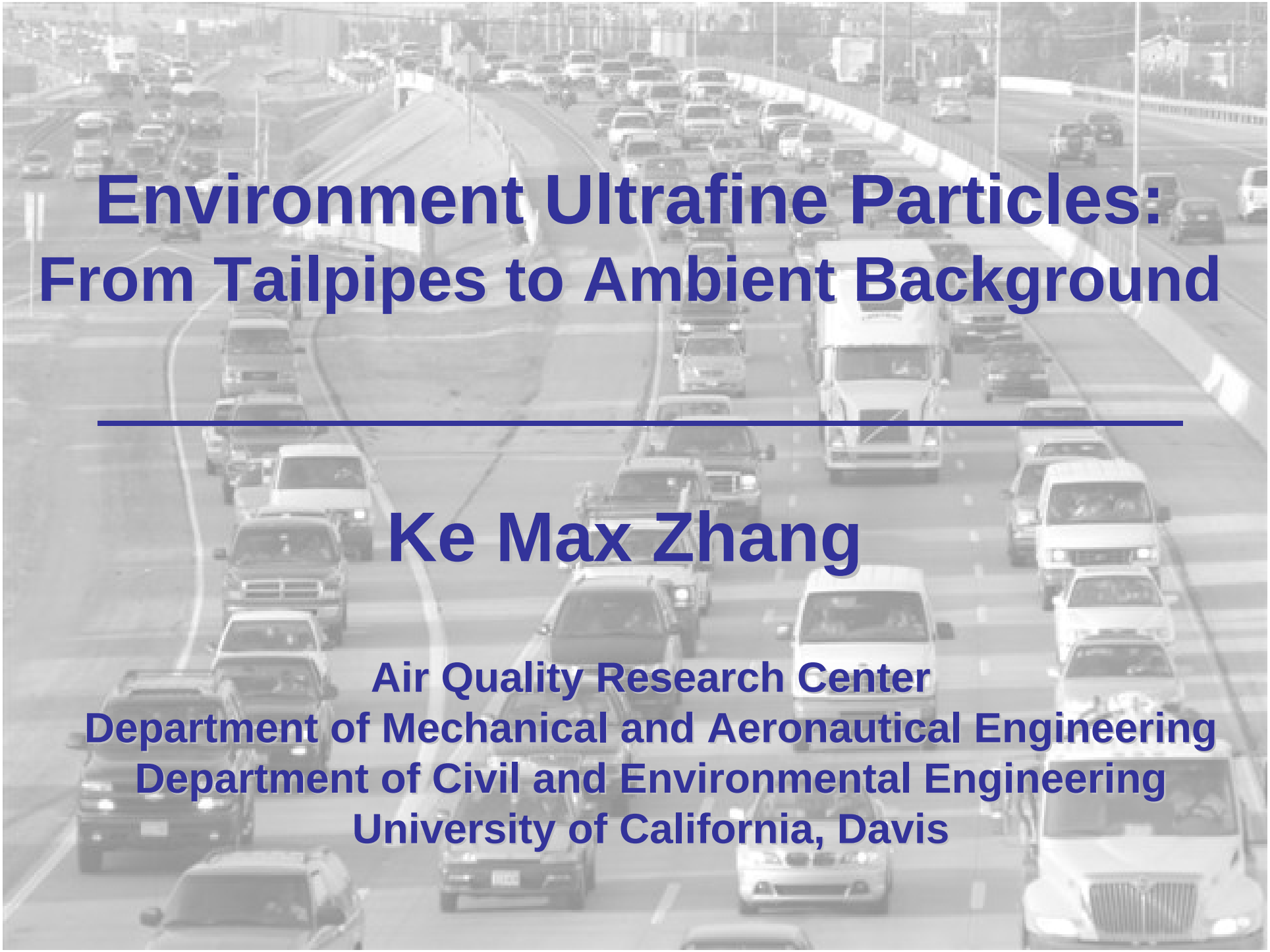

Environment Ultrafine Particles:
From Tailpipes to Ambient Background

Ke Max Zhang

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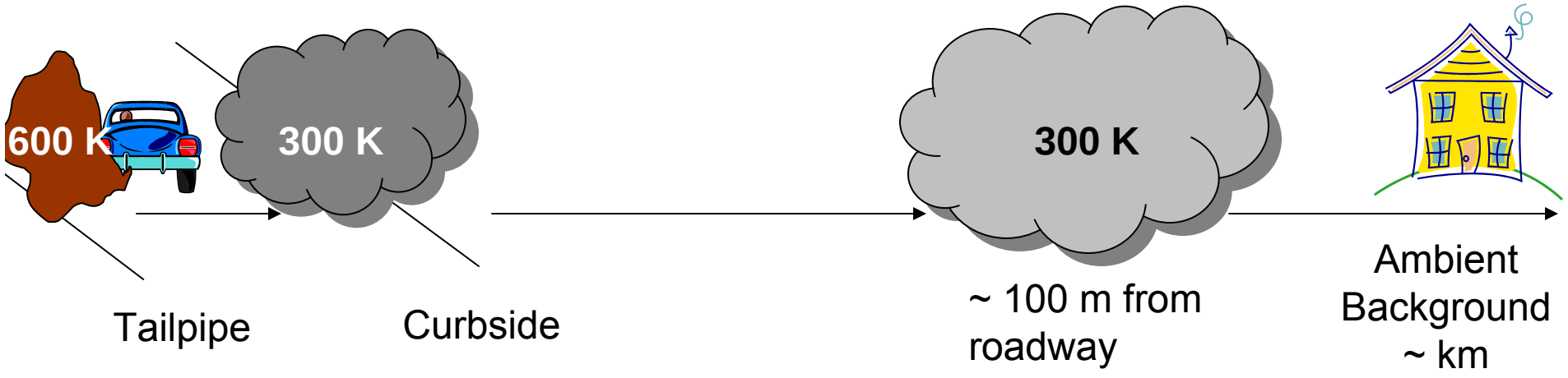
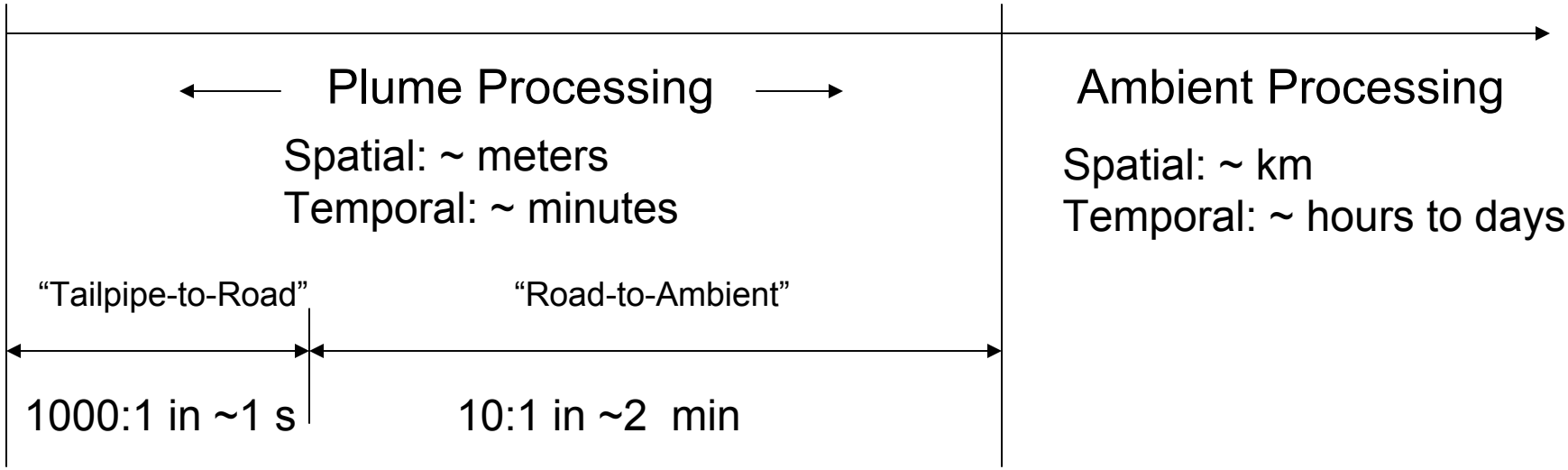
Department of Civil and Environmental Engineering
University of California, Davis

Acknowledgement

- Drs. Anthony Wexler and Debbie Niemeier at UC-Davis
- Dr. Yifang Zhu, Dr. William Hinds at UCLA; Dr. Constantinos Sioutas at USC
- Major funding supports from Electric Power Research Institute (EPRI), USEPA, CARB, National Science Foundation (NSF)

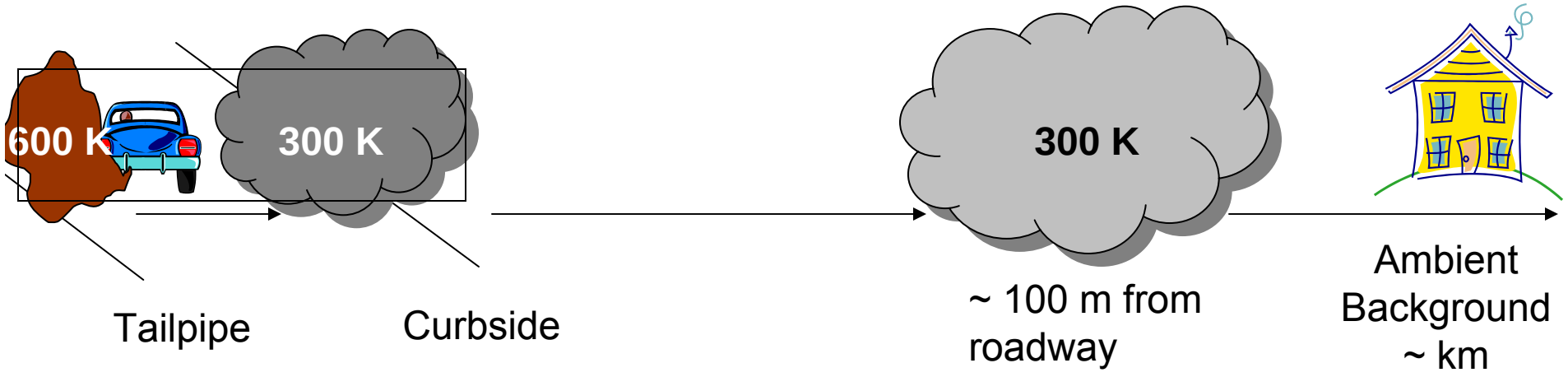
From Tailpipe to Ambient Background

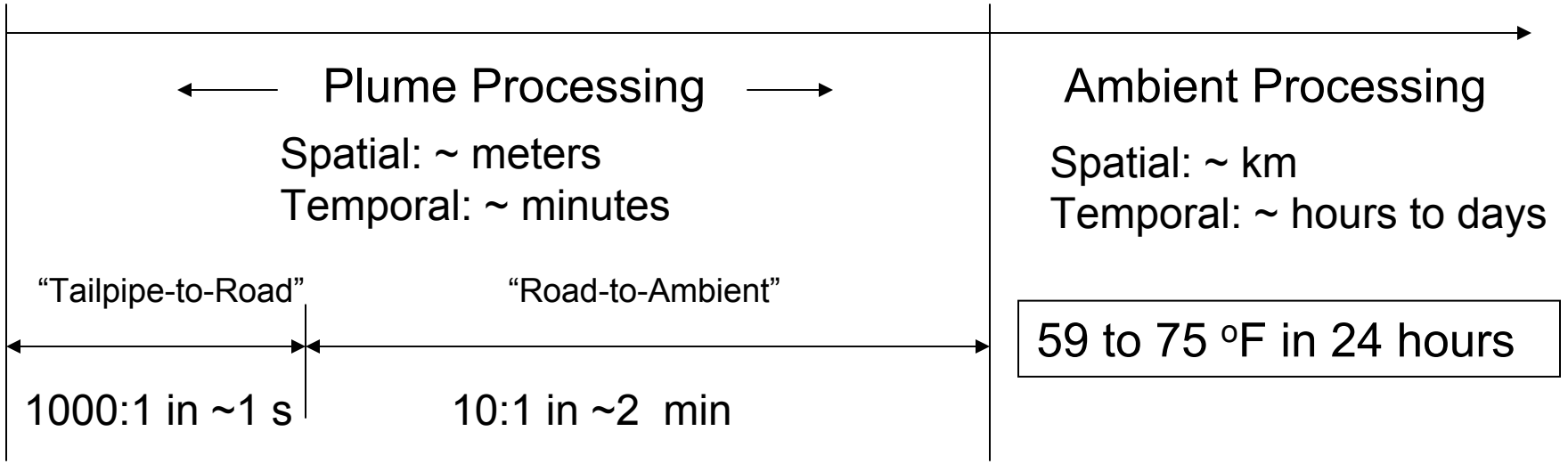




* Summarized in Zhang and Wexler, Atmos. Env. 38(38): 6643-6653 2004

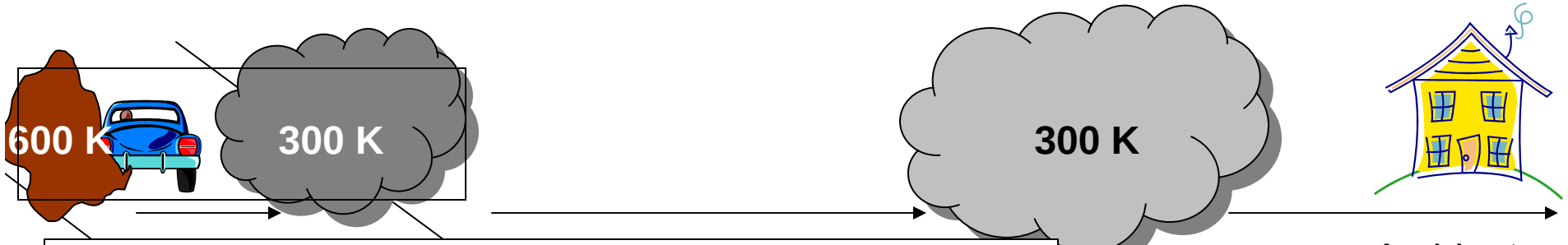
From Tailpipe to Ambient Background





* Summarized in Zhang and Wexler, Atmos. Env. 38(38): 6643-6653 2004

From Tailpipe to Ambient Background



- Steep temperature gradient triggers New Particle Formation and Gas/Particle Partition.

