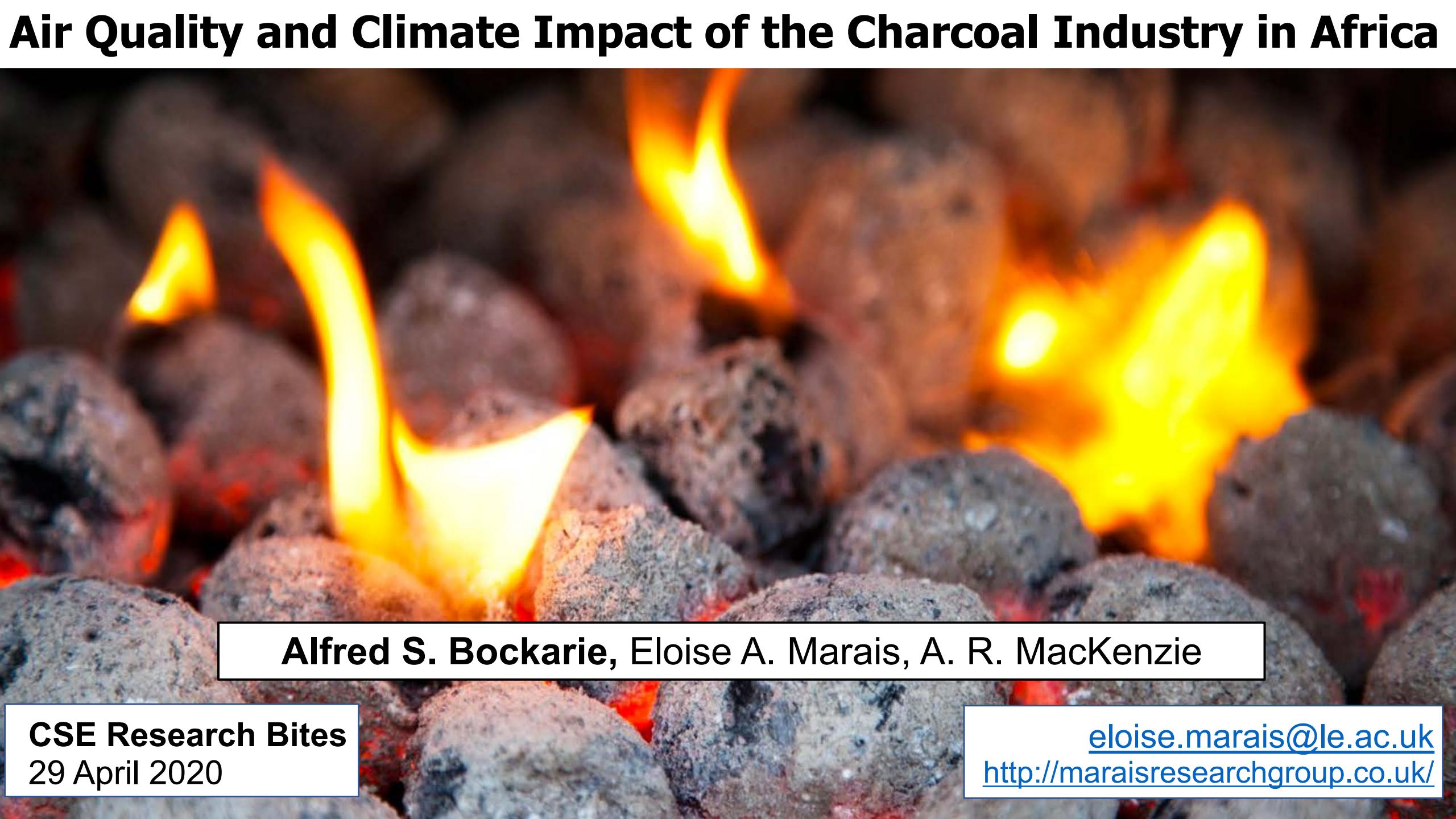
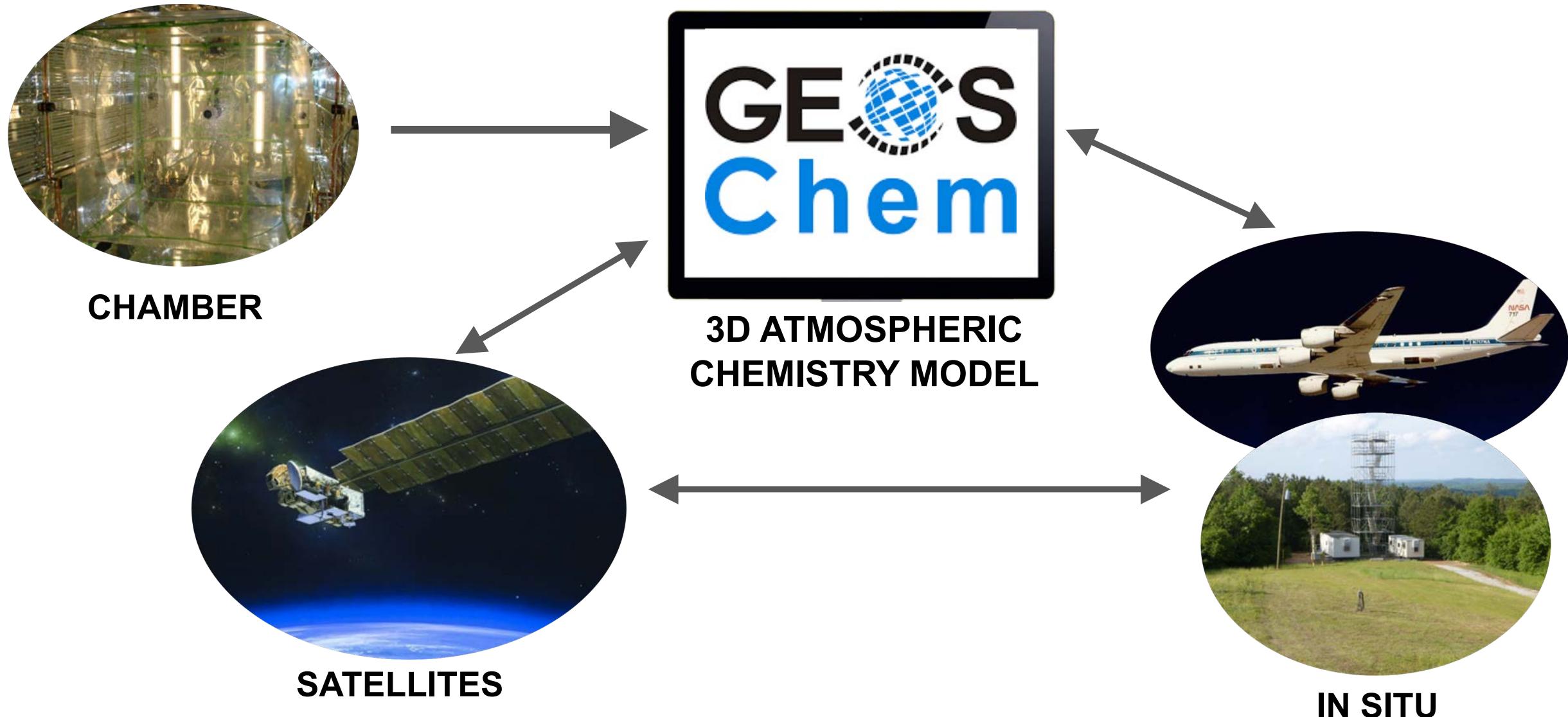


# Air Quality and Climate Impact of the Charcoal Industry in Africa



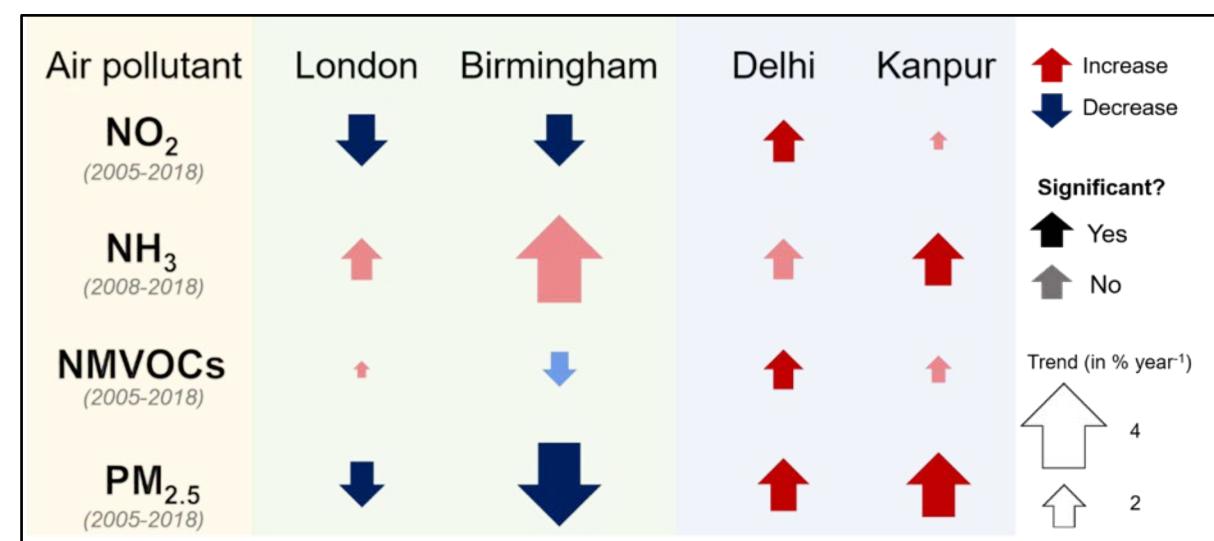
Alfred S. Bockarie, Eloise A. Marais, A. R. MacKenzie

# Multiplatform Approach to Solve Issues of Pressing Need

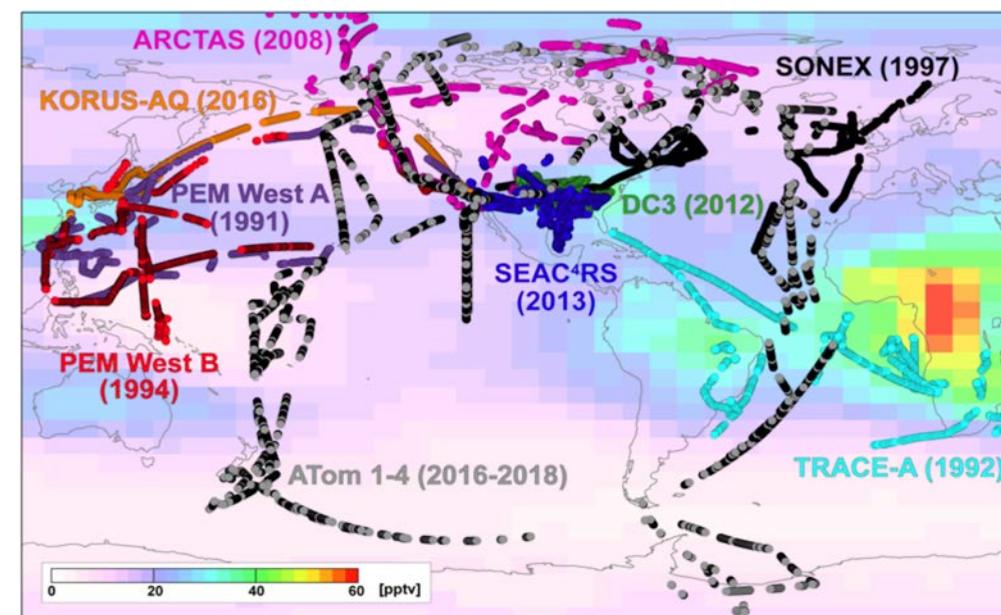


My group uses and develops state-of-science observations and tools to inform policy.

