23rd International Conference on
Harmonisation within Atmospheric Dispersion Modelling
for Regulatory Purposes
15-19 September 2025, Hamburg, Germany

EXTENDED ABSTRACT

Microplastics Long Range Dispersion over Canada with a Lagrangian Dispersion Model: from Receptor to Source and from Source to Receptor

Ziero S [1]., Musso M.M [2]., Qu M [3]., Ferrarese S. [1,2], Trini Castelli S.[2]*

[1] Department of Physics, Turin University, Torino, Italy
[2] CNR – Institute of Atmospheric Sciences and Climate, Torino, Italy
[3] Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Canada

**Email of Presenting author*: S.TriniCastelli@isac.cnr.it

***Abstract**:* The presence of microplastics (MPs) in areas with low anthropogenic activities suggests the atmospheric long-range transport as a possible cause. Atmospheric dispersion of MPs is typically investigated using numerical models working at the global scale, through forward in time simulations to assess their fate, or in backward to identify potential source regions. In this work, we present the application of the MILORD Lagrangian dispersion model to evaluate the possible impact of major Canadian and US cities on a remote site in the Ontario region. Backwards simulations were performed from the receptor to identify potential source areas, then forward simulations were carried out to study their potential contribution at the receptor location. The results identified the cities of Cleveland, London and Toronto as potential sources of MPs, with Toronto showing the highest impact in terms of both deposition and concentration, while the cities of Cleveland and London exhibited similar spatial impact but with lower values.

Keywords : *Microplastic atmospheric dispersion, MILORD model, source identification*

INTRODUCTION

The widespread of plastic materials in terrestrial and water environments has been extensively studied, and their impacts are increasingly well understood. However, assessing the presence of plastic particles in the atmosphere is a relatively new topic. The atmosphere as a potential transport vector has been considered only in recent studies, where small plastic particles (microplastics, hereafter MPs) were detected in remote regions with minimal anthropogenic activities of our planet (e.g. Zhang et al., 2022; Allen et al. 2019, 2021; Aves et al., 2022). One of the major challenges when studying the dispersion of MPs in the atmosphere in remote areas is the identification of the possible sources. While some recent attempts have focused on MPs emission from marine environments (see Shaw et al., 2023), most of the MPs emission data refer to road traffic emissions, i.e. emission from tyre and brake abrasion (see e.g. Evangeliou et al., 2020; Ward et al., 2024), where local traffic inventories are available. However, MPs detected in remote regions may originate from multiple, distant sources, making it difficult to disentangle their individual contributions along the transport pathways. To address this issue, observational campaigns are increasingly complemented by numerical simulations, trying to assess the future fate of MPs in the atmosphere (with forward-in-time simulations) or to identify the possible provenience areas of the air masses containing the pollutants (backward-in-time simulations).

In this study, we investigate a case presented by Welsh et al. (2022), reporting the presence of MPs in the Muskoka-Haliburton region of Ontario, Canada, based on one year of observations from February 2019 to March 2020. Samples were collected at six different stations, all located near lakes and far from any direct human activities to exclude possible local contamination, and included both dry and wet deposition. For the numerical simulations, we use the Lagrangian particle dispersion model MILORD (Model for the Investigation of LOng Range Dispersion), which has already been applied to study the MP long-range dispersion in case studies in Europe (Martina and Trini Castelli, 2023; Musso and Trini Castelli, 2025).

MILORD is used here to perform backward simulations from one of the sampling sites, distinguishing between particles travelling within the planetary boundary layer (PBL) or in the free atmosphere (FA). The backward simulations lead to identify the possible source area of MPs reaching the receptor locations. In the area of interest, different cities are then selected as potential sources, following the work of Ward et al. (2024). They estimated the MP road traffic emissions for several cities in Canada and the USA, starting from the local traffic inventories. Through the backward simulations, three cities in the potential source area are pinpointed: Cleveland (USA), London (CA) and Toronto (CA). The impact of these cities on the Great Lakes Region and their specific contribution to the receptor site are then investigated by performing several numerical simulations forward in time.

