Sunflower Expansion – Alternative Visibility Analysis Using the CAMx Modeling System

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Introduction

On December 15, 2006 the KDHE received comments from the U.S. Department of the Interior, Fish and Wildlife Service (FWS) concerning the potential visibility impact on the Wichita Mountains Wilderness Class I area from a proposed expansion of the Sunflower Holcomb plant. To address these visibility concerns, the Department and permit applicant representatives worked with the FWS and EPA in establishing a protocol to evaluate the impacts of this expansion on visibility in the Wichita Mountains. This protocol followed ENVIRONmental Protection Agency (EPA) and federal land manager (FLM) guidance in choosing CALPUFF as the tool to do this analysis. Unfortunately for this application, CALPUFF is being exercised beyond the normally recommended maximum source receptor distance of 300 km. Knowing that this potential problem could cause an overestimation of the visibility impacts, the KDHE did an additional alternative analysis using the Comprehensive Air Quality Model with Extensions (CAMx) model, which does not have this distance limitation.

CAMx overview and datasets used

CAMx version 4.42, available freely from ENVIRON Corporation www.camx.com, was used in this modeling analysis. CAMx is a photochemical grid model an Eulerian photochemical dispersion model that allows for an integrated "one-atmosphere" assessment of gaseous and particulate air pollution (ozone, $PM_{2.5}$, PM_{10}, air toxics, mercury) over many scales, ranging from sub-urban to continental (ENVIRON 2006a). CAMx simulates the emission, dispersion, chemical reaction, and removal of pollutants in the troposphere by solving the pollutant continuity equation for each chemical species modeled on a system of nested three-dimensional grids.

This version of CAMx includes the implementation of the particulate source apportionment technology (PSAT) within the full-science plume in grid (PiG). This version of CAMx uses a full-chemistry PiG module for near-source plume chemistry and dynamics and a three-dimensional grid model for plume chemistry, transport, and dispersion at further downwind distances and contains all of the scientific advantages of both CALPUFF and a photochemical grid model.

Because CAMx requires a very data and resource intensive meteorological and emissions inventory dataset, the KDHE relied on the work being done by the Central Air Planning Association (CENRAP) for the Regional Haze Rule. The Department obtained the 2002 MM5 meteorological data and 2002 Base F emissions inventory from EPA Region 7. This emissions inventory data was then augmented with projected emissions from Sunflower's proposed expansion along with the new stack parameters from the proposed expansion. The data used were very similar to those being used in the Texas BART determinations. Please see ENVIRON 2006b for addition description of the datasets used.

For the PSAT setup KDHE used the PSAT/OSAT "point source override" feature (ENVIRON 2006b). This was done by having a source region map with one source region for the entire domain and assigning a separate source region value in the point source input file that will override the source region that the point source resides in. In addition, a negative flag was set for Sunflower stack diameters in order for this point source to receive the PiG treatment. An example of the CAMx script used is provided in Appendix B.

Emissions Rates and Stack Parameters

During the development of the CALPUFF modeling protocol KDHE, FWS, and Sunflower representatives discussed appropriate emissions rates to use in the modeling. It was determined that for visibility impacts an expected worst-case normal operating rate should be used. This worst-case normal operating rate excluded startups, shutdowns, malfunctions, and maintenance activities. It was determined that the rates would be 0.09 lbs/MMBtu for SO_2 and 0.05 lbs/MMBtu for NO_x for each unit. Because these two pollutants dominate the visibility impacts no other pollutants were modeled. CAMx requires emissions to be speciated and expressed in moles/hour (ENVIRON 2006a), therefore, the emissions rates used in CAMx were NO – 5,769 moles/hour, NO_2 – 641 moles/hour, and SO_2 – 12,427 moles/hour (note this represents all three proposed units operating).

Additional information on the source characteristics can be found in the permit application and CALPUFF modeling protocol (Sunflower Electric Power Corporation. 2006).

Visibility Impacts - Methodology

Visibility impacts were calculated at the Wichita Mountains Class I area using the PSAT tool in CAMx to first estimate the pollutant concentrations of Sunflowers proposed expansion. Visibility impacts were then calculated following the procedures based on the Federal Land Managers' Air Quality Related Values Workgroup report (FLAG, 2000). The FLAG (2000) procedures were developed to estimate visibility impacts at Class I areas from proposed new sources as part of the Prevention of Significant Deterioration (PSD) and New Source Review (NSR) process.