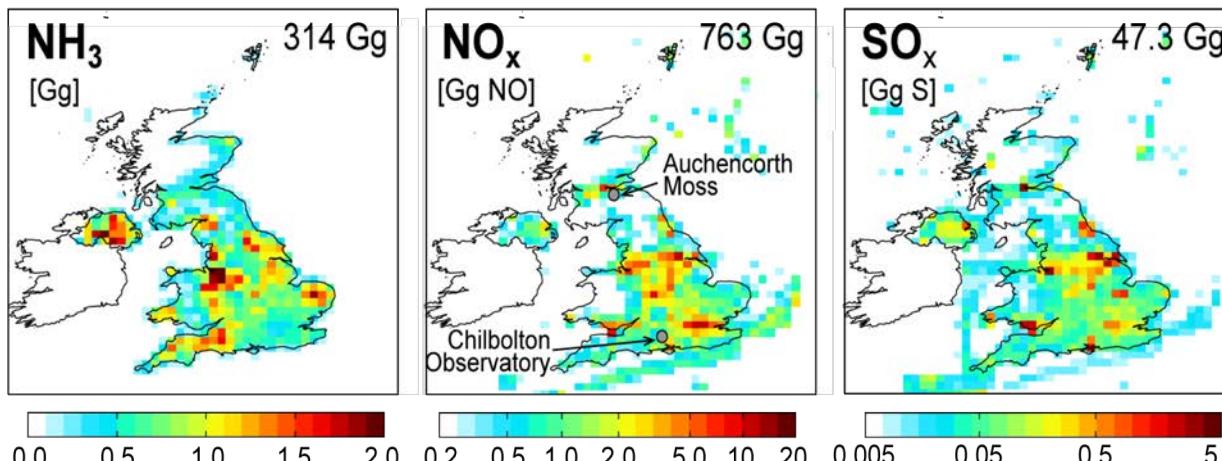
# Tracking Success and Absence of Air Quality Policies in Cities



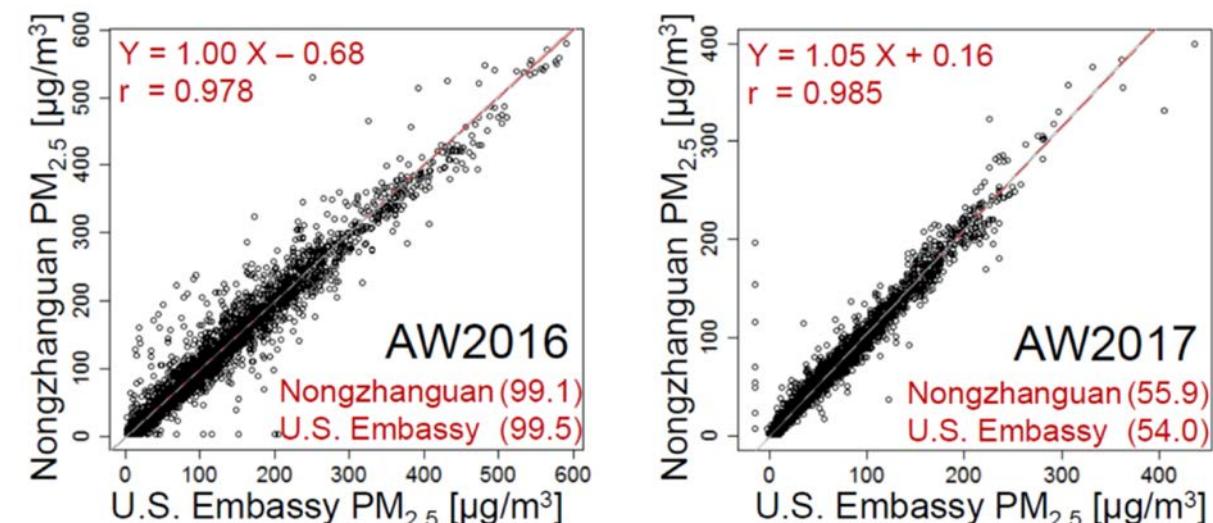
# The Underappreciated Upper Troposphere



# Assessing the UK Emission Inventory with Earth Observations



# Assessing strict air quality policies in North China





## Tracking Success and Absence of Air Quality Policies in Cities



Assessing the  
success of air quality  
policies

Air pollutant

**NO<sub>2</sub>**  
(2005-2018)

London



Birmingham



Delhi



Kanpur



↑ Increase

↓ Decrease

Significant?

↑ Yes

↑ No

**NH<sub>3</sub>**  
(2008-2018)



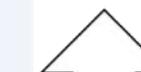
**NMVOCs**  
(2005-2018)



**PM<sub>2.5</sub>**  
(2005-2018)



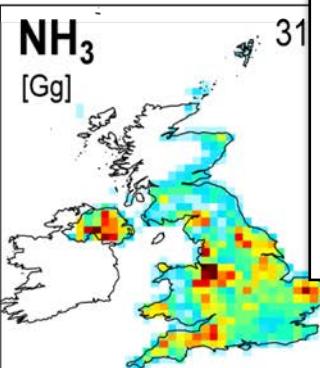
Trend (in % year<sup>-1</sup>)



4



2



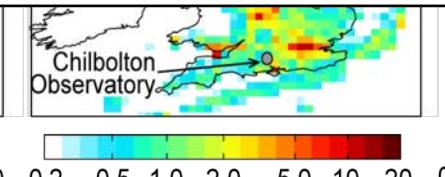
0.0

0.5

1.0

1.5

2.0



0.2

0.5

1.0

2.0

5.0

10

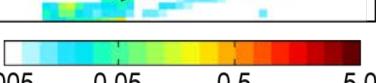
20

0.005

0.05

0.5

5.0



0.005

0.05

0.5

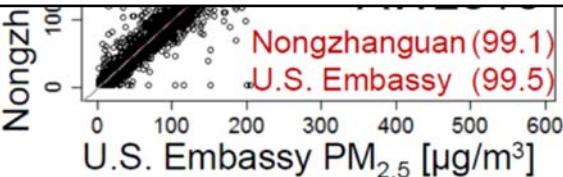
5.0

0.005

0.05

0.5

5.0



0

100

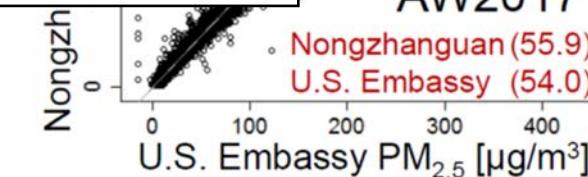
200

300

400

500

600



0

100

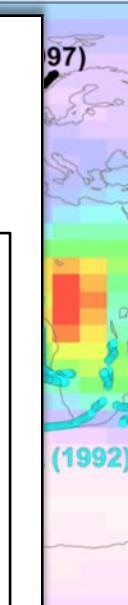
200

300

400

AW2017

Vohra et al., submitted, 2020



(1997)

(1992)

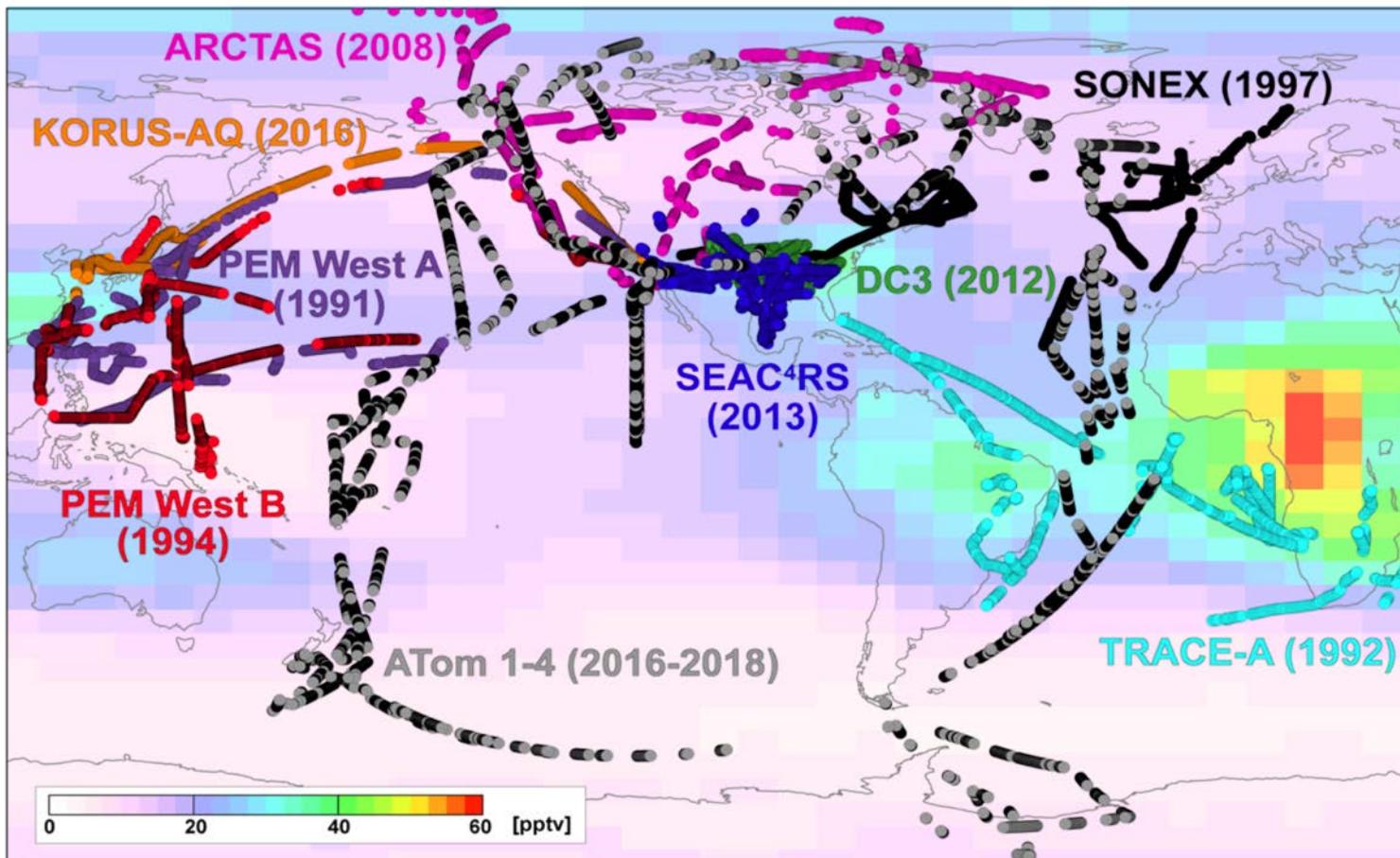
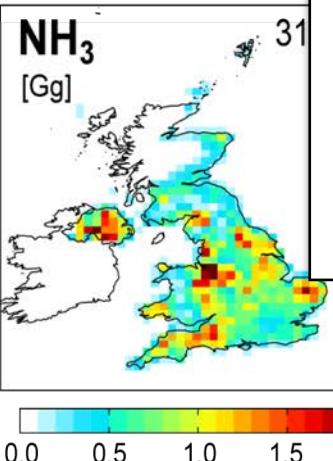


