Climatological Impact of Black Carbon Transport from European Major Population Centers.

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Introduction

Results of numerical simulations on **the climatological dispersion characteristics of air pollution plumes emanating from major population centers (MPCs) in Europe** are presented here.

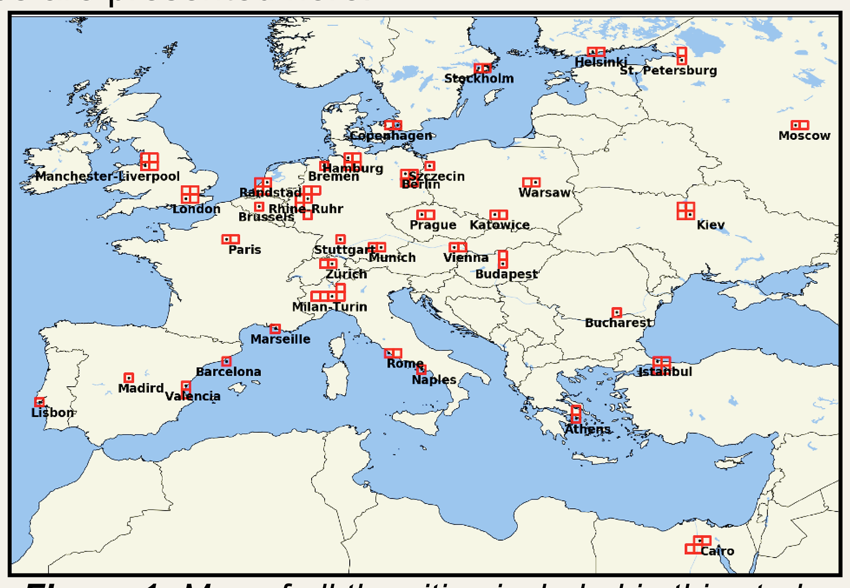

Figure 1: Map of all the cities included in this study. Red squares correspond to gridboxes of 0.5°.

The aim of this study was to develop methods of quantification **of the impact of black carbon (BC) emissions from selected European MPCs on air pollution levels at local, regional and hemispheric scales.**

Black carbon was chosen since it plays a significant role as a positive radiative forcer and impacts notably human health. Also it is well suited for transport studies due to its linear chemistry.

Methods

For this transport study, the offline Lagrangian particle dispersion model **FLEXPART** (v10.2beta) [2] driven by ECMWF ERA-Interim reanalysis data (resolution: *0.75°*) was run yearly (with one month spin-up) in forward mode from January 1980 to December 2014 (output resolution: *0.5°*). The time period of this climatological study was limited by meteorological and emission data. BC was modeled subject to removal processes by dry and wet deposition. Properties of this BC particle tracer were the following: density: *1400* $kg\ m^{-3}$, molar mass: *12.2* $g\ mol^{-1}$, aerodynamic mean diameter: $2.5 \cdot 10^{-7}\ m$, logarithmic standard deviation: *1.25*. [3] The model was run with normalized emissions of BC tracer as input to allow for scaling the results in the post processing with the CMIP6 anthropogenic BC emissions inventory (resolution: *0.5°*, monthly), see ***Figure 2***. This was possible because the BC loss processes are considered being linear.

