THE IMPACT OF METEOROLOGICAL VARIABILITY ON THE MODELLING OF AIR QUALITY SCENARIOS

Radenko Pavlovic*, Jack Chen, Sophie Cousineau, Louis-Philippe Crevier, Didier Davignon, Annie Duhamel, Gilbert Samuel, Jacinthe Racine, Mehrez Samaali and Mourad Sassi
Air Quality Modeling Applications Section, Environment Canada, Montreal, QC, Canada

1. INTRODUCTION

The Air Quality Modeling and Application Section of Environment Canada is transitioning its policy modeling platform from base year 2002 to base year 2006. This configuration of the platform uses the 2006 comprehensive Criteria Air Contaminants (CAC) emission inventory and the United-States 2005 National Emission Inventory (NEI). Mexican inventory is also included (year 1999). When modeling policy scenarios the emissions inventory year is generally used as a reference year for generating the meteorological fields.

An analysis of the meteorological fields is carried out in order to examine possible uncertainties in the air quality modeling. The verifications applied in this study consist of the following analyses:

- Objective scores: model performance verification, against observations, at the surface and on the upper air levels;
- Representativeness of the base case year with respect to the climatology: the presence of extreme weather (regions with heavy precipitation rates, droughts, high/low temperatures, etc.) with important discrepancies relative to climatology can affect significantly the representativeness of meteorological fields.

The precision of emission inventory can also be influenced by meteorological variations (example: relatively hot/cold year or season(s)). This possible type of uncertainty was not assessed in this study.

2. METHODOLOGY

2.1 Modelling Configuration

The meteorological inputs, prepared for the air quality modeling were generated by GEM (Global Environmental Multiscale model), which is the Canadian operational forecast model. The configuration used was the regional version with a 15km horizontal resolution over North America and a coarser resolution for the rest of domain (Mailhot *et al.*, 2006). The core of the meteorological grid is shown in grey in Figure 1. The 30-hour forecasts were simulated on a daily basis, using the first six hours as a spin-up period.

The air quality modeling was performed with the AURAMS model (A Unified Regional Air-quality Modelling System). In this study, AURAMS is run on a 22.5km polar stereographic grid, shown in blue in Figure 1. Before, all required meteorological fields were interpolated to this target grid.

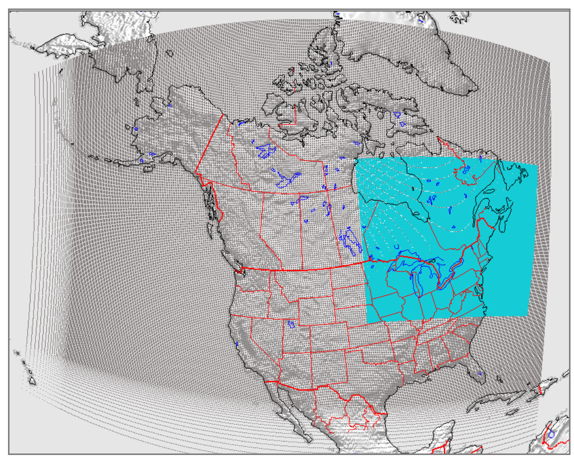

Fig 1.GEM (gray) and AURAMS (blue) grids used in our experience

2.2 Meteorological Analysis

The 2006 objective scores are analyzed for two series of meteorological fields, generated by different GEM versions: AQGEM (Air Quality GEM) and OPGEM (OPerational GEM used in 2006 by the Canadian Meteorological Centre). The first version is the one used for the policy modeling platform for 2006. There are some differences between these versions, mainly in the dynamic and physic libraries, where AQGEM uses more recent library versions. Objective scores were performed over the 15km GEM domain.

**Corresponding author:* Radenko Pavlovic , Air Quality Modelling Applications Section, Environment Canada, 2121 Rte Trans-canadienne, Dorval, QC, H9P 1J3;
e-mail: radenko.pavlovic@ec.gc.ca

The meteorological scores are calculated at surface level (for pressure, temperature, precipitation and dew point temperature) and on pressure levels (for geopotential height, temperature, wind and dew point temperature). Evaluation at the surface and upper air levels is done using standard deviation (SD) and bias except in the case of precipitation, where four metrics for categorical/probability forecasts have been used: Threat Score, Bias, Postagreement and Prefigurance. All four scores should be evaluated in the same time to avoid interpretation errors. It is also important to remind that the statistical scores applied are not perfect, and none can provide an accurate and complete evaluation of the meteorological forecasts (Stansky, 1982; Verret, 1984).

