Characterizing the Vertical Concentration Profiles of Ship Plumes with a Microscale Model – is it all Gaussian?

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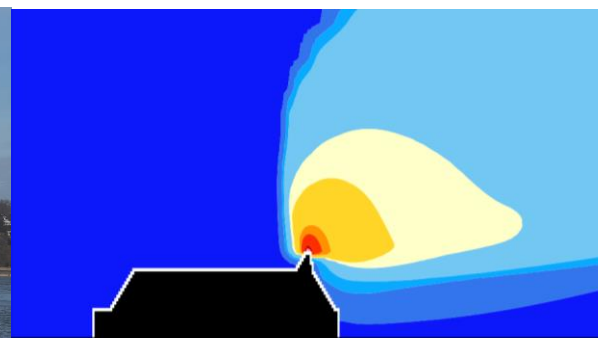

Helmholtz-Zentrum Geesthacht

Institute of Coastal Research

In cooperation with Fudan University Shanghai

Project **ShipChem**

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

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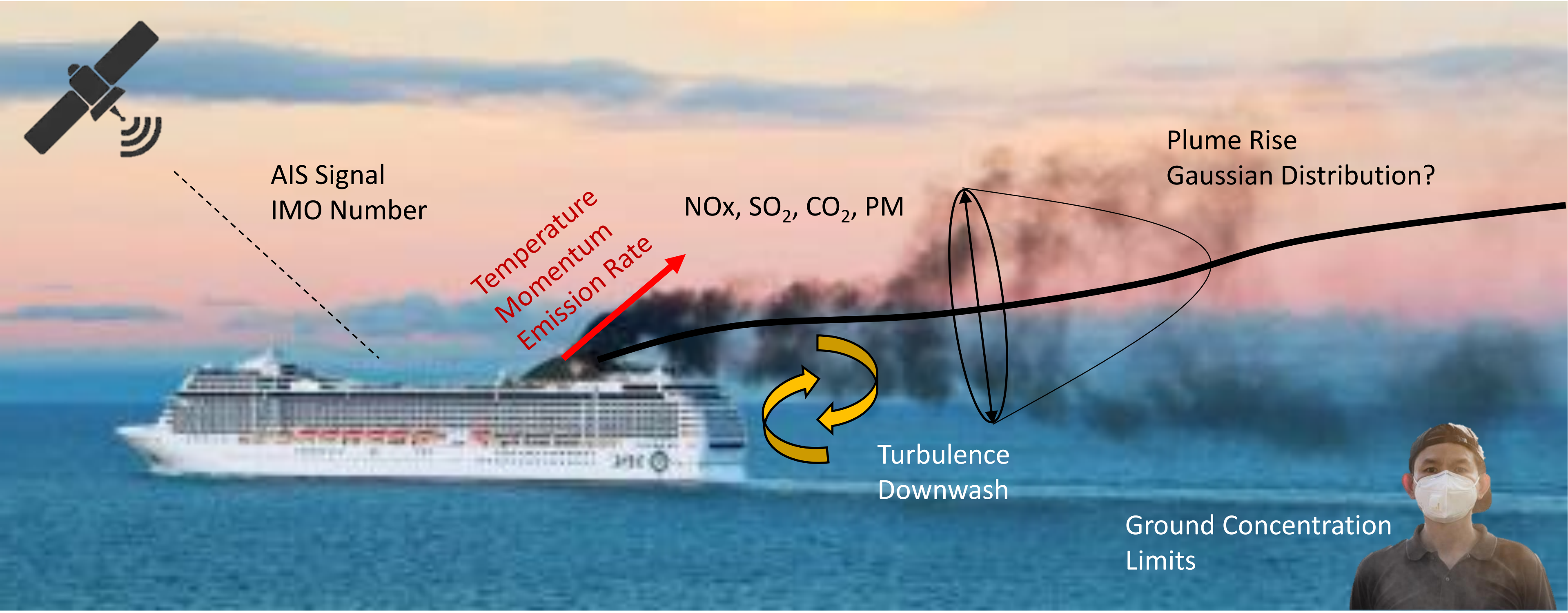
INTRODUCTION

