

# Recent Advances in Photochemical Air Quality Modeling Using the CAMx Model: Current Update and Ozone Modeling of Point Source Impacts

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## ABSTRACT

The Comprehensive Air-quality Model with extensions (CAMx) is a publicly available ([www.camx.com](http://www.camx.com)) photochemical grid model originally developed in the late 1990s to treat urban and regional ozone issues. With its first applications as part of the Ozone Transport Assessment Group (OTAG) process, it has undergone continuous development and refinements. Because it consists of all new computer coding in a modular framework, it is ideally suited for extension to other air quality issues. Recent advances in CAMx include:

Implementation of “Probing Tools”: A series of probing tools have been implemented in CAMx to obtain information on ozone source-receptor relationships, VOC versus NO<sub>x</sub> sensitivities, source apportionment, and to extract information on ozone formation processes. The probing tools implemented in CAMx include: Ozone Source Apportionment Technology (OSAT); Decoupled Direct Method (DDM); and Process Analysis (PA).

Treatment of Particulate Matter: State of the Science aerosol modules have been implemented in CAMx to treat particulate matter (PM) and visibility issues, including aerosol thermodynamics, aqueous-phase chemistry, secondary organic aerosol, and a sectional approach to treat PM size distributions.

Treatment of Air Toxics: Air toxics modules have been implemented in CAMx to treat both chemically reactive (e.g., benzene, 1,3-butadiene, formaldehyde, and acetaldehyde) and inert (e.g., chromium and diesel particulate) air toxics. A subgrid-scale plume module has also been implemented to treat the near source (fence line) impacts of air toxics from point sources.

Advanced Treatment of Point Source Ozone Impacts: CAMx has an all new flexi-nesting feature that allows the specification of nested fine grids with or without providing the fine grid inputs. This treatment is ideal for resolving the ozone impacts of point sources.

## INTRODUCTION

The Comprehensive Model with Extensions (CAMx) is a publicly available ([www.camx.com](http://www.camx.com)) three-dimensional multi-scale photochemical grid model that is developed and maintained by ENVIRON International Corporation<sup>1</sup>. CAMx was developed with all new code during the late 1990s using modern and modular coding practices. This has made the model an ideal platform for the extension to treat a variety of air quality issues including ozone, particulate matter (PM), visibility, acid deposition, and air toxics. The flexible CAMx framework has also made it a convenient and robust host model for the implementation of a variety of mass balance and sensitivity analysis techniques including Process Analysis, Decoupled Direct Method (DDM)<sup>2</sup>,

and the Ozone Source Apportionment Technology (OSAT). CAMx is currently in use to assist in the development of ozone abatement emission control strategies by a variety of regulatory agencies<sup>3,4</sup>. CAMx is designed to address multiscale ozone issues from the urban- to regional-scale. It is publicly available with no fees or restrictions on its use and contains the following features:

- Two-way grid nesting that supports multi-levels of fully interactive grid nesting (e.g., 36/12/4-km).
- CB4 or SAPRC99 Chemical Mechanisms.
- Two chemical solvers, the CAMx Chemical Mechanism Compiler (CMC) Fast Solver or the highly accurate Implicit Explicit Hybrid (IEH) solver.
- Multiple numerical algorithms for horizontal transport including the Piecewise Parabolic Method (PPM), Bott, and Smolarkiewicz advection solvers.
- Subgrid-scale Plume-in-Grid (PiG) algorithm to treat the near-source plume dynamics and chemistry from large NO<sub>x</sub> point source plumes.
- Ability to interface with a variety of meteorological models including the MM5 and RAMS prognostic hydrostatic meteorological models and the CALMET diagnostic meteorological model (others also compatible).
- Treatment of particulate matter (PM) using an empirical aerosol thermodynamics algorithm.
- Flexi-nesting capabilities that allow the specification of nested fine-grids with explicit fine-grid data for none to all of the inputs. Any fine grid data not supplied are interpolated from a "parent" grid.
- Support for shared memory multi-processor workstations.
- Implementation of a suite of "Probing Tools" that incorporate the latest mass balance, sensitivities, and source apportionment techniques:
  - The Ozone Source Apportionment Technology (OSAT) ozone apportionment technique that identifies the ozone contribution due to geographic source regions and source categories (e.g., mobile, point, biogenic, etc.).
  - The Decoupled Direct Method (DDM) sensitivity coefficient approach that allows for the calculation of sensitivities of ozone and other species to emission subgroups and initial and boundary conditions.
  - The Process Analysis technique that performs mass balancing and extraction of key chemical and physical processes from the model to help explain why the model got the answer it got.

## **CAMx 2002**

During the first half of the year 2002, ENVIRON expects to release a version of CAMx with full-science treatment of particulate matter (PM) and treatment of air toxic compounds.

In a joint study with Carnegie Mellon University (CMU, Dr. Spyros Pandis) and Sonoma Technology, Inc. (STI), ENVIRON is implementing a state-of-science treatment of aerosols in CAMx<sup>5</sup>. Multi-size particulate matter (PM) is being treated in CAMx using the sectional approach whereby the size distribution of PM is split into several (e.g., 10) size sections. Detailed aerosol thermodynamics (ISORROPIA), aqueous-phase chemistry (bulk and two-section approaches), mass transfer, and wet and dry deposition algorithms are utilized.

CAMx is also being updated to treat air toxic compounds including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, chromium, hexavalent chromium, and diesel particulate. Air toxics in CAMx will be treated using the “reactive tracer” approach whereby the air toxics are simulated in parallel to the host photochemical grid model. Information on chemical reaction and deposition rates are extracted from the host model at each time step and applied to the air toxics. This allows the easy addition of new air toxic compounds as well as the extension to other species. A unique aspect of the implementation of air toxics in CAMx is the use of a subgrid-scale Gaussian plume model to treat the near-source air toxics impacts of point sources within the CAMx grid model framework. The purpose of the air toxics GPM is quite different from the Plume-in-Grid (PiG) modules used for ozone modeling in CAMx, UAM-V, and CMAQ. Whereas the ozone PiG modules are designed to treat the early evolution, chemistry, and plume dynamics of large NO<sub>x</sub> point source plumes, the air toxics GPM is designed to simulate the near-source subgrid-scale “fence line” or “hot spot” impacts of air toxic point sources that can not be resolved by the host grid model.

## **POINT SOURCE OZONE IMPACTS**

As progress in reducing the peak ozone concentrations in urban areas is achieved, the ozone problem is expanding from a solely urban-focus to a mixed regional-scale and urban-scale issue. The Ozone Transport Assessment Group (OTAG) has shown that the ozone problem in some urban areas is influenced by upwind sources outside of the nonattainment area. The movement to the lower 8-hour ozone standard will further expand the area of influence of emission contributions to ozone exceedances.

When large new sources are proposed they must undergo a New Source Review (NSR) process. NSR involves Prevention of Significant Deterioration (PSD) analysis for Class I and Class II area impacts and analysis of the significance of the proposed projects impacts on criteria pollutants. If a project is to emit significant amounts of ozone precursors (VOC and/or NO<sub>x</sub>) and the source is to be located in an ozone nonattainment area, then the project must obtain emission offsets. If the source is located outside of a nonattainment area and the State believes that the source may have an impact on ozone attainment in a nonattainment area, then the State may request the permit applicant to address the project’s ozone impacts.