erc

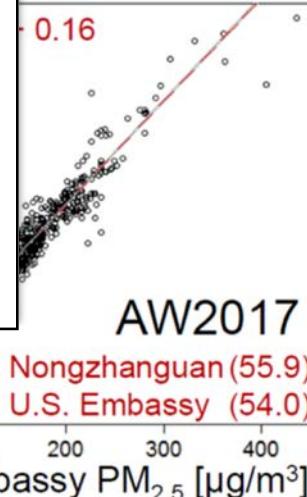


# The Underappreciated Upper Troposphere

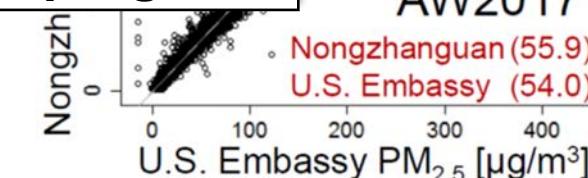
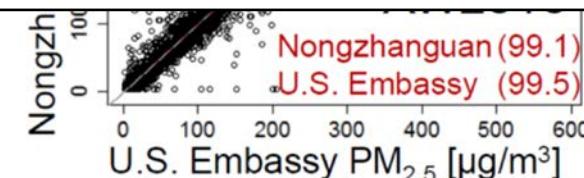
Air pollutant

 $\text{NO}_2$   
(2005-2018) $\text{NH}_3$   
(2008-2018)NMVOCs  
(2005-2018) $\text{PM}_{2.5}$   
(2005-2018)Assessing t  
with

North China



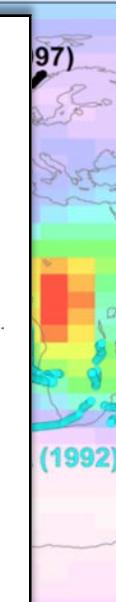
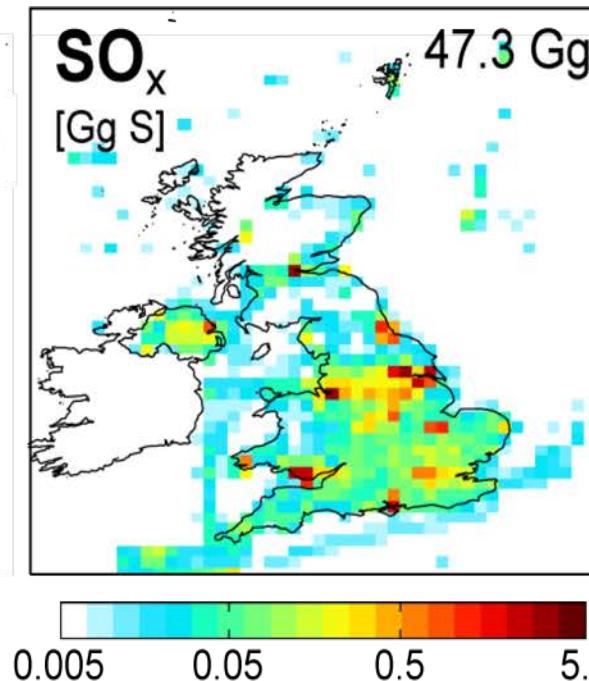
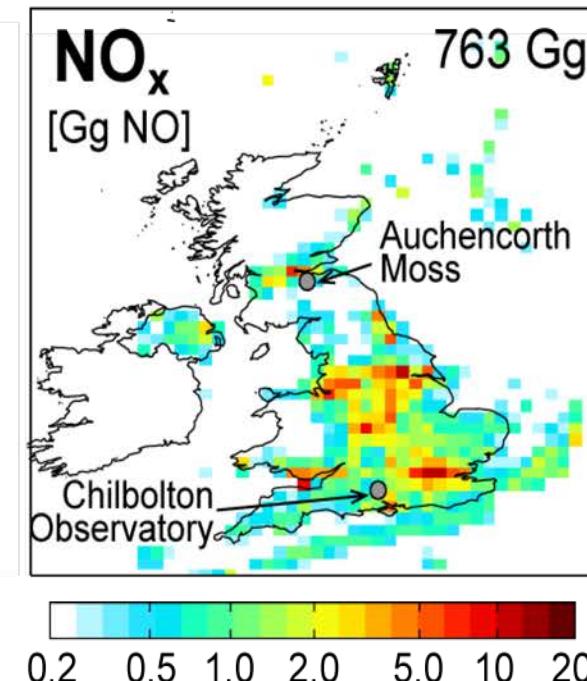
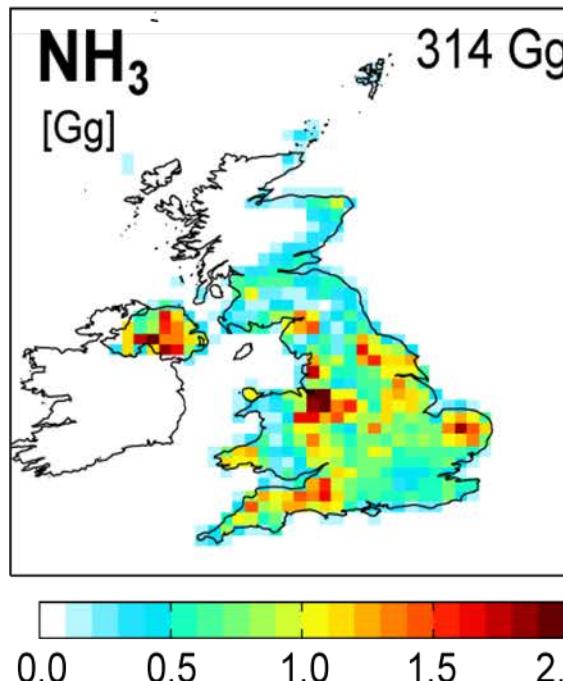
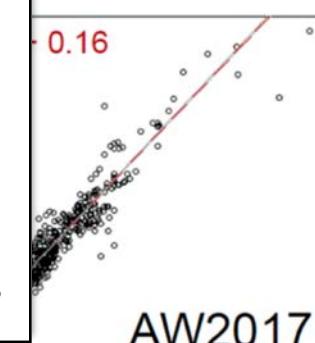
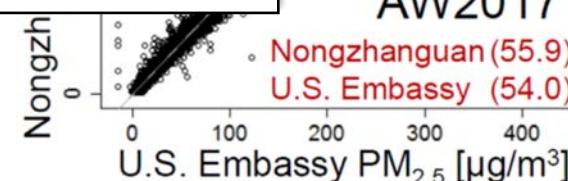
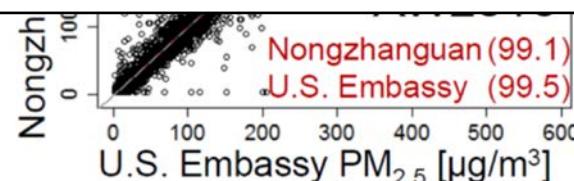
Wei et al., in progress



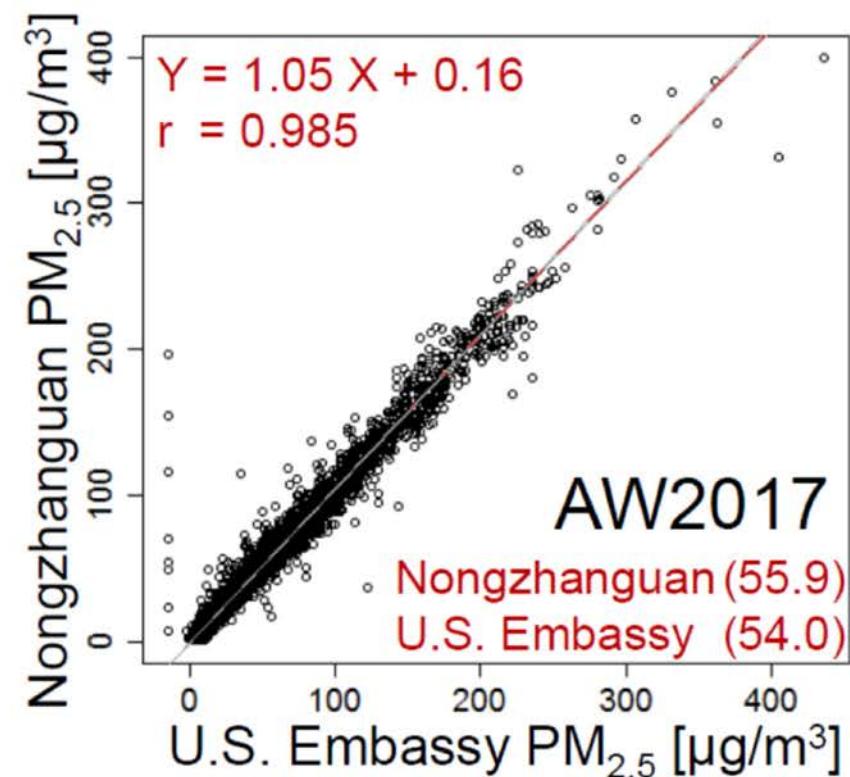
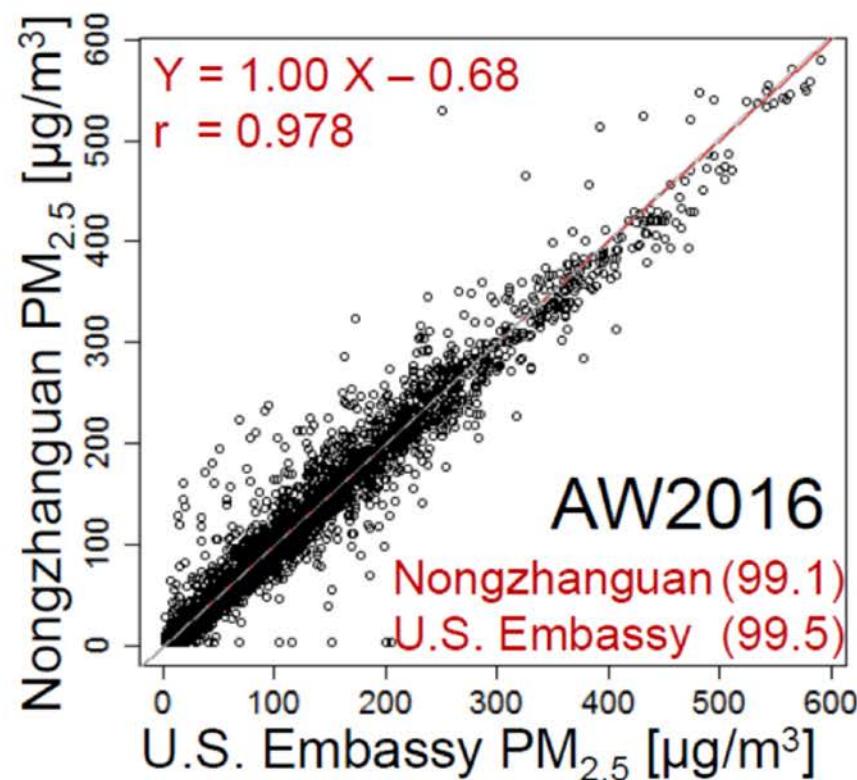
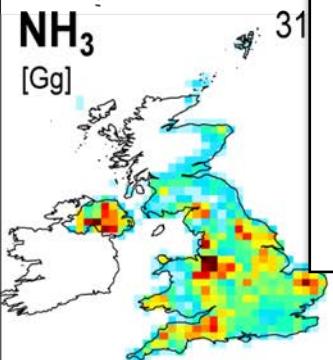
Air pollutant