Furthermore, the 2006 meteorological variability (in terms of anomalies from climate averages) has been compared against those of 2005 and 2007 on different scales: global, national (Canada and USA) and regional for 3 Canadian cities: Montreal, Toronto and Ottawa. Previous analysis done at Environment Canada, confirmed that the year 2006 has only positive annual temperature biases when compared with climate period 1951-1980 (Figure 2). The overview is different in the case of the precipitation analysis where the biases shows a large variability, both positively and negatively (Figure 3). The objective of this study is to determine how these discrepancies from climate averages compared with those of 2005 and 2007, and how they can affect air quality results for the policy modeling platform.

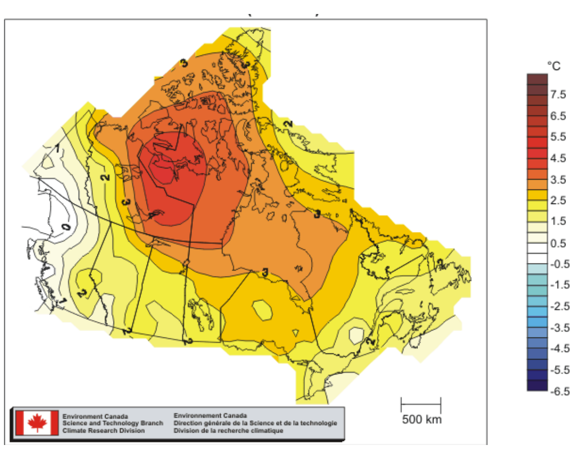

Fig 2. Canadian temperature departures for 2006 from national climate averages (EC, 2009)

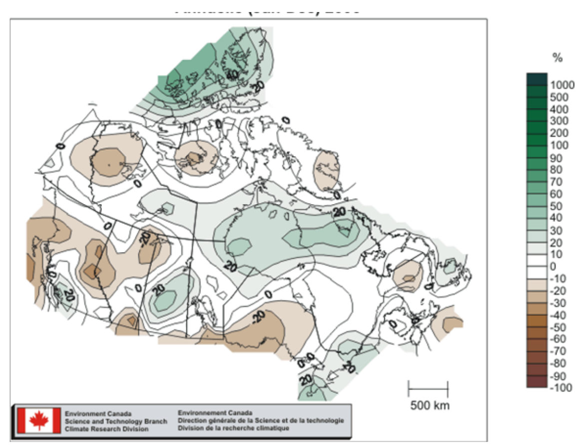

Fig 3 Canadian precipitation departures for 2006 from national climate averages (EC, 2009)

3. RESULTS

3.1 Objectives scores

The 2006 monthly and annual objectives scores results from the two model configurations have very similar scores for all examined meteorological fields. Figure 4 present the mean annual SD and biases for geopotential height, temperature, wind and dew point temperature. More detailed monthly and annual analysis is presented in the following subsections.

3.1.1 Geopotential Height

The standard deviation (SD) is almost the same for the two model configurations, with anomalies increasing with height. The mean monthly standard deviations are generally 1dam in the lower atmosphere (1000mb-850mb), and can go up to 6dam in the upper levels (near 10mb). The monthly and annual biases have values close to zero below 100mb. In the upper levels of the atmosphere, the AQGEM generally has higher anomalies than OPGEM.

3.1.2 Temperature

At the surface, the mean monthly standard deviation for both models is generally between 2ºC and 3ºC and the bias between 0ºC and 0.5ºC. AQGEM generally has slightly lower biases than OPGEM and OPGEM standard deviations are closer to observations. In the upper air, the monthly SD plots for the two model configurations are almost identical, with the highest discrepancies (compared with observations) near the ground and at the top of the model. The largest differences between

AQGEM and OPGEM are observed in the bias plots for the 24-hour forecast. From the ground up to 500mb the monthly and annual biases for both models at each forecast hour are generally below ±0.5ºC.