The EPA recommends that ozone impacts be estimated using a photochemical grid model. The development of a photochemical grid modeling database from scratch and conducting the necessary model performance evaluation and diagnostic testing are quite resource and time intensive and exceed the scope for most permit activities. More recently there have been instances in which states have asked proposed sources located outside of a nonattainment area to demonstrate that they would not interfere with the nonattainment area’s ozone attainment. Some states have allowed new sources to estimate their ozone impacts using the Lagrangian Reactive Plume Model (RPM)<sup>6</sup>. The RPM is a plume-segment model that treats just the emissions of the source under study and entrains user-specified background concentrations to perform the plume chemistry. Such background concentrations are not readily available and introduces a high degree of uncertainty in the RPM calculation of the source’s ozone impact.

Photochemical grid models are far more technically superior to Lagrangian photochemical models, such as RPM<sup>6</sup> and SCICHEM<sup>7</sup>. Photochemical grid models treat all sources at once and the effects of their interactions on photochemistry. However, for addressing single source

impacts, photochemical grid models can only resolve the point source plume to the grid spacing used, which is typically 4-5-km for urban-scale modeling to 12-36-km for regional-scale modeling. Thus, grid models will instantaneously distribute point source emissions across a grid cell thereby incorrectly characterizing the near-source chemistry of the point source plume. For ozone impacts, this instantaneous dilution of the NO<sub>x</sub> emissions across a grid cell results in faster and more ozone formation because it neglects the near-source high NO<sub>x</sub> plume where reactive NO<sub>x</sub> is lost and ozone formation is suppressed. Thus, many of the new advanced photochemical grid models have incorporated subgrid-scale Plume-in-Grid (PiG) modules that are used to model emissions from large NO<sub>x</sub> point sources so they are not instantaneously diluted across a grid cell.

## Plume-in-Grid Modules

Most of the current advanced photochemical grid models (e.g., CMAQ, CAMx, and UAM-V) incorporate a Plume-in-Grid (PiG) module to treat major NO<sub>x</sub> point sources. PiG modules are Lagrangian plume models that are embedded in the grid model and treat the early evolution and chemistry of the NO<sub>x</sub> point source plume. There are basically three stages of plume chemistry evolution in NO<sub>x</sub> point source plumes that have been both observed<sup>8</sup> and modeled<sup>9</sup>:

Initial Stage: The initial stage of the NO<sub>x</sub> plume evolution is dominated by high NO<sub>x</sub> concentrations and an initial deficit in ozone due to titration with NO. Chemistry is almost completely inorganic and ozone formation is highly VOC-limited with little or no ozone formed.

Plume Growth Stage: As the plume grows it entrains ambient air that is usually rich in VOCs. Ozone formation begins on the outer fringes of the plume that may grow to be above the ambient background even though an ozone deficit may still exist in the center of the plume where higher NO<sub>x</sub> concentrations reside.

Mature Plume Stage: The plume is “mature” when there is typically ozone enhancement across the plume, low NO<sub>x</sub> concentrations, and high VOC/NO<sub>x</sub> ratios.

The above description is for NO<sub>x</sub> plumes under ozone formation conditions (e.g., hot summer day). During conditions when ozone formation is suppressed (e.g., the winter), the plume may exhibit an ozone deficit throughout its lifetime.

The first PiG module was the embedding of the RPM within the Urban Airshed Model (UAM) in the early 1980s to form the Plume Airshed Reactive Interactive System (PARIS)<sup>10</sup>. The RPM was also embedded in the UAM-V<sup>11</sup> and in the SAQM<sup>12</sup> models. A PiG module is included in the CAMx model<sup>1</sup>. Two different PiG models have been added to EPA’s Models-3/CMAQ modeling system, the CMAQ-PinG module based on the Gillani reactive plume model<sup>13</sup> and the Advanced Plume Treatment module (CMAQ-APT)<sup>14</sup> that is based on a the second order closer reactive plume model (SCICHEM)<sup>7</sup>.

Each of these PiG modules is a little different in their formulation and philosophy for treating subgrid-scale plumes. The CAMx philosophy is that the grid model best represents the interactions of sources and their chemistry so uses the PiG module to treat the initial stage of the plume evolution. As soon as the plume size is commensurate with the grid cell size the plume’s

mass is leaked into the grid model. The UAM-V RPM PiG module runs two RPM simulations in parallel, one with and one without the plume's emissions. Ambient air is entrained from the grid model. When the plume size hits a user-specified dumping criteria, which typically occurs during the plume growth stage, the difference of the two RPM simulations' mass are released to the grid model.

The CMAQ PiG modules take a different approach in that they hold onto the NO<sub>x</sub> plume's mass until they reach chemical "maturity". Thus, the plumes get very large and may span several grid cells before the mass is released in the grid.

Although the current PiG modules represent different approaches, they all suffer from the same problems and limitations related to having an artificial Lagrangian plume model embedded in the photochemical grid model:

- Limited or no representation of horizontal and vertical wind shear that may advect different parts of the plume in different directions (this is especially important for the PiG modules that carry the plume to maturity);
- Limited or no representation of the concentration gradients across the NO<sub>x</sub> point source plumes;
- Limited or no treatment of the interaction of the plume with other sources;
- The procedures for transferring the plume mass to the grid model may not be mass conservative; and
- The criteria for transfer of the plume mass to the grid model is ill-defined and arbitrary.

Of particular concern is the interaction of the NO<sub>x</sub> point source plume chemistry with surrounding sources and the treatment of variable winds across the plume (e.g., wind shear). These are both processes that photochemical grid models treat quite well, given sufficient grid resolution to resolve the plume. Previous approaches for addressing the subgrid representation of emissions and their subsequent chemical evaluation using the grid model framework have followed three basic approaches: (1) static two-way fine-grid nesting<sup>11</sup> (e.g., CAMx and UAM-V); (2) static two-way nonuniform grids<sup>15</sup> or (3) adaptive grid meshing<sup>16</sup>. Of these, only the static fine-grid nesting approach has been successfully implemented in operational models. When a fine-scale grid is specified, then in most cases the model requires corresponding fine-scale meteorological, emissions, and topographical inputs. Performing such fine-scale meteorological and emissions modeling is time and resource intensive. In the case of proposed new sources, the a priori development of fine-grid inputs focused on the new source location would likely not exist. However, the CAMx flexi-nesting capability allows the introduction of fine-grid representation of the new point sources without the associated time and resource constraints of the other techniques. This is demonstrated next with a real-world example.

### **Example Point Source Impact Assessment**

A new source (the project) that would emit emissions of nitrogen oxides (NO<sub>x</sub>) was proposed to be located just south of the St. Louis nonattainment area. The state raised concerns that the source may interfere with the recently approved St. Louis State Implementation Plan (SIP) ozone attainment demonstration<sup>17</sup>. The state requested that the new source demonstrate that it would not interfere with the St. Louis SIP ozone attainment demonstration.

The St. Louis SIP ozone attainment demonstration included photochemical modeling of two severe ozone episodes in St. Louis, a July 1991 and a July 1995 episode. The two photochemical modeling databases used a grid resolution of 4-km. Concerns were raised that the 4-km grid resolution, even with the PiG treatment, is insufficient to represent the ozone chemistry and impact of the proposed point source. Thus, the CAMx flexi-nesting capability was employed to better resolve the ozone impacts from the new point source.

CAMx was applied for the 2003 St. Louis SIP Final Strategy and a 2003 new project emission scenario using several nests of fine grids over the location of the proposed project. Figure 1 displays the multiple grid nests centered on the new facility used in the refined CAMx flexi-nesting modeling. A 2-km grid was defined over the project and extending downwind toward the north and east. A 1-km grid was embedded in a 2-km grid that was defined south of St. Louis covering about 6 counties. The 4/2/1-km nested-grid set-up was designed to better resolve the project's plume impacts and interactions with other point sources in the area. Non point source emissions and meteorology inputs were provided at the 4-km resolution of the St. Louis SIP databases and were interpolated to the 2-km and 1-km resolution using the CAMx flexi-nesting capability.

