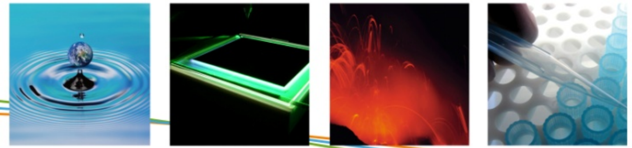


Accurately modelling UFP transformation processes inside a traffic tunnel

Peter Vos[1,2,*], Irina Nikolova[1,2] and Stijn Janssen[1]

[1]Flemish Institute for Technological Research (VITO), Mol, Belgium
[2]Department of Bioscience Engineering, University of Antwerp, Antwerp, Belgium
*peter.vos@vito.be

Content

- Introduction
- Model Description
- Model Verification and Validation
- Analysis of the UFP dynamics

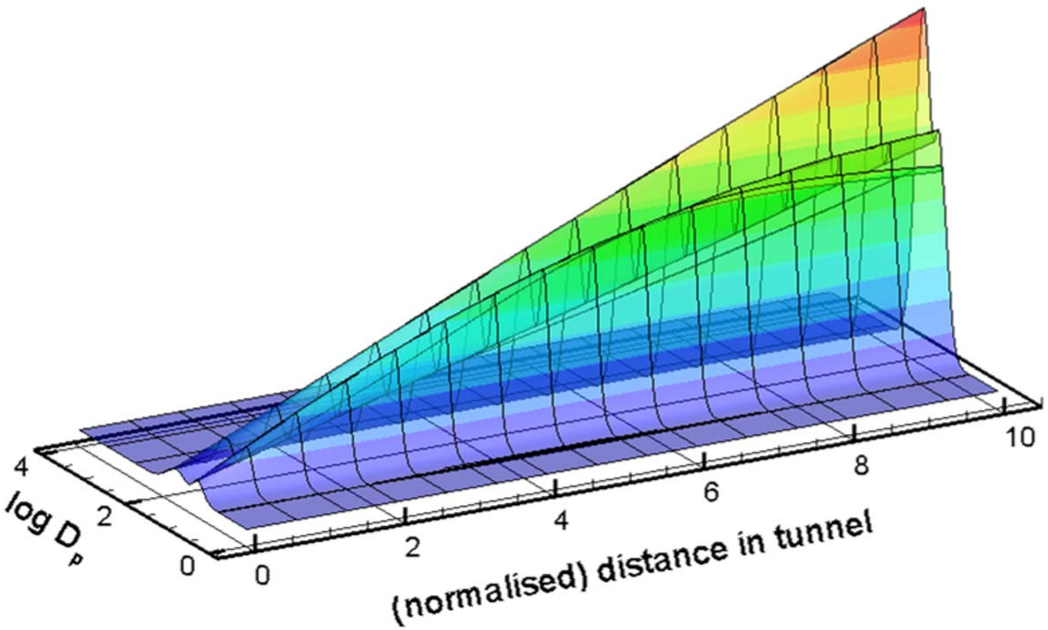
Introduction

- Relevance of UFP: more harmful than PM_{10}?
- Key question for UFP modelling
  - Which are the dominant processes that govern the UFP *number distribution* within an urban environment ?
    - How to quantify this?
- To obtain more insight before incorporation into 3D air quality model
  → Phase 1: **UFP tunnel model**
  - Confined and controlled environment
  - High concentrations
  - One-dimensional

vito
vision on technology

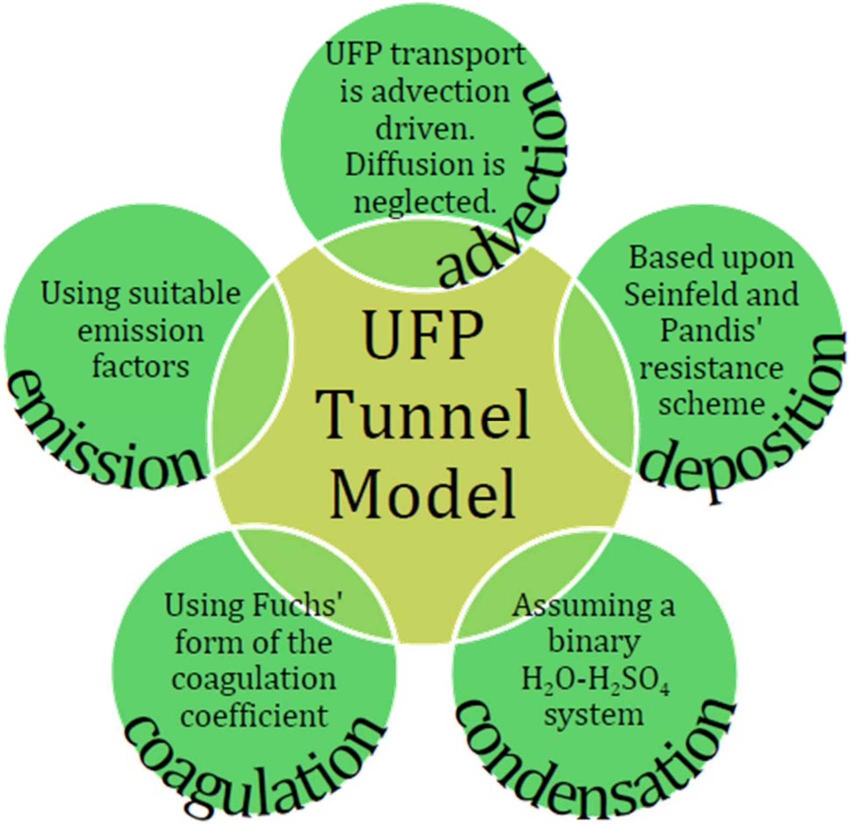
Model Description

» It calculates a continuous UFP number distribution at every location inside the tunnel (assuming a uniform concentration along every cross section).



