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

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Introduction

Results of numerical simulations on **the climatological characteristics of deposition of air pollution plumes emanating from European major population centers (MPCs) to the Arctic** are presented here.
The aim of this study was to develop methods of quantification **of the impact of black carbon (BC) emissions from European MPCs on BC levels deposited at the Arctic, starting with Greenland**, see ***Figure 1***.
Black carbon has been chosen as a tracer because it plays a significant role as a positive radiative forcer, and it is also well suited for transport studies due to its linear chemistry.

Figure 1: *Greenland's ice cap, [1].*

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, [3, 4]. 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, [6], (resolution: *0.5°*, monthly) including following sectors: 1) agriculture, 2) energy, 3) industrial, 4) transportation, *5) residential, commerical, other*, 6) solvents production and application, 7) waste, 8) international shipping, see the total in ***Figure 1***. This was possible because the BC loss processes are considered being linear.

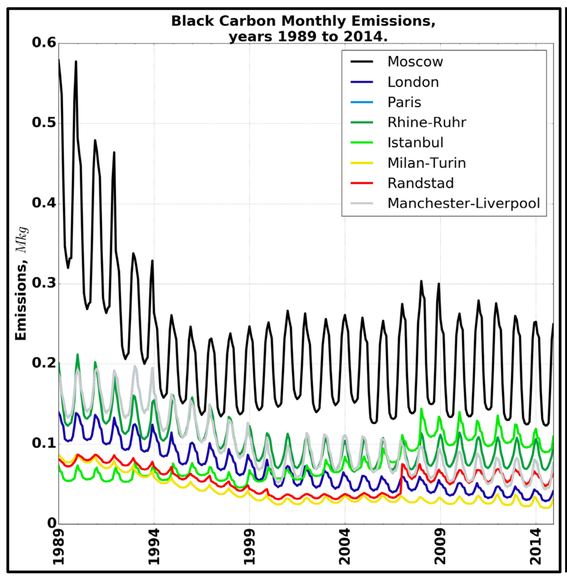

Figure 2: *Black carbon monthly emissions from all 8 sectors for selected urban areas, [6].*

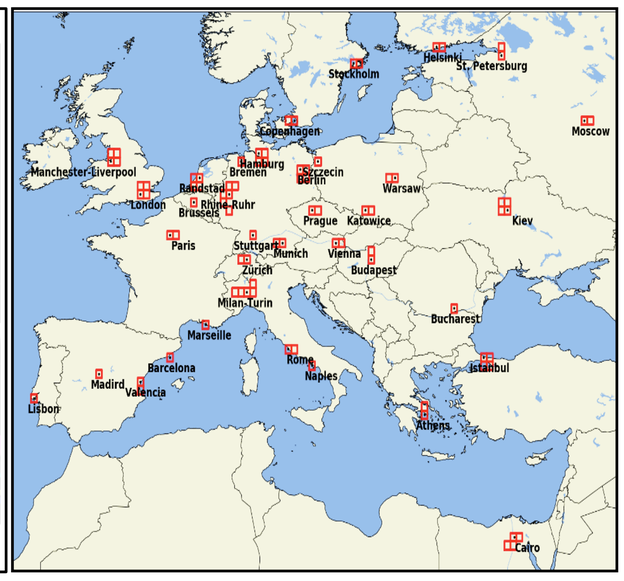

Figure 3: *Map of all the 36 cities included in this study. Red squares correspond to gridboxes of 0.5° .*

The anthropogenic BC emissions plotted in ***Figure 2*** from the European MPCs with the highest population are treated separately to allow the investigation of their individual impact on the deposition levels in the Arctic as compared to the cumulative impact of all the *36* studied MPCs. The area of the analyzed cities were ensembles of *0.5°* gridboxes, see ***Figure 3***.
From territories belonging to the Arctic, Greenland was chosen as a focus area since 80% of it (*1,71 mln* km^2) is covered by ice sheet, see ***Figure 1***, that is the second largest ice body after Antarctica's ice cap [1]. To filter the FLEXPART deposition outputs, a mask of Greenland territory was applied. It was defined as *0.5°* land gridboxes with minimum elevation of *720 m* above sea level within the following geographical bounds: *latitude = [58.25, 84.75]*, and *longitude = [-68.75, -20.25]*. The total area of such defined *„Greenland"* is: *1,79 mln* km^2, and as comparison of ***Figure 5*** with ***Figure 1*** indicate it mostly corresponds to the ice sheet of Greenland.