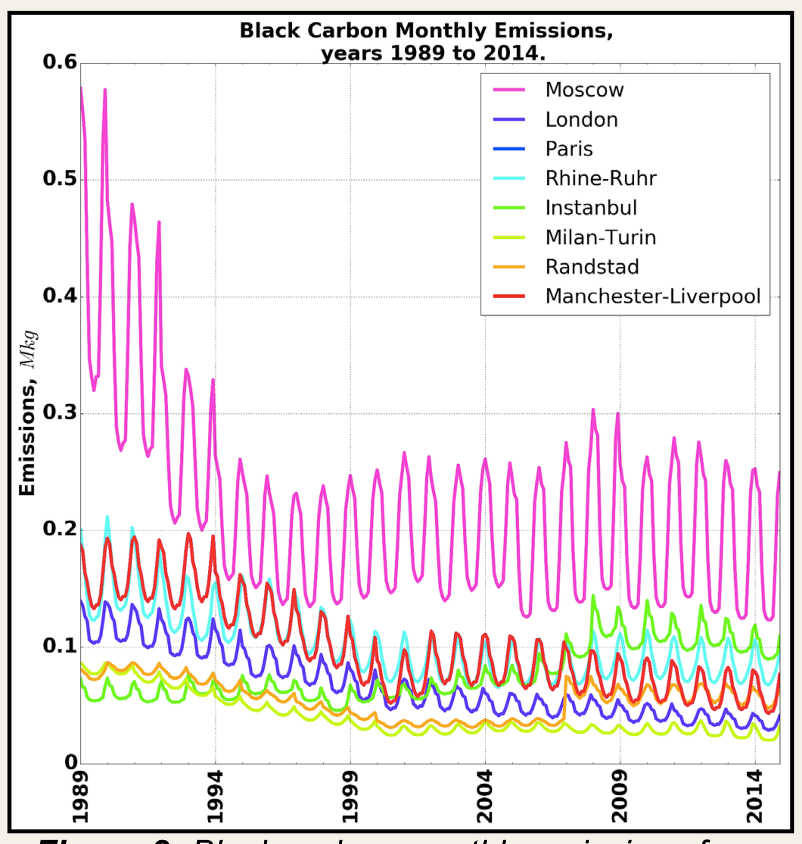

*Figure 2: Black carbon monthly emissions for urban areas defined in **Table 1**.*

The anthropogenic BC emissions (***Figure 2***) from the chosen MPCs are treated separately to allow both the investigation of their individual but also their cumulative impact, compared to other black carbon sources, on local atmospheric composition, and regional sites of pollution accumulation. The area of the analyzed cities were ensembles of *0.5°* gridboxes, see ***Figure 1***. The cities were classified by geographical location, economical situation, population size, and area. Here are presented those located in Europe with population above 5.5 mln (within their gridded area in 2005, SEDEC), see ***Table 1***.

	Latitude	Longitude	Gridboxes	Area [km2]	Population [mln]
Moscow	55.75	37.25	2.0	3478.0	13.71
London	51.25	-0.25	4.0	7694.0	10.77
Paris	48.75	2.25	2.0	4076.0	9.45
Rhine-Ruhr	37.75	23.75	6.0	11625.0	9.19
Istanbul	45.25	8.75	4.0	9328.0	8.34
Milan-Turin	41.75	12.25	5.0	10860.0	6.82
Randstad	41.25	2.25	4.0	7610.0	6.26
Manchester-Liverpool	50.25	18.75	4.0	7352.0	5.76

***Table 1:** Description of European cities. Longitude and latitude are the mid points of one of the gridboxes belonging to the city as presented in **Figure 1**. Area and population of the cities was calculated based on the number of gridboxes and SEDEC data from 2005.*

Motivation

This study of patterns of BC dispersion from Europe-MPCs addresses two general questions:

1 How are the levels of BC concentration impacted within a given distance from the city?

2 What is the size of the geographical area with a notable accumulation of pollution caused by the city, thus how many people are impacted by those additions to pollution levels?