Model Description

» Implementation of various transport and transformation processes

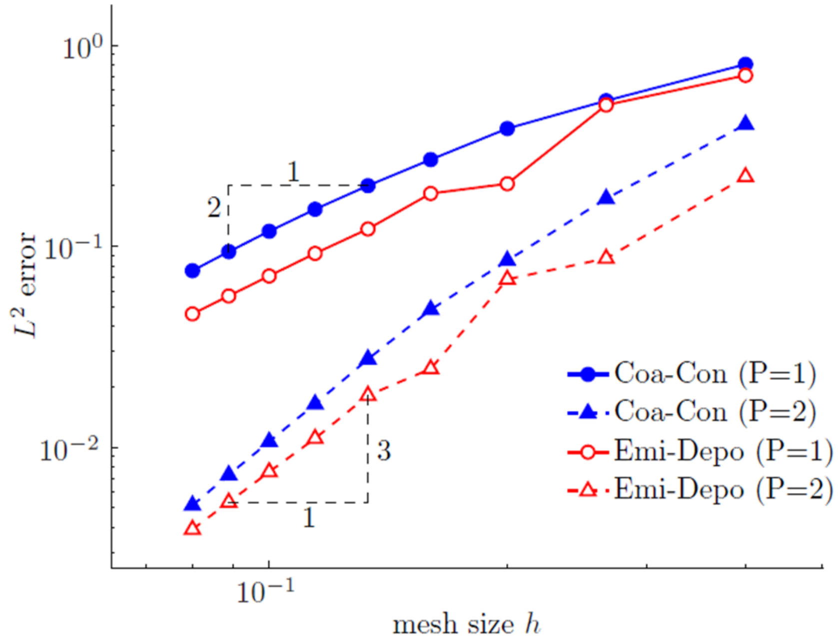


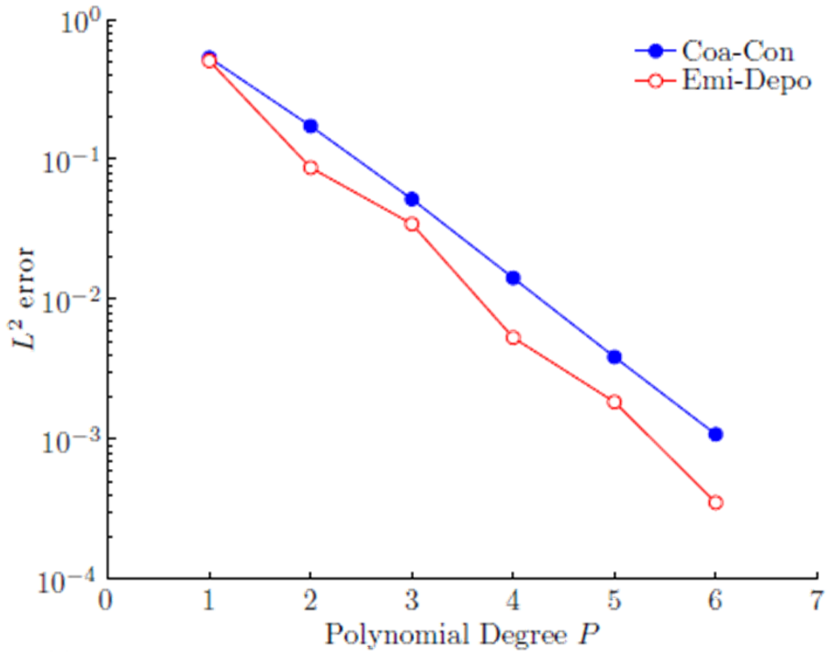
Model Description

- The model differs from existing (box) models in the following sense:
  - **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.
  - **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.
  - **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++.

Model Verification

- 2 cases with an analytical solution
  - Only advection, emissions and deposition
  - Only advection, condensation and coagulation

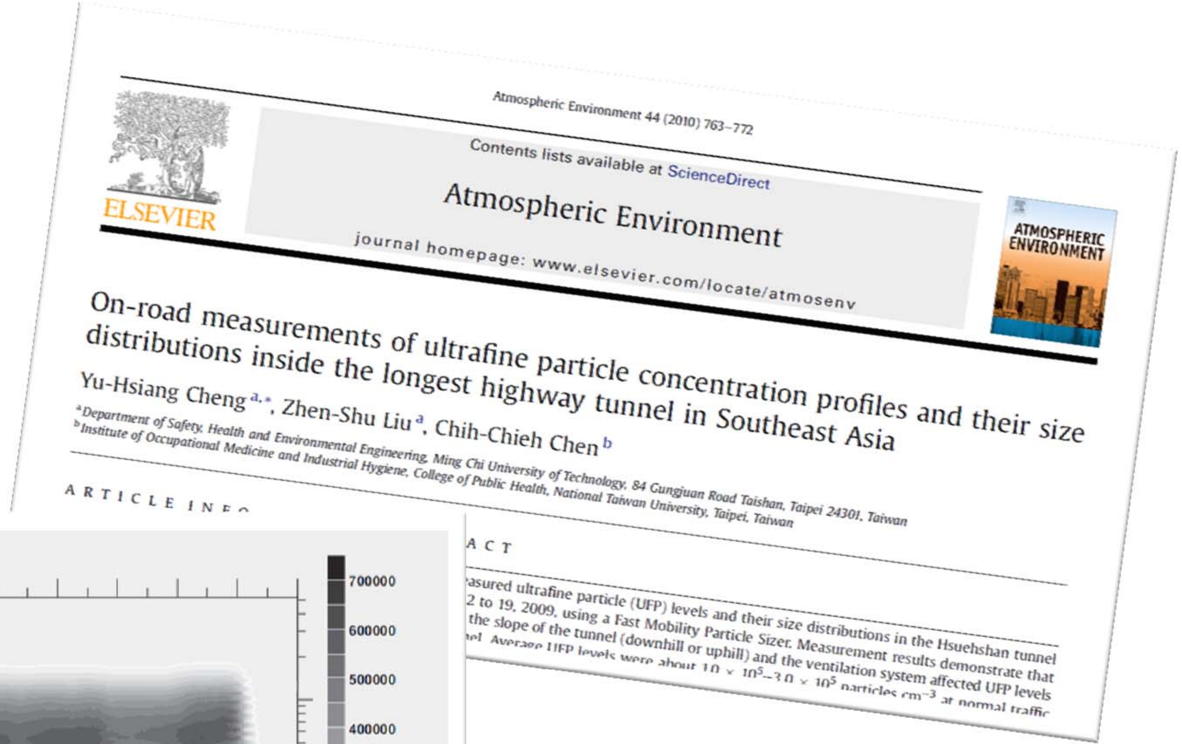




vito
vision on technology

Model Validation

- Comparison with measurements
- 13 km long tunnel


Atmospheric Environment 44 (2010) 763–772

Contents lists available at ScienceDirect

Atmospheric Environment

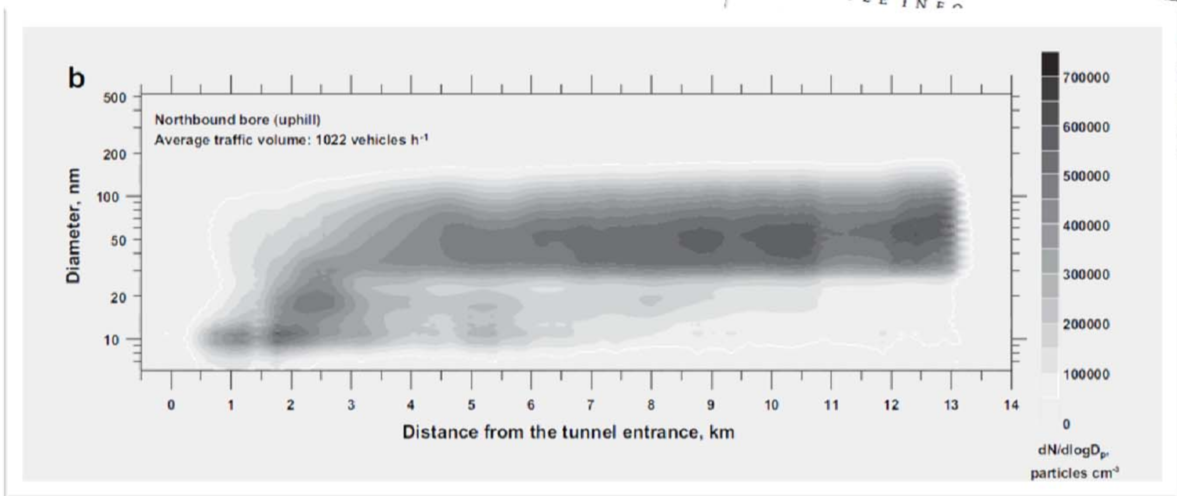
journal homepage: www.elsevier.com/locate/atmosenv

