Environment Canada / Environnement Canada

Application of a quantitative method to characterize uncertainty and variability to a national emissions inventory

Mehrez Samaali[1], Gilles Morneau[1], Michael Moran[2]

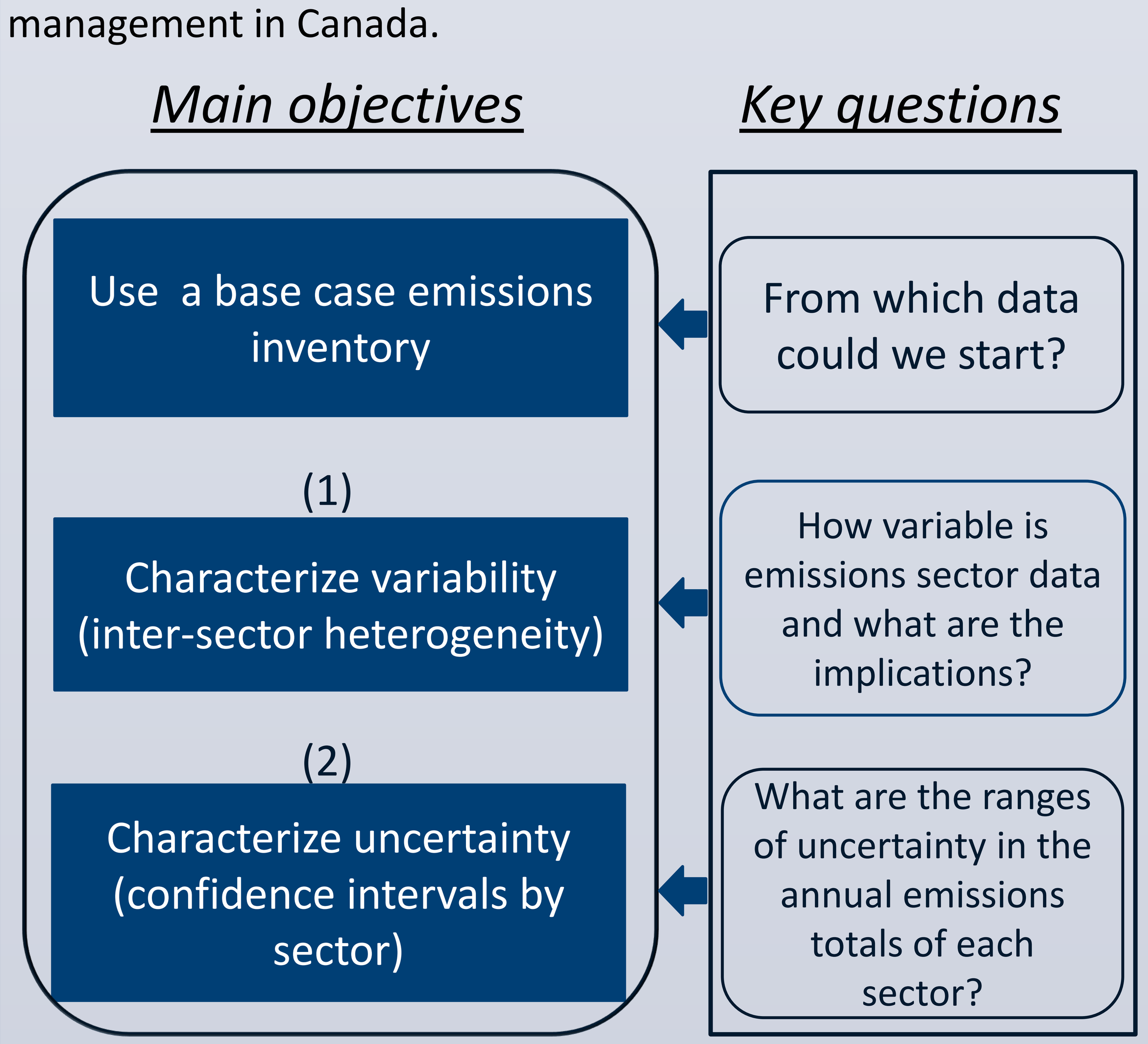
[1] Air Quality Modelling Application Section, Canadian Meteorological Centre, Environment Canada, 2121 Route Transcanadienne, Dorval, QC, H9P 1J3, Canada.
[2] Air Quality Research Division, Environment Canada, 4905 Dufferin Street, Toronto, ON, M3H 5T4, Canada.