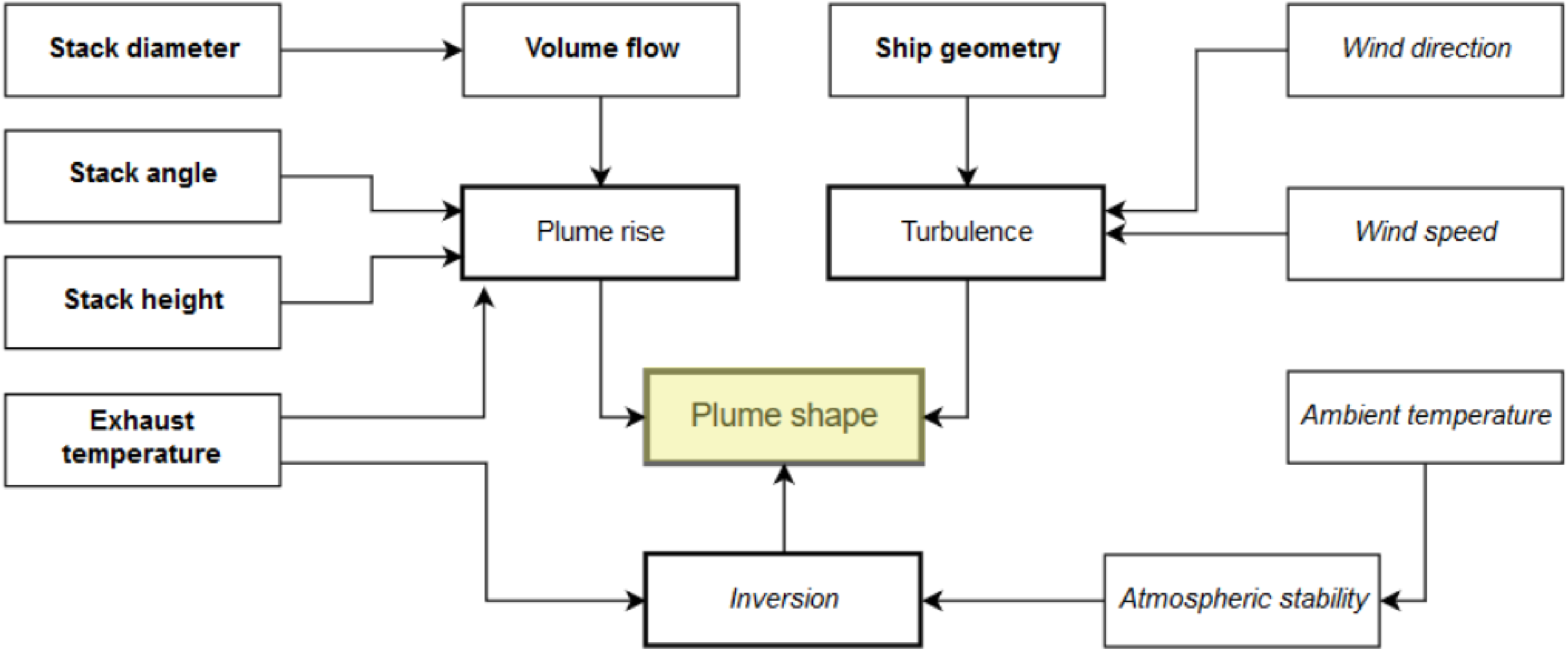
Ship Emission Impact in Harbor Areas



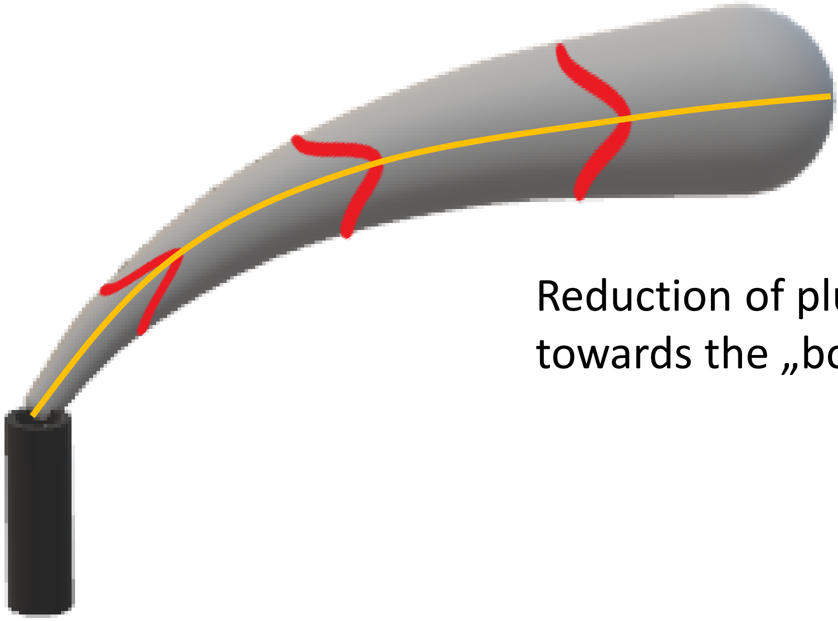
➔ Ships are often the dominant source of air pollution in port cities (e.g. Viana et al., 2014)