 $\text{NO}_2$   
(2005-2018) $\text{NH}_3$   
(2008-2018)NMVOCs  
(2005-2018) $\text{PM}_{2.5}$   
(2005-2018)

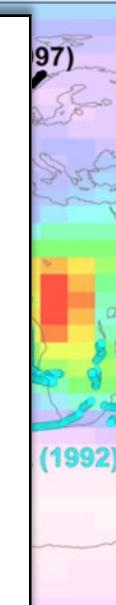
## Assessing the UK Emission Inventory with Earth Observations

**North China****Marais et al., in progress**

Air pollutant

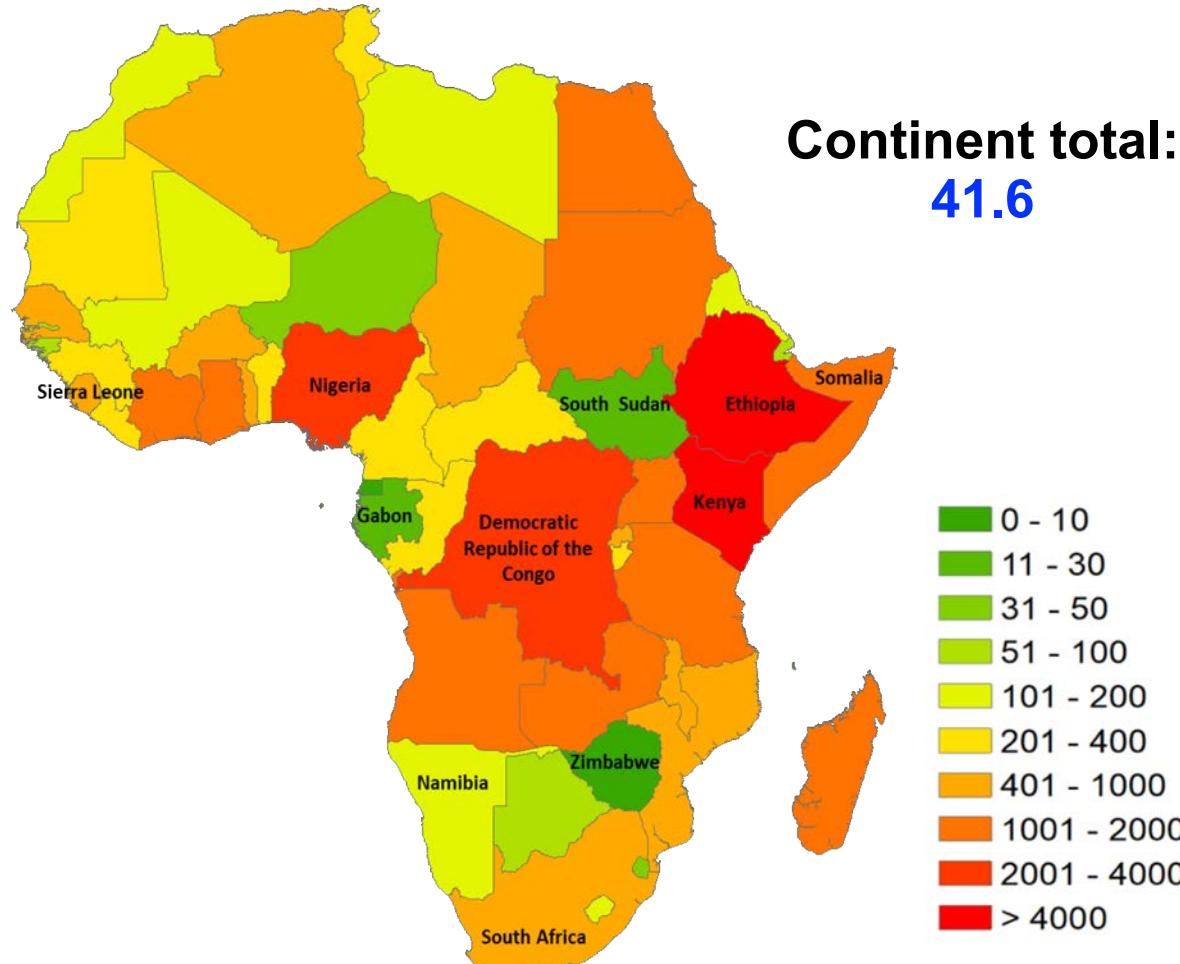
 $\text{NO}_2$   
(2005-2018) $\text{NH}_3$   
(2008-2018)NMVOCs  
(2005-2018) $\text{PM}_{2.5}$   
(2005-2018)Assessing the  
with strict  
air quality  
policies

Lu et al., in progress



# The Burgeoning Charcoal Industry in Africa

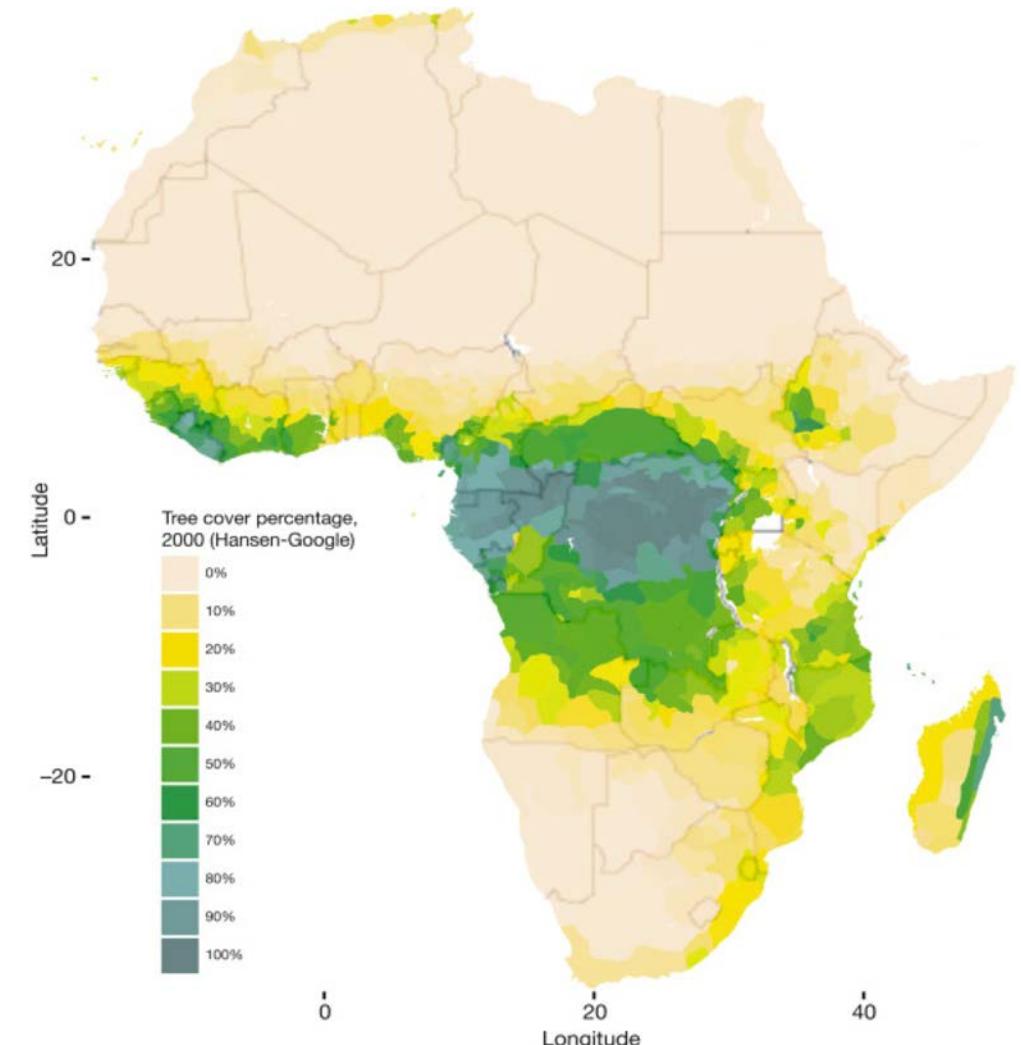
Charcoal Production in 2014 [million tonnes]



Data are from the UN (<http://data.un.org/Explorer.aspx>)

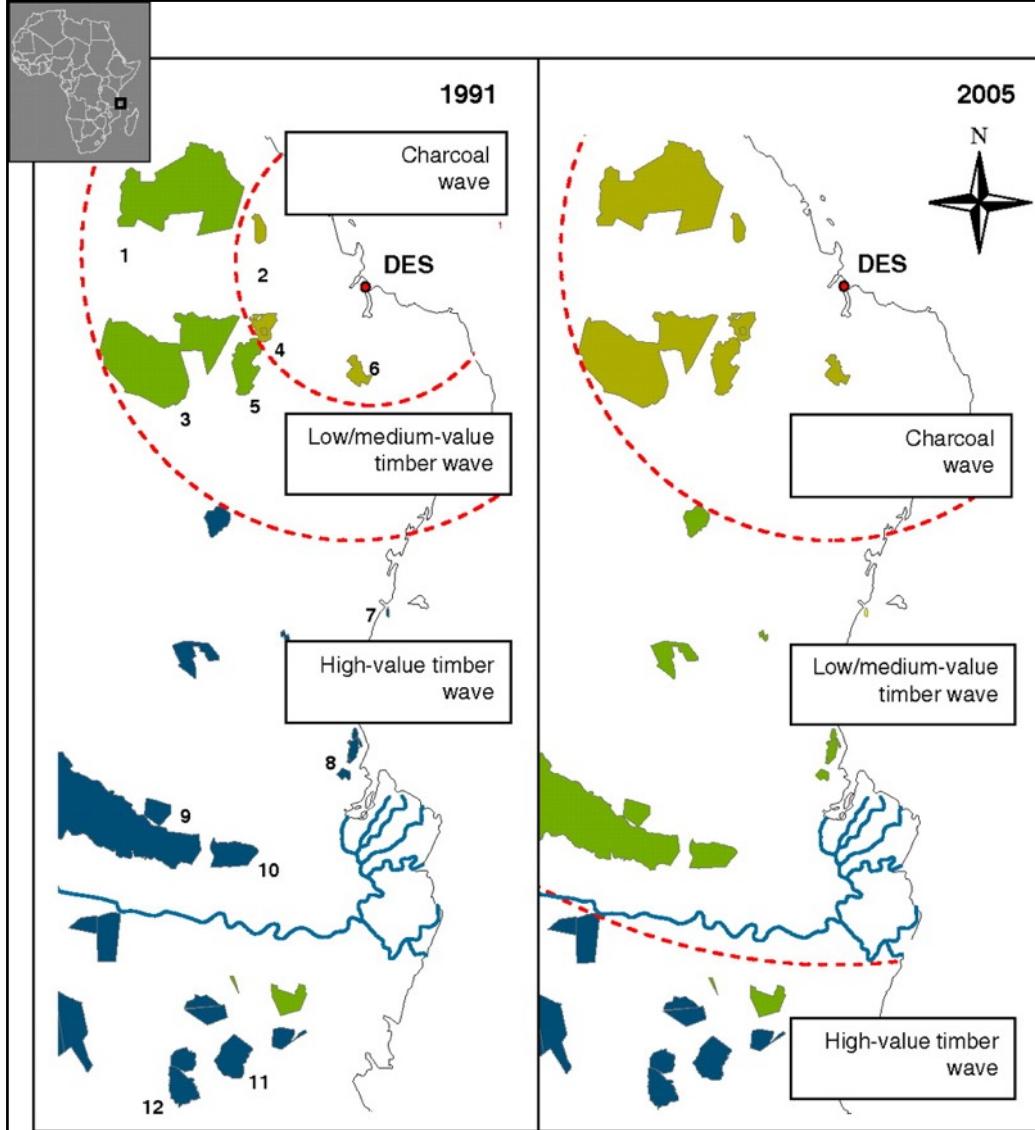
[Bockarie et al., in progress]