m from
way

Ambient
Background
~ km

Ambient Processing

Spatial: ~ km
Temporal: ~ hours to days

Temporal: ~ minutes

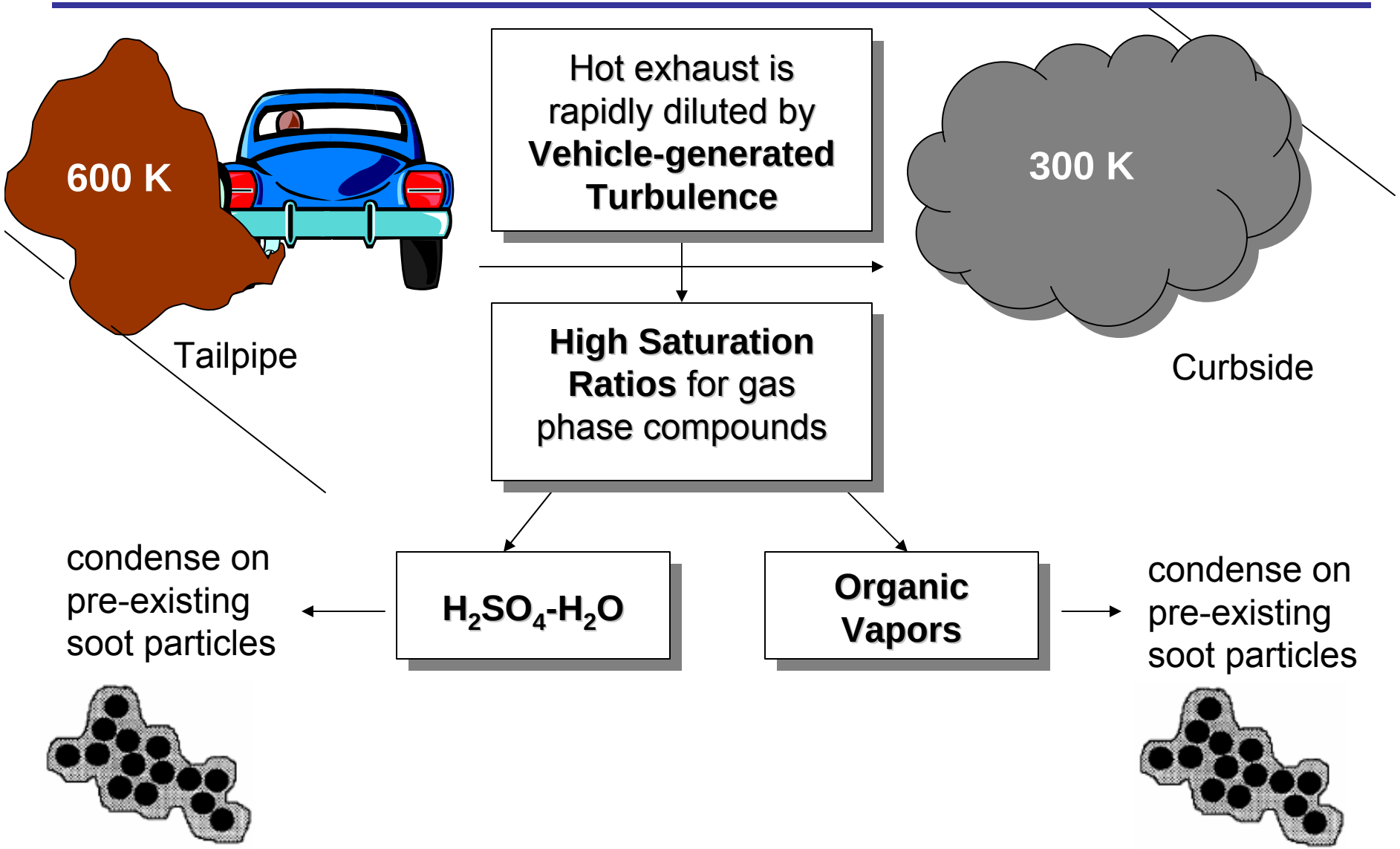
"Tailpipe-to-Road" "Road-to-Ambient"

1000:1 in ~1 s 10:1 in ~2 min

59 to 75 °F in 24 hours

* Summarized in Zhang and Wexler, Atmos. Env. 38(38): 6643-6653 2004

"Tailpipe-to-Road": 0 – 1 second



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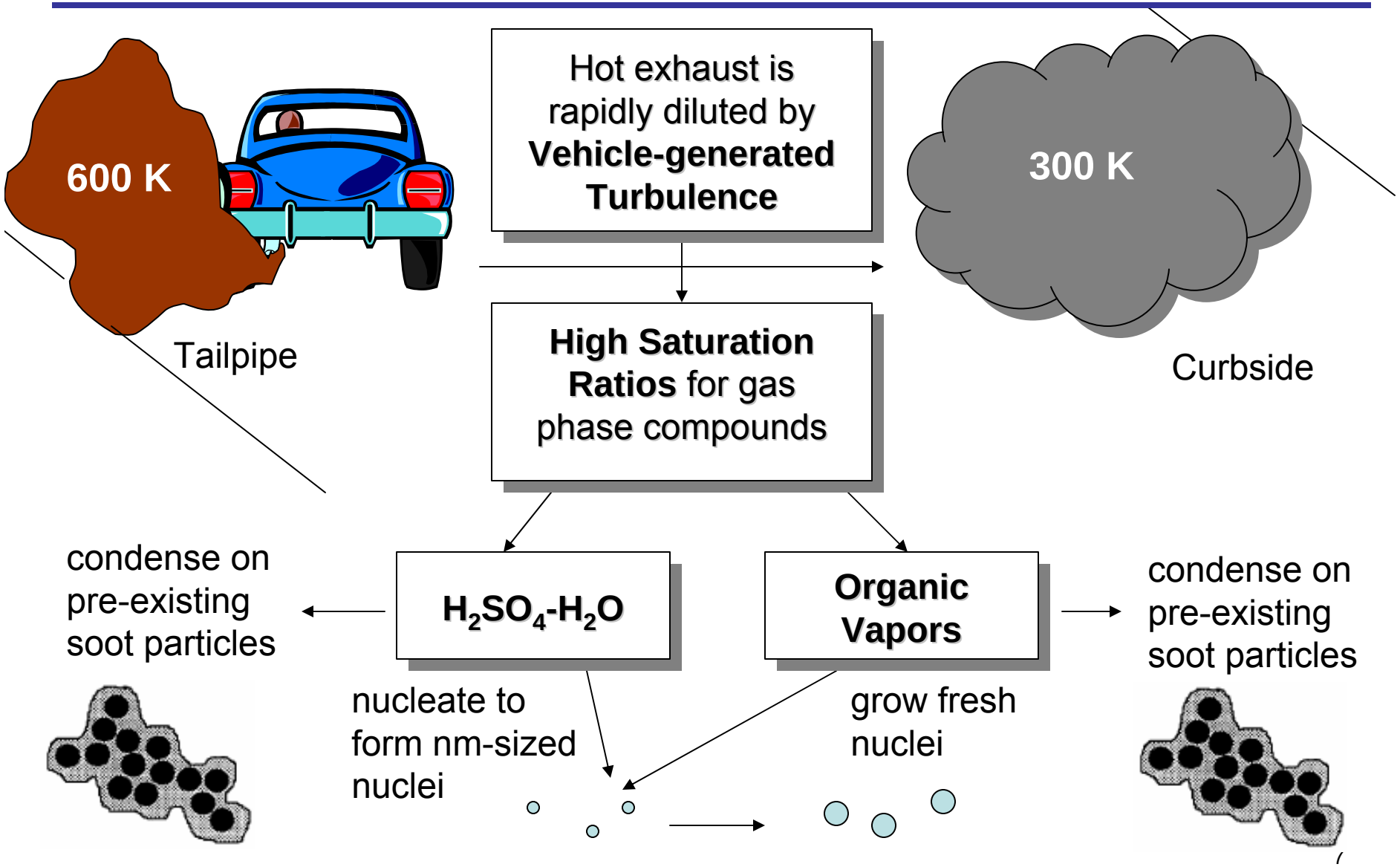
"Tailpipe-to-Road": 0 – 1 second



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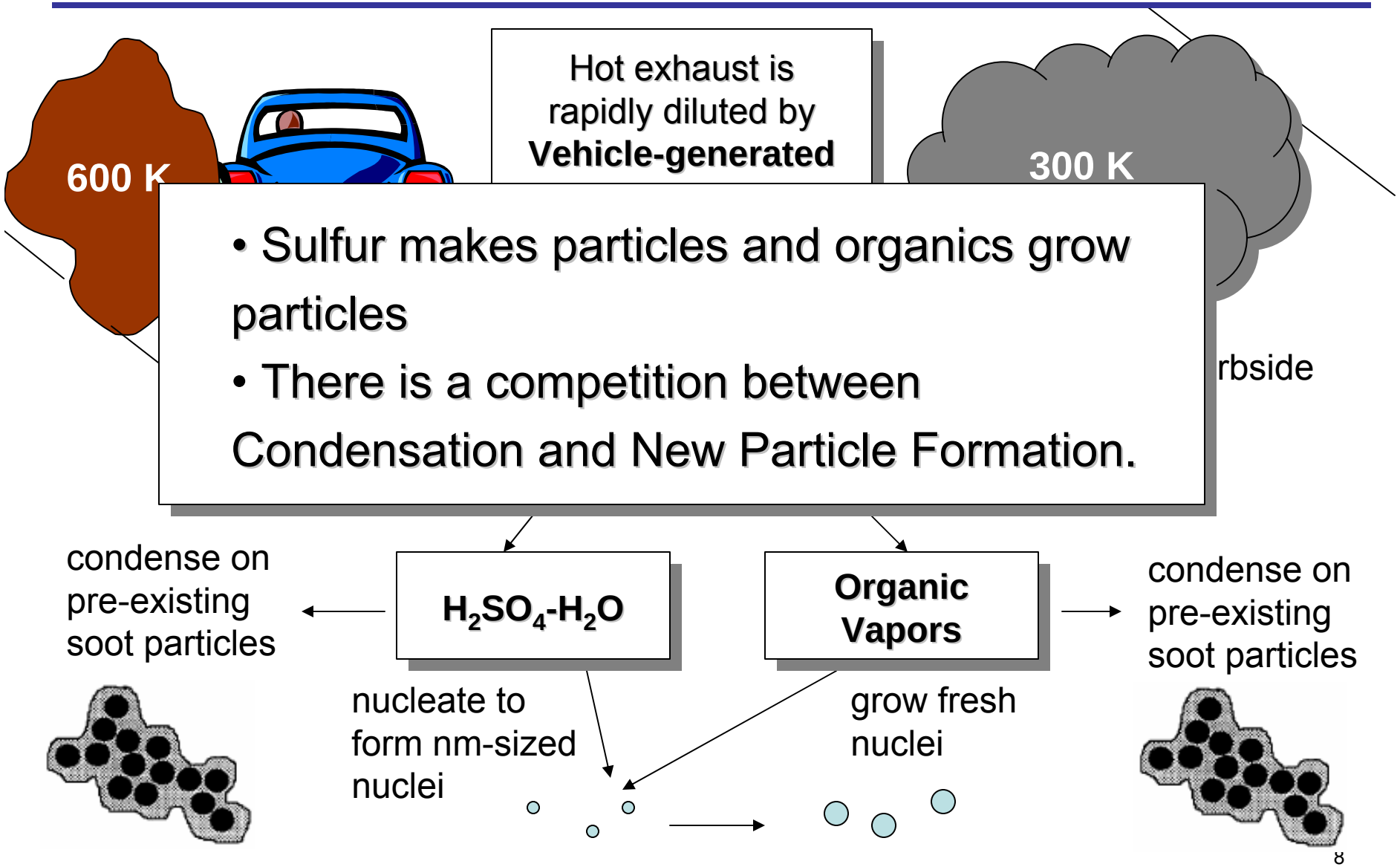
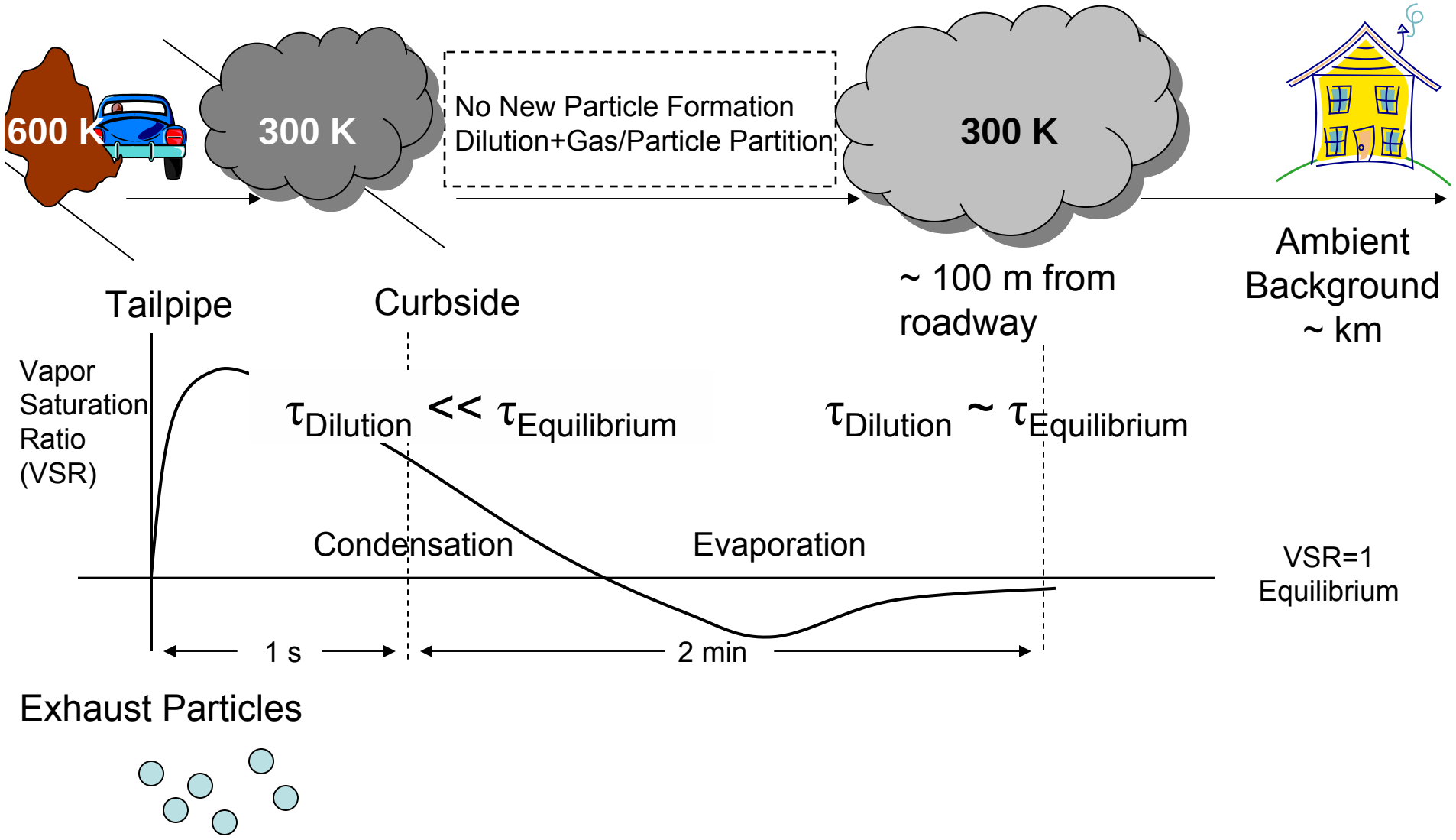
"Tailpipe-to-Road": 0 – 1 second



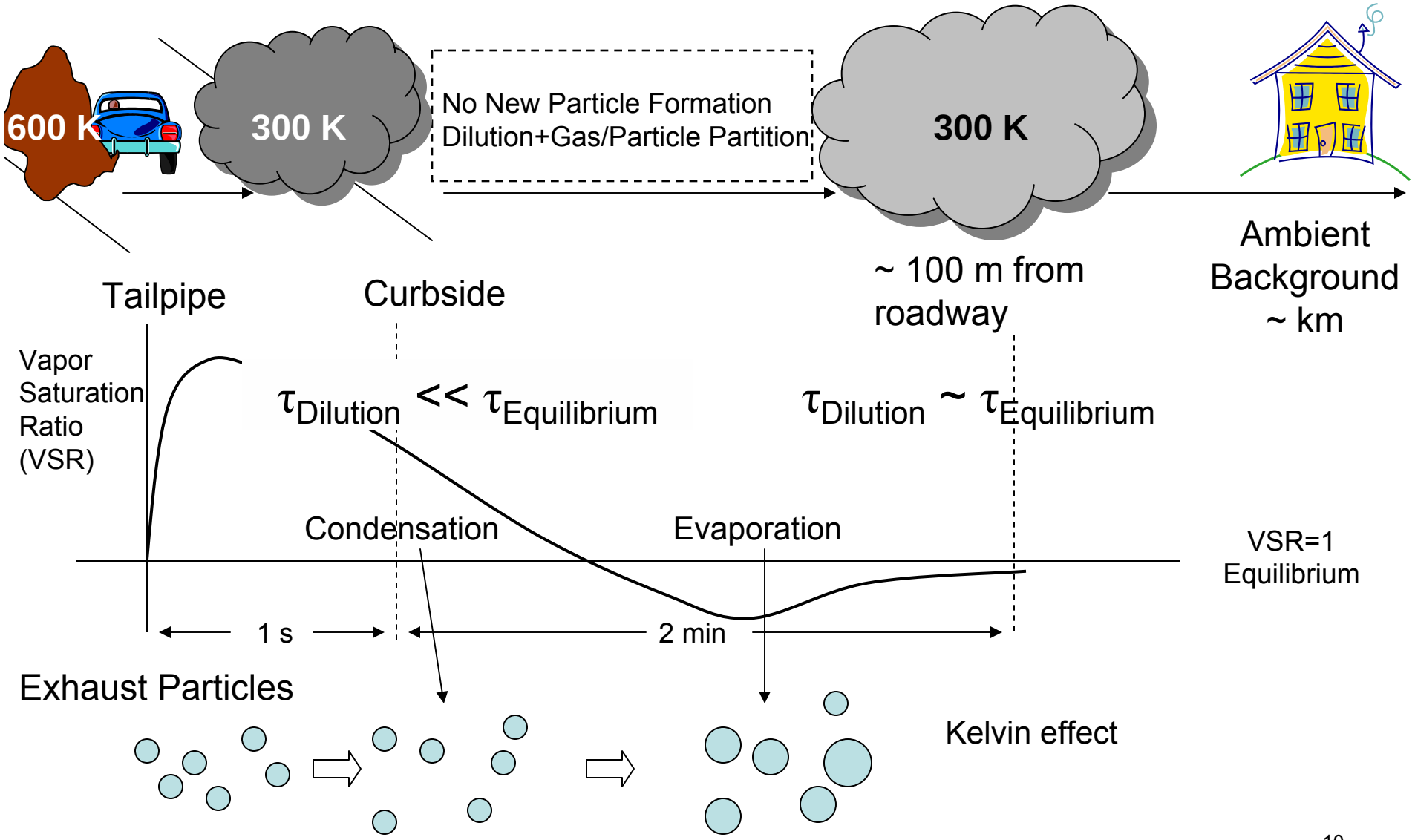
* Summarized in Zhang and Wexler, Atmos. Env. 38(38): 6643-6653 2004

