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Solutions to Urban Pollution

Multi-scale Modeling of Air Quality and Greenhouse Gases over Greater Boston, Part II: Sensitivity of Street-level Predictions to On-road Emissions from Traffic Activity Data

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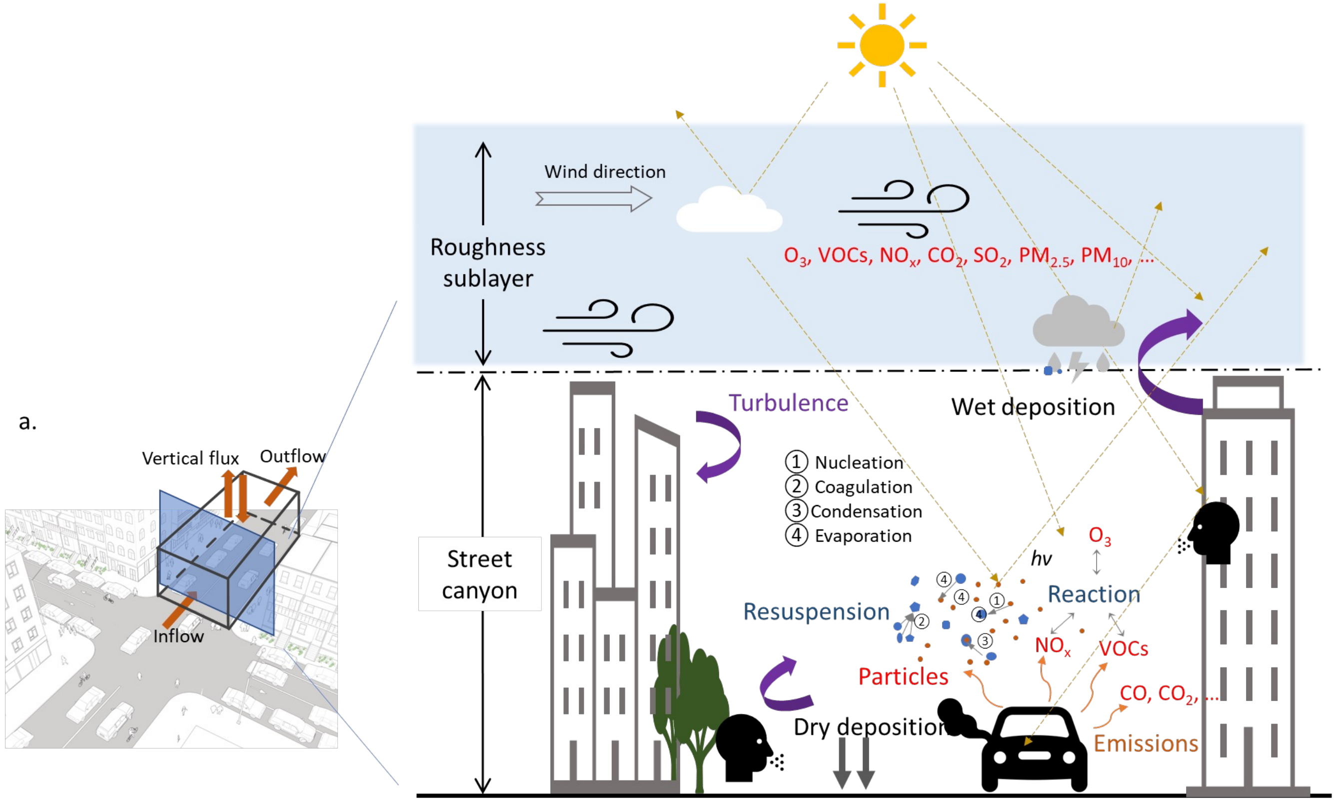
Background and Objectives

Background

- Regional air quality models have limited skills on streets where on-road emissions are a major source
- The street-network model, MUNICH, coupled with the SSH-aerosol model (MUNICH-SSH) can simulate gas-phase chemistry, and aerosol chemistry and dynamics at the hyperlocal scale

Objectives

- Intercompare $PM_{2.5}$ from MUNICH-SSH and WRF-Chem-GHG over Greater Boston
- Assess the impact of traffic activity data on on-road emissions and street-level air quality



Pollutant mass transfer in the street network (a) and processes inside the street canyon (b)

