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INVESTIGATION OF MICROPLASTICS LONG RANGE TRANSPORT WITH THE LAGRANGIAN PARTICLE DISPERSION MODEL MILORD

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Abstract: The relatively recent observation/collection of microplastics (MPs) in remote areas moved the scientific community to investigate this topic by mean of atmospheric numerical dispersion models. The study of MPs' atmospheric dynamics and their fate is still pioneering, aimed to shed light on the role of the atmospheric long range transport to explain the presence of MPs in remote sites. The use of dispersion models working at a synoptic scale is important to reconstruct the possible provenance of the air masses containing the pollutant, as well as to investigate the effectiveness of the long range transport together with the exchange mechanism between the planetary boundary layer (PBL) and the free atmosphere (FA). In this work, the application of the Lagrangian long-range dispersion model MILORD to two different case studies is presented.

In one case, MPs are released inside the PBL considering the city of Madrid as a source, to assess the spatial and time scale of their potential entrainment in the FA. In a second case, the possible areas of origin of MPs detected in the FA above a mountain top, and the pathways inside and above the PBL of the masses containing them, are investigated with backward simulations. It was found that particles released inside the PBL get entrained in the FA generally far from the original source, suggesting a limited contribution of a source inside the PBL to the pollution in the FA above it. The results for the second case study showed that the pollutant enrichment of the simulated air masses arriving at the remote site may occur both on land and water environments, revealing the possible role of seas and oceans as a MPs source.

Key words: *Atmospheric microplastics, MILORD model, Long range Transport*

INTRODUCTION

Plastic as an environmental issue is a well-established topic since the first works in the early '70s by Carpenter and Smith (1972), highlighting the presence of plastic material in the Sargasso sea. Since then, the scientific community has moved its attention to this problem, focusing on the presence of plastic in water and land and investigating the related impacts on the environment and human health (e.g. Alabi et al., 2019). In recent years, several works have highlighted the presence of microplastics (MPs) in remote areas, away from any significant anthropic source, such as Tibetan Plateau Glaciers (Zhang et al., 2021), European Alps and Pyrenees (Allen et al., 2019, Allen et al., 2021, Ambrosini et al., 2019) and Arctic ice (Bergmann et al., 2019). Microplastics are defined as small particles of plastic material with different shape (i.e. fragments or fibres) whose size is defined in the range $s = 0.1\ \mu m - 5\ mm$. The presence of such particles in remote areas is thought to be related to atmospheric long-range transport, whose role and effectiveness in explaining the observations is currently still under investigation, in particular by mean of numerical modelling (e.g. Allen et al. 2021, Evangeliou et al., 2022, Martina and Trini Castelli, 2023). In this framework, we present some results obtained applying the Lagrangian particle dispersion model MILORD (Trini Castelli, 2012) to two different case studies that highlighted the presence of MPs above the Planetary Boundary Layer (PBL), i.e. where particles are likely to be more susceptive to long-range transport. Specifically, the case studies refer to the works of Gonzalez et al. (2021), who reported the presence of MPs in the free atmosphere (FA) above the city of Madrid and the nearby rural areas, and Allen et al (2021), who detected the presence of MPs at the meteorological measuring station located at Pic Du Midi ($\approx 2900\ m$ a.s.l.) in the French Pyrenees. Here we report some examples of the analysis carried out for the two case studies, focusing mainly on the reconstruction of the back trajectories to understand the possible MPs provenience. An extensive investigation can be found in Musso and Trini Castelli (2024)

THE CASE STUDIES AND MILORD SIMULATIONS

The aim of this work focuses on the simulation of backward and forward trajectories of particles to reconstruct the possible pathways of the MPs observed and reported by the two selected case studies. Gonzalez et al. (2021) reported the presence of MPs within the FA of different areas nearby the city of Madrid. Three flights were performed on urban, rural and sub-rural areas during spring and summer periods in 2018 and 2019. The presence of microplastic fibres and fragments was detected, with a major concentration in the FA over high-density populated areas, such as Madrid, with respect to rural and sub-rural environments. On the basis of their results, they suggested the potential of cities such as Madrid as a direct source of MPs above their own PBL.

