A Survey-based Major Update to Spatial Surrogates for Processing Canadian Residential Wood Combustion Emissions

Junhua Zhang, Qiong Zheng, and Elisa Boutzis
Air Quality Research Division, Environment and Climate Change Canada,
4905 Dufferin Street, Toronto, ON, M3H5T4, Canada
junhua.zhang@ec.gc.ca

Mehrez Samaali, Daniel Rioux, and Philippe Martin
Integrated Approaches to Air Quality Unit, MSC, Environment and Climate Change Canada
305 rue René-Lévesque ouest, Montréal, QC, H2Z 1A6, Canada

2023 IEIC, Sept. 26th – 29th, 2023, Seattle, WA

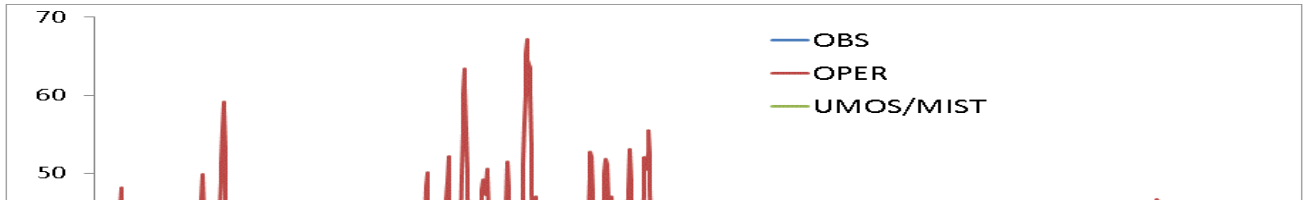
OUTLINE

- Motivation for this study
- 2012 survey on residential fuelwood burning activities in Canada
- Construction of spatial surrogates for Residential Wood Combustion (RWC) emissions based on the 2012 survey data and other factors
- Positive impacts of the new surrogates on model prediction of wintertime $PM_{2.5}$ concentration over large Canadian cities
- Summary remarks

MOTIVATION

- RWC is a very important source of $PM_{2.5}$ emissions in Canada, nationally accounting for 37% of non-dust $PM_{2.5}$ emissions for 2021
- Overpredictions of wintertime $PM_{2.5}$ concentrations for some cities by the Canadian Regional Air Quality Deterministic Prediction System (RAQDPS) (e.g., Moran et al. 2015) , largely caused by RWC emissions being over-allocated to urban areas mainly due to unreasonable split ratio of RWC emissions between urban and rural households

Vancouver $PM_{2.5}$ Concentrations (ug m^{-3}), Jan.-Feb. 2014: Observed, Forecast, and Adjusted (UMOS-AQ/MIST)



- A decade-old problem despite several attempts to improve the spatial surrogates for RWC emissions (e.g., *Qiong et al., 2015*; *Samaali et al., 2018*)
- As a major update to RAQDPS, RWC surrogates, along with many other spatial surrogates, were revisited and updated (*Qiong et al., 2023*, see poster session at this conference)

SURVEY ON RESIDENTIAL FUELWOOD BURNING ACTIVITIES IN CANADA: OVERVIEW

- Prepared by TNS Canada (www.tnsglobal.com) for Natural Resources Canada in May, 2012
- Survey of Canadian residential fuelwood burning activities at provincial level; first survey was done in 1997, second in 2006, and third in 2012
- Survey provided many useful pieces of information, such as:

- Number of Canadian households burning fuelwood and the quantity of fuelwood burned in rural versus urban households
- Classification of households based on the type of fuelwood burning equipment (fireplace, stove, and furnace)
- Quantities of wood burned in each of the various types of wood-burning equipment in rural and urban communities within each province
- Differences in wood burning behavior between rural and urban households.

