Improved CAMx Plume Rise

Ron Thomas

Southeast Texas Photochemical Modeling Technical Committee

August 18, 2010

Background

- Plume rise from point source stacks depends upon
  - the configuration of the stack
    - stack height
    - stack diameter
    - proximity to nearby structures
    - proximity to terrain features
  - physical properties of the exiting gases
    - initial vertical velocity
    - temperature
    - density
  - state of the ambient atmosphere
    - horizontal wind speed
    - stability class, vertical layer structure
- This relies on dispersion theory, with the difference being that in CAMx and other 3D models, we are interested in what happens in many vertical layers.

Background

Different Air Quality Models use different approaches to calculate plume rise

- CAMx
  - Internally-derived plume rise
  - Single layer (at calculated plume rise) in which to inject the elevated point source emissions
- CMAQ/SMOKE
  - Until v4.6, was calculated only externally in SMOKE
  - Distributes emissions vertically to multiple layers, putting more emissions into lower layers including surface layer
  - Seems more physically realistic

Question: Should TCEQ and others implement an alternative option to the standard CAMx plume rise algorithm?

The Investigation

Objectives (Work Plan)

1. Compare and evaluate several approaches to calculate plume rise
   a) Search and review technical literature
   b) Discuss state-of-the-science
   c) Study pros and cons of each option
   d) Recommend specific options

2. Implement recommended plume rise algorithm
   a) Develop the code for recommended options
   b) Test plume rise of each in a stand-alone test bed (idealized tests) of stack configurations and atmospheric stability conditions, holding everything else constant
   c) Compare plume rise results
   d) Explain differences

The Investigation

Objectives -continued

3. Test selected scheme in existing CAMx simulation
   a) For effect on ozone and precursor production
   b) Full test over large range of atmospheric conditions and stacks
   c) Chose the HGB SIP 2006 episodes (June, TexAQS II, Sept-Oct) to model
4. Provide any necessary training and support
   a) Installation
   b) Testing
5. Amend the CAMx User's Guide
   a) Documentation of the updated plume rise algorithm
   b) Documentation of the implementation of the new algorithm in CAMx
6. TCEQ test to make sure modelers see a difference also

The Investigation

Models researched

- CAMx (Environ, 2010)
- SMOKE/CMAQ (UNC, 2009; Byun and Schere, 2006)
- California Puff (CALPUFF) (Scire et al., 2000)
- Second-order Closure Integrated Puff (SCIPUFF) (EPRI, 2000)
- AERMOD Gaussian plume model (EPA, 2004)
- WRF-Chem (Peckham et al., 2009)

Some were eliminated quickly from further consideration based on similarities of algorithms.

Narrowing the Choices

Table 2-1. Comparison of important plume rise features for several models.

	CAMx	SMOKE/ CMAQ	CALPUFF	AERMOD
Multi-layer rise	X	X		
Multi-layer injection		X	n/a	n/a
Considers capping stable layer	X	X	X	X
Partial penetration into capping stable layer		X	X	X
Vertical wind shear effects			X	
Stack tip downwash	X		X	X
Combines buoyant and momentum fluxes			X	X

- Biggest delineator is the Eulerian vs. Lagrangian treatment.
- The most important advantage between these choices is the multi-layer meteorology that independently controls buoyant plume rise according to the local stability profile.

Narrowing the Choices

SMOKE/CMAQ vs. CAMx

- SMOKE/CMAQ Advantages
  - Residual emissions mass distributed through multiple layers
  - Partial plume penetration into capping stable layers above the mixing height
- SMOKE/CMAQ Disadvantages
  - Assumption that plume depth equals plume rise
  - Emissions distributed uniformly through that plume depth
    - Seems to be an arbitrary rule-of-thumb historically used for plume models
    - Could bias the model toward over-dilution of emissions

Narrowing the Choices

SMOKE/CMAQ vs. CAMx -continued

- CAMx Advantages
  - Does not explicitly require a “mixing height” parameter
  - Diagnoses changes in stability from the layer-to-layer change in the temperature profile
  - Does not require surface roughness
- CAMx Disadvantage
  - Assumption that emissions are injected into the single layer containing the final plume rise

CAMx vs. SMOKE/CMAQ Tests

Table 3-1. Meteorological conditions for the plume rise test bed.

		Surface temperature	298 K
		Surface pressure	1013.25 mb
		Surface roughness	1 m
		Constant wind profile	1, 5, 10 m/s
Stability Class	Temperature lapse rate (K/km)	Potential Temp. lapse rate (K/km)	mixing height (m)
stable	-5	5	25
neutral	-10	0	2000
unstable	-12	-2	2000
capping	-12 / -5	-2 / 5	500

For each stability class, the three wind speeds of 1,5, and 10 m/s were tested.

CAMx vs. SMOKE/CMAQ Tests

Table 3-2. Stack parameters for the plume rise test bed.

Stack #	Height, Diameter (m)	Temperature (K)	Velocity (m/s)
1	100, 5	450	20
2	100, 5	450	1
3	100, 5	320	20
4	100, 5	320	1
5	10, 1	450	20
6	10, 1	450	1
7	10, 1	320	20
8	10, 1	320	1

Tall stack = 100 m tall & 5 m wide, Short stack = 10 m tall & 1 m wide

Hot stack = 450 K, Cool stack = 320 K

Fast stack = 20 m/s, Slow stack = 1 m/s

For an overall combination of 8 stack types

CAMx vs. SMOKE/CMAQ Tests

A total of 96 test runs were performed to compare the two algorithms: 4 stabilities x 3 winds x 8 stacks

Summary of Test Results

In most cases, CAMx and SMOKE/CMAQ plume rise estimates are very similar.

Plume rise is mostly insensitive to neutral vs. unstable cases.

CAMx plume rise can be much higher than SMOKE/CMAQ for neutral/unstable light wind conditions.

CAMx plume rise is always much lower than the capping stable layer at 500 m.