MUNICH: Model of Urban Network of Intersecting Canyons and Highways
SSH: SCRAM-SOAP-H^2O
SCRAM: Size-Composition Resolved Aerosol Model
SOAP: Secondary Organic Aerosol Processor
H^2O: Hydrophilic/Hydrophobic Organics
WRF-Chem-GHG: Weather Research and Forecasting model coupled with Chemistry and Greenhouse Gases

MUNICH-SSH

MUNICH-SSH

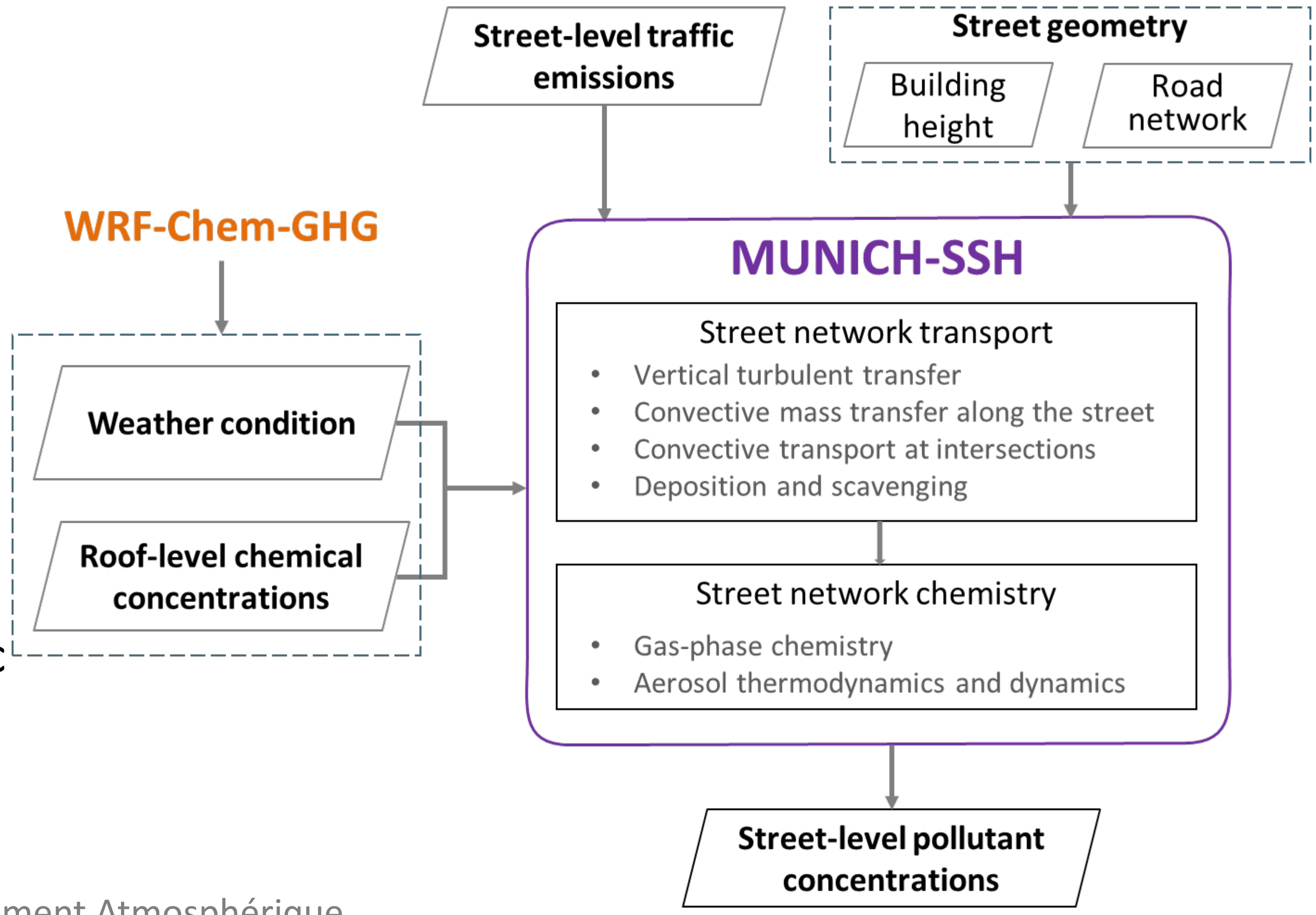
A street-network model developed at CEREA, France (Kim et al., 2018, 2022)