Motivation

The main scientific question of this study is to assess the impact of the European MPCs on levels of deposited BC on snow and ice surfaces of Arctic region, where it can influence the local climate by, for example, changing the surface albedo and contributing to melting of the Arctic ice cap. Motivated by analysis of surface concentration maps for BC as the one for Moscow presented in ***Figure 4***, this study focuses on deposition on Greenland (see example for Moscow in ***Figure 5***), defined as *„Greenland"* described in the ***Methods*** section.

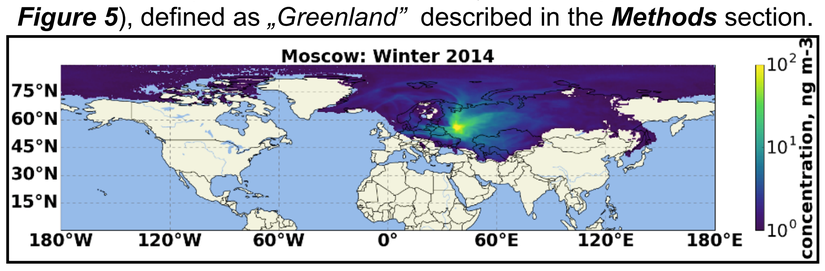

Figure 4: *Surface (50 m) concentration averages of BC from Moscow emissions for winter 2013/2014. The visible lack of BC concentration above 1 ng m-3 directly above Greenland implies that black carbon was deposited.*

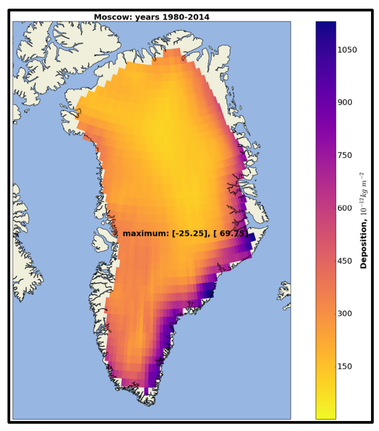

Figure 5: *Average over years from 1980 to 2014 of Moscow's contribution to deposited on „Greenland" BC accumulated during one year.*

Results

To quantify the climatology of BC deposition to Greenland from MPCs the metrics TYAD, WYAD, DYAD were introduced, which respectively stand for Total, Wet, and Dry Yearly Accumulated Deposition. The time series over years from 1980 until 2014 of the sum of the contributions from all *36* studied urban centers is given in ***Figure 6***. The overall decreasing trend is due to decrease in emissions.
Figure 7 shows that through all studied years from *8* most populated urban areas in Europe it is Rhine-Ruhr that deposits highest quantities to *„Greenland"* despite that it is Moscow which has highest black carbon emissions.

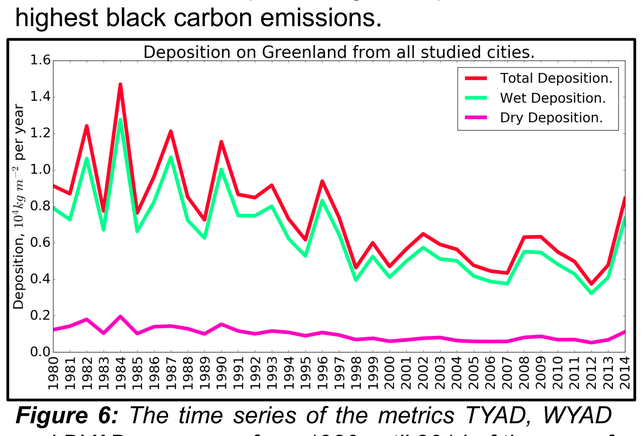

Figure 6: *The time series of the metrics TYAD, WYAD and DYAD over years from 1980 until 2014 of the sum of the contributions from all 36 cities included in this study.*

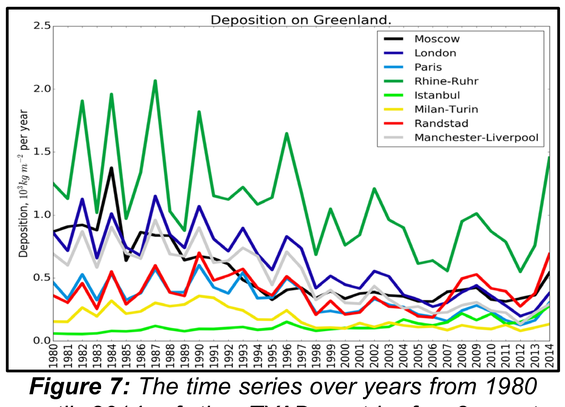

Figure 7: *The time series over years from 1980 until 2014 of the TYAD metric for 8 most populated European MPCs.*

Using the three developed metrics, the deposition maps to *„Greenland", see* ***Figure 8****,* were studied. Plots a), c), and d) give the average over years 1980-2014 of the metrics TYAD, WYAD, DYAD, respectively. They clearly show specific areas of deposition (exposed cliffs of the Watkins Range along the east coastline of Greenland), from which two *0.5°* gridboxes, with centers at *25.25W*, *69.75N* and *34.25W*, *66.75N*, stick out the most. Also, as indicated by ***Figure 6***, the plot c) shows that the majority of deposition to *„Greenland"* is through wet deposition. Plot b) indicates that half of total deposition originates from the 5th sector of emissions (*residential, commercial, other*).