Image source: https://www.nabu.de/umwelt-und-ressourcen/verkehr/schifffahrt/kreuzschifffahrt/14526.html

Conceptual Model



- Many analytical plume dispersion models assume a gaussian dilution away from the plume center line



- This behavior is a rather simple assumption

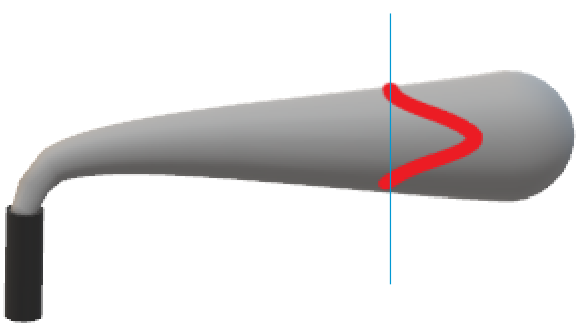
➔ It ignores turbulence effects

- How to transfer this concentration profile in a numerical grid model?

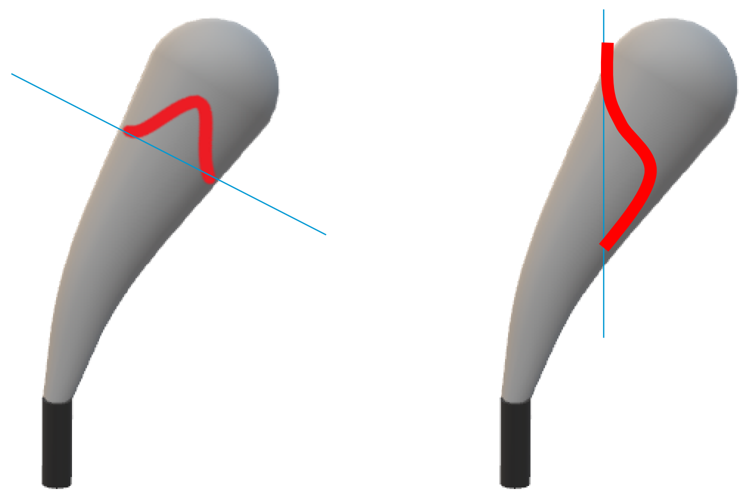
➔ Cutting **vertically** through the profile and distributing the concentration into different layers

➔ **Can we still do this with a Gaussian distribution?**

Probably yes, in case of strong horizontal wind speeds



Probably not in case of strong plume rise



- Improve the ship plume emission and transport modeling in city-scale models

➔ **Plume Rise & Downwash**

➔ **Vertical Concentration Distribution**

- Gather these information with the help of a microscale model

➔ **Plume Parameterization**

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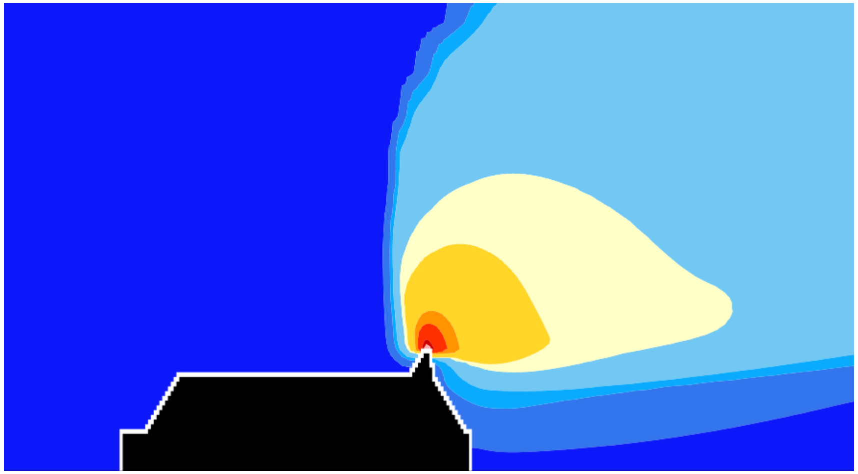
- Numerical 3D modeling of meteorological parameters, concentration, etc.