“Road-to-Ambient”: the next 2 minutes



* Summarized in Zhang et al.(2004) Atmos. Env. 38(38): 6643-6653 & 6655-6665

“Road-to-Ambient”: the next 2 minutes



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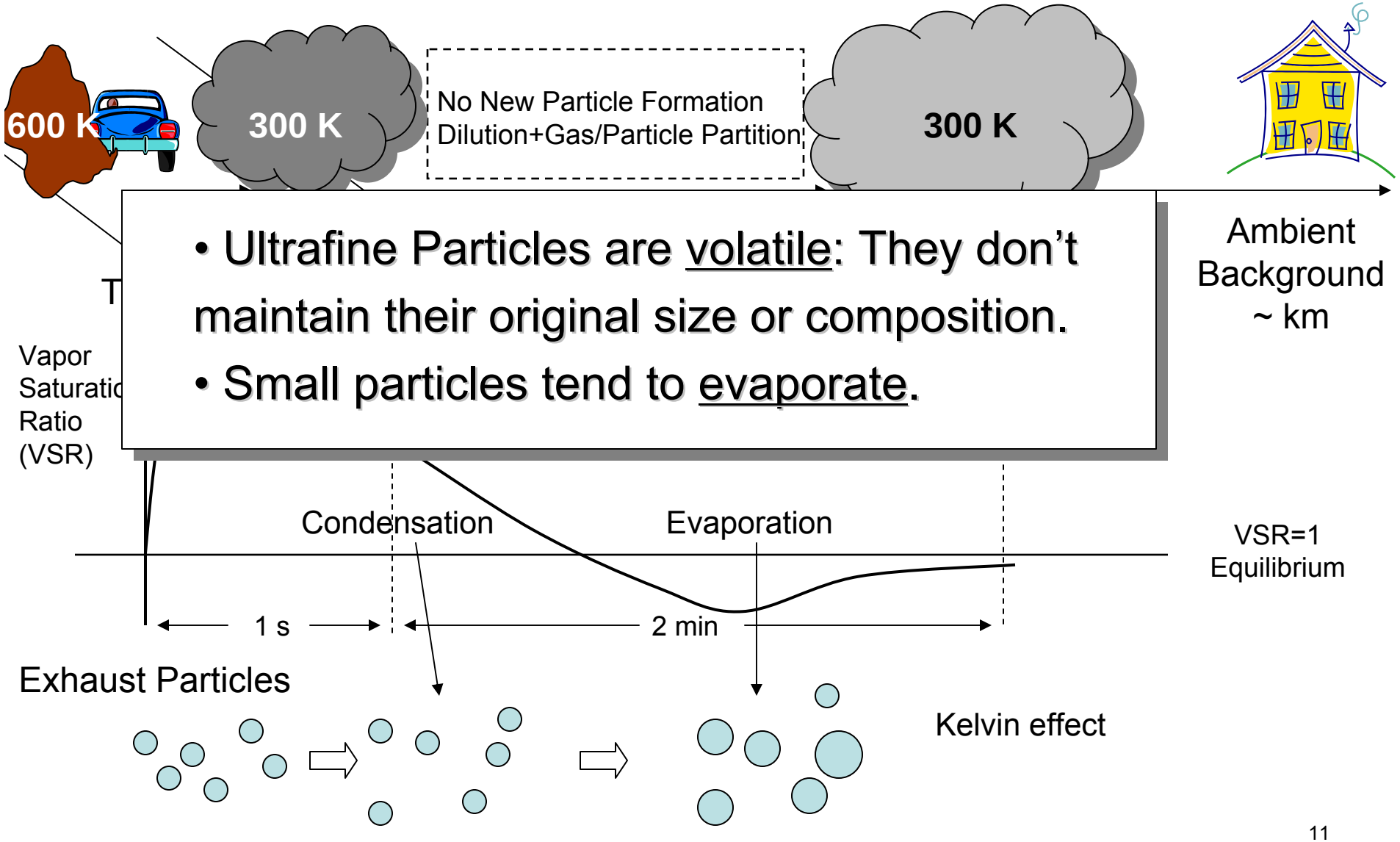
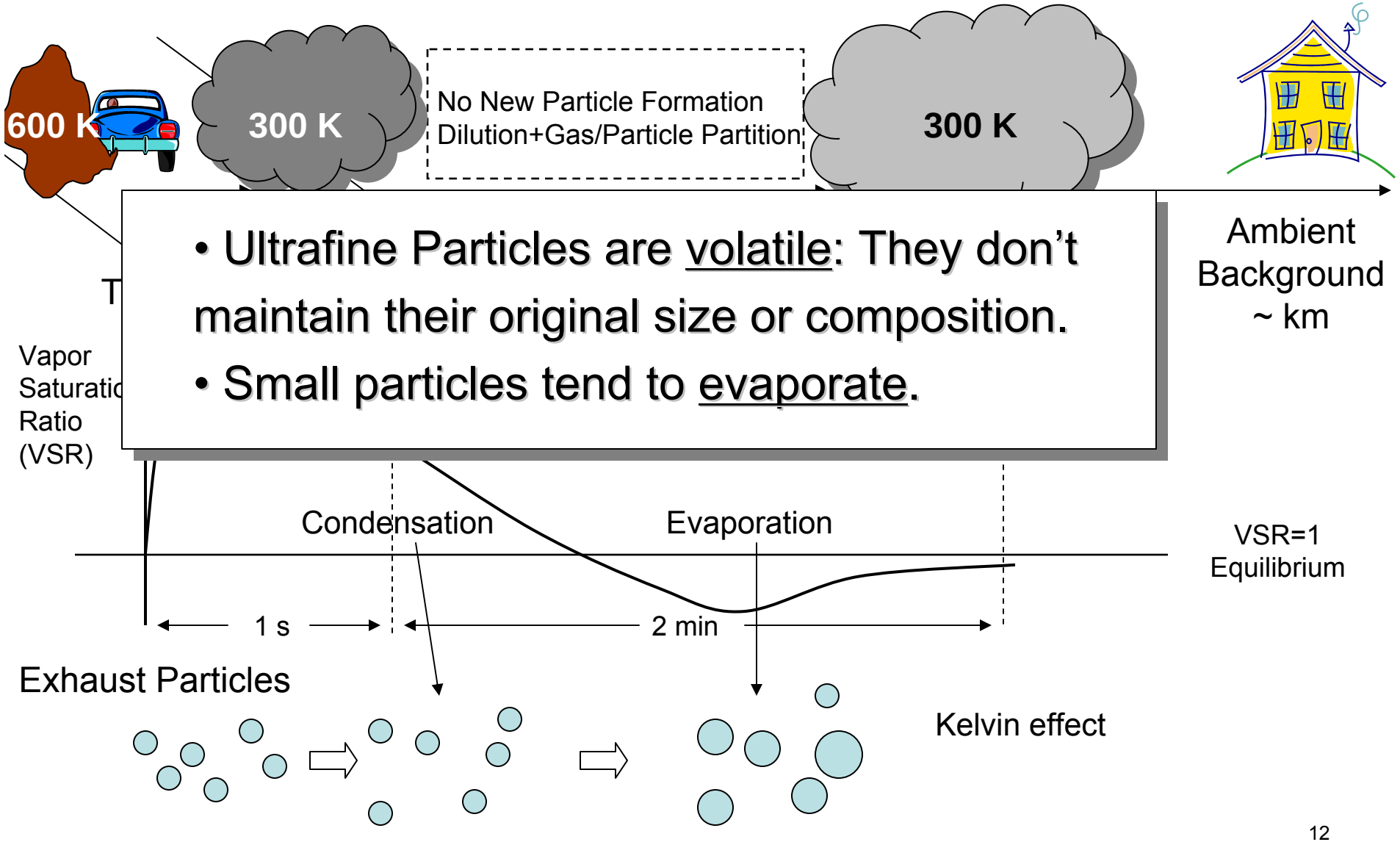
"Road-to-Ambient": the next 2 minutes



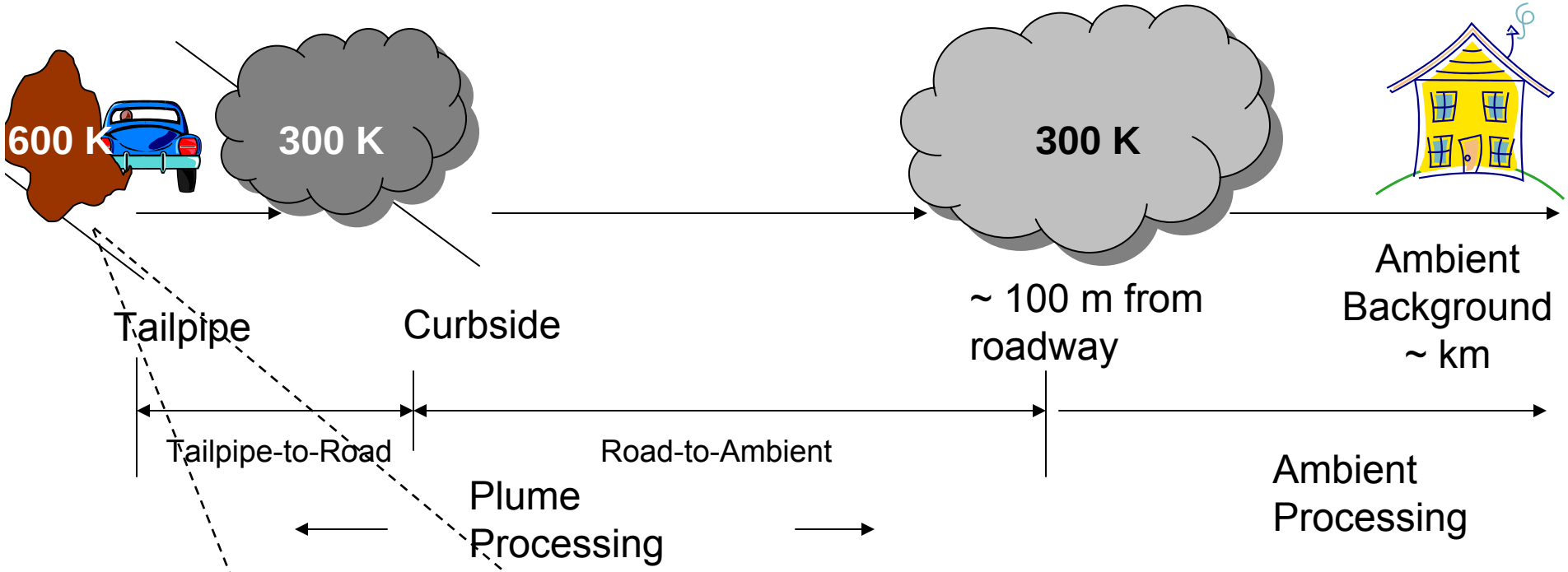
* Summarized in Zhang et al.(2004) Atmos. Env. 38(38): 6643-6653 & 6655-6665

Emission is dynamic



* Summarized in Zhang et al.(2004) Atmos. Env. 38(38): 6643-6653 & 6655-6665

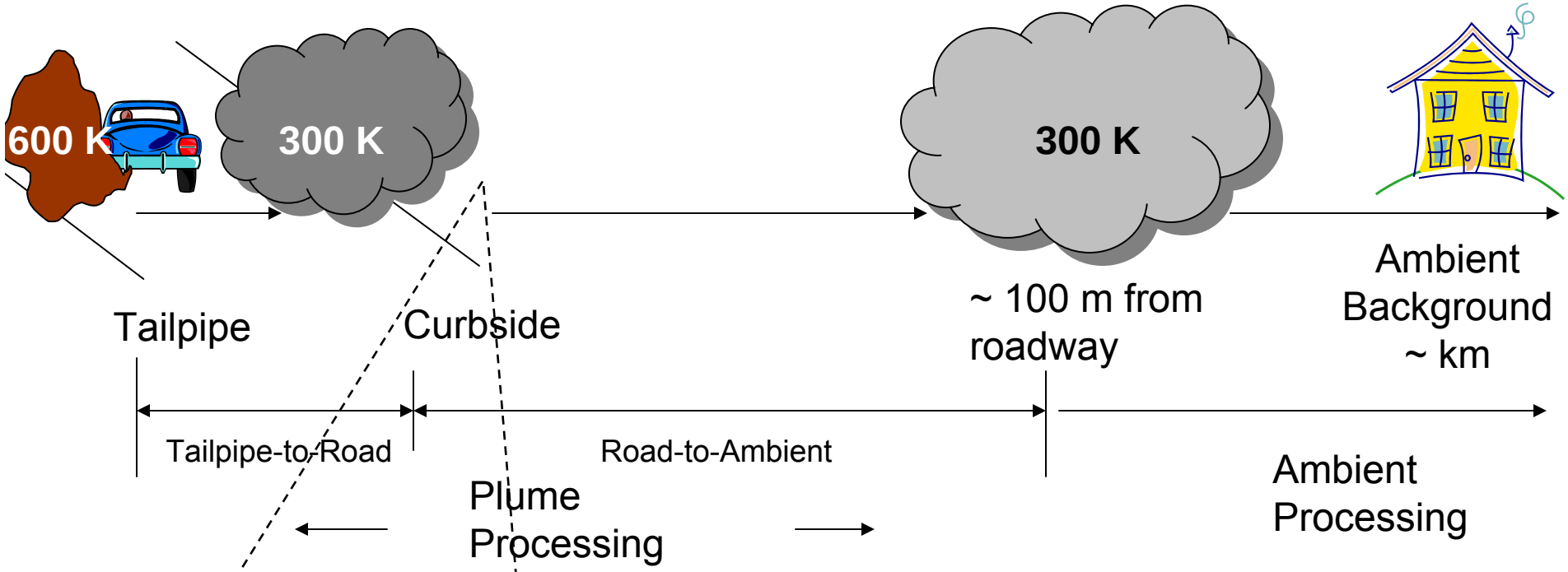
Receptor-dependent Emission Factors (EF)



***Tailpipe-level Emission**:*
The emission profiles near the exit of the tailpipe

* Summarized in Zhang et al., Atmos. Env. 39 (22): 4155-4166 2005

Receptor-dependent Emission Factors (EF)

