EXTENDED ABSTRACT

Implementation of a Resuspension Algorithm in the SPRAY Model

Matteo M. Musso[1], Gianni L. Tinarelli[2], Silvia Trini Castelli[1]*

[1]CNR – Institute of Atmospheric Sciences and Climate

[2]AriaNet-SUEZ s.r.l., Milan, Italy

Email of Presenting author: M.Musso@isac.cnr.it

Abstract: Resuspension is a fundamental mechanism consisting in the reintroduction back into the atmosphere of particles previously settled on a surface . Resuspension is crucial in particle dispersion because it drives the secondary dispersion of pollutants, affecting both the urban/local scale and the long-range scale. This mechanism is often addressed using a statical approach, providing the resuspension vertical flux by assuming the terrain as an unlimited source of material. In this work we present the implementation of a newly developed resuspension algorithm in the Lagrangian particle dispersion model SPRAY. This algorithm implements a dynamic approach, providing the resuspended flux for material deposited by the tracer plume during the simulation. The results of the first tests have shown that the resuspension algorithm affects both deposition and concentration, highlighting regions where resuspension exceeds deposition and, complementarily, increasing the concentration values near the ground.

Keywords: SPRAY model, dynamic resuspension

INTRODUCTION

Resuspension is the mechanism of reintroduction of particles previously settled on a surface back into the atmosphere. Resuspension is an essential mechanism that drives the secondary dispersion of pollutants in the air. The wide range of processes that can trigger resuspension effects, from road traffic (Casotti Rienda and Alves, 2021) to wind driven resuspension for desert dust (Figgis et al., 2018) up to walking induced resuspension for indoor environments (Qian et al., 2014) makes this mechanism affect a wide range of scales, from urban scale up to global scale. Particles that are light enough to overcome the effects of gravity, show a dynamics driven mainly by atmospheric turbulence and mean wind. These particles can affect the long-range scale, as in case of Sahara desert sand grains resuspended during sandstorms whose effects can be recorded on the northern part of the Mediterranean Sea (Mifka et al., 2023).

Resuspension of inert material is often addressed by simulating the erosion effects of dust and grains due to the wind, generating new particles to be transported by the wind flows (see e.g. the works of Marticorena and Bergametti, 1995; Shao, 2004; Ginoux et al., 2001). From a numerical standpoint, this implies that the terrain can be considered an "unlimited" source of new particles that contribute to the global population simulated by the numerical model. This approach is useful when considering numerical simulations involving the erosion effects of winds on terrain such as deserts, clay-rich soils or rocky cliffs. However, for other materials such as particulate matter (PMs) or even fully anthropic material like microplastics (MPs), this approach is not optimal because it involves the presence of a proper source of particles, which does not always exist. Instead of this "static" approach, a more "dynamic" concept can be adopted, using as a source the material deposited by the plume during a simulation inside each computational cell.

In the present work, we present a newly developed and tested algorithm to simulate the resuspension effect at the local scale. The algorithm is implemented in the Lagrangian Particle Dispersion Model SPRAY and it was designed to implement a dynamic approach that can be applied, especially in urban environments or for specific emergency scenarios, such as radioactive fallout, or volcanic eruptions.

THE ALGORITHM

The chosen algorithm is a modification of the Ginoux algorithm (Ginoux et al., 2001), expressing the resuspended flux as a function of the velocity at 10 m a.g.l. u_{10m}, and to a source term S, originally connected to the terrain concavity. The original expression was:

$$F = CSs_p u_{10m}^2(u_{10m} - u_t) \quad u_{10m} > u_t, \quad (1)$$

where C is a dimensional constant, S the source term, s_p the fraction of particles with a given size p, u_{10m} is the wind velocity 10 $m\ a.g.l.$ and u_t the relative velocity threshold. In this formulation, the resuspension is inhibited if the wind speed is lower than the threshold. Equation (1) was modified to express the flux to express the flux as a function of the mass available inside each cell:

$$F = C' \frac{m_{dep}}{\Delta t\ A} s_p u_*^2(u_* - u_{*t}) \quad u_* > u_{*t}, \quad (2)$$

where C' is a new numerical constant, m_{dep} is the cumulated deposited mass inside a cell, A is the cell area, Δt the time frame and u_* the friction velocity. The velocity threshold was chosen according to Shao et al. (2000), providing an expression for the friction velocity as:

$$u_{*t} = \sqrt{A_n \left(\frac{\Gamma + \varphi_p g d^2}{d\ \rho}\right)}, \quad (3)$$

Where $A_n \sim 0.0123$, $\Gamma \sim 3 \times 10^{-4} kgs^{-1}$ are empirical constants, φ_p is the particle to fluid mass density ratio, ρ is the particle's mass density, g the gravitational acceleration and d the particle's size. In the current implementation, the resuspension is inhibited if the soil is considered too wet on the basis of the last precipitation. If in the last three hours $P_{rain} > P_{th}$, where $P_{th} = 0.1\ mm\ hr^{-1}$ is the precipitation threshold and P_{rain} the precipitation intensity, the soil is considered too wet to give rise to resuspension.