SURVEY ON RESIDENTIAL FUELWOOD BURNING ACTIVITIES IN CANADA: RESULTS (1)

RURAL: <10K POPULATION; URBAN: 10K+ POPULATION

- Percentage of households reported having each of the three broad types of wood-burning equipment (Tables Exhibit C: 3a, Exhibit C: 4a, and Exhibit C: 5a)

	BC		AB		SK		MB		ON		QC		NB		NS		PE		NL	
(%)	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+
Fireplace	14	39	28	28	10	16	8	15	17	22	12	22	11	26	20	29	9	15	9	45
Stove	29	7	24	6	10	5	12	13	27	7	41	16	40	26	38	25	44	25	34	20
Furnace	4	2	2	1	5	1	6	1	6	2	10	2	21	1	18	4	23	2	27	2

- Percentage of main residence using wood burning equipment almost every day (Table Exhibit D: 3)

	BC		AB		SK		MB		ON		QC		NB		NS		PE		NL	
	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+
%	60	16	36	9	35	9	37	12	62	11	63	21	75	51	75	51	75	51	75	51

- Percentage of main residence using wood burning equipment more than 8 hours per day (Table Exhibit D: 5)

	BC		AB		SK		MB		ON		QC		NB		NS		PE		NL	
	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+
%	63	16	42	11	37	4	40	12	68	15	62	26	77	54	77	54	77	54	77	54

SURVEY ON RESIDENTIAL FUELWOOD BURNING ACTIVITIES IN CANADA: RESULTS (2)

RURAL: <10K POPULATION; URBAN: 10K+ POPULATION

- Possibility of a household using wood burning equipment almost every day for at least 8 hours per day, assuming burning behavior is the same for all types of equipment.

	BC		AB		SK		MB		ON		QC		NB		NS		PE		NL	
(%)	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+	<10k	10k+
Fireplace	5.3	1.0	4.2	0.3	1.3	0.1	1.2	0.2	7.2	0.4	4.7	1.3	6.4	7.2	11.6	8.0	5.2	4.1	5.2	12.4
Stove	11.0	0.2	3.6	0.1	1.3	0.0	1.8	0.2	11.4	0.1	16.0	1.0	23.1	7.2	21.9	6.9	25.4	6.9	19.6	5.5
Furnace	1.5	0.1	0.3	0.0	0.6	0.0	0.9	0.0	2.5	0.0	3.9	0.1	12.1	0.3	10.4	1.1	13.3	0.6	15.6	0.6

- Final calculated provincial equipment-specific rural to urban wood consumption ratios

Rural/Urban	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Fireplace	**5.3**	**15.3**	**22.5**	**5.5**	**19.7**	**3.6**	**0.9**	**1.4**	**1.3**	**0.4**
Stove	**61.2**	**61.1**	**71.9**	**9.5**	**98.6**	**16.7**	**3.2**	**3.2**	**3.7**	**3.6**
Furnace	**29.5**	**30.5**	**179.9**	**61.7**	**76.7**	**32.7**	**44.0**	**9.4**	**24.1**	**28.3**

- These rural to urban ratios are used for constructing three equipment-specific surrogates to replace the old single generic surrogate

CONSTRUCTION OF RWC SPATIAL SURROGATES

Determination of Urban, Suburban, and Rural Areas (1)

- Urban, suburban, and rural areas are defined by house density within the census Dissemination Areas (DAs) and Population Centres (POPCTRs)
- A DA is the smallest standard geographic area for which all census data are disseminated, targeted from 400 to 700 persons (can be much higher or lower for some DAs)
- A POPCTR has a population of at least 1,000 and a population density of 400 persons or more per square kilometre, DAs within a POPCTR considered as urban area
- DAs outside the POPCTRs are grouped into three areas:
  a) Urban areas: house densities above 150 house/km^2
  b) Suburban areas: house densities between 30 and 150 house/km^2, treated as 50% urban and 50% rural
  c) Rural areas: house densities below 30 house/km^2

CONSTRUCTION OF RWC SPATIAL SURROGATES

Determination of Urban, Suburban, and Rural Areas (2)