## Ozone Impacts

The spatial distribution of estimated daily maximum ozone concentrations for the 2003 Final Strategy Base Case and 2003 New Source emission scenarios and their differences during the July 11-13, 1995 episodes are shown in Figures 2 through 4. For those worst case ozone episode days in St. Louis, the ozone plume from the new source does not contribute to ozone concentrations approaching the ozone standard.

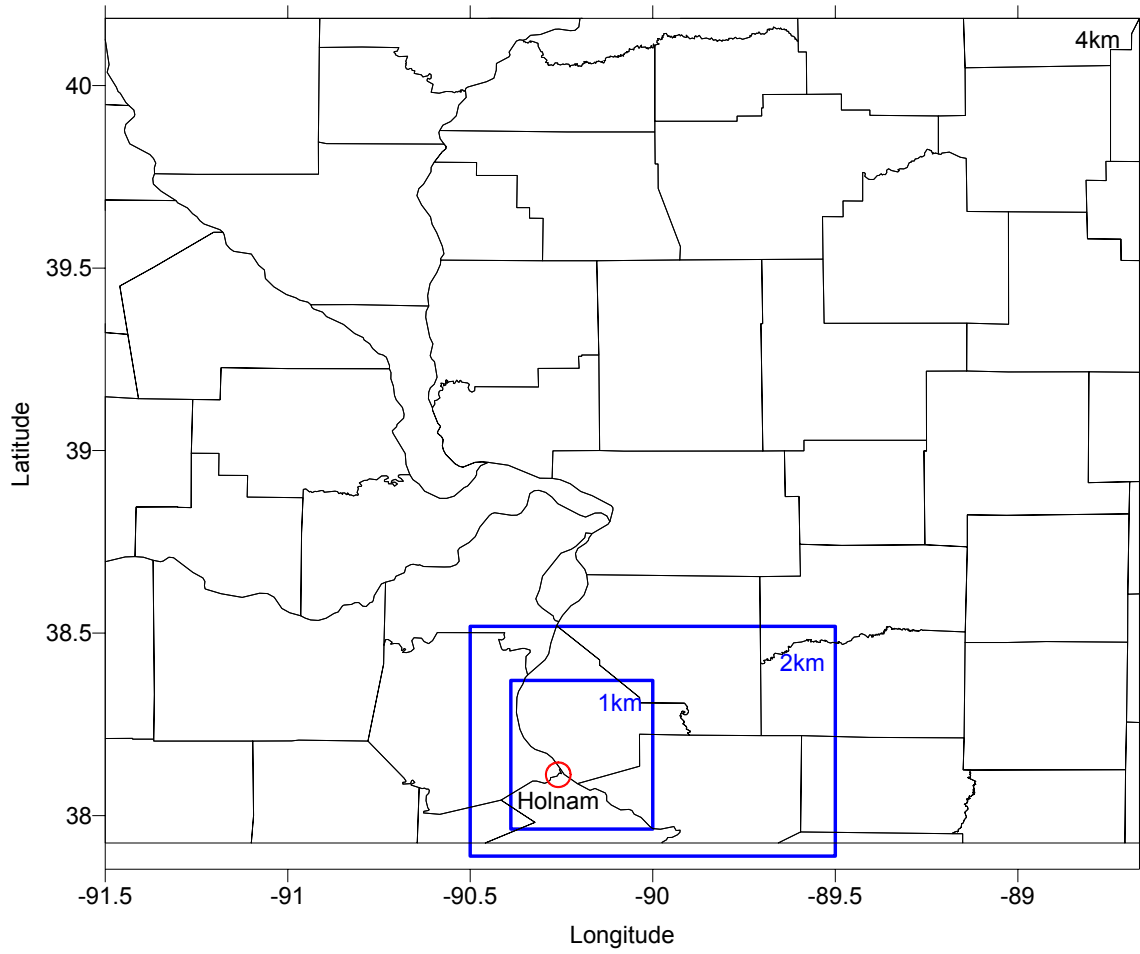
Table 1 summarizes the CAMx flexi-nesting daily peak ozone concentrations for the 2003 Final Strategy and 2003 New Source emission scenarios. For elevated peak ozone concentrations (> 100 ppb), the introduction of emissions from the New Source is estimated to increase the peak ozone concentrations from 0.00 to 0.24 ppb. Since observed ozone concentrations are reported to the nearest ppb in EPA's AIRS compliance database, then the modeling results show that emissions from the New Source would have no measurable effect on the peak ozone concentrations downwind of St. Louis and would have no effect on ozone exceedances in the St. Louis area.

**Table 1.** CAMx flexi-nesting estimated peak daily ozone concentrations for the 2003 St. Louis SIP Final Strategy and the 2003 Final Strategy with Holnam Lee Island emissions scenarios.

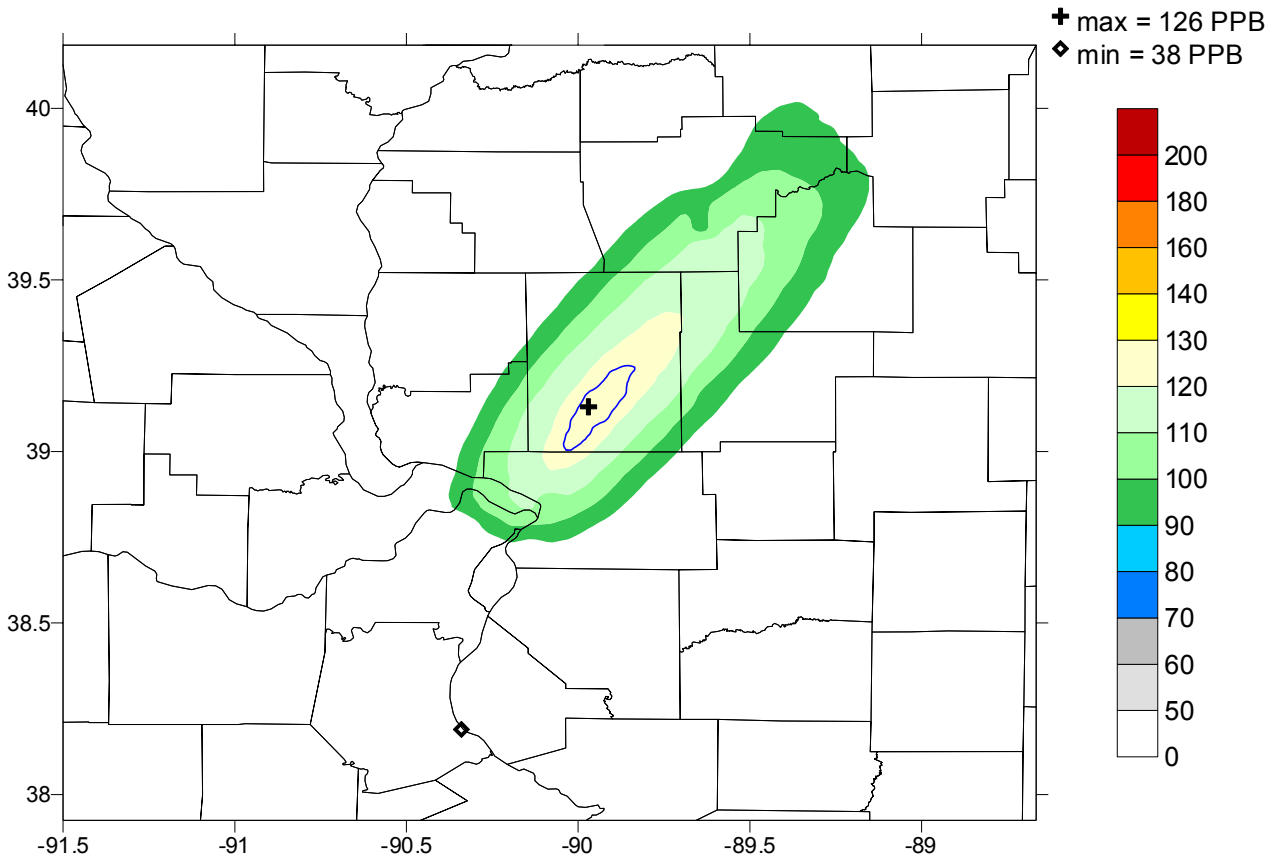
<b>Episode Day</b>	<b>2003 SIP Final Strategy (ppb)</b>	<b>2003 Holnam Lee Island (ppb)</b>	<b>Difference In Peaks (ppb O<sub>3</sub>)</b>
July 11, 1995	125.65	125.68	0.03
July 12, 1995	126.28	126.52	0.24
July 13, 1995	128.61	128.62	0.01
July 14, 1995	124.07	124.07	0.00

