Modelling sources of fine particles ($PM_{2.5}$) in UK cities

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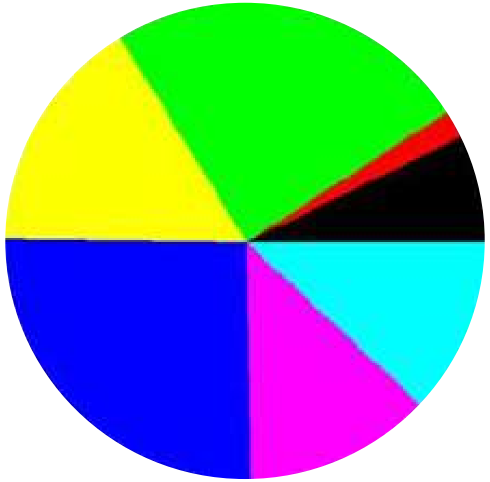
Particles are a mix of components that persist for days

Direct emission of $PM_{2.5}$ **(primary)**

Emission of gas-phase precursors **(secondary)**

$PM_{2.5}$ includes a mix of components



Black carbon primary

Sulfate
Nitrate
Ammonium
} secondary

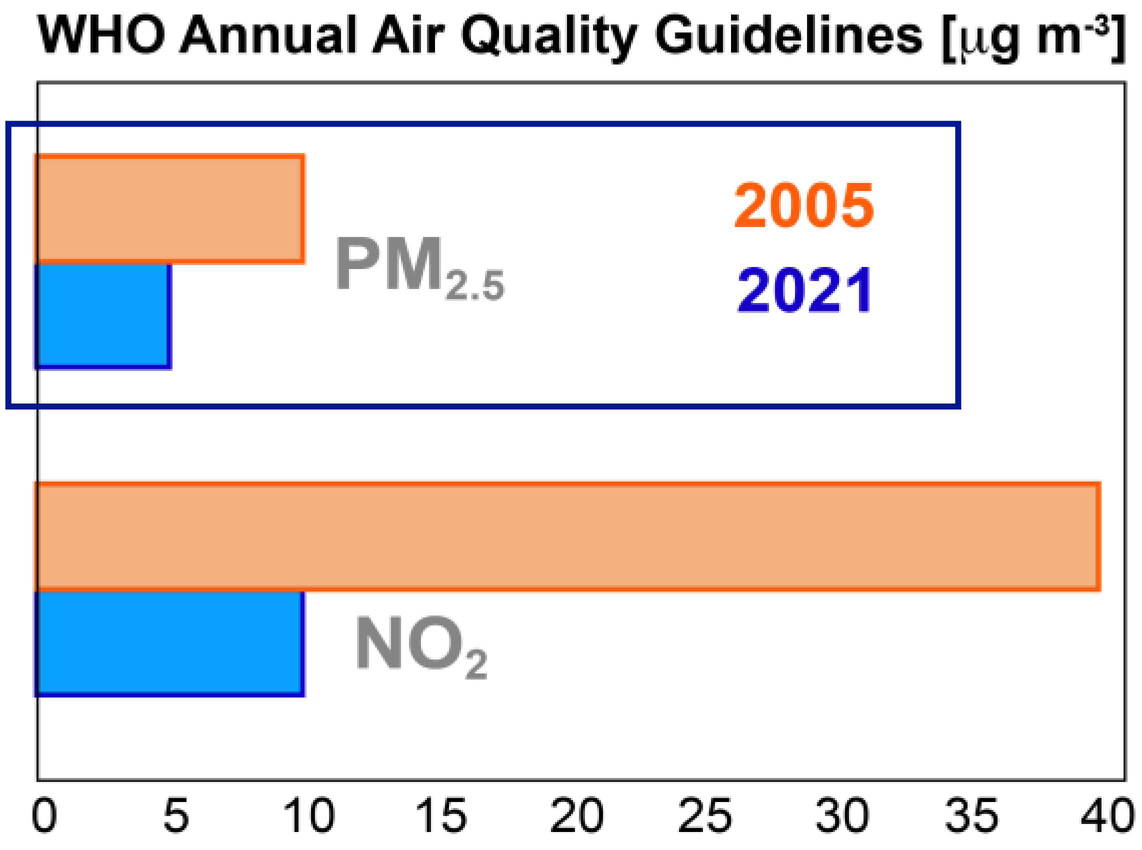
Other inorganics

Organic aerosols primary+secondary

$PM_{2.5}$ includes local and distant sources (long atmospheric lifetime)

Stricter World Health Organization (WHO) Guideline

(https://apps.who.int/iris/handle/10665/345329)

