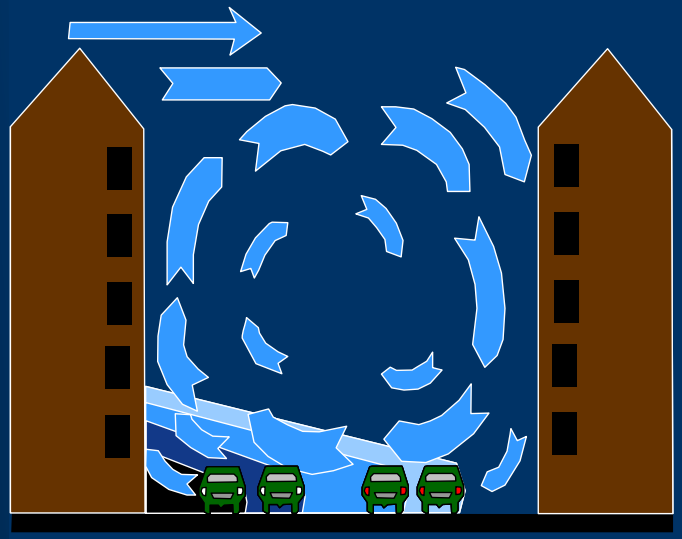
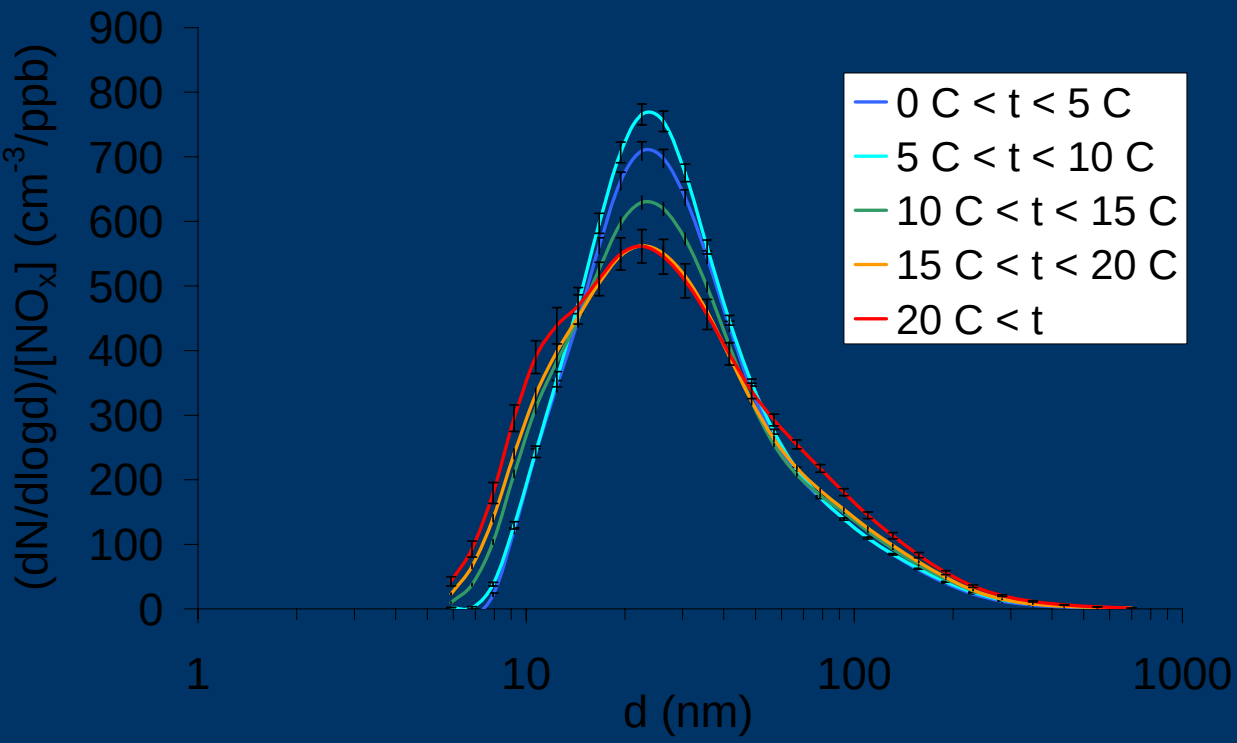
Modelling ultrafine particles in urban environments





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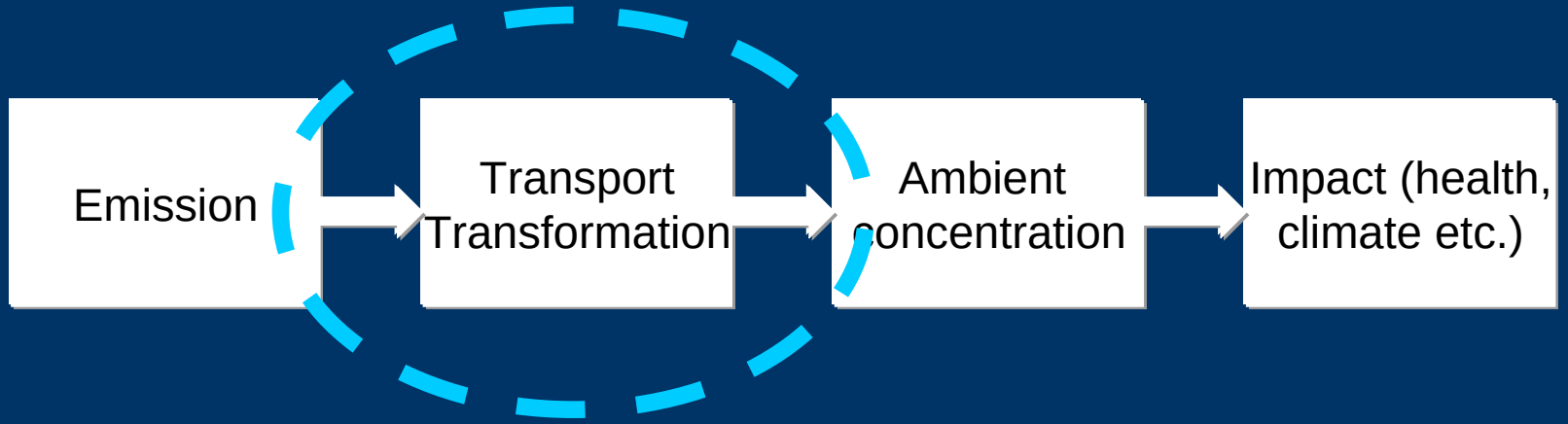
Outline

- Introduction
  - air pollution modelling
  - challenges for ultrafine particles:
- Emission factors
  - Temperature dependence
- Transformation processes
  - time scale analysis
- Applications / results
  - street scale => OSPM
  - urban scale => MAT
- Conclusions

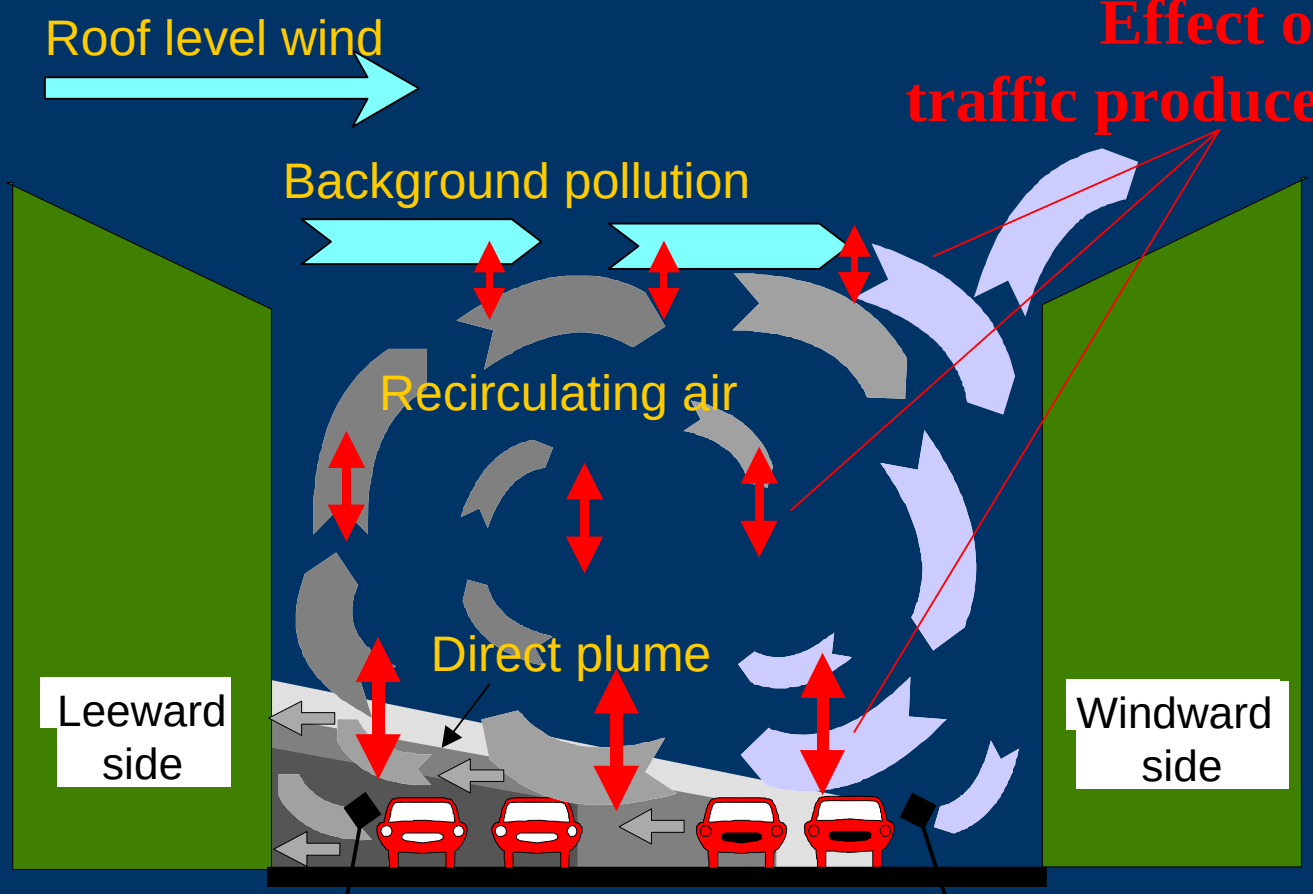
Air pollution modelling ...



well understood and modelled for pollutants as NOx NO2 CO …
and for all scales (street-urban-regional-global)

Danish Operational Street Pollution Model: OSPM

- Berkowicz et al. 198x …2007
- semi-empirical model (plume + box), fast, hour by hour
- worldwide used (incl. IfT Leipzig, soon NRW …)