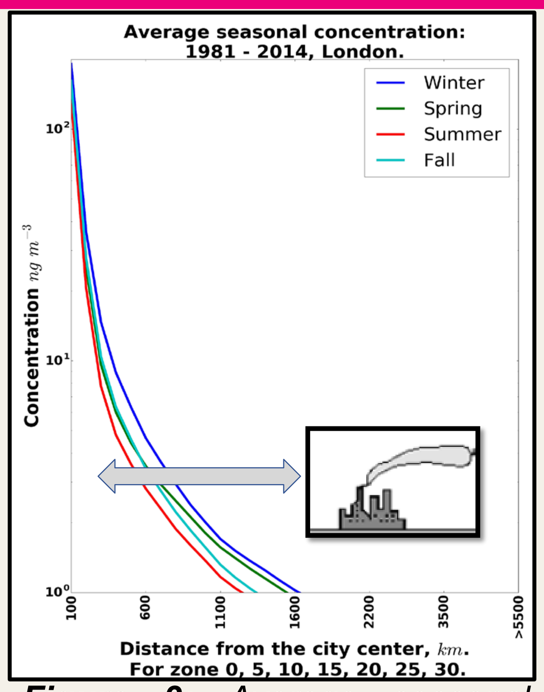

Figure 3: Average seasonal concentrations of BC from London for years 1981-2014.

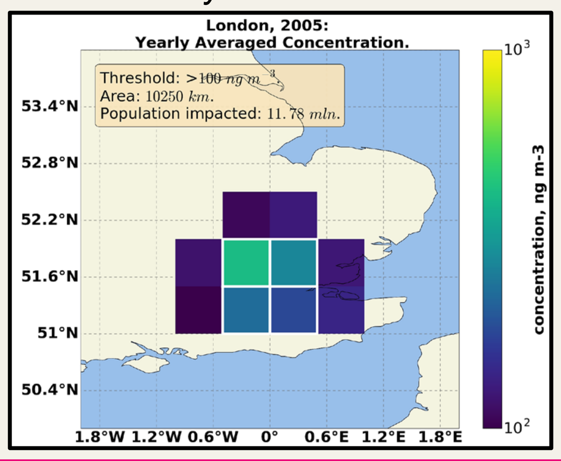

Figure 4: Yearly averaged concentration of BC from London emissions in year 2005 above threshold of 100 $ng\ m^{-3}$.

1 Distance

To describe BC buildup around the city and export over long ranges in the horizontal direction, a metric giving an average concentration of transported from the city BC called "Export over Different Ranges", $EDR_{Surface}(x_{min}\text{–}x_{max})$, was used. "*Surface*" corresponds to the lowest *50 m* and the "*x*"s define minimum and maximum radial distance from the city center. Zones created by different radiuses are illustrated for Moscow in ***Figure 5***.

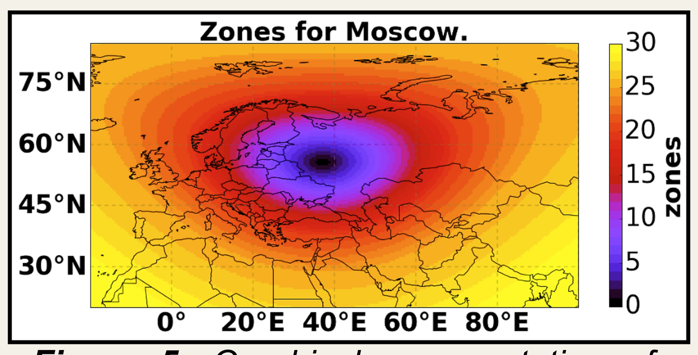

Figure 5: Graphical representation of zones.

This metric captures well seasonal variability of BC transport. In the ***Figure 3*** for London the plot shows very small seasonal dependency; whereas for Moscow (see ***Figure 6***) there is clear separation between curves indicating significant change in transport from summer to winter for example. This can be also clearly seen in concentration maps in ***Figure 7***.