The St. Louis SIP weight of Evidence (WOE) attainment demonstration was repeated with the new source and demonstrated that the new source had no effect on the St. Louis SIP ozone attainment demonstration.

**Figure 1.** CAMx flexi-nesting 4/2/1-km grid configuration used in the CAMx flexi-nesting ozone impact modeling of the new source.

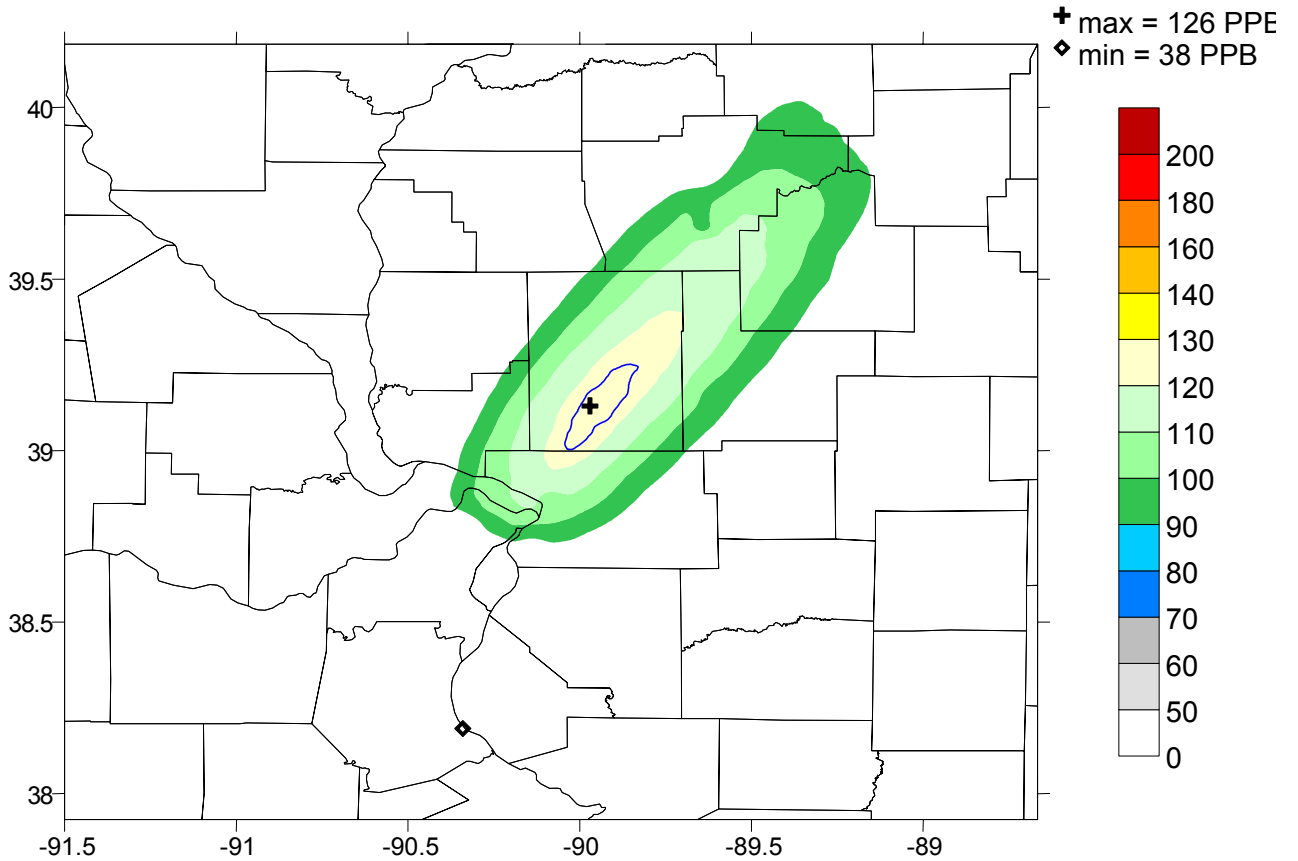


**Figure 2a.** Estimated daily maximum ozone concentrations (ppb) on July 11, 1995 for the 2003 Final Strategy Base case CAMx flexi-nesting simulation.



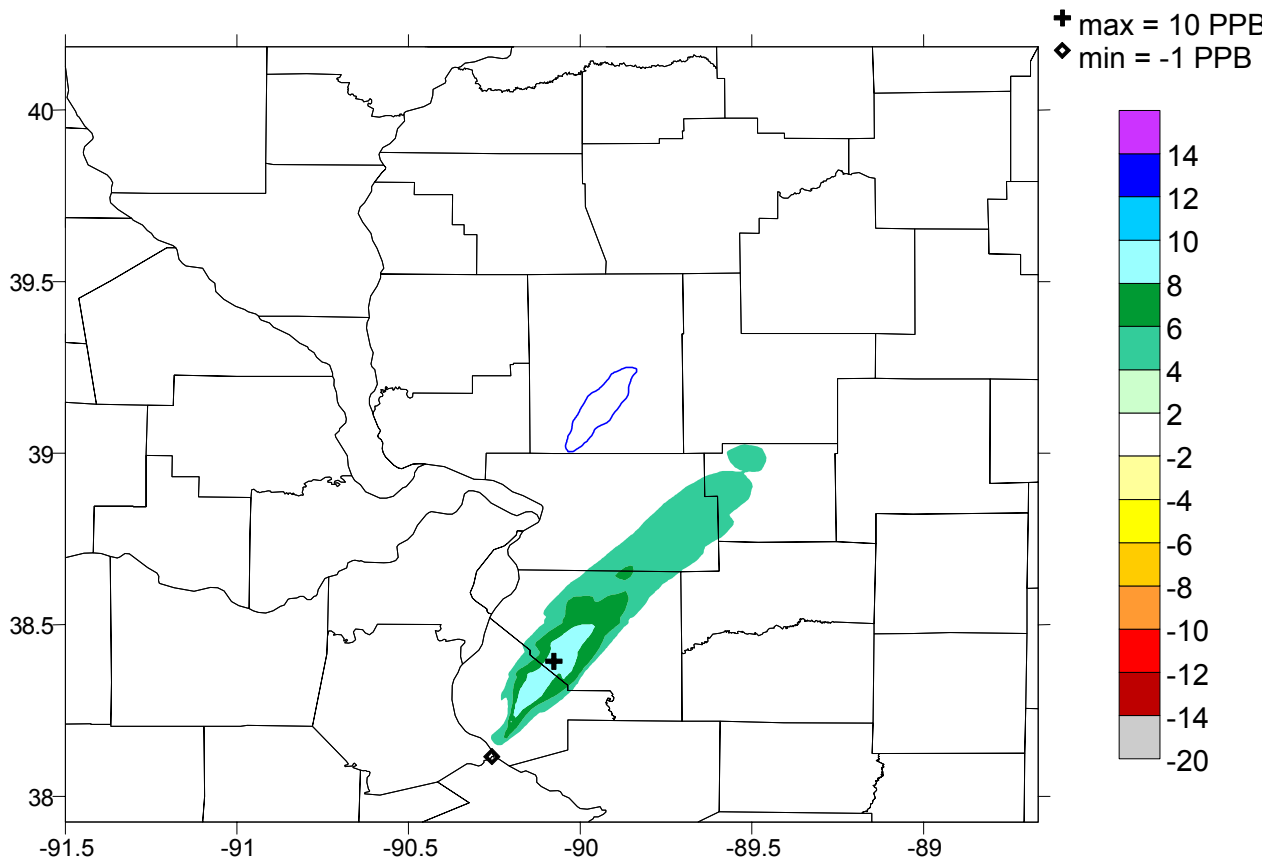
**Daily Max 1-Hour Ozone (ppb)**  
**July 11, 1995**  
**1995 CAMx3 Strat3a Base Case for 2003 with Flexi-Nesting**