- High resolution of
1 m * 1 m * 1 m possible

- Obstacle resolving
➔ considers object-induced turbulence

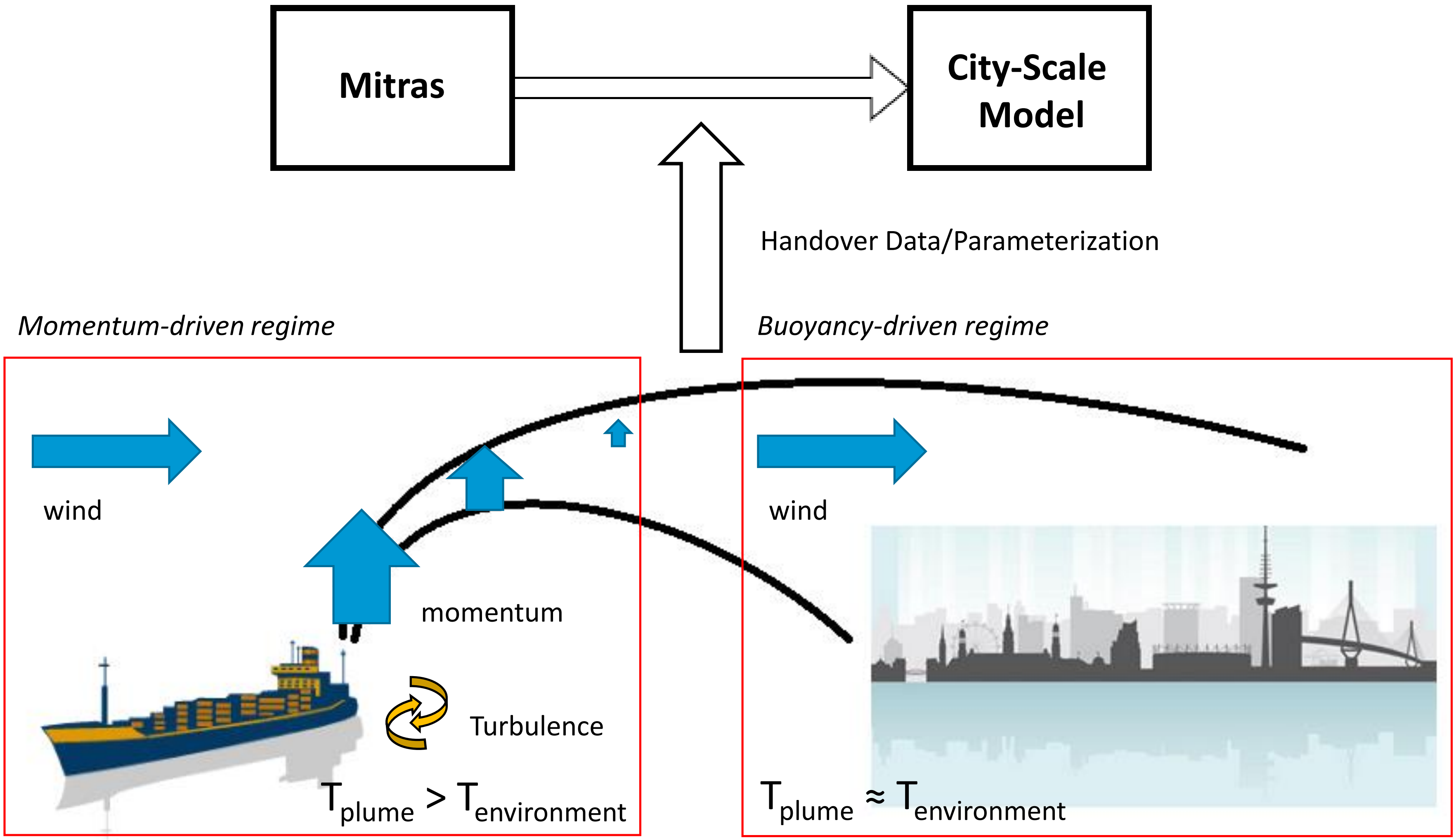
Equations:

- Navier-Stokes Equation
- Continuity Equation
- Conservation Equation for scalar quantities