Preliminary academic tests were conducted to study the effects of the resuspension algorithm. To do so, two different simulations were performed (a summary of the simulations is reported in Table 1):
- Simulation **0S**: This simulation is conducted in the absence of an active source of particle. The simulated material started with a homogeneously deposited quantity of material on a square of size 1 km. The wind field was homogeneous, with a wind speed of 2 m s^{-1} blowing from south to north. The simulation was performed on a squared domain of size 12 km with a grid mesh size of 0.1 km and a constant orography of 0 m a.s.l.. The simulation lasted 8 hours starting from 8:00 UTC to 16:00 UTC.
- Simulation **1S_nr**: This simulation is similar to the previous one but considering a continuous emission of particles from a point source of particles, during the entire simulation time. All the other parameters are the same as Simulation **0S**. This second test was performed to quantify the relative contribution of resuspension in deposition and concentration values in presence of an active source of particles.
- Simulation **1S_r**: This simulation is similar to 1S_nr but without the presence of resuspension. This was done in order to compare the differences only due to the presence of the resuspension algorithm.

Table 1: Summary of the SPRAY simulations

Simulation ID	Wind Speed (m s^{-1})	Domain (km x km)	Source	Resuspension
0S	2	12 x 12	Initial squared of deposited material	Yes
1S_r	2	12 x 12	Point like source	Yes
1S_nr	2	12 x 12	Point like source	No

RESULTS AND DISCUSSION

Figures (1)-(2) show the deposition fluxes expressed in terms of *mass Area^{-1} time^{-1}*, fig. (1), and the relative concentration pattern close to the ground expressed as *mass Volume^{-1}*, fig. (2), at 09:00, 11:00, 13:00 and 16:00 UTC. In the plots, the colour bar refers to positive deposition fluxes while the black colour refers to negative ones, i.e. more material being removed than deposited due to resuspension. The deposition pattern starts to get spread throughout the domain, reaching the domain's borders around 11:00 UTC. At the start, the initial square of deposited material exhibits negative deposition fluxes, as the resuspension of the abundant surface material exceeds any concurrent re-deposition. While the simulation evolves, negative fluxes start to appear due to the dilution of the particles in the domain. This effect reflects on the concentration pattern close to the ground, initially increasing close to the source in the first time frames. After most of the initial material was drained by the resuspension effects, the concentration values start to decrease, due to the spread of the material throughout the domain.
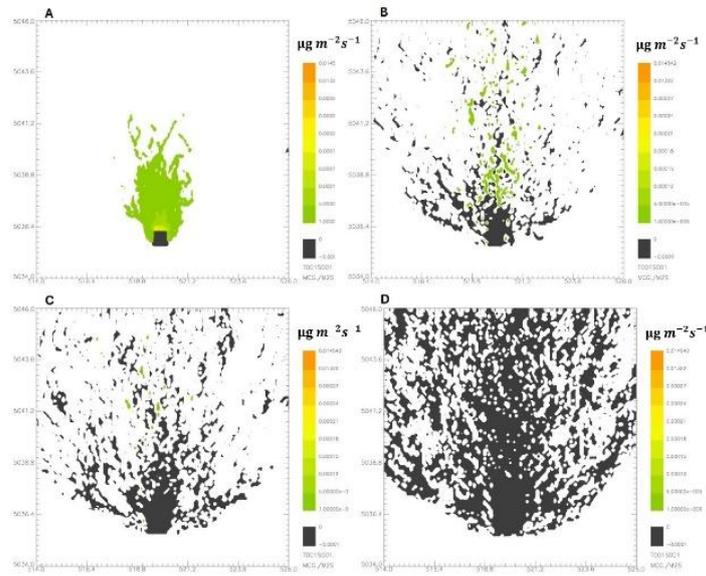

Figure 1: Deposition flux for the 0S simulation at 9:00 (A), 11:00 (B), 13:00 (C) and 16:00 (D). The black colour refers to negative deposition flux, i.e. more material resuspended than deposited.
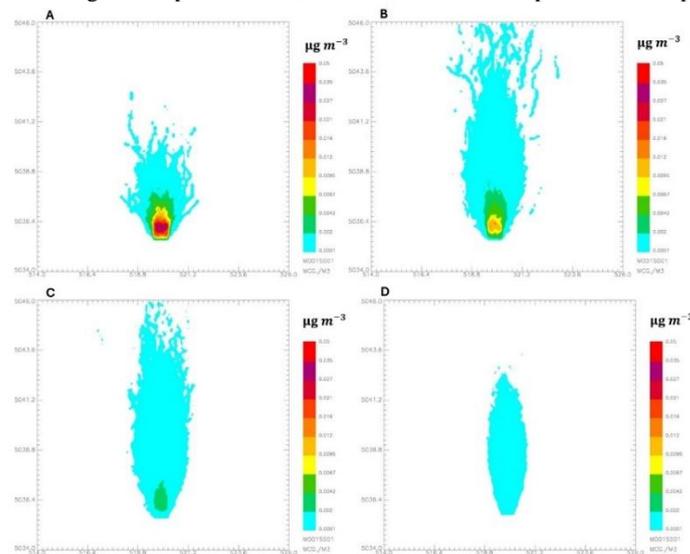

Figure 2: Concentration pattern for 0S simulation at 9:00 (A), 11:00 (B), 13:00 (C) and 16:00 (D).