Components:

- Street-canyon: atmospheric processes in the volume of urban canopy
- Street-intersection: horizontal transfer of pollutants between connected canyons

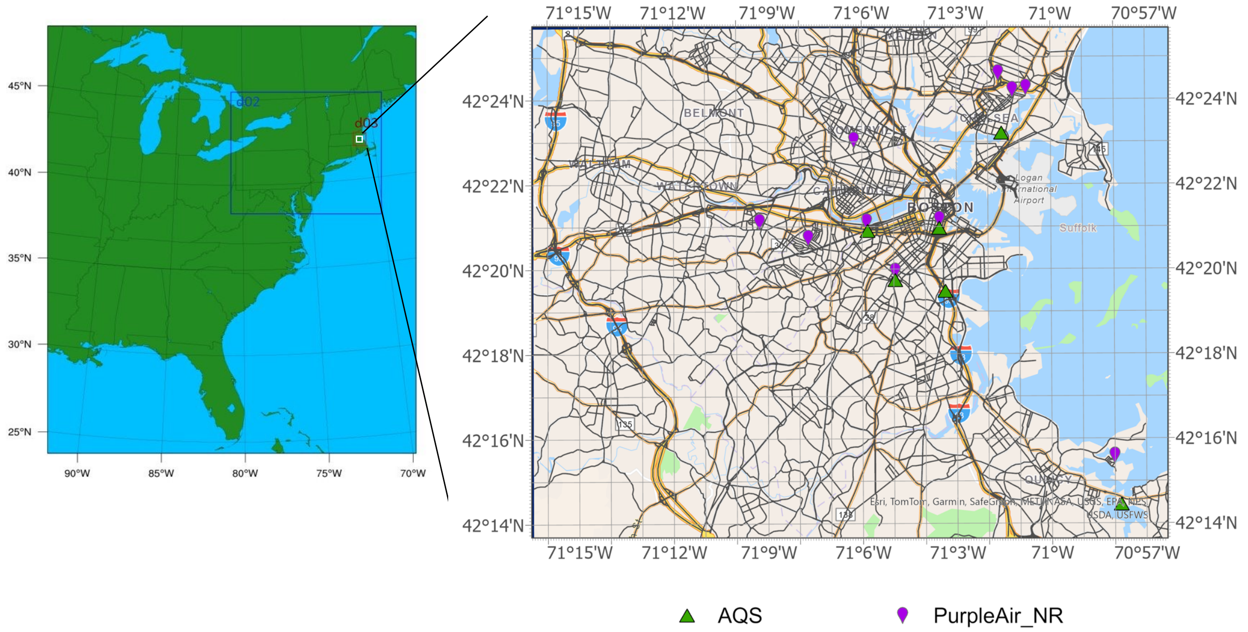
Physico-chemical processes: emissions, transport, chemistry, aerosol thermodynamic and dynamics, and deposition

Flowchart of MUNICH-SSH



CEREA: Centre d'Enseignement et de Recherche en Environnement Atmosphérique

Model Configuration



Domain: Greater Boston (28×21 km^2, ~14,000 segments)

Time period: Jan/Jul 2023

Input	Source
Background concentration	WRF-Chem-GHG 1-km results
Meteorological condition	WRF-Chem-GHG 1-km results
Street-level emissions	VEIN estimations
Street geometry	Road Inventory from MassDOT
Street/building height	Digital Synthetic City

Configuration	Option
Aerosol size distribution	6 bins from 0.01 μm to 10 μm
Gas-phase chemistry	CB05 (Yarwood et al., 2005)
Turbulent transfer	Schulte et al. (2015)
Wind speed	Soulhac et al. (2011)

CB05: Carbon Bond version 5
MassDOT: Massachusetts Department of Transportation
VEIN: Vehicular Emissions Inventory

Vehicle Emission Estimation

Hourly emission estimate for exhaust and non-exhaust vehicle sources:

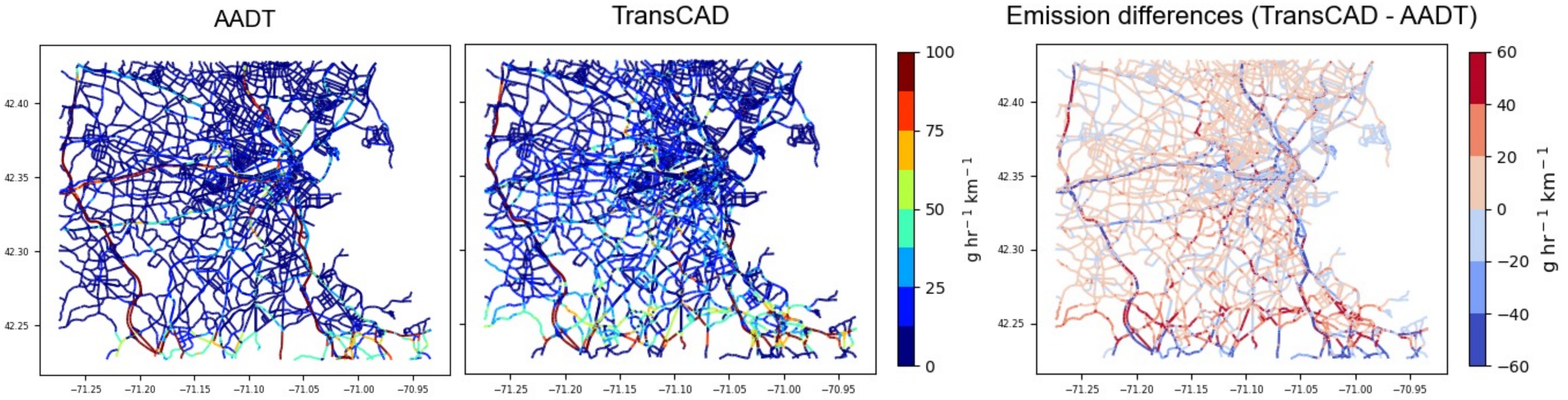
$$\text{Emission}_{\text{pollutant}} = \sum_{\text{activity}} (\text{AR}_{\text{activity}} \times \text{EF}_{\text{pollutant}})$$

- AR: activity rate, affected **by traffic flow, vehicle type, vehicle speed**, vehicle age, fuel type, engine size, and gross weight
- EF: emission factors, generated by EPA's MOVES3.1 model

	CASE 1: AADT	CASE 2: TransCAD
Data source	Massachusetts VMT 2022	Output from the transportation planning model TransCAD
Methods	Measurements, estimation and derivation from other years	Simulation based on socioeconomic data at the traffic analysis zone level and the capacity of each street
Information provided	Traffic flows and speed limit	Traffic flows, speed, and trip statistics

AADT: Annual Average Daily Traffic
MOVES: MOtor Vehicle Emission Simulator
VMT: Vehicle Miles Traveled