On-road measurements of ultrafine particle concentration profiles and their size distributions inside the longest highway tunnel in Southeast Asia

Yu-Hsiang Cheng[a,*], Zhen-Shu Liu[a], Chih-Chieh Chen[b]

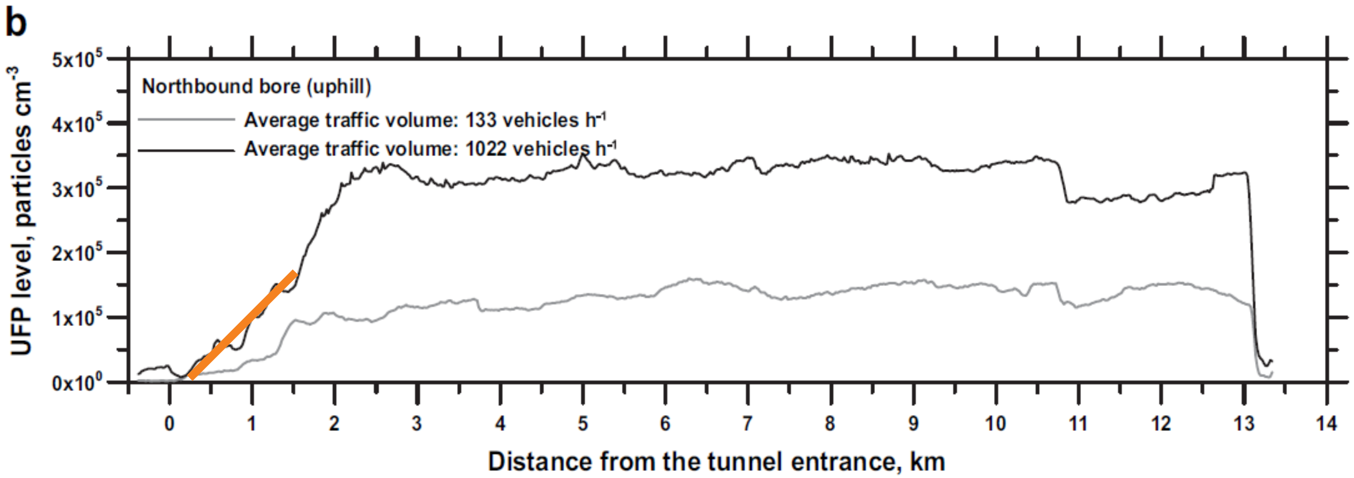
[a] Department of Safety, Health and Environmental Engineering, Ming Chi University of Technology, 84 Gungjuan Road Taishan, Taipei 24301, Taiwan

[b] Institute of Occupational Medicine and Industrial Hygiene, College of Public Health, National Taiwan University, Taipei, Taiwan