SMOKE/CMAQ algorithm is insensitive to stack or meteorological conditions for short stacks.

Issues with SMOKE/CMAQ Algorithm

- Discontinuities through the range of met conditions
- Counter-intuitive results that lower plume rise occurred under unstable/neutral conditions than under stable conditions
- Consistent upward bias in plume rise for short stacks
- Arbitrary assumption that plume depth equals plume rise when distributing mass to multiple vertical layers
- Requires an explicit mixing height, which is difficult to specify where there is complex vertical atmospheric structure, e.g., coastal regimes

Instead of incorporating this algorithm into CAMx and fixing the issues, Environ focused on improving weaknesses of the current CAMx plume rise algorithm identified in the test-bed experiments.

Upgrading the CAMx Algorithm

Based on the test-bed results, implement 3 specific modifications to the existing CAMx plume rise algorithm:

- Apply a lower limit of 1 m/s to the ambient wind speed to eliminate unrealistically large momentum and buoyancy rise under neutral/unstable light wind conditions
- Improve the capping inversion cases of layer-to-layer transition between neutral/unstable centerline rise to stable plume top rise that was giving artificially low plume rise
  - Allows for partial penetration into a capping inversion
- Add an algorithm to determine plume depth at final rise to allow for multi-layer plume injection
  - Using diffusion equations from the CAMX Plume-in-Grid (PiG) sub-model
  - Borrowed from SCIPUFF
  - Not the SMOKE/CMAQ rule-of-thumb approach

Testing the Updated CAMx Algorithm

Need to compare the existing CAMx plume rise with the updated CAMx plume rise algorithm

- Use the same plume rise test-bed as previously, except …

Table 4-1. Meteorological conditions for the plume rise test bed.

			Surface temperature	298 K
			Surface pressure	1013.25 mb
			Surface roughness	N/A
			Constant wind profile	1, 5, 10 m/s
Stability class		Temperature lapse rate (K/km)	Potential Temp. lapse rate (K/km)	Mixing height (m)
Stable		-5	5	N/A
Neutral/unstable		-12	-2	N/A
Capping		-12 / -5	-2 / 5	N/A

- Same 8 stack configurations (see Table 3-2 above)
- Yields 72 cases (3 stabilities x 3 winds x 8 stacks) that were run to compare the existing and updated algorithms

Testing the Updated CAMx Algorithm

Summary of Test Results (existing CAMx plume rise vs. updated CAMx plume rise)

- Identical plume rise estimates in most cases
- The updated plume rise is improved with a capping stable layer at 500m to better handle the transition between neutral/stable to stable layers
- The updated plume rise results in deeper mass injection
  - The current version injects all the emissions into the single layer that contains the plume centerline
  - The updated version injects emissions into all layers containing the bottom through the top of the plume
  - Using SCIPUFF plume spread equations from the PiG routine
  - Fractions of the emissions are injected at the same fraction of the plume depth spanning multiple layers
  - This affects slow (low velocity) stacks more since plumes take longer to reach final rise

Testing the Updated CAMx Algorithm in the Ozone (Photochemical) Model

That's all nice, but how does this affect ozone production?

Ran the HGB SIP 2006 episodes (all three periods) with the existing version of CAMx (v5.20) and the updated version of CAMx (v5.20pr) and compared

- Ran just the 36 km grid over all of Eastern US
  - Since point source effects on grid concentrations are resolution-dependent
  - To hold all other variables constant, so that differences could be assessed on a consistent basis for the entire domain
- Screened the CAMx output files for:
  - Specific NOx columns that had the largest concentration differences
  - Vertical NOx and O3 concentration profiles for those grid cells were extracted
- Evaluate the changes in plume rise and depth

Testing the Updated CAMx Algorithm in the Ozone (Photochemical) Model

NOx Results of CAMx v5.20pr minus CAMx v5.20

- Overall, peak NOx differences were small and negative (around -1 to -2 ppb) with some peaks as high as +3 ppb and as low as -8 ppb
- Largest differences associated with the largest NOx sources
- Suggests that the plume rise update tends toward either higher plume rise or more dilution by spreading emissions over multiple layers
- Generally, peak differences in June 2006 are roughly half the peak differences during Aug-Oct 2006, perhaps due to the more quiescent and stable conditions of autumn