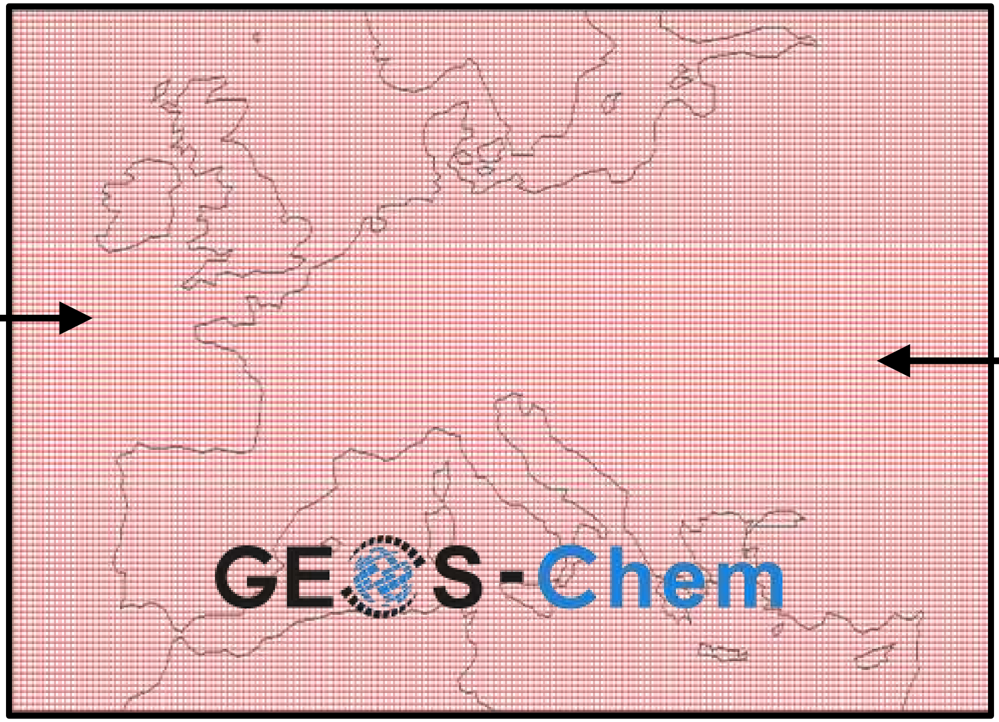


Source: WHO Facebook page

Simulate $PM_{2.5}$ with the 3D Model GEOS-Chem

Comprehensive emissions

3D Atmospheric Chemistry Transport Model



Chemistry, transport, loss processes

NASA Meteorology

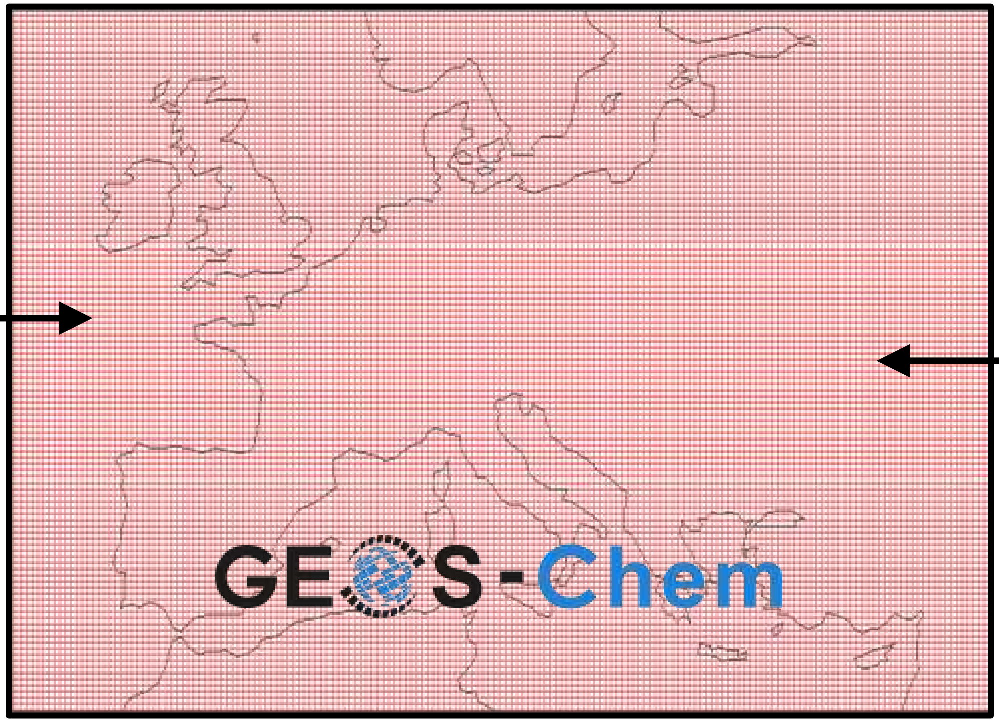
$PM_{2.5}$ from all but one source

GEOS-Chem manual: http://acmg.seas.harvard.edu/geos/

Simulate $PM_{2.5}$ with the 3D Model GEOS-Chem

Comprehensive emissions

3D Atmospheric Chemistry Transport Model



Chemistry, transport, loss processes

NASA Meteorology