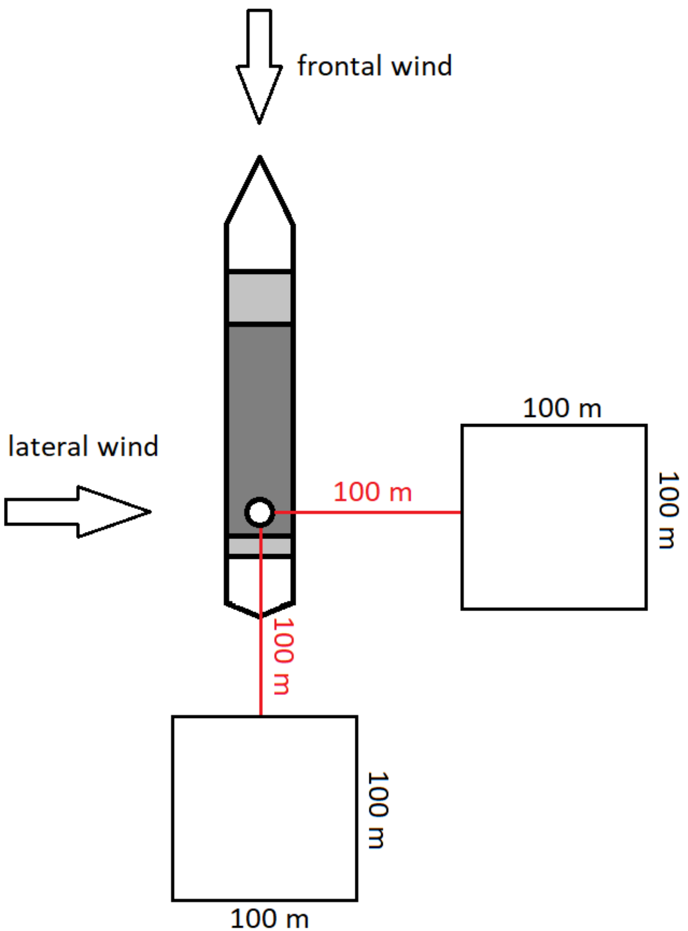
METHODS

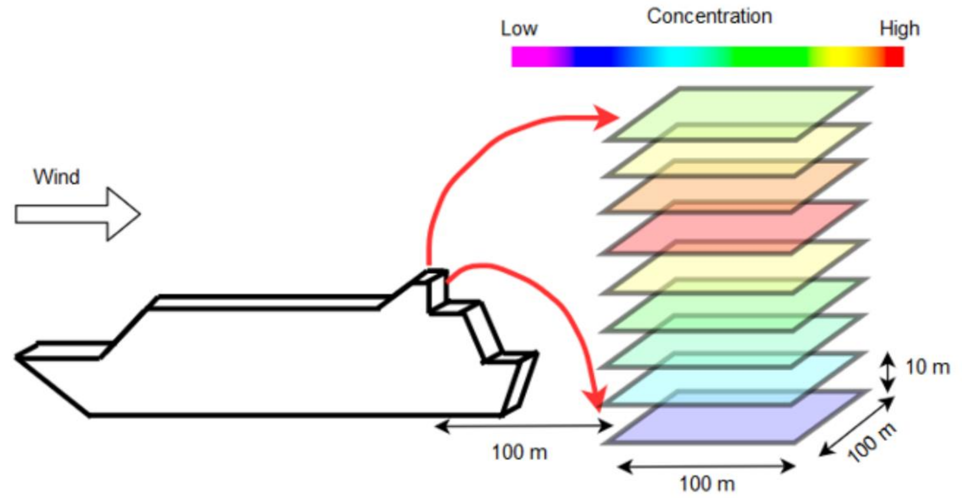
Model Chain



METHODS

Distribution of Concentration Values



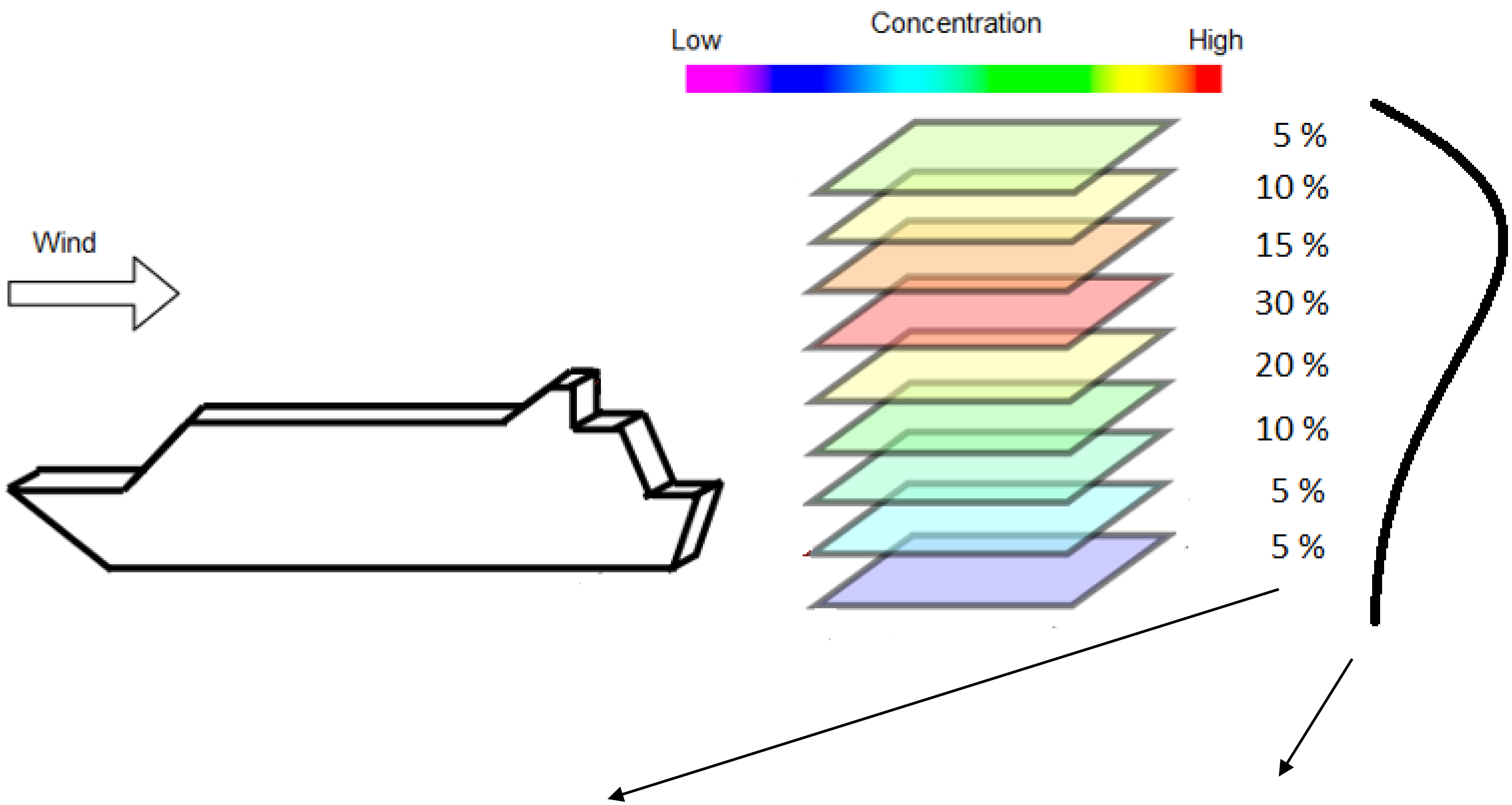


- Concentration values are calculated at a distance of 100 m from the ship (outside the momentum-driven regime)

- Values are layer averages of a 100 m * 100 m column
  ➔ allows for direct integration into a city-scale model of similar resolution