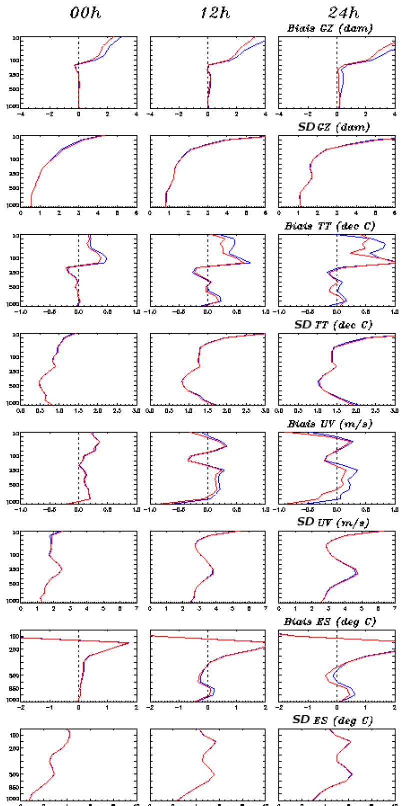

Fig 4. From top to bottom altering bias and standard deviation of upper air annual verification for geopotential height (GZ), temperature (TT), wind (UV) and dew points (ES). Red line represents OPGEM and blue lines AQGEM

3.1.3 Wind

The analysis of objectives scores for the wind field is focusing on upper atmospheric levels due to the limited number of surface stations with wind observations. The standard deviation plots are very similar for the two model configurations. There is however, larger differences observed for biases, caused by slightly stronger winds predicted by AQGEM, which leads to a stronger positive bias. The high SD anomalies (compared with observations) are close to 250mb, the height at which the jet stream is typically located.

3.1.4 Dew Point Temperature

At the surface the biases for both model configurations are almost identical, with values ranging between ±0.75ºC. The standard deviation at surface goes up to 4ºC in some months, and some deterioration is present from the 00 to 24 forecast hours. On the upper air levels, the SD plots for the two model configurations are almost identical. The monthly and annual SD values are under 4ºC below 850mb. The maximum value, close to 8ºC, is found around 500mb for the 24-hour forecast. The biases are also similar, with slightly higher dew point values predicted by AQGEM.

3.1.5 Precipitation

The results obtained for precipitation verifications per class are comparable for the two model configurations. Overall, the analysis of the four metrics presented in the methodology sections (prefigurance, postagreement, bias and threat), leads to the conclusion that the models achieved their best performance in the two first precipitation class (0.0mm – 0.2 mm and 0.2mm - 0.5mm), which represents the most frequent events (over 80% of all cases) (see Figure 5 and 6 for respectively an example of a monthly mean in winter and in summer). The heaviest precipitation rate (≥100mm) has the weakest monthly score with a bias below 1 (excluding only September 2006) and even frequently near 0, which means it is persistently underforecasted. This doesn't affect the overall model performance due to very weak monthly occurrence (under 0.1%).

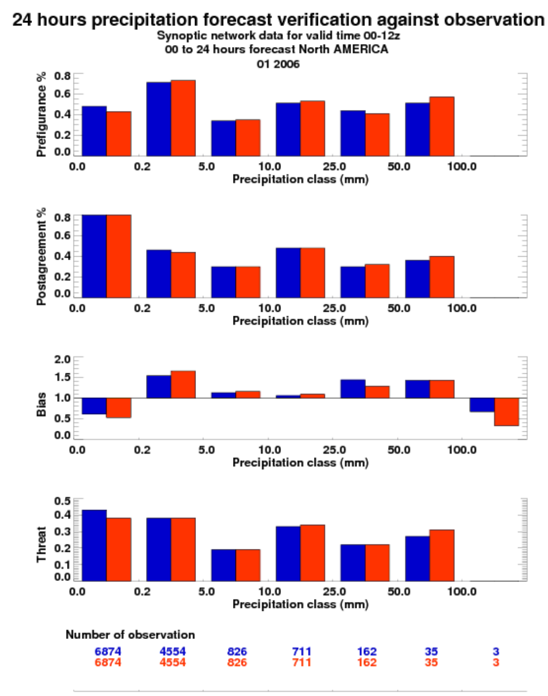

Fig 5. Precipitation verification for January 2006. Blue color represents OPGEM and red AQGEM**.**