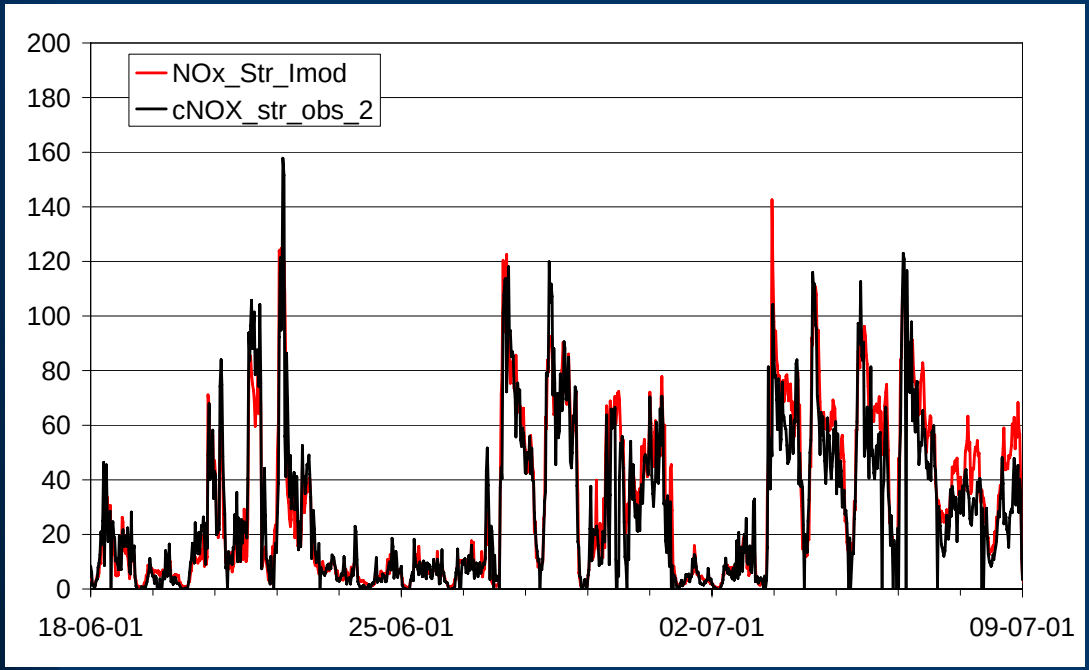


ospm.dmu.dk

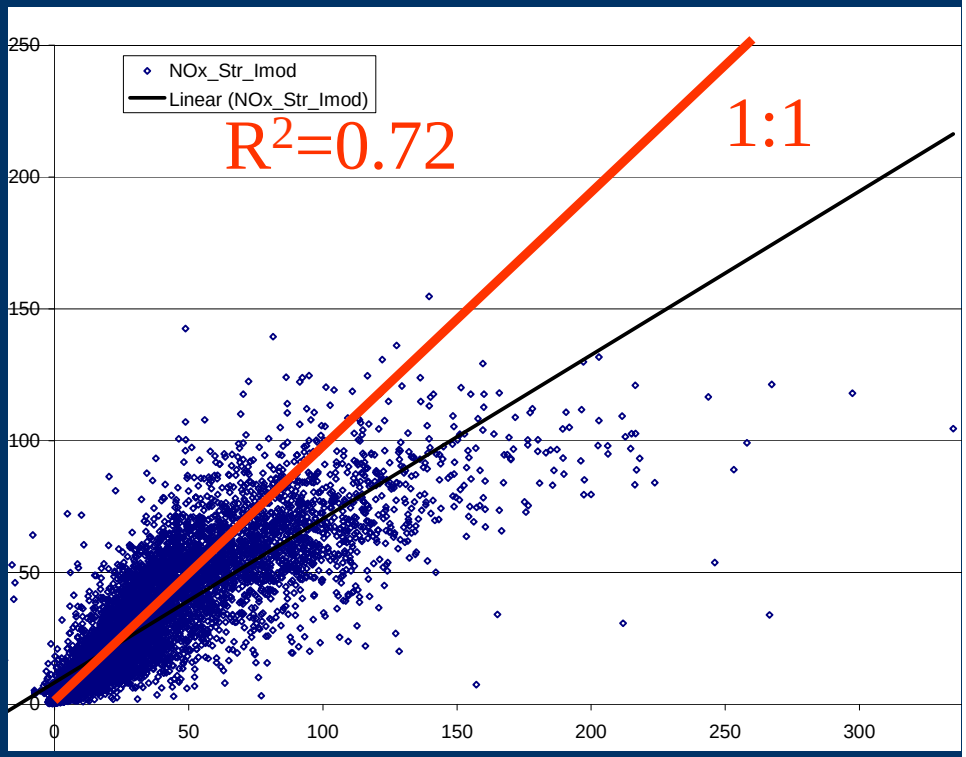
Modelling NOx at kerbside

- OSPM and emission factors from inverse modelling

background subtracted



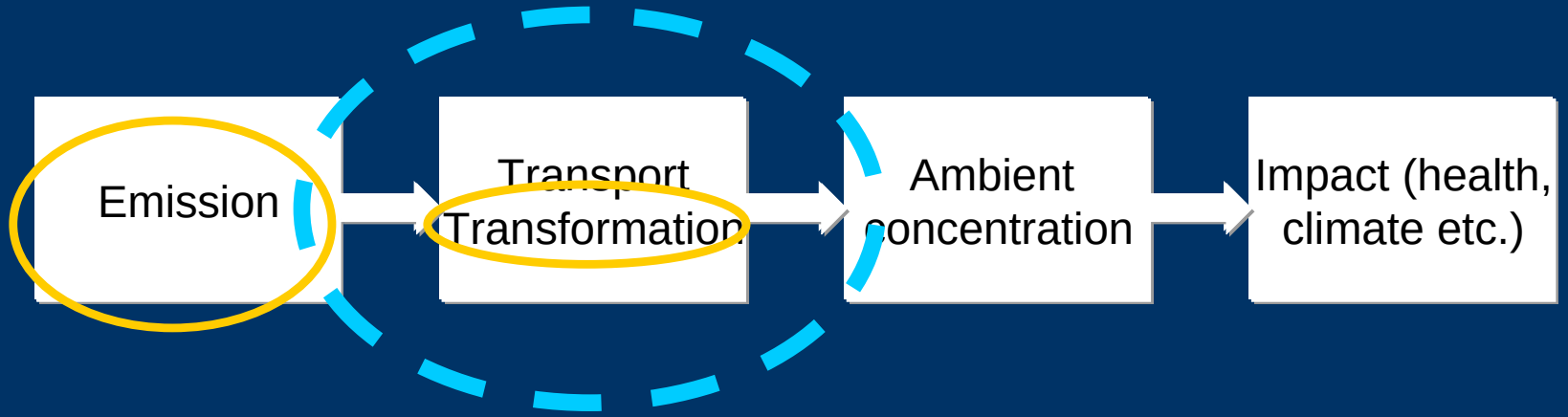
modelled



measured

Air pollution modelling ...

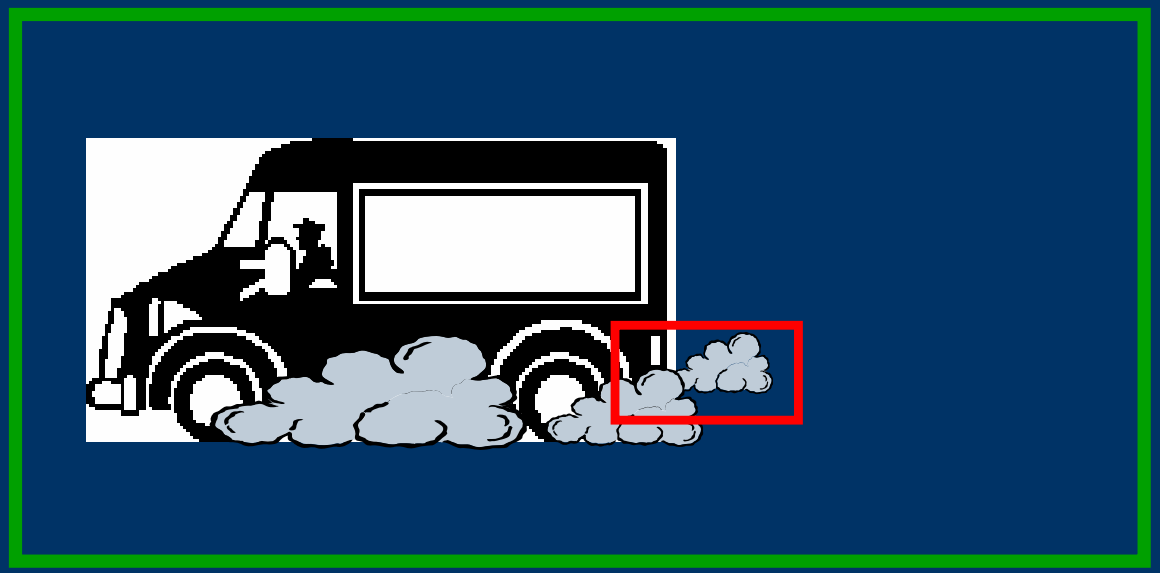
- **The two C's (challenges)**



well understood and modelled for pollutants as NOx NO2 CO …
and for all scales (street-urban-regional-global)

Challenge 1: emissions

- for PM: substantial part of the emissions comes from non-exhaust:
- for PNC: formation during dilution, temperature dependence
- use of “effective emissions”

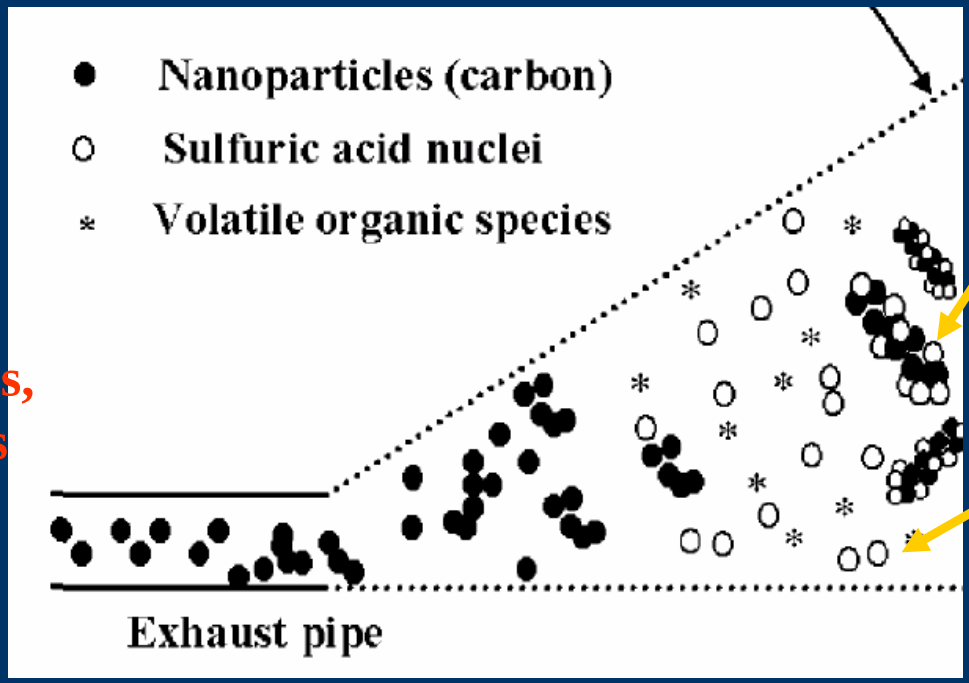


- need for field studies to estimate the emissions at: road tunnel, street canyon, highway, etc.
- using: NOx / C as tracer or ‘inverse’ modelling

Traffic Exhaust Particles

- **90% of the particle number formed by nucleation followed by condensational growth during dilution**

(Kittelson et al. 1999, Burtscher 2001)



•exhaust solids,
•gas phase organics,
•sulfur compounds

•solid particles
(≈ 50- 300 nm)