THE NUMERICAL SIMULATIONS

Numerical simulations using the MILORD model were conducted both backwards and forward in time for two samples collected in July 2019, a period characterised by increased road traffic associated with summer holidays, and in November 2019, when traffic is primarily driven by work activities. This also allows for comparing the dispersion pattern in two different seasons. As above, backward simulations aimed to reconstruct the possible provenience areas of the air masses reaching the receptor site, while forward simulations assessed the potential impact of emissions from major Canadian and USA cities at the receptor location. Among the six sampling stations referred to by Welsh et al. (2022), the PT1P (45.224° N, -78.933° E) was selected, as representative of the receptor site and and because it only considered dry contribution to deposition, therefore sparing simulations the additional uncertainty related to precipitation data, not available to us.. The simulation domain extension ranged from -150° E to -50° E in longitude and from 25° N to 75° N in latitude, with an integration time step of 18 minutes. Meteorological inputs were provided by the ECMWF analyses at 6-hour intervals, with a grid resolution of 0.25° both in longitude and latitude and 13 vertical pressure levels, from 1000 hPa to 200 hPa.

Several simulations were performed, here a subset for MP fragments and fibres is discussed, considering settling velocities respectively of 0.1 ms^{-1} and 0.01 ms^{-1}, as in our previous works (Martina and Trini Castelli, 2023; Musso and Trini Castelli, 2025). A summary is reported in the following and in Table 1:

- Simulations **BW_recp**: these are backward simulations from 30 to July 9 and from 13 to 3 November 2019. A number of 150 particles were released continuously inside the planetary boundary layer (PBL) each time step throughout the simulation at PT1P coordinates. The total pollutant mass emitted each time step was set to a reference unit (Table 1), but no computation related to the mass was made, since here only the trajectory frequencies are of interest.
- Simulations **FW_####**: these are three forward in time simulations, each corresponding to one of the cities identified as potential sources. The "#" symbols stand for the names of the cities, Cleveland, London and Toronto. The simulation setup, including settling velocity and simulation periods, is the same as for simulation **BW_recp**. Particles were emitted within a volume corresponding to the city's extension at a height ranging from 15 m to 100 m a.g.l.. The emitted mass was calculated based on the inventory provided by Ward et al. (2024).

Table 1: Summary of the simulation setup for MILORD simulation

Simulation ID	Type	Source/receptor coordinates	Source/receptor extension (lon × lat)	Emitted quantity (µg)
BW_recp	Backward	45.224° N, -78.933° E	0.00045°	1.0×10^{10}
FW_Clev	Forward	41.500° N, -81.690° E	0.15°	6.66×10^{9}
FW_Lon	Forward	42.980° N, -81.240° E	0.20°	1.0×10^{10}
FW_Tor	Forward	43.650° N, -79.380° E	0.25°	18.0×10^{10}

RESULTS AND DISCUSSION

To identify potential source areas, Figure 1 presents contour plots showing the normalized frequency of trajectories of particles travelling inside the PBL and arriving at the PT1P receptor, as calculated from the BW_PT1P backward simulations.As expected from the prevailing atmospheric circulation at these latitudes, the dominant flow direction is western, with contributions ranging from northwest to southwest. The area of interest covers only three of the cities listed in the Ward et al. (2024) emission inventory, marked as grey dots in the figure. These cities, Cleveland (USA), London (Canada) and Toronto (Canada), fall within the region most frequently traversed by the backward trajectories. Their identification as potential sources was further supported by analysing the distance travelled by particles inside the PBL, where most MP sources are located. Figure 2 displays the distribution of trajectories for particles travelling within the PBL (red line) and above it (blue line). Within the first 250 km, the majority of the particles remain inside the PBL; further than 500 km, particles are mostly moving above it, in the FA. Since the three cities are all located within 500 km of the receptor and fall within the high-frequency area of the backward trajectories, they were selected as the main source candidates.

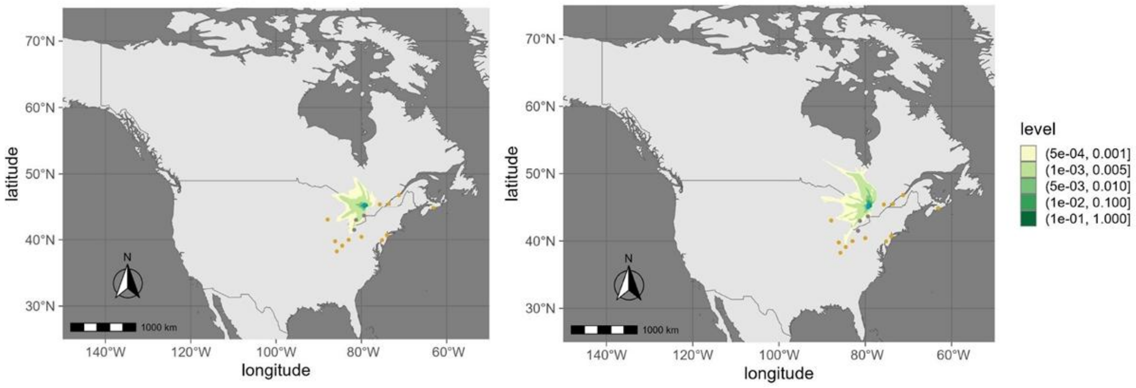

Figure 1: Contour plots of the normalised trajectory frequency, identifying the provenience area of particles travelling inside the PBL. Orange dots: all cities in Ward et al. (2024) inventory; grey dots: cities inside the area of interest, for July (left) and November (right) simulations.