$PM_{2.5}$ from all but one location

GEOS-Chem manual: http://acmg.seas.harvard.edu/geos/

Test Contribution of Potentially Influential Sources

Local

City

County

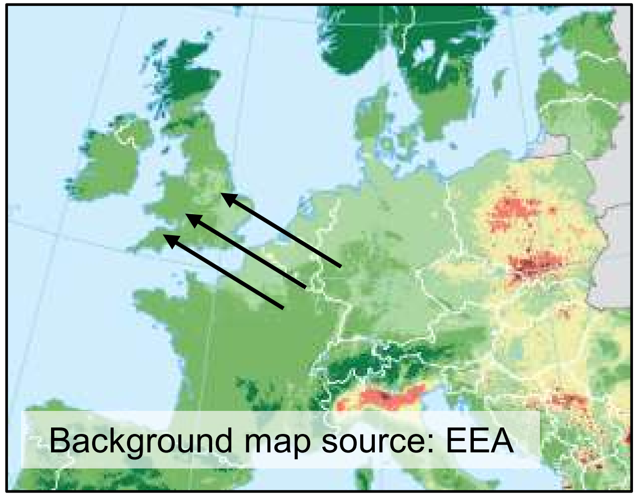
National

Nearby large cities

Transport

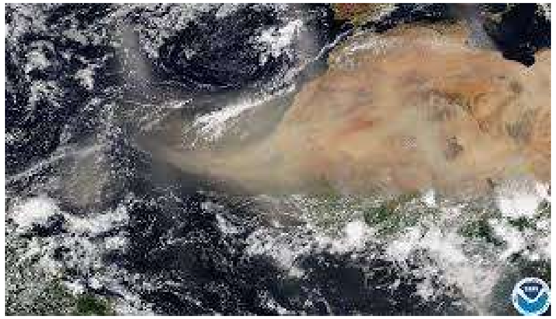
Agriculture

Regional



Mainland Europe

Global

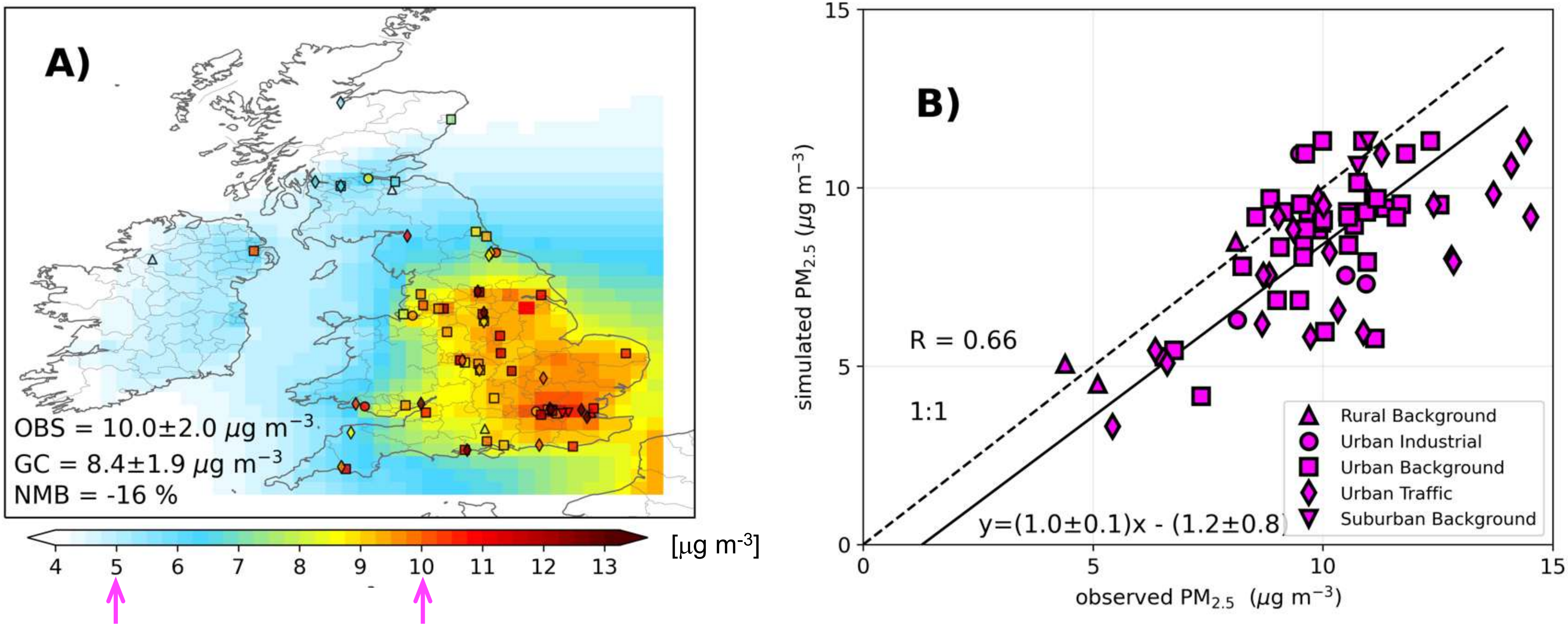


Desert Dust

Assess Validity of Model using Reference Monitors

Use total $PM_{2.5}$ observations from the Automatic Urban and Rural Network (AURN) to assess model