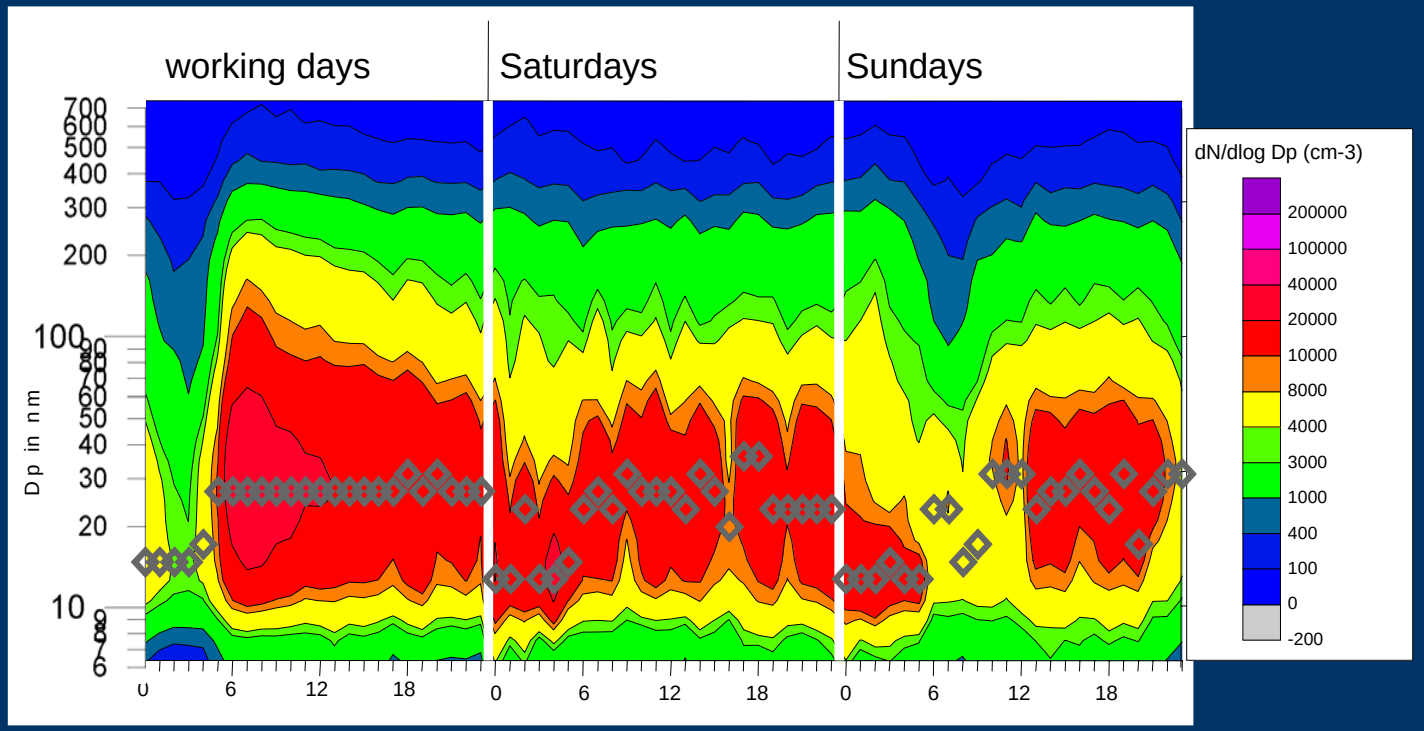
•volatile particles
(≈10-50 nm)

decreasing temperature

Average weekly profile of size distribution, Difference Street - background

period 15-05 to 23-11-2001 ca. 12 weeks of data (1h averages)

- !! continuous measurements
- !!! simultaneous measurements at background
- night time shift to smaller sizes
  - diesel taxi ??
  - nucleation ?!



time ('hour of the week')

Ketzel et al. 2003 Atmosph. Env. 37, 2735

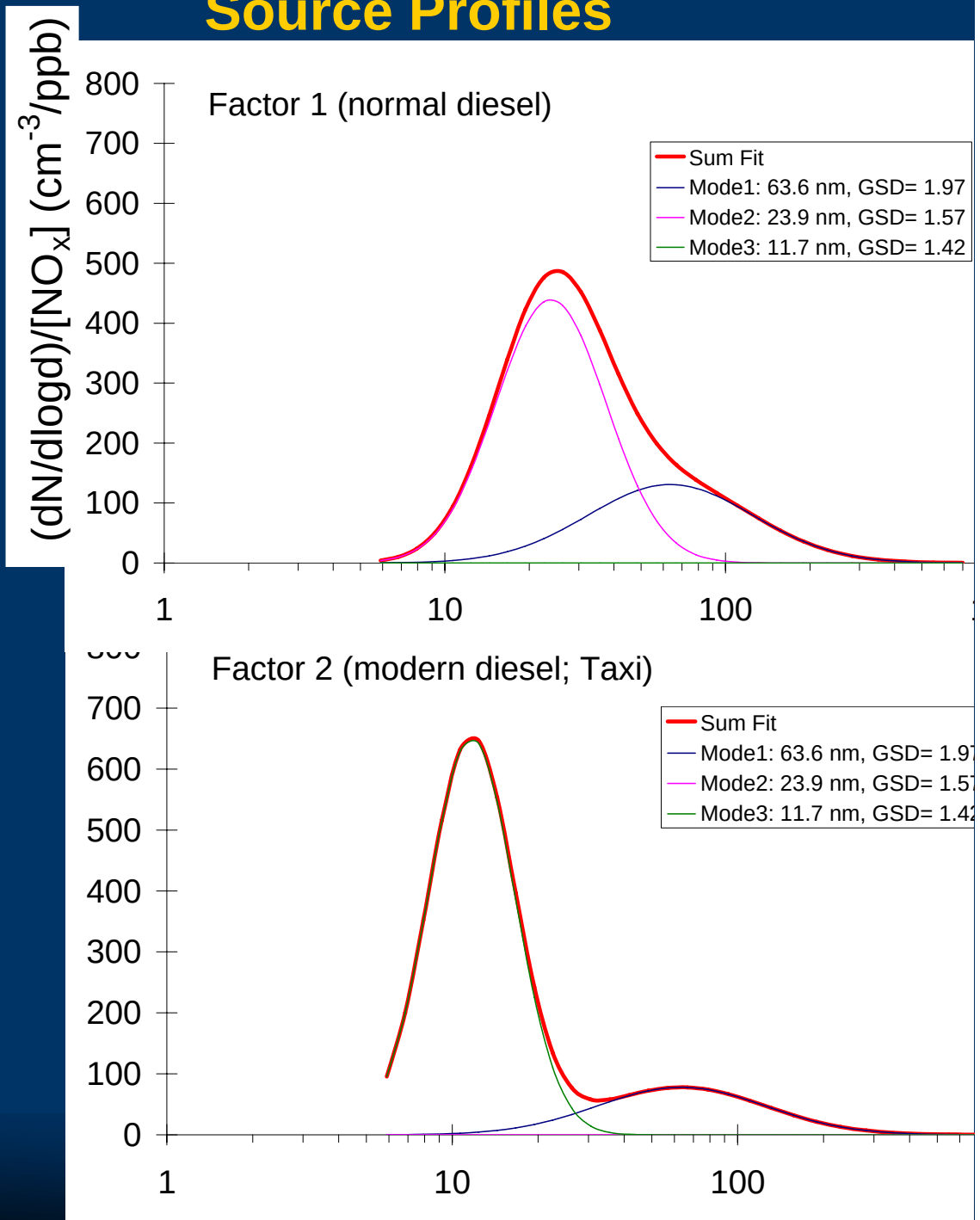
Factor Analysis

- **Average weekly variation of**
  - **NOx**
  - **CO**
  - **Strength of Mode 1-3**

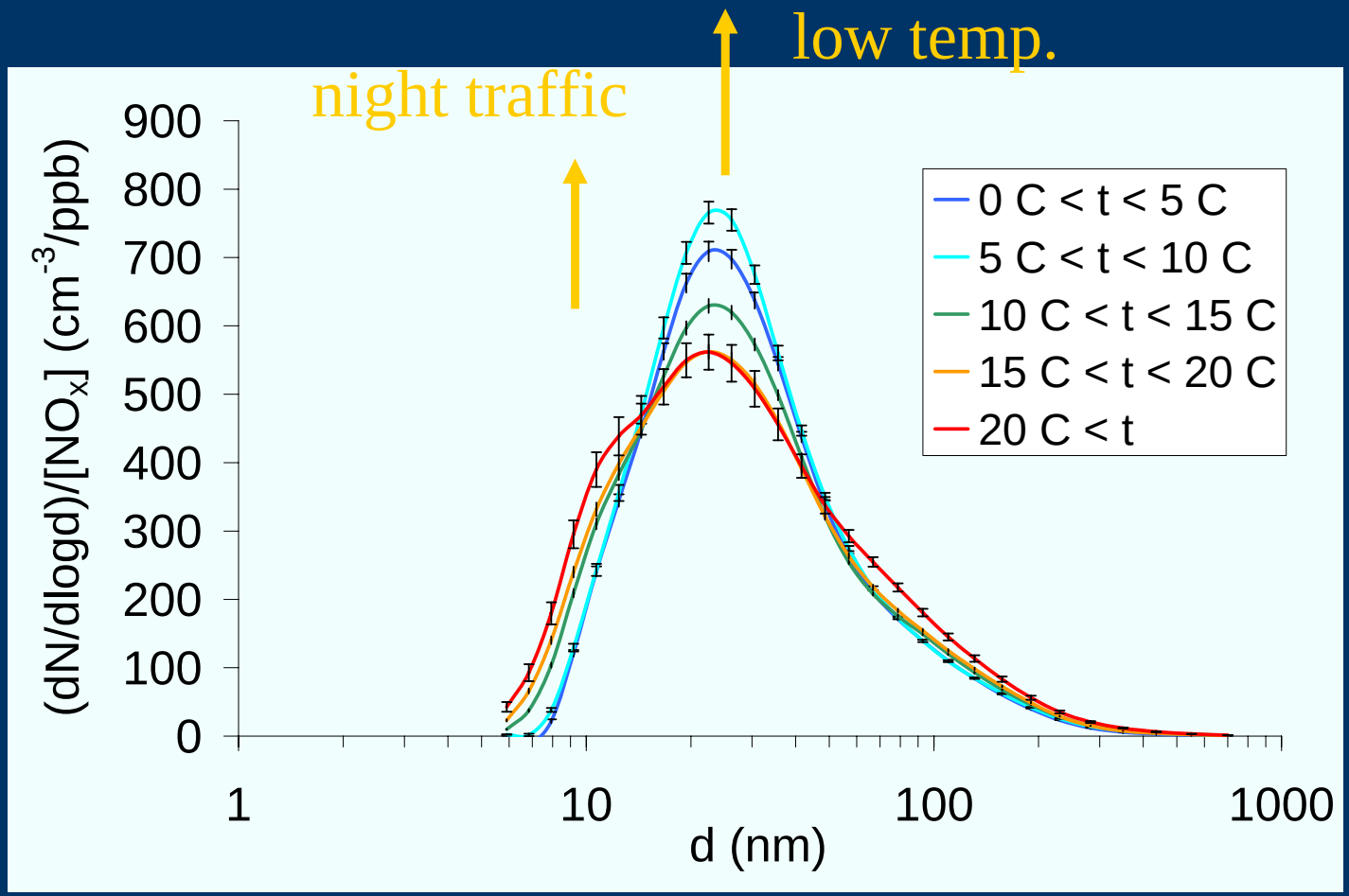
  (all corrected for background !)