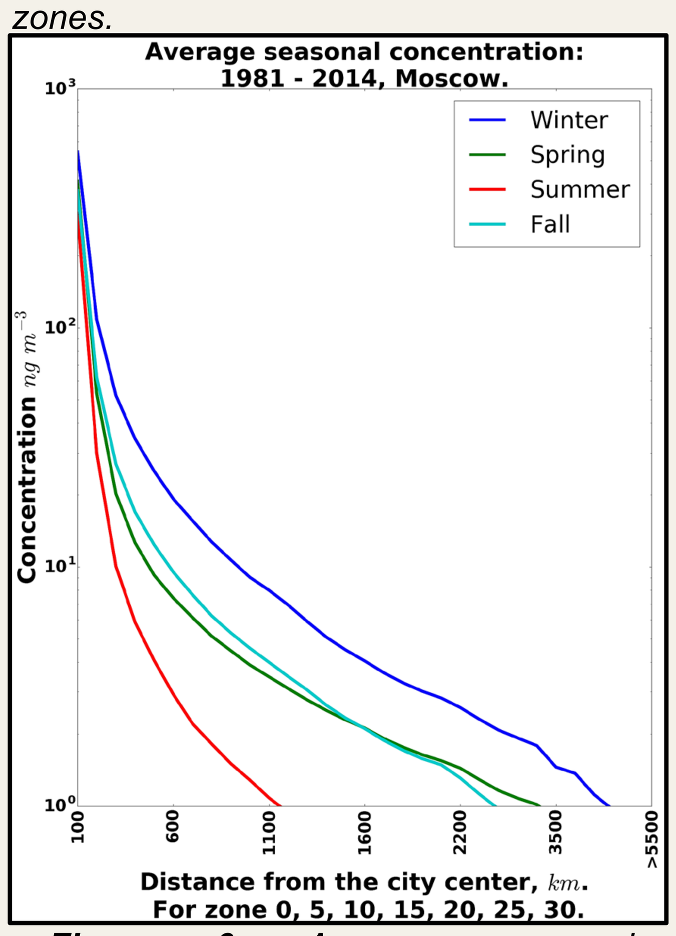

Figure 6: Average seasonal concentrations of BC for Moscow for years 1981-2014.

