Cloud Application of a Photochemical Grid Model with Reduced Resolution: An Alternative to Reduced Form Models

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MOTIVATION

Reduced form models (RFM) simplify calculations relating pollutant emissions to air quality impacts, exposure and risk. These models are used as screening tools enabling multitudes of emission scenarios to be quickly analyzed, but with a loss of fidelity to varying degrees.

RFMs are limited to specific chemical species and metrics (ozone and/or PM), emission sector granularity, and pre-defined spatial (county or state) and temporal (seasonal or annual) scales. Response surface models, developed with state-of-the-science photochemical grid models (PGMs), involve extensive resources to build and update, and require that scenarios of interest fit within the pre-defined matrix of sensitivities.

THIS STUDY

Applying PGMs directly alleviates most RFM limitations and enhances flexibility. We describe a Screening Model (SM) configuration of CAMx that leverages the power of a scalable cloud computing environment to run an entire year on a US-wide domain with reduced spatial resolution (36 km, 13 layers) well within a single wall clock day to support rapid screening of multiple emission scenarios.

GOALS

✓ Faster runtimes (annual simulation in ~ 1 day)

✓ Consistent model-measurement agreement with standard resolution models

✓ Consistent emission response/sensitivity with standard resolution models

✓ User interface (GUI) for easy operation

✓ Extendable to high resolution datasets for detailed analysis

MODELING PLATFORM

- Initial development and testing with CAMx v6.4
- Final implementation with CAMx v6.5 testing ISORROPIA and EQSAM aerosol chemistry
- **High Resolution Model (HR)**: 12km, 25 layers (EPA 2011 MP, version EN)
- **Screening Model (SM) :** 36km, 13 layers (Table 1)
- 24-core computer, parallelized for 12 MPI x 2 OMP

Table 1: Model scenarios and configurations for Screening Model development

Model Case	Model Configuration	Notes
HR baseline (HR)	12 x 12km, 25 layers	CAMx v6.4 and v6.5
36k_25l	36 x 36km, 25 layers	CAMx v6.4 only
36k_13l	36 x 36km, 13 layers	CAMx v6.4 only
36k_13l_freq60	36k_13l + aerosol partitioning once per hour	CAMx v6.4 only
Screening Model (SM)	36k_13l_freq60 + 900 second model timestep	CAMx v6.4 and v6.5

RUNTIME COMPARISON

Table 2: Annual runtimes by model configuration in wall clock hours; values in parenthesis are runtime factors with respect to High Resolution (HR)

Model Case	v6.4 Runtime (Hr) ISORROPIA	v6.5 Runtime (Hr) ISORROPIA	V6.5 Runtime (Hr) EQSAM
HR	306	342	426
36k_25l	41 (7x)		
36k_13l	27 (11x)		
36k_13l_freq60	24 (13x)		
SM	18 (17x)	29 (12x)	29 (15x)

MODEL PERFORMANCE

O_3 and $PM_{2.5}$ predictions were evaluated against measurements in January and July for 9 US regions. For O_3, SM reduced underpredictions (winter) and increased overpredictions (summer) due to NOx/VOC precursor mixing in the coarse grid cells. For $PM_{2.5}$, SM lowered concentrations, mostly due to dilution of primary emissions. Both HR and SM resulted in a mix of meeting and exceeding criteria performance benchmarks for bias.

