 (0.11)	0.42 (0.18)
n-Butane (C_4H_{10})	0.038 (0.023)	0.016 (0.013)	0.072 (0.036)	0.040 (0.018)	0.12	0.083 (0.10)	0.12 (0.14)
i-Butane (C_4H_{10})	0.011 (0.009)	0.0043 (0.0027)	0.025 (0.013)	0.014 (0.0063)	0.042	–	0.042
1-Butene (C_4H_8)	0.079 (0.024)	0.043 (0.022)	0.134 (0.060)	0.17 (0.077)	0.16	–	0.16
i-Butene (C_4H_8)	0.11 (0.051)	0.024 (0.0051)	0.117 (0.060)	0.11 (0.05)	0.11	–	0.11
1,3-Butadiene (C_4H_6)	0.039	0.052 (0.028)	0.151 (0.072)	–	0.14	–	0.14
trans-2-Butene (C_4H_8)	0.029 (0.013)	0.011 (0.0055)	0.057 (0.030)	0.050 (0.023)	0.040	–	0.040
cis-2-Butene (C_4H_8)	0.024 (0.010)	0.0084 (0.0043)	0.043 (0.023)	0.040 (0.018)	0.030	–	0.030
n-Pentane (C_5H_{12})	8.03×10^{-3} (8.03×10^{-3})	0.0032 (0.0032)	0.025 (0.012)	0.0056 (0.0025)	0.085	–	0.085
i-Pentane (C_5H_{12})	0.010 (0.010)	0.0022 (0.0032)	0.020 (0.012)	0.0074 (0.0033)	0.038	–	0.038
trans-2-Pentene (C_5H_{10})	3.30×10^{-3}	0.0045 (0.0028)	–	–	–	–	–
cis-2-Pentene (C_5H_{10})	1.90×10^{-3}	0.0025 (0.0018)	–	–	–	–	–
3-Methyl-1-Butene (C_5H_{10})	3.80×10^{-3}	0.0051 (0.0034)	–	–	–	–	–
2-Methyl-2-Butene (C_5H_{10})	4.00×10^{-3}	0.0048 (0.0035)	–	–	–	–	–
2-Methyl-1-Butene (C_5H_{10})	4.40×10^{-3}	0.0059 (0.0037)	–	–	–	–	–
Isoprene (C_5H_8)	0.13 (0.056)	0.039 (0.027)	0.38 (0.16)	0.12 (0.055)	0.15	–	0.15
Cyclopentane (C_5H_{10})	–	–	0.0019 (0.0012)	–	–	–	–
2+3-Methylpentane (C_6H_{14})	–	–	–	–	0.036	–	0.036
2-Methyl-1-Pentene (C_6H_{12})	2.80×10^{-3}	0.0035 (0.0021)	–	–	–	–	–
n-Hexane (C_6H_{14})	0.010	0.013 (0.0074)	–	–	0.055	–	0.055
Heptane (C_7H_{16})	5.60×10^{-3}	0.0070 (0.0072)	–	–	0.048	–	0.048
Benzene (C_6H_6)	0.39 (0.16)	0.20 (0.084)	0.15 (0.04)	0.70 (0.32)	1.11	–	1.11
Toluene ($C_6H_5CH_3$)	0.26 (0.13)	0.080 (0.058)	0.19 (0.06)	0.34 (0.15)	0.48	–	0.48
Xylenes (C_8H_{10})	0.11 (0.082)	0.014 (0.024)	–	0.11 (0.050)	0.18	–	0.18
Ethylbenzene (C_8H_{10})	0.050 (0.036)	0.006 (0.010)		0.067 (0.030)	0.051		0.051

Wildfires in Portugal: emissions and air quality

CO_2 eq. emissions from wildfires in Portugal





15-16/10/2017

15% of total annual GHG emissions

However….

- Emissions are probably underestimated and the associated uncertainties are very high
- Emission Factors are from Andreae and Marlet (2001) or Akagi et al. (2011), which do not represent the Portuguese forest ecosystems
- Difficulties in apportion wildfire emissions by receptor modelling because of the lack of source profiles

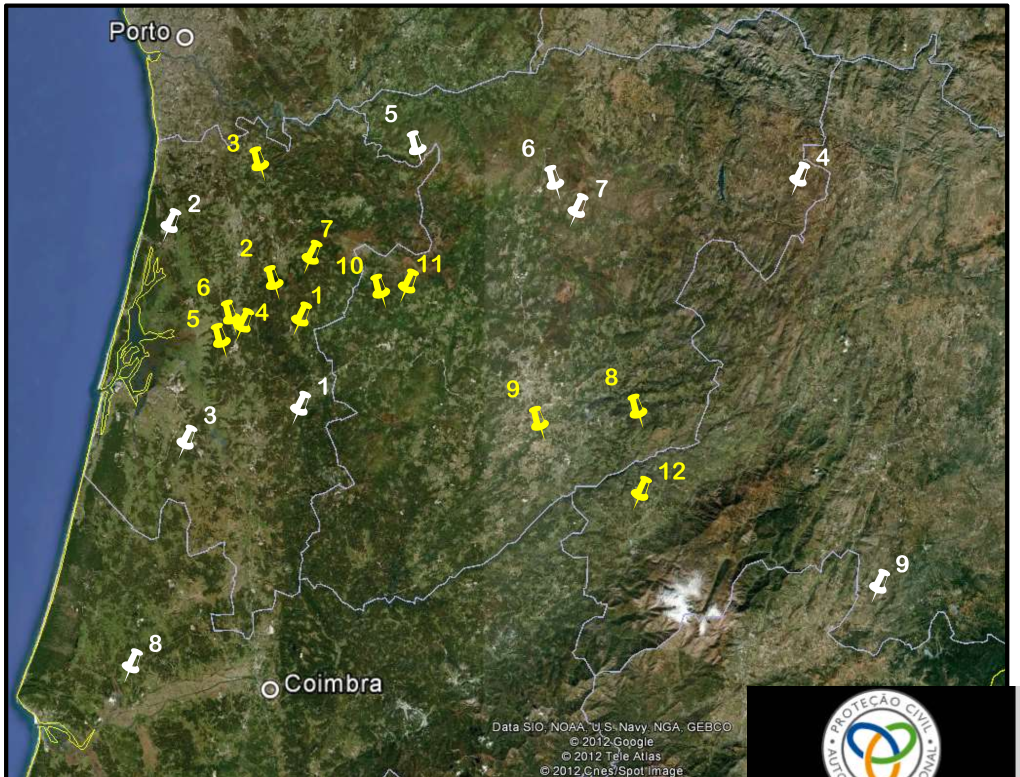
Objective of our work

Emission inventories, climate change, atmospheric photochemical and source apportionment models use emission profiles which should reflect the regional characteristics of biofuels

