A high-order size-resolved ultrafine particle model for a traffic tunnel

Peter Vos, Irina Nikolova, Stijn Janssen
Flemish Institute for Technological Research (VITO), Boeretang 200, 2400 Mol, Belgium
peter.vos@vito.be

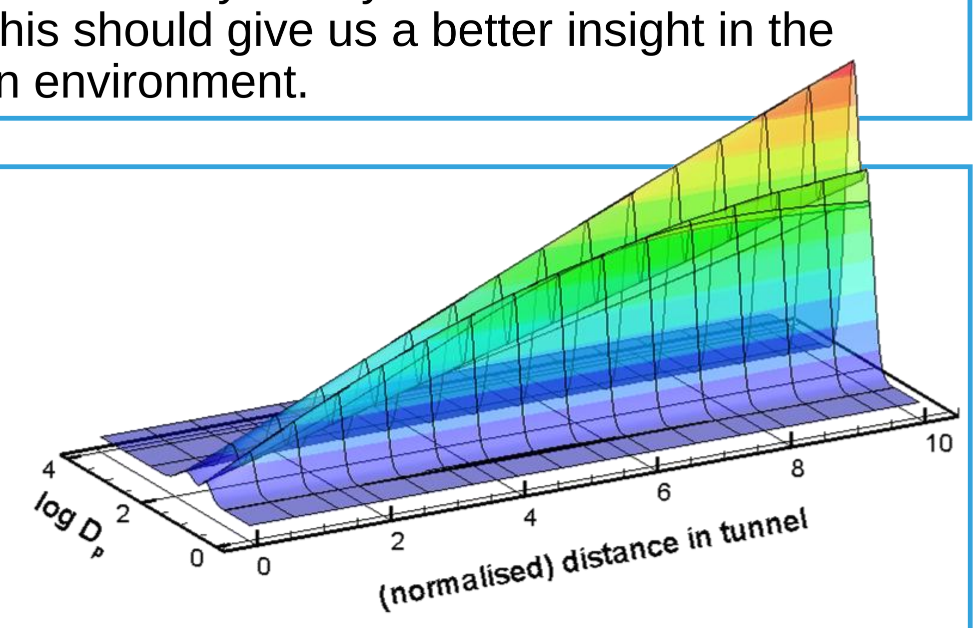
Key Question

Which are the dominant processes that govern the UFP number distribution inside a traffic tunnel?