Model Validation

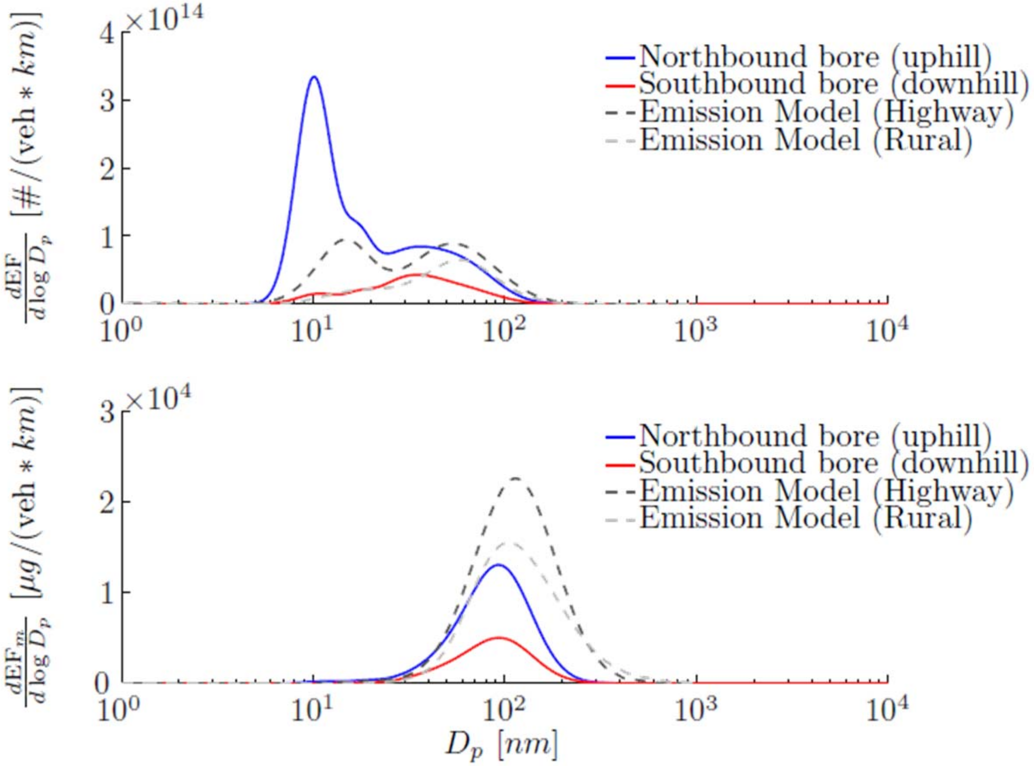
» Estimating UFP emission factors



vision on technology

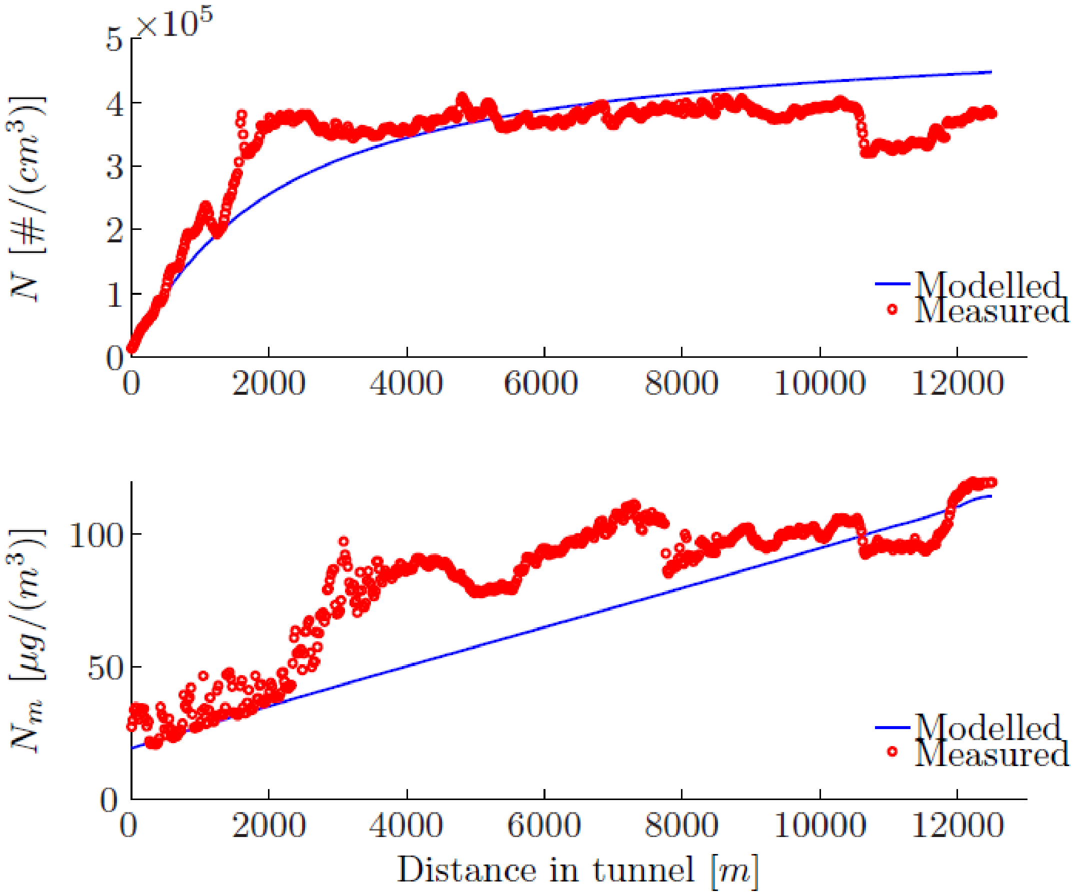
Model Validation

» Estimating UFP emission factors



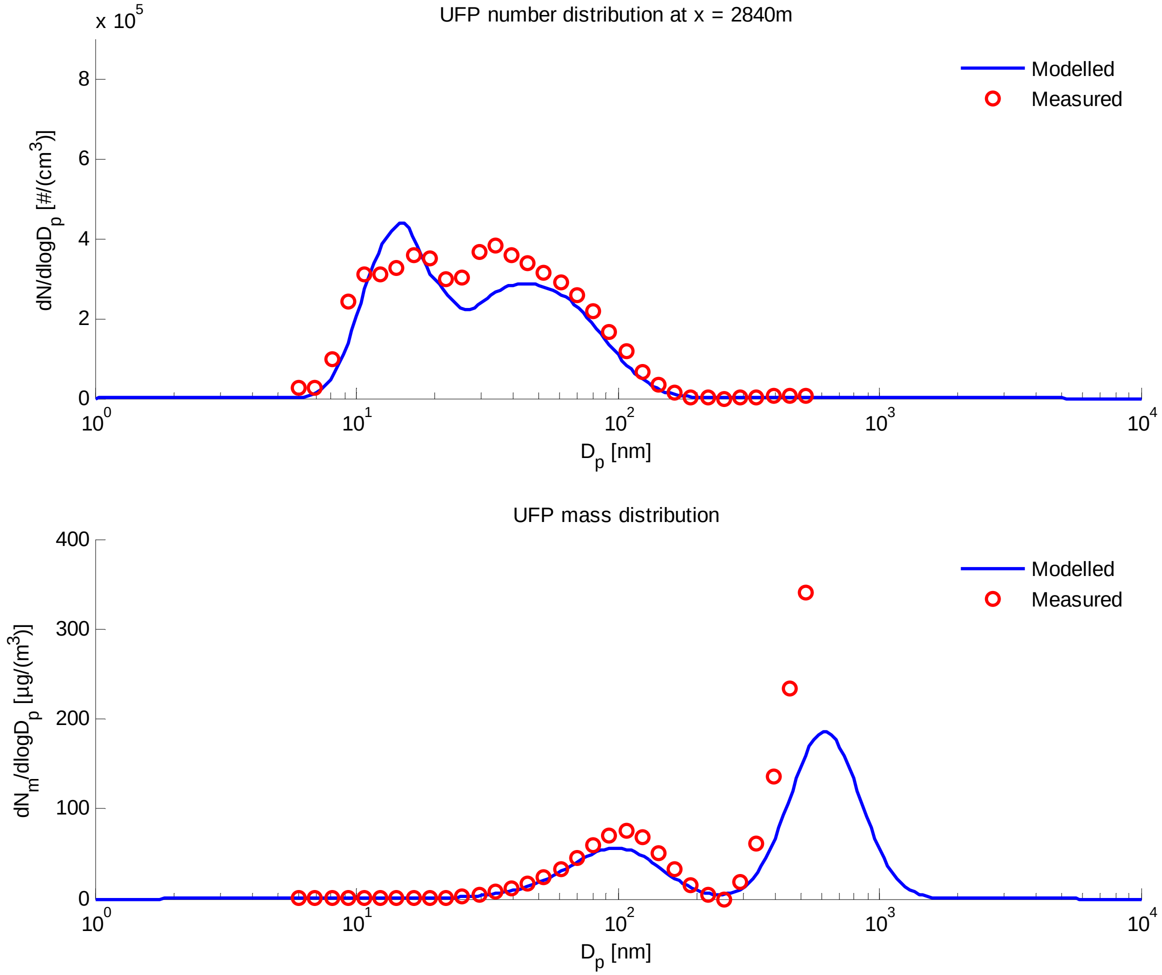
Model Validation

- Validation
  - Total concentration (NB)