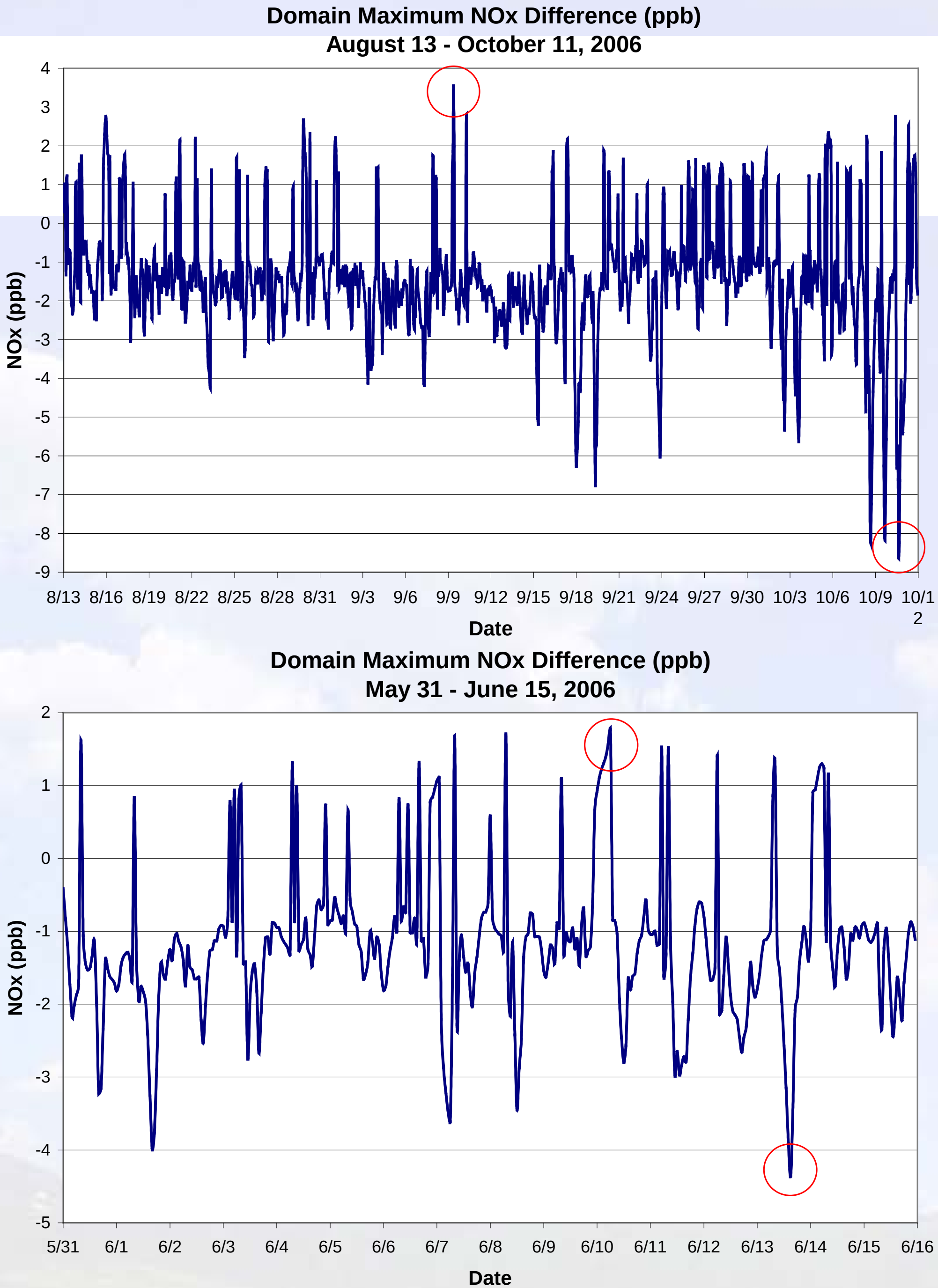


Figure 4-5. Hourly domain-wide peak NOx differences between two CAMx simulations of the TCEQ 2006 Houston modeling periods using the updated and original CAMx plume rise algorithm. Red circles highlight the hours shown in Figures 4-6 through 4-9.

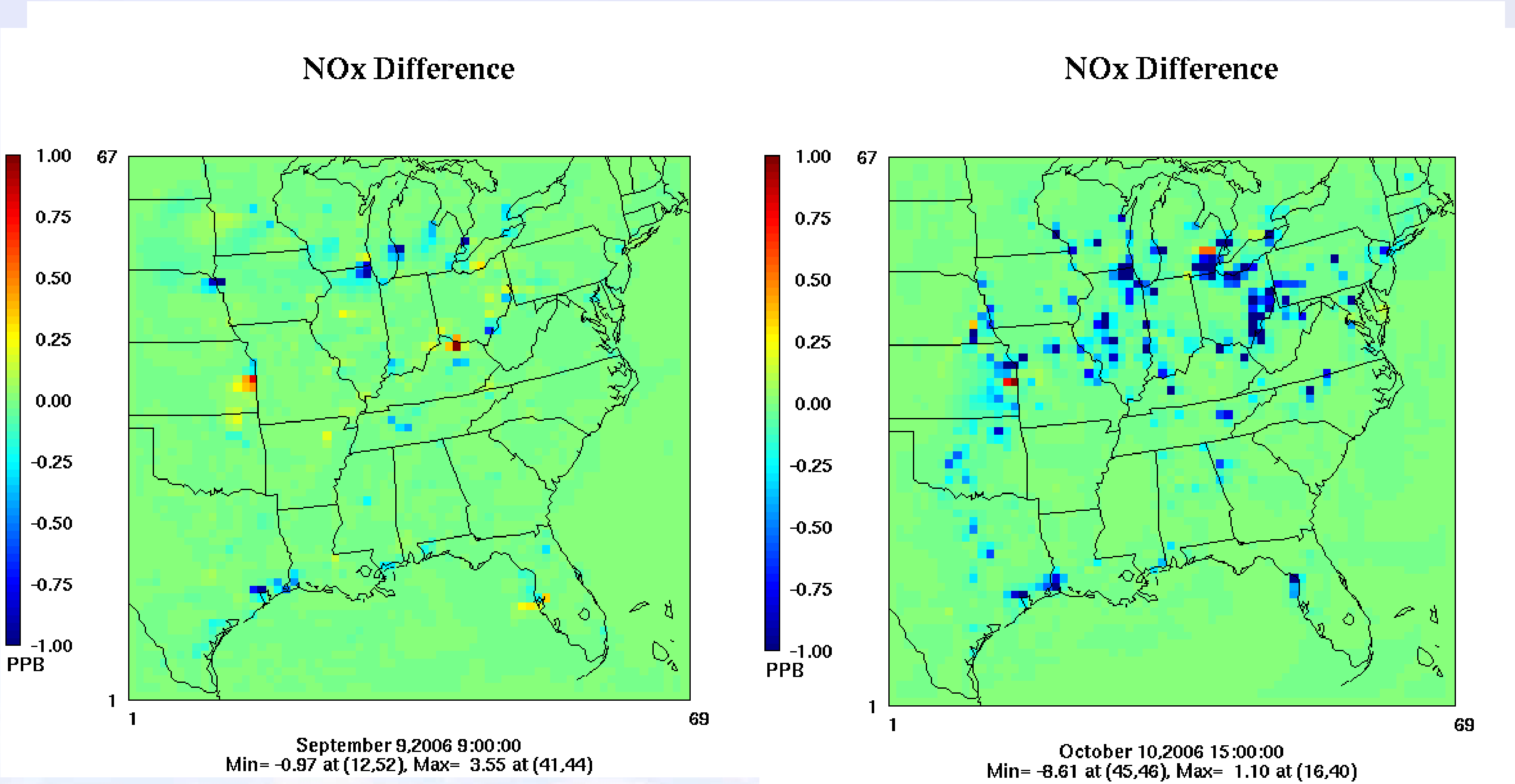


Figure 4-8. Domain-wide NOx differences during the hour of peak positive difference (left) and peak negative difference (right) during the August-October 2006 CAMx simulation using the updated and original CAMx plume rise algorithm.