INTRODUCTION

Spatially, temporally, and chemically disaggregated emissions are a key input for air quality regulatory and management applications using chemical transport models. However, the uncertainty of these input emissions is in most cases not well known. Thus, resulting regulatory and air quality (AQ) management emissions-control strategies may not be effective in practice due to lack of knowledge about emissions uncertainty. Air quality model development may also suffer from lack of knowledge about emissions uncertainty if errors in model results are wrongly attributed to errors in input emissions, overlooking other sources of error such as process representations, numerical schemes, chemical boundary conditions, and input meteorological fields.

OBJECTIVES

This poster focuses on the application of a quantitative method based on probabilistic analysis to characterize uncertainty and variability in the Canadian 2006 national criteria-air-contaminant emissions inventory. The method is based on the bootstrap method and Monte Carlo (MC) random sample technique. The work focuses on the emissions component of an emissions scenario modeling platform that was developed to support policy decisions related to air quality management in Canada.



EMISSIONS DATA & METHODOLOGY

1- Emissions Inventory Data

The 2006 base line emissions inventory was provided by Pollution Inventory and Reporting Division of Environment Canada and includes annual totals in tonnes/year/sector/pollutant for all Canadian provinces:

- Emissions for seven criteria air contaminants (CACs) were provided: carbon monoxide (CO), ammonia (NH_3), nitrogen oxides (NO_x), particulate matter less than 10 micron (PM_{10}), particulate matter less than 2.5 micron ($PM_{2.5}$), sulfur dioxide (SO_2) and Volatile Organic Compounds (VOC).
- Seven main sectors were part of the inventory (see Fig.1) with detailed contributions tabulated for each sub-sector.

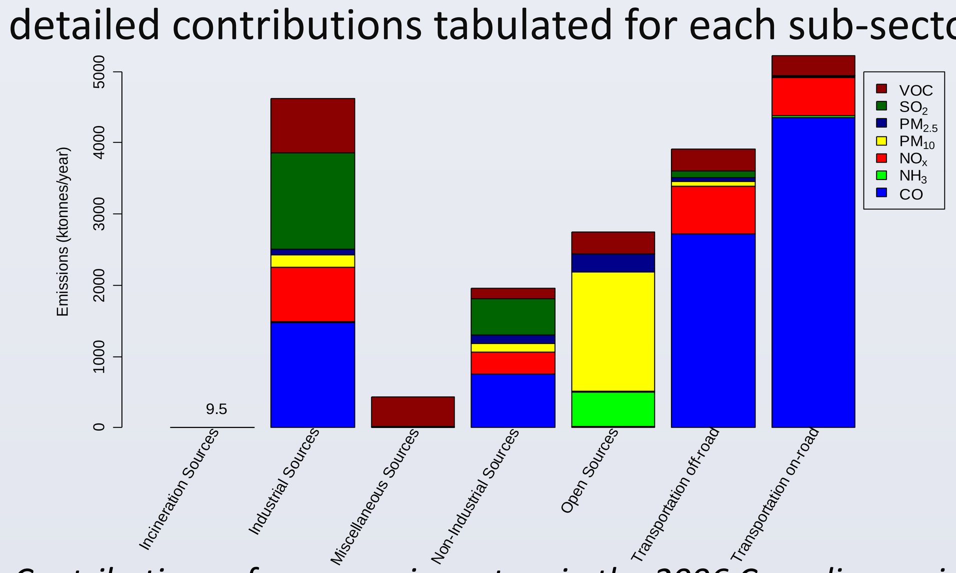
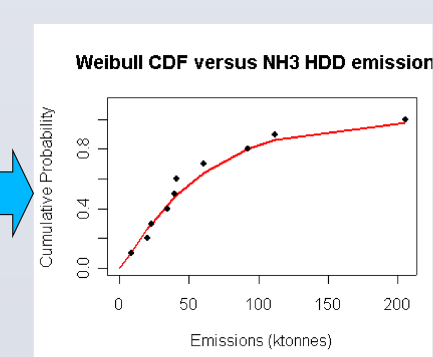


Fig.1. Contributions of seven main sectors in the 2006 Canadian emissions inventory

2- Methodology (Frey et al., 2002; Zheng and Frey, 2002)

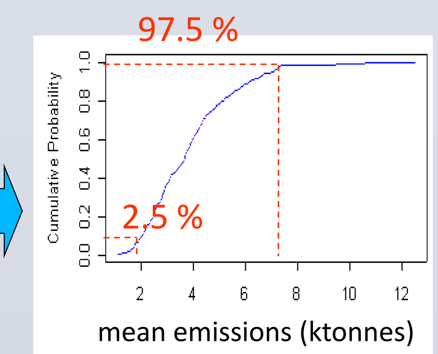
Variability

1- Check data quality and representativeness,
2- Analyze data dispersion,
3- Fit a probability distribution function (PDF) to the data.



