UFP Measurements and Modelling

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Outline

- Size definition of UFPs
- Experimental UFP observations
- UFP processes in the atmosphere
- Exemplary Model simulations

Atmospheric UFPs: Main questions

- Global climate:
  - Mechanism of particle nucleation in the atmosphere
  - Yield of cloud condensation nuclei (CCN) from newly formed particles
- Urban climate and exposure
  - Emission and formation rates of UFPs
  - Lifetime and persistence of UFPs
  - Exposure patterns of UFPs
  - Health effects of UFPs

On the definition of Ultrafine Particles

- Health-related research: D_p < 100 nm

  Coarse (2.5 – 10 µm), Fine (0-2.5 µm), Ultrafine (0-0.1 µm)

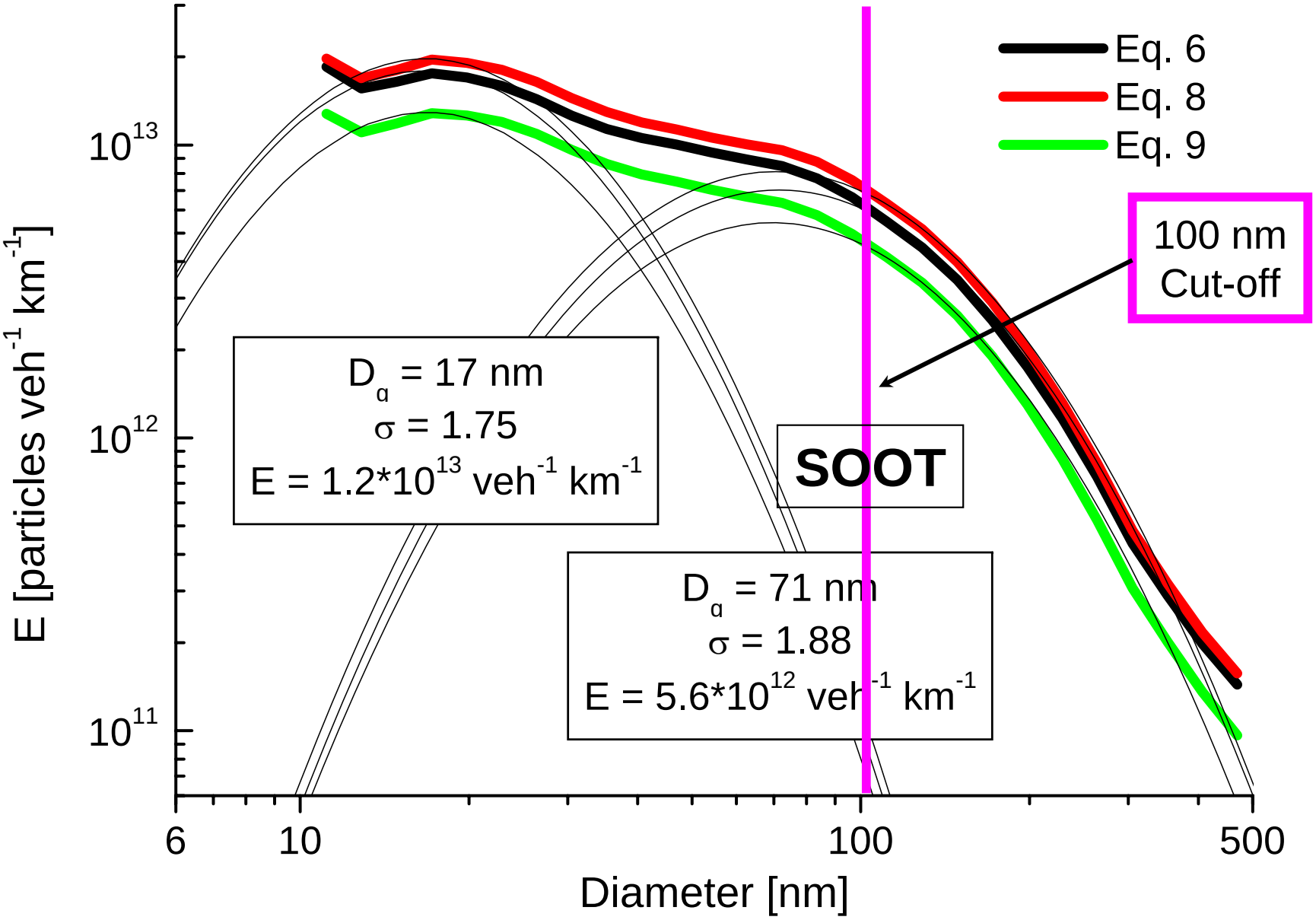
- „Nanoparticles“: D_p < 50 nm

  Size range where molecular effects become apparent

- Other definitions: D_p < 20 nm

  Ultrafine particles ~ Nucleation mode

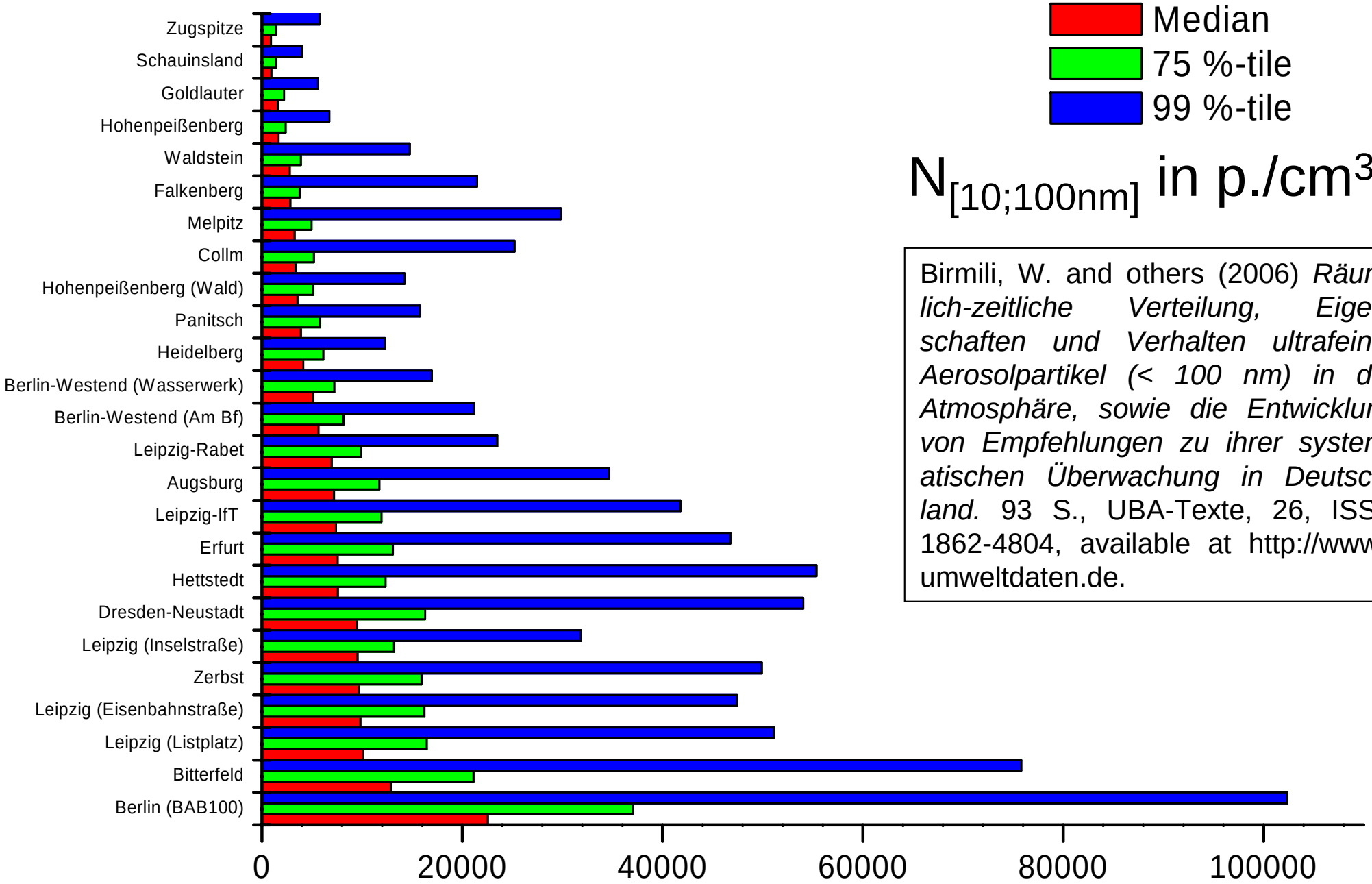
Particle emission spectrum of traffic (A100 motorway Berlin)