Objective:

Quantify emission factors for a wide range of particulate phase compounds (organics, metals, and ions), as well for gaseous pollutants, released by forest fires

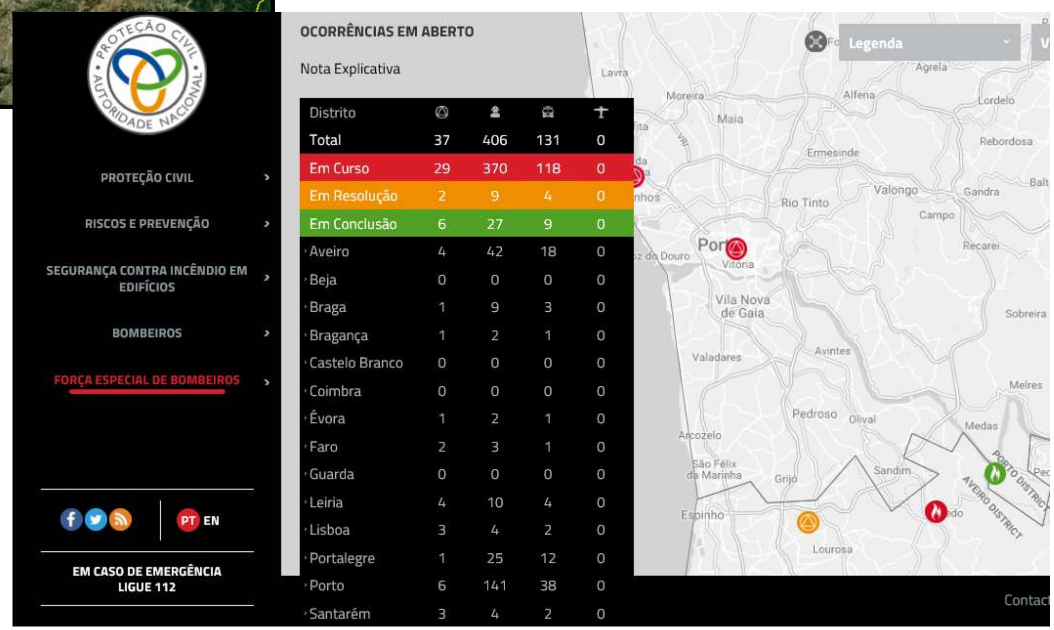
Sampling of wildfire emissions



Wildfires in which it was possible to sample smoke plumes:

- 2009 (white locations)
- 2010 (yellow locations)

http://www.prociv.pt/



Sampling of wildfire emissions

- **Tri-pod high-volume atmospheric particulate matter sampler**

Fine particles, < 2.5 μm ($PM_{2.5}$) & Coarse particles, 2.5-10 μm ($PM_{2.5\text{-}10}$)

