Microscale Ship Plume Dispersion Modeling for Harbor Areas

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Project ShipChem

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INTRODUCTION

Key Challenges of Ship Emission Modeling

Ship Emissions

- Ozone Concentration
- Smog
- Acid Deposition

Air Quality

- Reduction of Visibility

Human Health

- Premature Deaths
- Cardiopulmonary Diseases
- Lung Cancer

Climate Change

- GHG Emission
- Scattering
- Absorption
- Radiation Balance
- Altering Cloud Properties

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INTRODUCTION

Population Density of Hamburg

Population Density

- 0 - 570 people per sq km
- 570 - 6,800 people per sq km
- 6,800 - 13,100 people per sq km
- 13,100 - 15,400 people per sq km
- 15,400 - 600,000 people per sq km

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INTRODUCTION

Conceptual Model

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Conceptual Model

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Aims of the research

- Improve the ship plume emission and transport modeling in city-scale models
  ➔ Plume rise
  ➔ Turbulence

- Connecting Microscale and City-scale models
  ➔ Handover values for vertical concentration profiles
METHODS

Model Chain

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METHODS
Model Chain

PLURIS \rightarrow \text{Plume Rise} \rightarrow \text{EPISODE-CityChem}

Momentum-driven regime

Buoyancy-driven regime

Handover point

$T_{\text{plume}} > T_{\text{environment}}$

$T_{\text{plume}} \approx T_{\text{environment}}$

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METHODS
PLURIS

- Analytical solution of bent-over plumes by integral modeling
- Conservation of:
  - mass
  - momentum
  - energy
  - scalar quantities (e.g. T, c)
- Parametrization of entrainment function
RESULTS

PLURIS

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RESULTS
Calculation of Handover Values

Handover Criteria:
• Plume dispersion is dominated by buoyancy
• Plume temperature equals surrounding temperature

CityChem vertical layers
\[ v_{\text{wind}} = 5 \text{ m/s} \]
\[ v_{\text{plume}} = 10 \text{ m/s} \]
\[ T_{\text{air}} = 15 ^\circ \text{C} \]
\[ T_{\text{plume}} = 200 ^\circ \text{C} \]
\[ \text{Emission: 25 kg/h} \]
RESULTS
Dependency on Stack Height

K. Reinck

Microscale Ship Plume Dispersion Modeling for Harbor Areas
Numerical 3D modeling of meteorological parameters, concentration, etc.

High resolution of $1\,m \times 1\,m \times 1\,m$ possible

Obstacle resolving ➔ considers object-induced turbulence

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

Salim et al. (2018)
OUTLOOK

Model Chain

Microscale Ship Plume Dispersion Modeling for Harbor Areas
$v_{\text{wind}} = 5\ \text{m/s}$  
$v_{\text{plume}} = 10\ \text{m/s}$

$T_{\text{air}} = 15\ ^\circ\text{C}$  
Emission: 20 kg/h

$T_{\text{plume}} = 200\ ^\circ\text{C}$
What we want to do:

- Include (photo-)chemical transformation
  - $\text{NO}_x + \text{O}_3$
  - $\text{SO}_2$
  - PM2.5
- Simulate real situations and compare model results with measurements

What we need:

- Ship-specific data
  - Number of stacks, engine type, engine power use
  - Emission data (chemical composition, emission rate)
- Close collaboration between measurement groups and (other) modelers (CFD, LES)
REFERENCES