The IMPROVE reconstructed mass extinction equation is used to estimate visibility at Class I areas using IMPROVE monitoring data, and has also been used for evaluating visibility impacts at Class I areas due to new sources using modeling output of a single source or group of sources. The total light extinction due to a source (bsource), in units of inverse megameters (Mm^{-1}), is assumed to be the sum of the light extinction due to the source's individual species concentration impacts times an extinction efficiency coefficient:

bsource = bSO4 + bNO3 + bOC + bEC+ bsoil + bcoarse
bSO4 = 3 [(NH4)2SO4]f(RH)
bNO3 = 3 [NH4NO3]f(RH)
bOC = 4 [OMC]
bEC = 10 [EC]
bSoil = 1 [Soil]
bcoarse = 0.6 [Coarse Mass]

Here f(RH) are relative humidity adjustment factors. The concentrations in the square brackets are in µg/m3 and are based on the PSAT results. For Wichita Mountains the f(RH) values used are 2.75 2.55 2.35 2.35 2.74 2.51 2.2 2.37 2.67 2.5 2.59 2.78 for January through December, respectively (EPA, 2003).

The following species mappings are used to map the CAMx species to those used in the IMPROVE reconstructed mass extinction equation given above (ENVIRON, 2006b):

[(NH4)2SO4] = 1.375 x PSO4
[NH4NO3] = 1.290 x PNO3
[OMC] = POA + SOA1 + SOA2 + SOA3 + SOA4 + SOA5
[EC] = PEC
[Soil] = FPRM + FCRS
[Coarse Mass] = CPRM + CCRS

Here PSO_4 and PNO_3 are the CAMx particulate sulfate and nitrate species. POA is the CAMx primary particulate organic aerosol species, whereas SOA1-5 are the five secondary organic aerosol species carried in CAMx. Primary elemental carbon is represented by PEC in CAMx. CAMx carries two species that represent the other $PM_{2.5}$ components (i.e., fine particles that are not SO_4, NO_3, EC, or OC), one for the crustal (FCRS) and the other for the remainder of the primary emitted $PM_{2.5}$ species (FPRM). Similarly, CAMx carries two species to represent coarse mass ($PM_{2.5\text{-}10}$), one for crustal (CCRS), and one for other coarse PM (CPRM). For the Sunflower expansion project only PSO_4 and PNO_3 were evaluated.

The haze index (HI) for the source is calculated in deciviews (dv) from the source's extinction plus natural background using the following formula:

$$HIsource = 10 \ln[(bsource + bnatural)/10]$$

Here, bnatural is the Class I area specific clean natural visibility background, and EPA's default values were used in this analysis. For Wichita Mountains the natural visibility background value used were bnatural = 20.6061 (EPA 2003).

The source's HI was compared against natural conditions to assess the significance of the source's visibility impact. EPA guidance lists natural conditions (bnatural) by Class I area in terms of Mm^{-1} (ENVIRON, 2006) and assumes clean conditions with no man-made or weather interference. The visibility significance metric for evaluating visibility impact is the change in deciview (del-dv) from the source's and natural conditions haze indices:

$$del\text{-}dv = HIsource – HInatural = 10 \ln[(bsource + bnatural)/10] - 10 \ln[bnatural/10] = 10\ln[(bsource + bnatural)/bnatural]$$

Using CAMx PSAT, Sunflowers proposed expansion was modeled as a source group and the sulfate and nitrate species impacts were determined. Using the above methodology the species were reconstructed for visibility and the del-dv was calculated. A threshold of 0.5 del-dv maximum will be used to assess potential contribution to visibility impairment. This is the same threshold established in the Regional Haze Rule. This del-dv threshold is also being considered by the FLMs as the replacement to the current Method 2 analysis in CALPUFF.

Visibility Impacts – Results

The visibility impacts from Sunflower's proposed expansion were calculated at the Wichita Mountains Class I area and only included the impacts of sulfate and nitrate formation resulting from the sources proposed expansion. Again, the sulfate and nitrate impacts are expected to represent the great majority of the visibility impairment from this source.