Percent Tree Cover in Africa



[Map: Zabala (2011). Data: Hansen et al. (2013)]

# Rapid Expansion in Charcoal Producing Zones



[Ahrends et al., 2010]

**Major driver of forest loss/degradation**



[\[https://www.worldatlas.com\]](https://www.worldatlas.com)

# Contributes Outdoor and Indoor Air Pollution

... during charcoal production with earth kilns



$\text{PM}_{2.5} > 100 \mu\text{g m}^{-3}$

[<https://www.smallstarter.com>]



[<https://blog.worldagroforestry.org/>]

... and during charcoal use for cooking



$\text{PM}_{2.5} > 400 \mu\text{g m}^{-3}$

[<https://www.economist.com>]



[<https://envirofit.org>]

# Mapping Charcoal Industry Activities (Fuel Use)

Produce



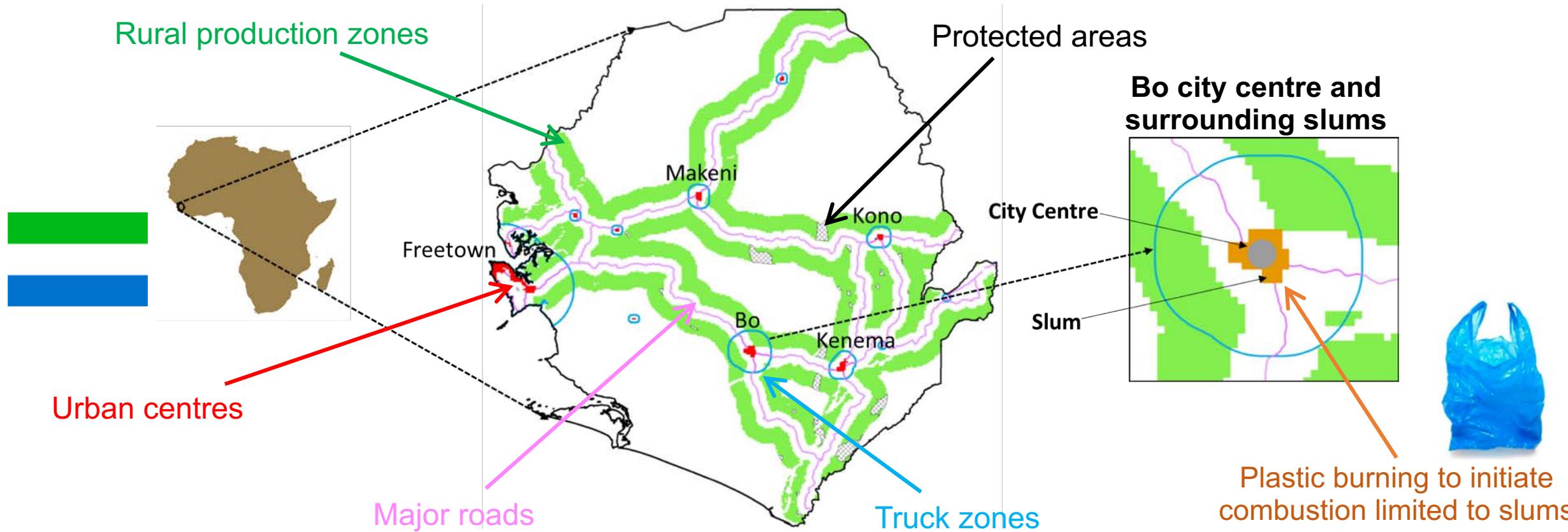
Transport



Use



Rural production zones



Urban centres

Major roads

Truck zones

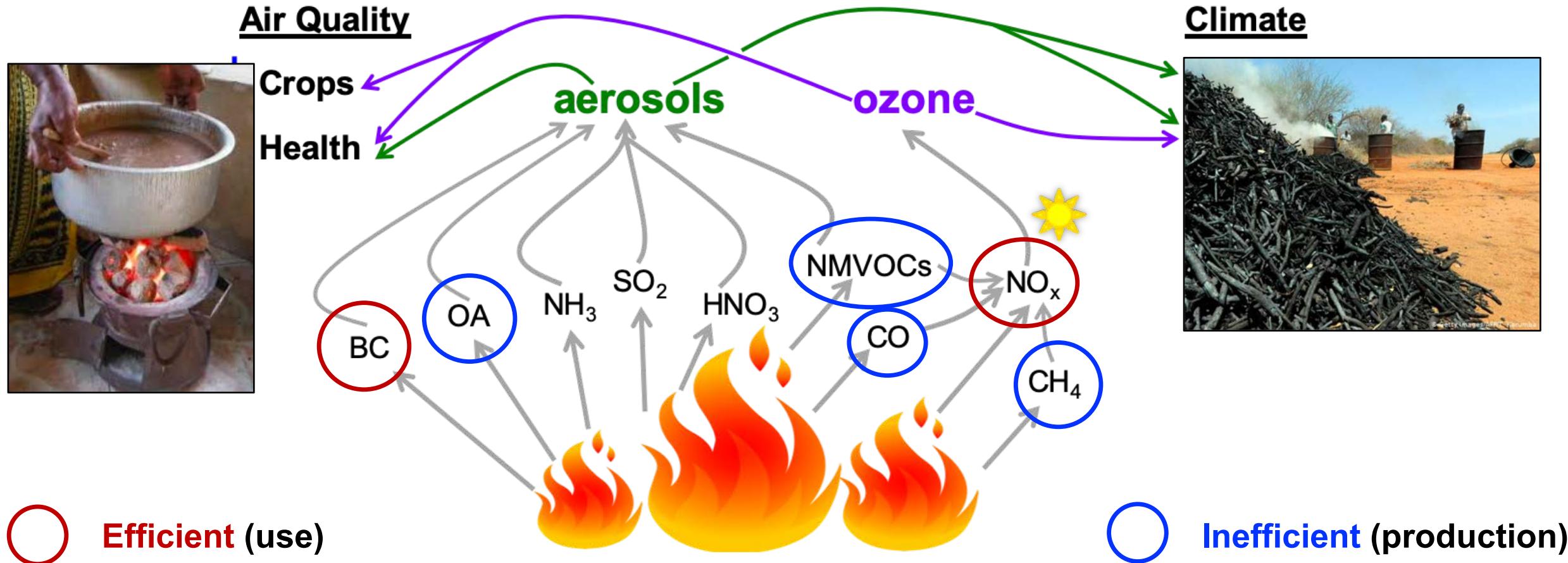
Bo city centre and surrounding slums

City Centre

Slum

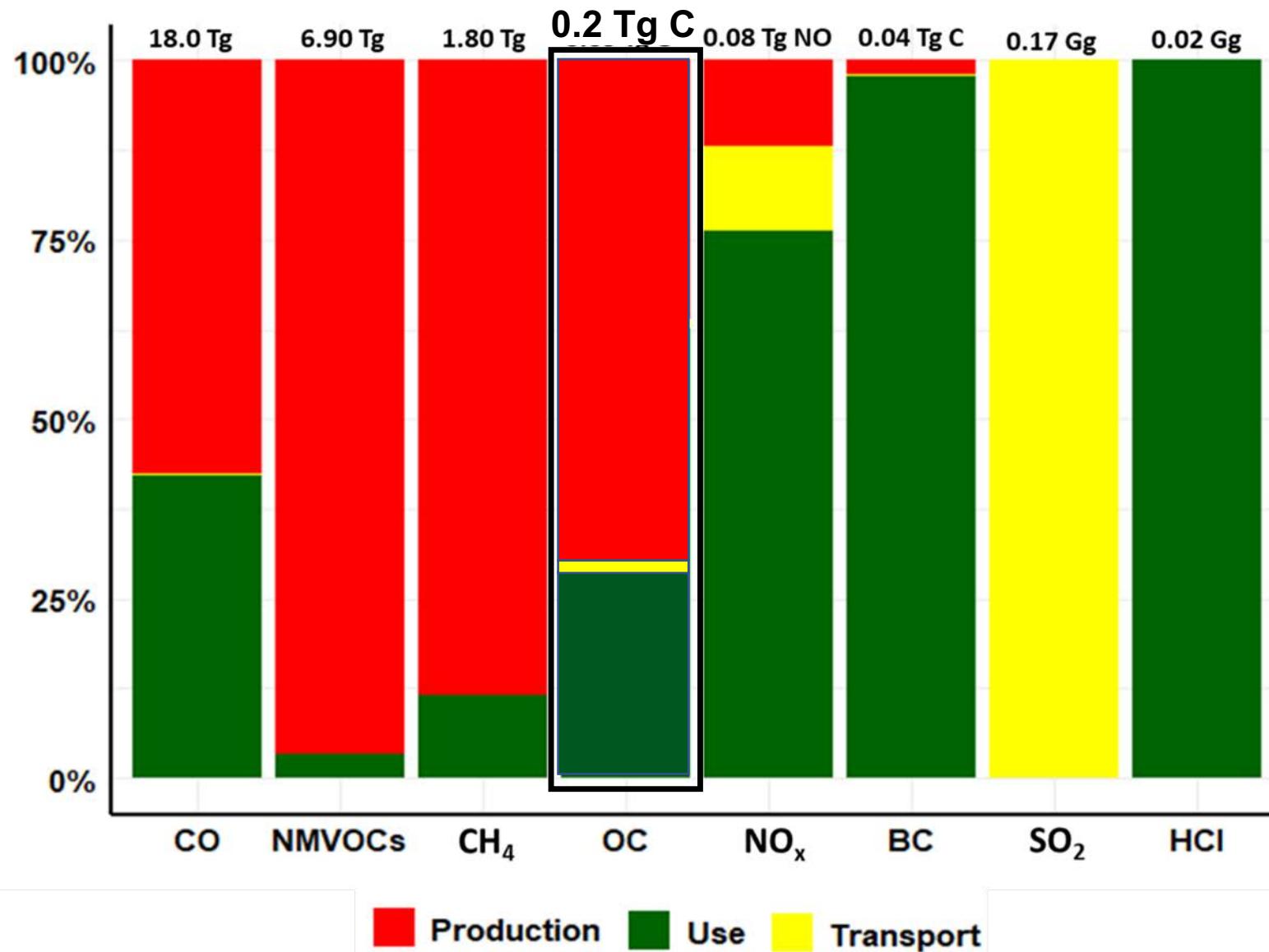
Plastic burning to initiate combustion limited to slums