$PM_{2.5}$ Emissions on Weekdays, Jul



$\bar{\mu}$: 23.0; σ: 48.1

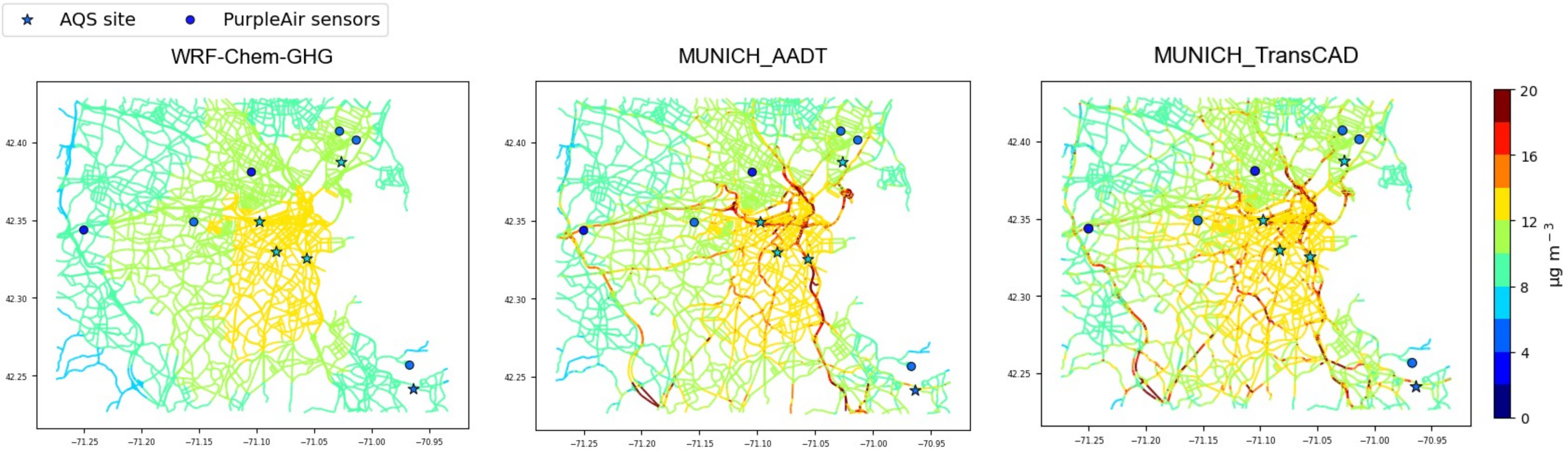
$\bar{\mu}$: 27.5; σ: 45.9

$\bar{\mu}$: 4.5; σ: 49.4

- Emission hotspots by AADT located along principal streets because of higher traffic volumes
- TransCAD gives higher estimates in most streets

$\bar{\mu}$: average
σ: standard deviation

$PM_{2.5}$ Evaluation: Jan



Simulation	Obs. data	MB (μg m^{-3})	NMB (%)	NME (%)	R
WRF-Chem-GHG	AQS	5.1	79.1	82.1	0.7
	PurpleAir	5.8	128.7	129.6	0.6
MUNICH_AADT	AQS	7.1	111.4	112.3	0.7
	PurpleAir	6.0	132.8	133.9	0.6
MUNICH_TransCAD	AQS	6.3	98.1	99.2	0.7
	PurpleAir	7.1	156.3	157.5	0.6

- Stronger spatial variation and more hotspots along streets in MUNICH-SSH
- Overpredictions likely caused by uncertainties in emissions and inaccurate meteorological predictions

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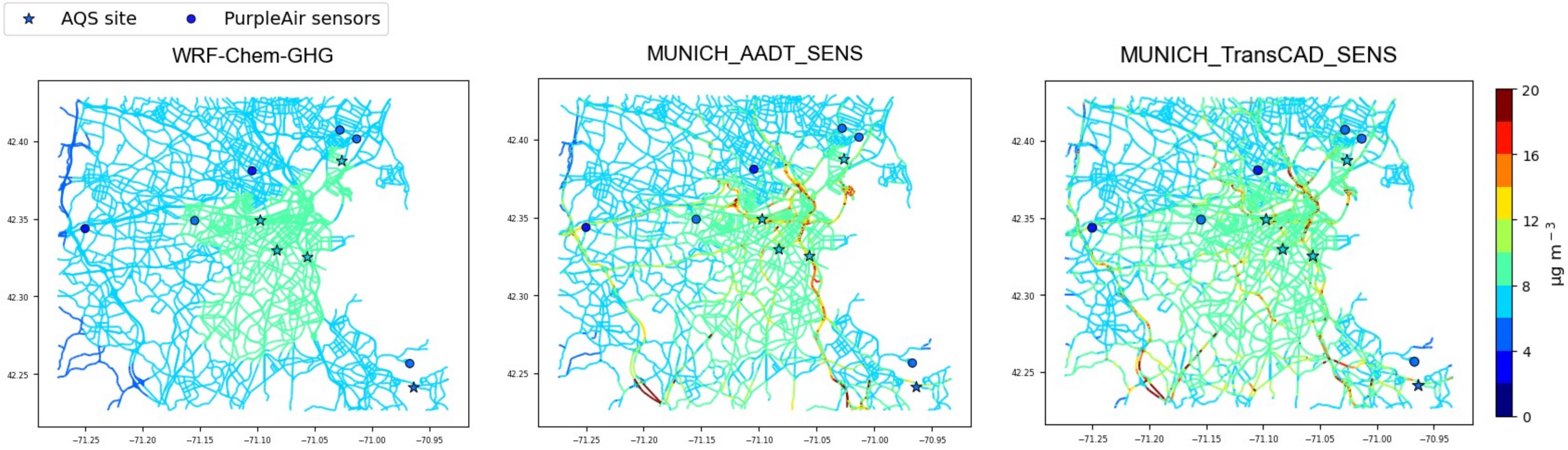
$PM_{2.5}$ Evaluation: Jan_SENS