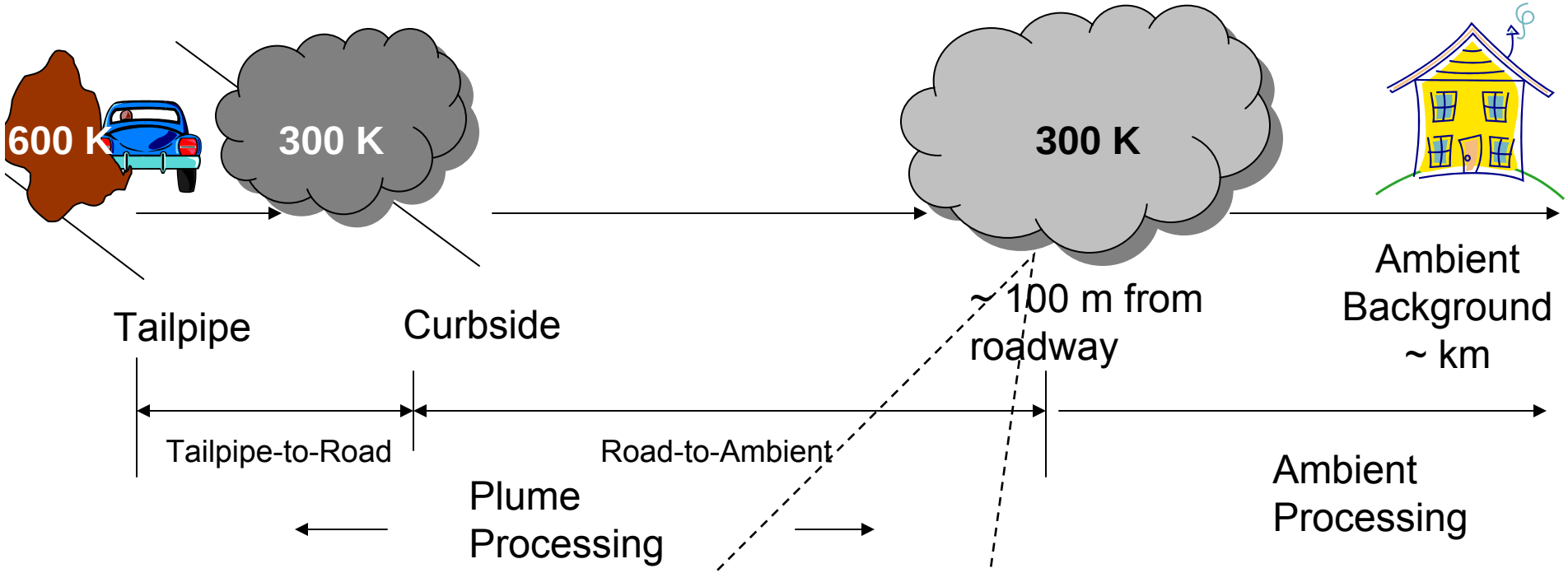


***Road-level Emission**:*

The emission profiles on or near the roadway curb

* Summarized in Zhang et al., Atmos. Env. 39 (22): 4155-4166 2005

Receptor-dependent Emission Factors (EF)

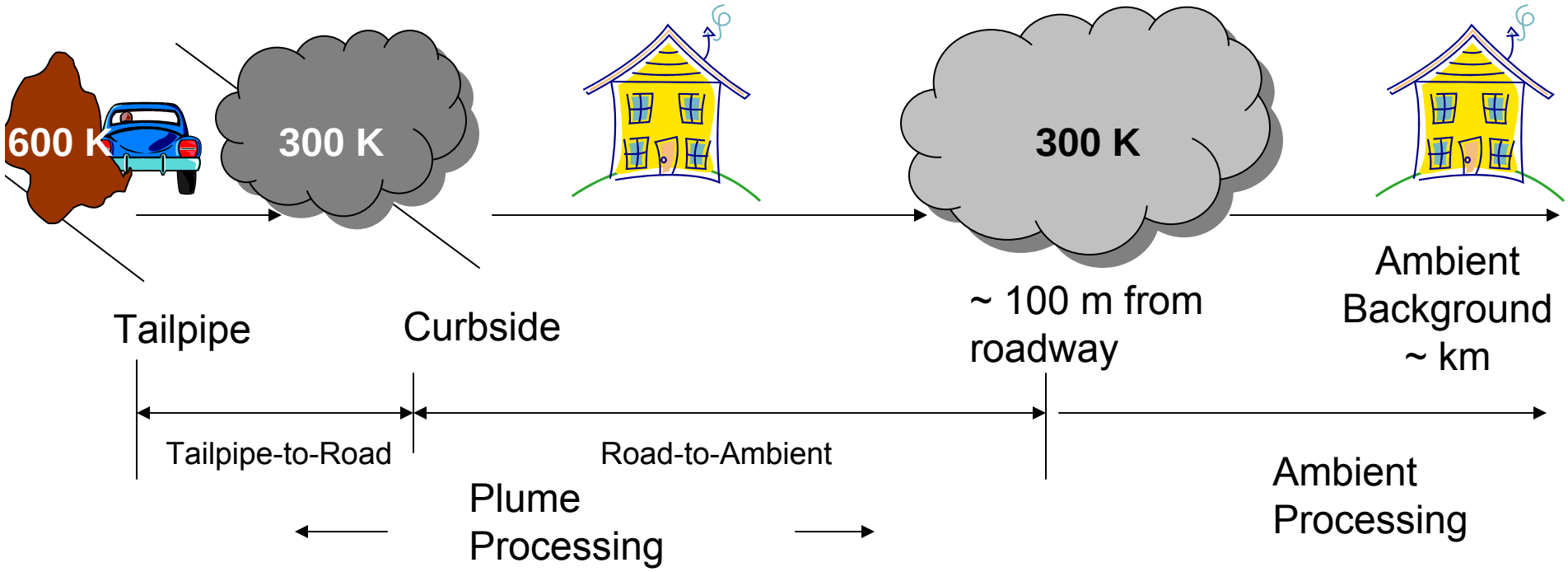


***Grid-level Emission**:*

The emission profiles near the end of plume processing (particle dynamics slows down significantly at this point)

* Summarized in Zhang et al., Atmos. Env. 39 (22): 4155-4166 2005

Receptor-dependent Emission Factors (EF)



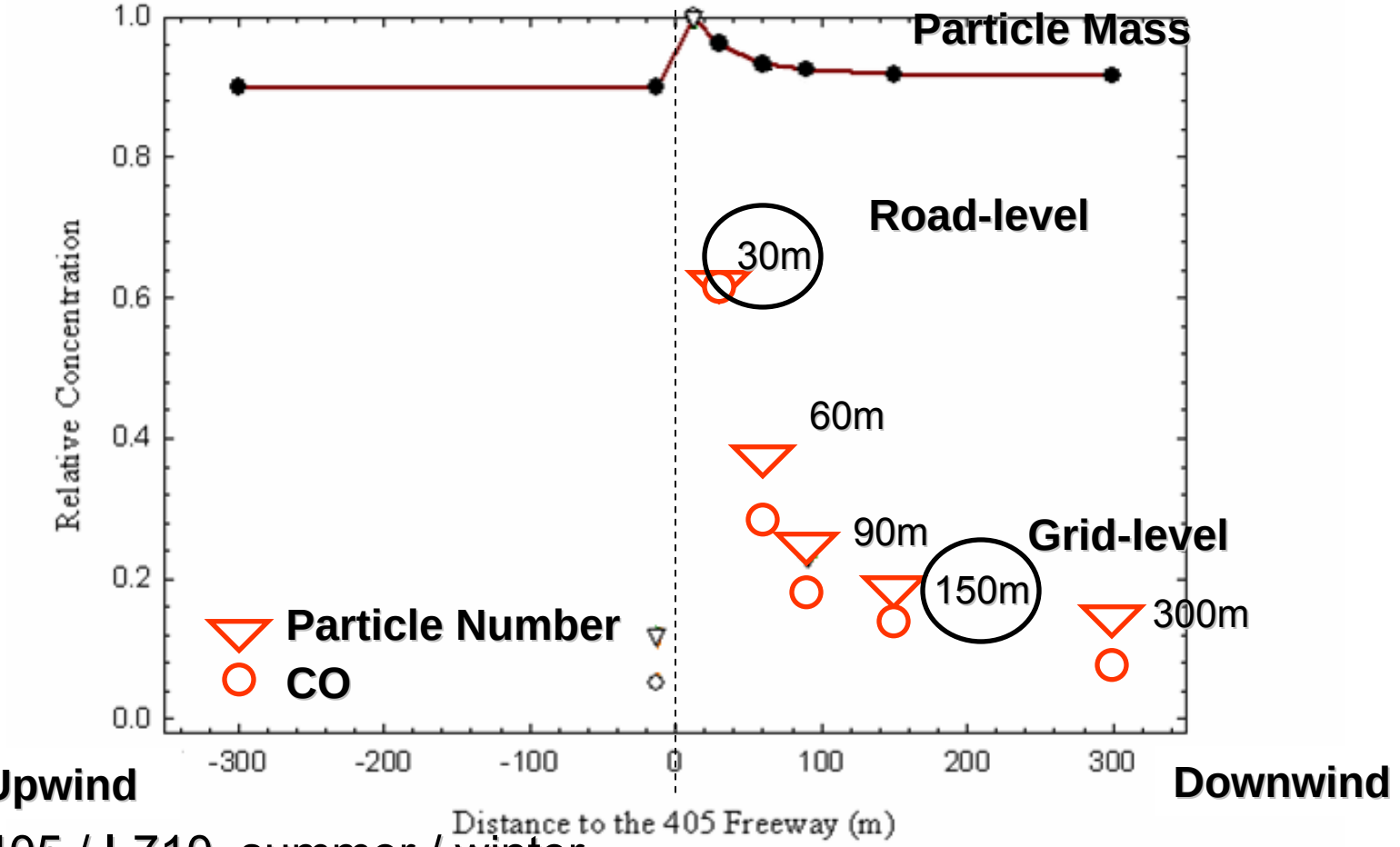
*"**Emission** is in the eyes of the beholder"*

* Summarized in Zhang et al., Atmos. Env. 39 (22): 4155-4166 2005

Deriving Ultrafine Particle Emission Factors

* Summarized in Zhu et al., JAWMA 52: 1032-1042 and Zhang et al., Atmos. Env. 39 (22): 4155-4166 2005

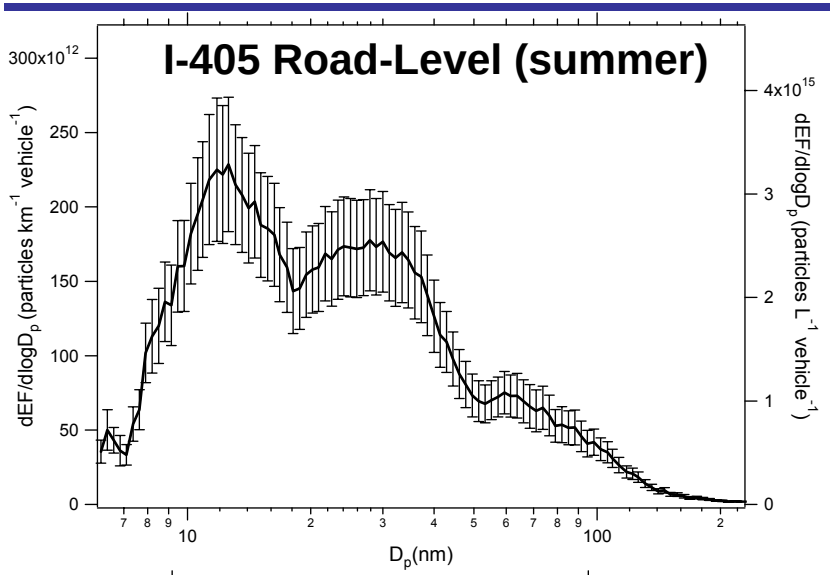
Deriving Ultrafine Particle Emission Factors

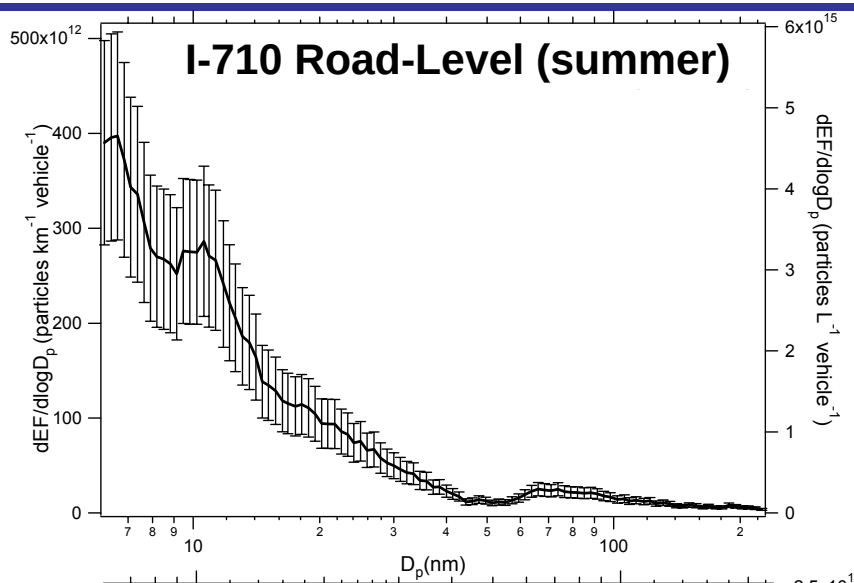


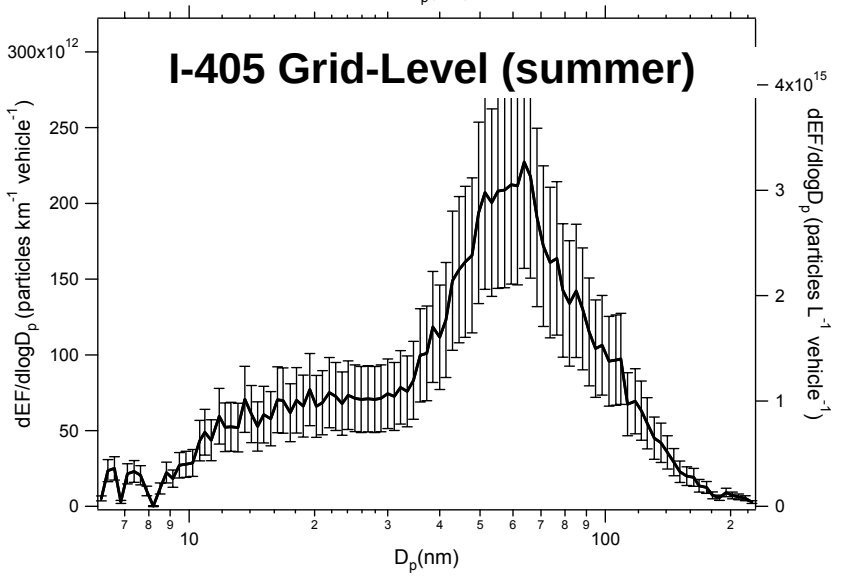
- I-405 / I-710, summer / winter
- Measured at gradually increasing downwind distances (17/30m to 300m)
- **Particle size distribution** $\xrightarrow{CO}$ **Particle Emission Factor distribution**

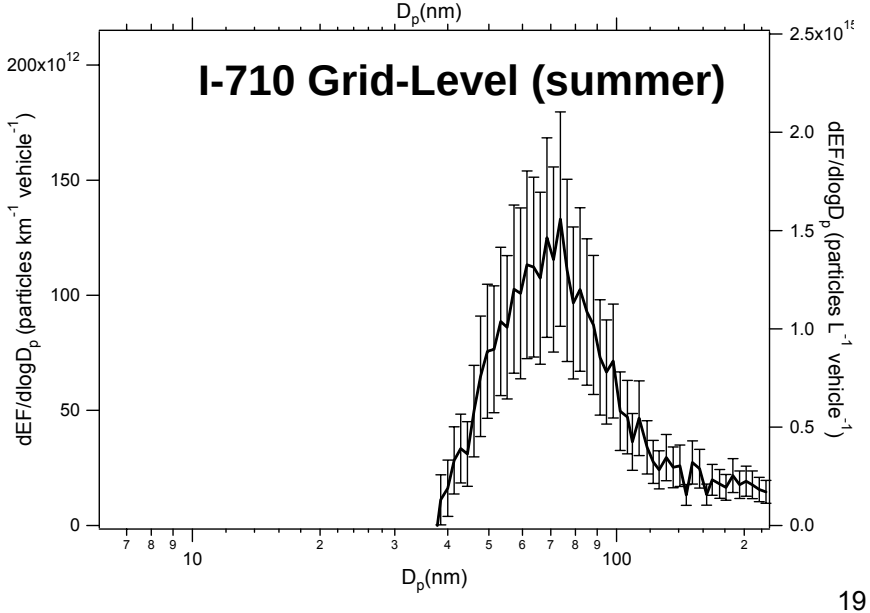
* Summarized in Zhu et al., JAWMA 52: 1032-1042 and Zhang et al., Atmos. Env. 39 (22): 4155-4166 2005