Allen et al. (2021) carried out an extensive observational campaign at Pic Du Midi (PDM) meteorological station (2877 m a.s.l.) in the periods of summer and fall 2017. Weekly based concentration measurements were performed and the average concentration of MPs was estimated. Additionally, several backward simulations with the HYSPLIT and FLEXPART numerical model were also performed to address and support the outcomes of the observational campaign. Their simulations showed that samples with larger values of concentrations were associated to a greater number of back trajectories arriving from northern Africa, while samples with a lower content of MPs presented a major number of back trajectories arriving from North America and the Atlantic Ocean. Their results also indicated that MPs might have been produced by water environments such as seas and Atlantic Ocean.

One of MILORD numerical simulations for the Gonzalez et al. (2021) case study was performed to test whether Madrid could be a possible active source of MPs above in the FA above its area. The simulation reported here (G_for) to test this possibility is based on the flight above the city of Madrid from 7:00 to 11:00 UTC on June 17, 2019. To this purpose, a continuous emission within Madrid's PBL was considered. Here we focus on the analysis of the quotes at which the Lagrangian particles are moving, to keep track of the number of simulated particles inside and above the PBL. The emission was set at Madrid coordinates (40°30′00″N 3°40′24″W) at an altitude of 677 m a.s.l. (~15 m a.g.l) at 00:00 UTC of June 16, 2019 (i.e. a day before the observations were collected) and followed for four further days. MILORD simulations used in input the meteorological and orographical data provided by the ECMWF analyses with a resolution of 0.5° × 0.5°.

Three backward numerical simulations were performed for the Allen et al. (2021) case study, to reconstruct the pathways of the air masses through the backward trajectories and identify the possible source areas. The MILORD simulations regard three different samplings, one with a very low number of MPs m^{-3} (A07_back), one with concentration values comparable to the calculated average (A14_back) and one with high values of concentration (A02_back). The meteorological and orographical input data are the same as for simulation G_for. The backward continuous releases lasted for the monitoring time periods, from 21:00-14:00 UTC for each day, and the source was set at Pic Du Midi coordinates (42°56′11″N 0°08′34″E) at an altitude of ~ 2900 m a.s.l.. The motion of the particles was followed for one week. Table 1 reports a summary of the numerical setup for the MILORD simulations.

Table 1. Summary of MILORD simulations set up

Run	**Case Study**	**Location**	**Simulation type**	**Release quote (a.s.l.)**	**Run Duration**	**Release time and date**
G_for	Gonzalez	Madrid	Forward	677 m	4 days	24 h, 06/16, 2019
A02_back	Allen (A02)	PDM	Backward	2900 m	1 week	17 h each day, 07/11-4 2017
A07_back	Allen (A07)	PDM	Backward	2900 m	1 week	17 h each day, 08/22-15 2017
A14_back	Allen (A14)	PDM	Backward	2900 m	1 week	17 h each day 10/17-10 2017

RESULTS AND DISCUSSION

Numerical results for simulation G_for are reported in Figure 1, as two contour plots for the relative frequency normalised to the total number of the particle trajectories travelling above the PBL (left panel) and within it (right panel). The green point indicates the location of Madrid. As shown by the contour plots, trajectories were mainly directed to the northern Europe, covering France and Germany up to Denmark. Particles travelling within the PBL tend to cover an area which is closer to the source. The 90-95% of the total trajectories close to Madrid were found inside the PBL, while only 5-10% of the total particles travelled above it. In fact, most of the particles travelling in the FA are localised at an average distance from the source between 180 and 200 km, while the distance covered by particles travelling inside the PBL is up to 70 km. This highlights that the exchange process between the PBL and the FA occurs within a certain time frame, during which the particles are subjected to horizontal motions and may entrain within the FA away from the original emission source. The fact that less than 10% of the trajectories entered the FA within an area relatively close to Madrid suggests that the possible correlation between the MP pollution produced by the city itself and the MPs detected in the FA above it might be feeble. This leads to the consideration that other and farther sources might be responsible for the MP pollution in the FA, through the long-range transport. Starting from these results, exchanges between the urban PBL and FA need to be more deeply investigated by means of models working at the regional and local scale.