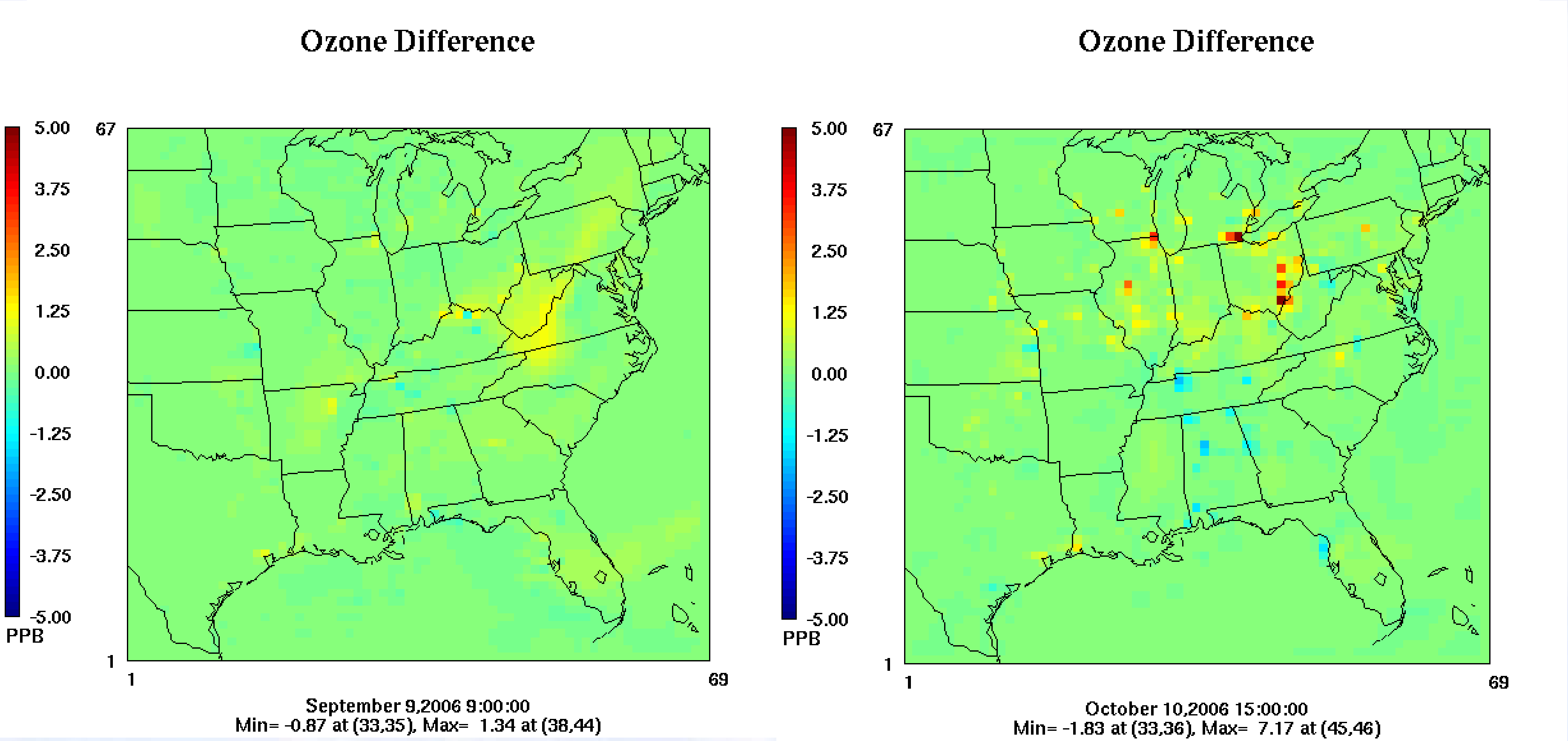


Figure 4-9. Domain-wide ozone differences for the same hours shown in Figure 4-8 during the August-October 2006 CAMx simulation using the updated and original CAMx plume rise algorithm.