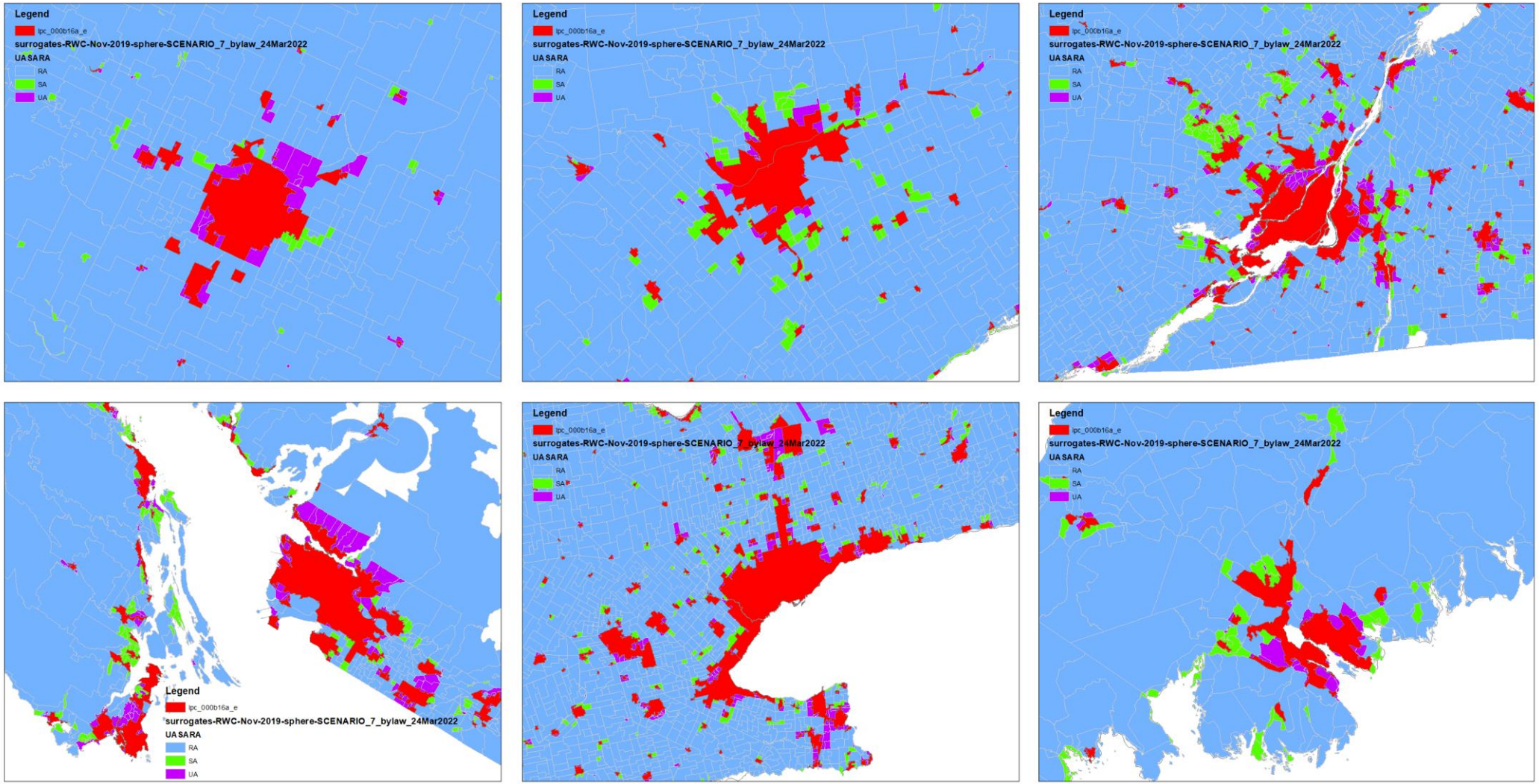
Urban, suburban, and rural areas around a few main cities in Canada