Distribution of Concentration Values

Distribute emmited concentration into several vertical layers…



… with calculated microscale model data
➔ Time consuming

… with a parameterized vertical concentration profile

RESULTS

Gaussian Fit

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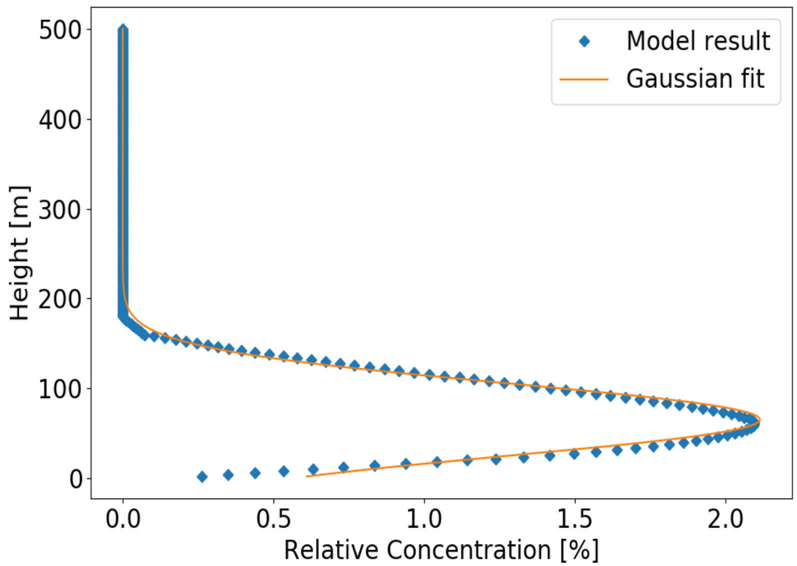
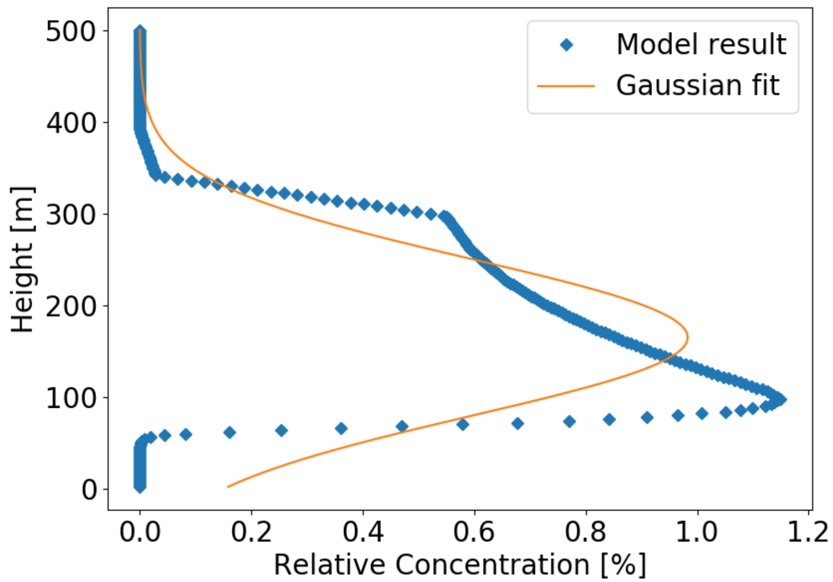
Low plume rise example