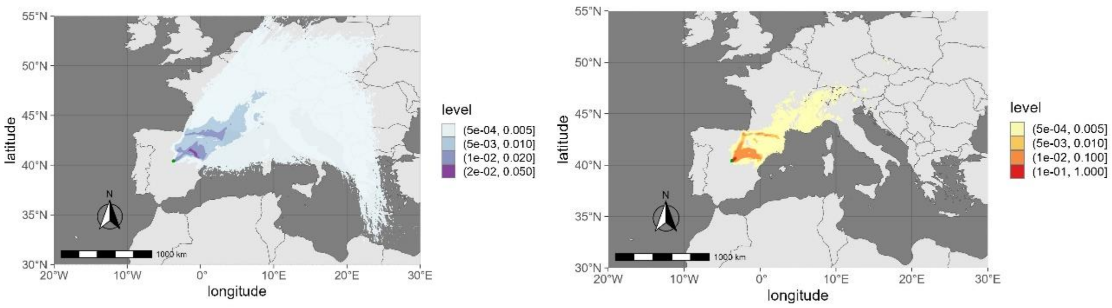

Figure 1: Contour plots of the simulated particles trajectories frequency. Red colours refer to trajectories inside the PBL (right) while blue colours refer to trajectories above the it (left panel). The frequencies are normalised to the total number of trajectories.

Results for Allen et al. (2021) simulations showed that the trajectories for the three cases A02_back, A07_back and A14_back followed two main long range pathways: one coming from the western Atlantic Ocean and the second from northern Africa. In Figure 2 two snapshots for each case are reported. In the plots, different colours refer to different particles' height. From the figure the Atlantic Ocean pathway is tracked for all cases, while a signal coming from northern Africa is highlighted only for simulations A02_back and partially A14_back. MILORD simulates the pollution enrichment of the backward-simulated air masses only for those particles travelling within the PBL. Particles found at a low height (red signal) travelled mainly over land environments close to the source. Yet, a not negligible portion of particles travelled at low quotes over both the Mediterranean Sea and the Atlantic Ocean (e.g. A02_back left and right panels, A07_back right panel), suggesting that marine environments may be a possible source of MPs. This result confirms what was already suggested by, e.g., Allen et al (2021) and Shaw et al. (2022), whose work investigated the possible mechanism for the MPs exchanges between the sea and the atmosphere.

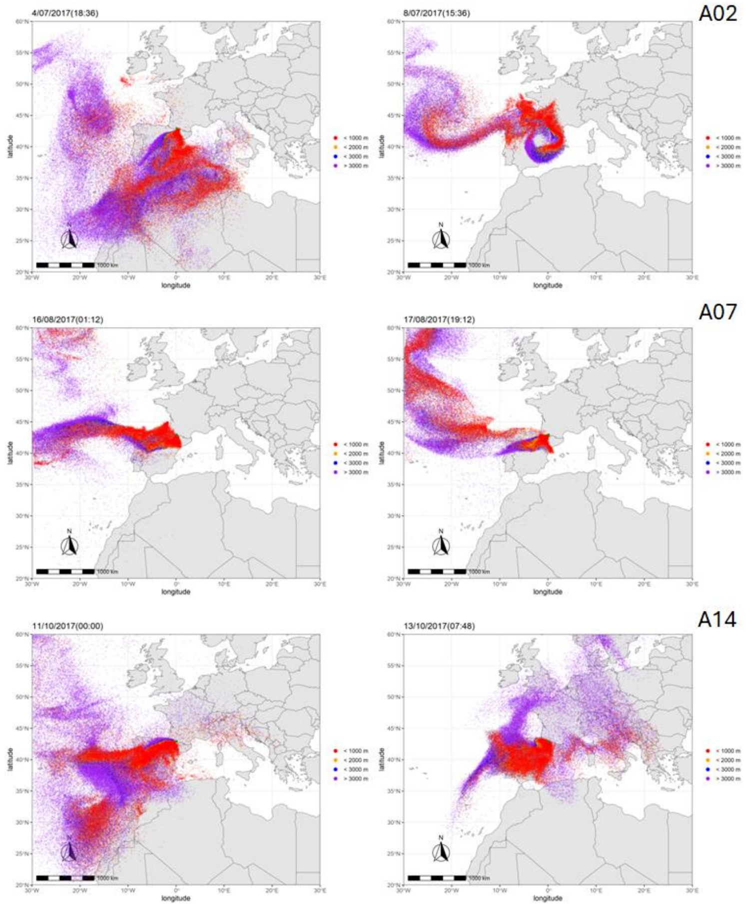

Figure 2: series of snapshots for simulations A02_back (top panels), A07_back (middle panels) and A14_back (bottom panels). The timeframes were chosen mostly at the end of the runs, to highlight the provenance of the air masses (Atlantic Ocean and northern Africa).