Comparison of annual mean surface concentrations of $PM_{2.5}$ for 2019



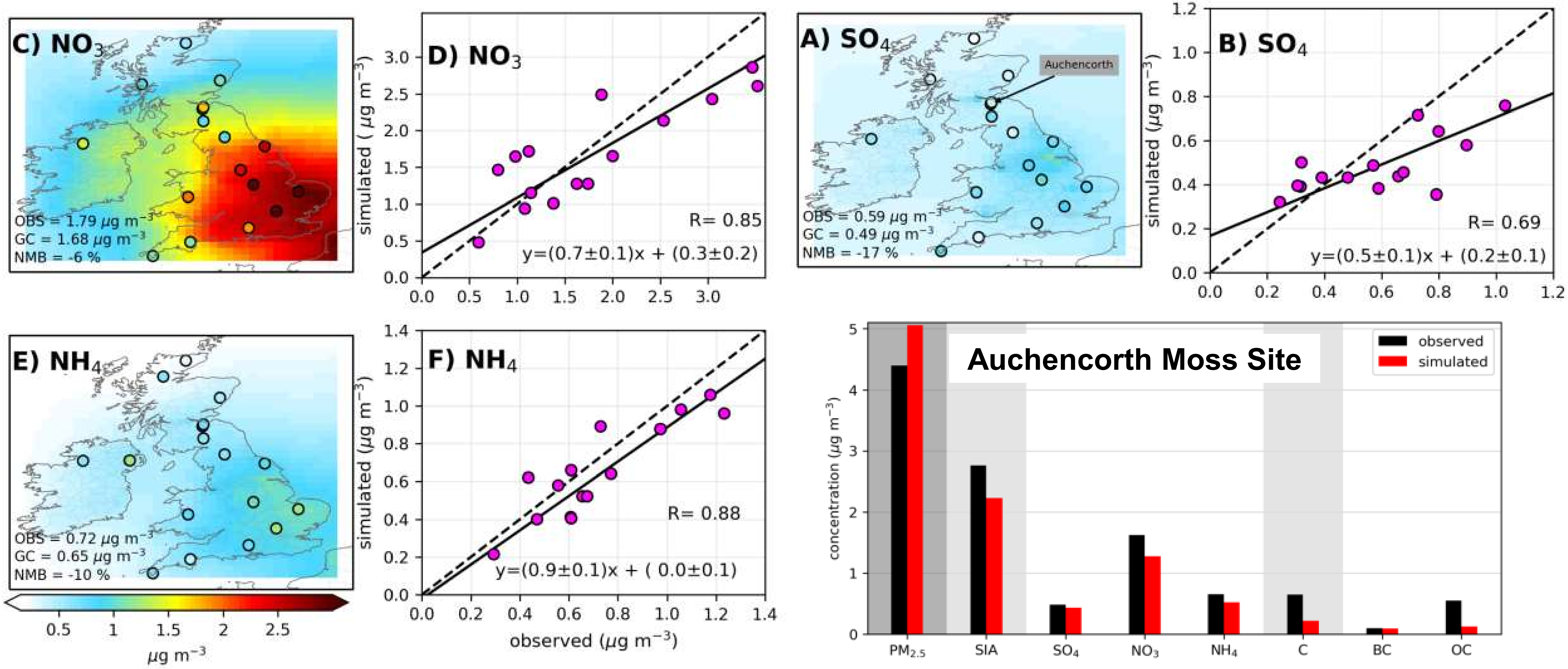
WHO (2021) **WHO (2005)**

74% of UK exceeds updated WHO guideline

Consistent spatial pattern (**R = 0.66**) and variance (**slope = 1.0**). Model **16% less** than observations

Assess Validity of Model using Reference Monitors

Use $PM_{2.5}$ composition measurements from UKEAP and EMEP sites to assess model