**Figure 2b.** Estimated daily maximum ozone concentrations (ppb) on July 11, 1995 for the 2003 New Sources emissions scenario CAMx flexi-nesting simulation.



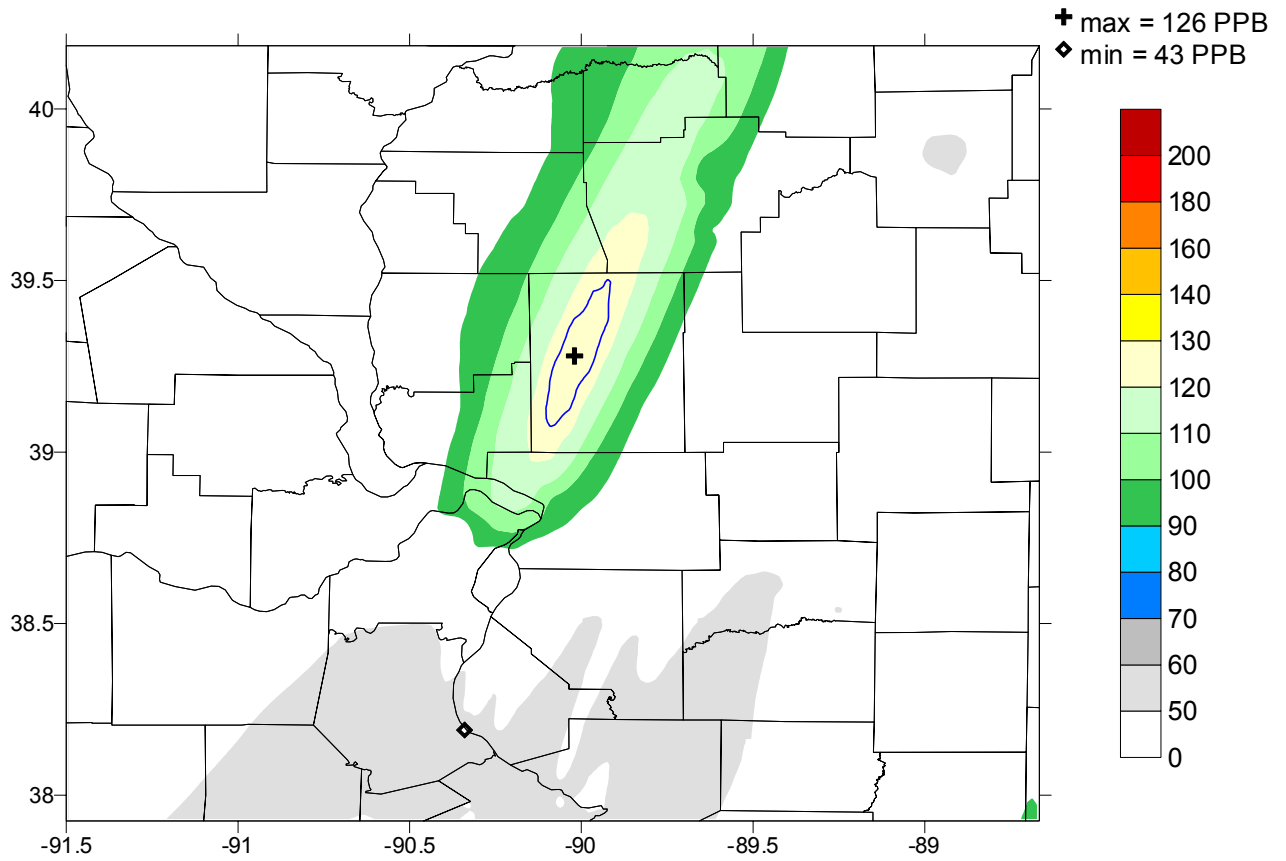
**Daily Max 1-Hour Ozone  
July 11, 1995  
2003 with the New Source using CAMx3 and Flexi-Nesting**

**Figure 2c.** Differences in daily maximum ozone concentrations (ppb) on July 11, 1995 between the 2003 final strategy base case and 2003 New Sources emissions scenarios (New Sources – Base).



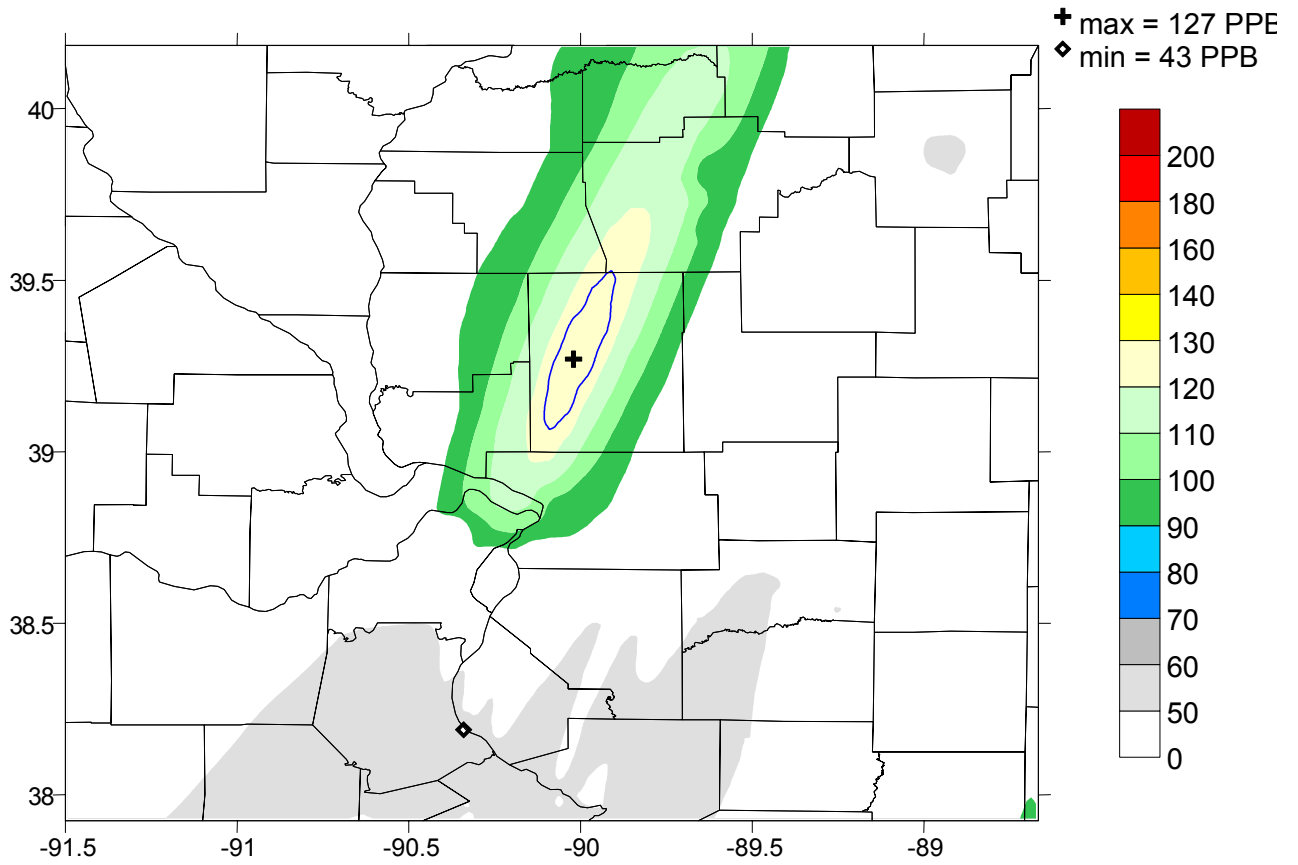
**Difference in Daily Max Ozone with the Addition of the New Source  
July 11, 1995 for  
1995 Episode using CAMx3 and Flexi-**