- **Possible Solution:**
  - **Factor 1: Mode 1+2; NOx**
  - **Factor 2: Mode 1+3; NOx**
  - **Factor 3: - NOx; CO**

Source Profiles



Ambient temperature influences emission profile

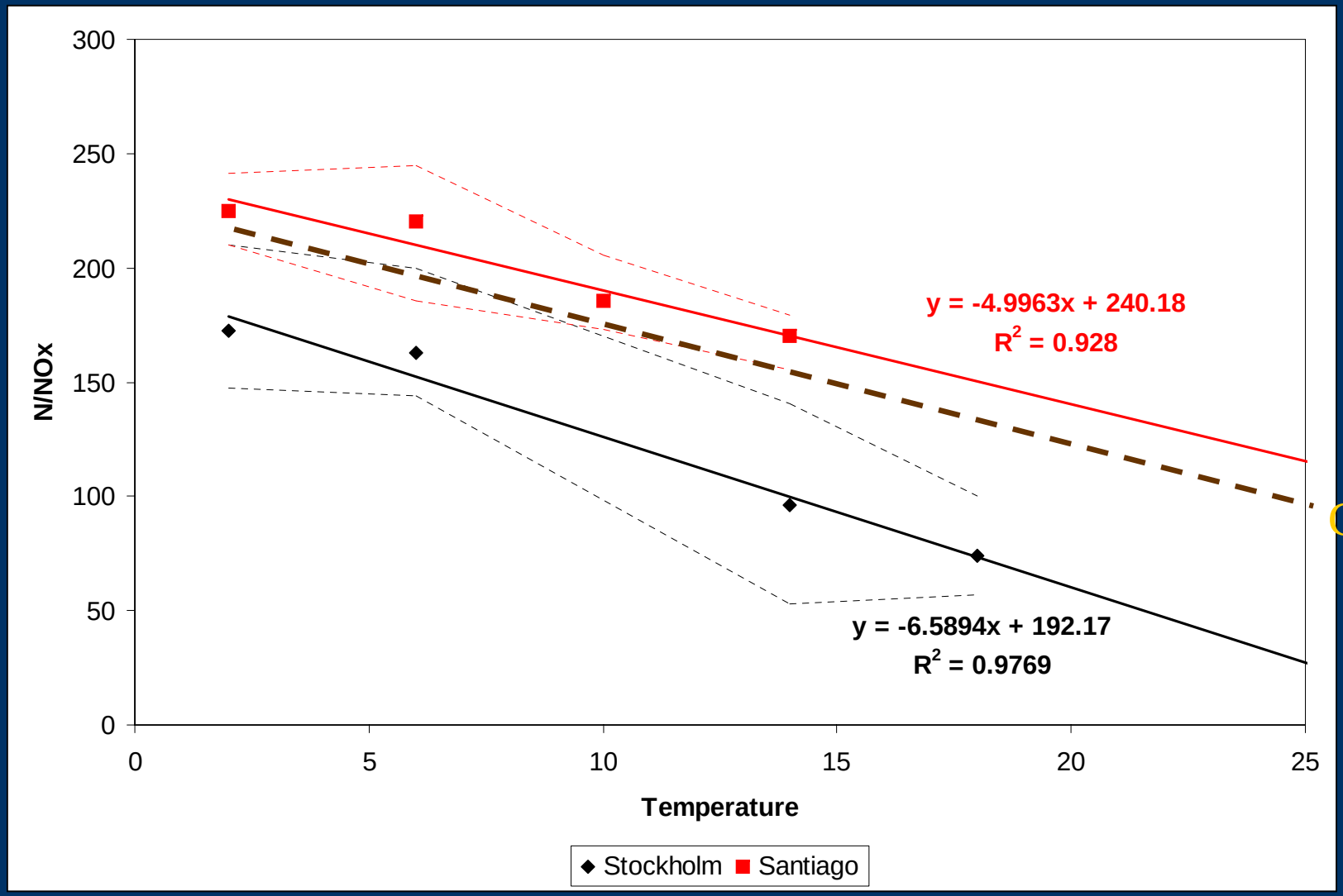


Ratios between particle number concentration (versus size) and the NOx concentration at HCAB (street station).

by P.Wåhlin

NERI Technical report no. 460. (2003)

Temperature dependent Emissions



Copenhagen

Olivares, et al. 2007

Emission factors from field studies

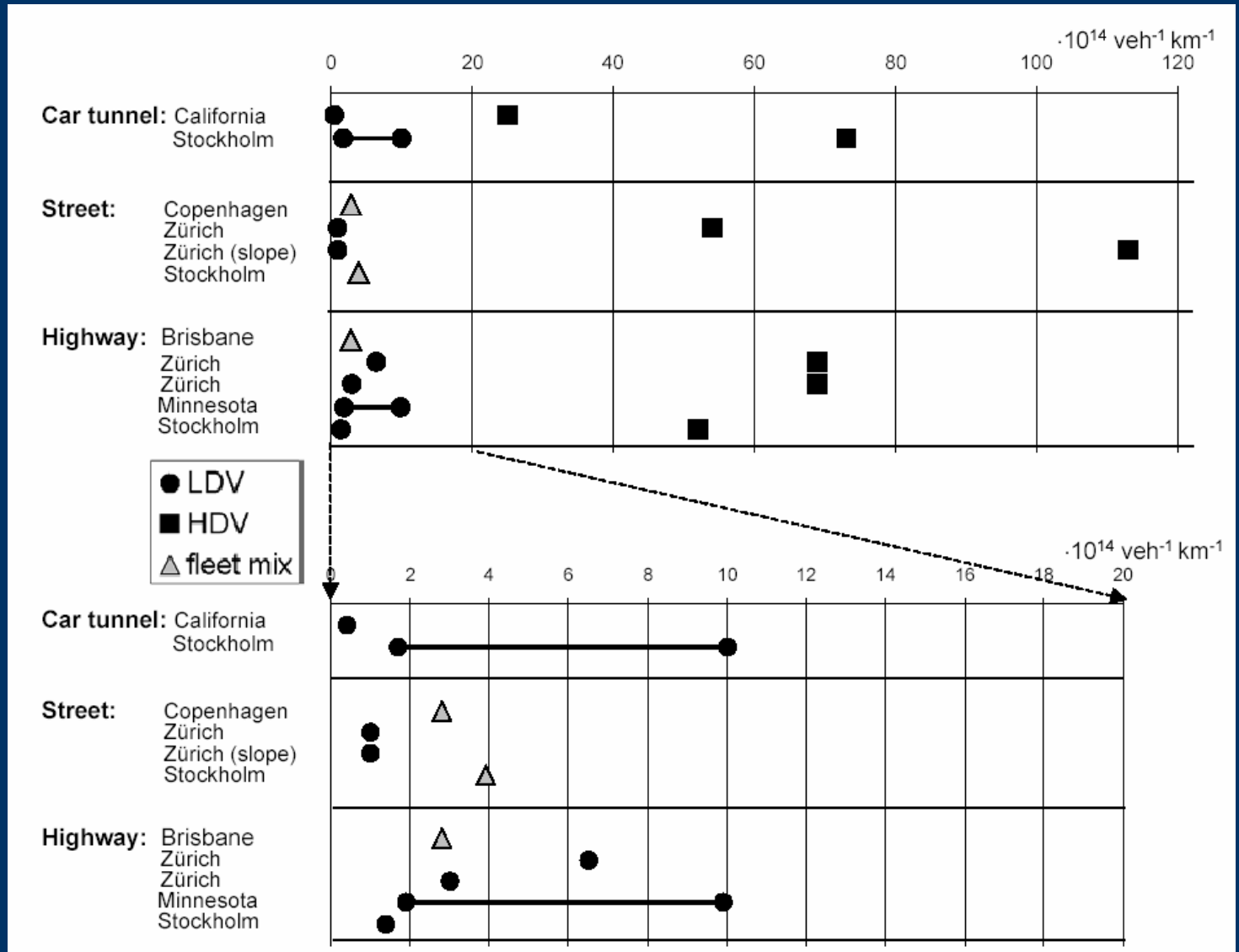
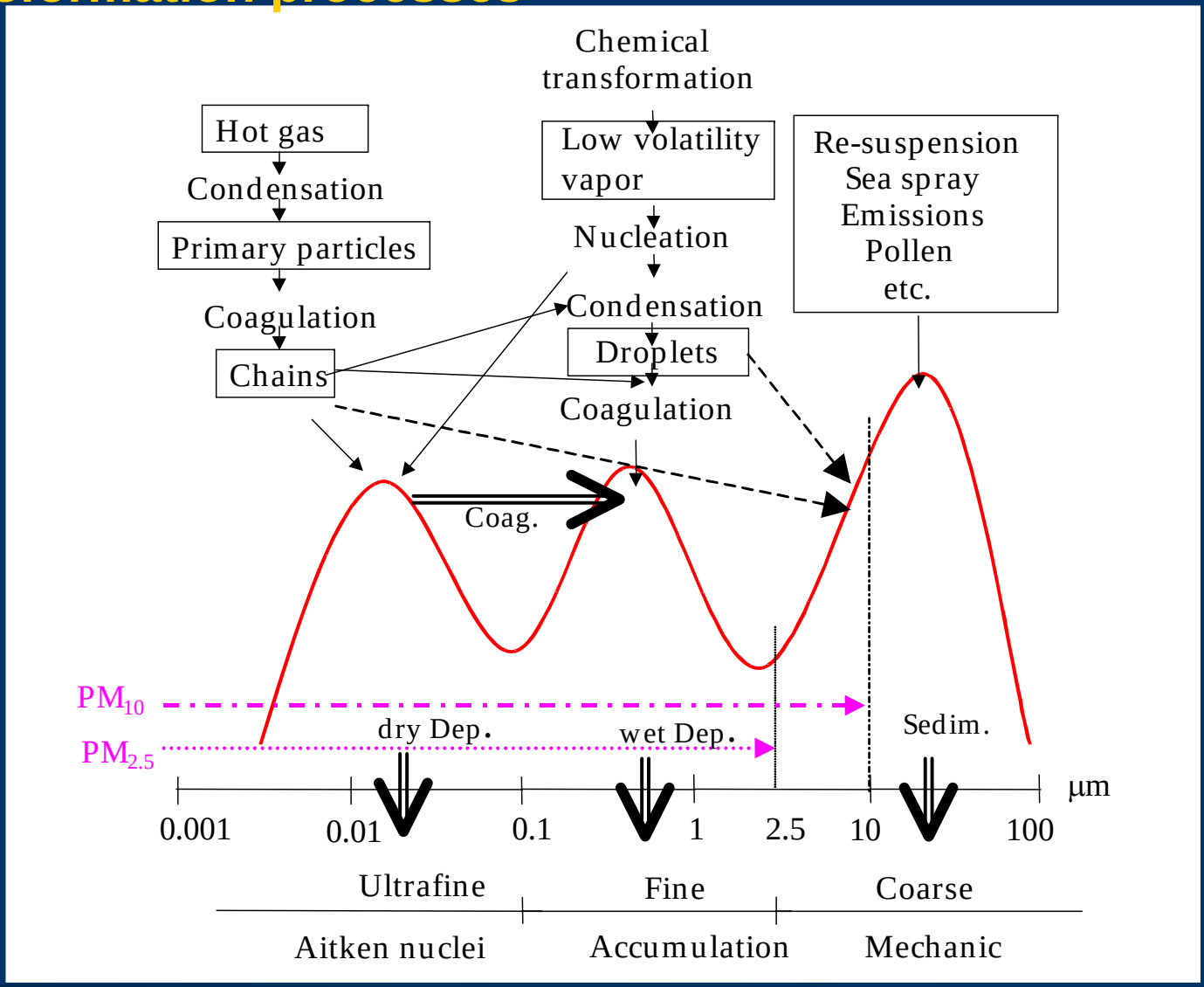