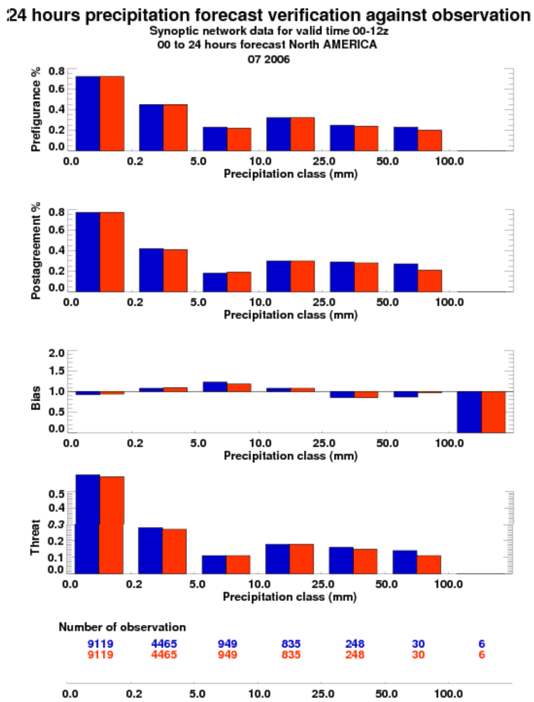

Fig 6. Precipitation verification for July 2006. Blue color represents OPGEM and red AQGEM

3.2 Climatological Representativeness of Selected Base Case Year, 2006, in Comparison to 2005 and 2007

The meteorology representativeness analysis was done for the two following fields: temperature and precipitation, at different spatial scales.

On a global and/or national level, 2005 and 2006 were the years with the most extreme weather, recording even the standing absolute records. Globally, 2005 was the hottest year recorded over the 1900-2008 period (Table 1) and also the wettest recorded in Canada (over the 1948-2008 period). Year 2006 is recorded as the second hottest year in Canada and the USA over 1948-2008 and 1985-2007 respectively (Table 1).

On a more regional level, the mean annual discrepancies, in terms of precipitation and temperature, were compared against climate values (1971-2000) for 3 Canadian cities: Montreal, Toronto and Ottawa. Among these 3 years, 2006 recorded the highest biases for temperature and precipitation with exclusively positive anomalies for temperature (Figure 7) and precipitation (Figure 8).

ANOMALY	PRECIPITATION	TEMPERATURE
Global (1900-2008)	*2005 non extreme year* *2006 (among 10 wettest)* *2007 non extreme year*	*2005 hottest recorded* *2006 5th hottest* *2007 6th hottest*
Canadian (1948-2008)	*2005 wettest recorded* *2006 non extreme year* *2007 non extreme year*	*2005 6th hottest* *2006 2nd hottest* *2007 not extreme year*
USA (1895-2007)	*2005 non extreme year* *2006 non extreme year* *2007 non extreme year*	*2005 9th hottest* *2006 2nd hottest* *2007 10th hottest*

Tab 1. Recorded meteorological anomalies in 2005, 2006 and 2007 at global and national levels. Data/analysis sources are Environment Canada (2009) for Canada and National Climate Data Center (2009) for global and USA data.

The monthly temperature anomalies for Toronto and Montreal (the two largest Canadian cities inside the AURAMS domain, used in this study, goes up to 6ºC-7ºC in January and December. Precipitation anomalies are higher for Montreal, with monthly discrepancies going up to 155%.

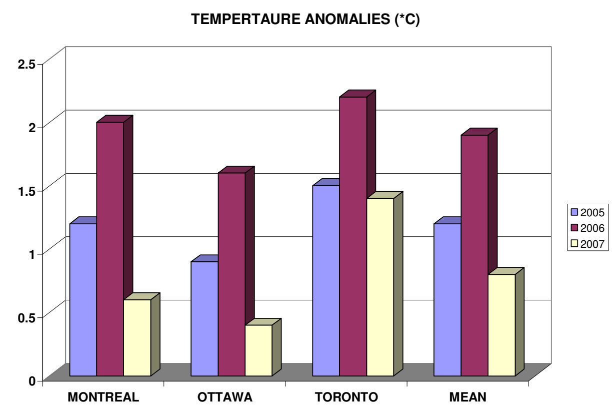

Fig 7. Temperature anomalies for 2005, 2006 and 2007 from climate averages (1971-2000) for Montreal, Toronto and Ottawa.