On the definition of Ultrafine Particles

- A size-cut at 100 nm is not very useful
- Size cuts around 50 nm and 200 nm better separate 2 main types of ultrafine particles:
- 50 nm < D_p < 200 nm ~ solid particles (soot)
- D_p < 50 nm ~ condensation particles (H_2SO_4, OC)

Ambient UFP concentrations in Germany

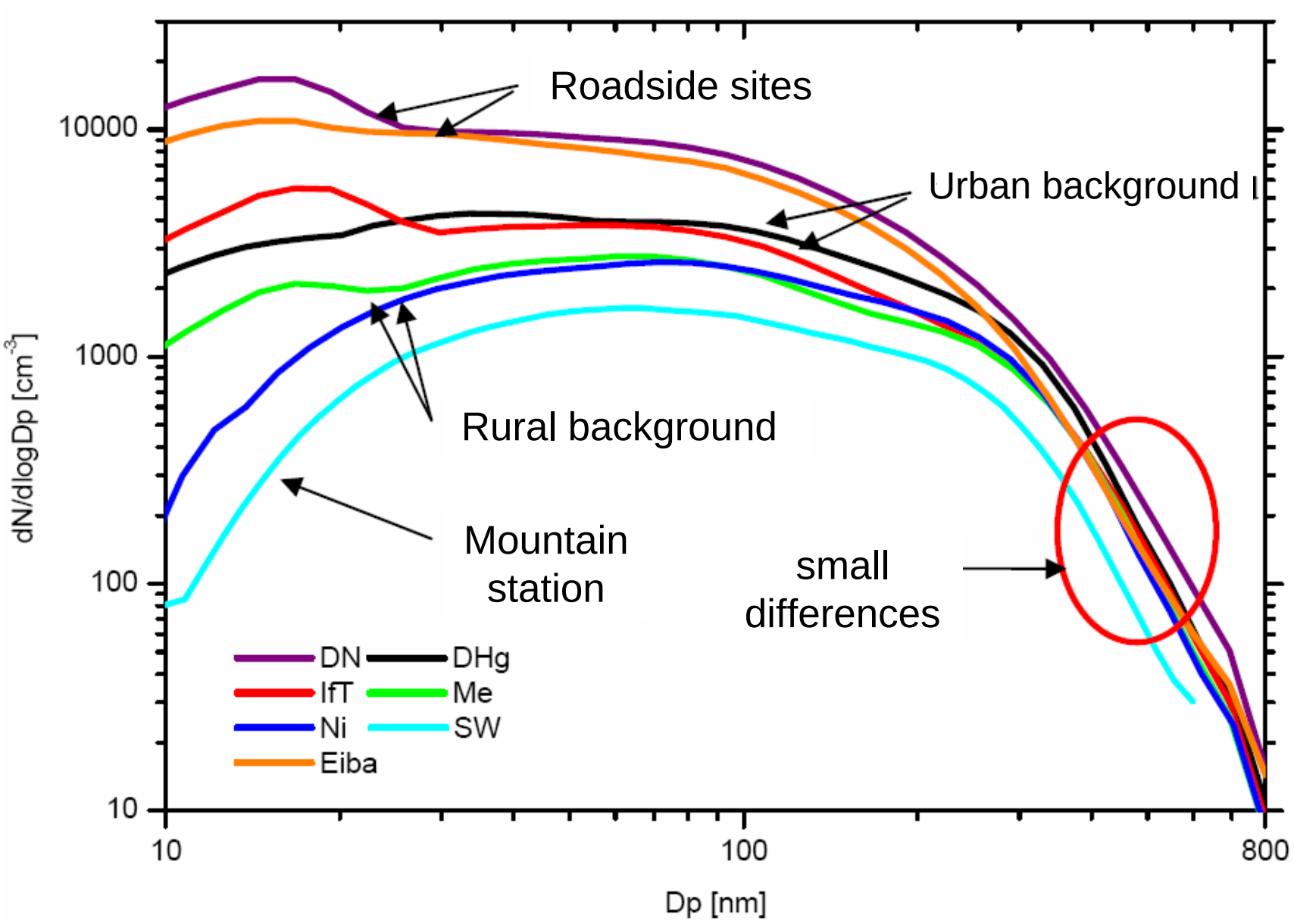


Birmili, W. and others (2006) *Räumlich-zeitliche Verteilung, Eigenschaften und Verhalten ultrafeiner Aerosolpartikel (< 100 nm) in der Atmosphäre, sowie die Entwicklung von Empfehlungen zu ihrer systematischen Überwachung in Deutschland.* 93 S., UBA-Texte, 26, ISSN 1862-4804, available at http://www.-umweltdaten.de.

Typical levels of ambient UFP concentrations in Germany

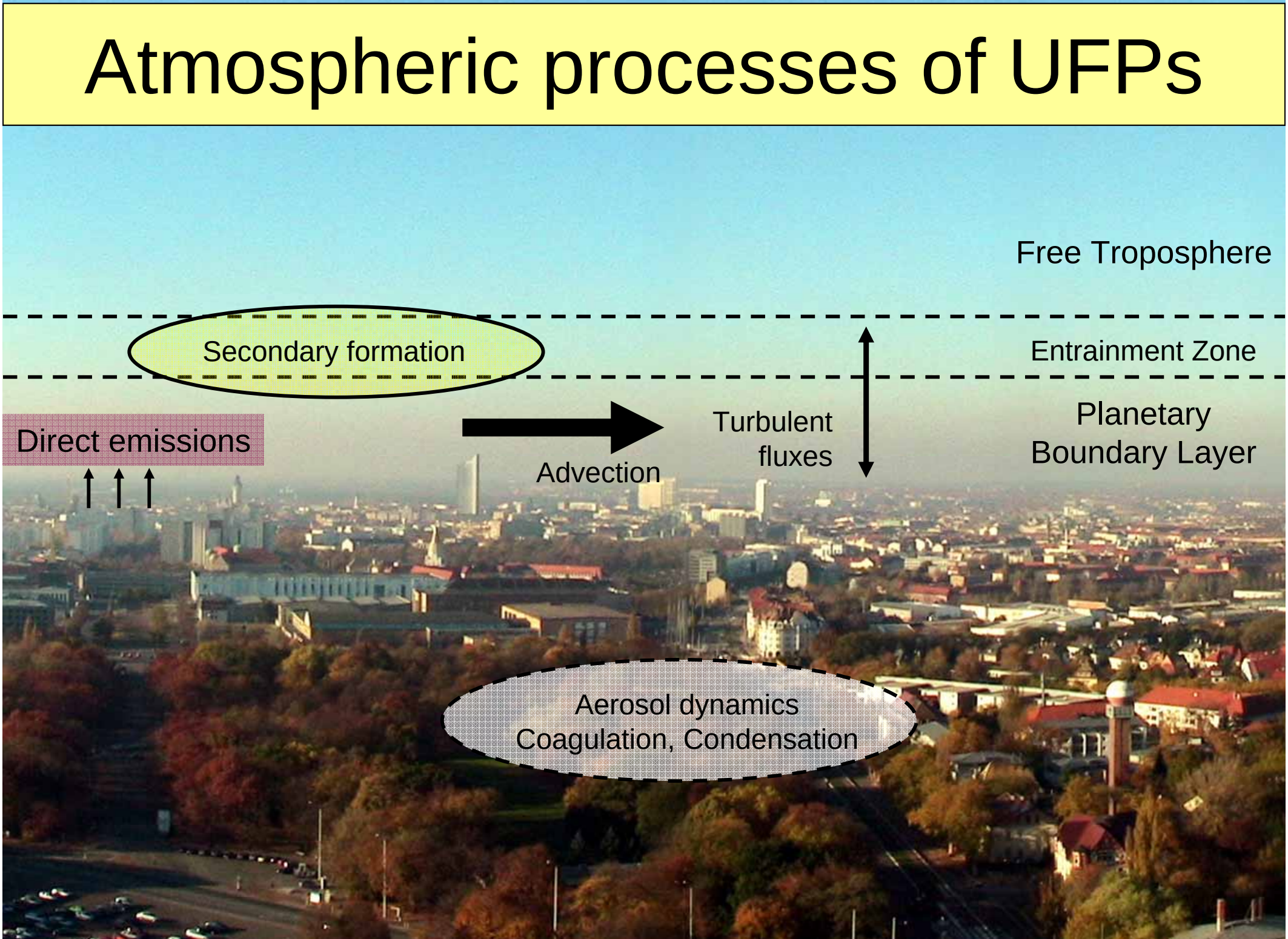
Site characteristic	**cm^{-3}**
Continental Background	600 - 1400
Rural	1000 - 5000
Near city	2800 - 6000
Urban background	3500 - 16000
Urban background (Ruhr area)	8000 - 24000
Near roads	5500 - 37000