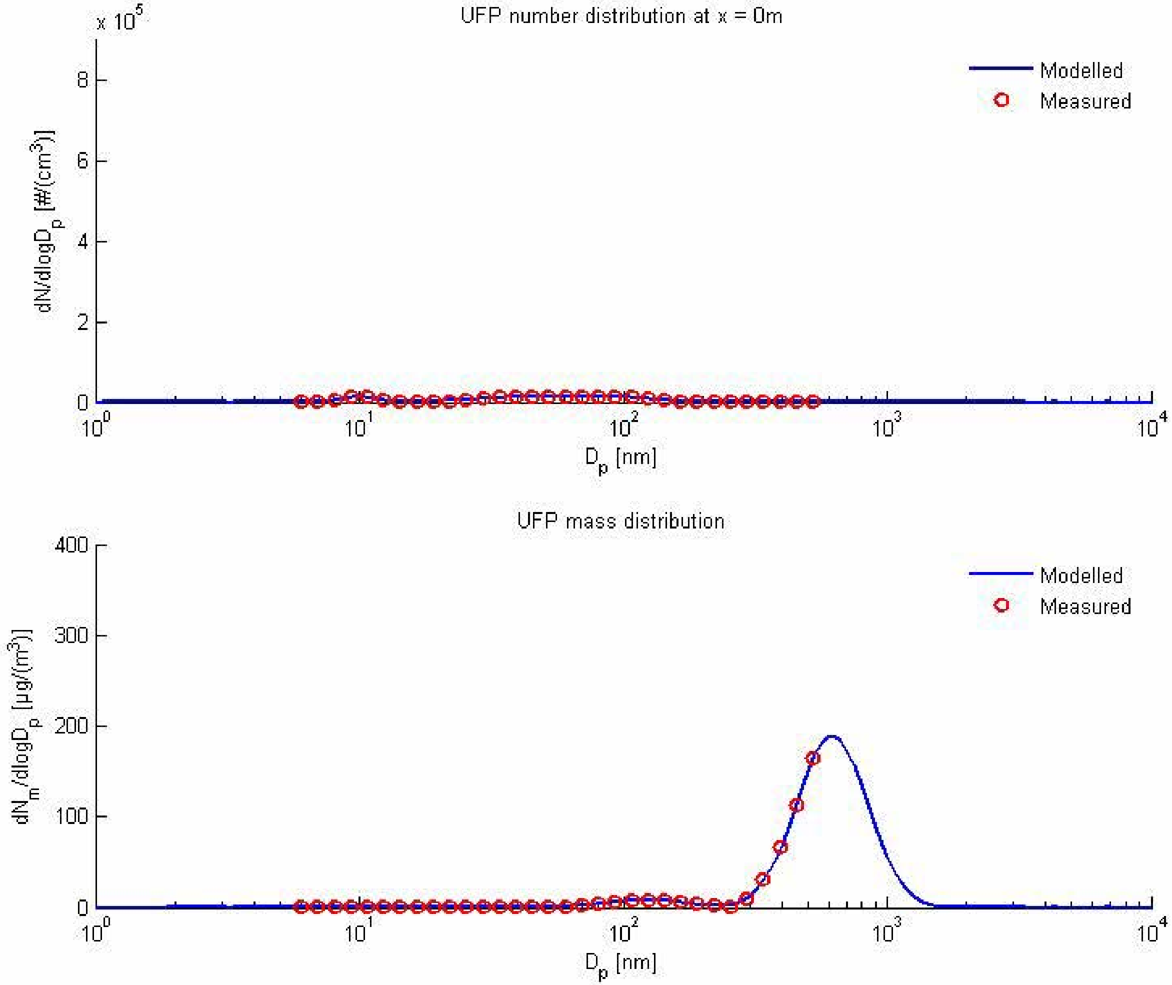
Model Validation

- Validation
  - Northbound pipe (uphill)



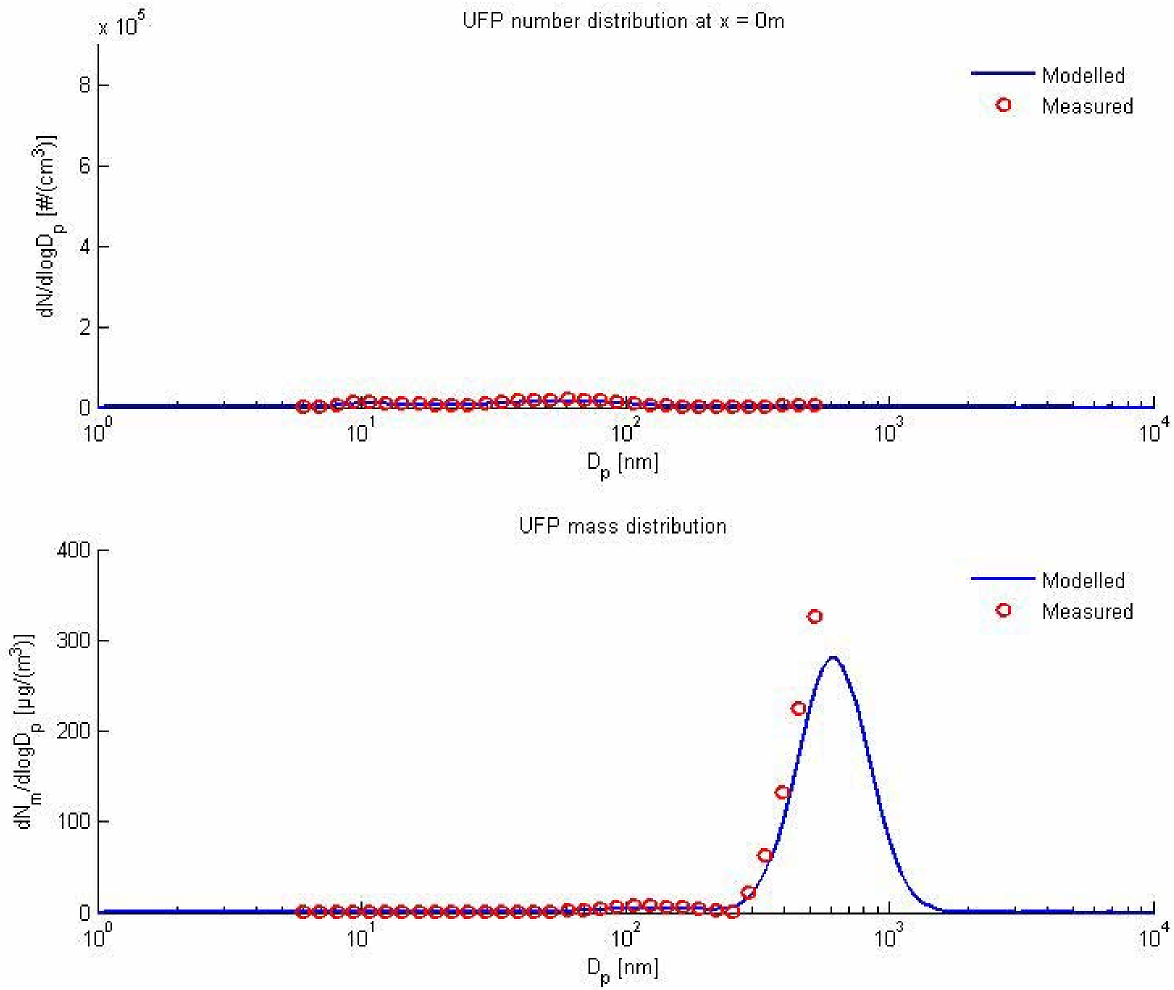
Model Validation

- Validation
  - Northbound pipe (uphill)