Red
urban area within POPCTR

Purple
Urban area outside POPCTR

Green
suburban area outside POPCTR

Blue
Rural area

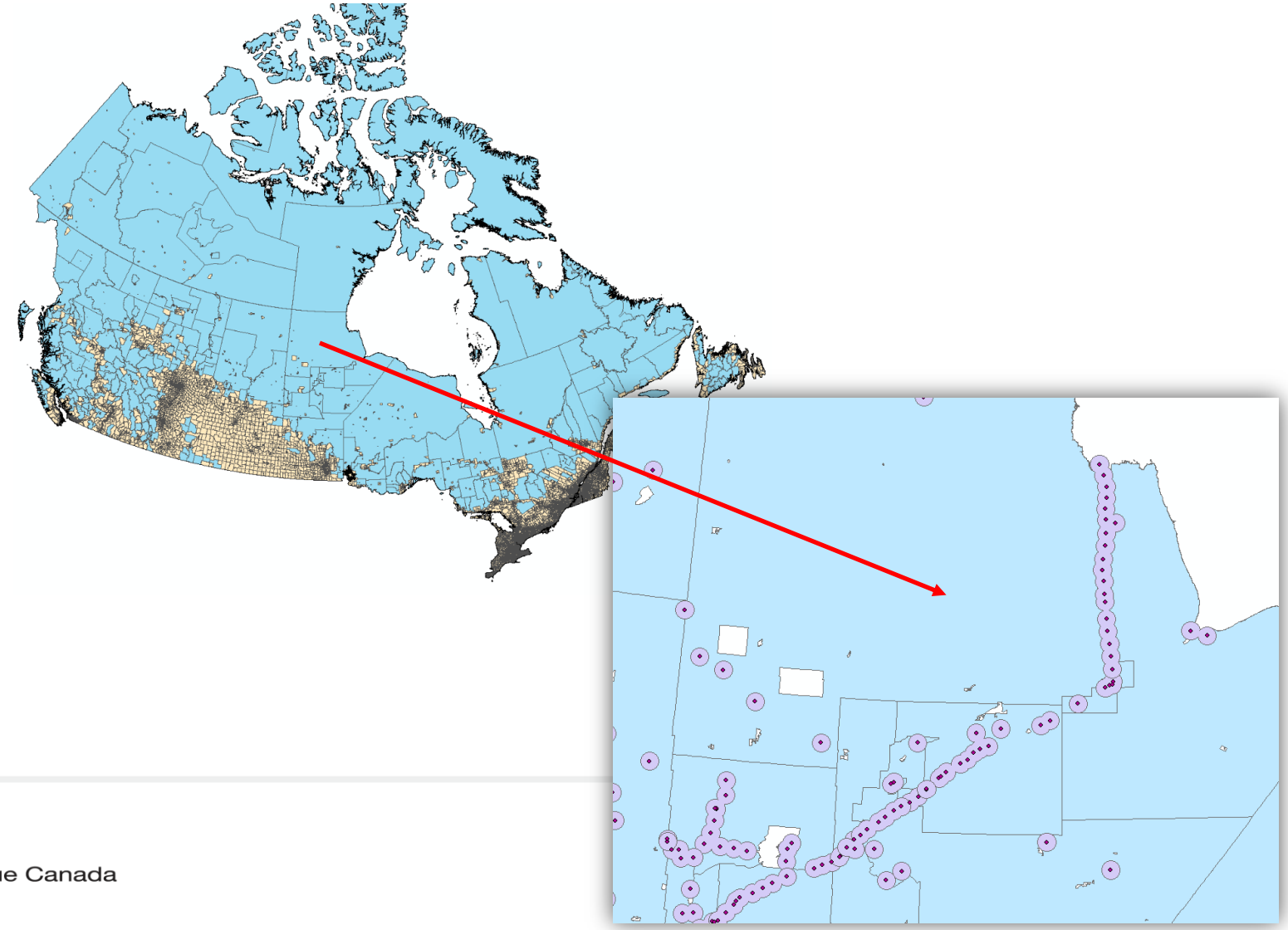


Environment a
Climate Chan

CONSTRUCTION OF RWC SPATIAL SURROGATES

Consideration for Rural Communities in the Remote Areas

- DAs are small in populated areas, but very large in the remote areas with isolated small local communities
- For those large remote DAs, RWC emissions were allocated to the villages/hamlets with a 10km buffer