- **Tedlar bags to collect gaseous samples**

Sampling emissions from field burning of agriculture residues

Burning of tree prunings

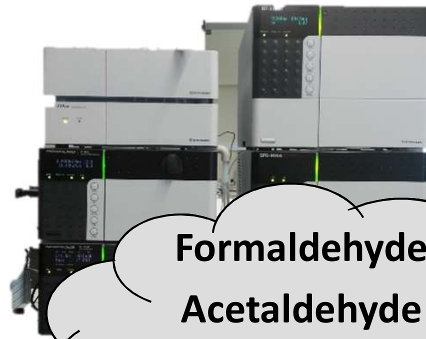
High-volume PM_{10} sampling

PM_{10} quartz fibre filter

Water condensation unit, flowmeter, pump and Tedlar bag

Analytical methodologies – gaseous compounds

DNPH cartridges



HPLC

Formaldehyde
Acetaldehyde
Propionaldehyde

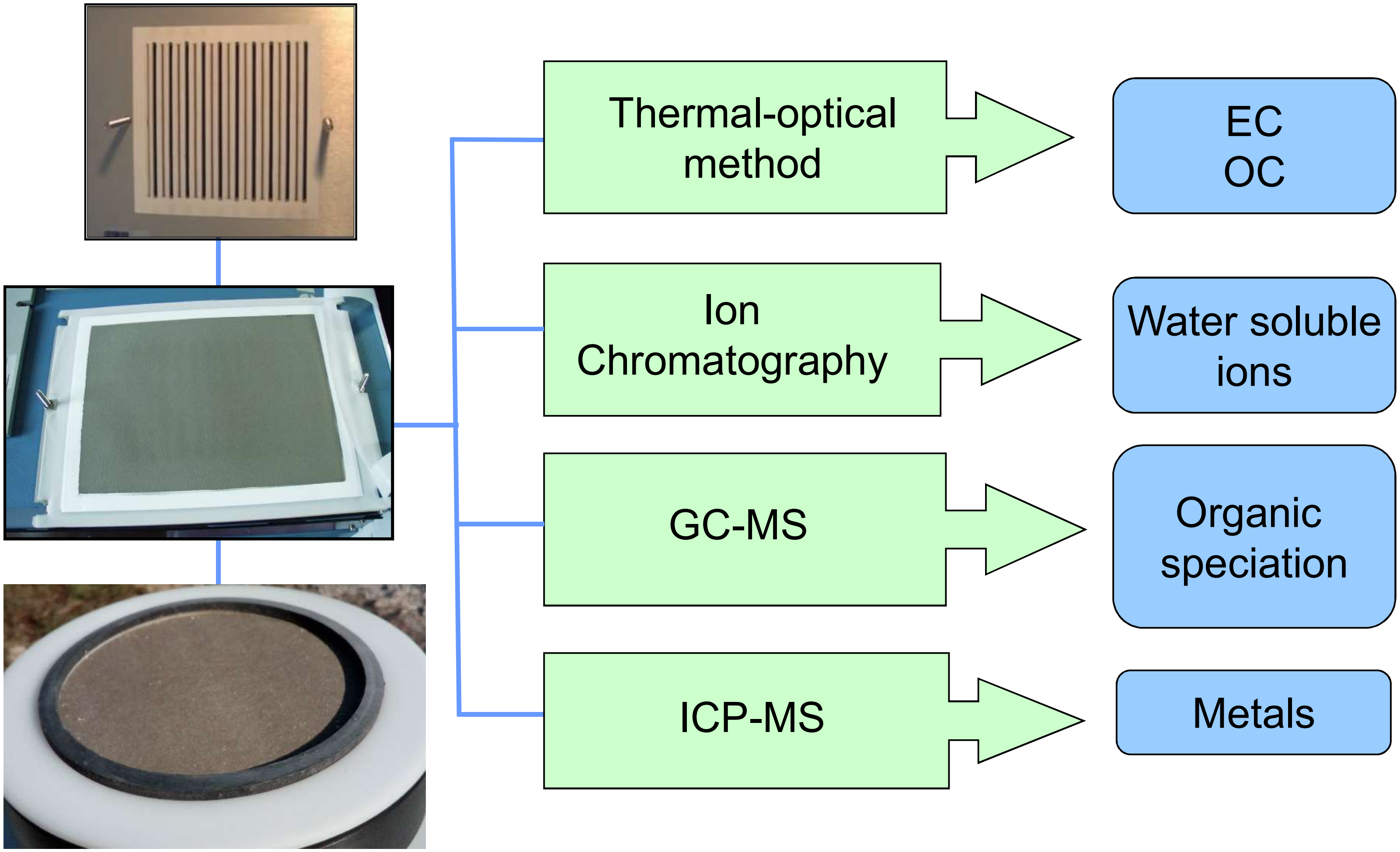
non-dispersive infrared analyser

CO and CO_2

flame ionisation analyser

Total hydrocarbons

Analytical methodologies – particulate matter



Calculations

- **Modified combustion efficiency:**

$$MCE = \frac{[CO_2]}{[CO_2] + [CO]}$$

> 0.90 (flaming phase)

< 0.85 (smouldering phase)

- **Emission factors (g/kg):**

The carbon combusted in a fire is emitted in 4 forms: CO_2, CO, hydrocarbons, and particulate carbon. The emission factor of a species, *n*, is calculated from the ratio of the mass concentration of that species to the total carbon concentration emitted in the plume:

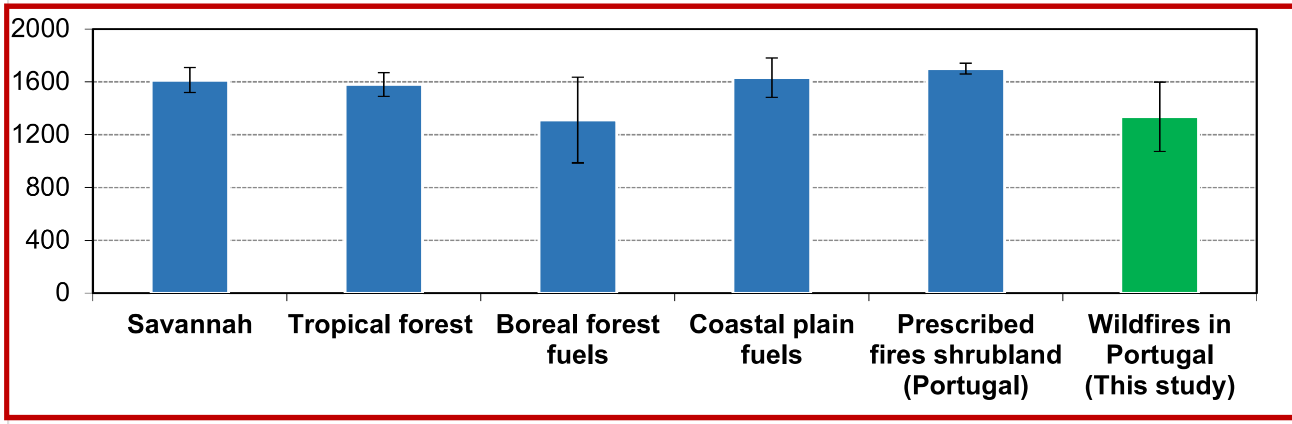
$$EF_n = \frac{[n]}{[CO_2]+[CO]+[THC]+[TC]} \text{ x } 48\%$$

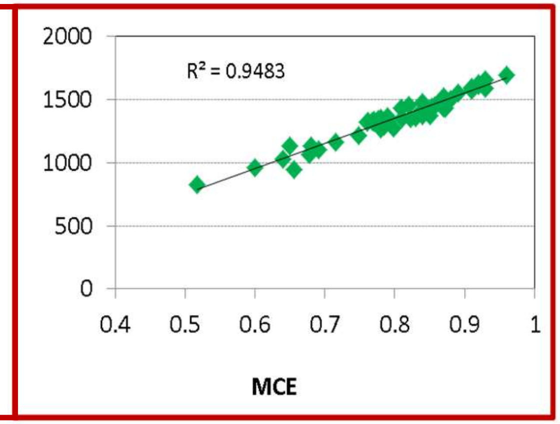
mass of species *n* emitted per unit mass of carbon burned