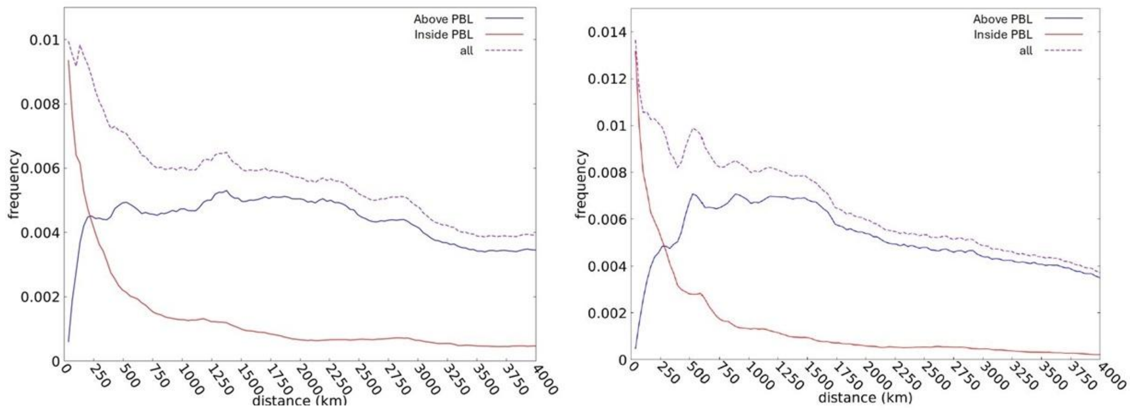

Figure 2: Frequency distribution of the trajectories as a function of the distance from the source for particles travelling above the PBL (blue line) and inside it (red line) and the sum of the two (violet line), for July (left) and November (right) simulations.

Figure 3 reports the cumulated deposition of MP fibres for July (left column) and November (right column) for the forward simulations **FW_Clev**, **FW_Lon** and **FW_Tor.** In the plots, the green dot marks the emission source, while the black dot represents the receptor (PT1P). As can be seen by the figure, the deposition patterns extend primarily to the northeast, affecting parts of the eastern USA and Canada, extending north up to the Labrador coast.

The contour maps show that the deposition distributions include the receptor area. Fragments, in contrast, tend to settle closer to their emission source. Their corresponding deposition maps (not shown) only brush the receptor location, as the air parcels reaching this area have already lost most of their pollutant mass by that point. This highlights the different contributions of long-range transport over different types of MPs. Deposition values close to the receptor for plastic fibres and fragments range respectively between 0.05-50 $\mu g\ m^{-2}$ and <0.05-1$\mu g\ m^{-2}$ in July, between 0.5-50 $\mu g\ m^{-2}$ and <0.05-5 $\mu g\ m^{-2}$ in November. Therefore, while the pattern of the particle dispersion is similar for the two months, higher deposition values are found at the receptor for November. The stronger signal is found for Toronto and can be attributed to its higher emissions estimate in the inventory by Ward et al. (2024), which assigns it a mass release nearly an order of magnitude greater than that of Cleveland and London. Our results concur with the findings of Welsh et al. (2022), given that in their samples most of the collected MPs were fibres, and with the simulations performed by Ward et al. (2024), showing maps with larger deposition areas for fibres, and smaller areas but with higher values near the source for fragments.