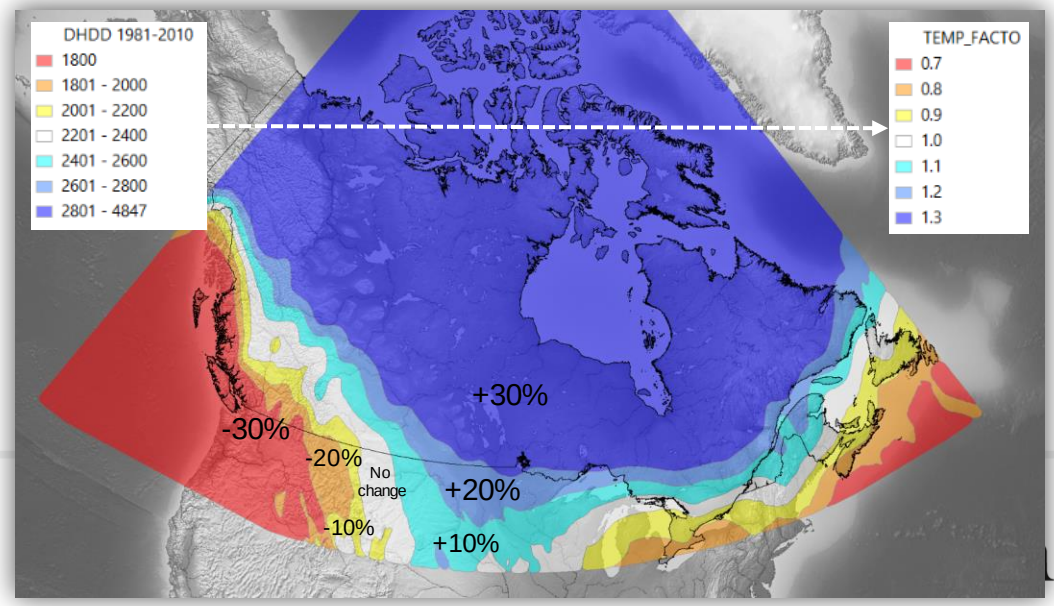


CONSTRUCTION OF RWC SPATIAL SURROGATES

Consideration of Climate Zone Based on Heating Degree Day

- Heating Degree Day (HDD) is a measurement designed to quantify the demand for energy needed to heat a building: number of degrees that a day's average temperature is below 65º Fahrenheit (18º Celsius)
- Temperature-dependent factors (TF) applied based on average of annual sum of Daily Heating Degree Days (DHDD) over 1981-2010 for 7 climate zones

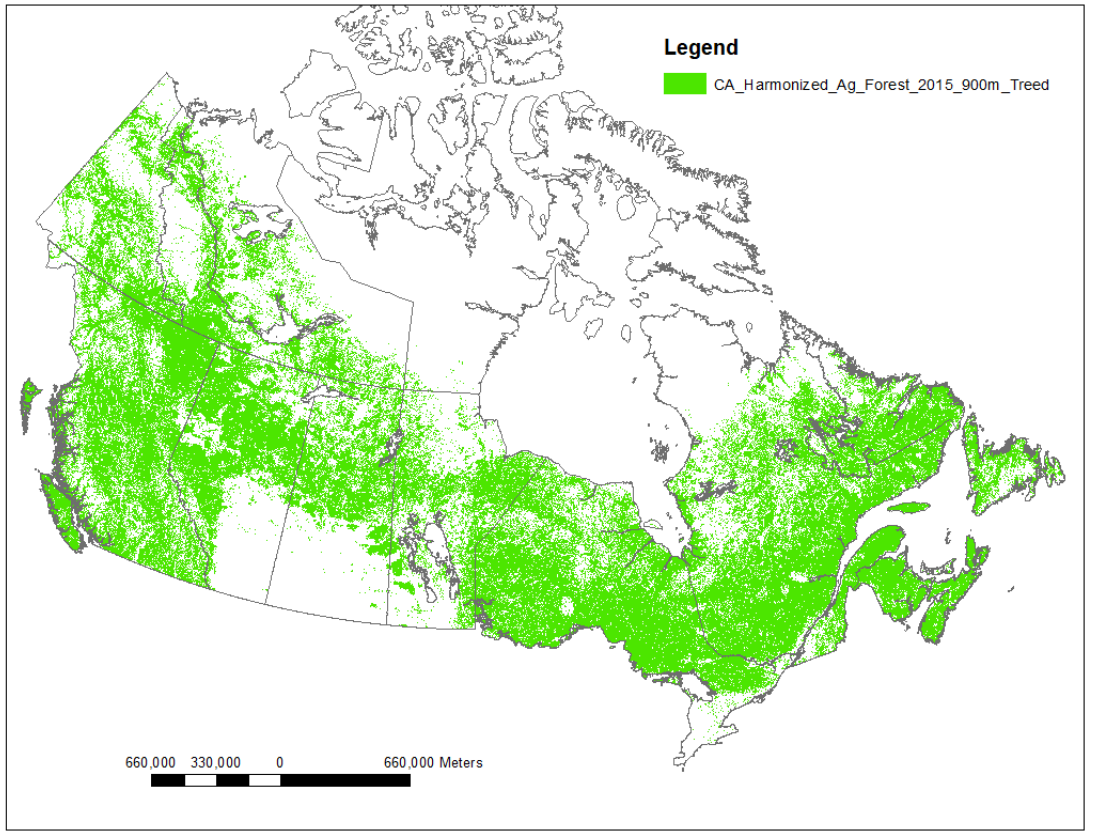
Zone 1:
if DHDD ≤ 1800 then TF = 0.7 or -30%
Zone 2:
if 1800 < DHDD ≤ 2000 then TF = 0.8 or -20%
Zone 3:
if 2000 < DHDD ≤ 2200 then TF = 0.9 or -10%
Zone 4:
if 2200 < DHDD ≤ 2400 then TF = 1 or 0%
Zone 5:
if 2400 < DHDD ≤ 2600 then TF = 1.1 or +10%
Zone 6:
if 2600 < DHDD ≤ 2800 then TF = 1.2 or +20%
Zone 7:
if 2800 < DHDD ≤ 4850 then TF = 1.3 or +30%