Fig. 2 Emission factors for particle number. The results from PAPER I, II and III are shown in comparison to recently reported factors (for more details and references, see Fig. Table 2, PAPER IV)

(L. Gidhagen 2004)

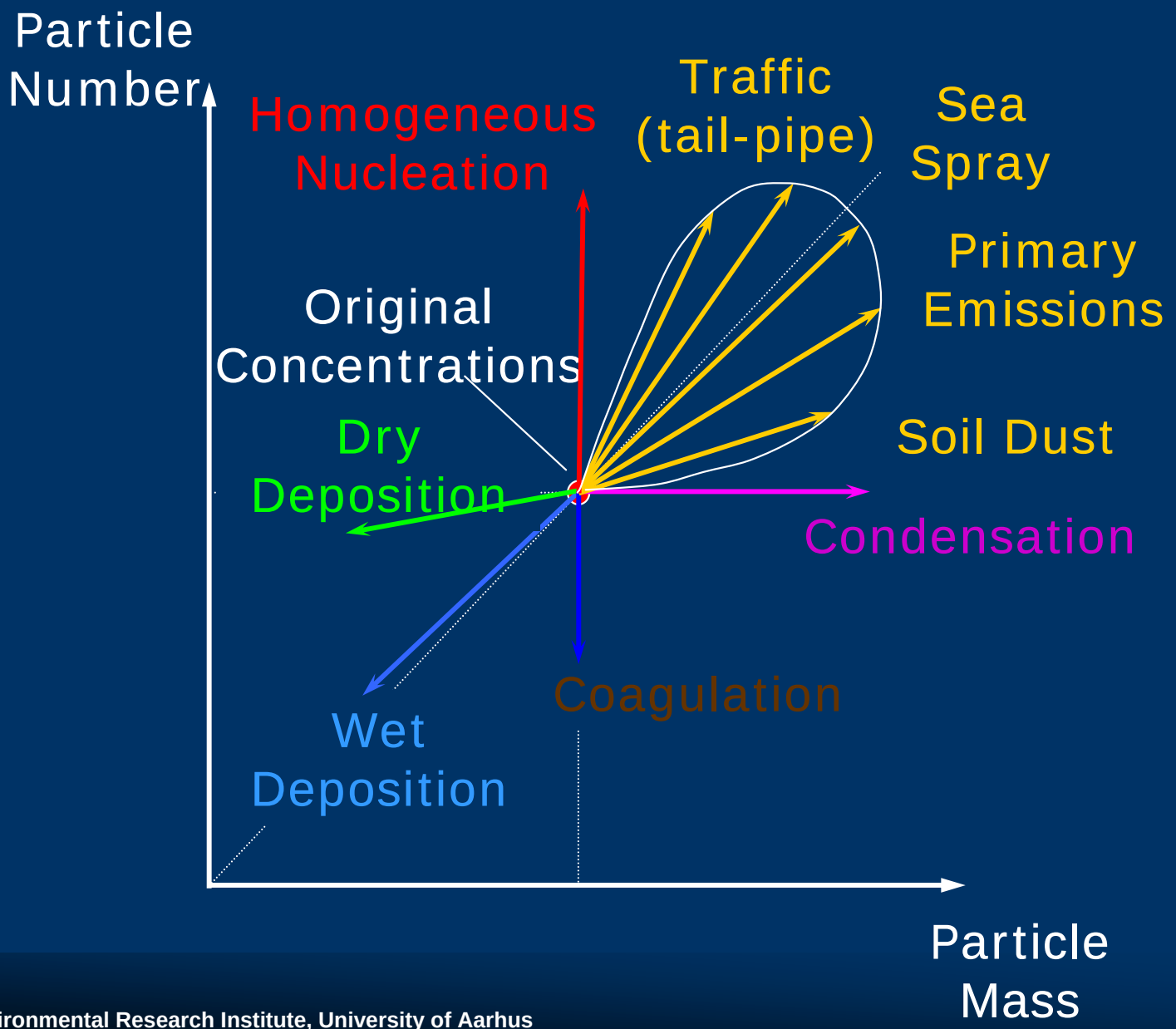
Challenge 2: transformation processes

Schematics of a urban particle size distribution with major sources and transformation processes



(adopted from Whitby and Cantrell, 1976)

Atmospheric Aerosol Processes
Effect on number and mass Concentrations



Time scales for various processes

$$\tau_{process\,X} = \left| \frac{C}{\dot{C}} \right| \quad ; \quad \dot{C} = \left| \frac{\partial C}{\partial t} \right|_{process\,X}$$

$$\tau_{dilution,plume}(t) = N(t) \Big/ \left| \frac{dN}{dt} \right| \cong \frac{D_R}{\dot{D}_R} + \frac{N_b}{N_E - N_b} \cdot \frac{D_R^{\,2}}{\dot{D}_R}$$

$$\tau_{dilution,street} = \frac{H}{\sigma_w}$$

$$\tau_{coag} = \frac{2}{K \cdot N}$$

$$\left| \frac{\partial N}{\partial t} \right|_{coag} = -\frac{1}{2} \sum_i \sum_j K_{ij} N_i N_j$$

$$\tau_{depo} = \frac{H_m}{v_d}$$

?? Which processes are important to model ??

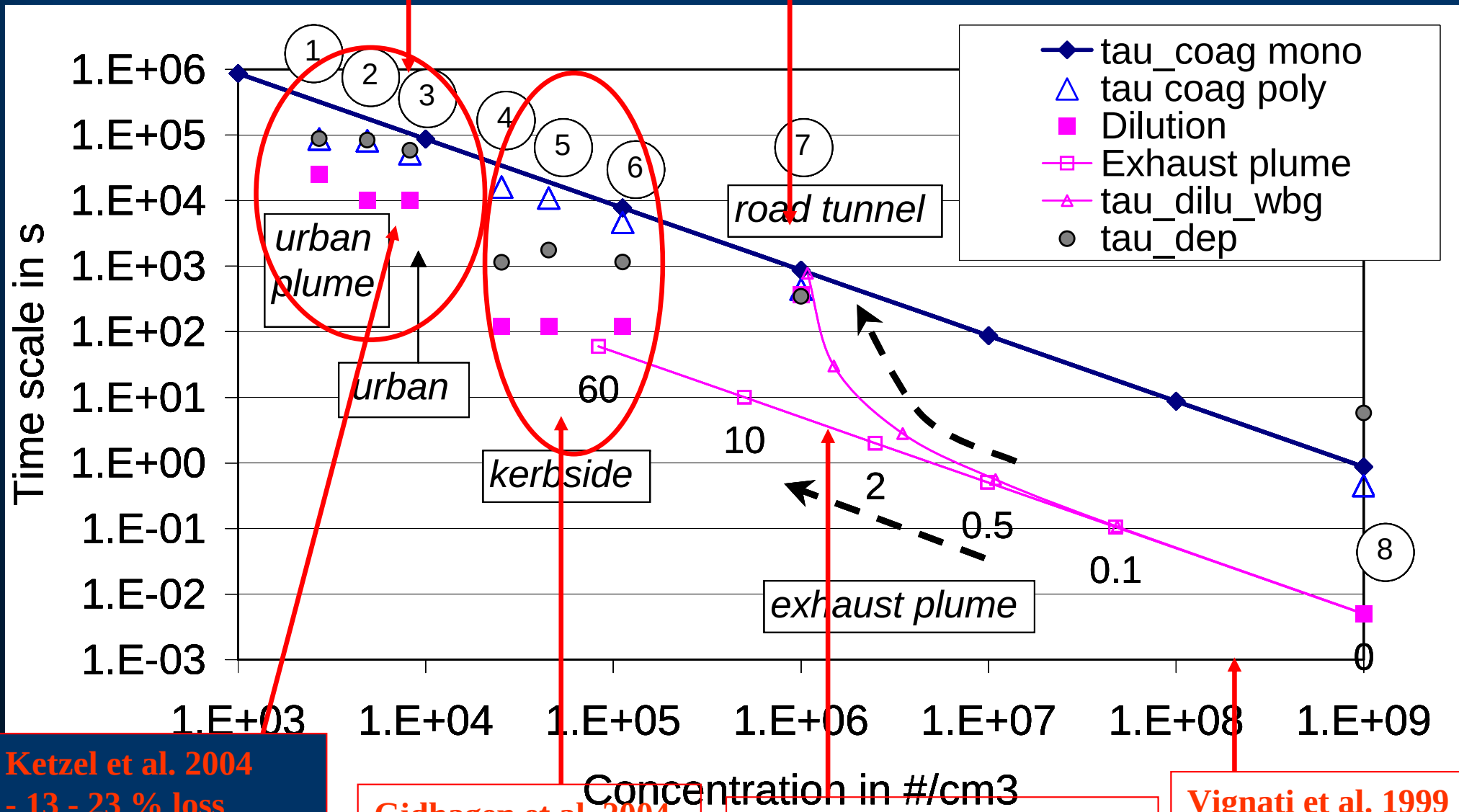
- depends on metric:
number (PNC), size distribution (PSD), mass (PM)

- depends on scale / location

Con cales on steps

Gidhagen et al. 2004
- 25 % loss

Gidhagen et al. 2003
- 77% loss for Dp < 10nm
- 41% loss for Dp 10-29nm



Ketzel et al. 2004
- 13 - 23 % loss

Gidhagen et al. 2004
10-30% effect of coa/dep

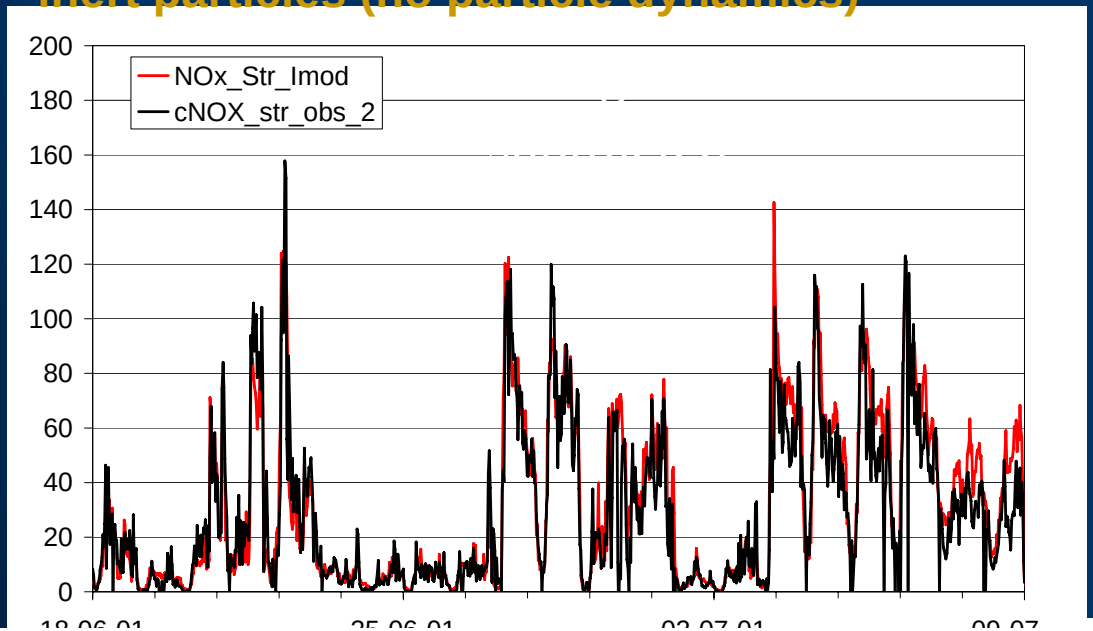
Capaldo and Pandis, 2001
Kim, 2002: -> dilution is dominating effect