Figure 1 : Normalized Mean Bias (%) of O_3 at AQS sites

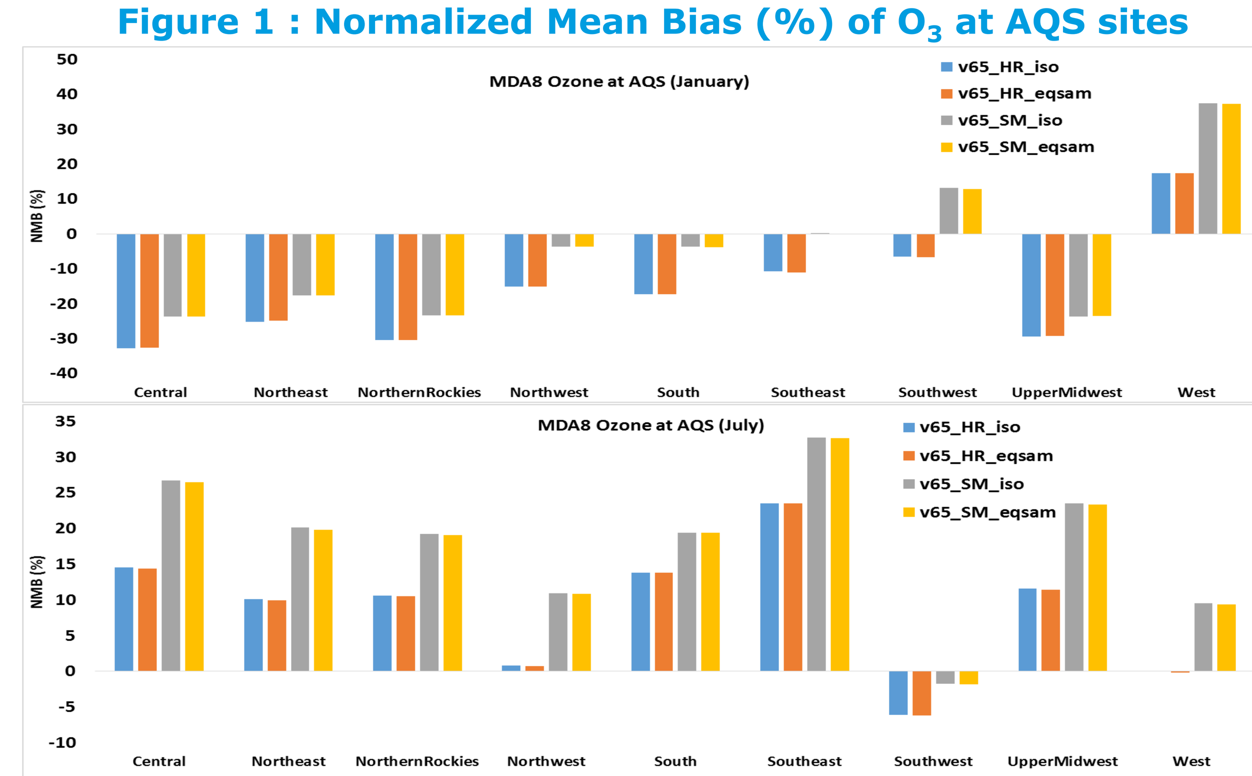
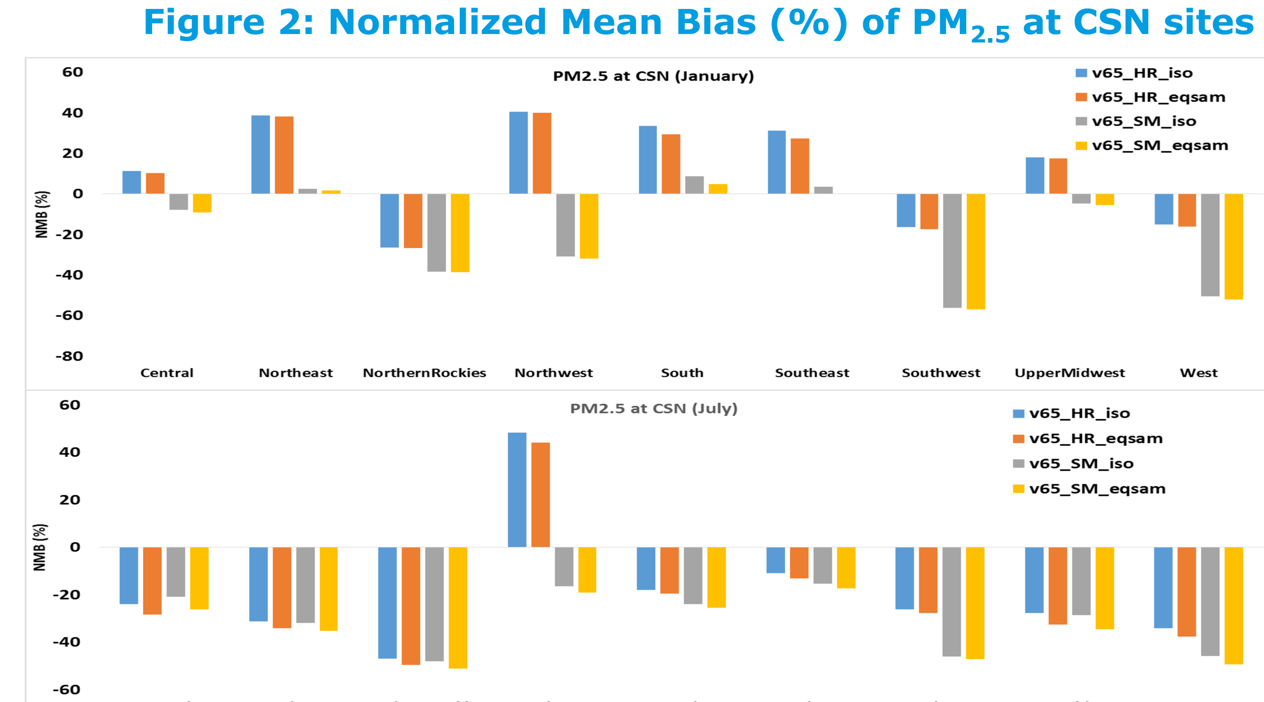