8 m/s wind speed
4 m/s exhaust speed
200°C exhaust temperature
lateral wind
R^2 = 0.99



High plume rise example

2 m/s wind
10 m/s exhaust speed
400°C exhaust temperature
frontal wind
R^2 = 0.80



Fitting procedure: Least Square Minimization with the Levenberg-Marquardt Algorithm

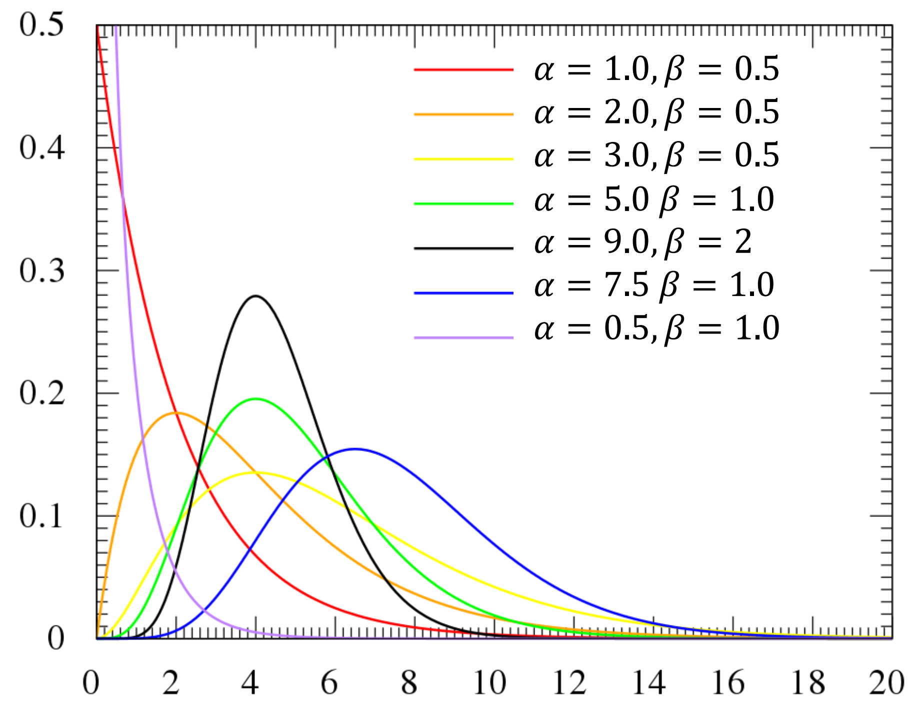
RESULTS

Gamma Distribution

$$f(x) = m \cdot \frac{\beta^{\alpha} x^{\alpha-1} e^{-\beta x}}{\Gamma(\alpha)} + n$$

$$\Gamma(\alpha) = (\alpha - 1)!$$

- The shape of the Gamma distribution seems to represent the high plume rise example better (e.g. orange curve right)