Sources of UFPs in Saxony (6 months)

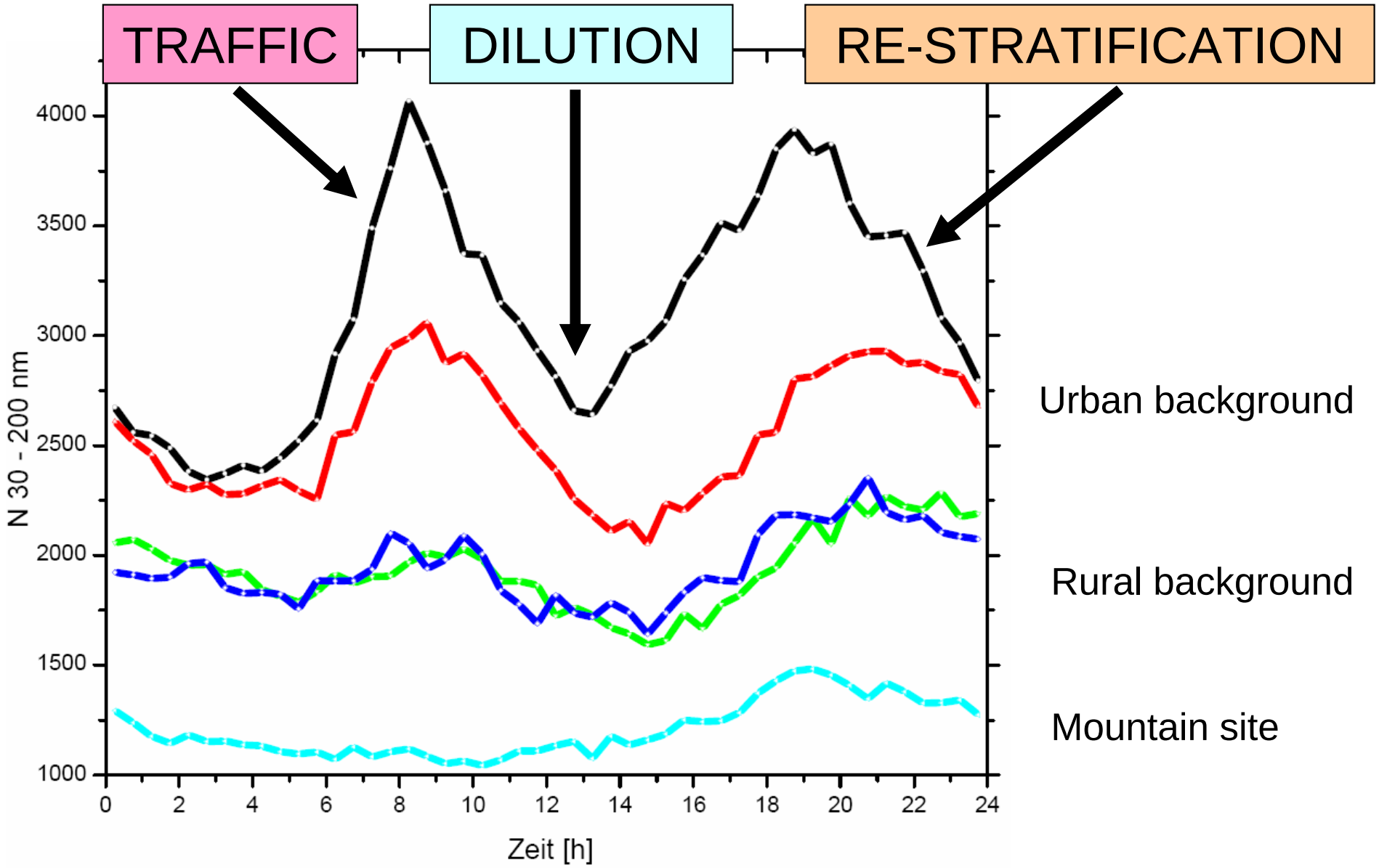


Kay Weinhold, Master thesis, University of Leipzig, 10/2007.

Atmospheric processes of UFPs



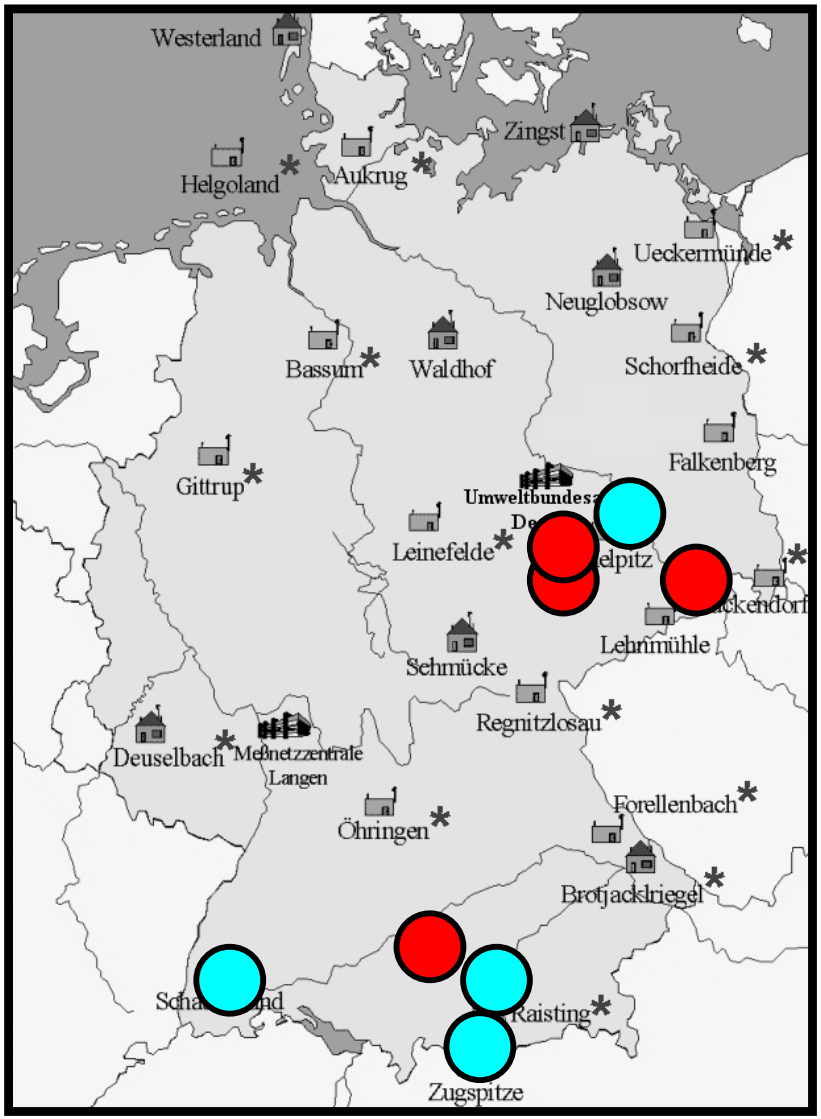
Diurnal pattern of UFPs in Saxony



Kay Weinhold, Master thesis, University of Leipzig, 10/2007.