Road-Level vs. Grid-Level: I-405 (L) and I-710(R)

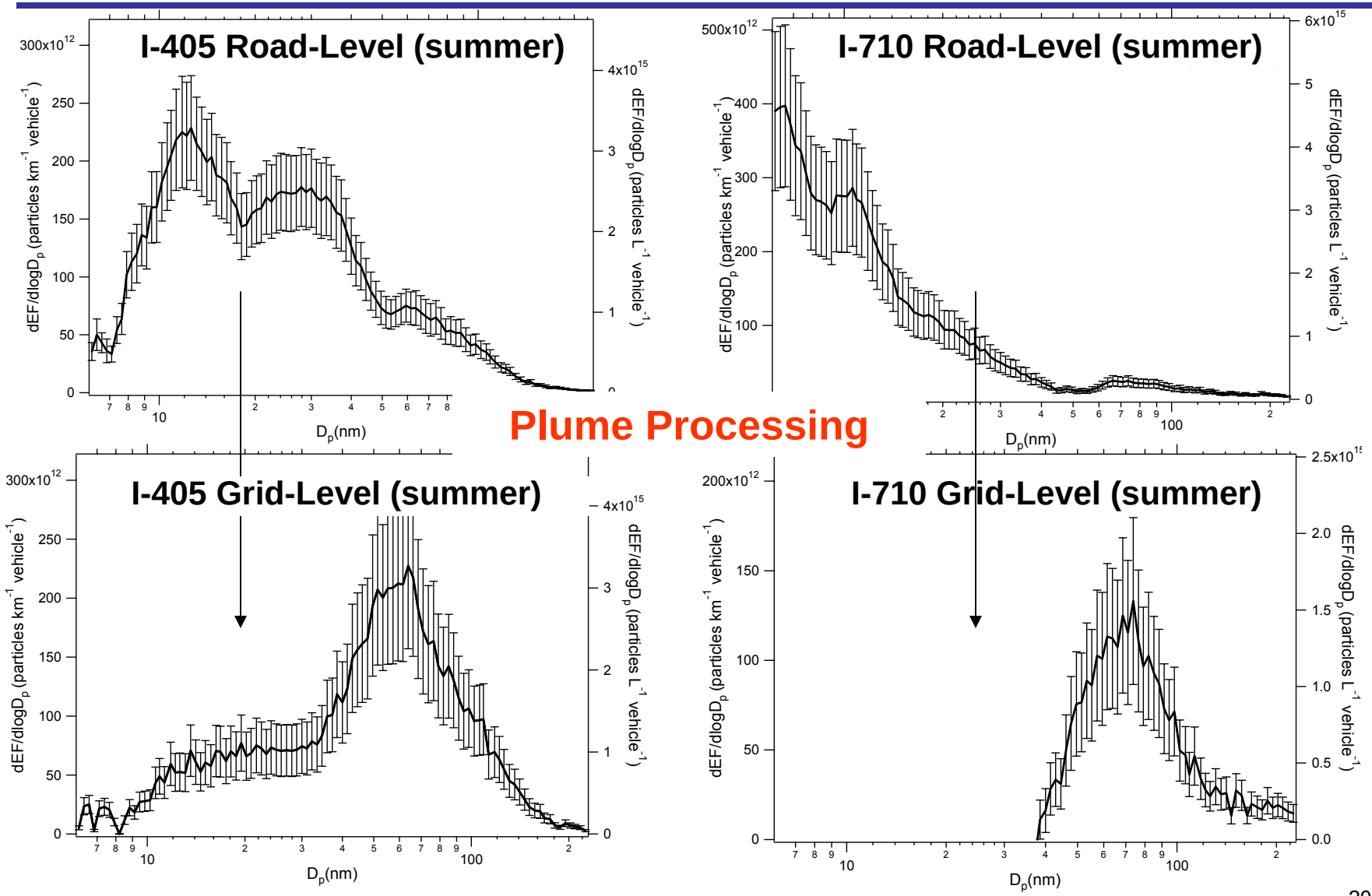




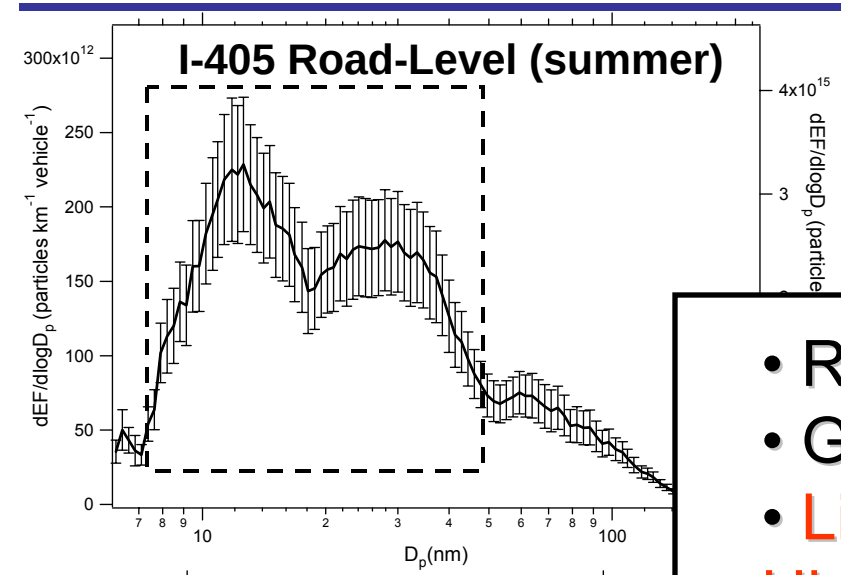


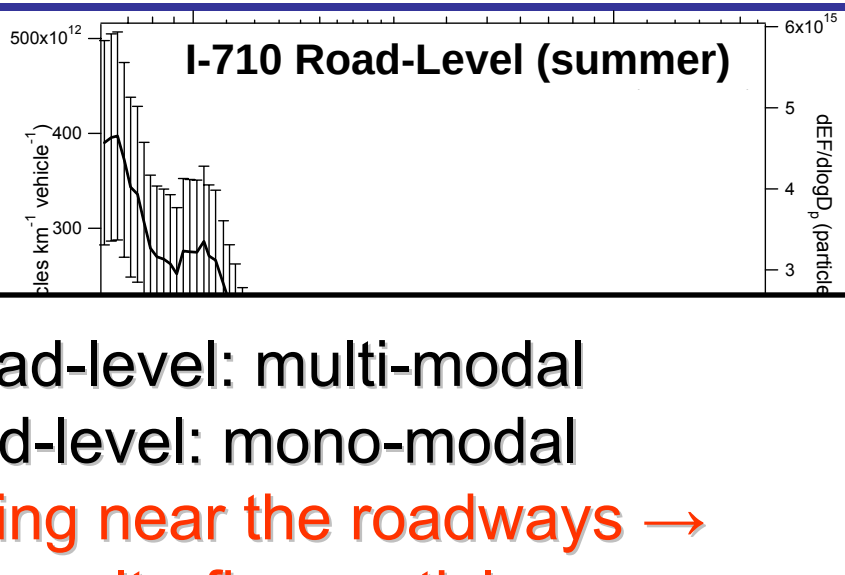


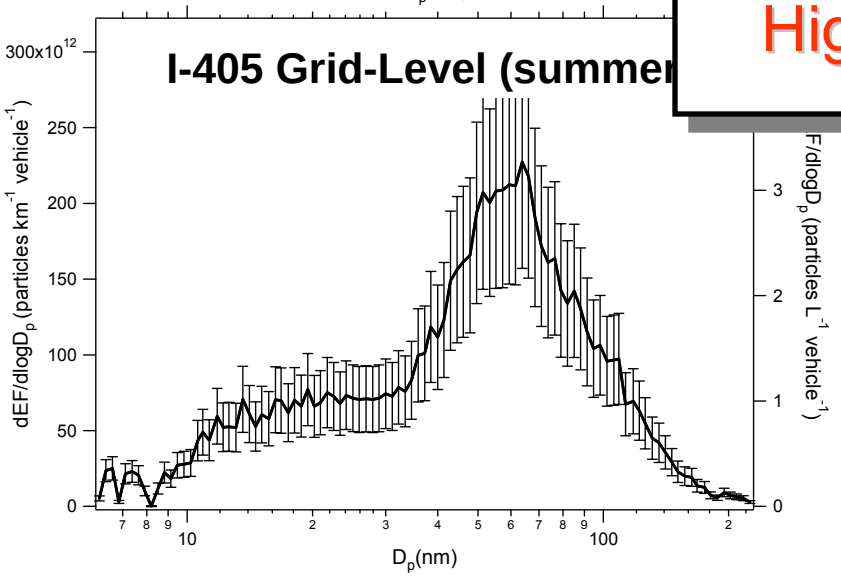
Road-Level vs. Grid-Level: I-405 (L) and I-710(R)

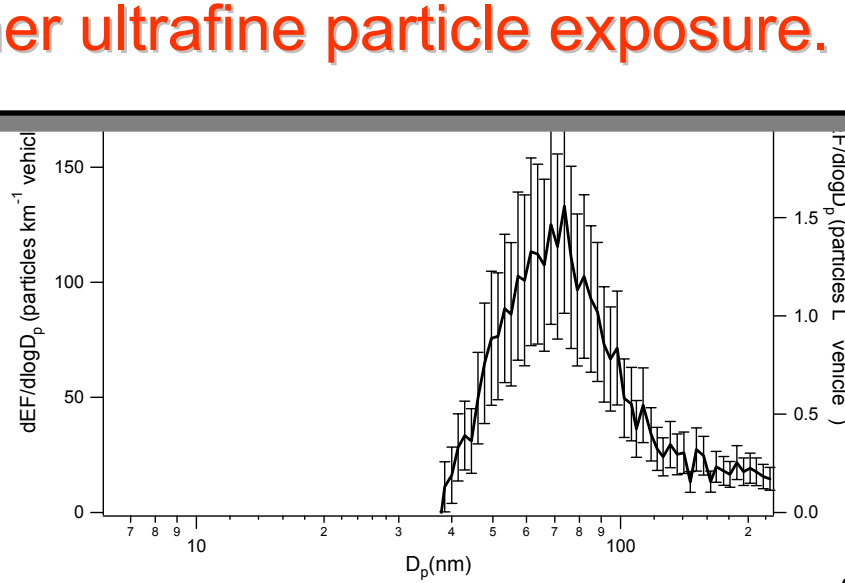


Road-Level vs. Grid-Level: I-405 (L) and I-710(R)



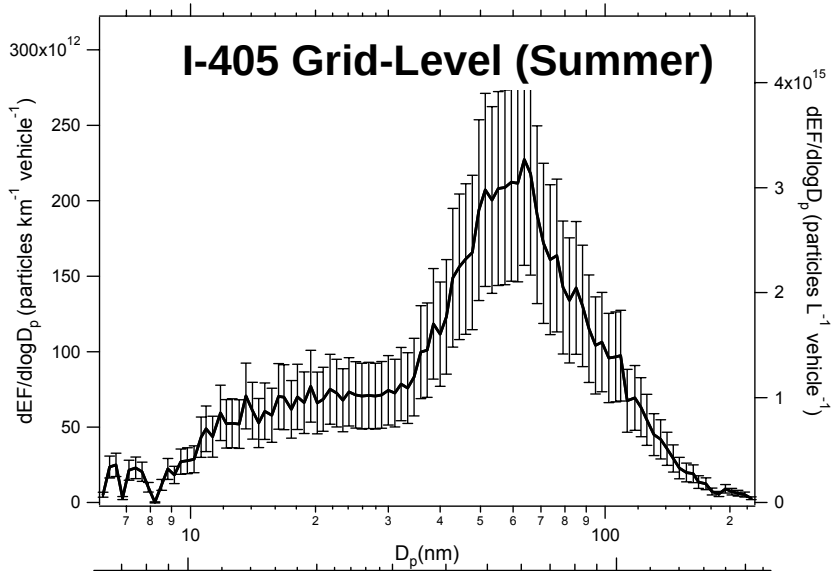


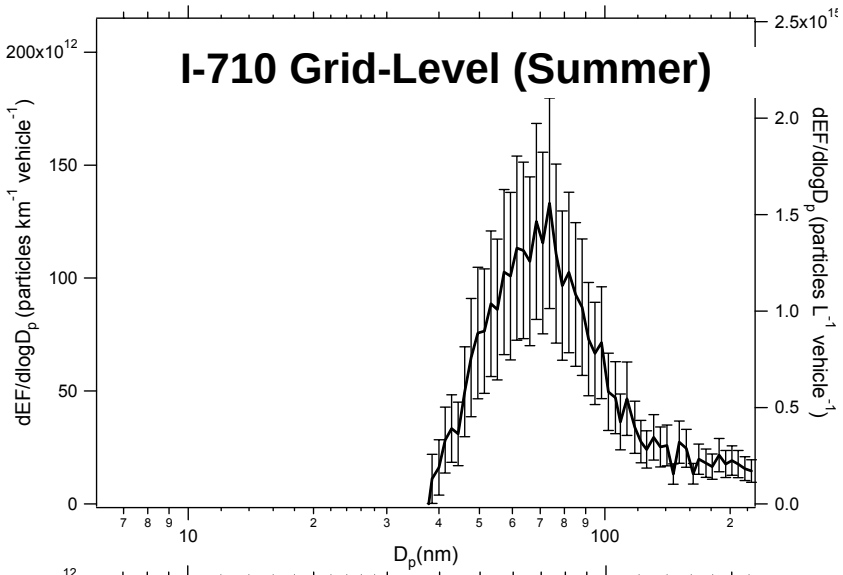


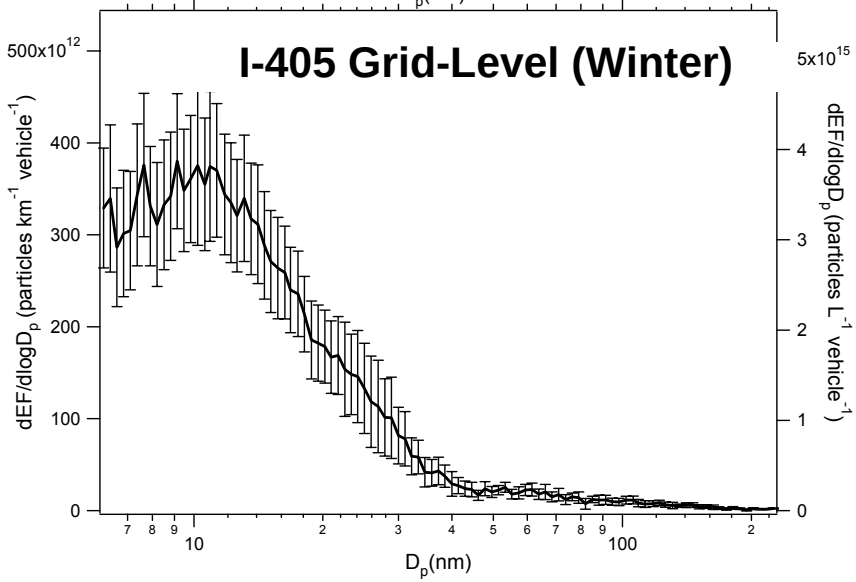


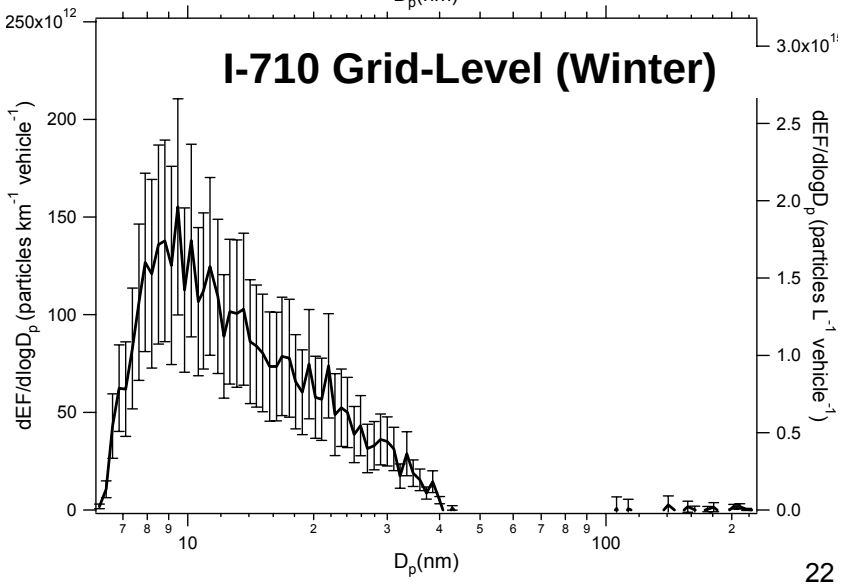
- Road-level: multi-modal
- Grid-level: mono-modal
- Living near the roadways → Higher ultrafine particle exposure.