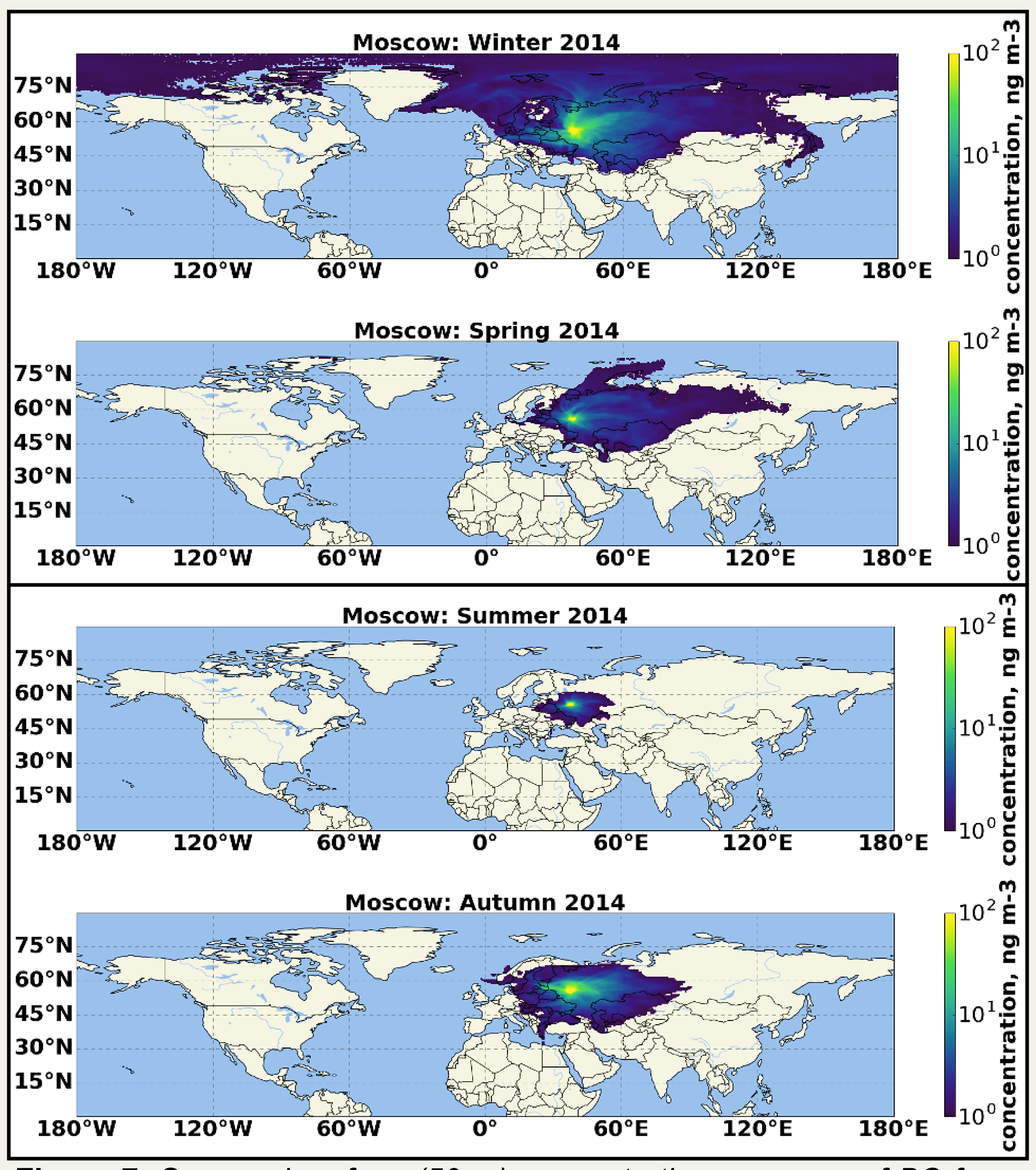

Figure 7: Seasonal surface (50 m) concentration averages of BC from Moscow emissions for year 2014.

2 Impacted Area and Population

To consider the geographical area impacted by the emissions emanating from a considered city (including the grids representing the city) a metric *a_x* was defined. „*x*" stands for the BC average threshold concentration, in $ng\ m^{-3}$, in the surface layer (*50 m*). Here are presented two yearly averaged threshold concentrations, *>1* and *>100* in $ng\ m^{-3}$. ***Table 2*** shows that threshold of *>100* $ng\ m^{-3}$ is found on local to regional scales (< 10^6 *km*) as an example see ***Figure 4*** for London and Figure 9 for Rhine-Ruhr area. On the other hand, the threshold of *>1* $ng\ m^{-3}$ on continental (> 10^6 *km*) or even hemispheric scales, see ***Figure 8***. Therefore, this metric can be used to classify the geographical extend of the impact of BC from individual cities.