CONCLUSIONS

Employing the Lagrangian particle dispersion model MILORD, we investigated the atmospheric dynamics and pathways of airborne plastic particles in application to two case studies reporting their presence within the free atmosphere. The numerical simulations were aimed to verify the potential of a city such as Madrid to be a possible source of microplastics above its own planetary boundary layer (Gonzalez et al. 2021) and the possible provenience of plastic particles detected in a remote mountainous area (Allen et al. 2021). The effectiveness of the long range transport was primarily investigated. The results suggested that the city of Madrid occurs not to be an effective source of microplastics in the free atmosphere above its area.
Before arriving at the mountain site in the French Pyrenees, particles travelling at low heights passed prevalently over land environment (Spain, France). This indicates that the pollutant enrichment of the air masses is likely to mostly occur over regions where anthropic activities are expected. However, the significant trace of particles travelling at low quotes over water environments (Atlantic Ocean and Mediterranean sea) suggests that seas may contribute as a source of microplastics in the atmosphere.

REFERENCES:

Alabi, Okunola A., Kehinde I. Ologbonjaye, Oluwaseun Awosolu, and Olufiropo E. Alalade. "Public and environmental health effects of plastic wastes disposal: a review." *J Toxicol Risk Assess* 5, no. 021 (2019): 1-13.

Allen, S., Allen, D., Phoenix, V. R., Le Roux, G., Durántez Jiménez, P., Simonneau, A., ... & Galop, D. (2019). Atmospheric transport and deposition of microplastics in a remote mountain catchment. *Nature Geoscience*, *12*(5), 339-344.

Allen, S., Allen, D., Baladima, F., Phoenix, V. R., Thomas, J. L., Le Roux, G., & Sonke, J. E. (2021). Evidence of free tropospheric and long-range transport of microplastic at Pic du Midi Observatory. *Nature communications*, *12*(1), 7242.

Ambrosini, R., Azzoni, R. S., Pittino, F., Diolaiuti, G., Franzetti, A., & Parolini, M. (2019). First evidence of microplastic contamination in the supraglacial debris of an alpine glacier. *Environmental pollution*, *253*, 297-301.

Bergmann, M., Mützel, S., Primpke, S., Tekman, M.B., Trachsel, J. and Gerdts, G., 2019. White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. *Science advances*, *5*(8), p.eaax1157.

Carpenter, Edward J., and K. L. Smith Jr. "Plastics on the Sargasso Sea surface." *Science* 175, no. 4027 (1972): 1240-1241.

Evangeliou, Nikolaos, et al. "Sources and fate of atmospheric microplastics revealed from inverse and dispersion modelling: From global emissions to deposition." *Journal of Hazardous Materials* 432 (2022): 128585.

González-Pleiter, M., Edo, C., Aguilera, Á., Viúdez-Moreiras, D., Pulido-Reyes, G., González-Toril, E., ... & Rosal, R. (2021). Occurrence and transport of microplastics sampled within and above the planetary boundary layer. *Science of the Total Environment*, *761*, 143213.

Martina, M. and Castelli, S.T., 2023. Modelling the potential long-range dispersion of atmospheric microplastics reaching a remote site. *Atmospheric Environment*, *312*, p.120044.

Shaw, Daniel B., Qi Li, Janine K. Nunes, and Luc Deike. "Ocean emission of microplastic." *PNAS nexus* 2, no. 10 (2023): pgad296.

Trini Castelli, S. (2012). *MILORD-reload. Model for the Investigation of Long Range Dispersion*. Internal Report ISAC-TO/02-2012, 10 September 2012.

Zhang, Y., Gao, T., Kang, S., Allen, S., Luo, X., & Allen, D. (2021). Microplastics in glaciers of the Tibetan Plateau: Evidence for the long-range transport of microplastics. *Science of the total environment*, *758*, 143634.