Summer vs. Winter: I-405(R) and I-710(L)

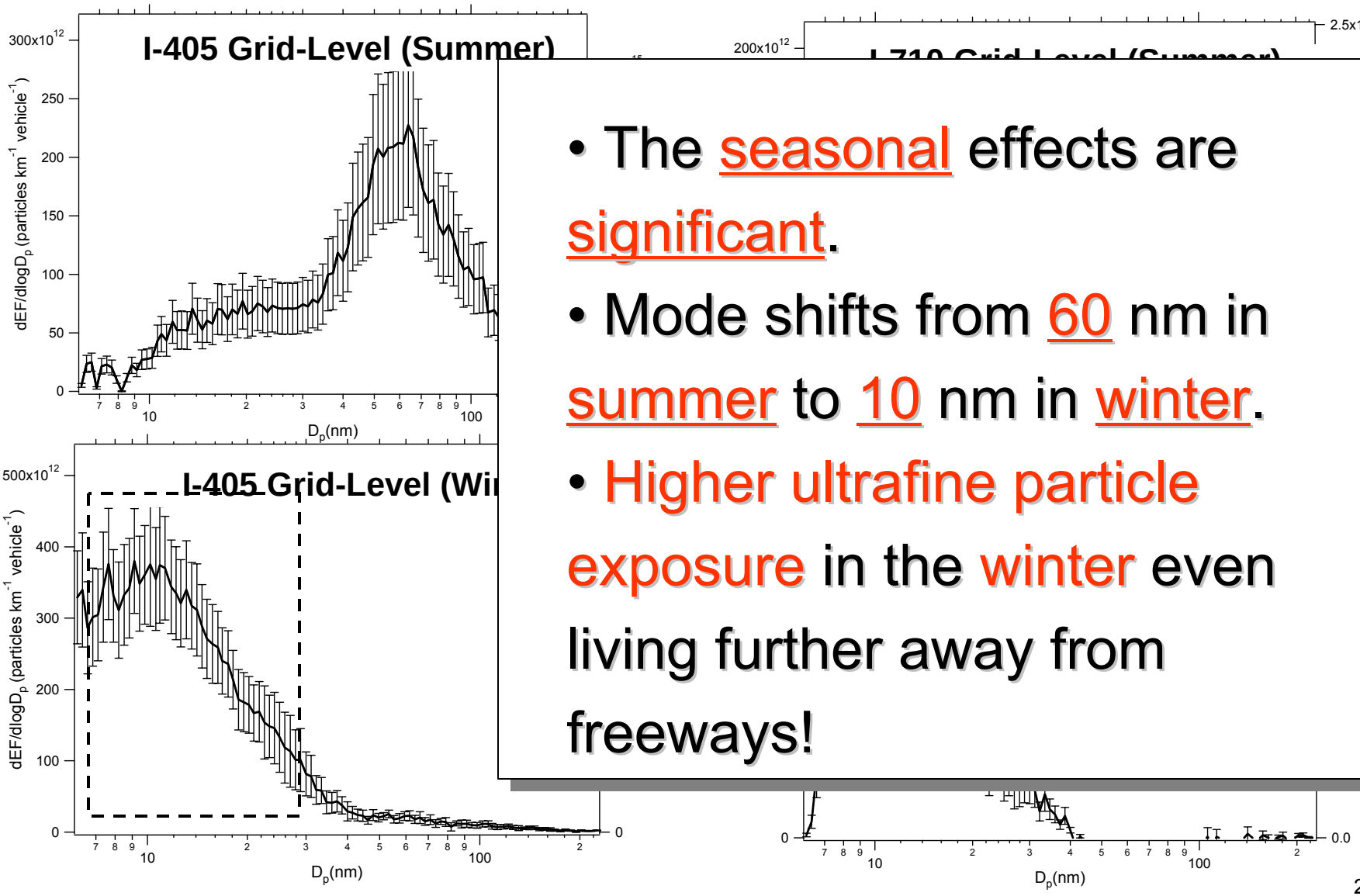






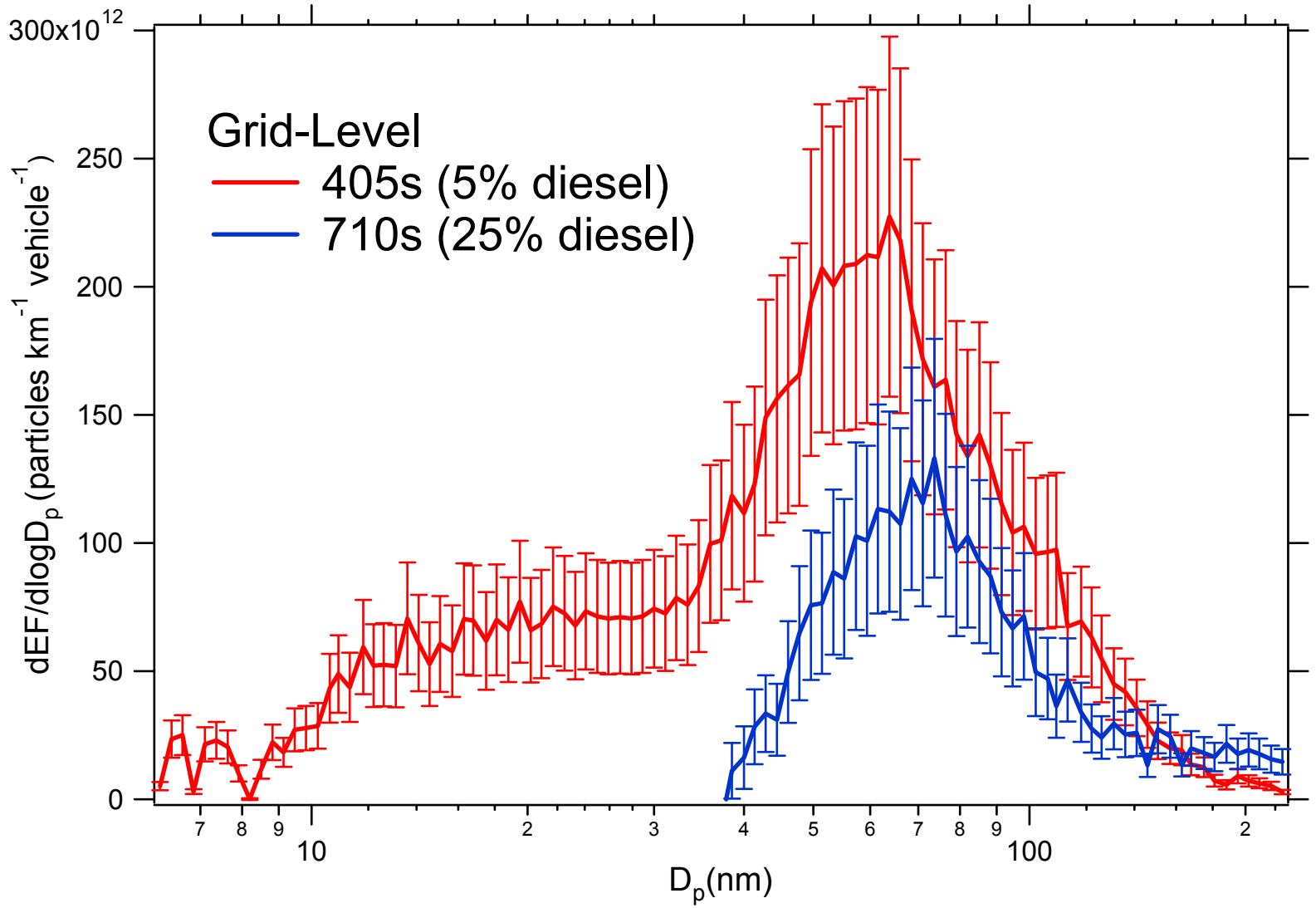


Summer vs. Winter: I-405(R) and I-710(L)



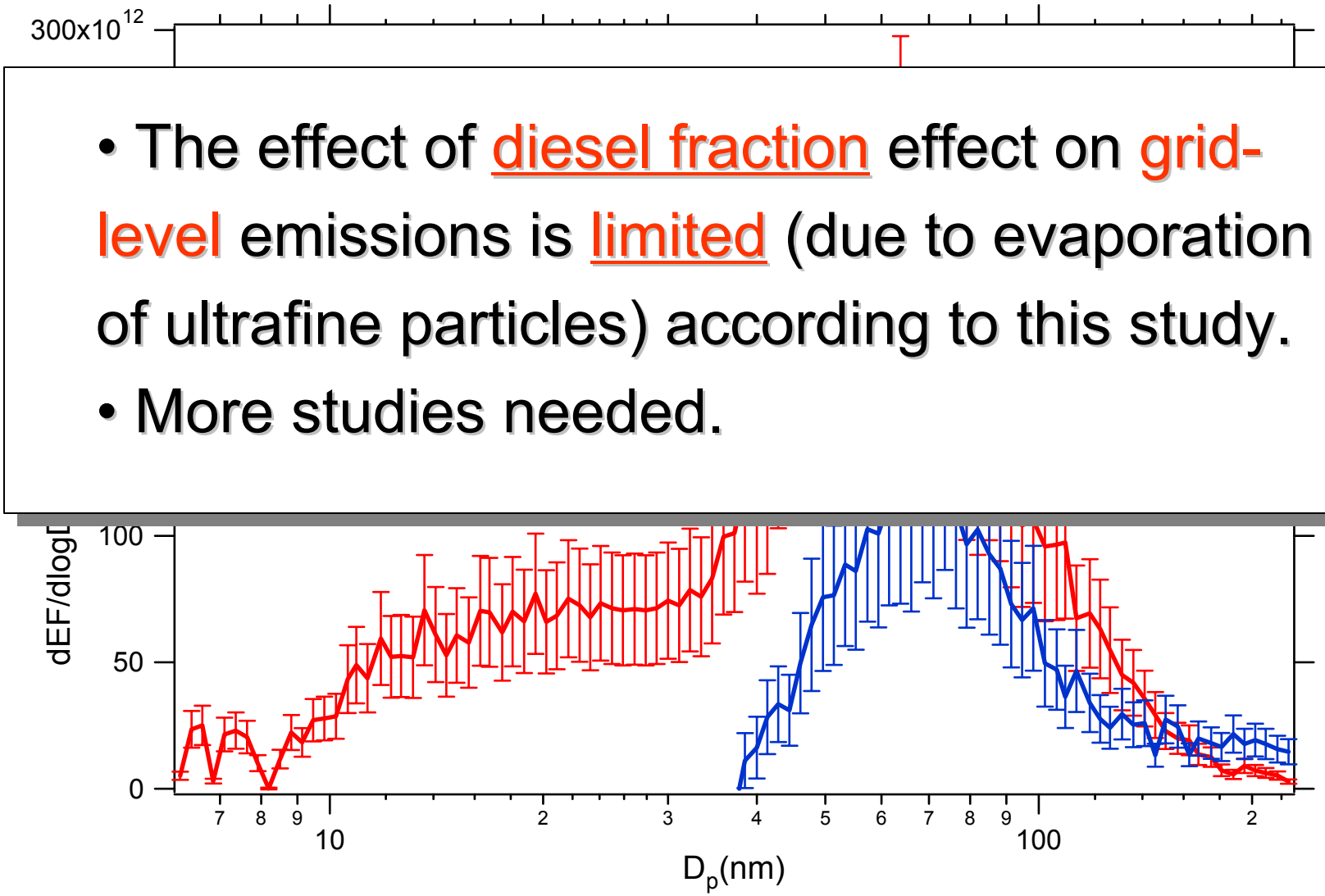
- The seasonal effects are significant.
- Mode shifts from 60 nm in summer to 10 nm in winter.
- Higher ultrafine particle exposure in the winter even living further away from freeways!

I-405 (5% diesel) vs. I-710 (25% diesel) : Grid-Level

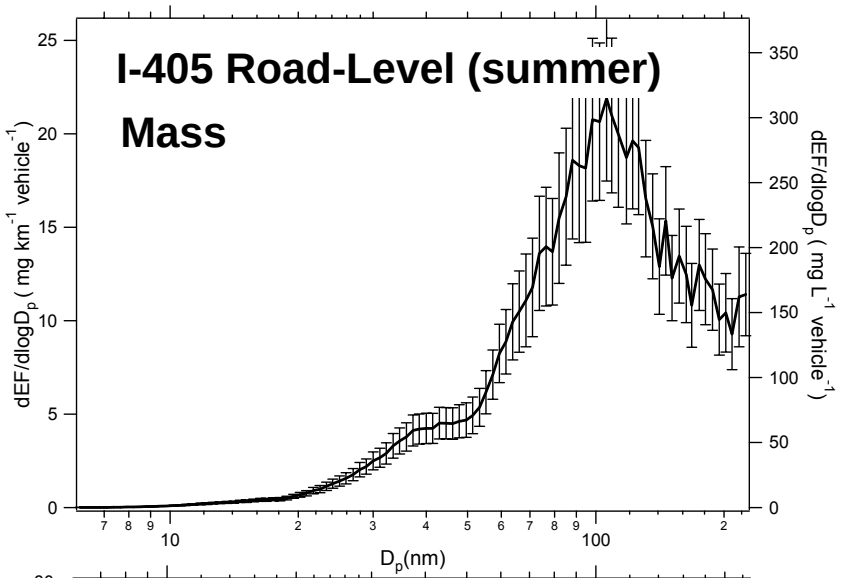


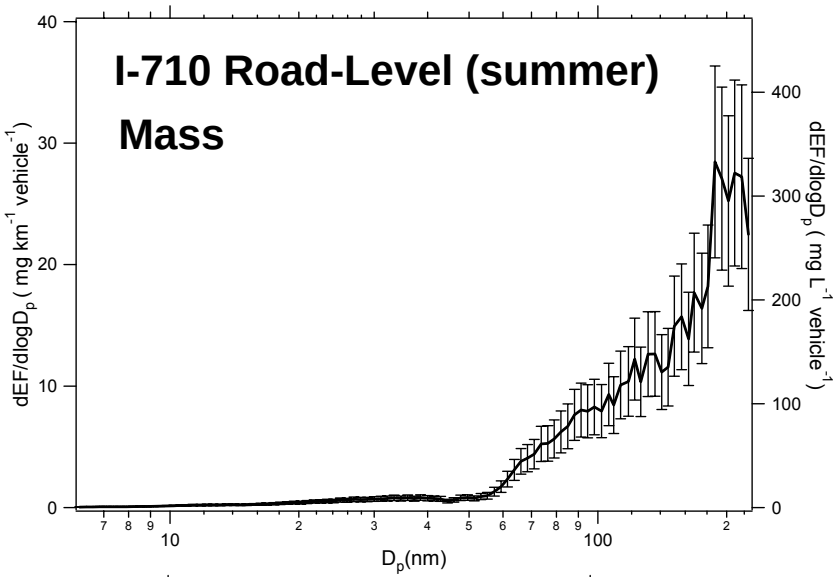
I-405 (5% diesel) vs. I-710 (25% diesel) : Grid-Level

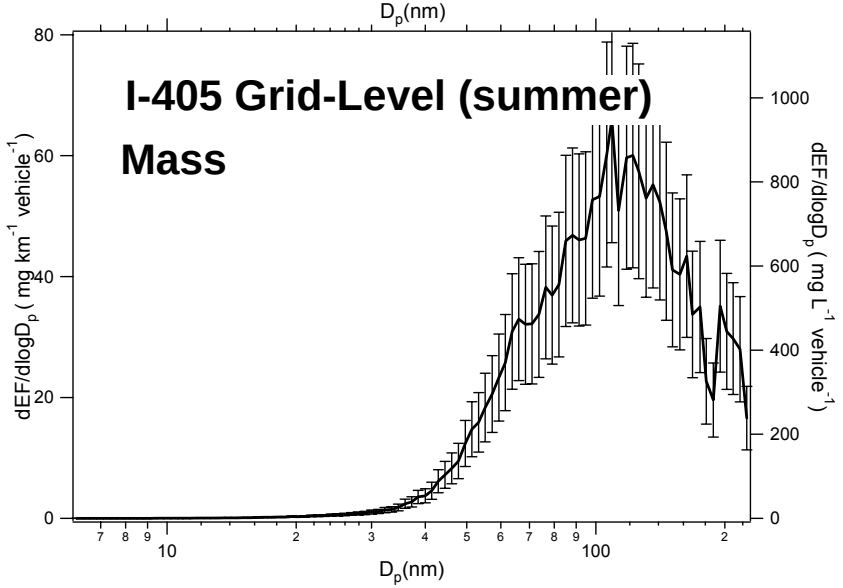
- The effect of diesel fraction effect on grid-level emissions is limited (due to evaporation of ultrafine particles) according to this study.
- More studies needed.