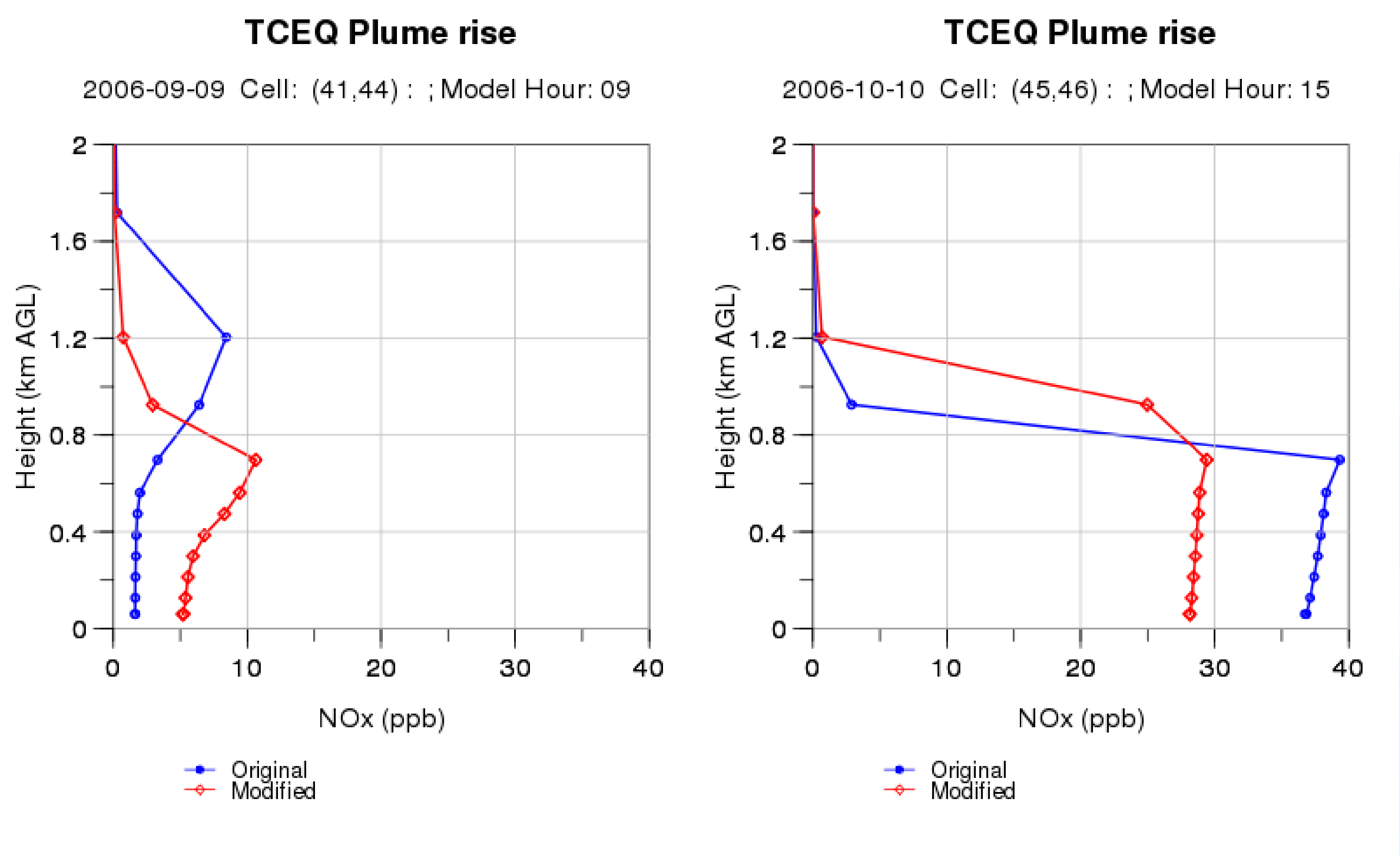


Figure 4-10. NOx concentration profiles at selected hours during the August-October 2006 CAMx simulations. Results are shown using the original plume rise algorithm (blue) and updated algorithm (red). Morning profiles on the left show episode-peak positive surface NOx concentrations. Afternoon profiles on the right show episode-peak negative surface NOx concentrations.