Using the methodology described above, the visibility impacts due to sulfate and nitrate on a daily basis (sorted by descending del-dv) were:

Class I Area	Julian Date	bSO_4	bNO_3	Del-dv
WIMO1	342	6.86E-01	3.06E-01	0.47
WIMO1	340	5.54E-01	1.97E-01	0.36
WIMO1	38	4.07E-01	2.76E-01	0.33
WIMO1	4	3.86E-01	2.20E-01	0.29
WIMO1	277	5.24E-01	4.02E-02	0.27
WIMO1	360	0.175223	3.16E-01	0.24
WIMO1	39	2.58E-01	2.28E-01	0.23
WIMO1	343	3.30E-01	1.23E-01	0.22
WIMO1	317	2.21E-01	2.09E-01	0.21
WIMO1	111	0.426719	2.35E-03	0.21

WIMO1	299	3.16E-01	9.70E-02	0.20
WIMO1	341	3.29E-01	8.13E-02	0.20
WIMO1	112	3.88E-01	1.29E-02	0.19
WIMO1	359	0.108471	0.247125	0.17
WIMO1	3	2.31E-01	1.11E-01	0.16
WIMO1	361	0.182219	1.50E-01	0.16
WIMO1	347	1.43E-01	1.73E-01	0.15
WIMO1	308	2.04E-01	8.92E-02	0.14
WIMO1	325	6.88E-02	2.15E-01	0.14
WIMO1	346	2.06E-01	7.01E-02	0.13
WIMO1	309	1.71E-01	7.07E-02	0.12
WIMO1	321	8.84E-02	1.26E-01	0.10
WIMO1	20	0.0598496	1.25E-01	0.09
WIMO1	300	1.54E-01	2.81E-02	0.09
WIMO1	324	5.50E-02	1.24E-01	0.09
WIMO1	345	1.43E-01	3.53E-02	0.09
WIMO1	5	0.0870633	6.99E-02	0.08
WIMO1	51	1.25E-01	3.19E-02	0.08
WIMO1	114	1.57E-01	1.28E-06	0.08
WIMO1	258	1.49E-01	5.95E-03	0.07
WIMO1	353	3.57E-02	1.16E-01	0.07
WIMO1	279	1.48E-01	1.28E-03	0.07
WIMO1	351	0.038806	1.01E-01	0.07
WIMO1	344	1.05E-01	3.18E-02	0.07
WIMO1	278	1.14E-01	1.78E-02	0.06
WIMO1	316	8.74E-02	4.39E-02	0.06
WIMO1	12	0.0340993	9.64E-02	0.06
WIMO1	302	1.11E-01	1.73E-02	0.06
WIMO1	320	5.18E-02	7.37E-02	0.06
WIMO1	52	0.0682877	0.0536748	0.06
WIMO1	13	4.13E-02	7.87E-02	0.06
WIMO1	26	5.13E-02	6.58E-02	0.06
WIMO1	19	3.24E-02	8.31E-02	0.06
WIMO1	6	0.0227102	9.04E-02	0.05
WIMO1	348	2.94E-02	7.91E-02	0.05
WIMO1	35	3.23E-02	7.14E-02	0.05
WIMO1	326	3.40E-02	6.55E-02	0.05
WIMO1	356	0.025068	7.44E-02	0.05
WIMO1	333	5.02E-02	4.87E-02	0.05
WIMO1	332	3.27E-02	6.60E-02	0.05
WIMO1	263	8.10E-02	1.39E-02	0.05
WIMO1	14	2.04E-02	7.36E-02	0.05
WIMO1	25	0.0228009	6.99E-02	0.04
WIMO1	7	2.26E-02	6.85E-02	0.04
WIMO1	33	0.0245823	0.0618755	0.04
WIMO1	47	0.0297575	5.55E-02	0.04
WIMO1	1	4.55E-02	3.92E-02	0.04
WIMO1	307	6.57E-02	1.85E-02	0.04
WIMO1	2	3.68E-02	4.55E-02	0.04
WIMO1	327	4.06E-02	4.14E-02	0.04