mass fraction of carbon in the fuel

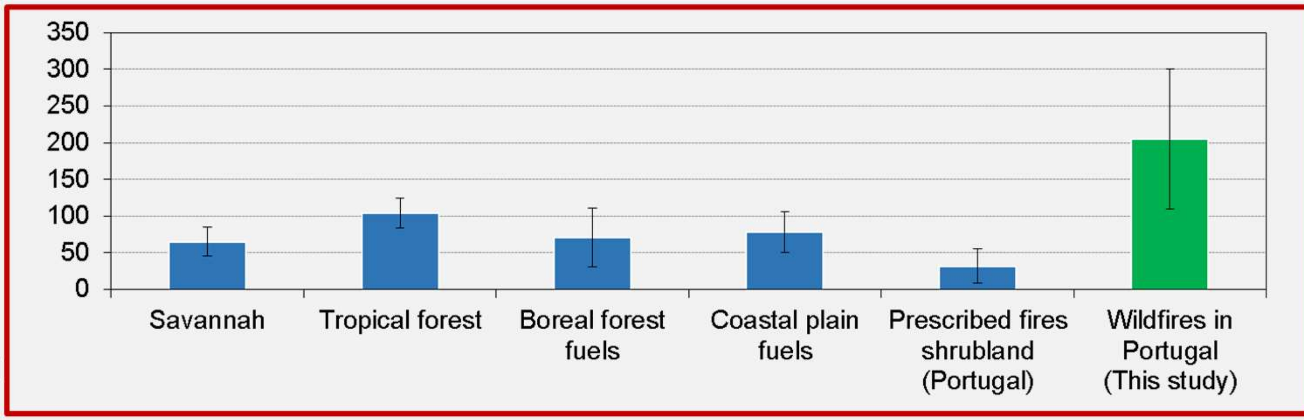
Emission Factors

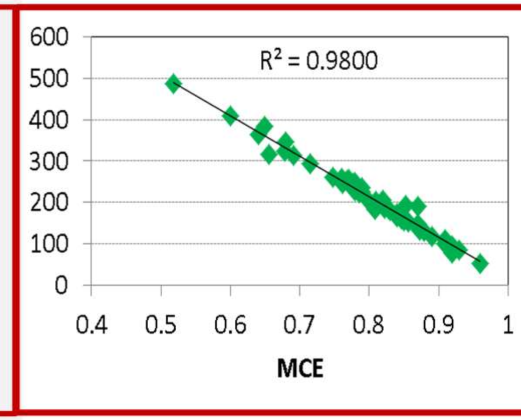
CO_2 (g kg^{-1} fuel burned, dry basis)



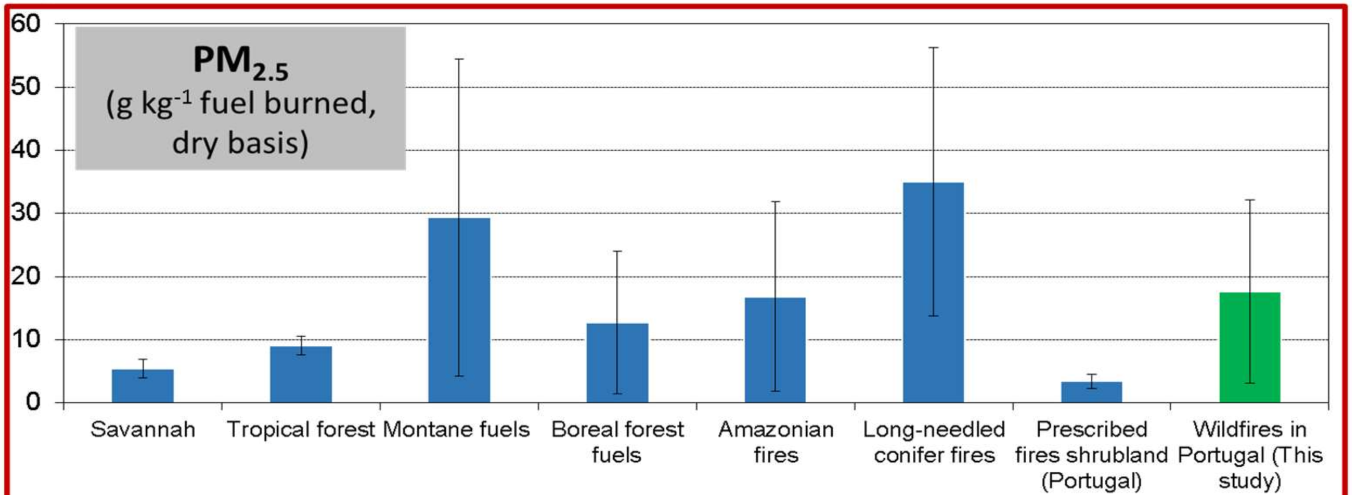


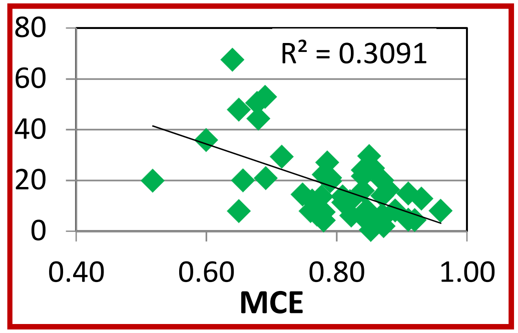
CO (g kg^{-1} fuel burned, dry basis)