# Pollutant and Precursor Emissions from Charcoal



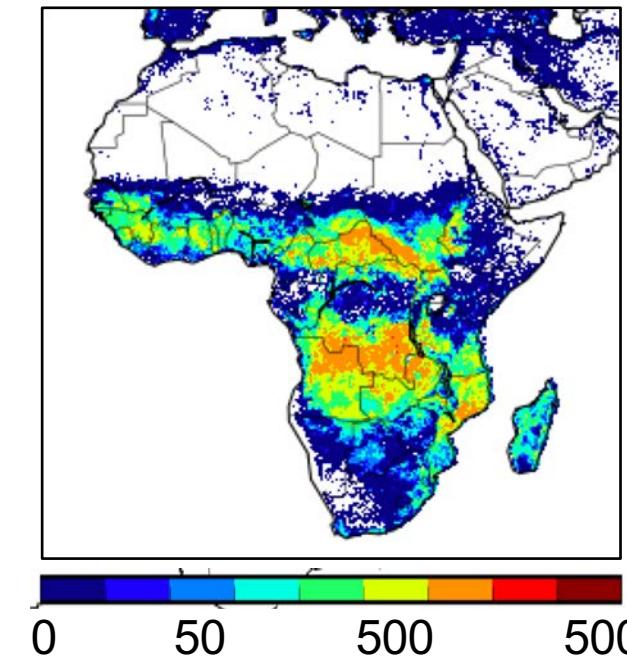
# Charcoal Activities and Pollutant Emissions

## Total and Relative Emissions



## Comparison to Open Fires

Inventory (GFED4) carbon emissions  
[g C m<sup>-2</sup> year<sup>-1</sup>]



[\[https://daac.ornl.gov/\]](https://daac.ornl.gov/)

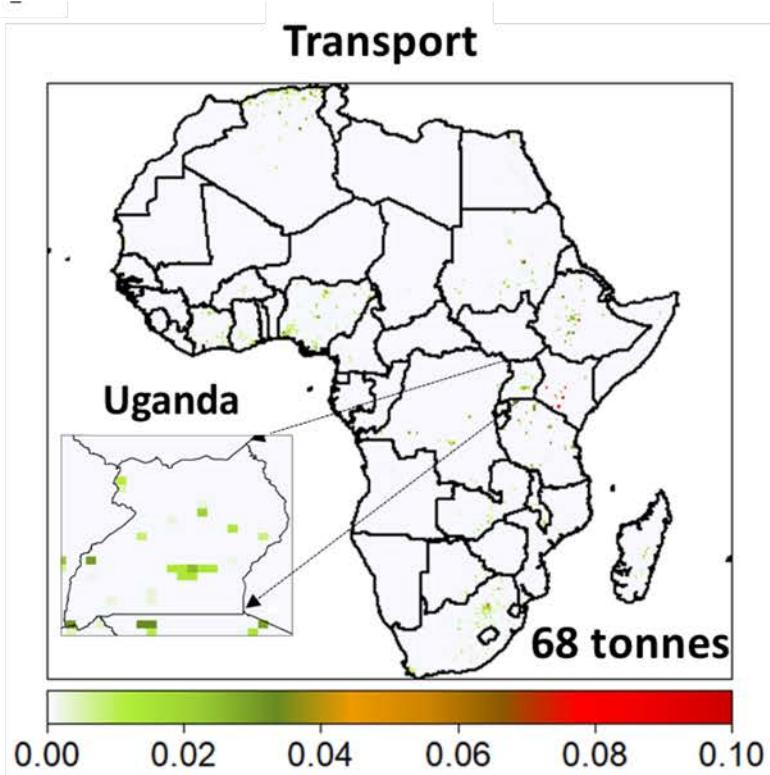
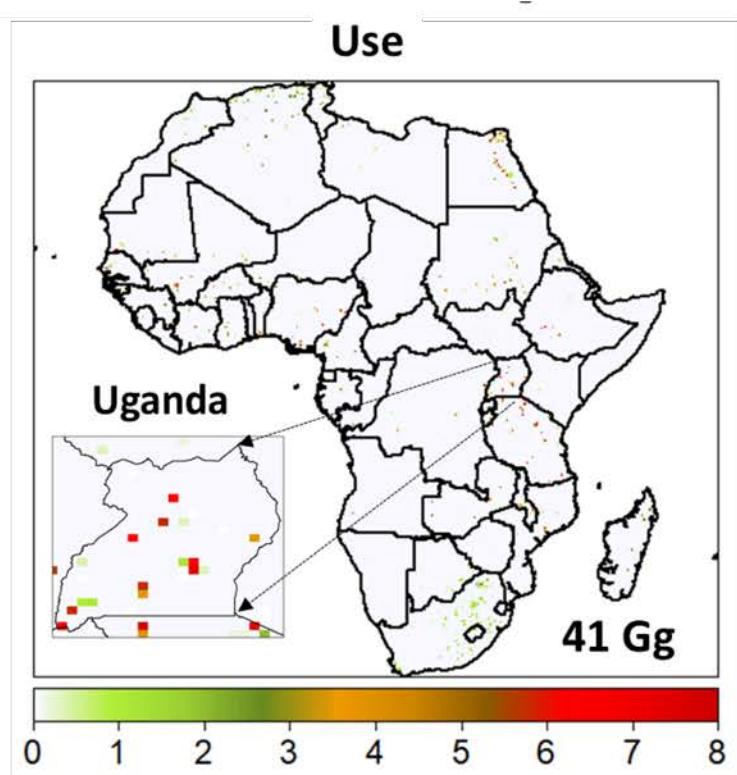
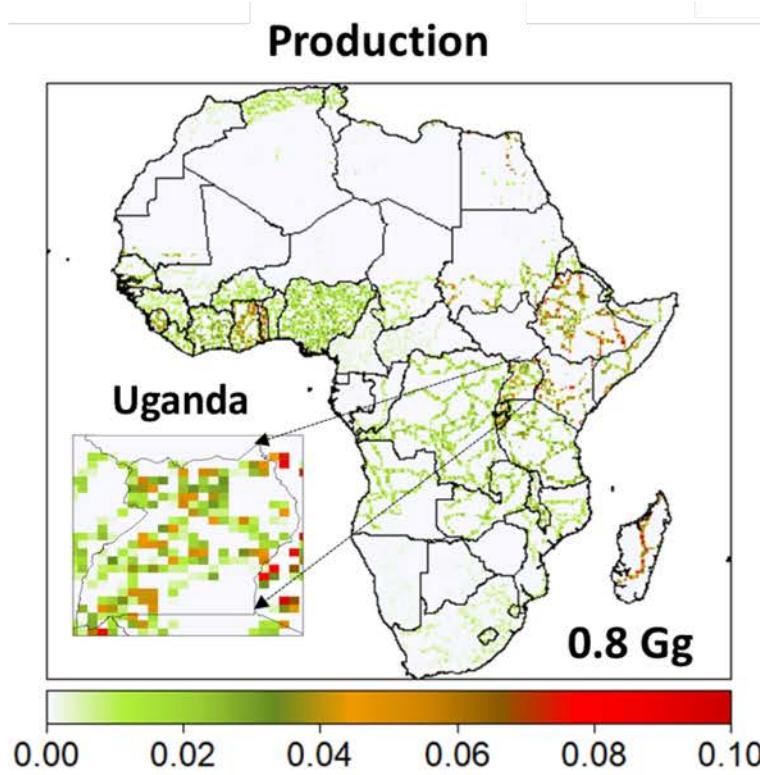
**CH<sub>4</sub>:** 4.6 Tg  
**BC:** 0.81 Tg C  
**CO:** 136 Tg  
**OC:** 5.6 Tg C

# Spatial Distribution of Emissions

Apply reported emission factors of air pollutants to mapped activities



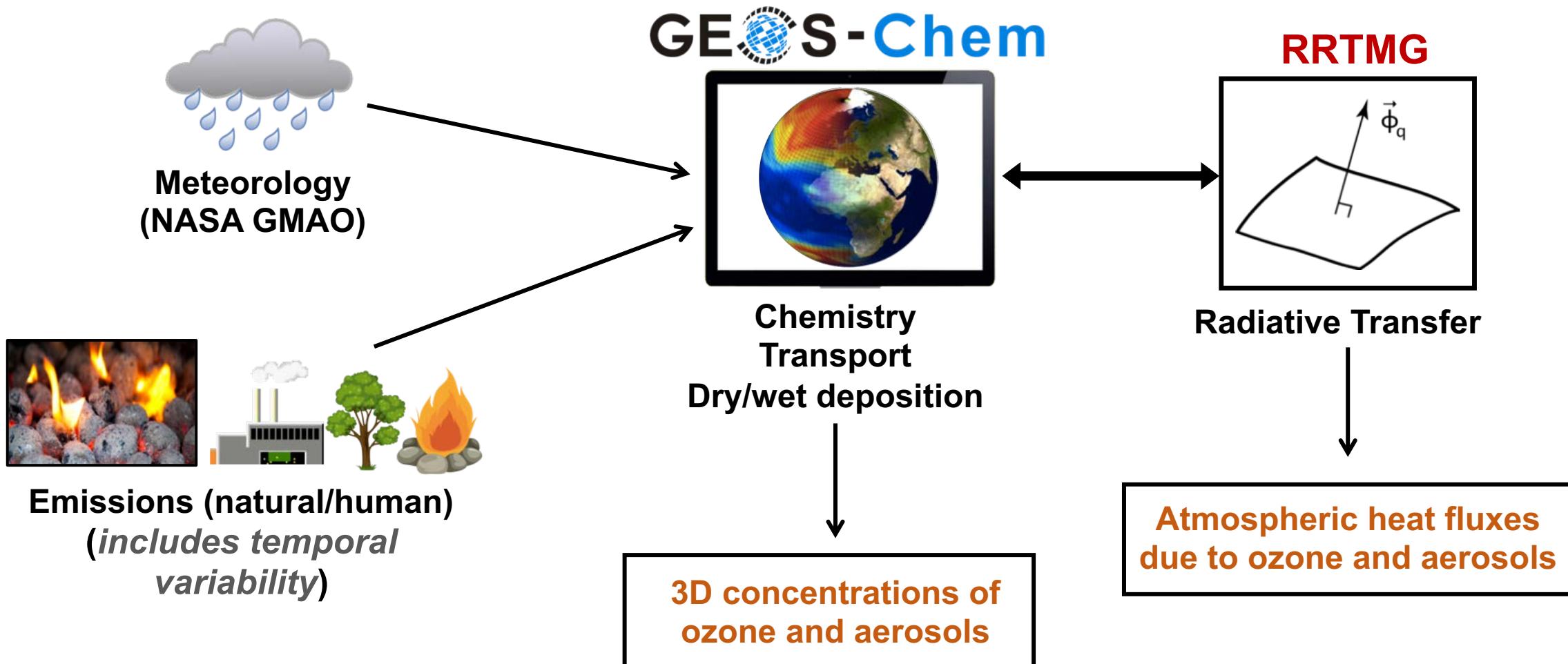
**Black carbon emissions at  $0.1^\circ \times 0.1^\circ$  grid for 2014 [tonnes per year]**