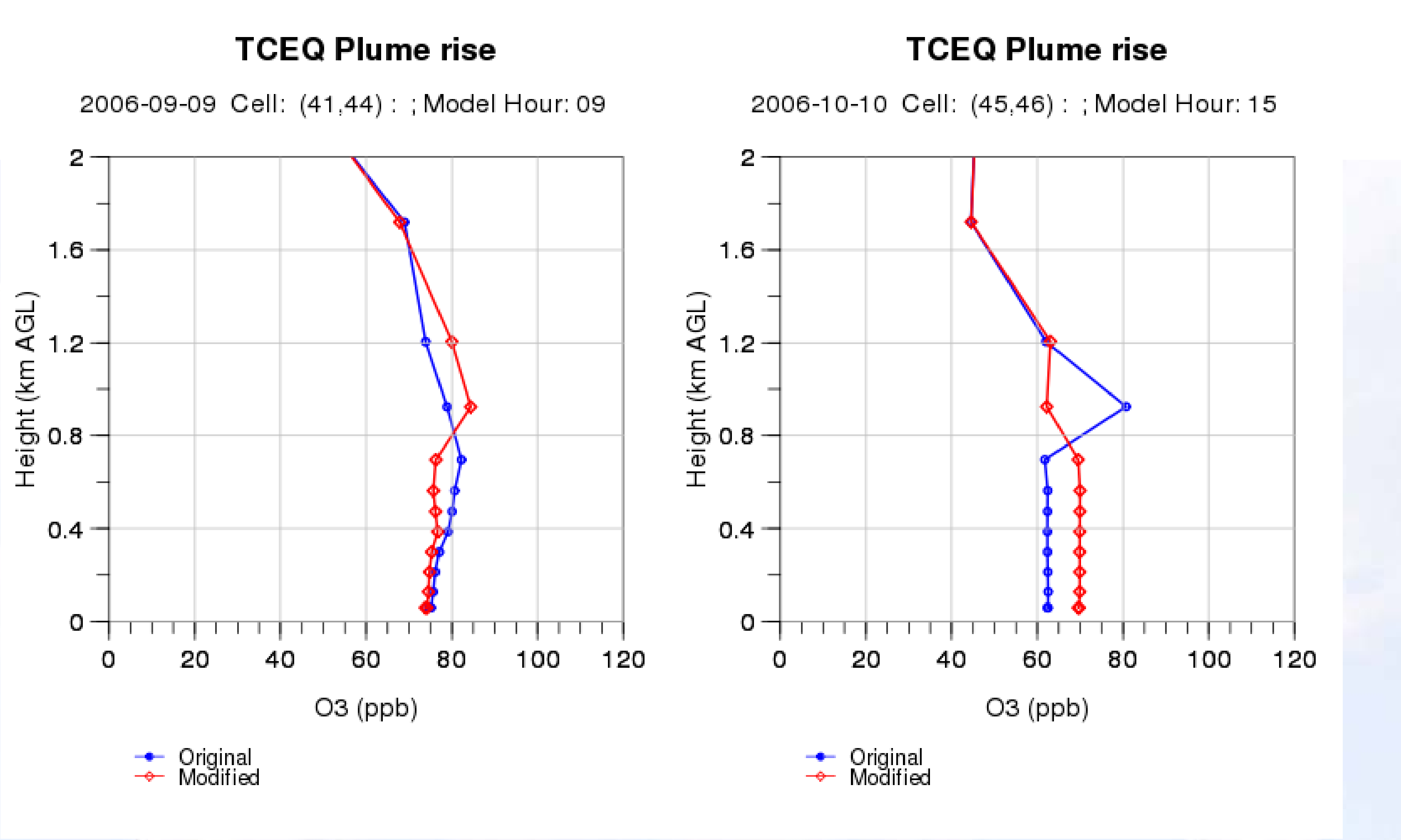


Figure 4-11. Ozone concentration profiles at selected hours during the June 2006 (top) and August-October 2006 (bottom) CAMx simulations. Results are shown using the original plume rise algorithm (blue) and updated algorithm (red). Dates and times are identical as Figure 4-10.

Testing the Updated CAMx Algorithm in the Ozone (Photochemical) Model

More Results of CAMx v5.20pr minus CAMx v5.20

- The plume rise update results in mostly NOx reductions during daytime hours, due to higher plume rise and more NOx dispersion from multi-layer injection
- NOx increases generally occurred during evening, through early morning hours, during periods of maximum stability, due to the multi-layer injection placing more NOx into lower layers (including the surface)
- See the report for more detailed analyses of the max and min differences in the domain

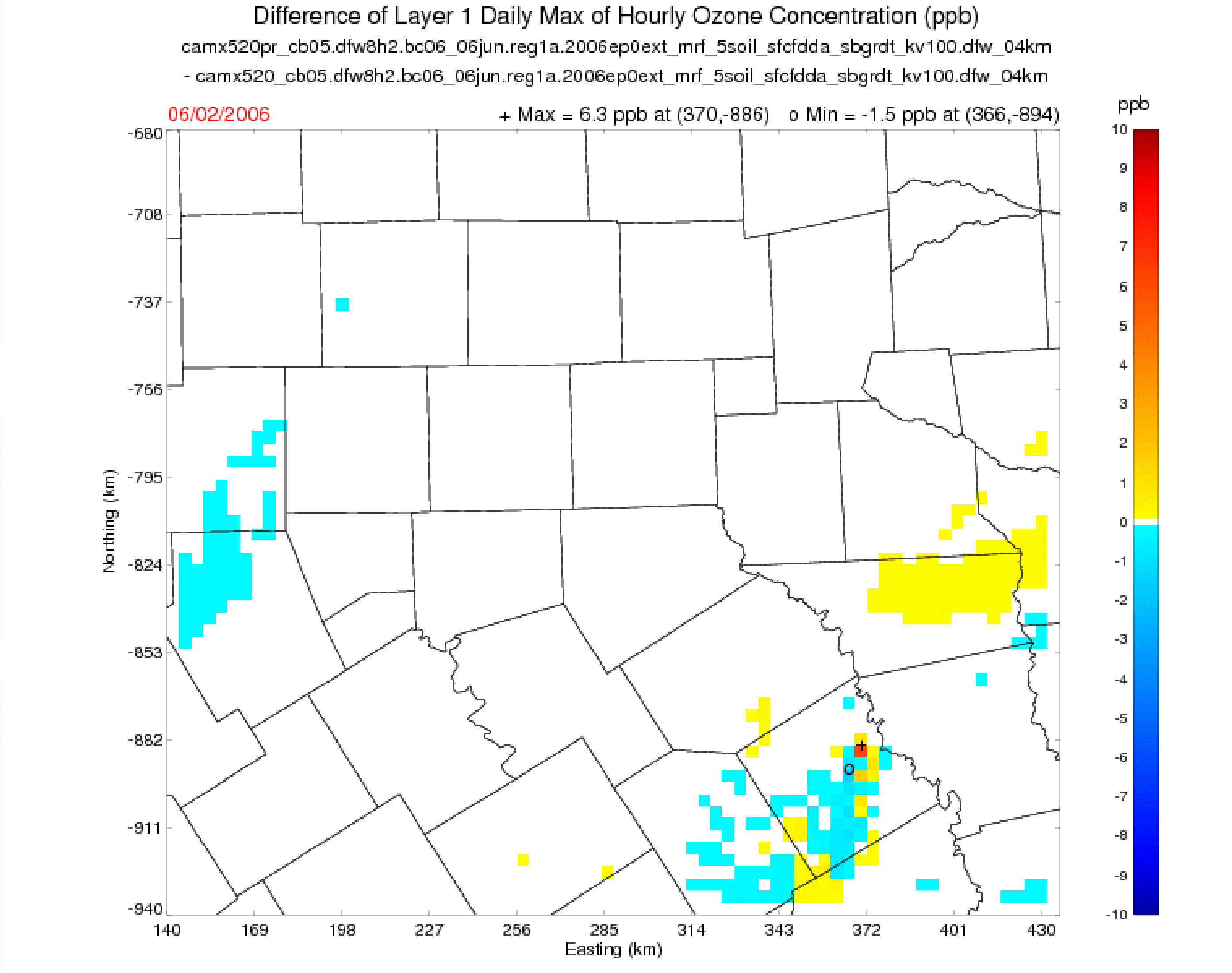
TCEQ’s Testing in the DFW June 2006 Episode

The TCEQ modelers installed the new Fortran source code files (three) on the TCEQ computer and recompiled to generate CAMx 5.20pr

The goal was to test and confirm the improved plume rise (look for explainable differences as Environ did).