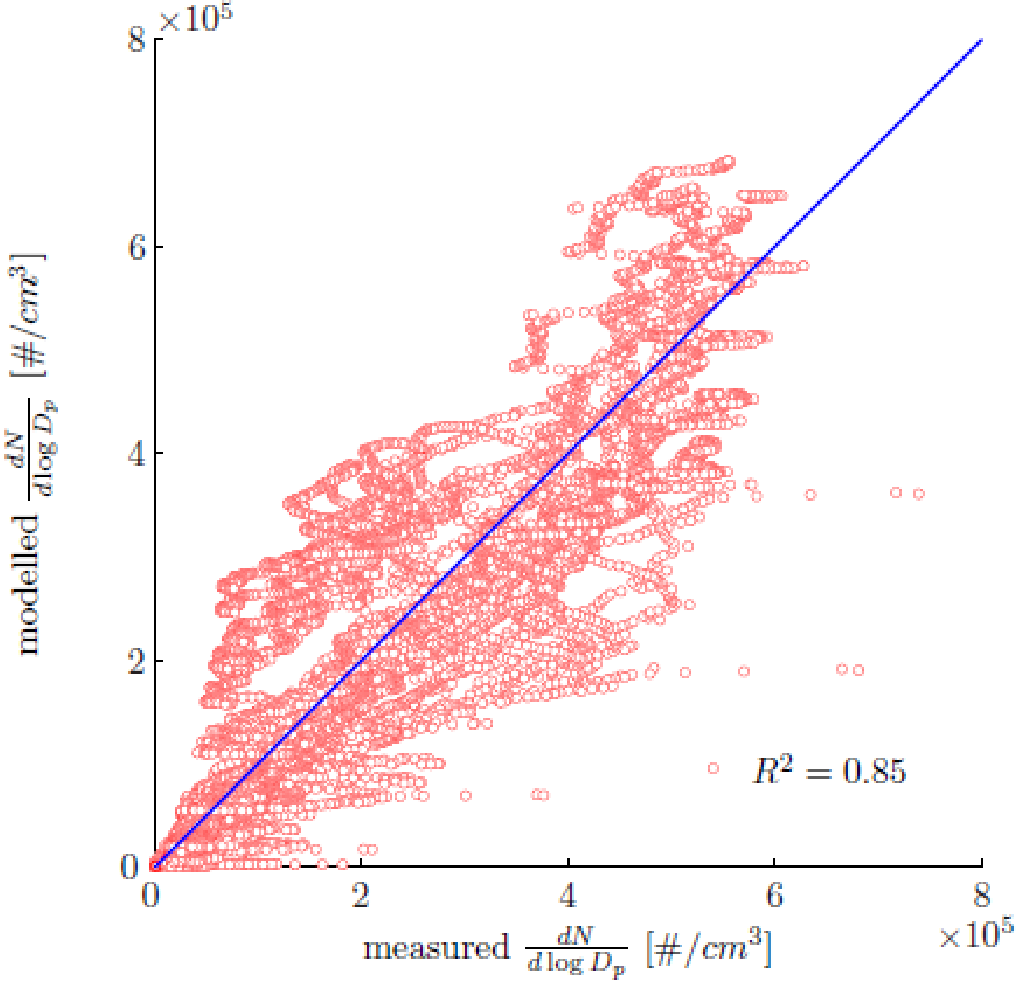


Model Validation

- Validation
  - Southbound pipe (downhill)



Model Validation



Analysis of the UFP dynamics

- Which are the dominant processes that govern the UFP *number distribution* within an urban environment ?
  - How to quantify this?

Analysis of the UFP dynamics

- Which are the dominant processes that govern the UFP *number distribution* within an urban environment ?
  - How to quantify this?

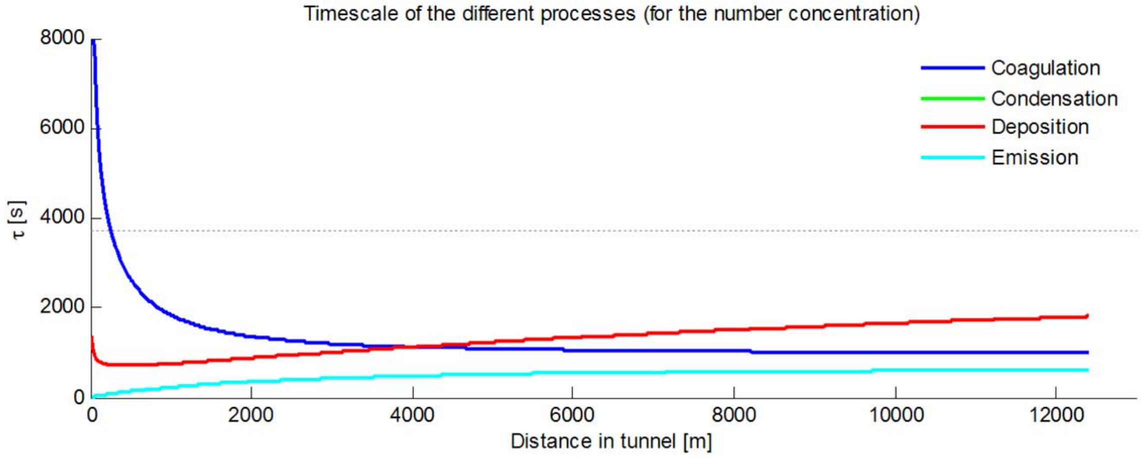
- Time-scale analysis
  - Definition

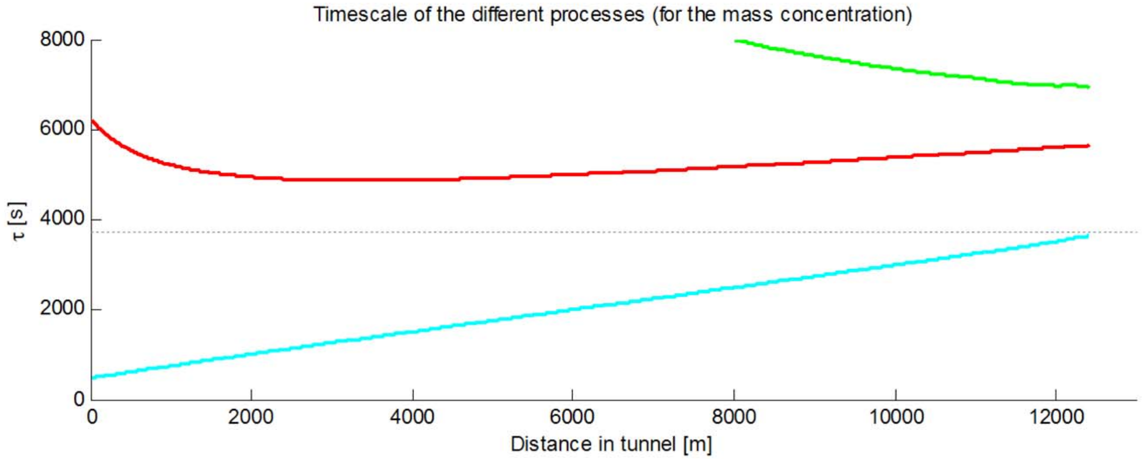
$$\tau_i = \left| \frac{N}{\left.\frac{\partial N}{\partial t}\right|_i} \right|$$

Analysis of the UFP dynamics

- Time-scale analysis
  - Northbound pipe (uphill)