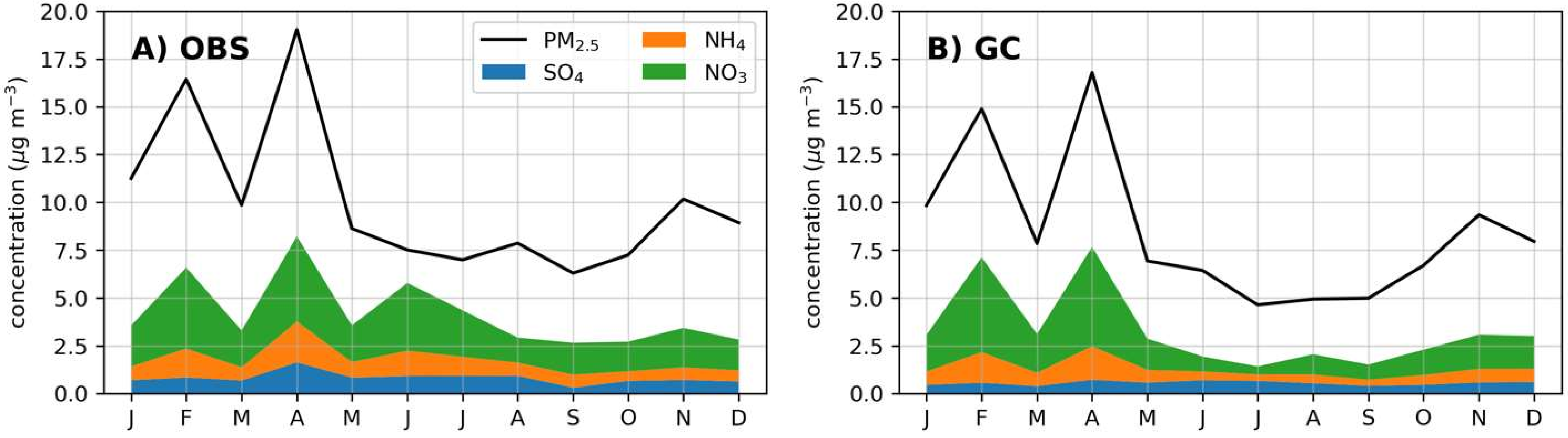


Model underpredicts observed (sulfate, nitrate, ammonium) and possibly overpredicts unobserved (dust) components. Model captures variance of components from NO_x (nitrate) and ammonia (ammonium)

Assess Validity of Model using Reference Monitors

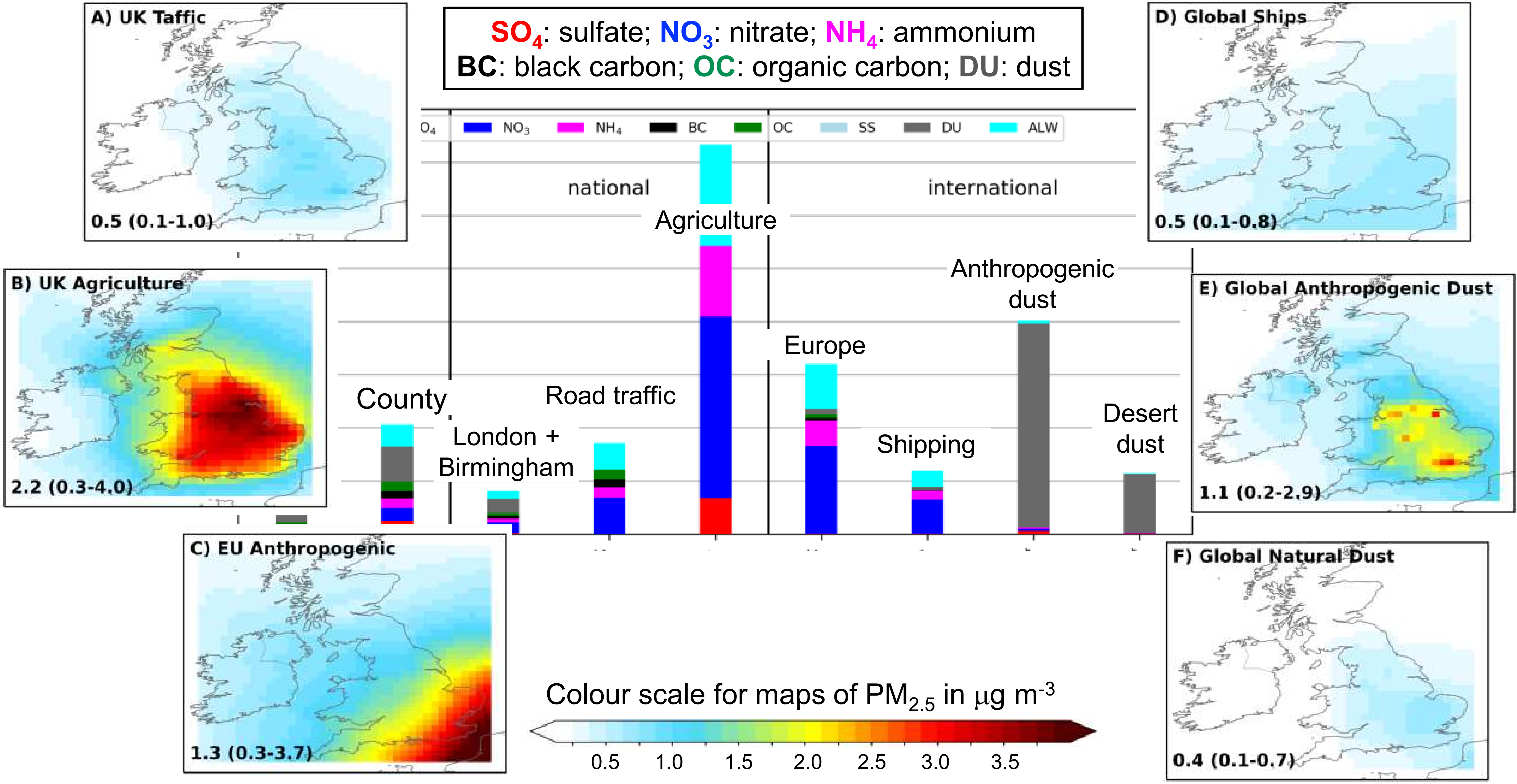
Also evaluate model skill at reproducing observed seasonality in $PM_{2.5}$