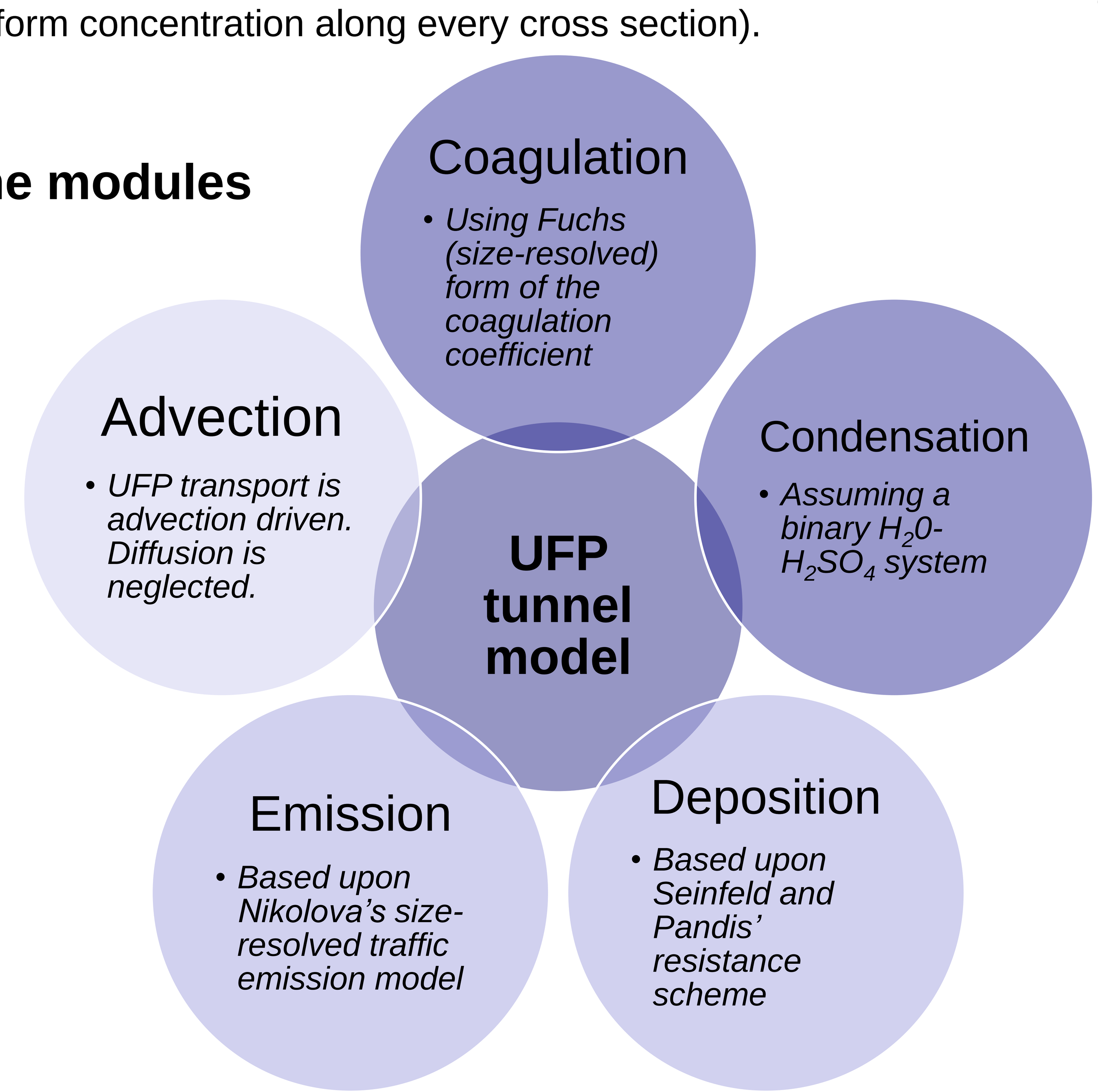
Due to its confined space and the high concentration of emitted particles, traffic tunnels form an ideal environment to study the dynamics of ultrafine particles (UFP). Therefore, we have developed a computational model simulating such a tunnel environment. This should give us a better insight in the relevant processes that govern the UFP size-distribution in a traffic tunnel, but also more general, within a urban environment.

The model

The model consists of a number of modules that implement the most important transport and transformation processes. It calculates a continuous UFP number distribution at every location inside the tunnel (assuming a uniform concentration along every cross section).



The modules



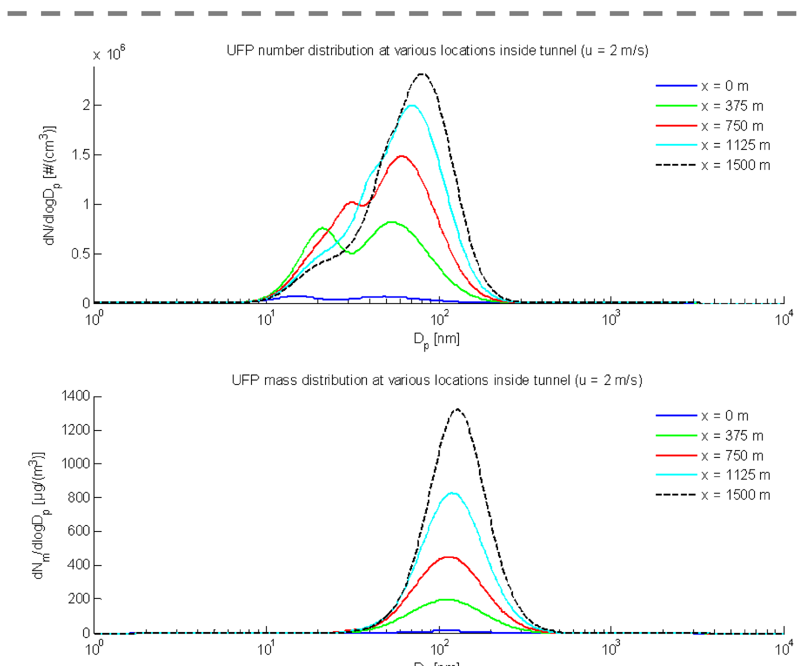
Model characteristics

The presented model differs from existing models in the following sense:

- **2D versus 1D**
  Aerosol dynamics box-models generally only depend on the particle size. The presented model also depend on a spatial coordinate, i.e. the distance in the tunnel.
- **A fully size-resolved approach**
  Next to a size-resolved description of the solution, we have also adopted a fully size-dependent description of the various processes. As such, as well the deposition speed, the coagulation coefficient as the condensation rate do depend on the particle size.
- **A continuous model**
  Various UFP models use discrete methods (such as the size bin approach) based upon the discrete formulation of the General Dynamic Equation. We start from the continuous formulation and use corresponding numerical methods.
- **State of the art numerical methods**
  We have combined the Discontinuous Galerkin method with a high-order spectral element approach. Such high-order method yields high-accurate solutions. The implementation is based upon the open-source C++ spectral-element library Nektar++.