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



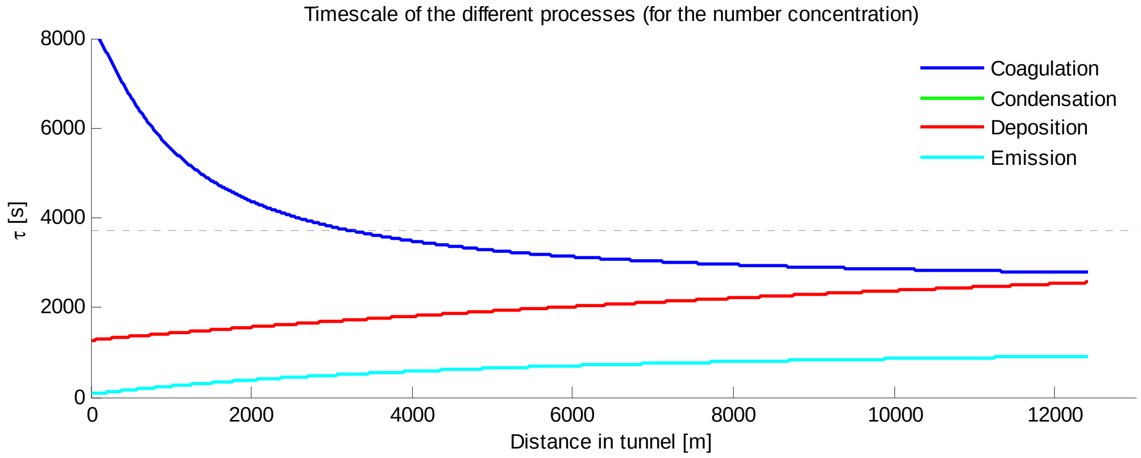


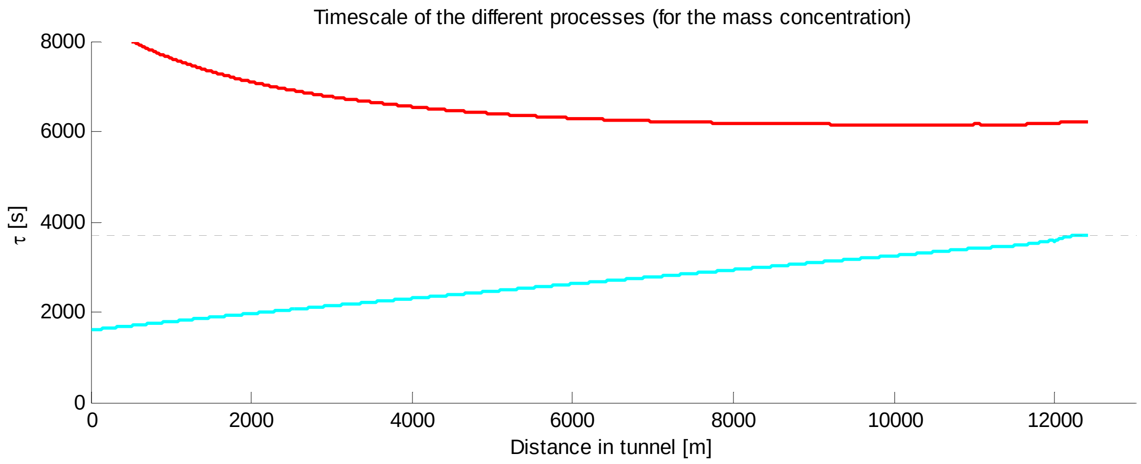
vision on technology

Analysis of the UFP dynamics

- Time-scale analy
  - Southbound pipe (downhill)

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





vito
vision on technology

Analysis of the UFP dynamics

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

- Time-scale analysis
  - Size-resolved time-scale?