SO_4: sulfate; **NO_3**: nitrate; **NH_4**: ammonium

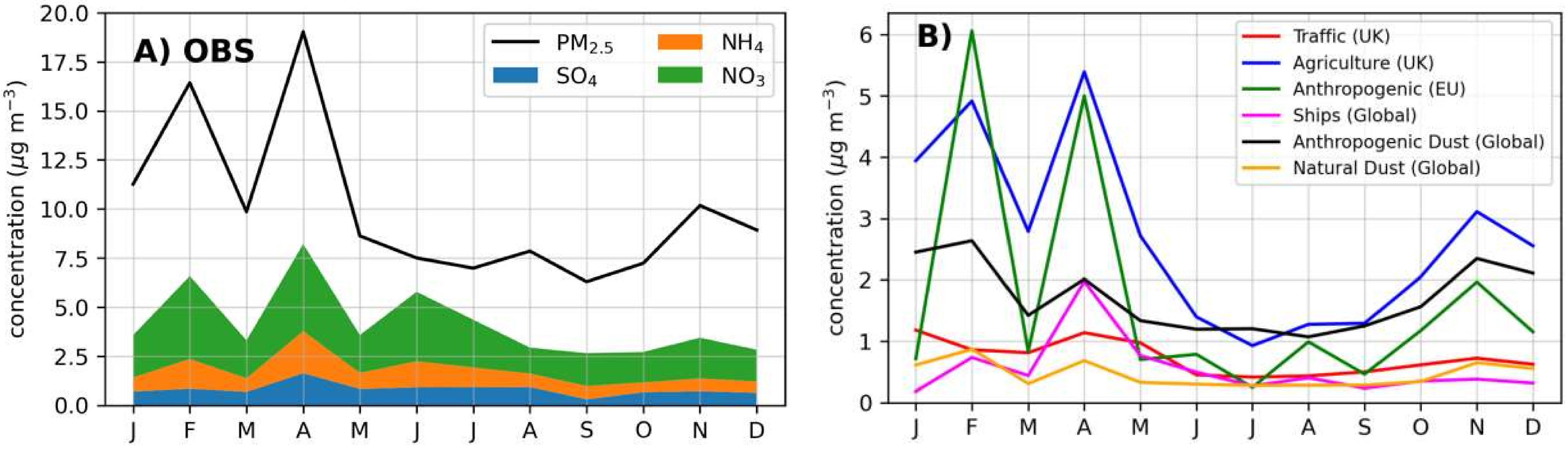


Enhancements in cold months and when ammonia emissions from agriculture peak due to application of synthetic fertilizer in March-April

Contribution of Sources to annual $PM_{2.5}$ in Leicester



Contribution of Sources to $PM_{2.5}$ seasonality in Leicester



Comparable contributions from road traffic (exhaust) and shipping emissions

Agriculture largest contributor in every month except February

Mainland Europe contribution peaks in November to April, due to long atmospheric lifetime of $PM_{2.5}$ in winter (cold temperatures, calm conditions, low planetary boundary layer)

Corroborating Evidence from Low-Cost Sensors

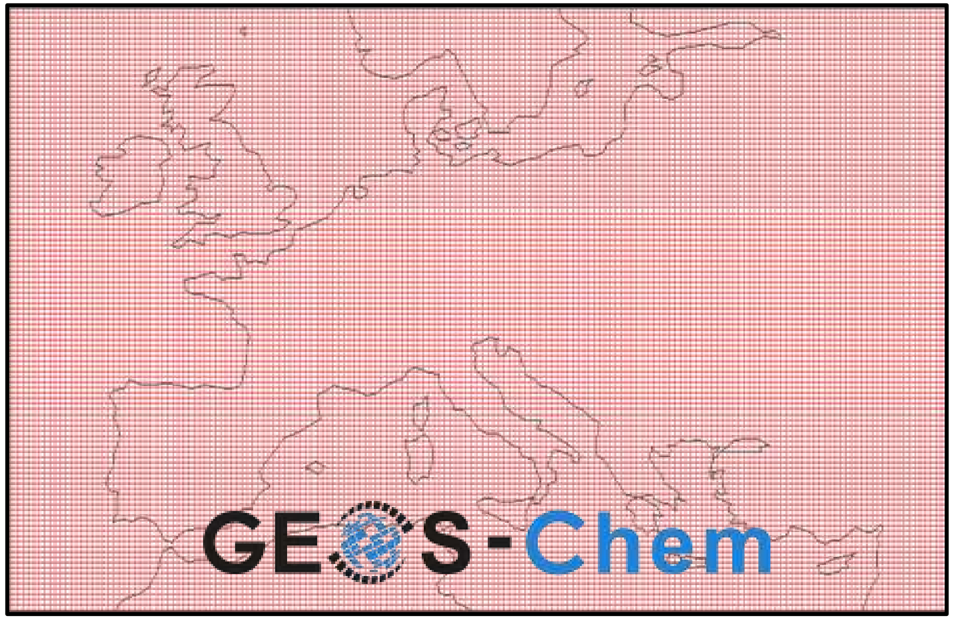
Low-cost network of Zephyr® sensors distributed throughout Leicester since November 2020