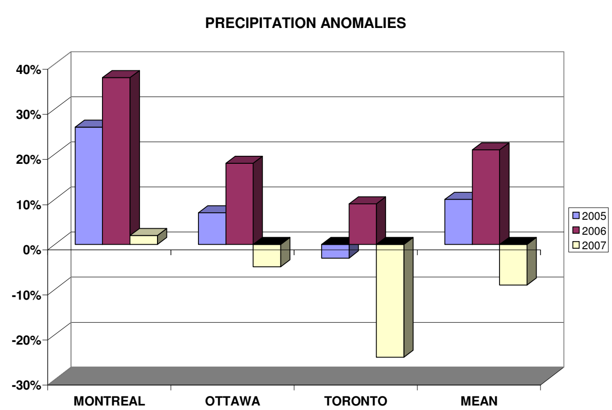

Fig 8. Precipitation anomalies for 2005, 2006 and 2007 from climate averages (1971-2000) for Montreal, Toronto and Ottawa.

Finally, the months of August and December were chosen for the analysis of meteorological variability on air quality modeling (results in next subsection). Air quality results will be shown for August 2006 and 2007, as well as results for December 2005 and 2006. Before analyzing the air quality results, the short summary for each summer and winter month pairs is given in the following paragraphs.

Observed precipitations for August 2007 have biases (compared with climate averages) of -13% and -74% for Montreal and Toronto respectively, compared with +67% and -49% in 2006. For the same time frame, temperature biases were stronger: 0.5ºC and 2.5ºC for Montreal and Toronto respectively, compared with -0.3ºC and 1.2ºC in 2006.

December 2005 has modest temperature anomalies (0.5ºC and -0.6ºC for Montreal and Toronto), compared with 5.1ºC and 4.8ºC in 2006. In terms of precipitations, both cities are relatively close to climate average for both 2006 and 2005 years. The selection of the months to be analyzed was not done based on the highest monthly anomalies.

3.3 Impact of Meteorological Variability on Air Quality Modeling

In this study, it was noted that different meteorological inputs has non-negligible impact on predicted PM2.5 (fine particulate matter of 2.5 microns and smaller) and ozone ambient levels. The analysis will focus on differences of predicted PM2.5 concentrations for the month of December and of predicted ozone concentrations for the month of August.

The spatial pattern for predicted average daily maximum 24-hour concentrations of PM2.5 is very similar for December 2006 and 2005 (Figures 9 and 10). However, when analyzing the differences, it seems that the month of December 2005 shows generally higher predicted PM2.5 levels (Figure 11). Also, the highest discrepancies are located in urban areas. The main meteorological difference between the months of December 2005 and 2006 comes from remarkably higher temperatures in 2006, as explained in section 3.2 for Toronto and Montreal. It can lead to a less stable atmosphere near the ground and a higher possibility of air mixing and ventilation in urban areas. The difference between the two forecasts goes up to 6µg/m^3 in some urban areas, such as Montreal, Boston, Quebec, Sherbrooke and Minneapolis.

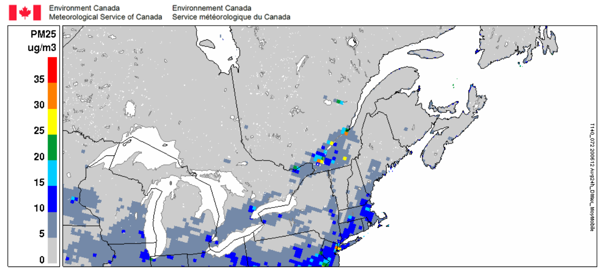

Fig 9. Average daily maximum 24-hour PM2.5 concentrations for December 2006

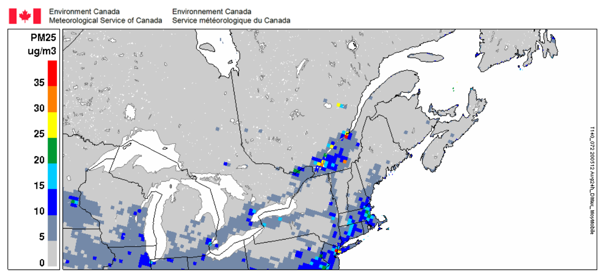

Fig 10. Average daily maximum 24-hour PM2.5 concentrations for December 2005

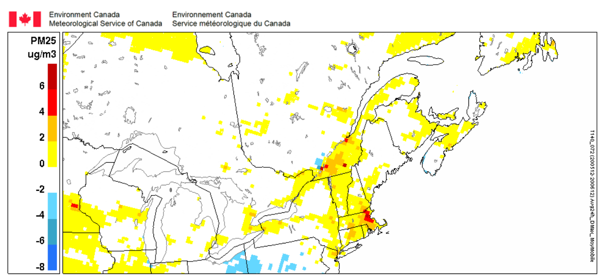

Fig 11 Average of daily maximum 24-hour PM2.5 concentrations, differences between December 2005 and 2006