Long-term observation strategies for UFPs

Germany: 8 sites in 2007

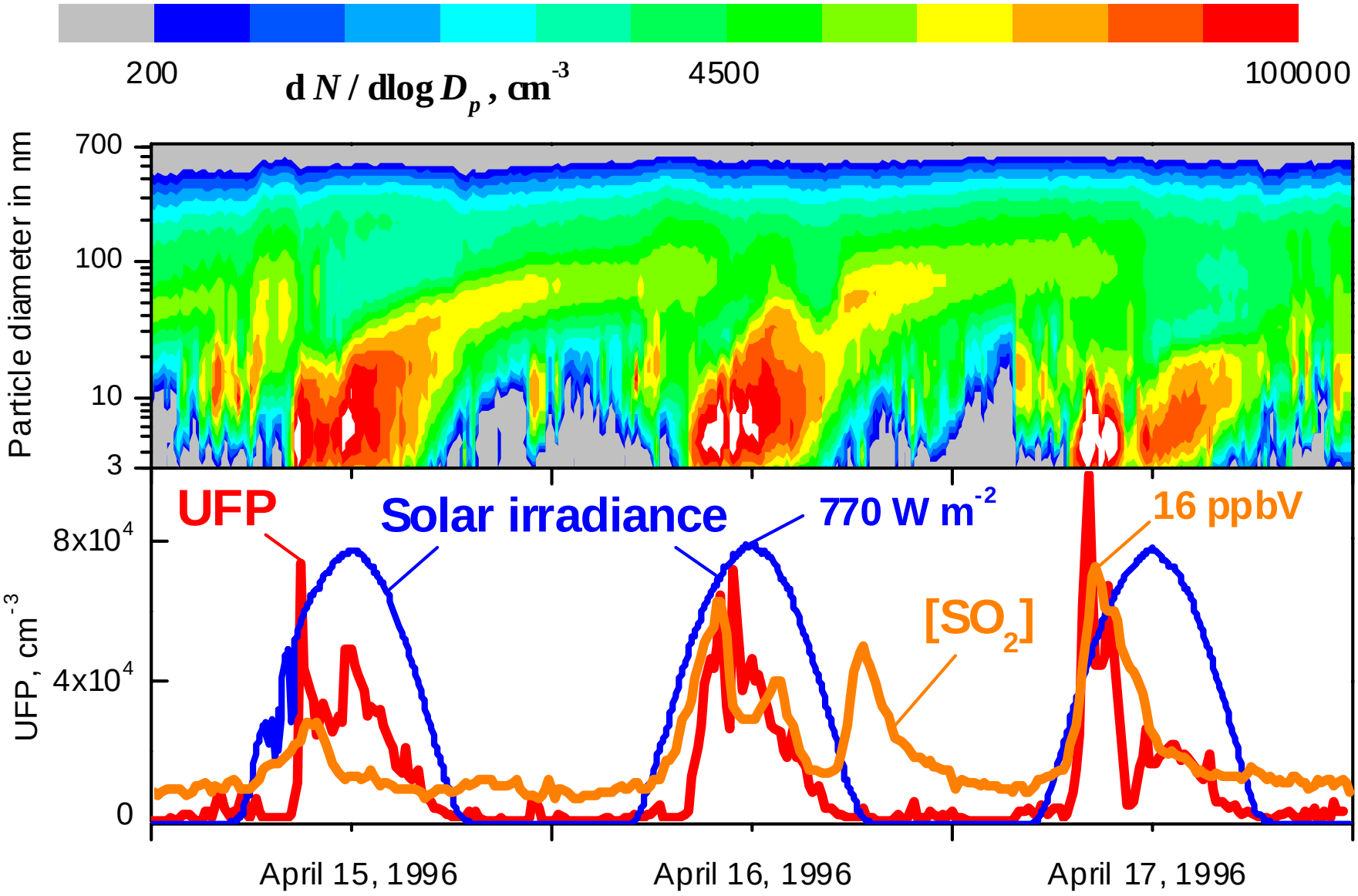


EUSAAR: > 20 sites in 2007

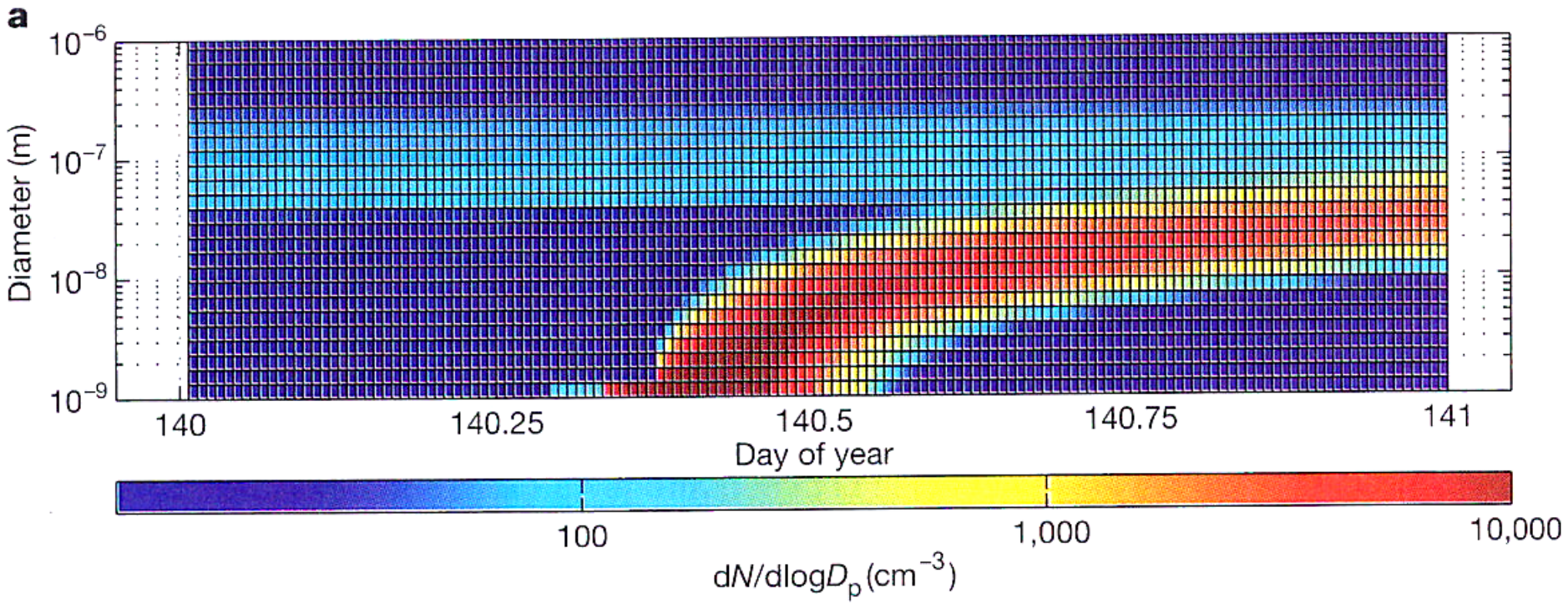
Process scales

Model Scale	Transport phenomena	Aerosol particles
Global	Hemispheric oscillations	Particle mass
Europe	Synoptic winds	Particle number
Region	Boundary layer convection	Size distribution
1 City	Surface roughness	Chemical composition
Area in 1 city	Obstacle effects	Particle emission
Street canyon	Vehicle-induced turbulence	Processing (Coagulation, Condensation,
Tailpipe plume	Non-equilibrium expansion	Particle deposition