**Figure 3a.** Differences in daily maximum ozone concentrations (ppb) on July 12, 1995 between the 2003 final strategy base case and 2003 New Sources emissions scenarios (New Sources – Base).



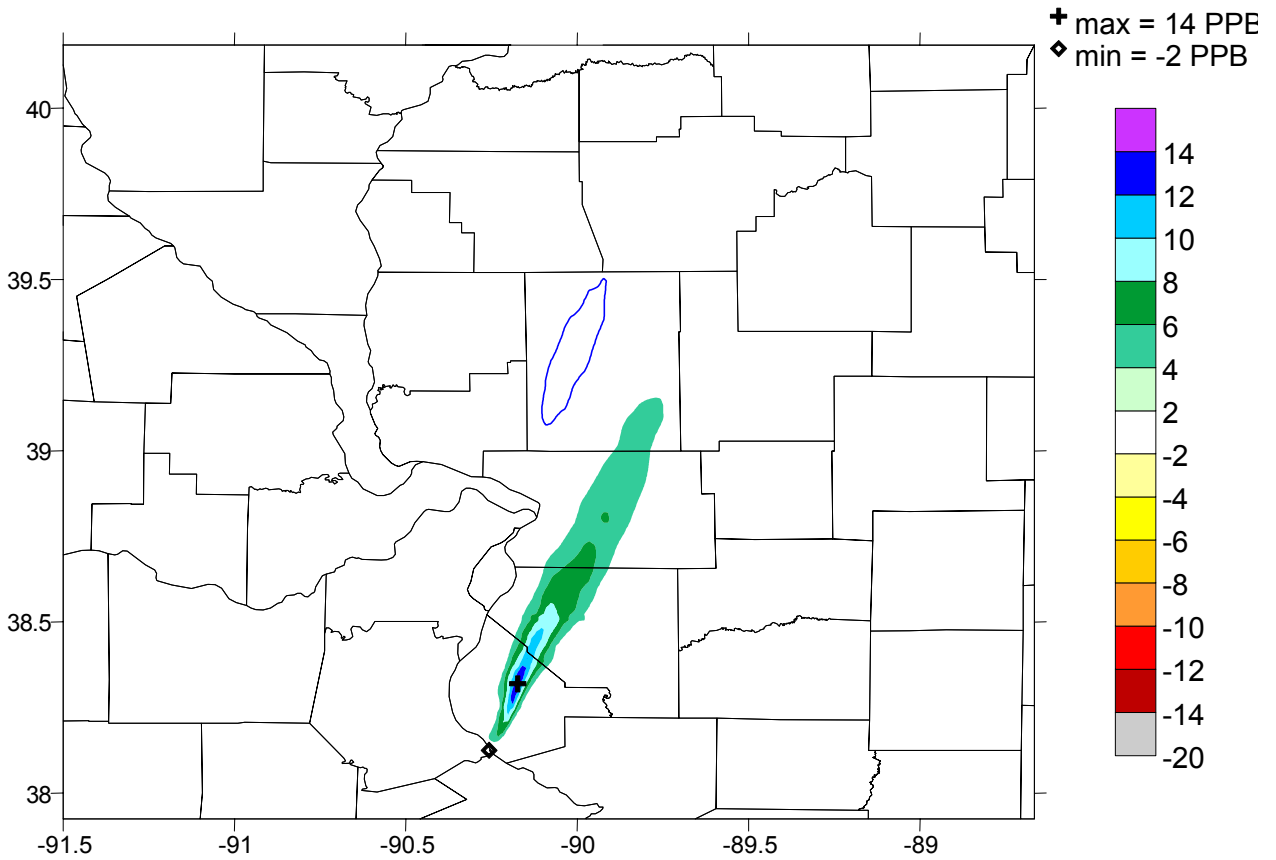
**Daily Max 1-Hour Ozone (ppb)  
July 12, 1995  
1995 CAMx3 Strat3a Base Case for 2003 with Flexi-Nesting**

**Figure 3b.** Estimated daily maximum ozone concentrations (ppb) on July 12, 1995 for the 2003 New Source emissions scenario CAMx flexi-nesting simulation.



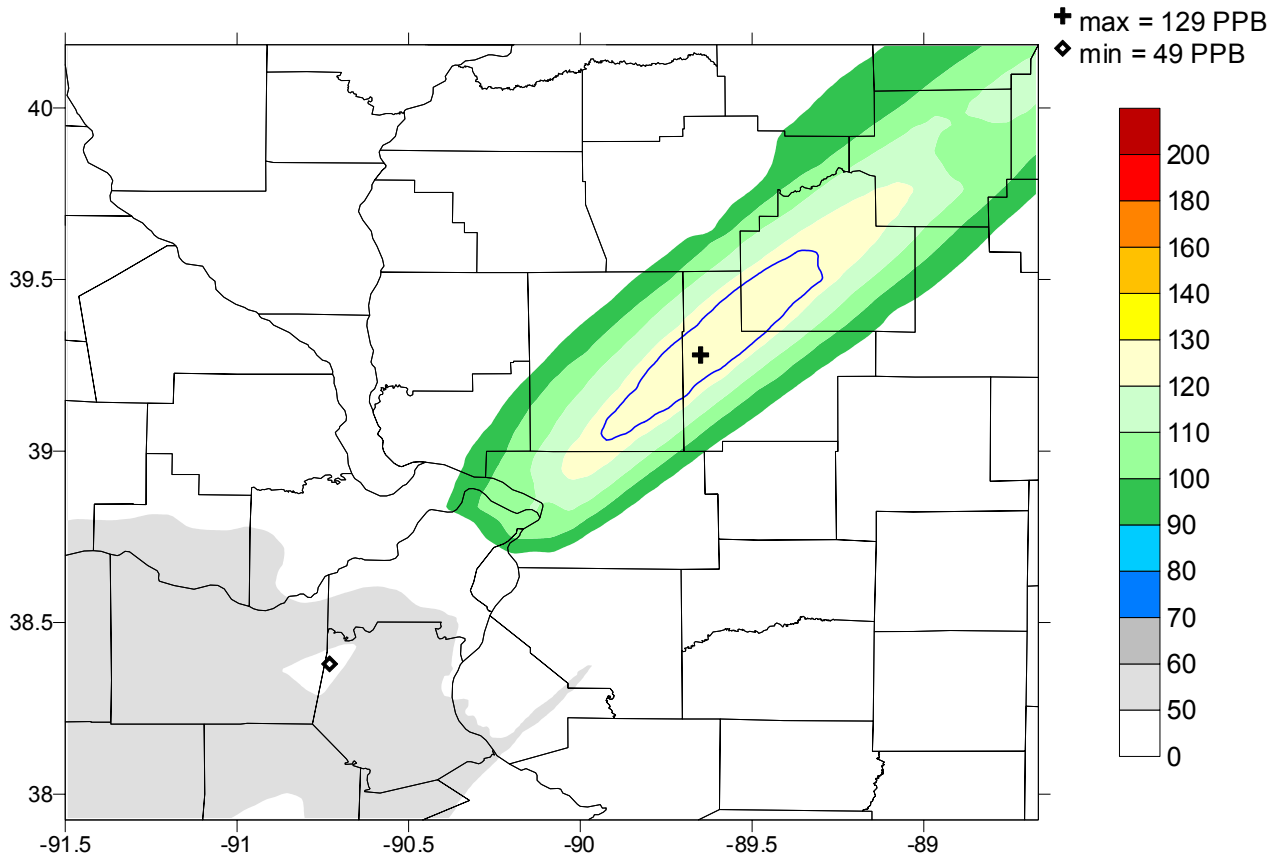
**Daily Max 1-Hour Ozone  
July 12, 1995  
2003 with the New Source using CAMx3 and Flexi-Nesting**