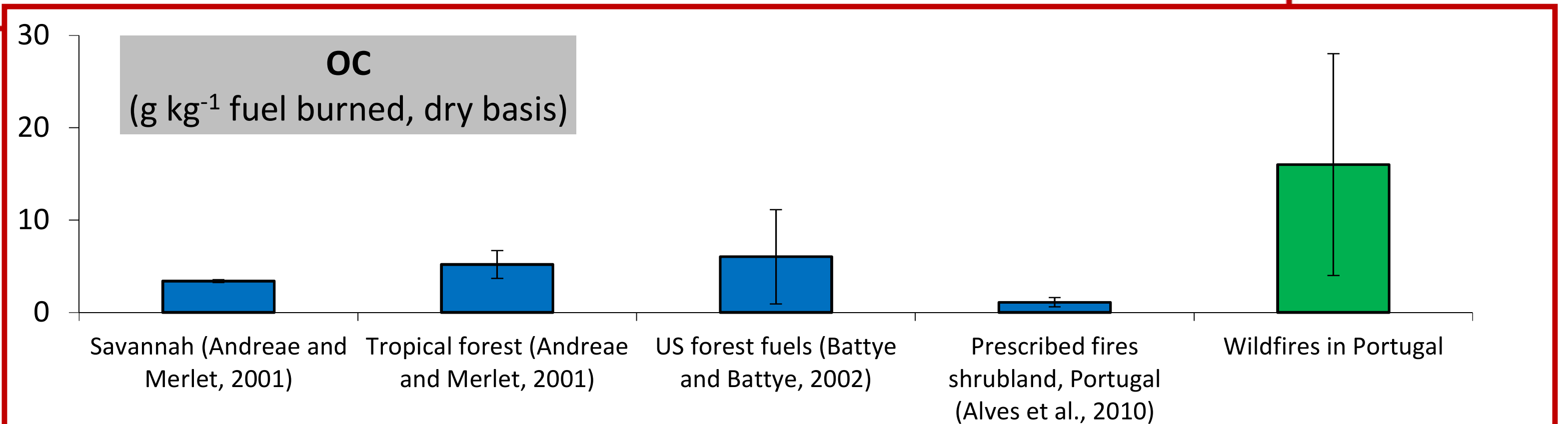


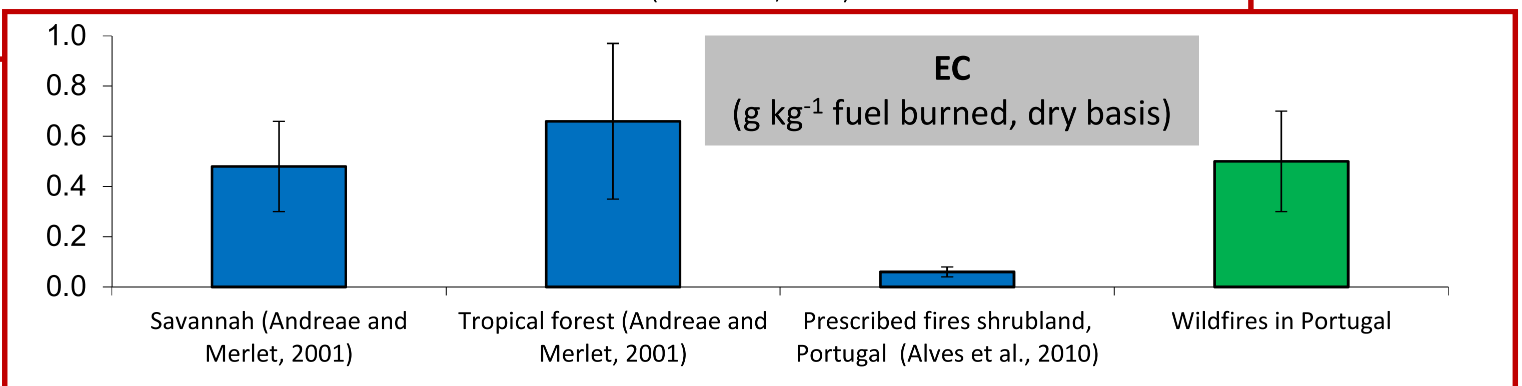


Emission Factors



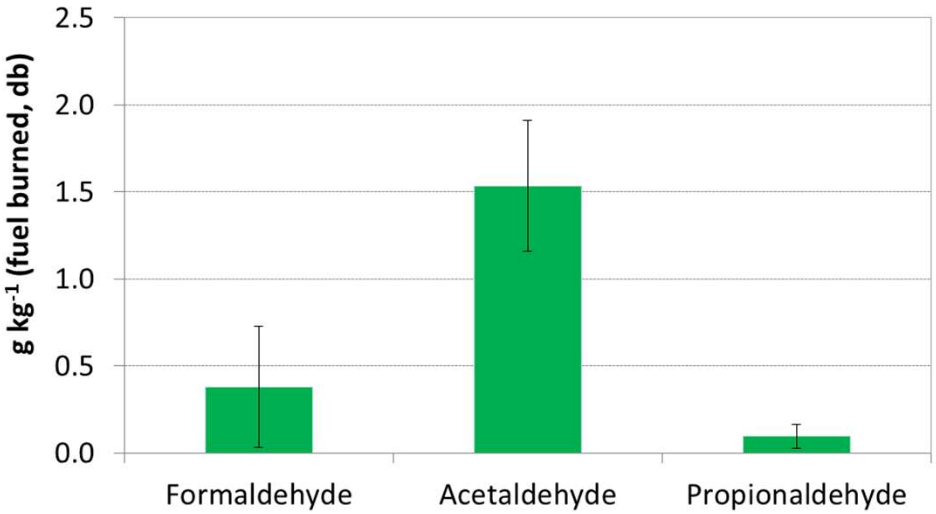


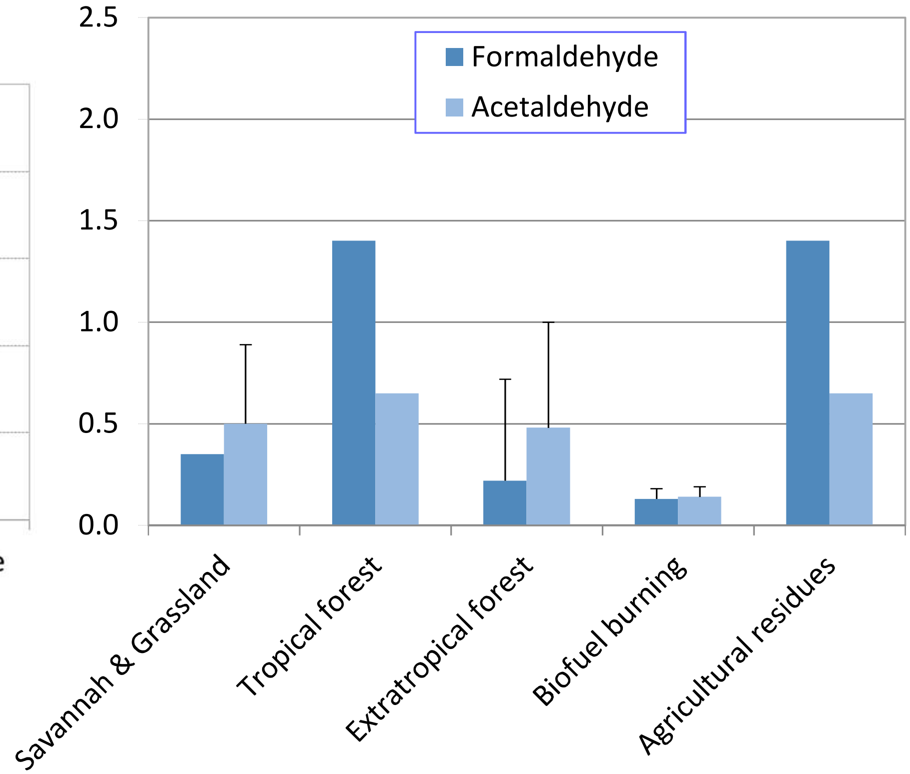




Emission Factors

Carbonyl compounds

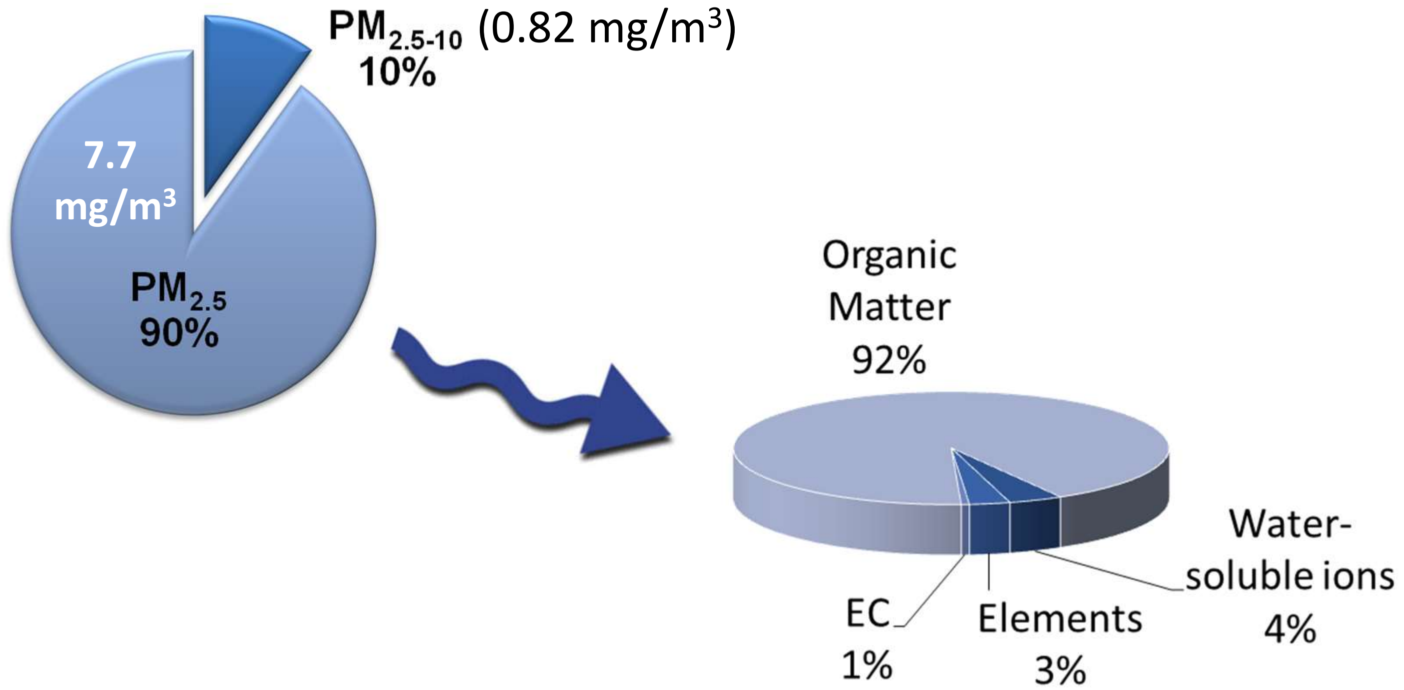




F/A ratios:

- At traffic impacted sites, F/A > 1 are generally obtained
- In Brazil, this ratio tended to values < 1 due to heavy use of ethanol as a vehicular fuel
- Wildfires in Portugal: F/A = 0.25

Chemical composition of smoke particles

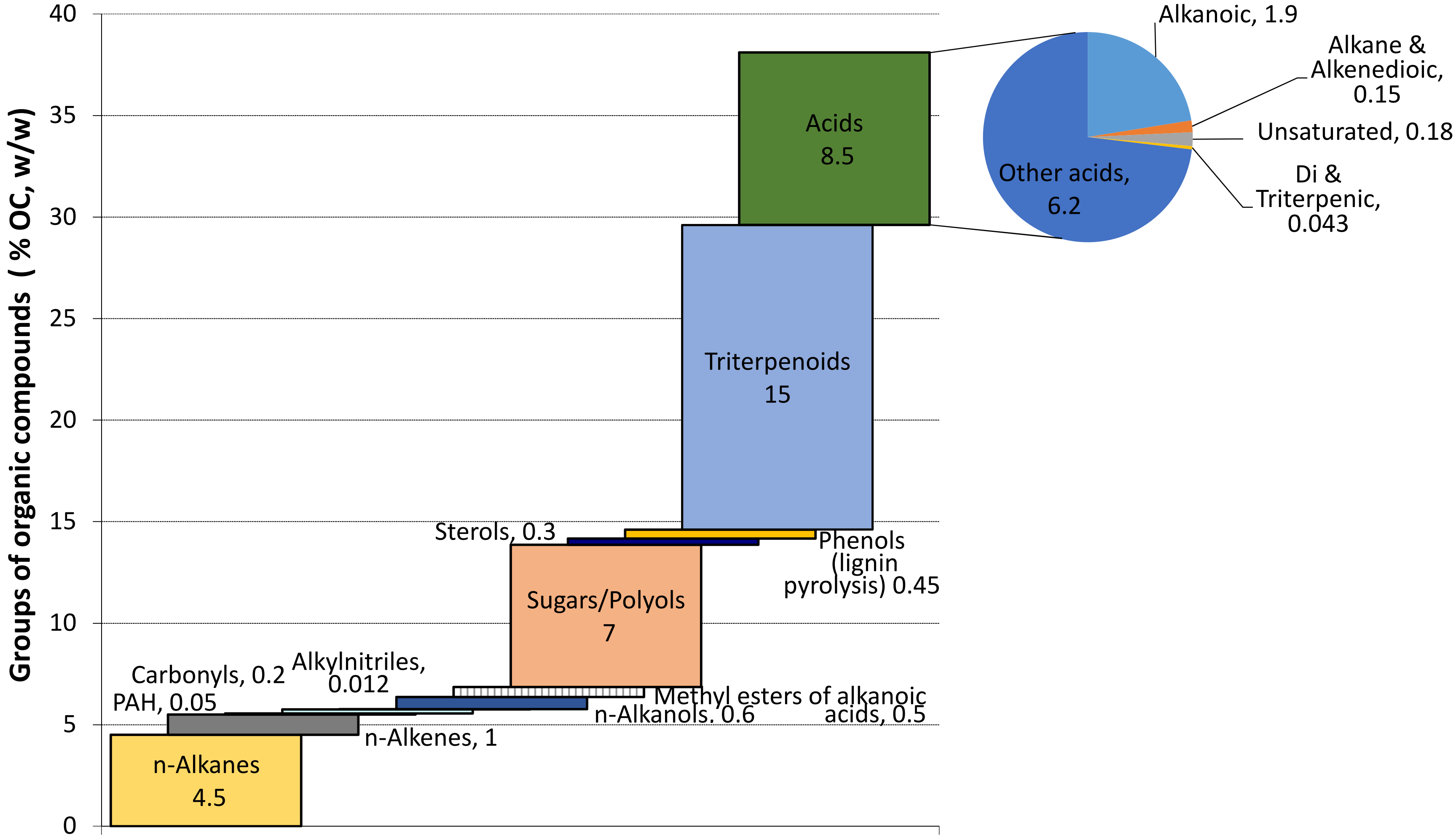


OC/EC = 1.7 for MCE = 0.93 (flaming)