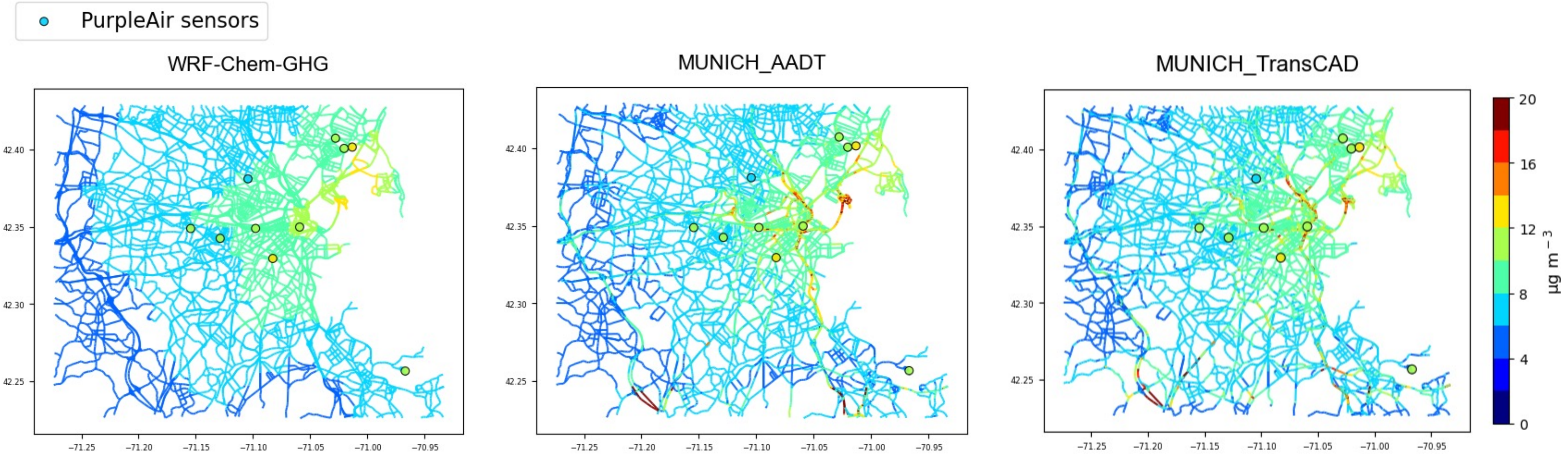
iSUPER



Simulation	Obs. data	MB ($\mu g\ m^{-3}$)	NMB (%)	NME (%)	R
WRF-Chem-GHG_SENS	AQS	1.7	26.2	38.8	0.7
	PurpleAir	2.9	65.0	70.1	0.6
MUNICH_AADT_SENS	AQS	3.8	59.8	64.7	0.6
	PurpleAir	3.2	69.7	74.2	0.6
MUNICH_TransCAD_SENS	AQS	2.9	45.8	52.0	0.6
	PurpleAir	4.2	93.0	97.0	0.6

- Emission adjustments reduce $PM_{2.5}$ overprediction significantly
- Higher bias against PurpleAir compared to AQS

$PM_{2.5}$ Evaluation: Jul



Simulation	Obs. data	MB (μg m^{-3})	NMB (%)	NME (%)	R
WRF-Chem-GHG	PurpleAir	-2.4	-21.4	44.0	0.2
MUNICH_AADT	PurpleAir	-2.7	-24.2	45.5	0.2
MUNICH_TransCAD	PurpleAir	-2.2	-19.8	46.0	0.1

- Better performance with smaller differences between the two models in Jul than Jan
- Underpredictions and poor correlations

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Site-specific Performance: Jul