**Figure 3c. .** Differences in daily maximum ozone concentrations (ppb) on July 12, 1995 between the 2003 final strategy base case and 2003 New Sources emissions scenarios (New Sources – Base).



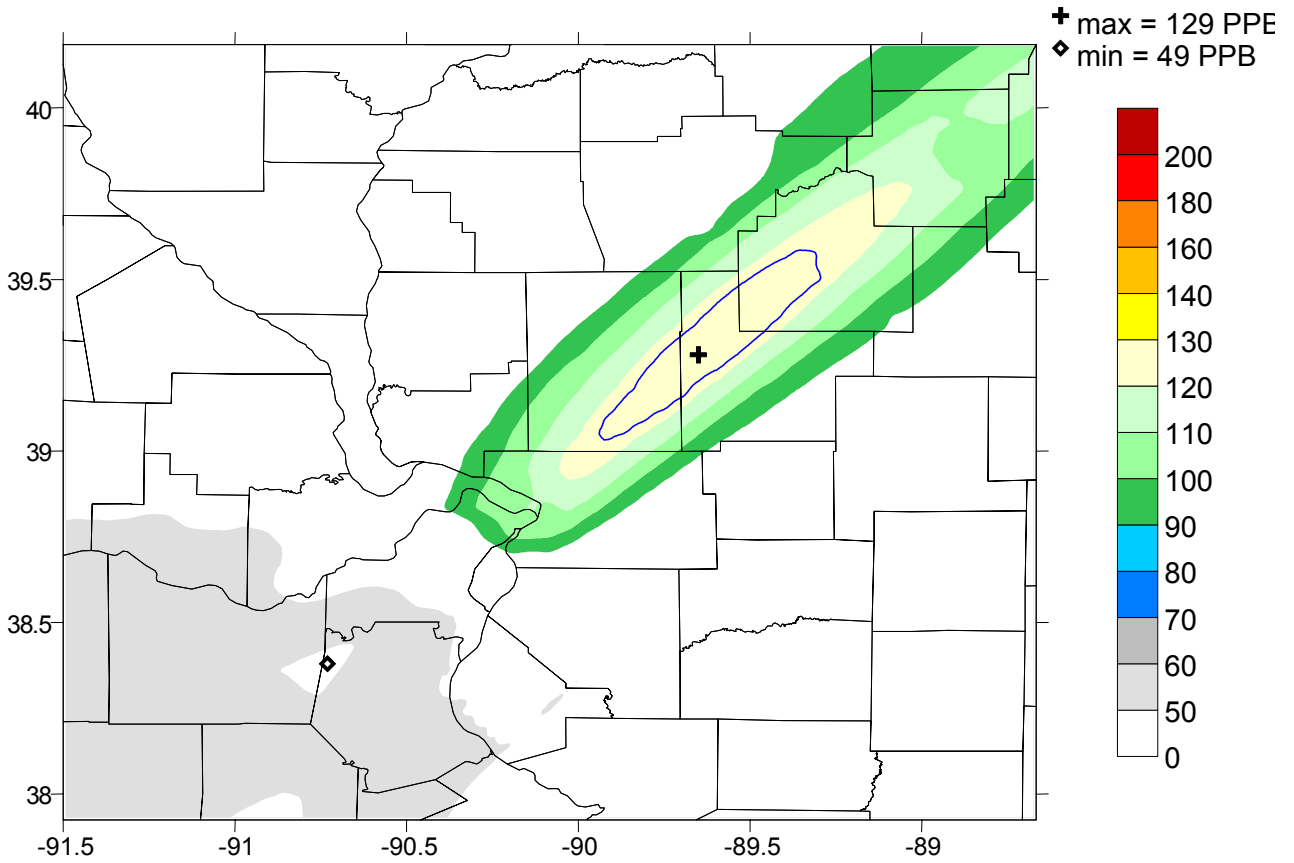
**Difference in Daily Max Ozone with the Addition of the New Source  
July 12, 1995 for  
1995 Episode using CAMx3 and Flexi-**

**Figure 4a.** Estimated daily maximum ozone concentrations (ppb) on July 13, 1995 for the 2003 Final Strategy base case CAMx flexi-nesting simulation.



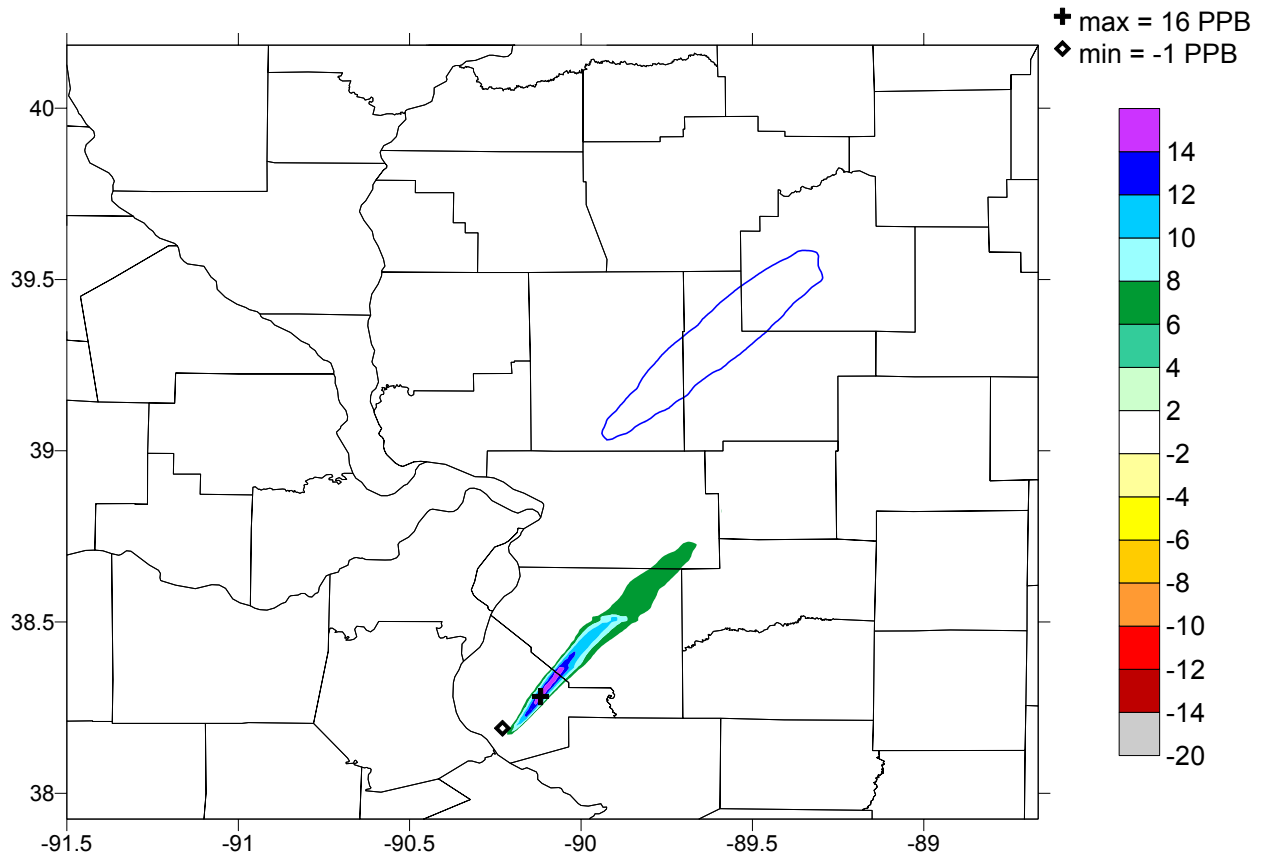
**Daily Max 1-Hour Ozone (ppb)**  
**July 13, 1995**  
**1995 CAMx3 Strat3a Base Case for 2003 with Flexi-Nesting**