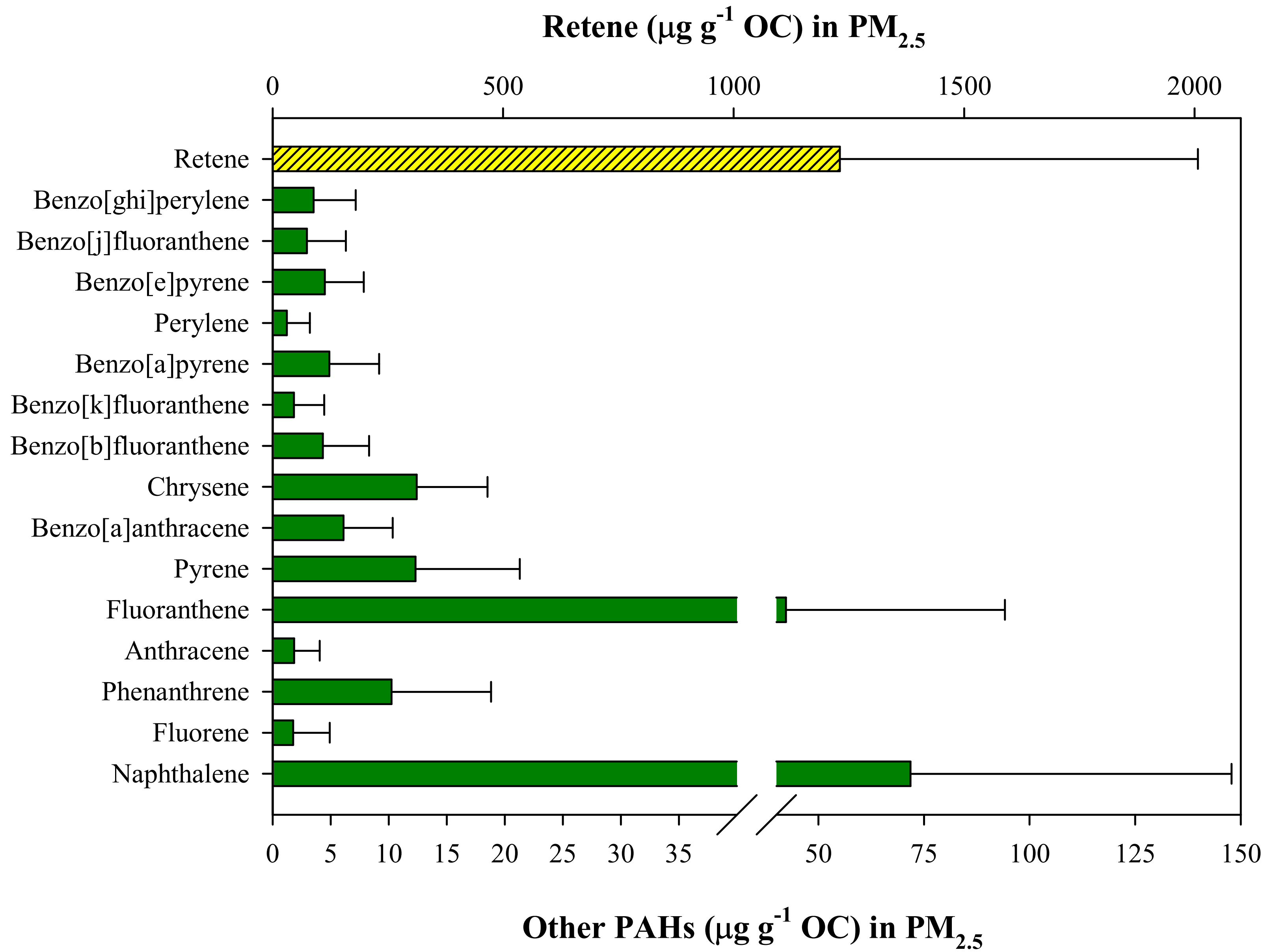
OC/EC ~ 112 000 for MCE = 0.60 (smouldering)