Uncertainty

1- Use MC method to generate bootstrap random samples (500, for example) from PDF (step 3, above),
2- For each sample calculate statistics (mean, standard deviation, etc.)
3- Use the 500 values of each statistic to build a sampled PDF,
4- Calculate confidence intervals from cumulative PDF calculated from the sampled PDF.



95% confidence interval for the mean [1.8;7.4]

Two random sampling methodologies were compared:

- **Equally-weighted data method:** each data value was given the same weight in the MC sampling.
- **Unequally-weighted data method:** each data value was given a weight in the MC sampling based on its contribution to the emissions total.

RESULTS

On-road transportation: Heavy Duty Diesel (HDD) sub-sector.

- Equally-weighted data method

Dataset Name	Number of Data	Distribution Type	Estimation Method	Relative 95% confidence interval on mean
CO	11	Weibull	Moment	-58% to +77%
NH_3	11	Weibull	Moment	-50% to +70%
NO_x	11	Weibull	Moment	-55% to +92%
PM_{10}	11	Weibull	Moment	-52% to +69%
$PM_{2.5}$	11	Weibull	Moment	-60% to +77%
SO_2	11	Weibull	Moment	-49% to +87%
VOC	11	Weibull	Moment	-62% to +80%

- Unequally-weighted data method

Uncertainties

Dataset Name	Number of Data	Distribution Type	Estimation Method	Relative 95% confidence interval on mean
CO	100	Weibull	Moment	-15% to +17%
NH_3	100	Weibull	Moment	-12% to + 12%
NO_x	100	Weibull	Moment	-15% to + 16%
PM_{10}	100	Weibull	Moment	-17% to + 15%
$PM_{2.5}$	100	Weibull	Moment	-13% to + 15%
SO_2	100	Weibull	Moment	-12% to + 15%
VOC	100	Weibull	Moment	-13% to + 14%

➡ High uncertainty ranges from ~(-62%) to 92% and asymmetric confidence intervals (skewed positive) when using the equally-weighted data method.
➡ Lower uncertainty ranges than those obtained using the equally-weighted data method and most uncertainty ranges are symmetric when using the unequally-weighted data method.

Off-road transportation: all sub-sectors

- Equally-weighted data method

Uncertainties

Dataset Name	Number of Data	Distribution Type	Estimation Method	Relative 95% confidence interval on mean
CO	100	Weibull	Moment	-19% to +21%
NH_3	100	Weibull	Moment	-15% to +14%
NO_x	100	Weibull	Moment	-15% to +16%
PM_{10}	100	Weibull	Moment	-15% to +16%
$PM_{2.5}$	100	Weibull	Moment	-13% to +14%
SO_2	100	Weibull	Moment	-16% to +18%
VOC	100	Weibull	Moment	-18% to +24%

➡ Lower uncertainty ranges (from -19% to 24%) than those obtained using the unequally-weighted data method (uncertainty ranges lies between ~(-100%) and 470%).
➡ Most confidence intervals are symmetric.

Industrial sector: all sub-sectors

- Equally-weighted data method

Uncertainties

Dataset Name	Number of Data	Distribution Type	Estimation Method	Relative 95% confidence interval on mean
CO	100	Weibull	Moment	-24% to +25%
NH_3	100	Weibull	Moment	-18% to +24%
NO_x	100	Weibull	Moment	-26% to + 41%
PM_{10}	100	Weibull	Moment	-11% to +12%
$PM_{2.5}$	100	Gamma	Moment	-13% to +14%
SO_2	100	Weibull	Moment	-17% to +21%
VOC	100	Weibull	Moment	-26% to +32%

➡ Higher uncertainty ranges compared to on-road and off-road sectors when using the equally-weighted data method.
➡ Most confidence intervals are symmetric.