Emissions on a trajectory to double by 2030

# Quantify the Contribution to Air Pollution and Climate Change

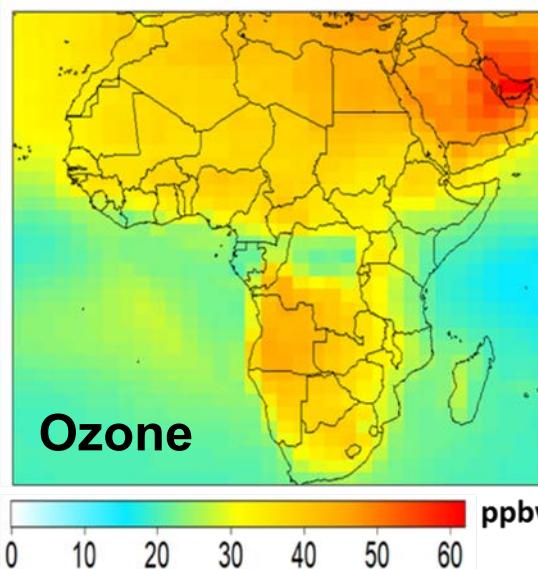
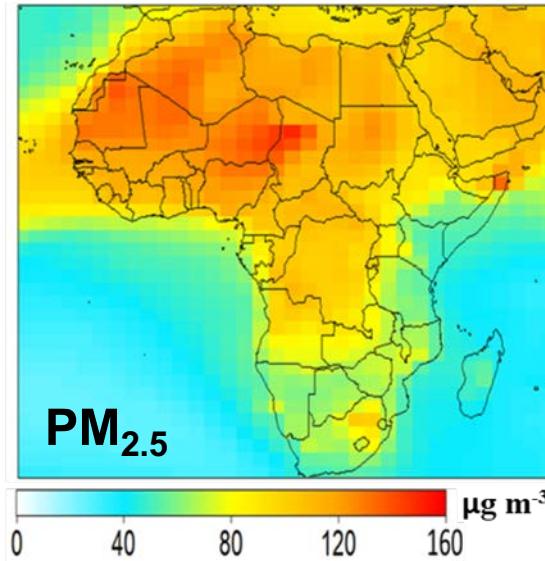
Coupled 3D atmospheric chemistry and radiative transfer models



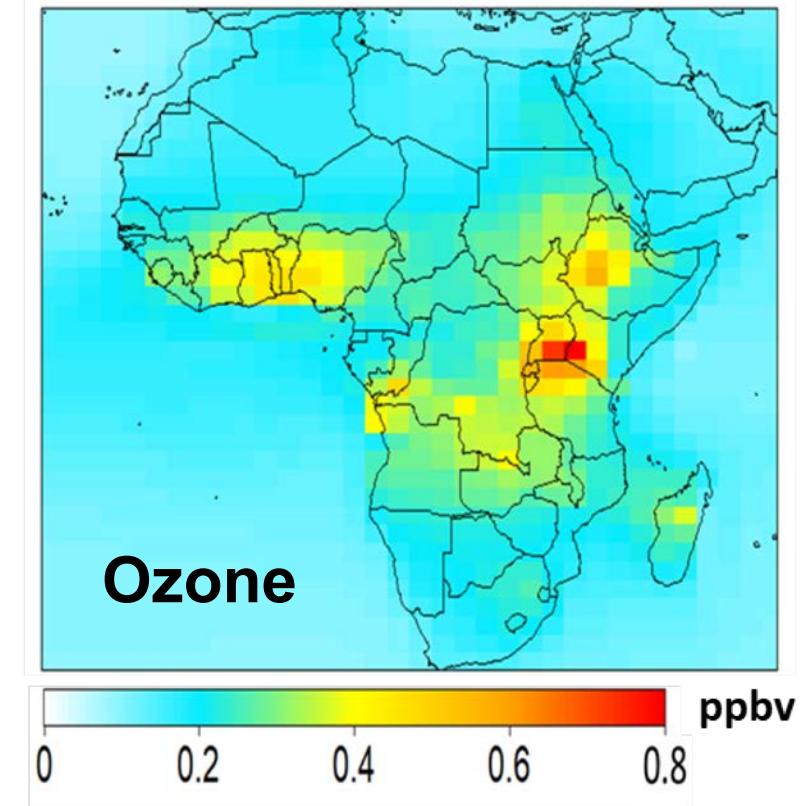
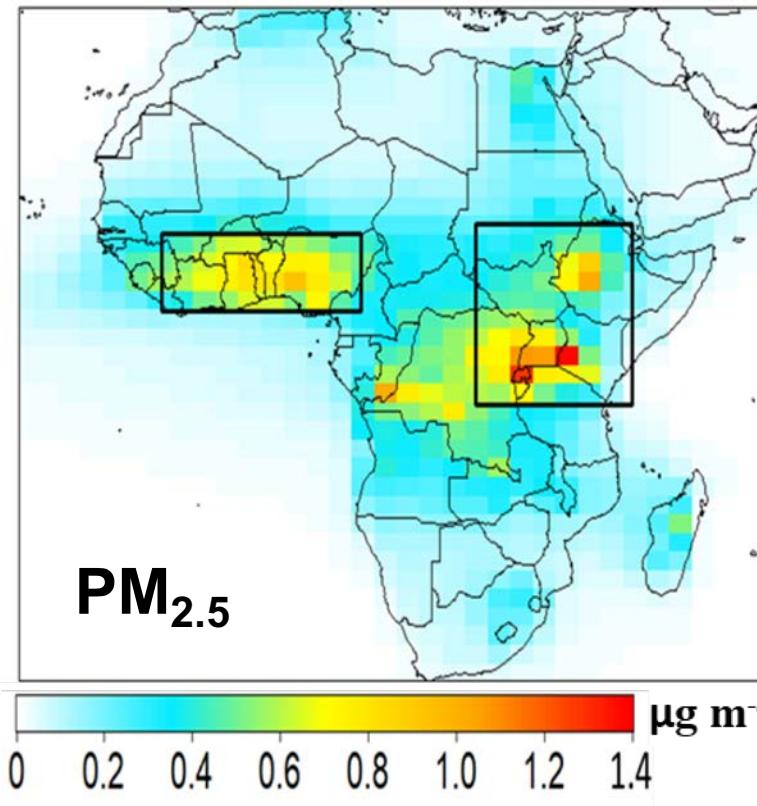
To find out more about GEOS-Chem: <http://acmg.seas.harvard.edu/geos/index.html>

# Total and Charcoal Industry Surface PM<sub>2.5</sub> and Ozone

PM<sub>2.5</sub> and Ozone from All Sources



PM<sub>2.5</sub> and Ozone from the Charcoal Industry



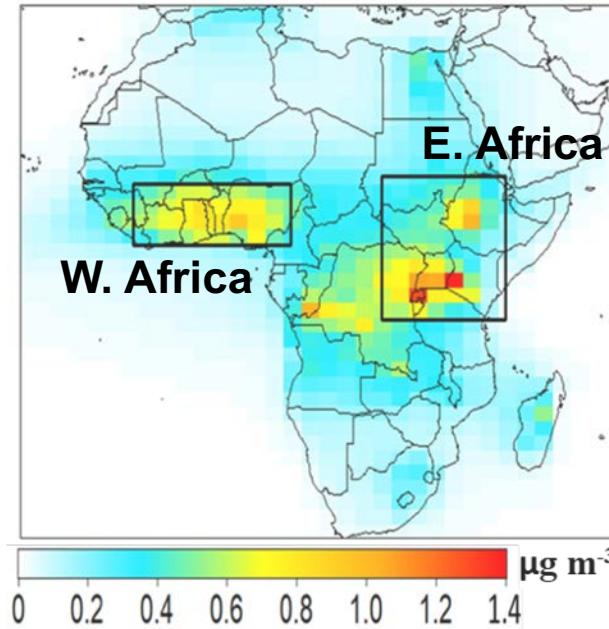
Peaks in urban areas in East, West and Central Africa, as expected from spatial distribution of emissions

PM<sub>2.5</sub> > 0.8  $\mu\text{g m}^{-3}$  in East Africa has serious health implications

Increase in surface ozone is small (at most 0.8 ppbv)