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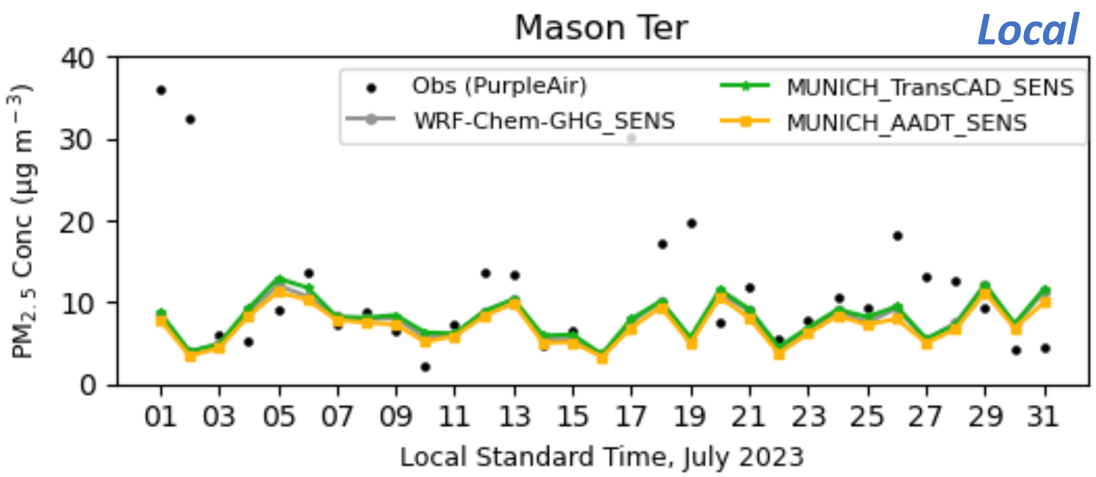
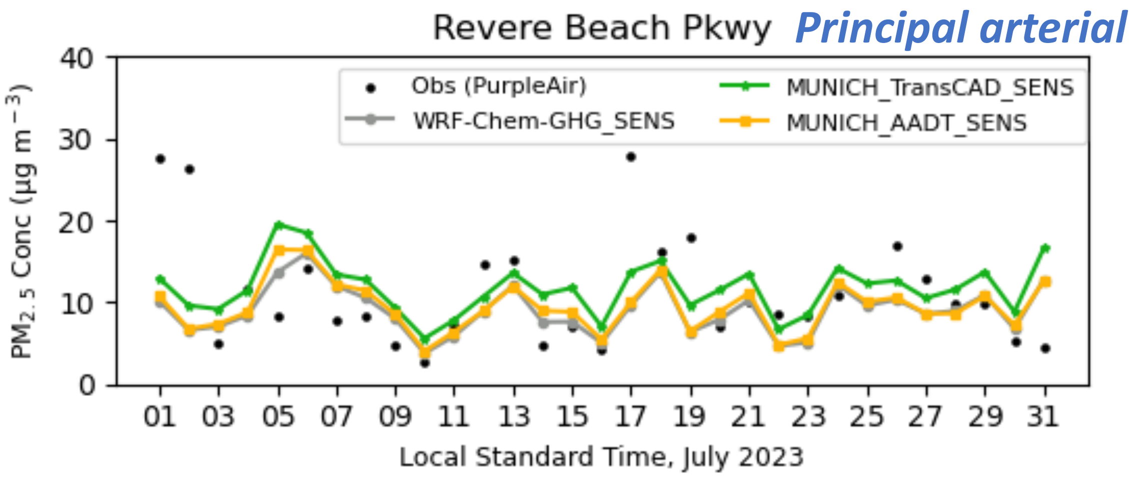