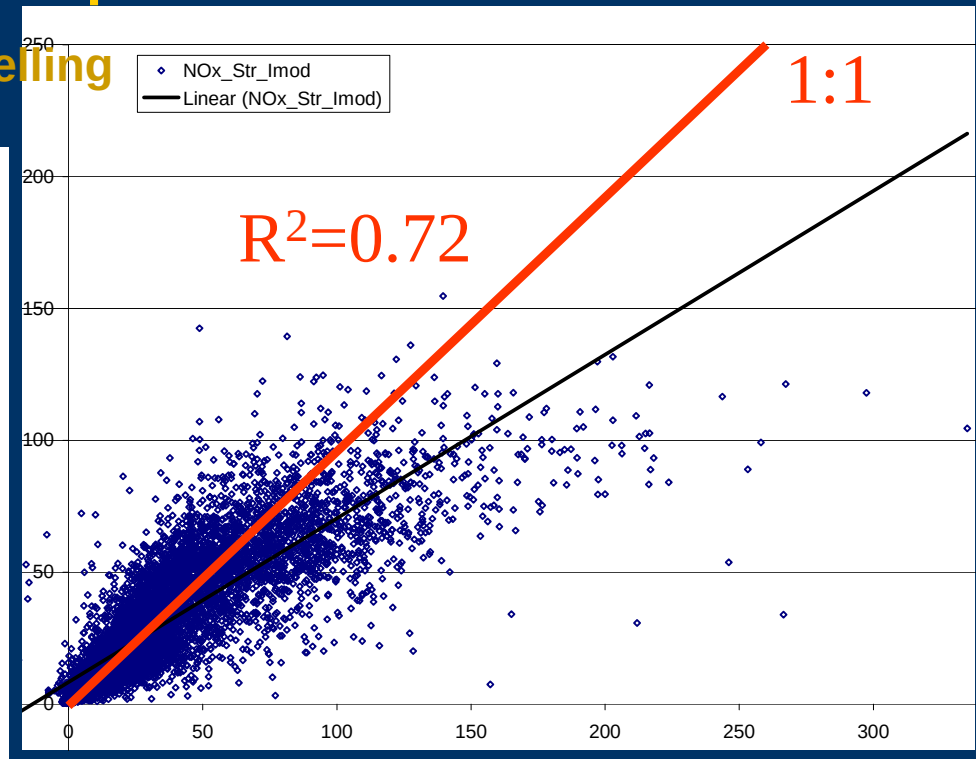
Vignati et al. 1999
Pohjola et al. 2003
-no effect of coag.

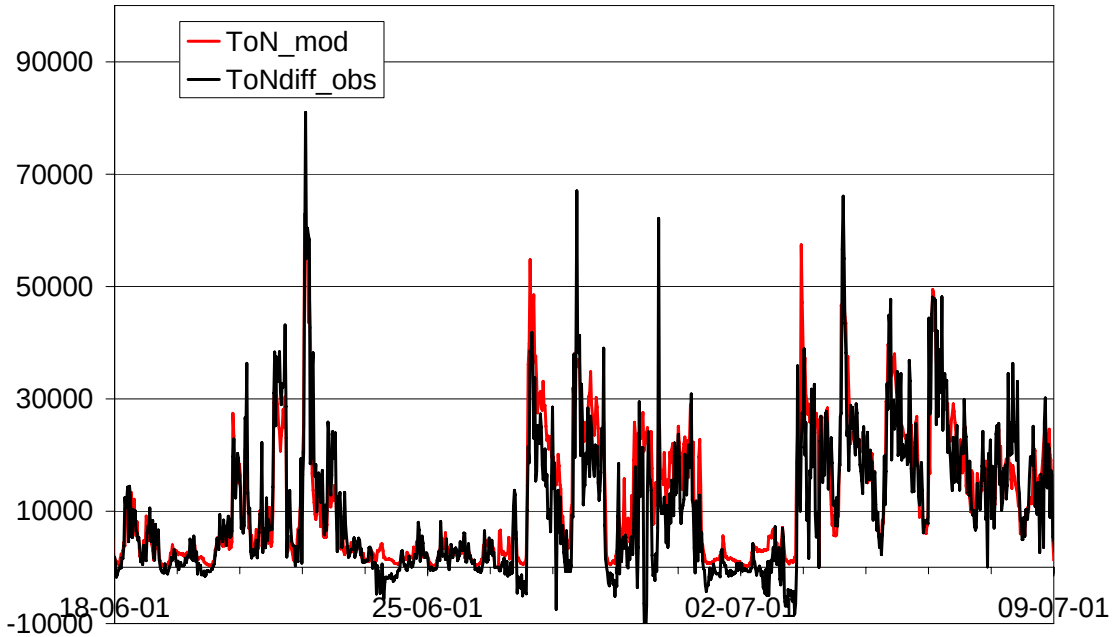
Application street scale - OSPM

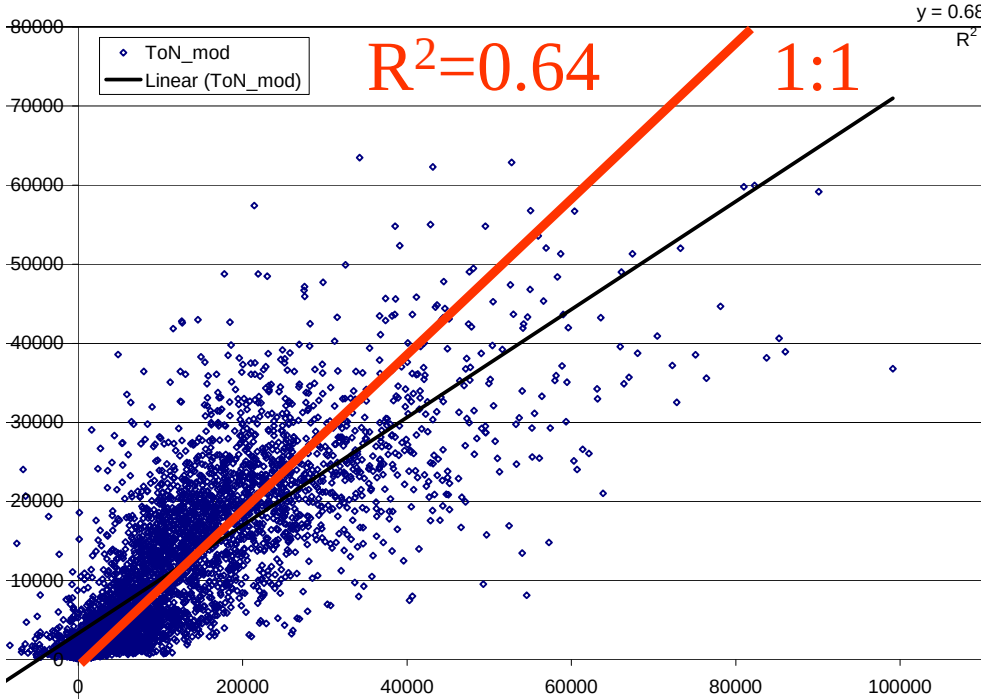
Modelling at kebside for NOx and total particle number

- OSPM and emission factors from inverse modelling
- inert particles (no particle dynamics)