An appropriate modeling scenario of the current ongoing DFW June 2006 episode was chosen, in which the only difference in the model run was the newly-compiled CAMx v5.20pr with the plume rise improvement

Ozone concentration difference plots were generated (see next slides)

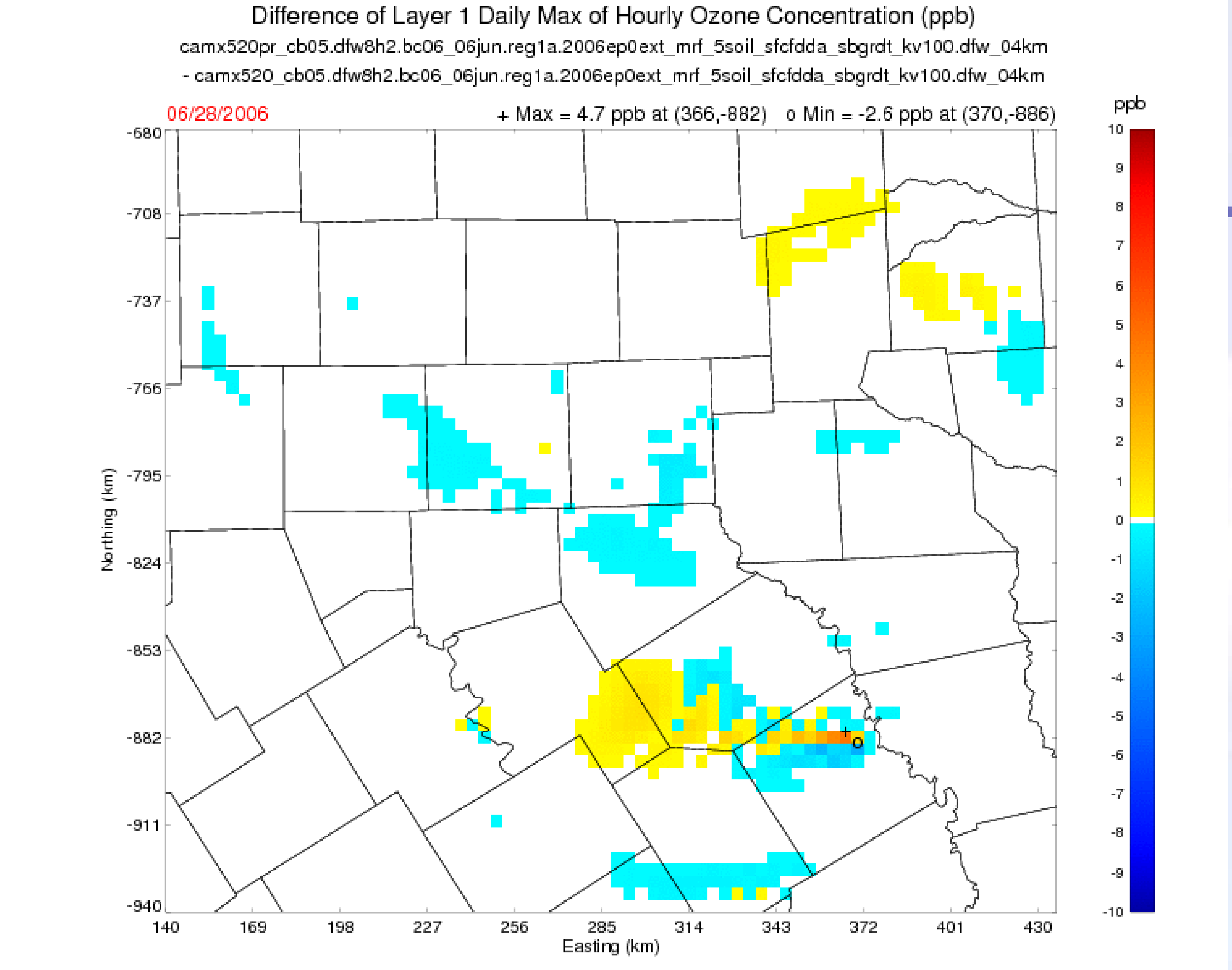


June 2, 2006

Improved plume rise minus existing plume rise

Difference of daily max of 1-hour ozone

Note: Max and Min differences occurred in adjacent cells in Freestone County (outside the nonattainment area) near a power plant. Big Brown has two, 137-m (450 ft) stacks.



June 28, 2006

Improved plume rise minus existing plume rise

Difference of daily max of 1-hour ozone

Note: This was the second most dramatic day (second largest difference) of the episode. Again, min and max in adjacent cells near a power plant. This was not the case for most days in the episode.