Photochemically produced UFPs in the continental boundary layer (Melpitz)



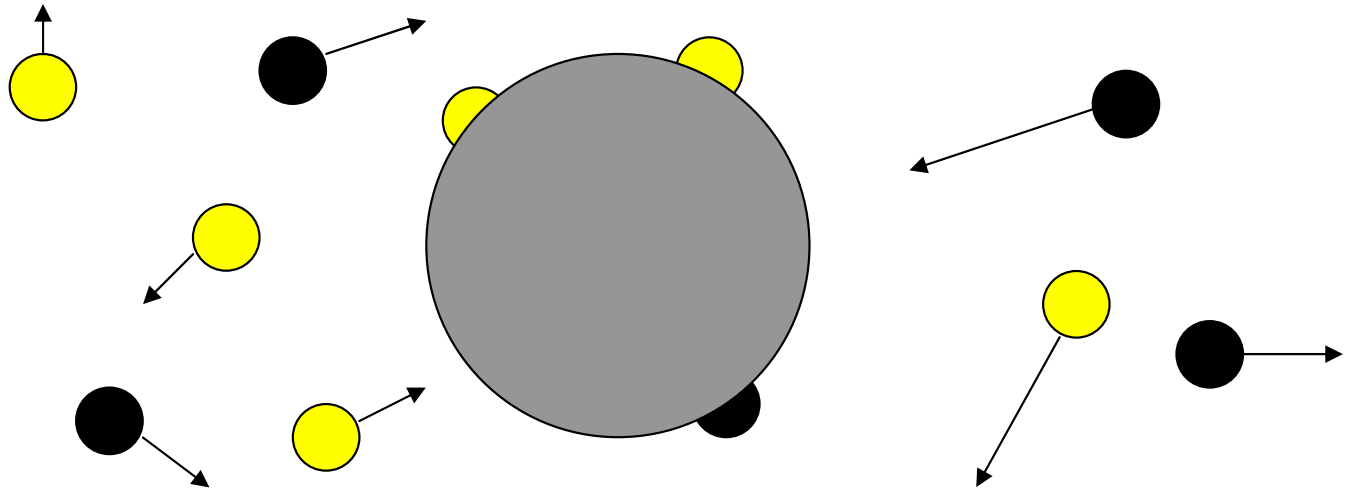
Box model: Nucleation & growth



Kulmala, Pirjola, and Mäkelä (2000) *Stable sulphate clusters as a source of new atmospheric particles*. Nature 404, 66-69.

The exact nucleation mechanism is subject to many uncertainties.

Coagulation of UFPs



A major determinant of the lifetime of UFPs is the coagulation with larger particles

Lifetime estimation of UFPs

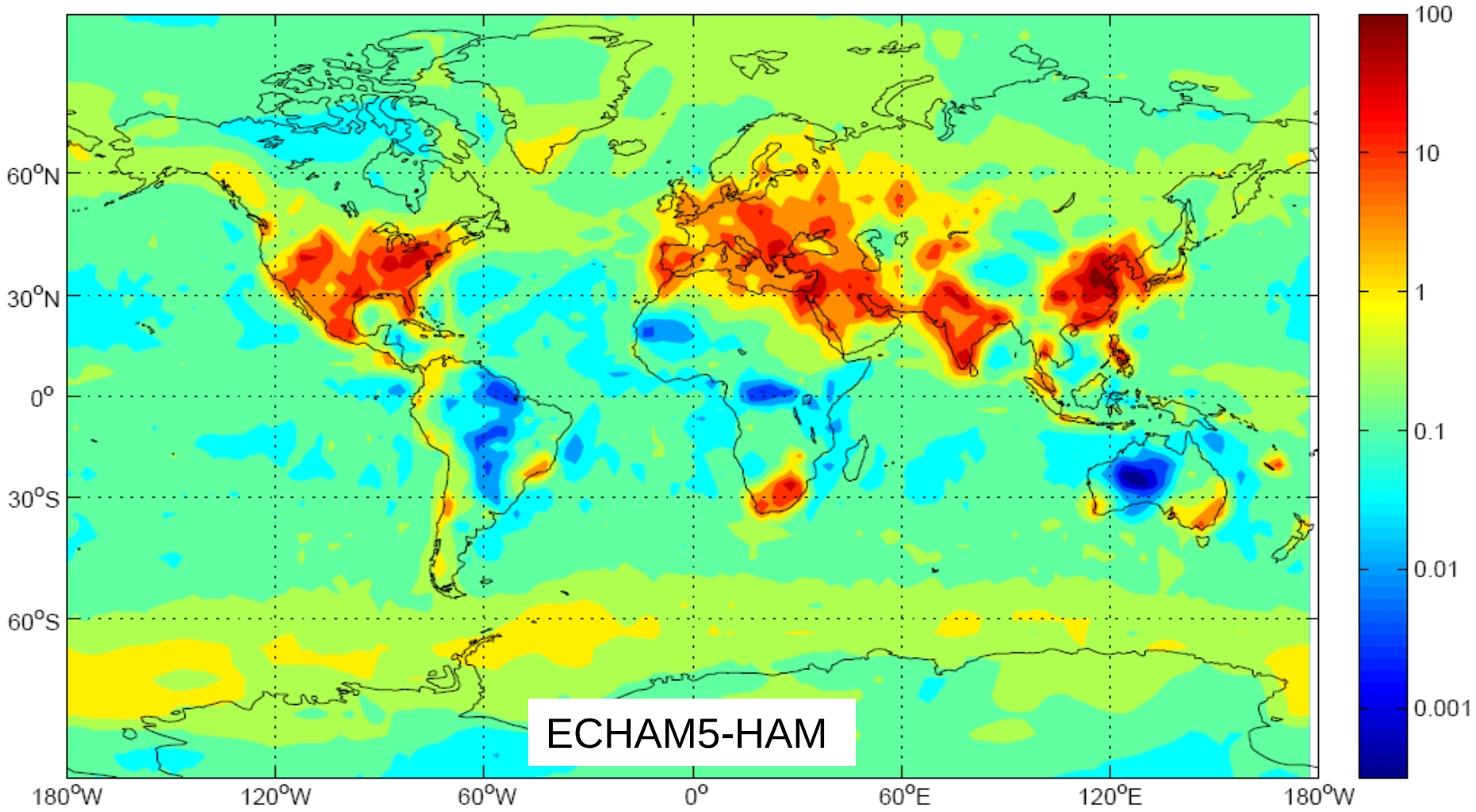
12 nm particles in a street canyon (Leipzig)

Size distribution percentile	Numer concentration in cm-3	Dmax	Half-life-time
50	33000	90 nm	**61 min**
75	43000	103 nm	**49 min**
95	92000	75 nm	**31 min**
99	140000	72 nm	**22 min**

18 nm particles near a motorway in Berlin

Size distribution percentile	Numer concentration in cm-3	Dmax	Half-life-time
50	25000	90 nm	**240 min**
75	52000	90 nm	**120 min**
95	110000	91 nm	**63 min**
99	180000	96 nm	**43 min**