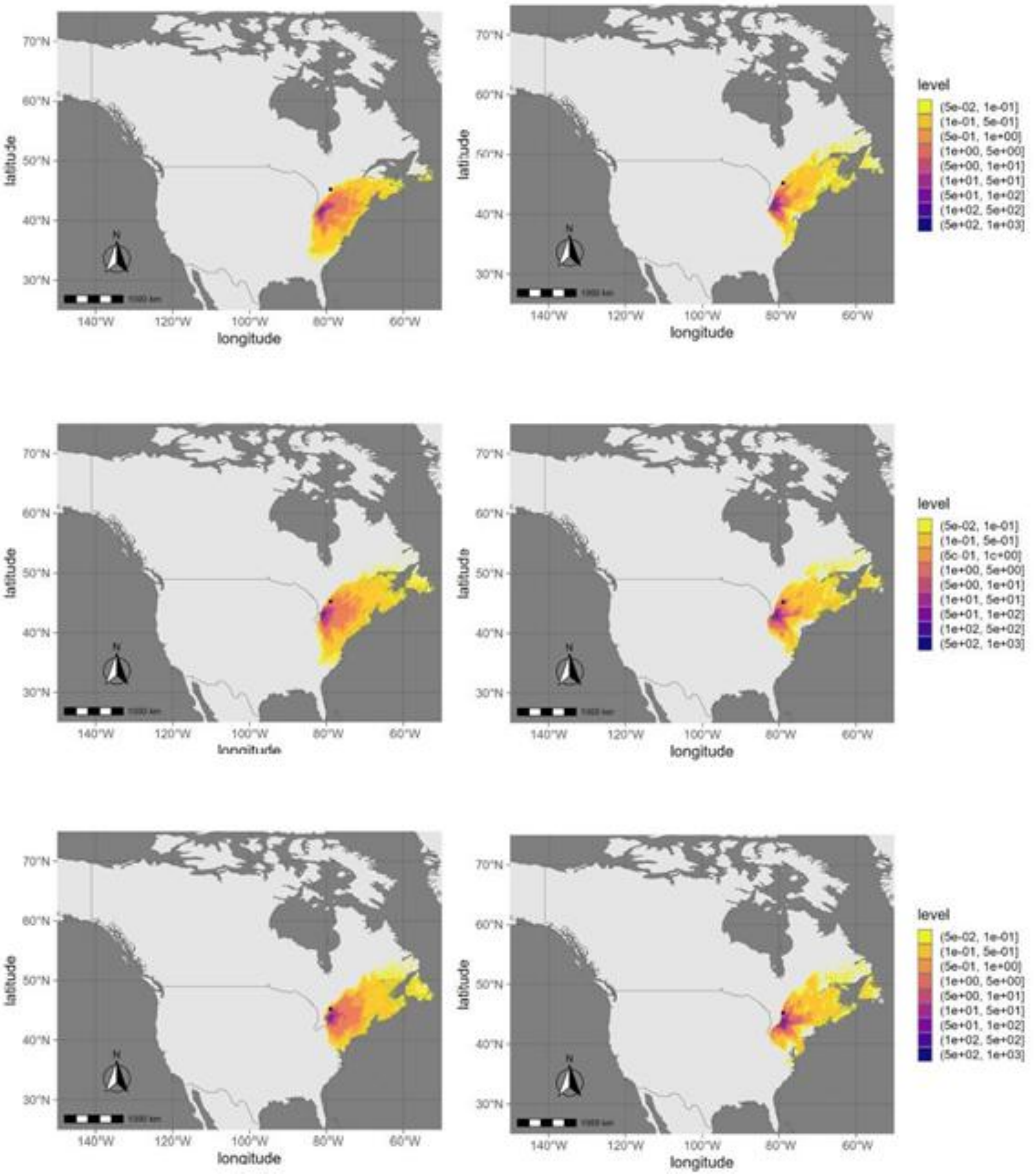

Figure 3: Contour of the cumulated deposition of fibre (0.1 ms^{-1} settling velocity) for July (left) and November (right) simulations, for Cleveland (top row), London (middle row) and Toronto (bottom row) emissions. Green dot: source location; black dot: receptor point (PT1P).

CONCLUSIONS

In this work, we investigated the potential impact of major Canadian and US cities on a remote receptor site in the Ontario region of Canada. Numerical simulations were performed for July and November 2019, following the observational campaign described by Welsh et al. (2022). The backward simulation goal was to identify the possible provenience area for the air masses containing the MP pollutant, which led to the selection of the cities of Cleveland, London and Toronto as likely contributors. Forward simulations were then performed to evaluate the impact of MP emissions from these cities at the receptor coordinates. The results indicated that the transport occurred primarily toward the northeast, reaching as far as the Labrador coast. Among the three cities, Toronto showed the greatest contribution to both deposition and concentration at the receptor, consistent with its higher emission estimates compared to London and Cleveland, together with being the closest city to the receptor. It was possible to evaluate the role of the long-range transport and its effectiveness in dispersing different types of MPs. Based on a further sensitivity analysis, the long-range model proved to be reliable also when assessing its results at finer scales.

The present work lays the groundwork for future simulations aiming at assessing the potential impact of urban sources on remote areas in the Canadian province of Quebec, where an observational campaign for monitoring atmospheric MPs is currently underway.

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