CONSTRUCTION OF RWC SPATIAL SURROGATES

Readiness for Accessing Fuelwoods

- Households located within or close to forests are more likely to burn wood than households located in prairie or cleared (agricultural) locations (e.g. southwestern Ontario)
- A forest map is applied with an assumption that households close to the forests are 4 times more likely to burn fuelwoods than other households



CONSTRUCTION OF RWC SPATIAL SURROGATES

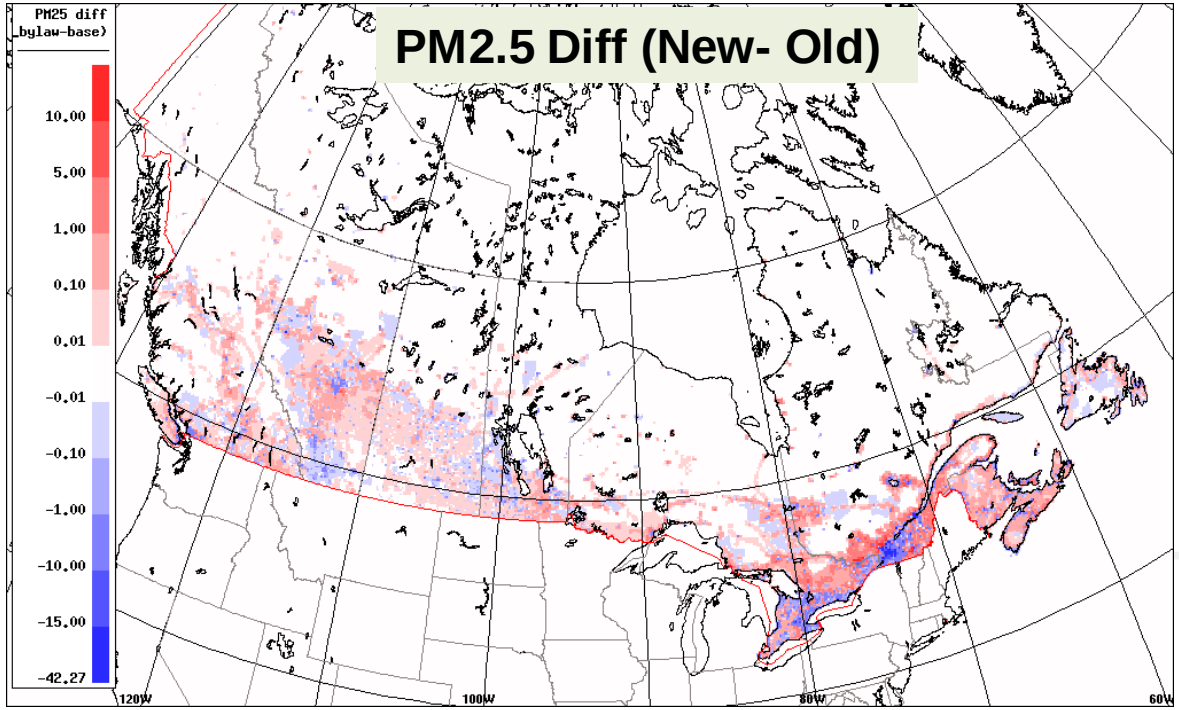
Other Considerations and Final Formula