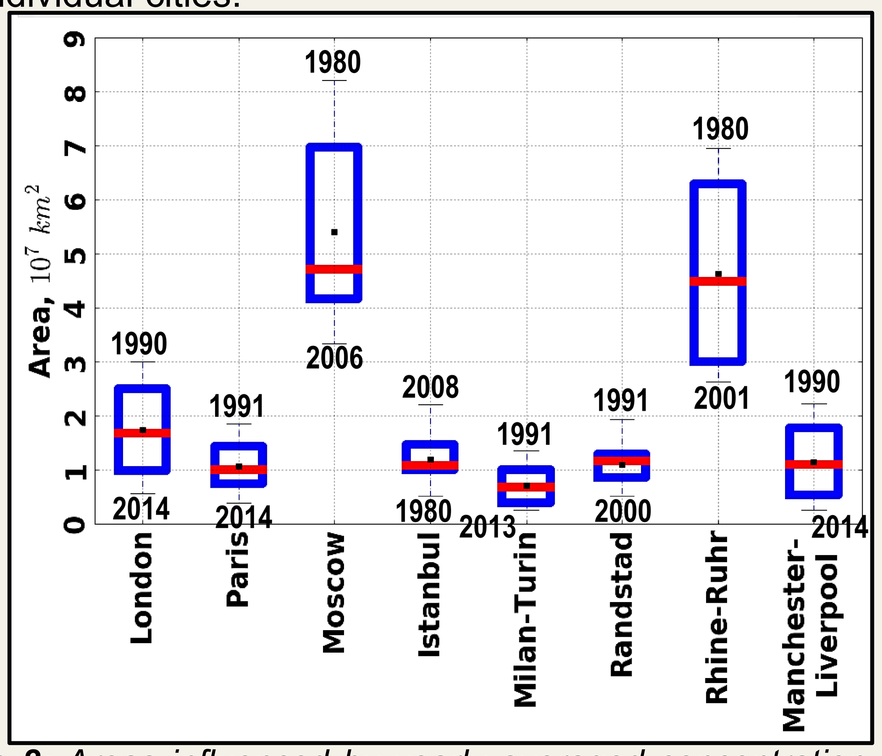

Figure 8: Areas influenced by yearly averaged concentration of BC coming from respective city exceeding 1 $ng\ m^{-3}$*. 50% of values lay within blue boxes, median is denoted by red line and mean by black dot. The dates given are for minimum and maximum values.*

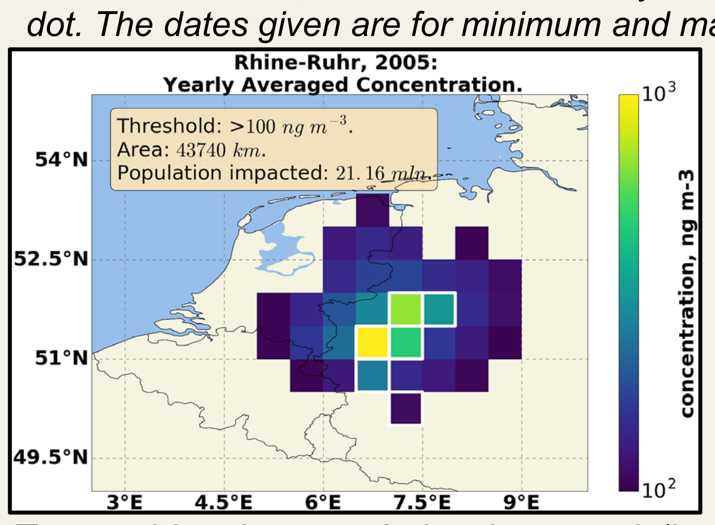

Figure 9: Yearly averaged concentration of BC from Rhine-Ruhr emissions in year 2005 above threshold of 100 $ng\ m^{-3}$.

To consider the population impacted (including the population residing within the city borders) an additional metric *p_x* was defined, where *x* are the same thresholds as for metric *a_x*. SEDAC data set of population density for 2005 was used (regridded to *0.5°*), see ***Table 2***.

	a_1 [$mln\ km^2$]	p_1 [mln]	a_100 [$10^3\ km^2$]	p_100 [mln]
Moscow	41.26	859.41	41.27	17.71
London	9.77	491.36	10.25	11.78
Paris	7.78	472.83	9.5	10.53
Rhine-Ruhr	34.02	1185.29	43.74	21.16
Istanbul	12.98	543.08	22.84	12.48
Milan-Turin	4.18	305.63	17.17	8.69
Randstad	5.39	395.84	9.19	6.78
Manchester-Liverpool	5.9	334.55	7.35	5.76

***Table 2:** Summary of values of area and popualtion threshold based metrics for year 2005 for the European cities described in **Table 1**.*

Outlook

A metric to quantify the MPCs emission outflow to climatologically sensitive areas as the Arctic regions visible for example in ***Figure 7*** (average winter concentration in 2014) is under the development.

Based on *p_x* metric the plan is to study consequences for human health of the exposure to elevated BC concentrations in detail.

Presented here concentration levels of BC come from all sectors defined within CIMP6 inventory database. The plan is to look at the sectors individually.

References

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[6] Eyring et al., Geosci. Model Dev., 9, 1937-1958, doi:10.5194/gmd-9-1937-2016, 2016; (CIMP6)

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