UFP production rate (at 3 nm) from neutral cluster activation by H_2SO_4



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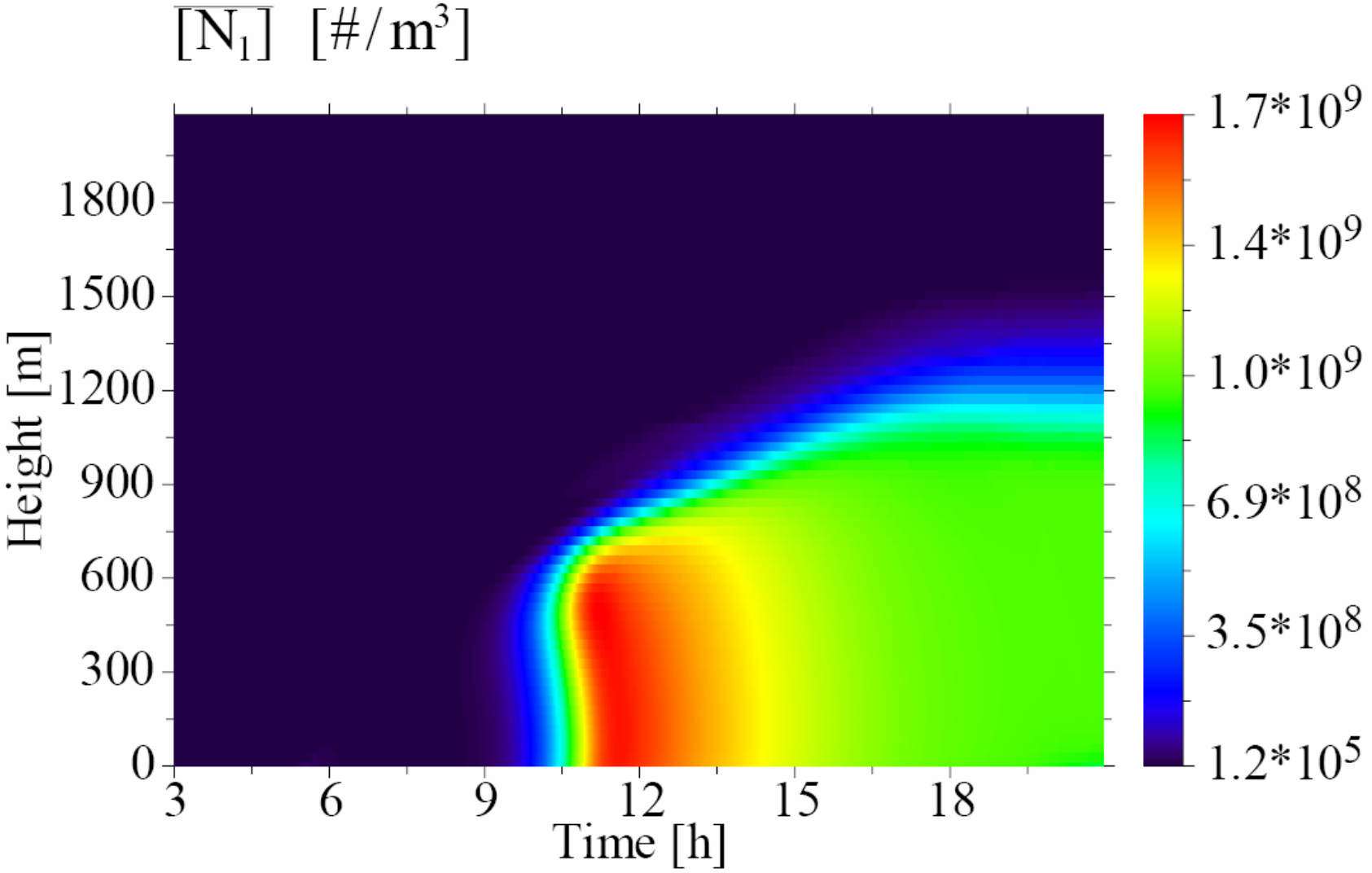
UFP concentrations resulting from a nucleation burst (H_2SO_4/H_2O)

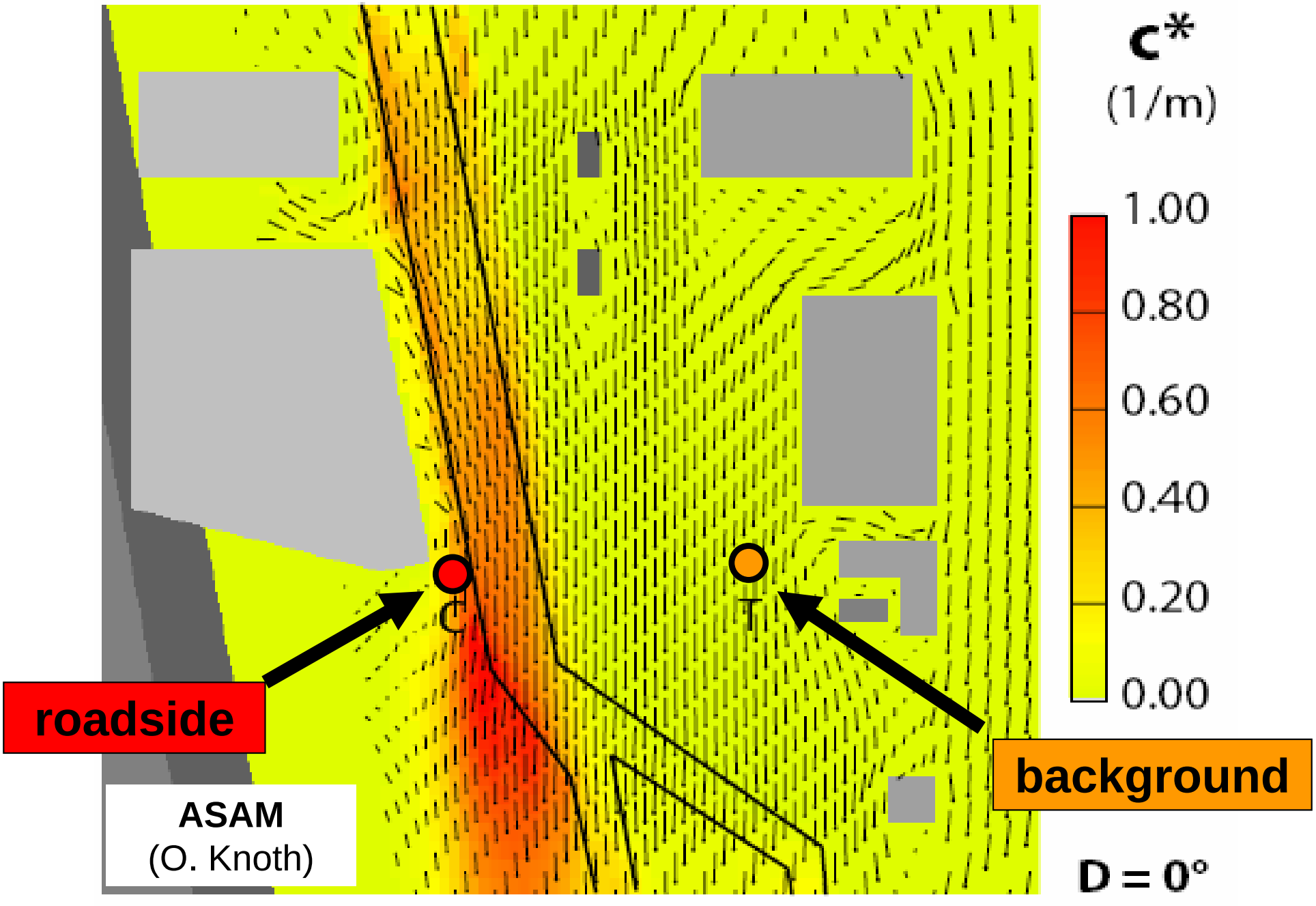


Hellmuth, O. (2006) Atmos. Chem. Phys., 6, 4231-4251, 2006.