AURN network

GEOS-Chem model

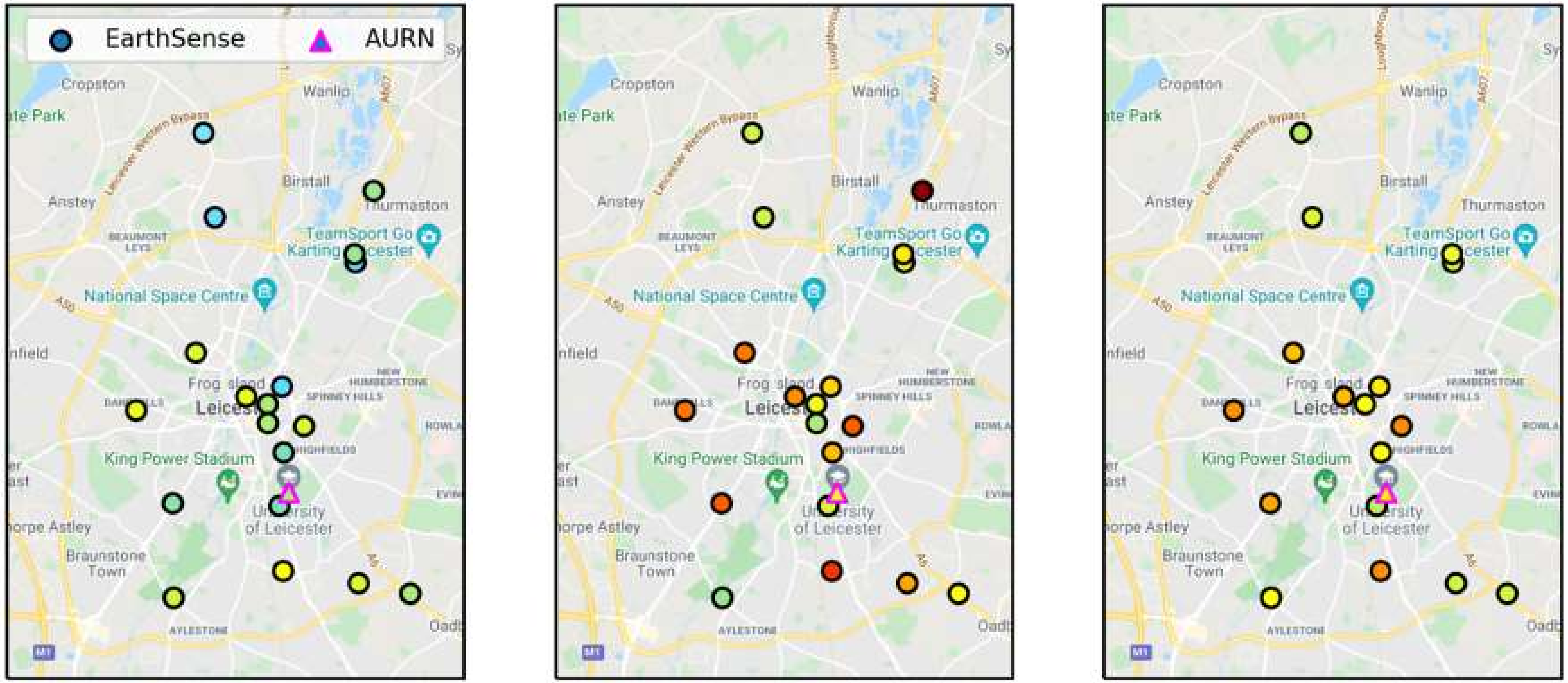
EarthSense low-cost sensors

Jan 2019 | Jul 2019 | Jan 2020 | Jul 2020 | Jan 2021 | Present

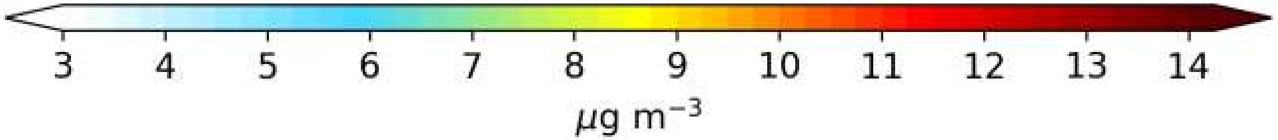


Corroborating Evidence from Low-Cost Sensors

December 2020 | January 2021 | February 2021

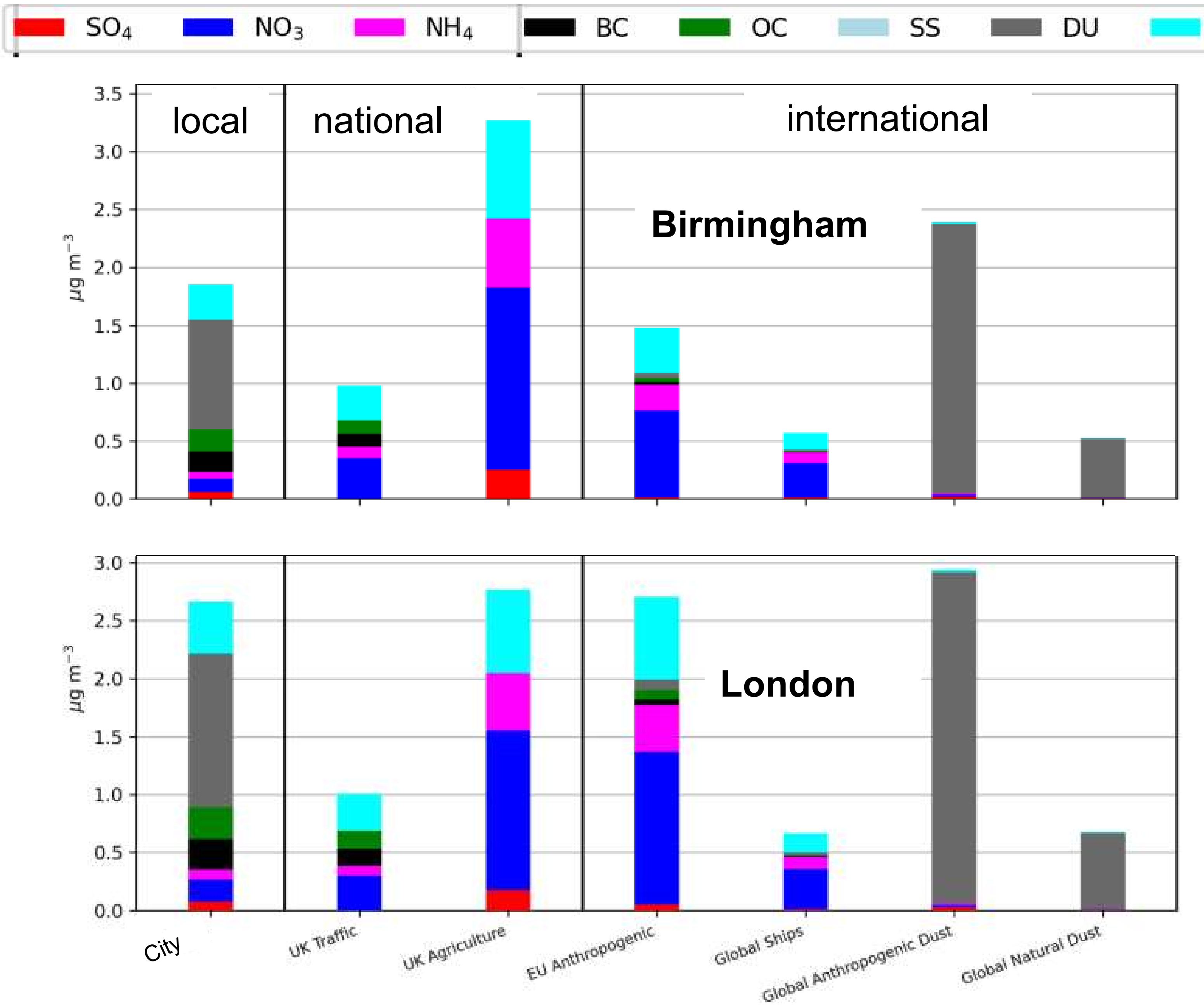


Mean ± std dev:	7.2 ± 1.0 μg m^{-3}	9.2 ± 1.4 μg m^{-3}	8.7 ± 0.8 μg m^{-3}



According to low-cost sensors, local sources contribute **5-11%**. Similar to the model (**3-5%**)

Results for Large Cities like London and Birmingham



SO_4: sulfate; **NO_3**: nitrate; **NH_4**: ammonium; **BC**: black carbon; **OC**: organic carbon; **DU**: dust

London: 1,600 km^2

Birmingham: 270 km^2

Leicester: 70 km^2

Broad applicability to other cities

Only in London is local $PM_{2.5}$ similar to agriculture

Conclusions and Acknowledgements

- Under-regulated agricultural sector dominates $PM_{2.5}$ year-round
- Mainland Europe makes large seasonal contribution to $PM_{2.5}$ in November to April.
- Policies targeting local sources only likely to be effective for large cities like London
- Results reinforce the need for continued and strengthened international agreements and measures to control ammonia emissions from agriculture
- Anthropogenic dust is a large source of uncertainty due to challenges representing emissions and evaluating the model

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Leicester City Council

Department for Environment Food & Rural Affairs