# Seasonality of Charcoal Surface PM<sub>2.5</sub> and Ozone

Charcoal industry PM<sub>2.5</sub>

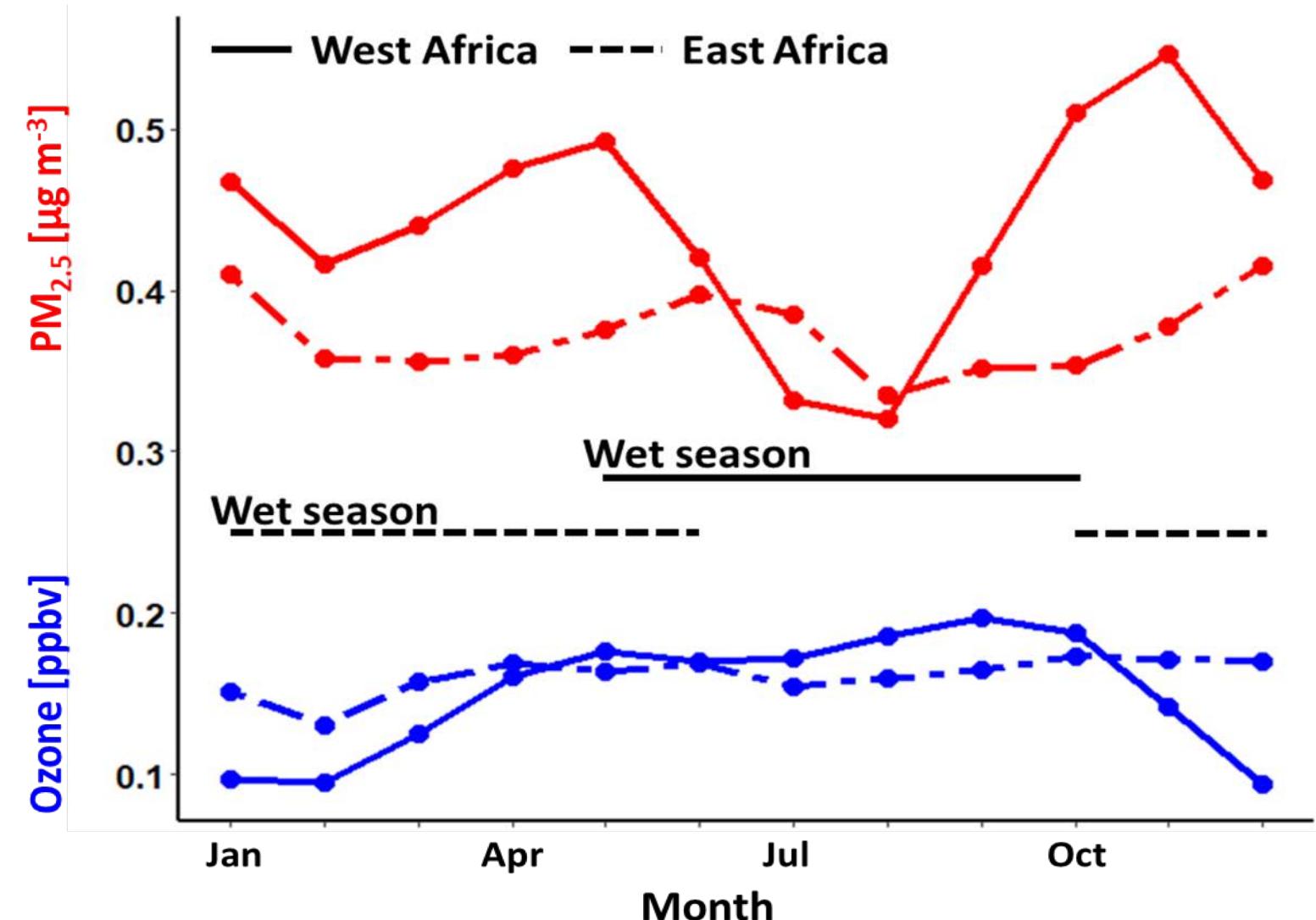


Seasonality most pronounced in West Africa

PM<sub>2.5</sub> seasonality due to monsoon and Harmattan winds

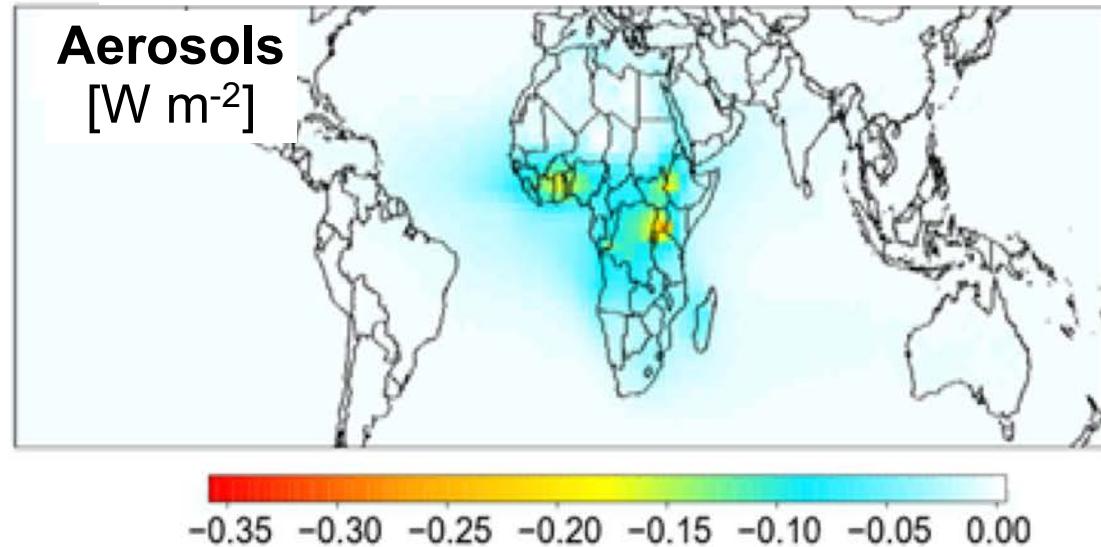
Ozone formation sensitive to NO<sub>x</sub> in wet season

Charcoal PM<sub>2.5</sub> and ozone seasonality where these peak



# Total and Charcoal Industry Surface PM<sub>2.5</sub> and Ozone

Top-of-atmosphere direct all-sky radiative forcing



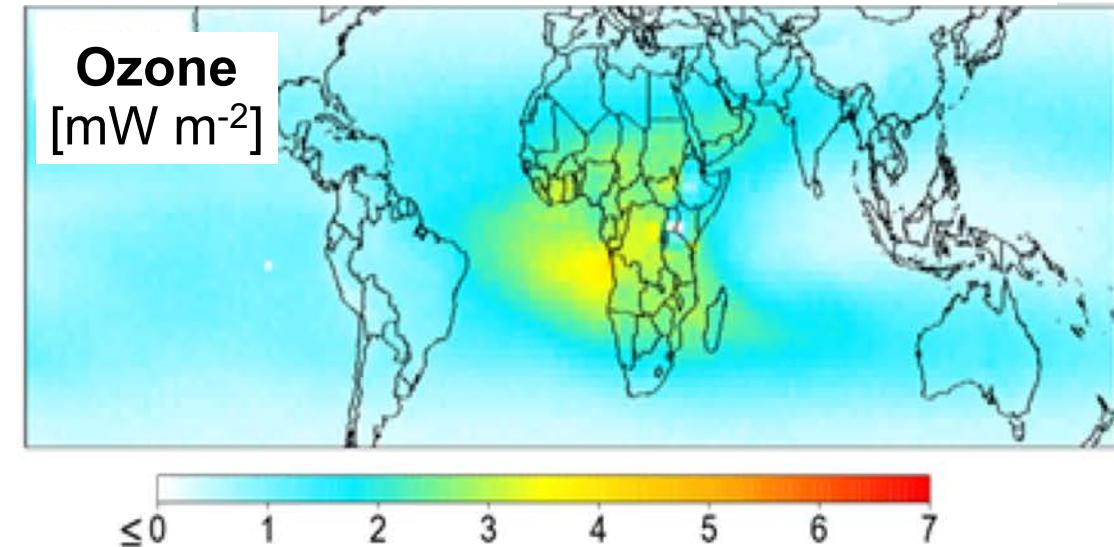
## Shortwave cooling

Due mostly to scattering by organic aerosols

Localized effect, peaking in dense urban areas

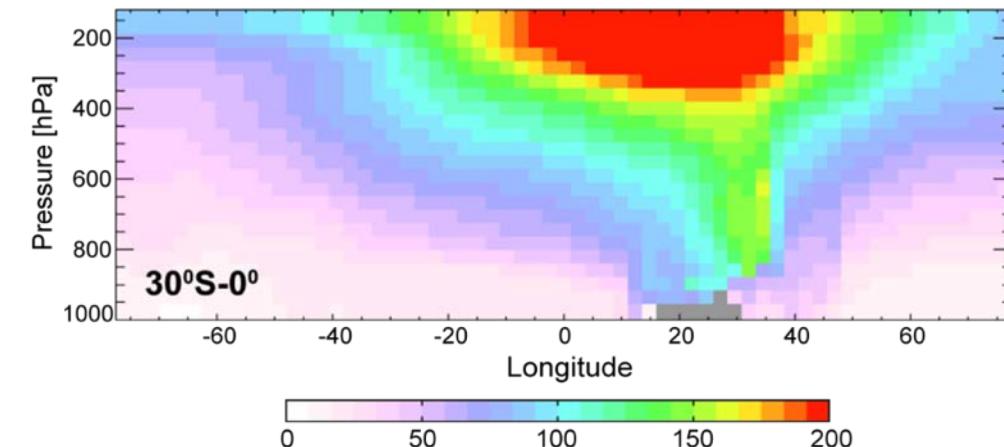
Continent mean: **-30 mW m<sup>-2</sup>**

Greater response than 10% reduction in biomass burning emissions of -4 mW m<sup>-2</sup> [Naik et al., 2007]



## Long- and short-wave heating

Mostly due to ozone in the upper troposphere



# The Environmental Impact of Charcoal will Worsen, as by 2100 the Largest Cities in the World will be in Africa

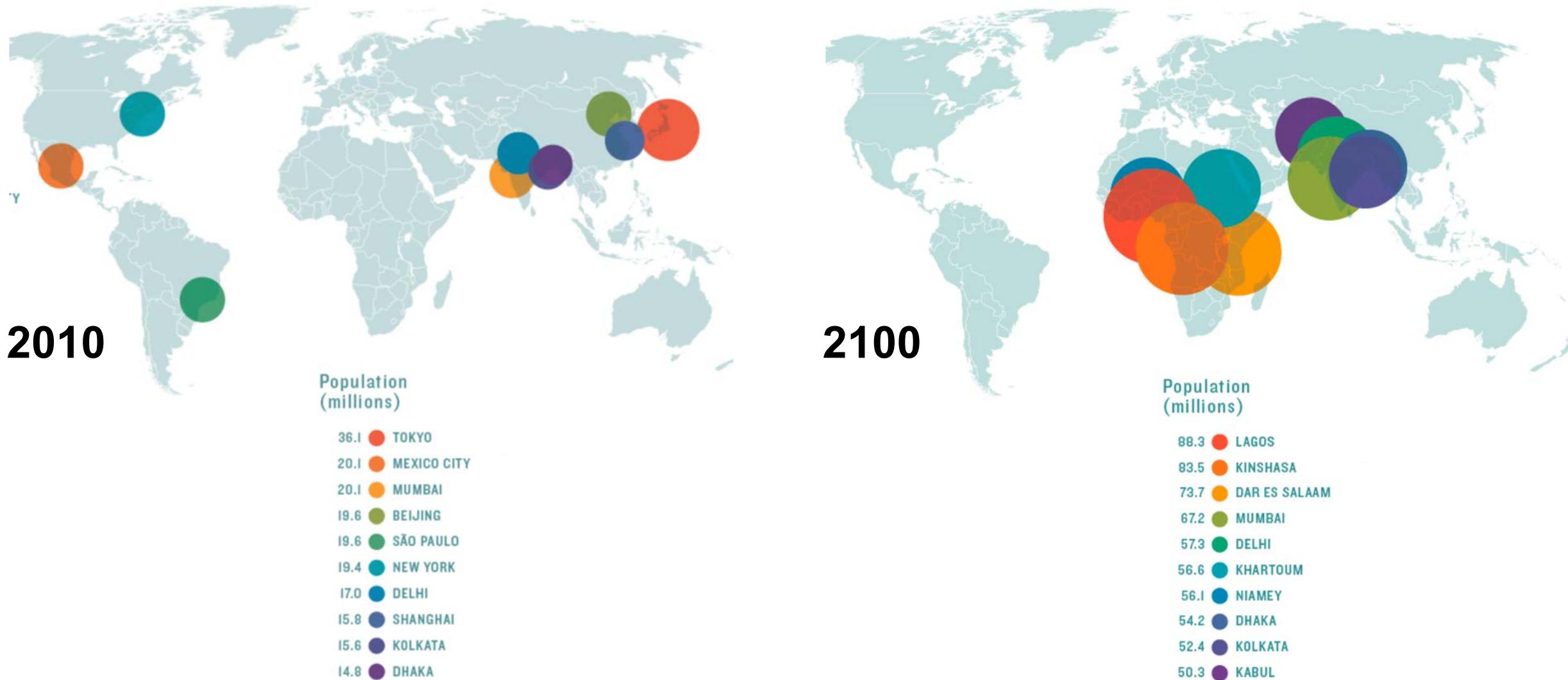


Image source: <http://edge.ensia.com/here-come-the-megacities/>

Data source: <https://journals.sagepub.com/doi/pdf/10.1177/0956247816663557>