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

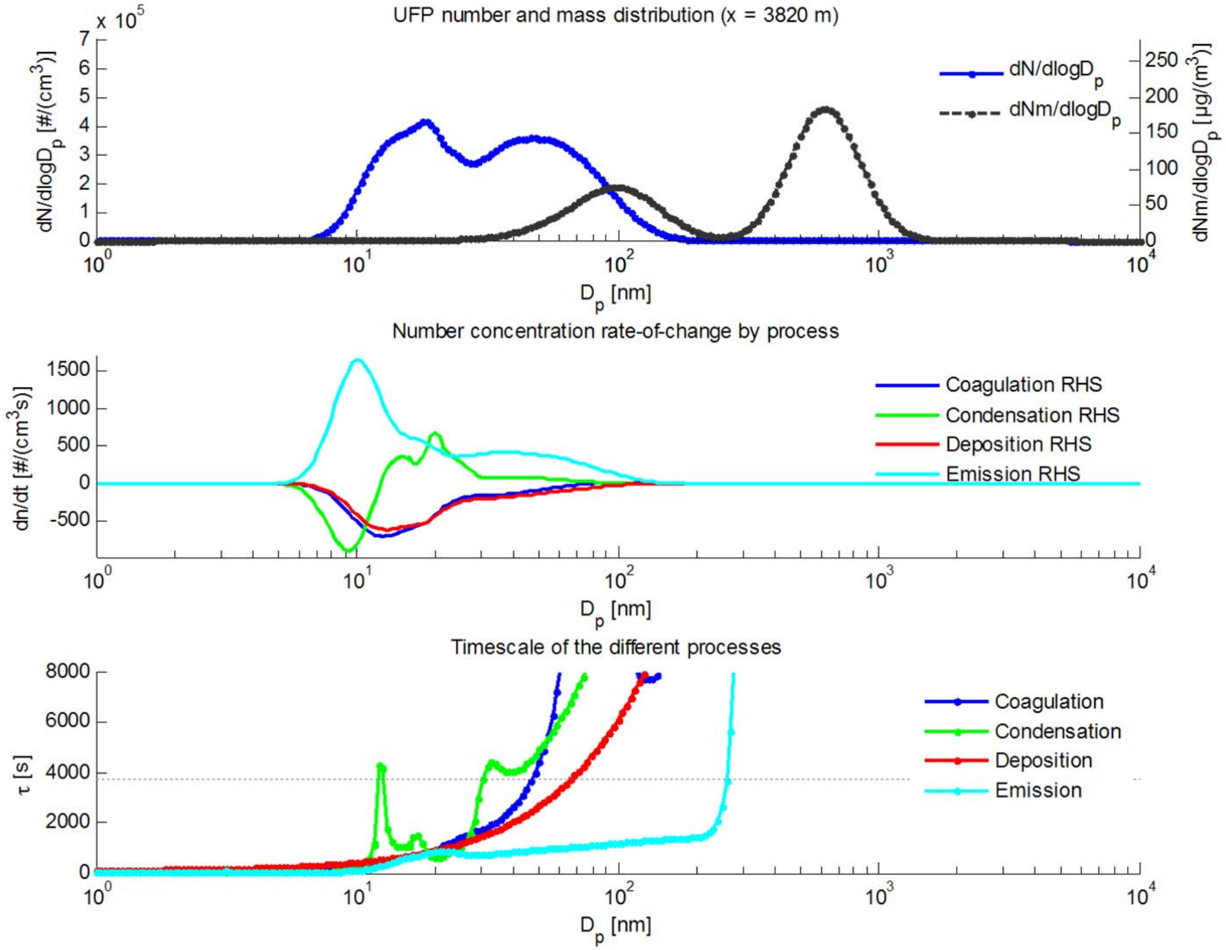
- where $n = \frac{dN}{d \log D_p}$

vito
vision on technology

Analysis of the UFP dynamics

- Time-scale analysis
  - Size-resolved time-scale

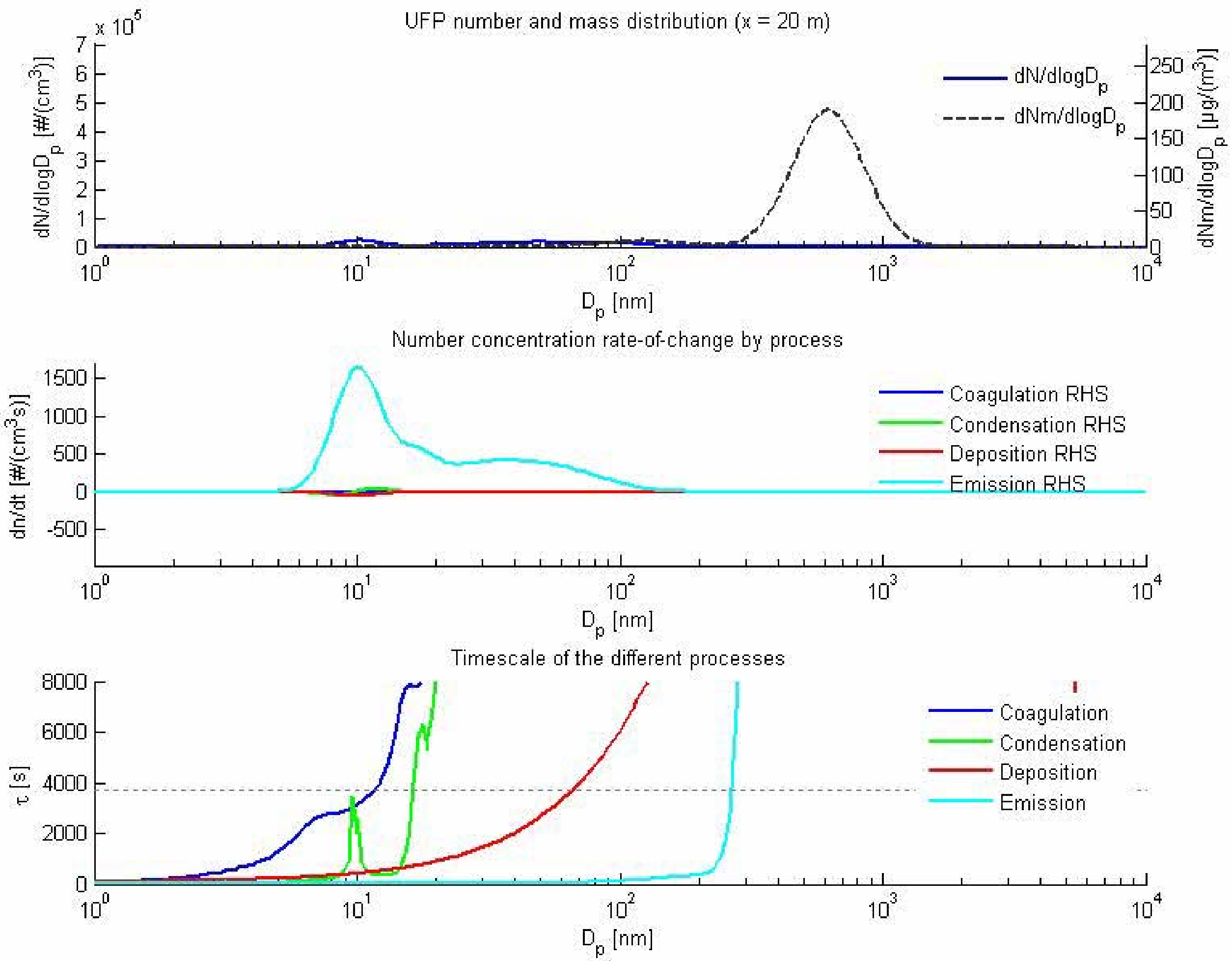
$$\tau_i(D_p) = \left| \frac{n}{\left.\frac{\partial n}{\partial t}\right|_i} \right|$$



Analysis of the UFP dynamics

- Time-scales
  - Size-resolved time-scale
  - Northbound pipe (uphill)

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



Analysis of the UFP dynamics

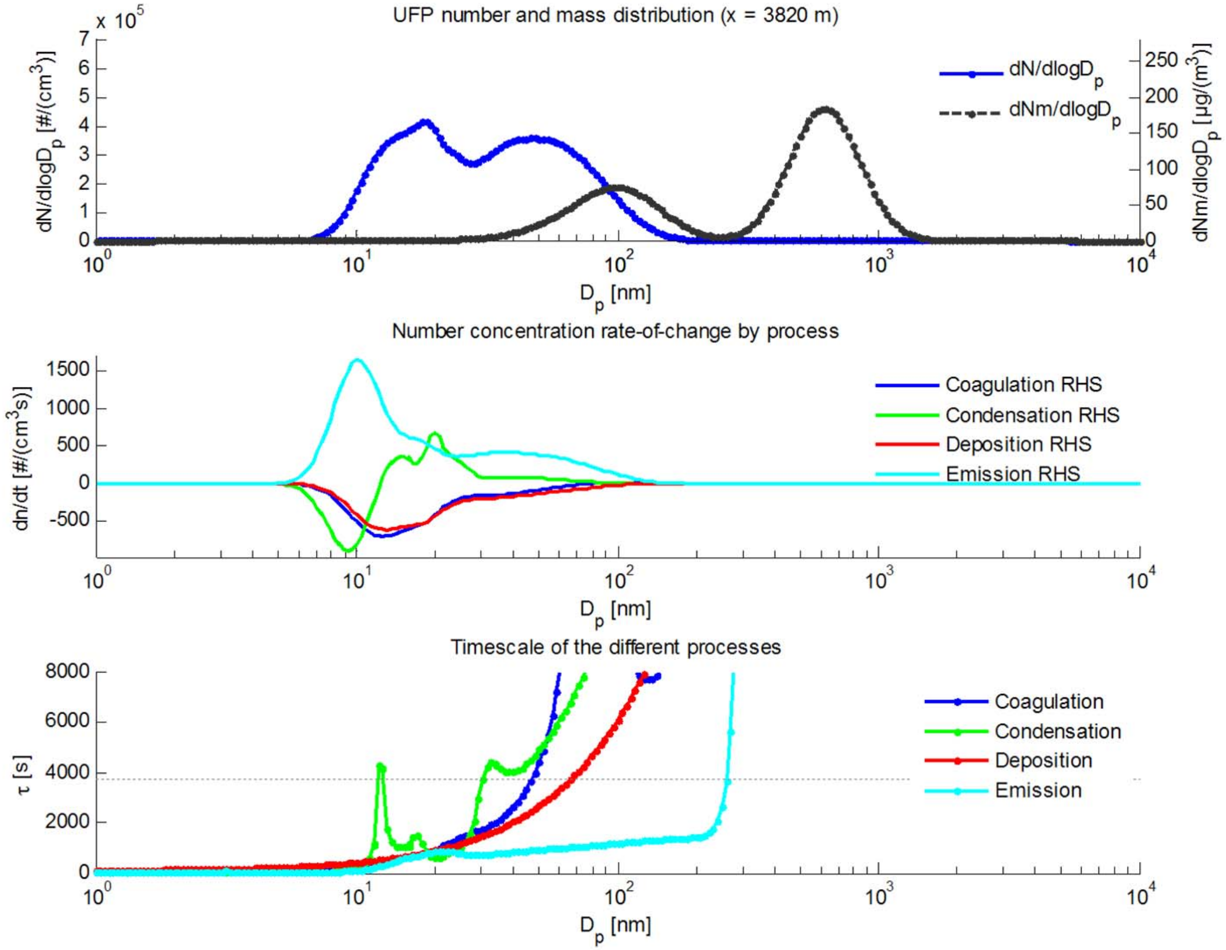
- Time-scale analysis
  - Size-resolved time-scale
  - **Identical for mass and number concentration**

$$\tau_i(D_p) = \left| \frac{n}{\left.\frac{\partial n}{\partial t}\right|_i} \right| = \left| \frac{\frac{1}{6}\pi D_p^3 \rho n}{\frac{1}{6}\pi D_p^3 \left.\frac{\partial n}{\partial t}\right|_i} \right| = \left| \frac{n_m}{\left.\frac{\partial n_m}{\partial t}\right|_i} \right|$$

- where $n_m = \frac{dN_m}{d \log D_p}$

Analysis of the UFP dynamics

- Time-scale analysis
  - Size-resolved time-scale



Conclusions

» Model successfully verified and validated

> » Key question for UFP modelling
>
> » Which are the dominant processes that govern the UFP *number distribution* within an urban environment ?
>
> » How to quantify this?

» Condensation, coagulation and deposition do all significantly affect the UFP *number* distribution inside a *long* traffic tunnel

» Using *size-resolved* time-scale to assess the affect

Questions?