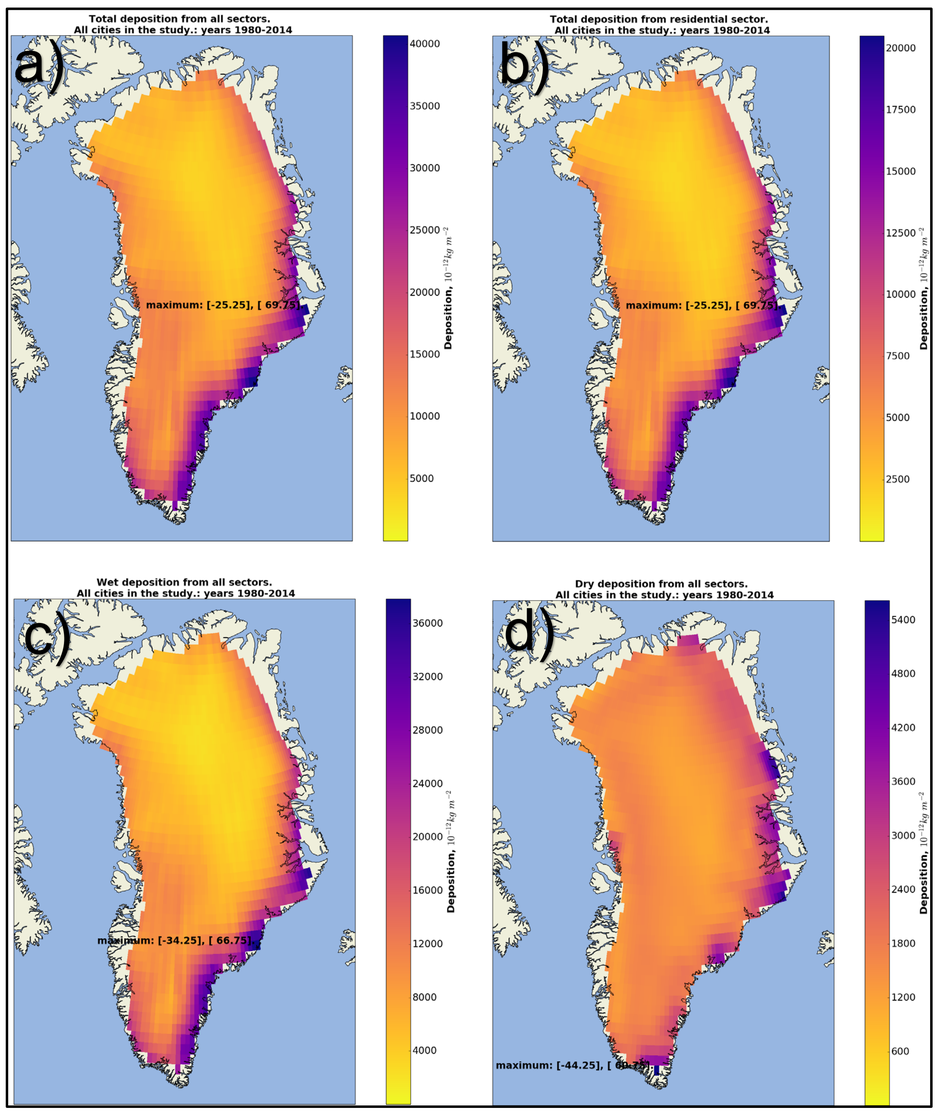

Figure 8: *Averages over years from 1980 to 2014 of the metrics: a) TYAD b) TYAD from residential, commercial, other BC emission sector. c) WYAD, d) DYAD.*

Conclusions and Further Questions

Initial analysis of dry and wet deposition to the Arctic, exemplified by Greenland, of BC originating from European MPCs was performed. The three developed metrics TYAD, WYAD, DYAD successfully identified some of the climatological trends of the BC deposition patterns to Greenland.

As next steps, more thorough study of sector attibution is planned; characterization of the free troposphere transport to Greenland; and analysis of seasonal variations of transport and deposition. The study will be extended to include other territories of the Arctic together with their ice cap, as well as and the sea-ice in order to fully describe the deposition in this sensitive to climate changes region. It is foreseen that such comprehensive description might require different metrics.

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