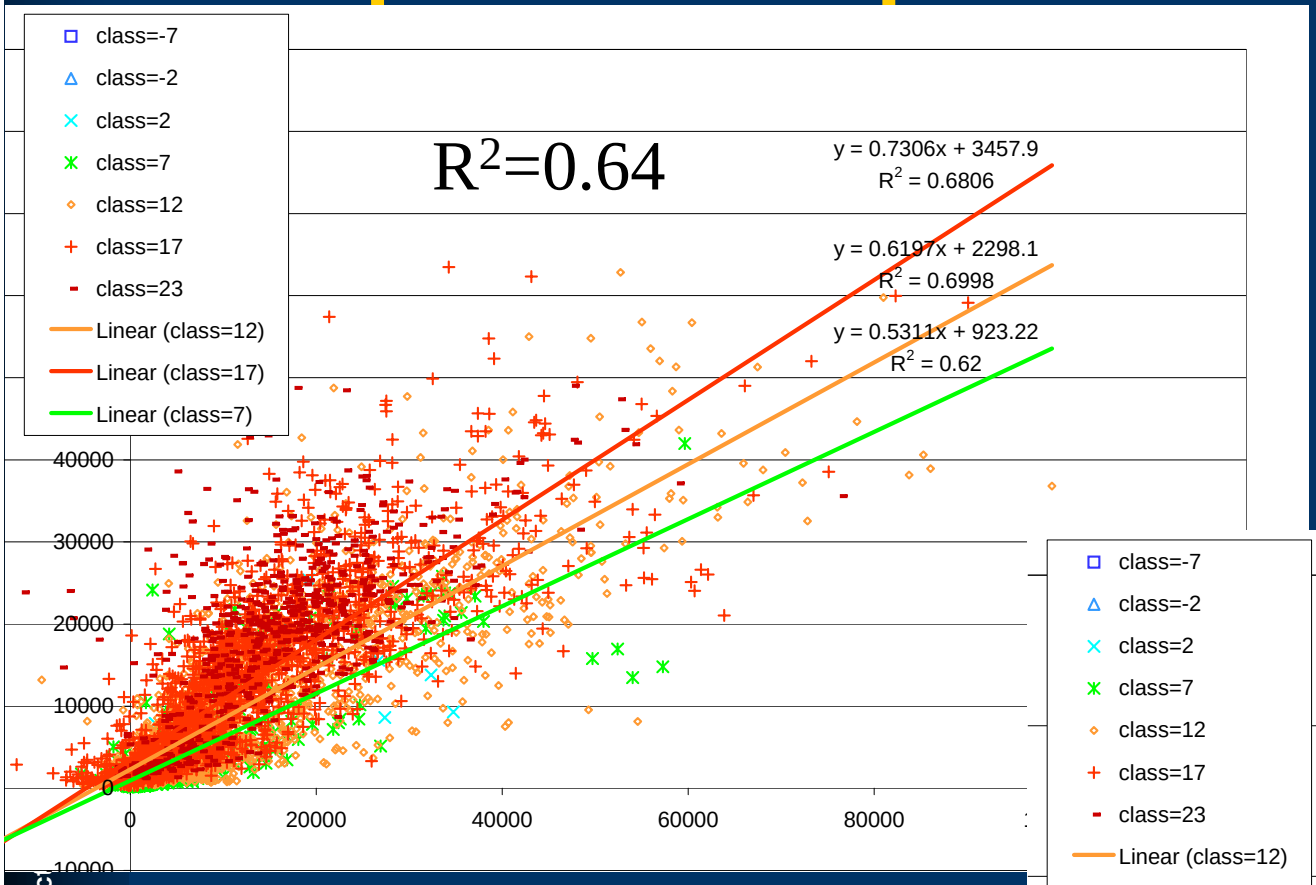


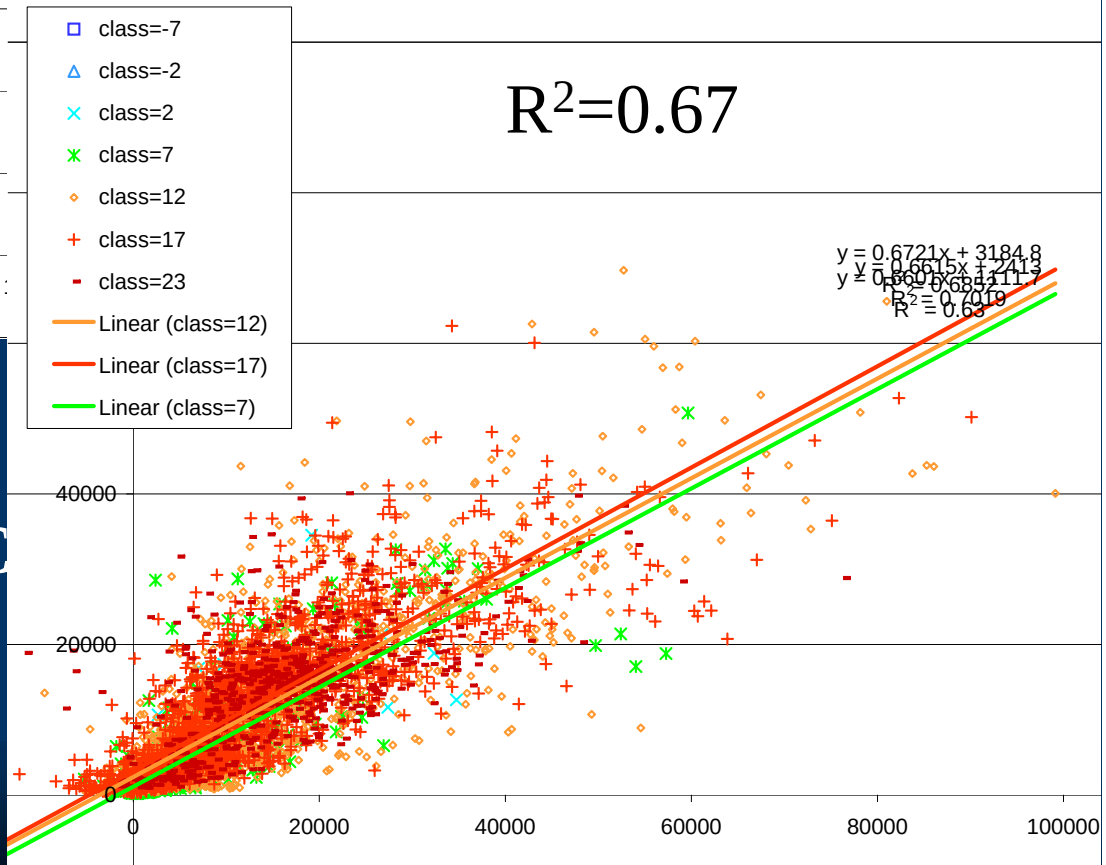






Temperature dependent Emissions

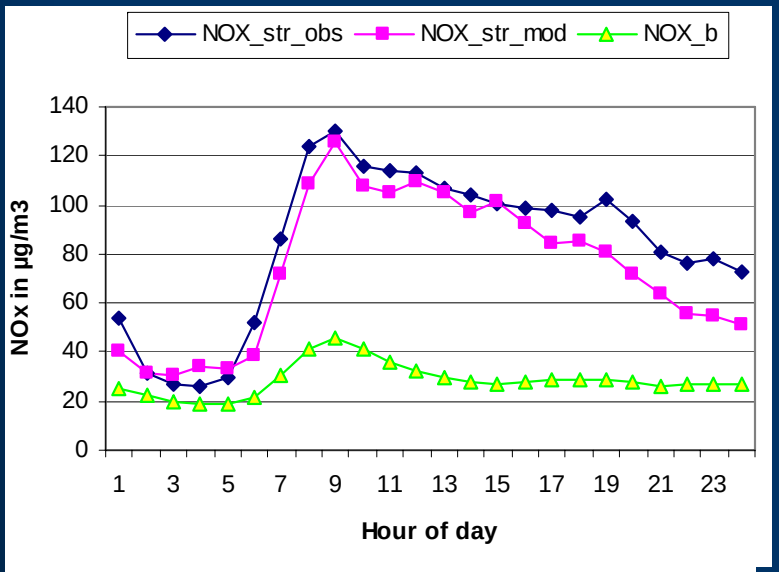


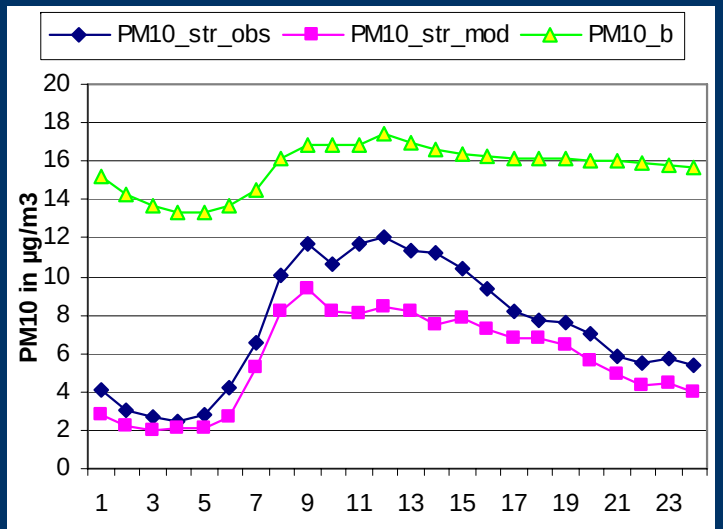


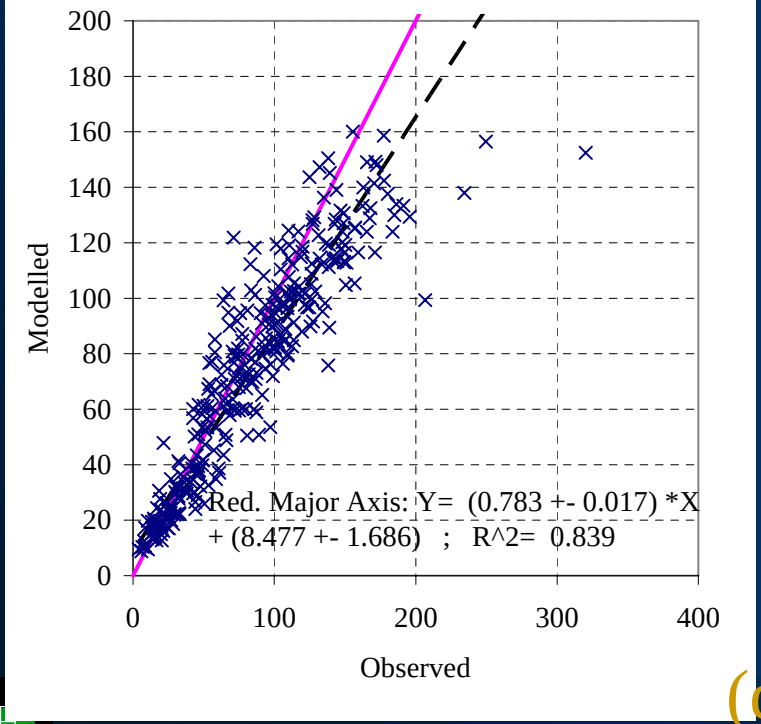
$E(T) = E(15C)*[1 - 0.034 (T-15C$

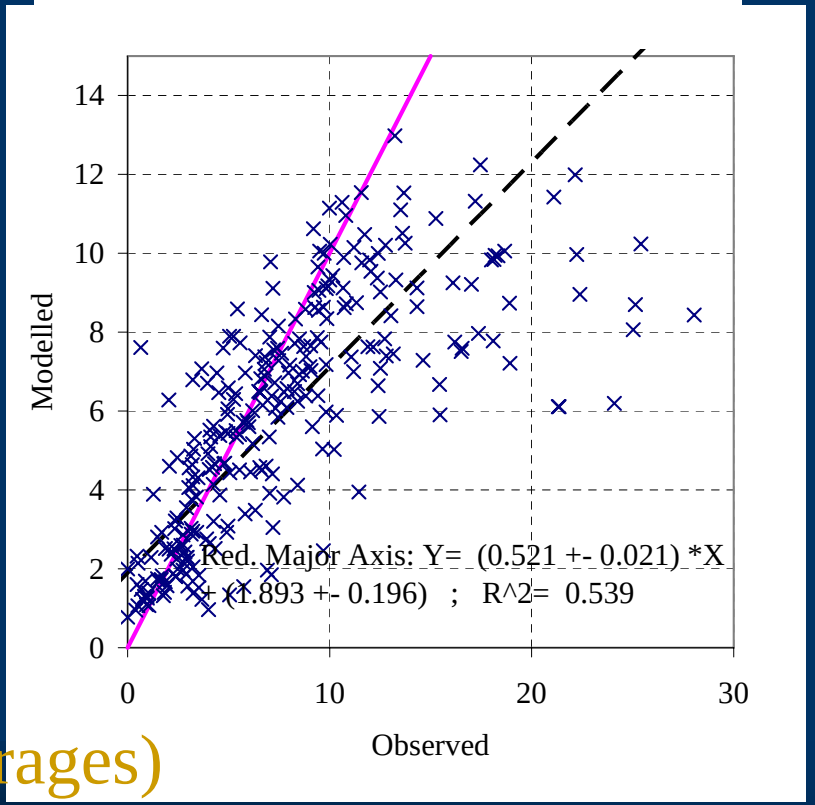
$E(0)/E(15) \sim 150\%$

OSPM for NOx and PM10 at JGTV, 2003





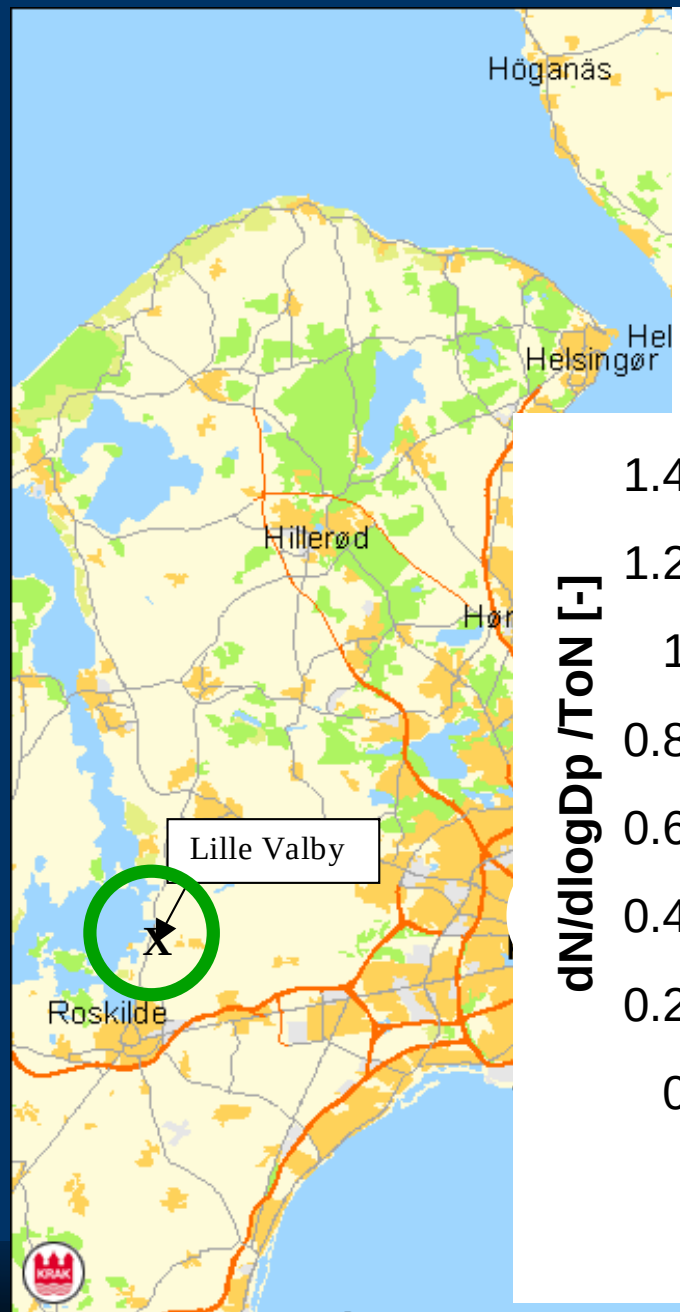


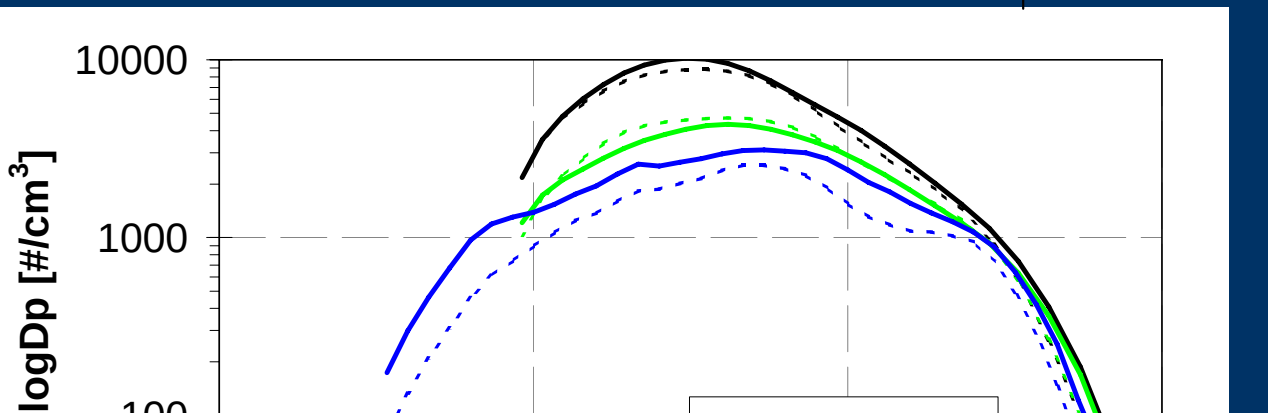


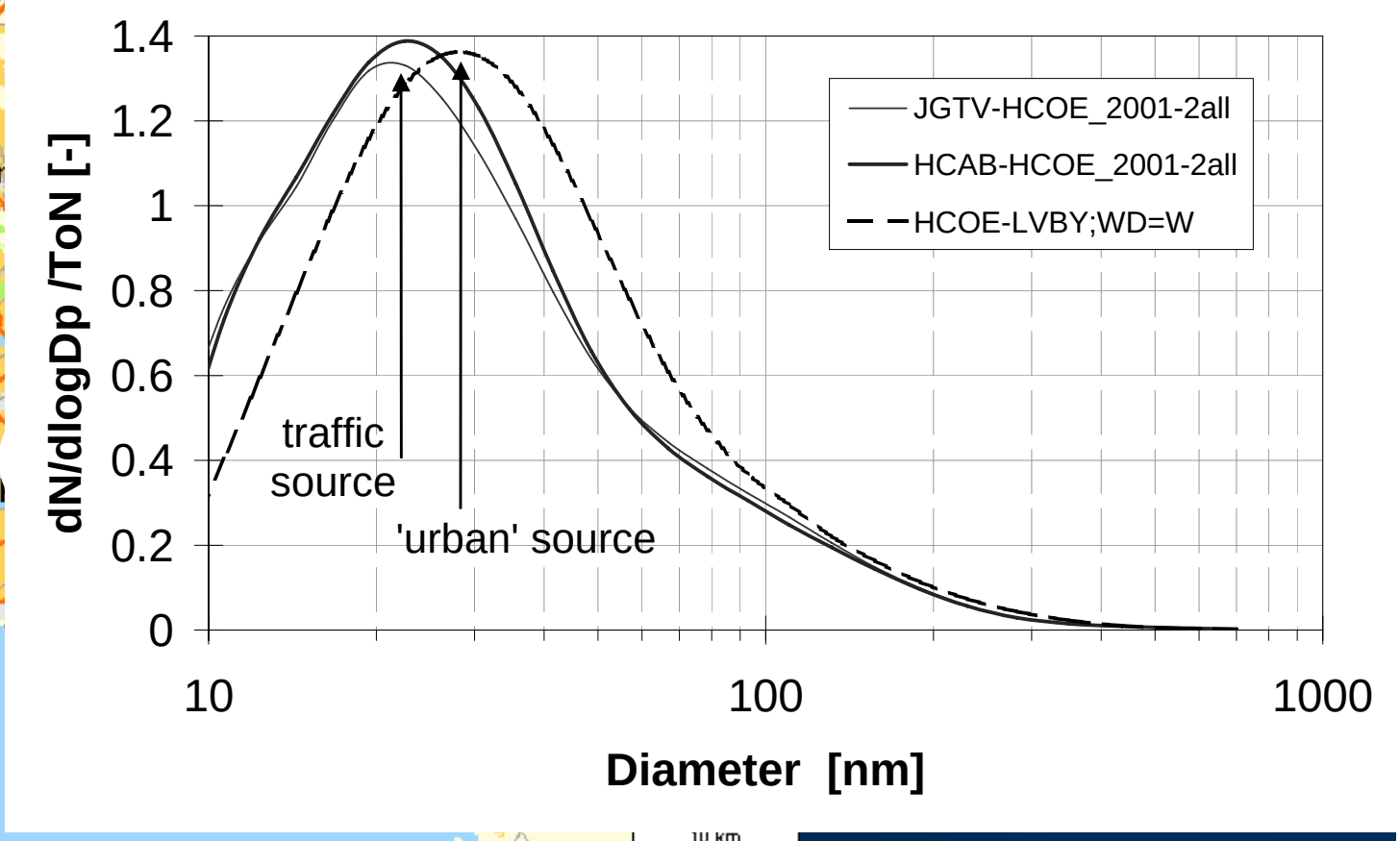
(daily averages)

urban scale – multi-plume model (MAT)

westerly winds: LVBY=background

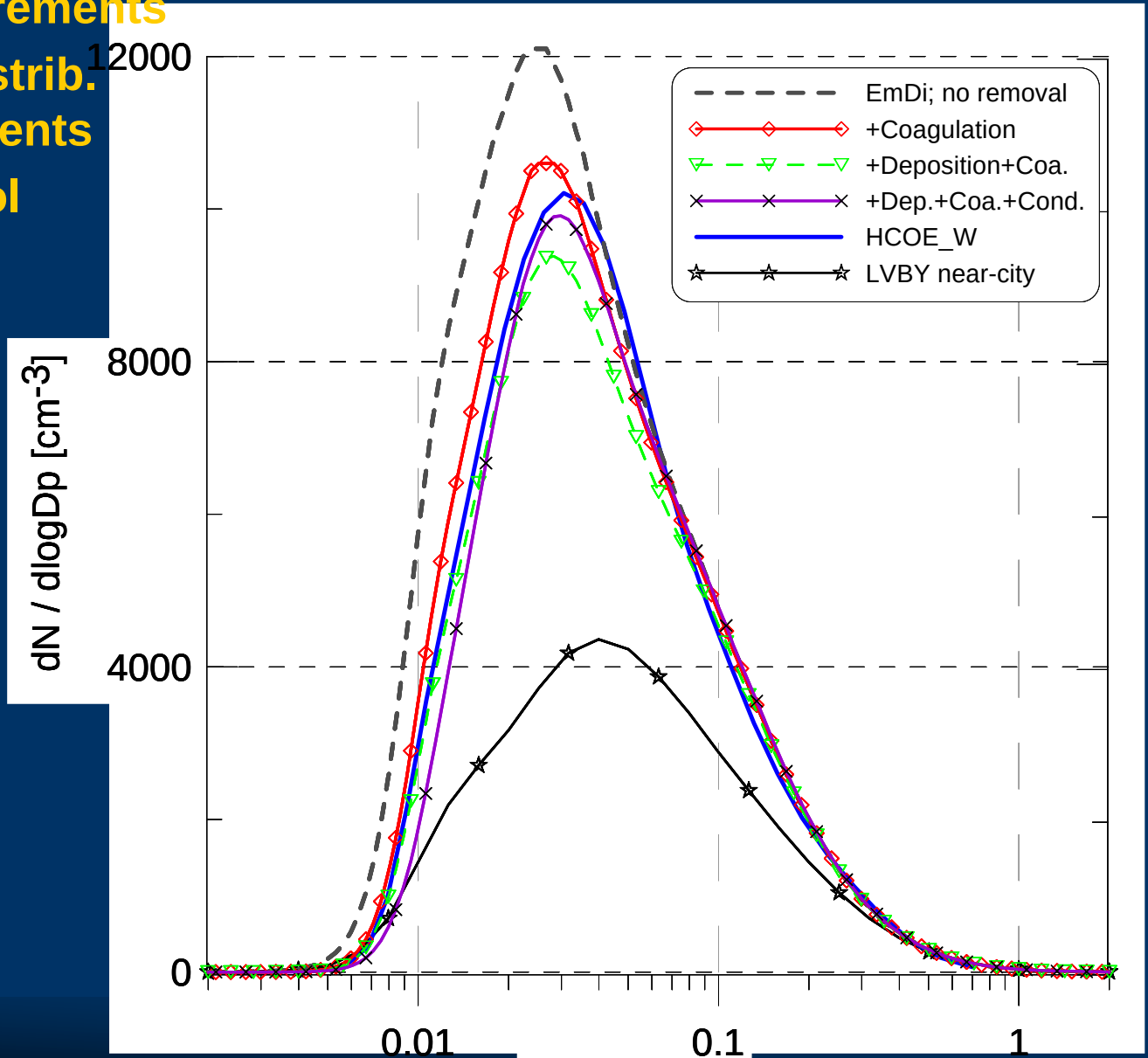






Modelling of the urban background

- ‘multi-plume’ model for vertical dispersion
- background from measurements
- emission factor + size distrib. from kerbside measurements
- sectional model for aerosol dynamics including
- processes modelled:
  - background
  - emission
  - vertical dilution
  - deposition
  - coagulation
  - condensation



Main Conclusions:

- particle emission factors and size distribution estimated
- time scale analysis
- street level:
  - in general very high correlation particle number - NOx
  - dilution is the dominant process
  - coagulation is too slow to alter the particle size distribution
  - OSPM (without particle dynamics) can be applied also for particle number ***using temperature depending emission factors***
- urban scale:
  - the two ***L***'s
  - 15-30% reduction in particle number compared to NOx
  - shift of particle size distribution to larger sizes
  - Multi-plume Aerosol dynamics and Transport (MAT) model is able to reproduce this

Acknowledgements

Co-operation

- SMHI / ITM – Lars, Christer
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- Germany: IfT Leipzig, Büro Lohmeyer
- NERI - Particle + Monitor Group

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