Figure 2: Normalized Mean Bias (%) of $PM_{2.5}$ at CSN sites



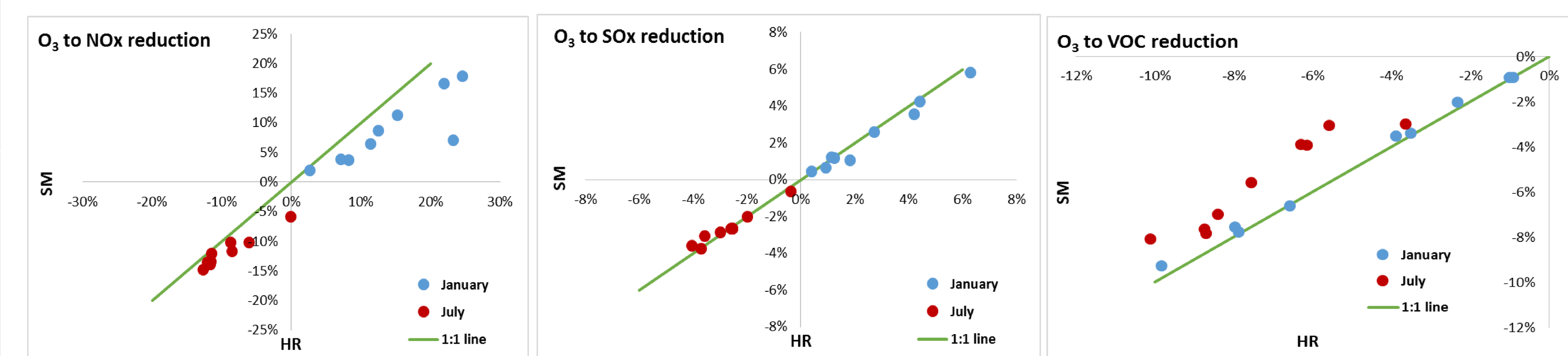
SENSITIVITY ANALYSIS

We ran HR and SM models with across-the-board 50% NOx, SOx, VOC reductions and compared responses by season and region. Figure 3 shows mean relative responses to summarize the difference between SM and HR responses.

$$\textbf{Mean Relative Response (\%)} = \frac{100}{NxM}\sum\frac{Reduction_{i,j}-Base_{i,j}}{Base_{i,j}}$$

where *i* is monitor among all *N* monitors, and *j* is day among all *M* days

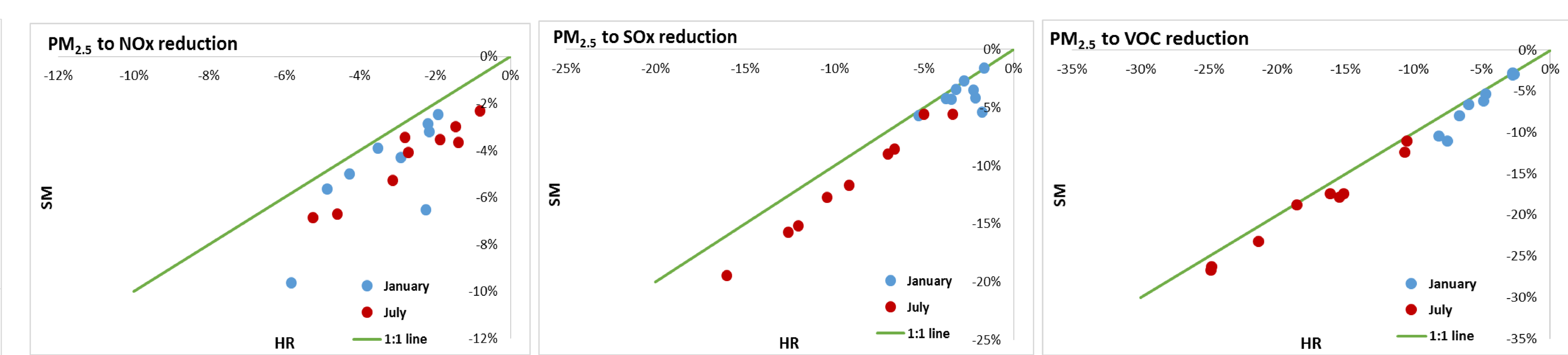
Figure 3 : Comparison of SM and HR mean relative responses for O_3 (top) and $PM_{2.5}$ (bottom) by season and 9 US regions (colored dots) from NOx, SOx and VOC reduction scenarios



SR and HR show similar responses, differing by 1-5%

Good agreement in responses

Similar responses, differing <1% in winter and <2.5% in summer



SR and HR responses deviate, but reasonable correlation and differences of <3–4%

Similar responses, differing by <2% in winter and <3.5% in summer

Similar responses, differing by <2.5%

FINDINGS

Model Performance: SM vs HR O_3 performance is consistent: SM affects model bias by 5-20% depending on season and urban/rural. SM vs HR $PM_{2.5}$ performance is more variable: SM affects model bias by 5-40% depending on season and urban/rural.

Sensitivity Analysis: SM generally replicates HR O_3 and $PM_{2.5}$ sensitivity to NOx, SOx, VOC reductions, with high correlation, consistent directionality, and acceptable signal-to-noise. $PM_{2.5}$ responses to NOx reductions are the only exception, but absolute $PM_{2.5}$ concentration impacts are small in both HR and SM.

Conclusion: A reduced-resolution PGM configuration run on a scalable cloud platform can be viable alternative to RFMs.

NEXT STEPS

1) Perform speed/cost tests on Microsoft Azure Cloud; 2) Develop and test on-line emission pre-processor, NAAQS-relevant post-processor and GUI; 3) Demonstrate and document.