The predicted daily maximum 8-hour ozone concentrations for August 2006 and August 2007 (Figure 12 and 13) are spatially very similar, with August 2007 having slightly higher predicted concentrations. The month of August was generally warmer and drier in 2007 compared to 2006. The difference between the two months (Figure 14) spans roughly from 6 to 14ppb (with the maximum of 14.2ppb occurring near New York City). This difference represents a 20-35% increase in predicted ozone concentrations close to some urban areas (Figure 15).

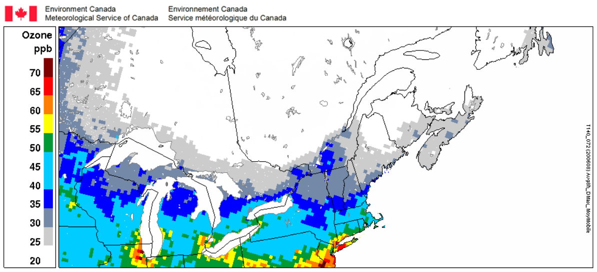

Fig 12. Average daily maximum 8-hour ozone concentrations for August 2006

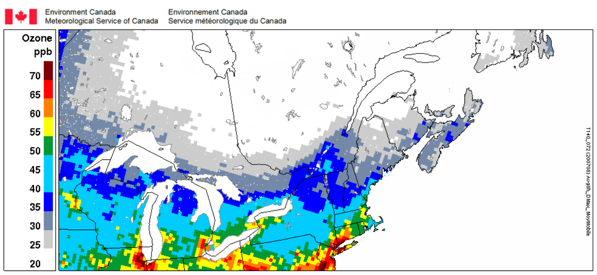

Fig 13. Average daily maximum 8-hour ozone concentrations for August 2007

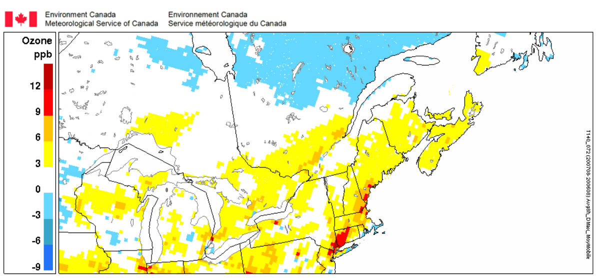

Fig 14. Average of daily maximum 8-hour ozone concentrations differences between August 2007 and 2006

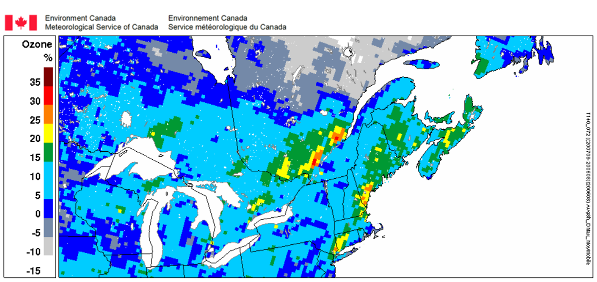

Fig 15. Average of daily maximum 8-hour ozone concentration, relative differences between August 2007 and 2006

4. SUMMARY AND CONCLUSIONS

Meteorological fields can vary significantly on the regional and global scales compared from one year to another. It is almost inevitable to have some regions with high anomalies (monthly, seasonal, etc) for large scale modelling over long forecast periods.

The objective scores analysis for the two model configurations are very similar. Comparing the selected base year of 2006 with the climate averages, it is observed that some important meteorological anomalies were present that year in Canada and the United States.

The impact of meteorological variability on air quality modeling was examined for two selected months for two consecutive years: August for 2006/2007 and December for 2005/2006. For winter months, we obtained differences in predicted average 24-hour PM2.5 concentrations of up to 6µg/m^3 in some urban areas. For summer months, the difference in 8-hour ozone concentrations goes up to 35% close to some urban centers. In our future work, we will try to determine the final impact of meteorological variability on air quality policies when different emission scenarios are applied.

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