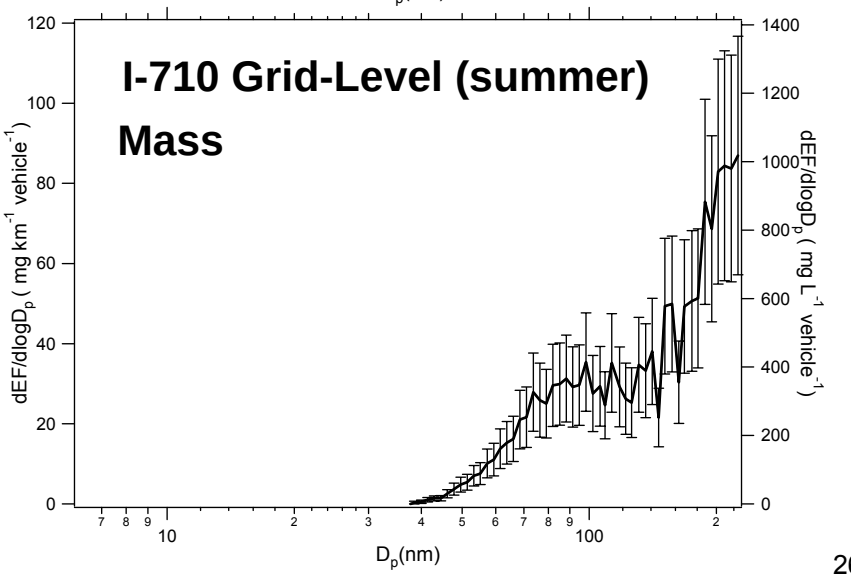


Number vs. Mass: I-405(R) and I-710(L)

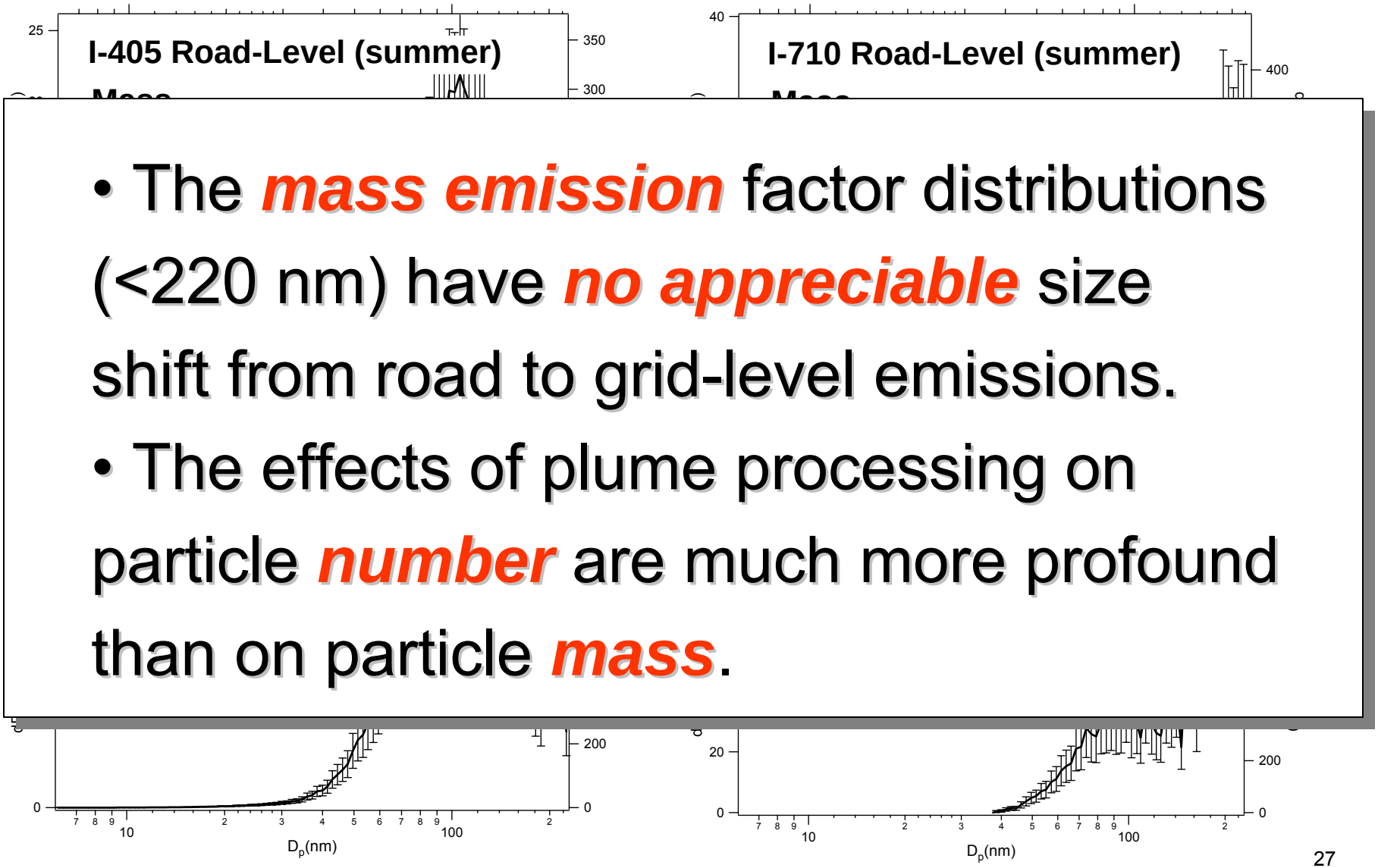






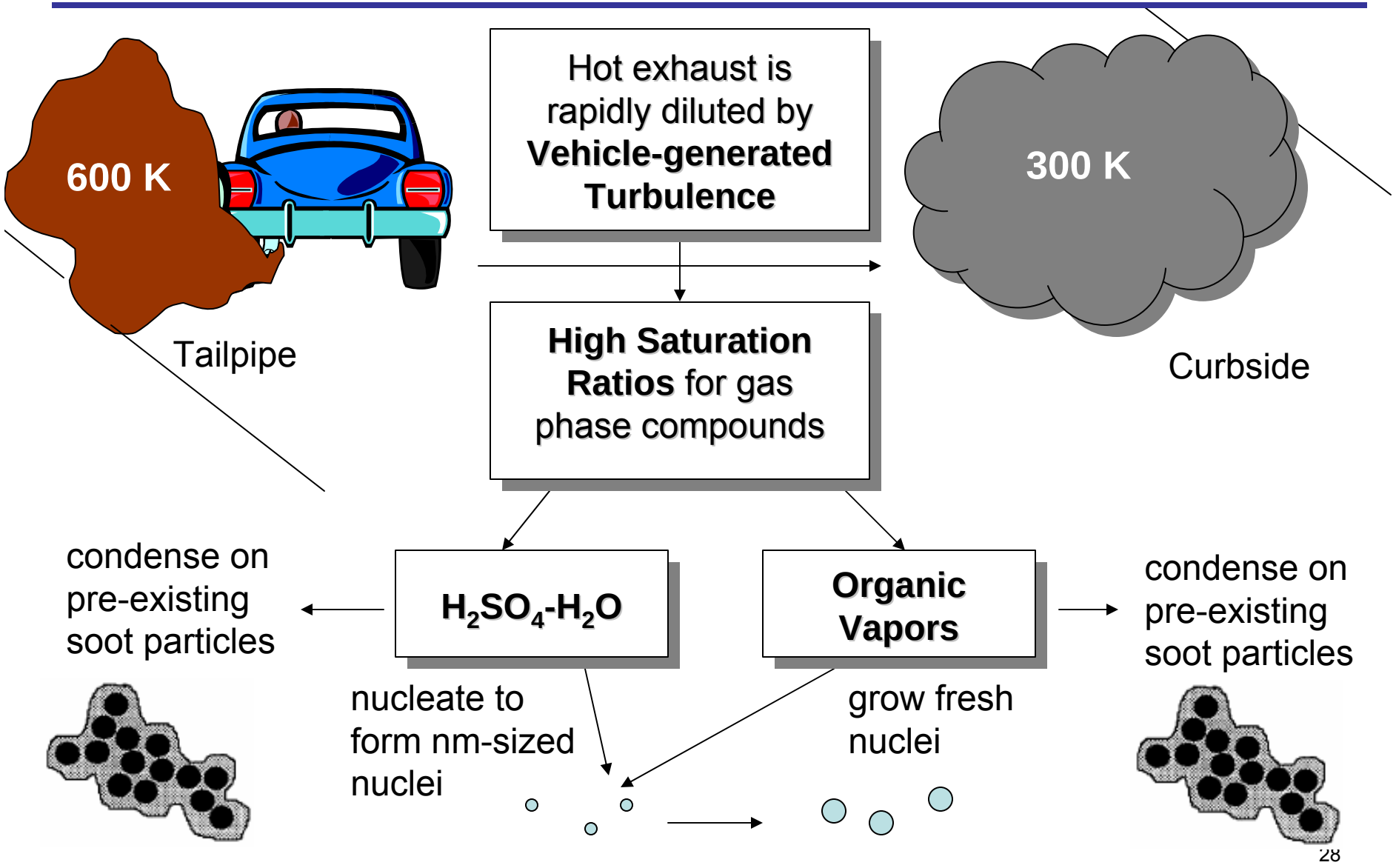


Number vs. Mass: I-405(R) and I-710(L)



- The ***mass emission*** factor distributions (<220 nm) have ***no appreciable*** size shift from road to grid-level emissions.
- The effects of plume processing on particle ***number*** are much more profound than on particle ***mass***.

How to Control Ultrafine Particles?



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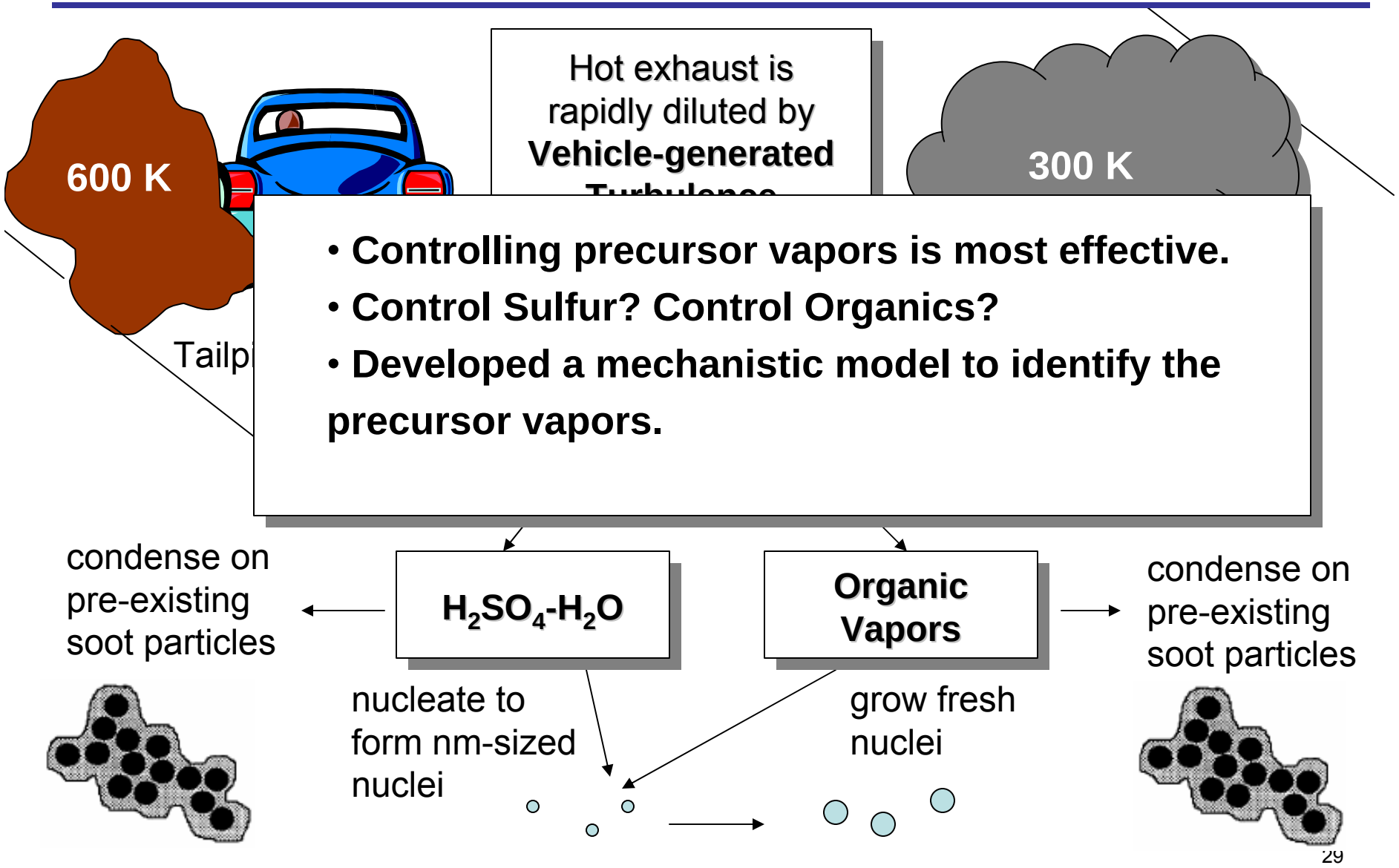


A Mechanistic Aerosol Dynamics Model for "Road-to-Ambient" Process

Road-level Emission Profiles (30 m)

Compositions

Dilution

Particle / Gas:

$$N_i^{\,j}(x) = \frac{f(x)}{f(x-\Delta x)} \cdot N_i^{\,j}(x-\Delta x)$$

f was determined by measured CO profile.

