Modeling subgrid scale variability in pollutant concentration due to heterogeneous urban emission

Myrto Valari\textsuperscript{1} and Vlad Isakov\textsuperscript{2}

\textsuperscript{1}NRC Post Doc at US Environmental Protection Agency
\textsuperscript{2}US Environmental Protection Agency
Specificities of the modeling approach

- **Urban** air-quality: anthropogenically driven
- **Exposure** estimates: 1 km and below
- **Health impact**: assess correlation with health outcomes

**AQ network**: limited spatial representativeness

**AQ models**: resolution limits

Residential

Busy road
Conceptually

Emissions

\[ C = \frac{\sum \text{Moles}_i}{\sum \text{Area}_i} \]

CTM world

'dead' world

Concentrations

\[ c_1 \quad c_2 \quad c_3 \]
The model

- Force the CTM with local emission terms

\[ E_i = E + E' \]

\[ \bar{E} = \sum_{i=1}^{N} a_i \cdot E_i \]

with \( a_i \) some parameter of the subgrid distribution, such as landuse

- Advection, diffusion, chemical transformations etc. act on the ‘perturbation’

- CTM model ‘local’ concentrations \( \bar{C}_i \) along with \( \bar{C} = \sum_{i=1}^{N} a_i \cdot C_i \)

\[ \frac{\partial c_i}{\partial t} + \bar{U}_j \frac{\partial c_i}{\partial x_j} = - \frac{\partial (u'_j c')}{\partial x_j} + E_i + P(\bar{c}_i) + L(\bar{c}_i) \cdot \bar{c}_i - \frac{(c_i - \bar{c})}{T_{mix}} \]

local emission

local concentration

subgrid mixing (implicit)
The downscaling approach here is **hybrid**: 

**Explicit**: because direct downscaling towards 1 km

**Statistical**: because of emission allocation

**Implicit**: because of the subgrid mixing term (not yet implemented)
Downscaling from 12km...

East US

Georgia

12km x 12km
How close?

Issues raised:
- Uncertainties in the input
- Parameterization limitations
- Unknown subgrid processes
- Model evaluation issues
Typical emission model (SMOKE) output (or CTM input)

All sources included NOx emissions (8a.m. LT)

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Explicit:

Statistical:

• **add** subgrid-scale information
• calculate grid **distribution**

Subgrid-areas or ‘micro-environments’:

1. On-roads
2. Residential (heating)
3. Commercial areas
4. Industrial areas
5. Recreational areas (parks, golf courses...)
Add subgrid scale information

Population
census block

Residential heating

m²/census tract

Road miles

Commercial
Grid distributions: 1 km grid ratios

**Roads**
- Max ≈ 17%
- Median ≈ 2%

**Residential**
- Max ≈ 0.2%
- Median ≈ 0.006%

**Commercial**
- Max ≈ 0.6%
- Median ≈ 0.006%

**Industrial**
- Max ≈ 0.4%
- Median ≈ 0.004%

**Recreational**
- Max ≈ 100%
- Median ≈ 33%
Source-specific emissions (NOx at noon)

- Roads: µg s\(^{-1}\)m\(^{-2}\)
- Residential: µg s\(^{-1}\)m\(^{-2}\)
- Commercial: µg s\(^{-1}\)m\(^{-2}\)
- Industrial: µg s\(^{-1}\)m\(^{-2}\)
- Recreational: µg s\(^{-1}\)m\(^{-2}\)
1km grid area ratios %

- **R**oads: median at 2% with uniform distribution
- **R**esidential: narrow but relatively uniform
- **C**ommercial and **I**ndustrial: narrow and rare
- **R**e**c**reational: may be 0 or 100%

Source-specific Emissions at noon

Sector-specific vs. all sectors

\[ E_i = \frac{N_i}{A_i} \] subject to speciation & temporal

**Subgrid emissions** \[ E_i = \frac{N_i}{A_i} \] subject to speciation & temporal
**Forcing terms** \[ \frac{E_i}{\overline{E}} \] express local deviations from averaged flux
Results for NOx: local emission forcing

Road emissions are ‘diluted’ by a factor of 40

Residential by a factor of 500
Results for NOx: local emission forcing

Industrial

Commercial

\[ E_i / \bar{E} \]

median 1200

median 700
Results for NOx: local emission forcing

\[ \frac{E_i}{\overline{E}} \]

Recreational

median .02
Comparison between 1 and 4 km

1km

4km

Roads

Residential

1km

4km

Roads

Residential

µg s⁻¹ m⁻²
Differences in temporal profiles

NOx

Residential

Hour of day

Roads

Hour of day

$E_i/E$

between grid-cells variability

median
Differences between counties

De Kalb County

Residential

Fulton County

NOx

$E_i / \overline{E}$

Median

Variability between grid-cells

Hour of day
Differences between pollutants

Residential

\( \frac{E_i}{E} \)

- NVOL
- NO\textsubscript{x}

\( \times 2 \)

Hour of day

Roads

\( \frac{E_i}{E} \)

- NO\textsubscript{x}
- NVOL

\( \div 4 \)

\( \frac{1600}{800} \)

\( \frac{40}{10} \)
**In progress:**

- Implementation into CMAQ
- Parameterization of the subgrid mixing $T_{mix}$
- Evaluation (available measurements, local scale model)

**Medium term conclusions:**

High variability in forcing terms:
- spatially between grid cells
- between counties
- temporally
- between pollutants

Attenuation of resolution effects (similar results for 1 and 4 km)

**Tips:**

- Low computational cost (selected grids, selected ‘sectors’)
- Link between local concentrations and time activity
- Concentrations ‘ready to use’ for exposure estimates