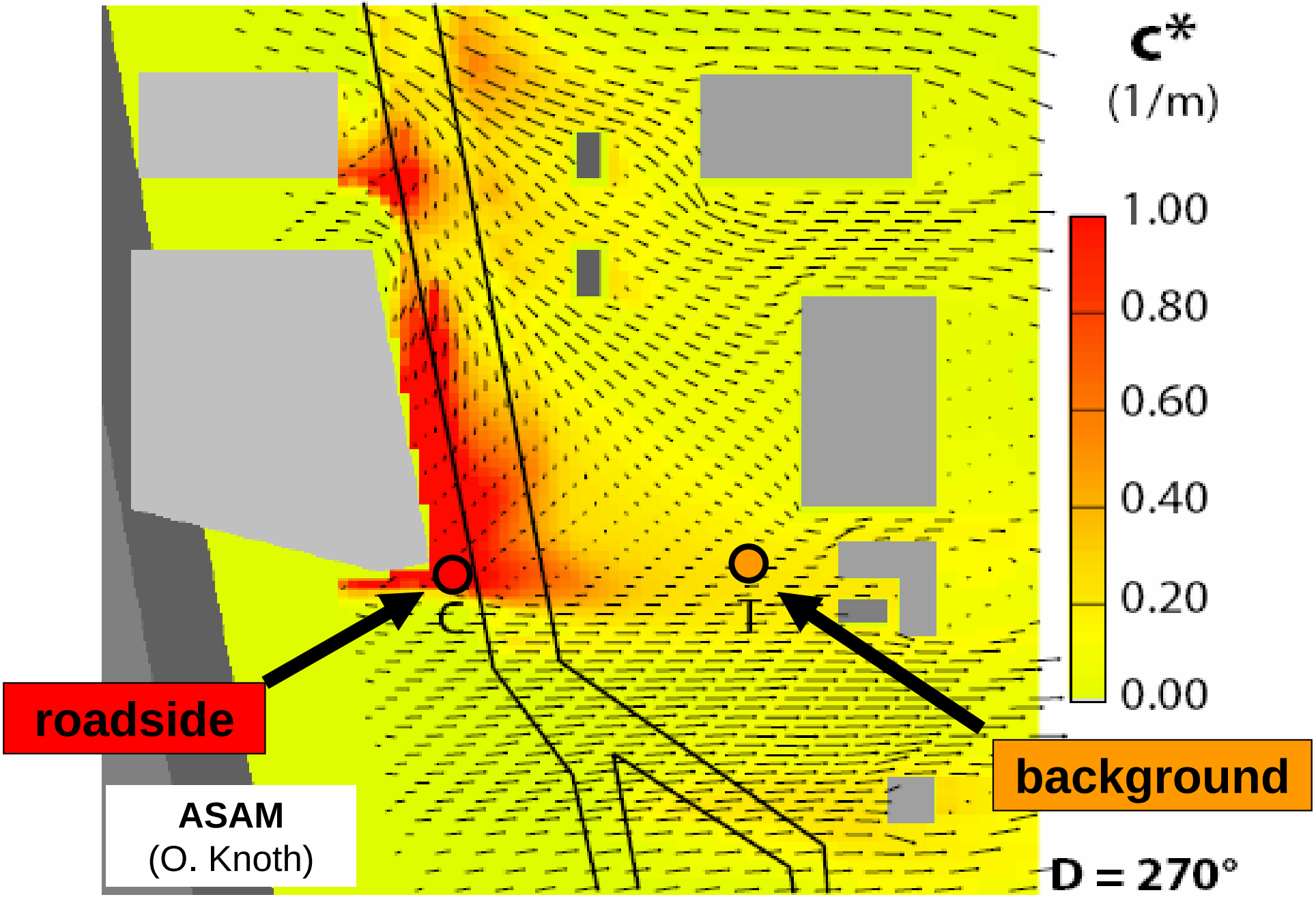
Aerosol transport models

- Due to computational restrictions, the representation of aerosol particles is usually limited to a few modes;
  dynamic processes tend to be parametrised
- High uncertainties exist with regard to
  - Particle number emissions & formation rates
  - Liquid phase and wet scavenging processes

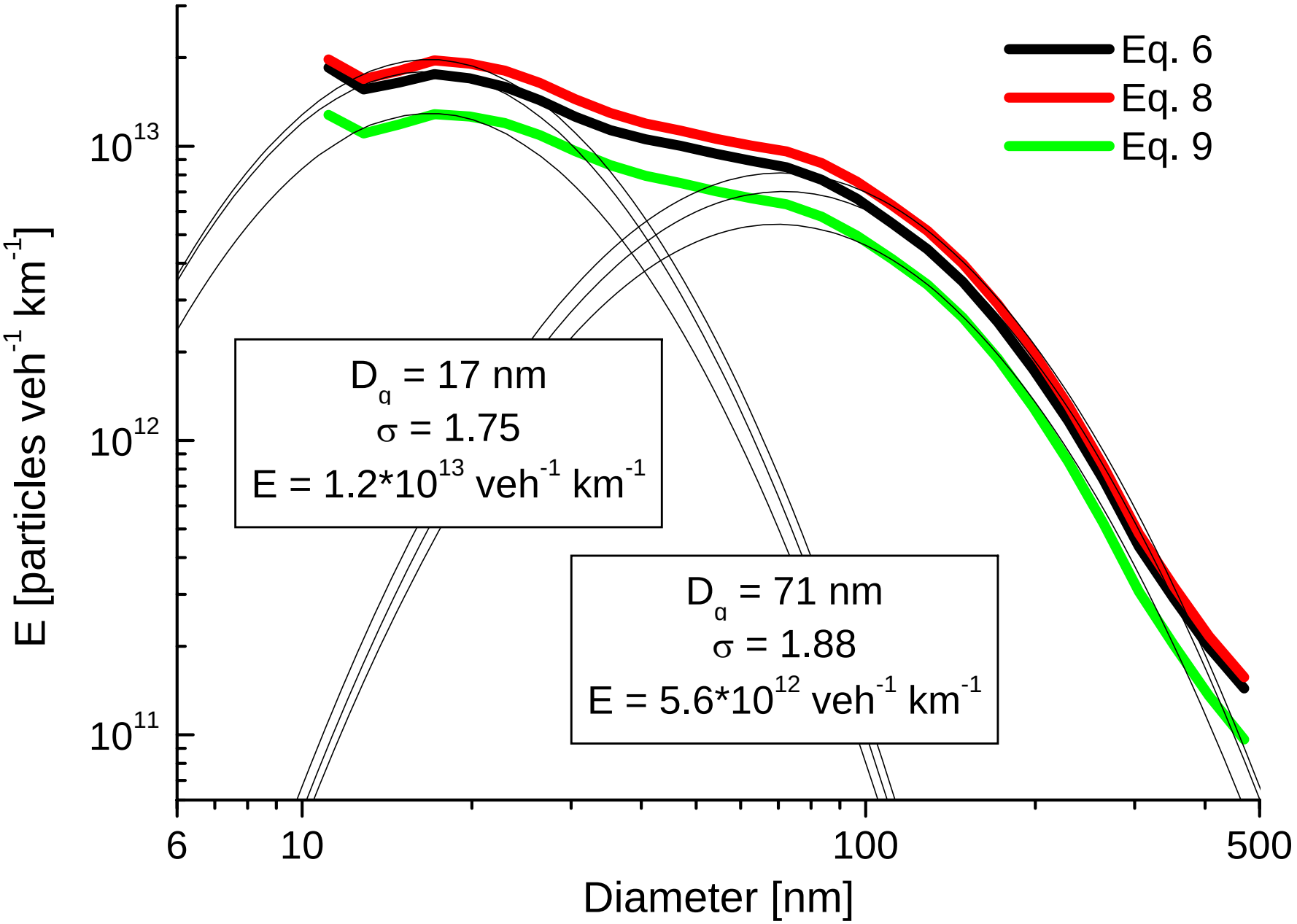
Dispersion of motorway emissions (D=0°)