Mean OC/EC = 66

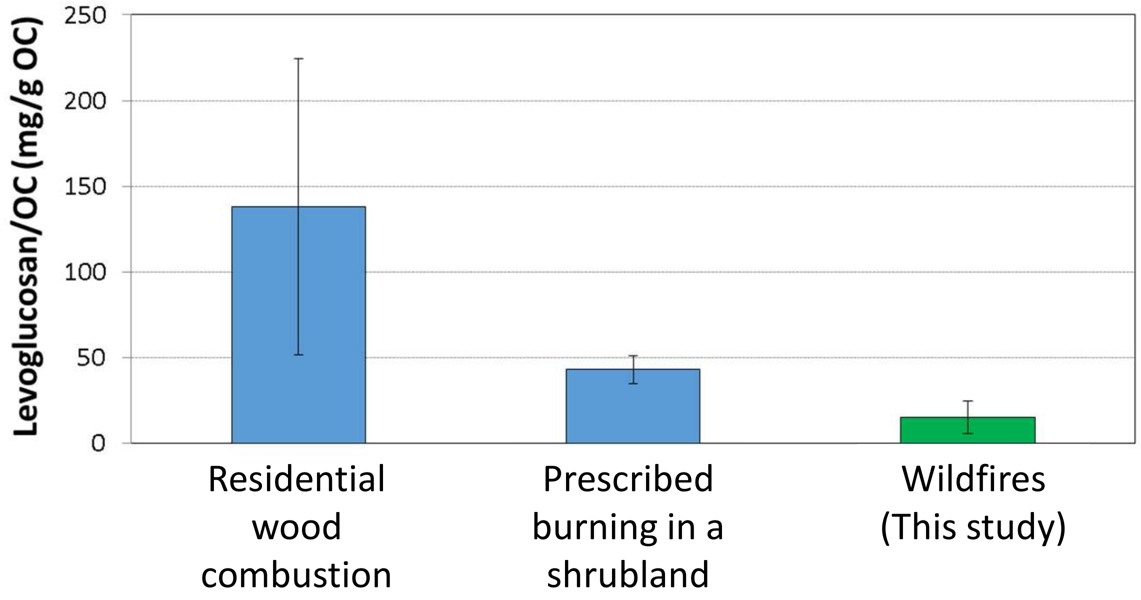
$PM_{2.5}$ organic composition



$PM_{2.5}$ organic composition



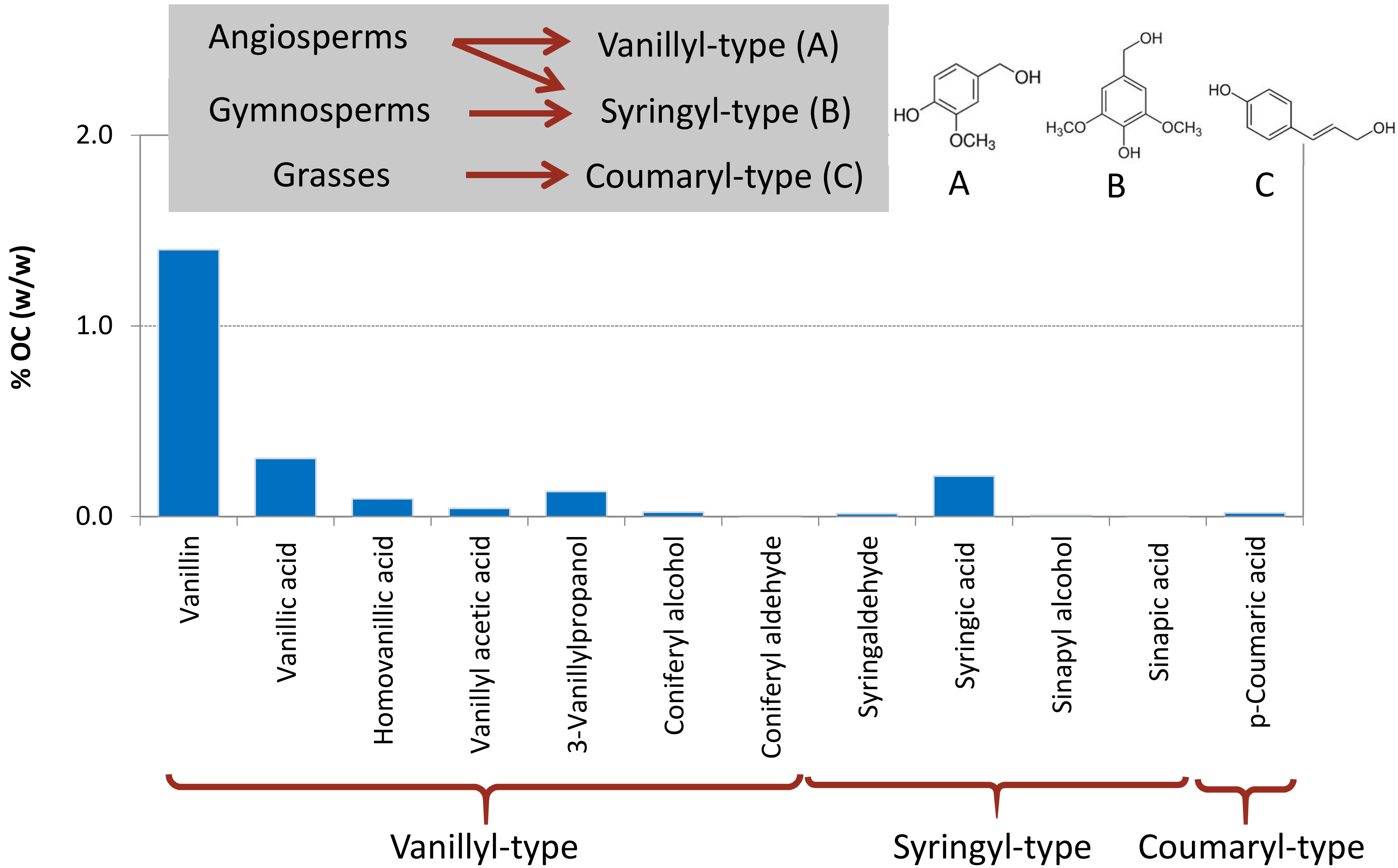
$PM_{2.5}$ organic composition



- Levoglucosan emissions decrease with increasing combustion temperatures
- It may be a good tracer for the smouldering phase, but it is not present in emissions from intense flaming fires

PM$_{2.5}$ organic composition

Phenolic compounds



Conclusions

- The comprehensive databases obtained may be useful for numerical models to evaluate the impact of wildfires in the Mediterranean region, which is particularly uncover by this type of studies. This research may also contribute to improve source apportionment models allowing to estimate the input of wildfires to the atmospheric levels at monitoring sites. It has yet to be estimated more specific emission profiles for wildfires under extreme weather conditions (heat waves).

- Our results consolidate previous argumentations that smouldering emissions make a significant contribution to the total emissions.

- The smoke plume is mainly composed of fine particles containing carcinogenic (e.g. PAHs) and compounds that cause oxidative stress (e.g. phenolics).

- Smoke particles are carbonaceous in nature with a clear dominance of OC and much higher OC/EC values than those reported in the literature for other sources.

- Since EC plays a key role in radiative forcing, and taking into account the discrepancies between the various studies, the magnitude of the emission factor for EC remains uncertain and deserves further investigation.

Prevent forest fires, but…

Databases available at:

https://zenodo.org/record/3345669

Vicente, A., Calvo, A., Gonçalves, C., Nunes, T., Fernandes, A.P., Monteiro, C., Mirante, F., Evtyugina, M., Alves, C. (2019). Emission factors of trace gases and aerosols from wildfire events in central Portugal [Data set]. Zenodo. http://doi.org/10.5281/zenodo.3345669

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