Results

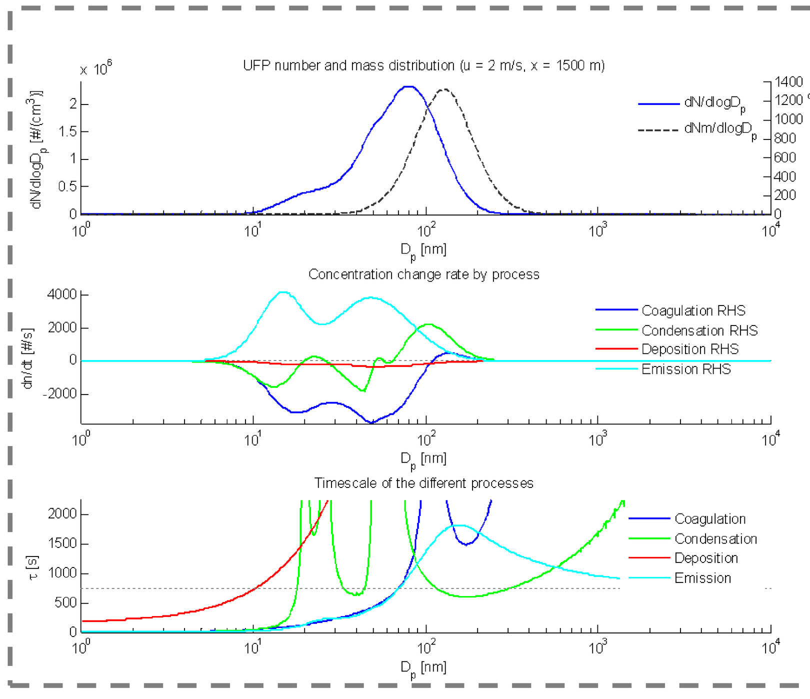
The figures below show the first results of the UFP tunnel model. The model is configured in accordance with the Craeybeckx Tunnel (Antwerp, Belgium). However, the results are not fully validated yet (concentrations are currently overestimated).



Evolution of number and mass distribution

It can be observed that both the shape and size of the number distribution change significantly throughout the tunnel. The nucleation mode disappears.

The shape of the mass distribution remains similar. We mainly observe a quasi-uniform increase in mass-concentration.



Time-scale of the processes

The time-scale of a process can be defined as the concentration divided by the concentration rate-of-change due to the process, i.e.

$$\tau_i = \left| \frac{n}{\left.\frac{\partial n}{\partial t}\right|_i} \right|$$

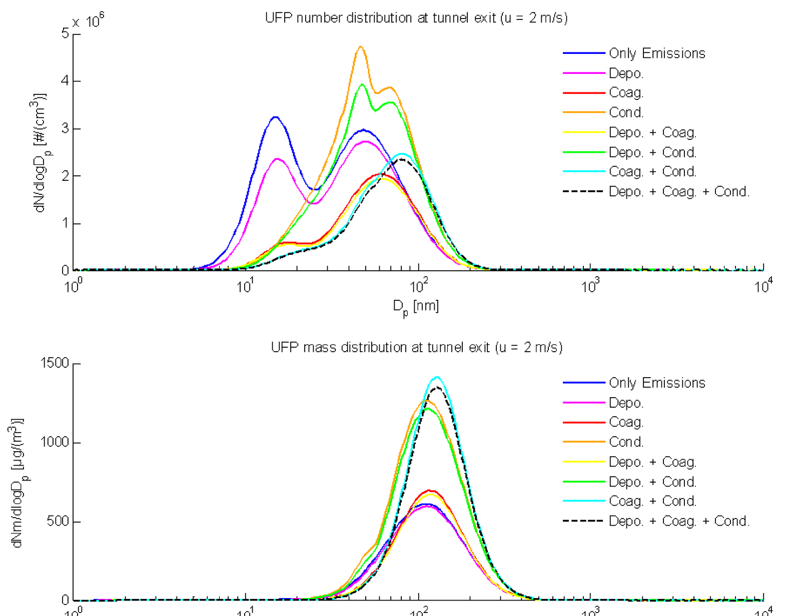
- The (size-resolved) time-scale is identical for number and mass distribution (only the region of interest differs)
- At the tunnel exit, we observe
  - Coagulation is as fast as the emissions for the nucleation mode (which explains the disappearance of this mode)
  - Condensation is the fastest for the Aitken mode (which explains the growth in the mass distribution and the shift towards the right for both distributions)