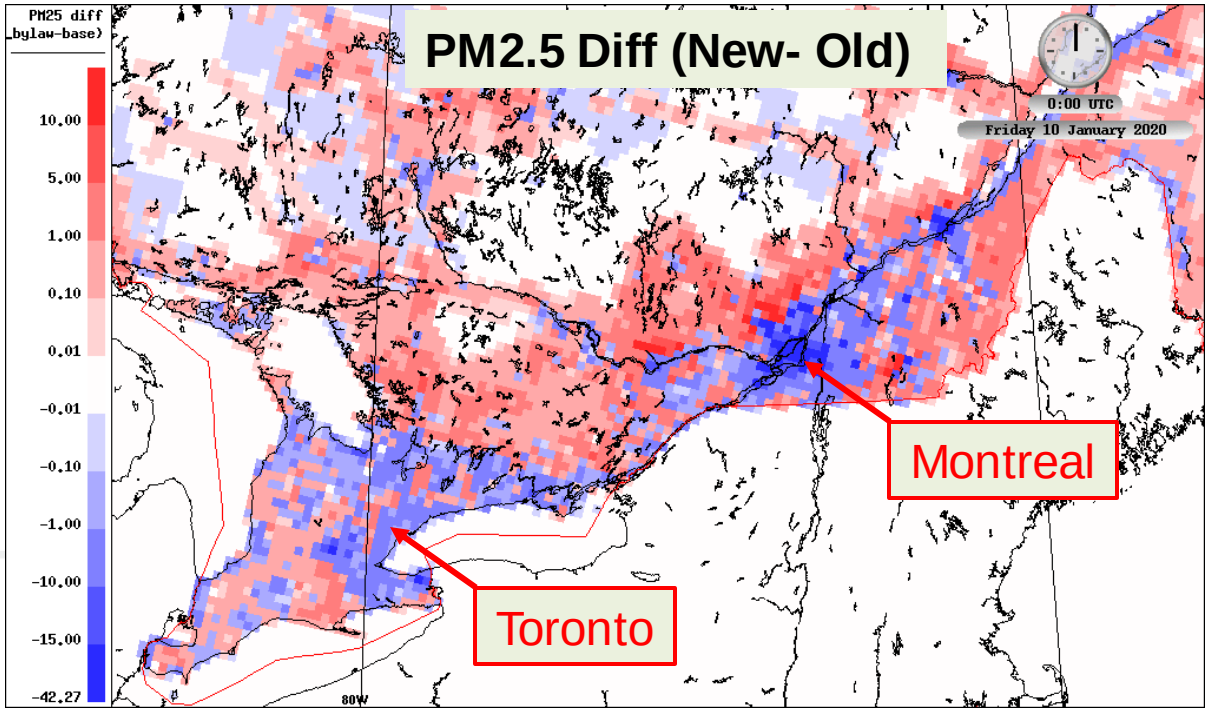
- Wood burning is unlikely to occur in high-density, multi-storey, multiple-unit buildings. For DAs with dwelling density larger than 3000 dwelling/km^2, assumed zero RWC emissions. Only single, semi, and row houses are accounted
- Single and semi houses are much more likely to use wood for space heating than the row houses which don't have space for storing the wood.

RWC Weight = (single dwelling + semi + row/4) * forest_factor * house density cap factor * DHDD FACTOR * rural_urban_ratio