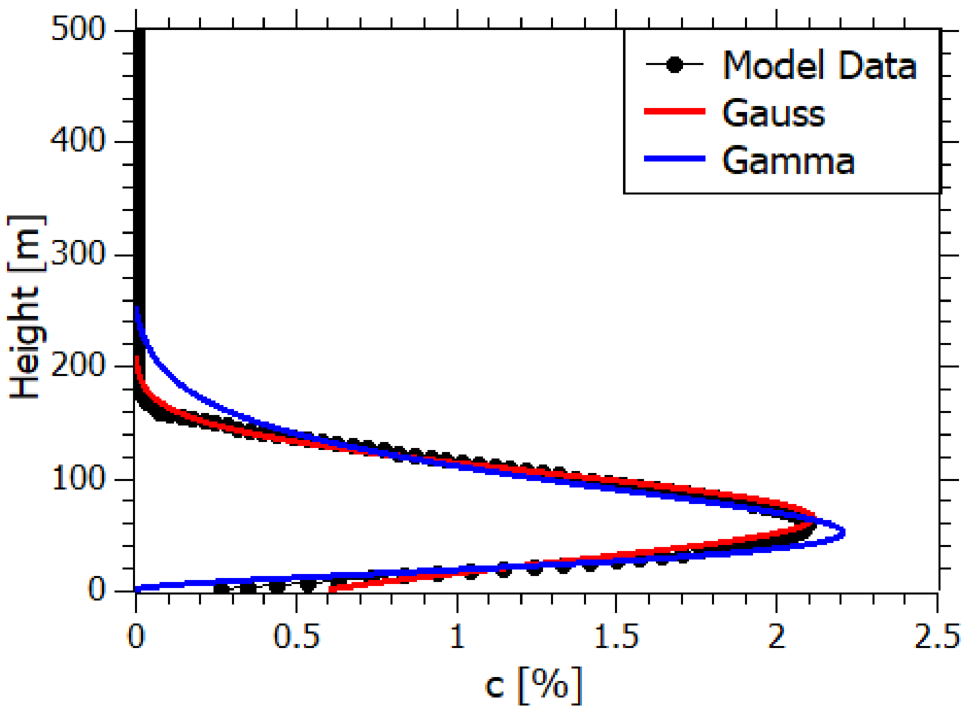


Probability Density Functions of the Gamma Distribution for different scale parameters (α) and rate parameters (β) (after https://en.wikipedia.org/wiki/Gamma_distribution)

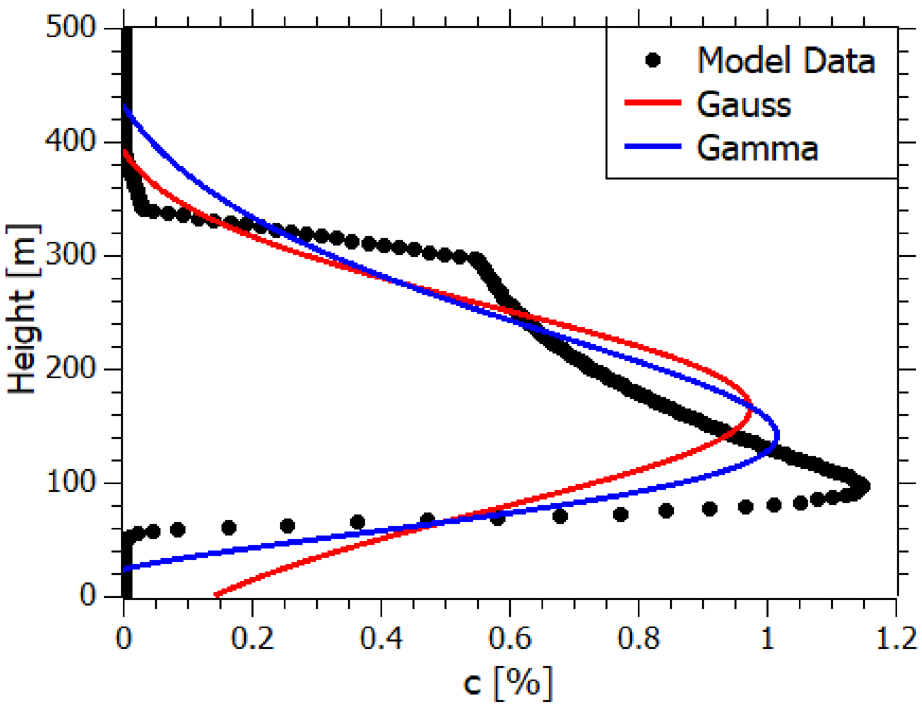
RESULTS

Gaussian vs. Gamma Fit

Low plume rise example
Gauss: **$R^2 = 0.99$**
Gamma: $R^2 = 0.98$



High plume rise example
Gauss: $R^2 = 0.8$
Gamma: **$R^2 = 0.9$**



CONCLUSION & OUTLOOK

- Microscale models are a powerful, yet time-consuming tool to improve plume characterizations for city-scale models
- Gaussian distribution can be used to describe the concentration profile under low plume-rise conditions
- Under high plume-rise conditions, the vertical concentration profile can be better described by a Gamma distribution
- **Next steps:**
  - Parameterize the scale and shape parameters for the Gamma distribution depending on different input parameters (e.g. by multilinear regression analysis) with the help of microscale model results
  - Use the parameterization in city-scale model runs