Effect of the different processes on the number and mass distribution

A computational model allows us to simulate different scenarios with certain processes switched off in order to study the effect of the different processes on the UFP distribution.

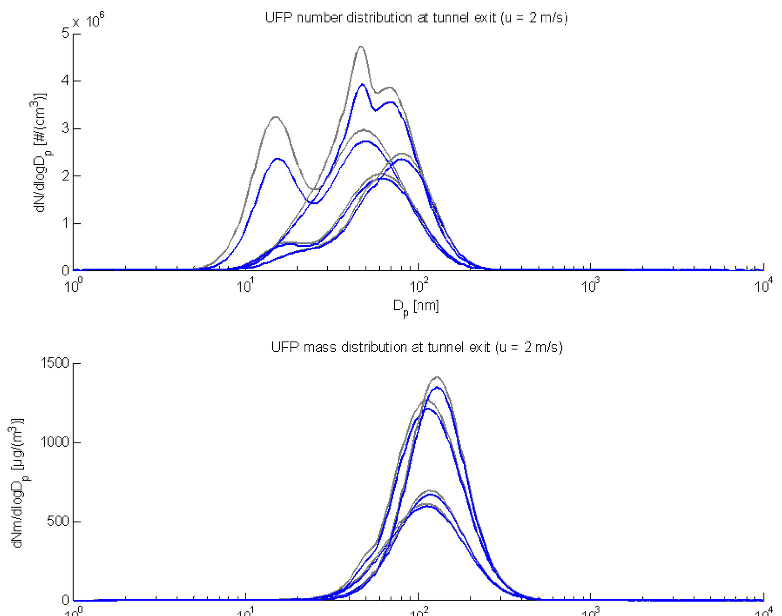
All scenarios

The figure below gives an overview of the exit concentration for all scenarios. The other figures highlight the scenarios corresponding to a certain process.



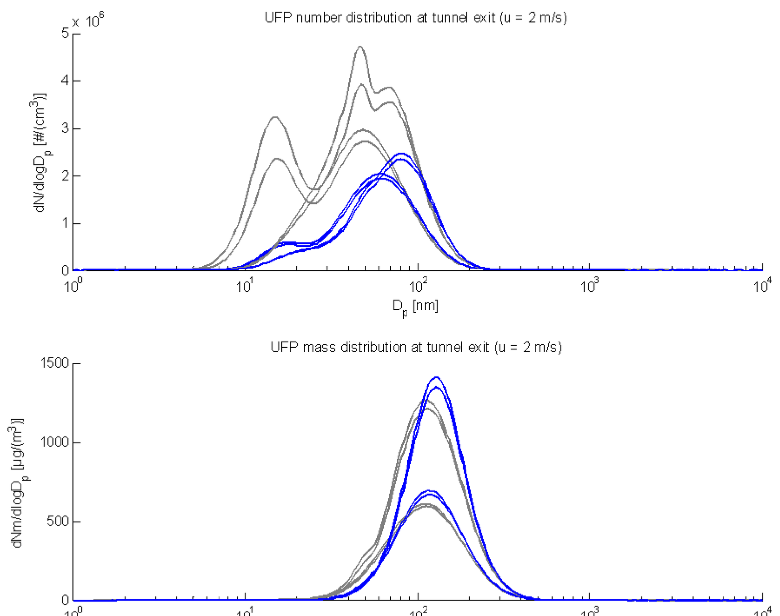
Effect of deposition

number distribution: a quasi-uniform decrease in concentration
mass distribution: a quasi-uniform decrease in concentration



Effect of coagulation

number distribution: concentration decrease (mainly nucleation mode), small shift towards right
mass distribution: narrowing (conservation of mass) + small shift towards right



Effect of condensation

number distribution: narrowing (conservation of the total number) + shift towards right
mass distribution: significant increase in concentration