CONCLUSIONS

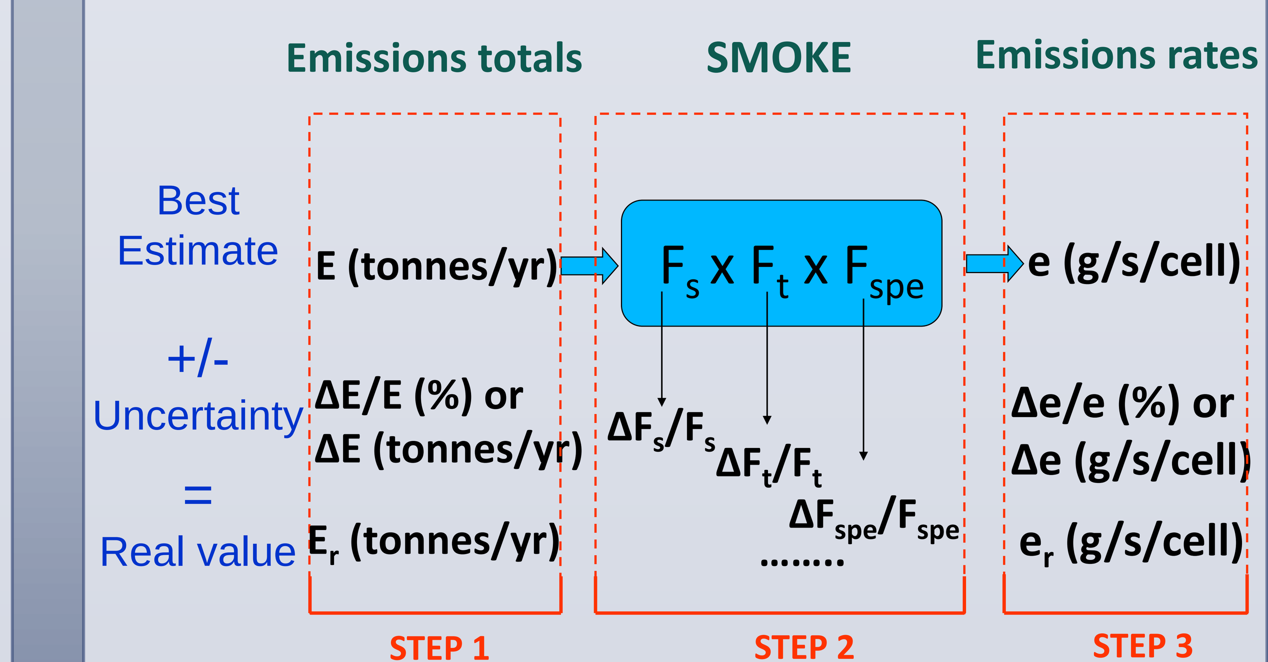
- A quantitative method based on bootstrap method and Monte Carlo sampling technique was successfully applied to characterize variability and uncertainty in the 2006 Canadian base case emissions inventory.
- Weibull distribution seems to represent best the variability in the emission sectors although several distribution types were available.
- A significant variability between the sectors and the sub-sectors was noticed not only in terms of their respective contributions to the inventory but also in terms of their uncertainty ranges.
- The unequally-weighted data method showed lower and more plausible uncertainty ranges than the equally-weighted method for all sectors.

FUTURE WORK

Step 1: *characterize uncertainty and variability in the emissions totals for all main sectors and CAC. This step was already completed.*

Step 2: characterize uncertainty and variability in the temporal allocation, spatial allocation and chemical speciation based on the literature (e.g., Tao et al., 2004; Sowden et al., 2008) and expert judgments, and propagate these uncertainties through processing with the SMOKE tool.

Step 3: generate sets of perturbed model-ready emissions for sensitivity analysis with the Canadian chemistry transport model (AURAMS).



REFERENCES & CONTACT

Frey, H.C. and Li, S., 2002. Extended abstract. 1–14 (available at the EPA website: www.epa.gov/ttnchie1/conference/ei11/ef/frey.pdf).

Zheng, J. and Frey, H.C., 2002. Technical report. 126 pages (available at http://foodrisk.org).

Tao, Z. et al, 2004. *Atmos. Environ.*, 38, 6279–6285 (available at www.sciencedirect.com).

Sowden, M. et al, 2008. *Atmos. Environ.*, 42, 7155–7164 (available at www.sciencedirect.com).

*Email address: mehrez.samaali@ec.gc.ca