Final Report

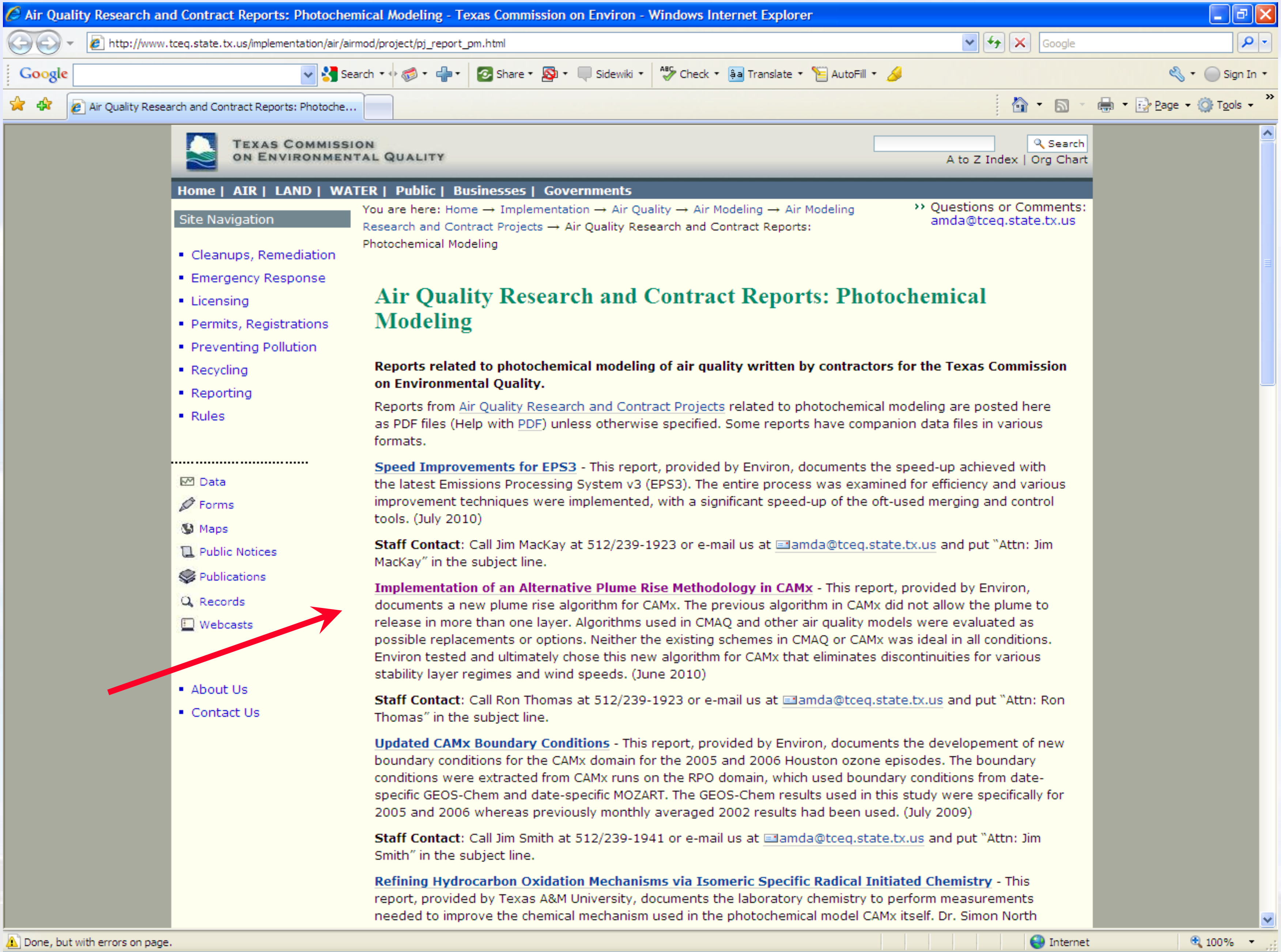
Environ Contract

- "Implementation of an Alternative Plume Rise Methodology in CAMx"
- Prepared for TCEQ
- Prepared by Christopher Emery, Jaegun Jung, Greg Yarwood, ENVIRON International Corporation
- June 11, 2010

Submitted to EPA by Environ for comment/review under separate cover on July 7, 2010

Download from http://www.tceq.state.tx.us/implementation/air/airmod/project/pj_report_pm.html

Where you can find other Modeling reports…



Air Quality Research and Contract Reports: Photochemical Modeling - Texas Commission on Environ - Windows Internet Explorer

http://www.tceq.state.tx.us/implementation/air/airmod/project/pj_report_pm.html

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

Search

A to Z Index | Org Chart

Home | AIR | LAND | WATER | Public | Businesses | Governments

You are here: Home → Implementation → Air Quality → Air Modeling → Air Modeling Research and Contract Projects → Air Quality Research and Contract Reports: Photochemical Modeling

›› Questions or Comments: amda@tceq.state.tx.us

Site Navigation

- Cleanups, Remediation
- Emergency Response
- Licensing
- Permits, Registrations
- Preventing Pollution
- Recycling
- Reporting
- Rules

- Data
- Forms
- Maps
- Public Notices
- Publications
- Records
- Webcasts

- About Us
- Contact Us

Air Quality Research and Contract Reports: Photochemical Modeling

Reports related to photochemical modeling of air quality written by contractors for the Texas Commission on Environmental Quality.

Reports from Air Quality Research and Contract Projects related to photochemical modeling are posted here as PDF files (Help with PDF) unless otherwise specified. Some reports have companion data files in various formats.

Speed Improvements for EPS3 - This report, provided by Environ, documents the speed-up achieved with the latest Emissions Processing System v3 (EPS3). The entire process was examined for efficiency and various improvement techniques were implemented, with a significant speed-up of the oft-used merging and control tools. (July 2010)

Staff Contact: Call Jim MacKay at 512/239-1923 or e-mail us at amda@tceq.state.tx.us and put "Attn: Jim MacKay" in the subject line.

Implementation of an Alternative Plume Rise Methodology in CAMx - This report, provided by Environ, documents a new plume rise algorithm for CAMx. The previous algorithm in CAMx did not allow the plume to release in more than one layer. Algorithms used in CMAQ and other air quality models were evaluated as possible replacements or options. Neither the existing schemes in CMAQ or CAMx was ideal in all conditions. Environ tested and ultimately chose this new algorithm for CAMx that eliminates discontinuities for various stability layer regimes and wind speeds. (June 2010)

Staff Contact: Call Ron Thomas at 512/239-1923 or e-mail us at amda@tceq.state.tx.us and put "Attn: Ron Thomas" in the subject line.

Updated CAMx Boundary Conditions - This report, provided by Environ, documents the developement of new boundary conditions for the CAMx domain for the 2005 and 2006 Houston ozone episodes. The boundary conditions were extracted from CAMx runs on the RPO domain, which used boundary conditions from date-specific GEOS-Chem and date-specific MOZART. The GEOS-Chem results used in this study were specifically for 2005 and 2006 whereas previously monthly averaged 2002 results had been used. (July 2009)

Staff Contact: Call Jim Smith at 512/239-1941 or e-mail us at amda@tceq.state.tx.us and put "Attn: Jim Smith" in the subject line.

Refining Hydrocarbon Oxidation Mechanisms via Isomeric Specific Radical Initiated Chemistry - This report, provided by Texas A&M University, documents the laboratory chemistry to perform measurements needed to improve the chemical mechanism used in the photochemical model CAMx itself. Dr. Simon North

Done, but with errors on page. Internet 100%