**Figure 4b.** Estimated daily maximum ozone concentrations (ppb) on July 13, 1995 for the 2003 New Sources emissions scenario CAMx flexi-nesting simulation.



**Daily Max 1-Hour Ozone  
July 13, 1995  
2003 with New Source using CAMx3 and Flexi-Nesting**

**Figure 4c.** Differences in daily maximum ozone concentrations (ppb) on July 13, 1995 between the 2003 final strategy base case and 2003 New Sources emissions scenarios (New Sources-Base).



**Difference in Daily Max Ozone with the Addition of the Holnam Cement Plant  
July 13, 1995 for 2003  
1995 Episode using CAMx3 and Flexi-Nesting**

## CONCLUSIONS

The CAMx model is continued to be updated and enhanced to provide a platform to address all air quality issues using state of science algorithms, mass balance, and sensitivity techniques.

The CAMx powerful flexi-nesting capability extends the model's applicability from regional-scale and urban-scale bases down to the plume-scale. The use of the flexi-nesting capability to model the ozone impacts of a proposed new source to be located near the St. Louis nonattainment area demonstrates the usefulness of this capability and allows the regulatory planner to have a new tool for analyzing single source ozone impacts in a technically justifiable manner.

## REFERENCES

1. ENVIRON International Corporation. 2000. *User's Guide Comprehensive Air Quality Model with Extensions (CAMx) Version 3.00*. ENVIRON International Corporation, Novato, California. December. Available at [www.camx.com](http://www.camx.com).
2. Dunker, A.M., G. Yarwood, J. Ortman and G. Wilson. 2000. Implementation of the Decoupled Direct Method for Sensitivity Analysis in a Detailed Air Quality Model. Presented at Institute for Mathematics and Its Applications Workshop on Atmospheric Modeling. March 15-19, 2000.
3. TNRCC, 2001. "Revisions to the State Implementation Plan (SIP) for Control of Air Pollution –Attainment Demonstration for the Dallas-Fort Worth Ozone Nonattainment Area." Texas Natural Resources Conservation Commission (TNRCC), Austin, Texas, August 22.
4. TNRCC, 2001. "September 2001 Houston/Galeston Area SIP Revisions." Texas Natural Resources Conservation Commission (TNRCC), Austin, Texas. ([www.tnrcc.state.tx.us/oprd/sips/houston.html](http://www.tnrcc.state.tx.us/oprd/sips/houston.html)).
5. Yarwood G., G. Mansell, R. Morris, and F. Lurmann, 2002. "Enhancements to the Comprehensive Air Quality Model with extensions (CAMx) to Treat Particulate Matter (PM) and Visibility Issues." ENVIRON Corporation, Novato, California. Present at 95<sup>th</sup> Annual Conference and Exhibition of the Air and Waste Management Association in Baltimore, Maryland. June.
6. Morris R. E., C. C. Chang, S. B. Shepherd, and M. P. Ligoeki. 1992. "User's Guide to Version IV of the Reactive Plume Model (RPM-IV)" prepared for the Environmental Protection Agency, Systems Applications International, San Rafael, CA.
7. Santos, L.P. and R.I. Sykes. 2000. "SCICHEM Version 1.2 Technical Documentation." Prepared for EPRI, by Titan Corporation, Princeton, NJ.
8. Ryerson, T.B., et al., Emissions lifetimes and ozone formation in power plant plumes, *J. Geophys. Res.*, 103 (D17), 22, 569-22, 583, 1998.

9. Gillani, N.V. and W.E. Wilson, Formation and transport of ozone and aerosols in power plant plumes, *Ann. N.Y. Acad. Sci.*, 338, 276-296, 1980.
10. Seigneur, C., T.W. Tesche, P.M. Roth, and M.K. Liu, On the treatment of point source emissions in urban air quality modeling, *Atmos. Environ.*, 17, 1655-1676, 1983.
11. Morris, R.E., M.A. Yocke, T.C. Myers, and V. Mirabella, Overview of the variable grid Urban Airshed Model (UAM-V), 85<sup>th</sup> Meeting of the A&WMA, June 21-26, AWMA, Pittsburg, PA, 1992.
12. Myer, T.C. , P.D. Guthrie, and S.Y. Wu, The implementation of a plume-in-grid module in the SARMAP air quality model (SAQM), SYSAPP-96-06, Systems Applications International, Inc., 1996.
13. Gillani, N.V. and J.M. Godowitch, Plume-in-grid treatment of major point source emissions, In *Science Algorithms of the EPA Models-3 Community Multi-scale Air Quality (CMAQ) Modeling System*, Eds. D.W. Byun and J.K.S. Ching, EPA/600/R-99/030. Available from National Exposure Research Laboratory, Research Triangle Park, NC, 1999.
14. Karamchandani, P, K. Vijayaraghavan, S.-Y. Wu, C. Seigneur, L. Santos, I. Sykes, J.-F. Louis, T. Nehrkorn, and J. Henderson, Development and evaluation of a state-of-the-science plume-in-grid air quality model, Document No. CP017-00-1, EPRI, Palo Alto, CA, 2000a.
15. Mathur, R., L.K. Peters, and R.D. Saylor, Sub-grid Representation of Emission Source Clusters in Regional Air Quality Modeling, *Atmos. Environ.*, 26A, 3219-3238, 1992.
16. Odman, M.T., Khan, N.M., and McRae, D.S., Adaptive grids in air pollution modeling: towards an operational model, Millennium NATO/CCMS International Technical Meeting on Air Pollution Modelling and its Applications, Boulder, Colorado, June 15-19, 2000.
17. MDNR, 2000. "Revised Attainment Demonstration for the St. Louis Nonattainment Area.." Missouri Department of Natural Resources, Jefferson City, Missouri, June 29.

## **Key Words**

CAMx

Ozone

New Source Review (NSR)

Prevention of Significant Deterioration (PSD)

Air Toxics

Particulate Matter (PM)

Source Apportionment

Source Culpability

Process Analysis

Decoupled Direct Method