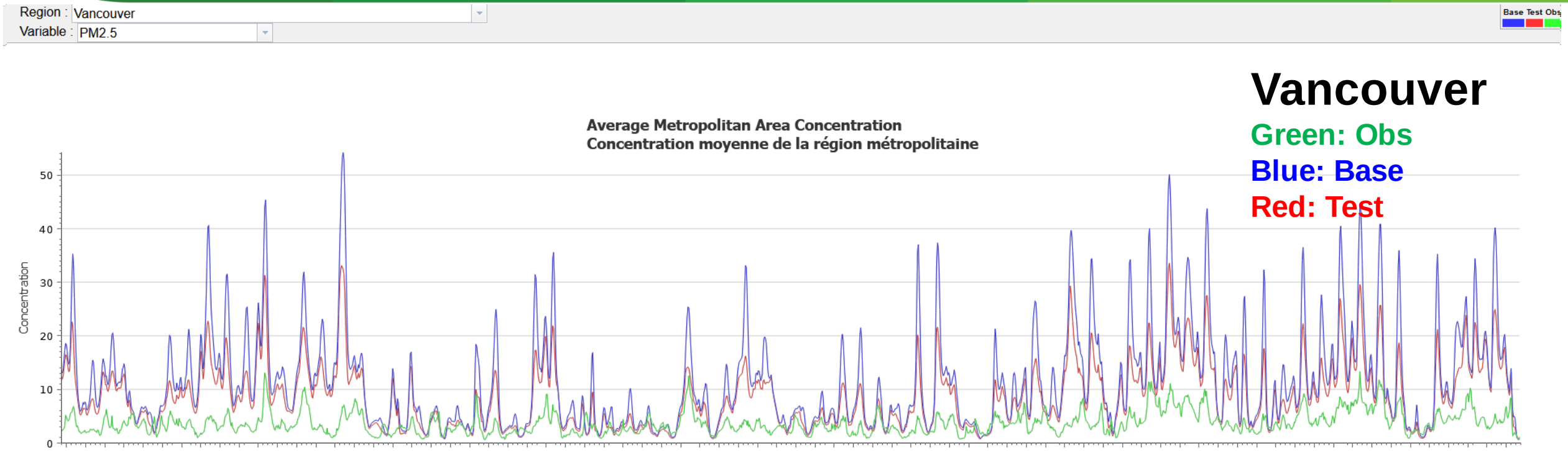
IMPACTS OF THE NEW SURROGATES ON $PM_{2.5}$ EMISSIONS FOR THE NATIONAL 10KM GRID

- RWC emissions for major Canadian cities decreased significantly using the three new equipment-specific surrogates
- RWC emissions for the rural areas increased accordingly





IMPACTS OF THE NEW SURROGATES ON MODEL PREDICTION OF $PM_{2.5}$ CONCENTRATION FOR LARGE CITIES



- New RWC surrogates significantly improve model prediction of $PM_{2.5}$ concentration for most of the large Canadian cities
- Overprediction of $PM_{2.5}$ concentration is still seen for some cities; $PM_{2.5}$ emissions from other sources need to be investigated and/or the factors used for constructing the RWC surrogates need to be further adjusted

SUMMARY

- Wintertime $PM_{2.5}$ concentrations have been overpredicted for many large Canadian cities by the Canadian RAQDPS, largely caused by RWC emissions being over-allocated to urban areas
- Three equipment-specific rural-to-urban ratios were derived from detailed survey of Canadian residential fuelwood burning activities at the provincial level
- These ratios, combined with other factors, were used to construct a new set of RWC surrogates
- The new surrogates reallocate a fraction of the RWC emissions from urban areas to rural areas
- Prediction of wintertime $PM_{2.5}$ concentrations was significantly improved using these new surrogates

Thank You for Your Attention!

Moran, M.D., et al., 2015. Contribution of improved spatial allocation of emissions to reducing urban overpredictions of NO2 and PM2.5 concentrations. *14th CMAS Conference*, 5-7 Oct., Chapel Hill, North Carolina. [see https://www.cmascenter.org/conference/2015/slides/0930_michael_moran_spatial_concentrations.pptx]

Samaali, M., et al., 2018. Updating spatial surrogates for the Canadian Regional Air Quality Deterministic Prediction System. Poster, *9th International Workshop on Air Quality Forecasting Research*, Nov. 7-9, Boulder, Colorado [see https://esrl.noaa.gov/csd/events/iwaqfr/2018/presentations/posters/45_Samaali.pdf].

Zheng, Q., et al., 2015. Development of some improved Canadian spatial surrogates. Poster, *21st International Emissions Inventory Conference*, 13-17 April, San Diego. [see https://www.epa.gov/sites/default/files/2015-09/documents/qzheng.pdf]

Zheng, Q., et al., 2023. Recent improvements of Canadian Spatial Surrogates for Air Quality Modelling . Poster, *2023 International Emissions Inventory Conference*, 26-30 September, Seattle. [see poster session at this conference]