Gas/Particle Partition

Particle (Gibbs-Thompson effect and Raoult's Law):

$$\frac{dm_{i,k}^{j}}{dt} = \frac{2\pi D_k D_{p,i}^{j}\left[C_k^{\infty} - y_{i,k}^{j} C_k^{0} Ke\right]}{1+\frac{8\lambda}{\alpha D_{p,i}^{j}}}$$

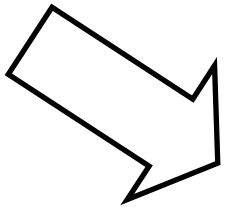
Gas:

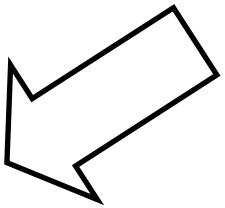
$$\frac{dC_k^{\infty}}{dt} = N_i^{\,j}\,\frac{dm_{i,k}^{j}}{dt}$$

Emission Profiles at Each Distances (60, 90 m …)

A Mechanistic Aerosol Dynamics Model for "Road-to-Ambient" Process

Road-level Emission Profiles (30 m)





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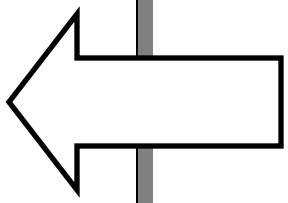
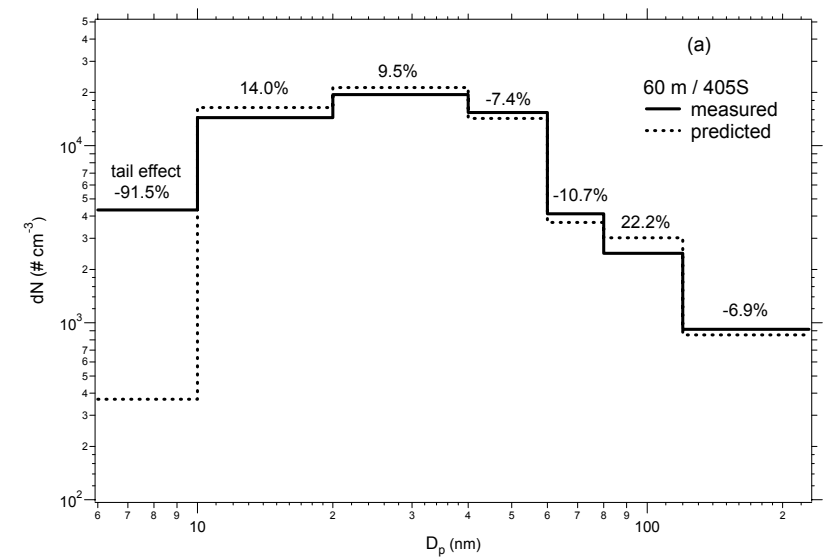
Gas:

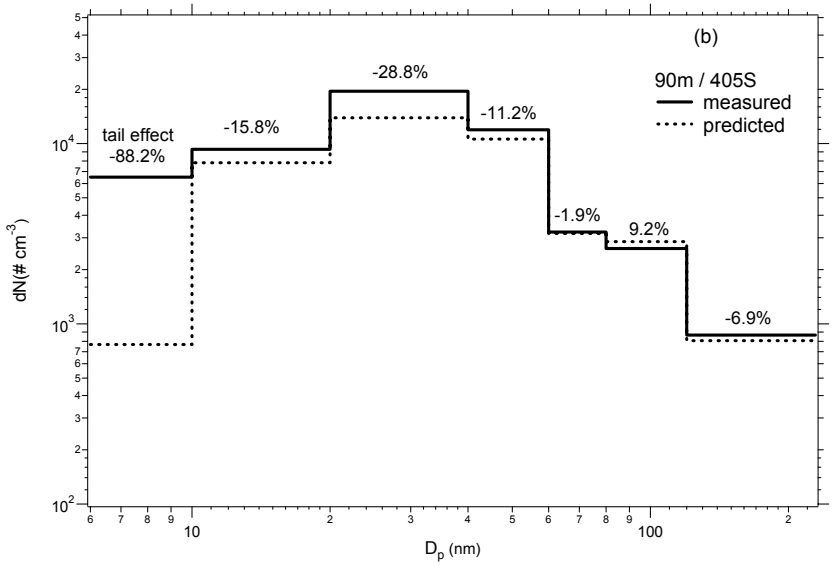
$$\frac{dC_k^{\infty}}{dt} = N_i^{\,j}\,\frac{dm_{i,k}^{j}}{dt}$$

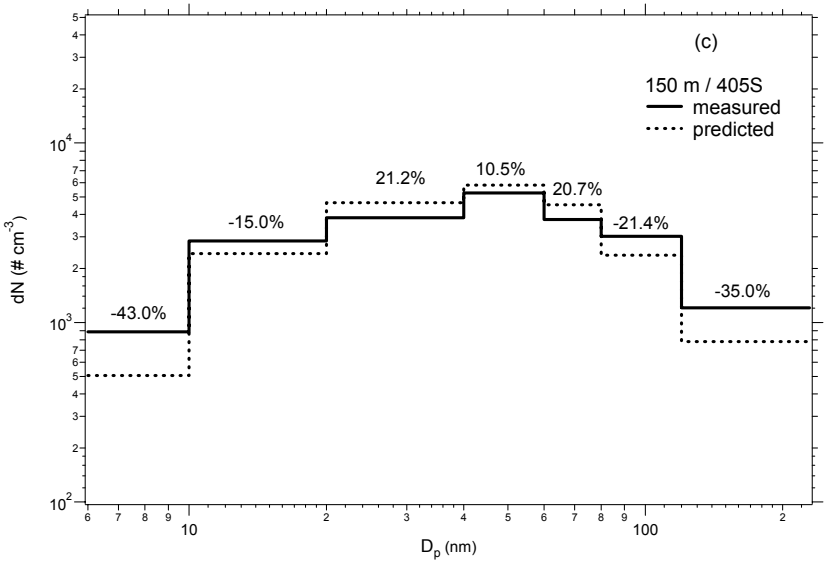


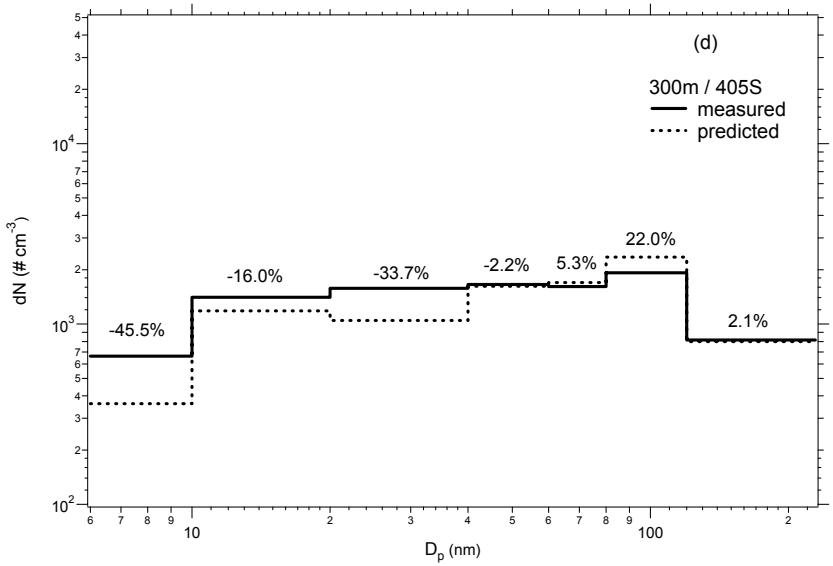
Emission Profiles at Each Distances (60, 90 m …)

Simulation Results: I-405 Summer

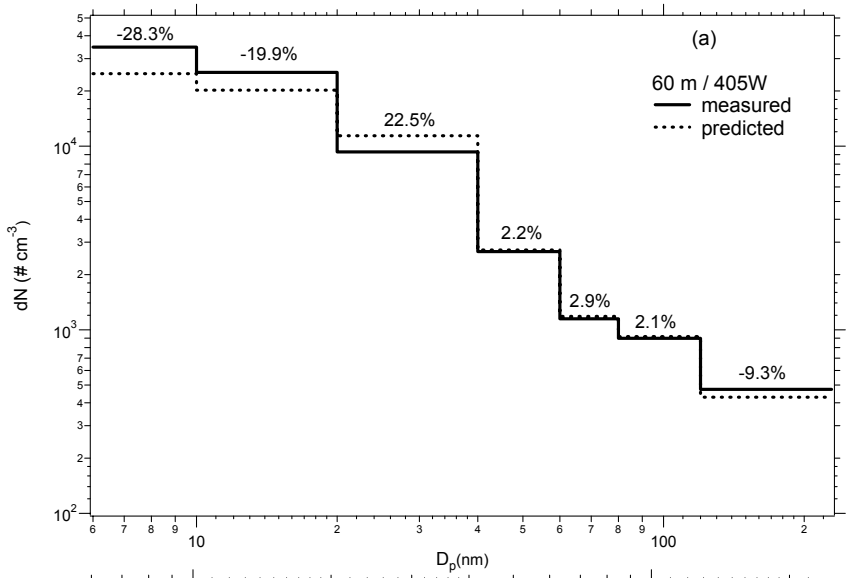


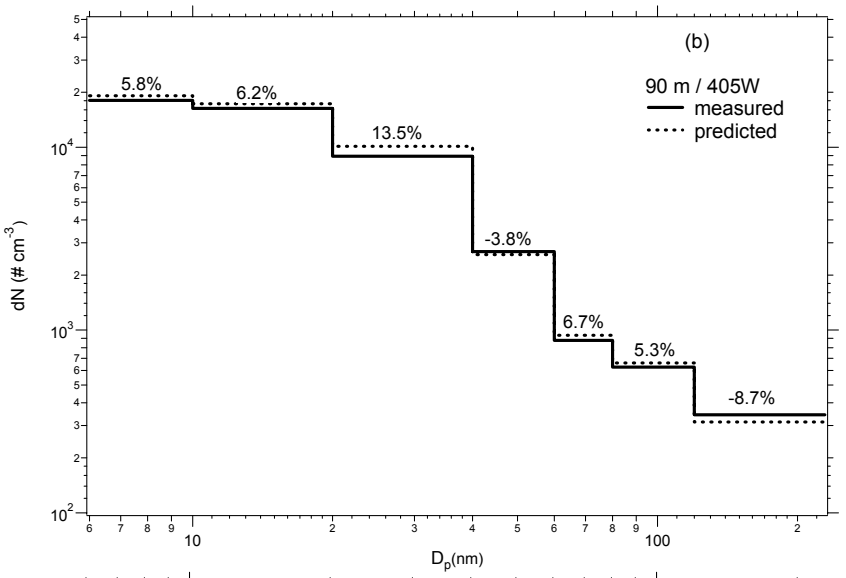


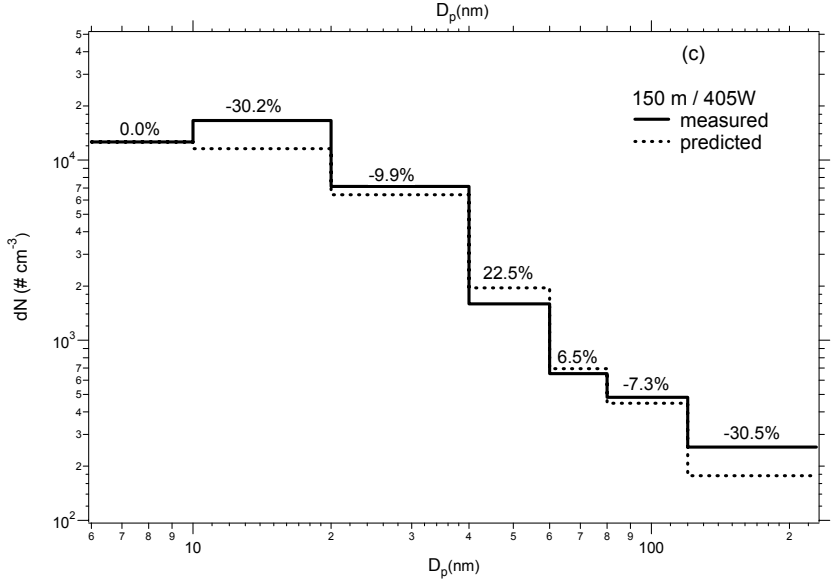


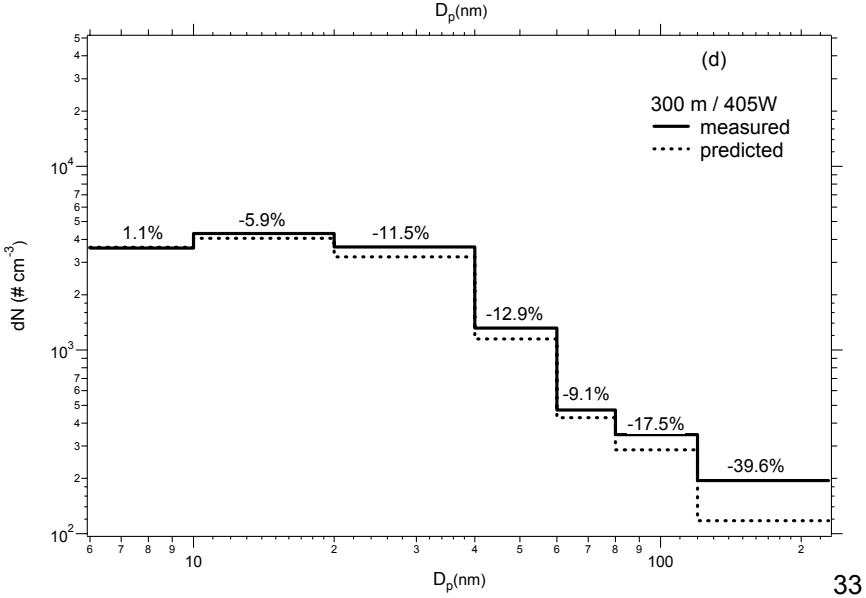


Simulation Results: I-405 Winter

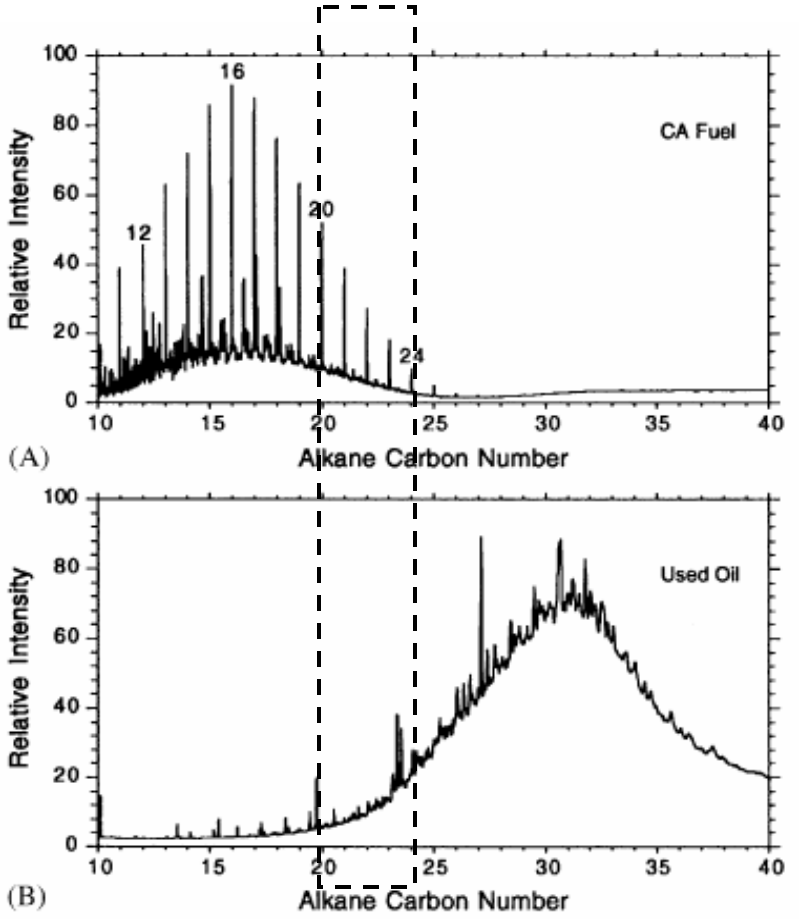








Fuel, Oil or both?



Sakurai et al.(2003)

- We identified that the precursor organic vapors have carbon number between ***20 to 24***.
- It is in the range where the largest fuel molecules and smallest lubrication oil molecules reside.
- **Fuel or Oil or Both** contribute to the ultrafine particle dynamics.

Conclusions

- Steep temperature gradient triggers New Particle Formation and Gas/Particle Partition.
- There is a competition between Condensation and New Particle Formation.
- Ultrafine Particles are volatile and their emission profiles are dynamics.
- People living near freeways have much higher ultrafine particles exposure.
- Meteorological conditions significantly affect ultrafine particle emissions.

I-405 (5% diesel) vs. I-710 (25% diesel) : Road-Level