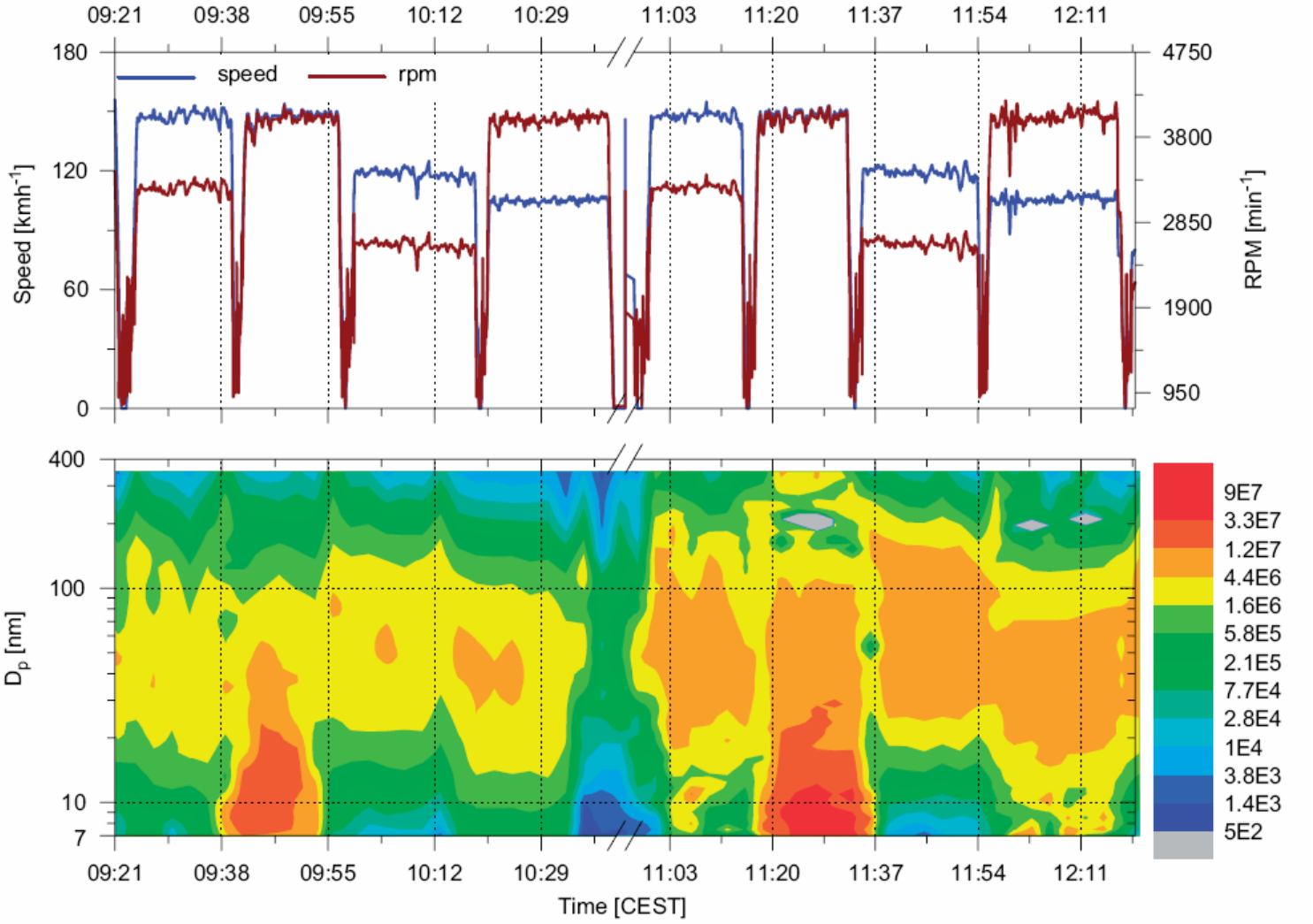
Dispersion of motorway emissions (D=270°)



Size distribution emission factor

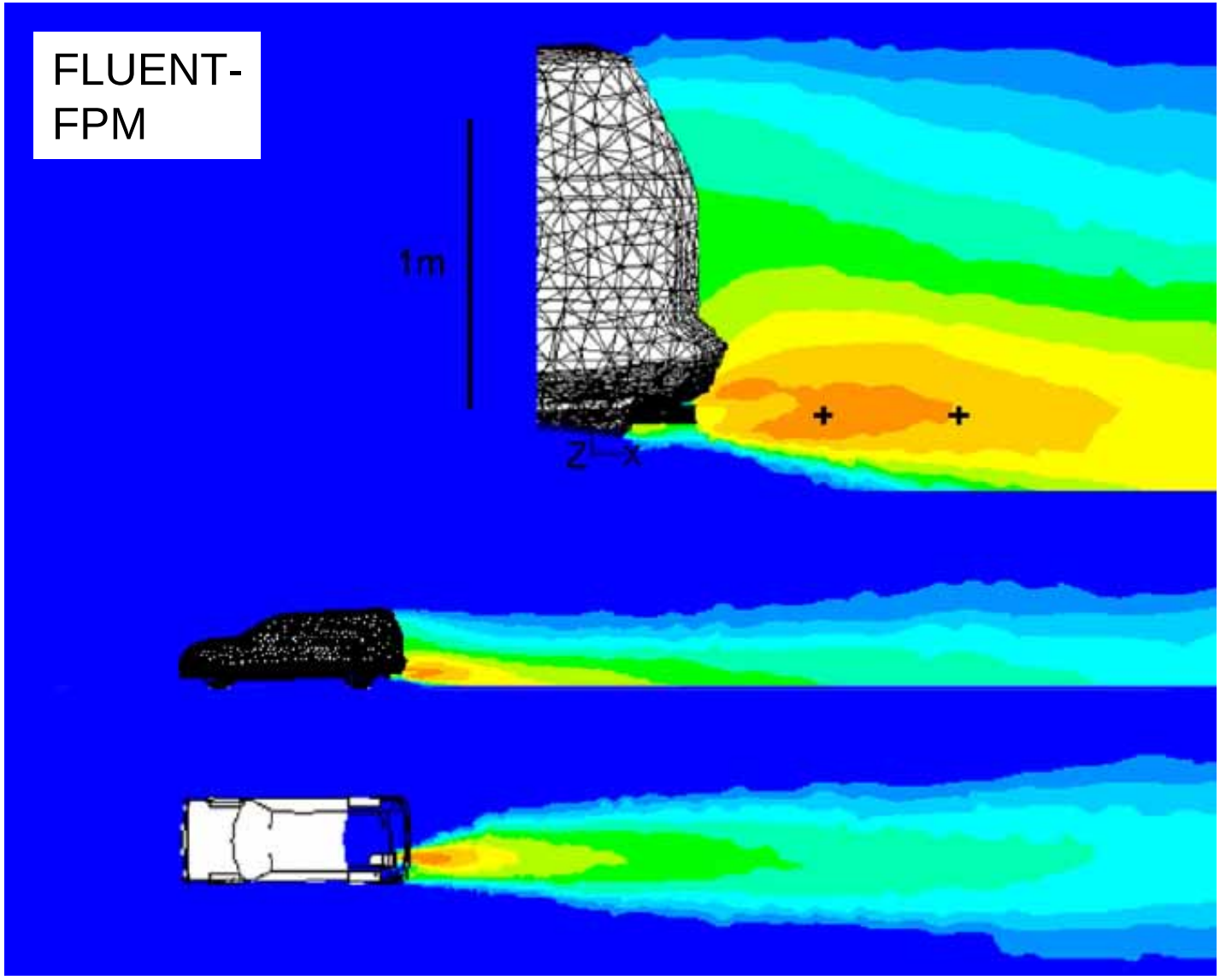


Tailpipe Measurements of UFPs



Uhrner, Löwis, Vehkamäki, Wehner, Bräsel, Hermann, Stratmann, Kulmala, Wiedensohler (2007) Atmos. Env., in press.

Tailpipe CFD & aerosol modelling



Particle nucleation within the turbulent tailpile of a vehicle

Uhrner, Löwis, Vehkamäki, Wehner, Bräsel, Hermann, Stratmann, Kulmala, Wiedensohler (2007) Atmos. Env., in press.

Summary

- Experimental data confirm that besides secondary formation, traffic is the most important source of UFPs in Germany.
- Atmospheric models are now handling aerosols as a dynamic variable at all atmospheric scales
- Qualitative understanding of most processes
- Need to develop transport models for the intermediate (urban scale)
- More need for model validation experiments

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