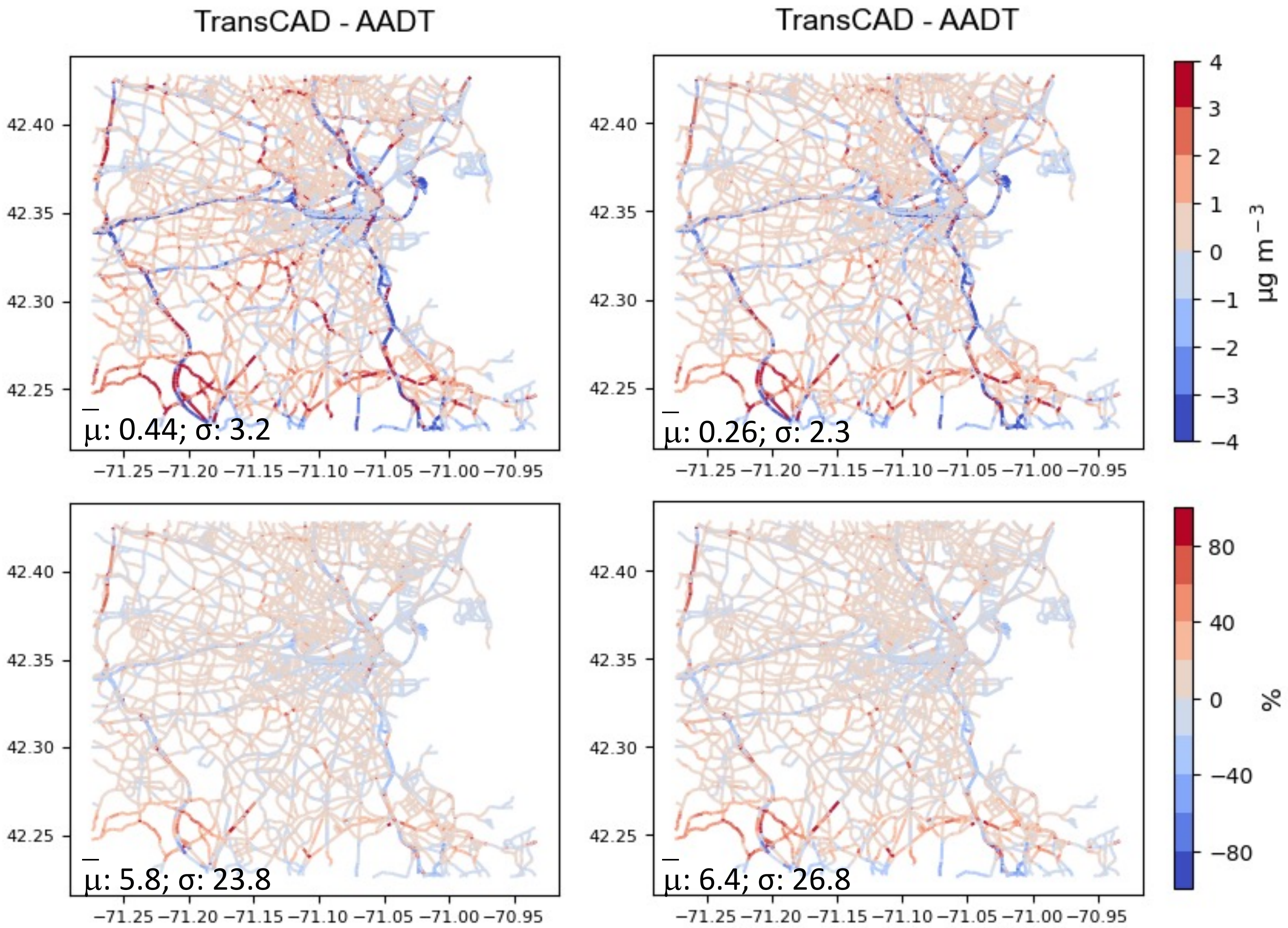
Simulation	Obs. data	Obs. (μg m^{-3})		MB (μg m^{-3})		NMB (%)		NME (%)		R	
		w.	w.o.	w.	w.o.	w.	w.o.	w.	w.o.	w.	w.o.
WRF-Chem-GHG	PurpleAir	11.0	9.1	-2.4	-0.3	-21.4	-3.4	44.0	34.8	0.2	0.4
MUNICH_AADT	PurpleAir	11.0	9.1	-2.7	-0.6	-24.2	-6.7	45.5	36.3	0.2	0.3
MUNICH_TransCAD	PurpleAir	11.0	9.1	-2.2	-0.1	-19.8	-1.2	46.0	37.7	0.1	0.3

w.: include Canadian wildfire days; w.o.: exclude Canadian wildfire days

- The impact of Canadian wildfires is not well captured
- Satisfactory performance during non-wildfire days on different types of streets

Sensitivity to On-road Emissions

January   July



- Different traffic activity data result in ~6% differences on average in $PM_{2.5}$ predictions
- Higher $PM_{2.5}$ with TransCAD, except heavy traffic streets

$\bar{\mu}$: average
σ: standard deviation

Summary and Future Work

- Traffic activity data significantly impacts on-road emission estimation and hyperlocal $PM_{2.5}$ modeling, with better $PM_{2.5}$ predictions by TransCAD
- MUNICH-SSH effectively identifies hyperlocal pollution hotspots. Overpredicted $PM_{2.5}$ in Jan. due likely to uncertainties in emissions and meteorological biases
- **Future work:** (1) improve the on-road emission inventory using neighborhood-specific fleet compositions from automatic traffic recording (ATR) data; (2) improve background conditions from WRF-Chem-GHG

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