Figures (3)-(4) report the deposition flux and concentration for simulation 1S. Panel (A) and (C) refer to the 9:00 and 16:00 hours of the simulation without the resuspension, while panel (B) and (D) refer to the same hours but evaluated in presence of resuspension effects. The plots clearly show that the differences between panel A and C are negligible both for deposition and concentration. When the resuspension is switched on, the deposition flux at the end of the simulation shows major differences with respect to the corresponding pattern in the absence of resuspension, showing areas for which the net flux is zero. Also in this case, the effects of resuspension reflect on the concentration levels, showing an increase close to the point source. This remarks that the main contribution of resuspension, with these specific meteorological conditions, acts mainly at the scale of ~ 1 km, following the wind direction and the turbulent diffusion.
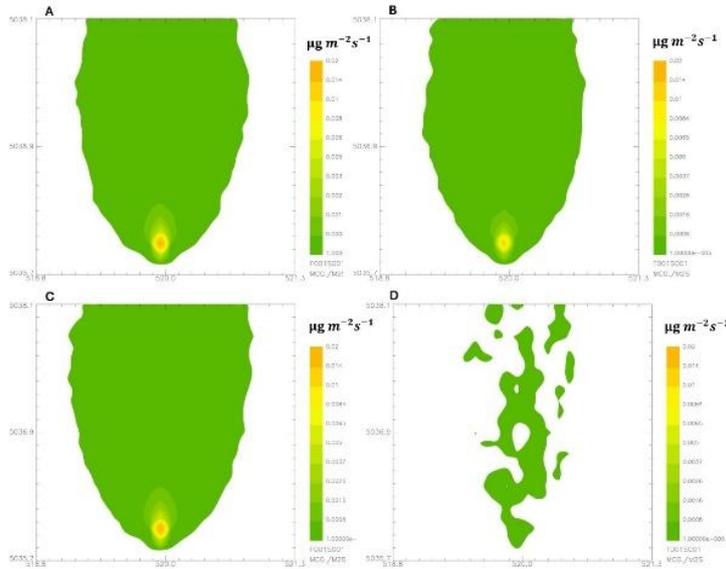

Figure 3: deposition flux evaluated at 9:00 and 16:00 UTC without the resuspension (panels A and C) and in presence of it (panels B and D)
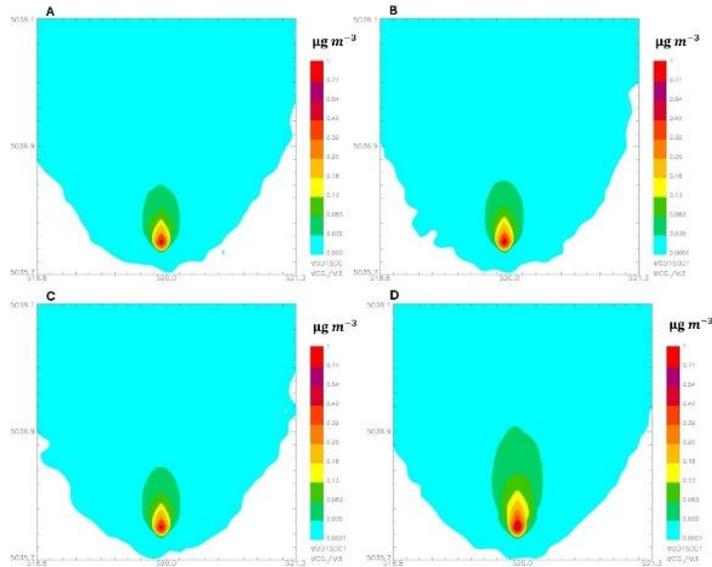

Figure 4: Concentration pattern for at 9:00 (upper row) and 16:00 (bottom row) for simulation 1S_nr (left panel) and 1S_r (right panel)

CONCLUSIONS

In this work we presented the implementation of a dynamical resuspension algorithm designed to simulate the secondary local dispersion of pollutants. The newly developed algorithm was based on the one proposed by Ginoux et al. (2001), modified to take into account the cumulated mass inside each computational cell, representing the material available for resuspension. The preliminary results of the academic tests have shown that the algorithm affects both deposition and concentration patterns. Deposition fluxes might show regions of the domain where the resuspension becomes more efficient than deposition, providing a net flux from the ground to the atmosphere. This effect reflects on the concentration values close to the surface, showing higher values in regions where net resuspension occurs. These effects are more evident in absence of emitting sources, whereas the effects of resuspension can be majorly seen at a scale of 1 to 10 km from the source. At the present state, this algorithm can be applied to any particulate matter and, due to the connection between the resuspended flux and the cumulated mass on the computational cells, it is suitable for simulations of emergency scenarios such as fires or radioactive fallouts. Future work will focus on validating the algorithm against real-case data.

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