WIMO1	354	1.88E-02	6.07E-02	0.04
WIMO1	11	0.0147696	6.38E-02	0.04
WIMO1	63	0.022538	5.42E-02	0.04
WIMO1	40	0.0594941	1.67E-02	0.04
WIMO1	80	0.0622436	0.0132052	0.04
WIMO1	264	7.10E-02	4.11E-03	0.04
WIMO1	48	0.0399502	3.41E-02	0.04
WIMO1	318	6.74E-02	5.08E-03	0.04
WIMO1	34	2.54E-02	4.50E-02	0.03
WIMO1	68	0.0511927	0.019053	0.03
WIMO1	15	0.0209406	4.78E-02	0.03
WIMO1	31	0.024684	0.043762	0.03
WIMO1	271	6.65E-02	1.42E-03	0.03
WIMO1	303	5.43E-02	1.28E-02	0.03
WIMO1	56	0.0536982	1.17E-02	0.03
WIMO1	270	6.30E-02	1.06E-03	0.03
WIMO1	58	0.0206062	4.26E-02	0.03
WIMO1	337	2.79E-02	3.52E-02	0.03
WIMO1	32	0.0182816	4.41E-02	0.03
WIMO1	334	2.88E-02	3.28E-02	0.03
WIMO1	322	5.10E-02	1.05E-02	0.03
WIMO1	79	0.0533059	7.91E-03	0.03
WIMO1	82	0.0506305	1.03E-02	0.03
WIMO1	8	2.01E-02	4.07E-02	0.03
WIMO1	301	5.21E-02	8.59E-03	0.03
WIMO1	257	6.00E-02	4.14E-04	0.03
WIMO1	87	0.0591416	3.33E-04	0.03
WIMO1	315	3.11E-02	2.80E-02	0.03
WIMO1	310	3.27E-02	2.35E-02	0.03
WIMO1	21	0.0175148	3.86E-02	0.03
WIMO1	314	2.93E-02	2.56E-02	0.03
WIMO1	285	5.02E-02	3.82E-03	0.03
WIMO1	71	0.0448433	8.70E-03	0.03
WIMO1	88	0.0525789	0.000398339	0.03
WIMO1	74	0.0419255	1.08E-02	0.03
WIMO1	319	3.67E-02	1.36E-02	0.02
WIMO1	123	4.68E-02	5.50E-04	0.02
WIMO1	83	0.046307	4.39E-04	0.02
WIMO1	50	4.56E-02	6.07E-04	0.02
WIMO1	37	0.0321769	1.35E-02	0.02
WIMO1	27	3.14E-02	1.42E-02	0.02
WIMO1	84	3.44E-02	9.00E-03	0.02
WIMO1	72	3.83E-02	4.48E-03	0.02
WIMO1	59	2.28E-02	1.98E-02	0.02
WIMO1	43	0.0167564	2.47E-02	0.02
WIMO1	336	3.65E-02	4.99E-03	0.02
WIMO1	41	0.024677	1.62E-02	0.02
WIMO1	73	0.040452	5.51E-05	0.02
WIMO1	328	3.09E-02	9.24E-03	0.02
WIMO1	62	9.85E-03	2.98E-02	0.02

WIMO1	350	1.80E-02	2.15E-02	0.02
WIMO1	280	3.77E-02	1.40E-03	0.02
WIMO1	122	0.0385415	2.15E-04	0.02
WIMO1	311	3.11E-02	7.32E-03	0.02
WIMO1	124	0.0355916	1.97E-04	0.02
WIMO1	54	0.0206799	1.46E-02	0.02
WIMO1	49	0.0288634	5.57E-03	0.02
WIMO1	30	0.0164938	1.79E-02	0.02
WIMO1	42	1.11E-02	2.32E-02	0.02
WIMO1	265	3.24E-02	1.77E-03	0.02
WIMO1	323	1.50E-02	1.87E-02	0.02
WIMO1	312	3.15E-02	3.68E-04	0.02
WIMO1	24	0.0121605	0.0191778	0.02
WIMO1	86	0.0272782	4.04E-03	0.02
WIMO1	168	3.10E-02	1.79E-04	0.02
WIMO1	330	1.24E-02	1.85E-02	0.01
WIMO1	355	1.15E-02	1.86E-02	0.01
WIMO1	119	0.0285772	0.00129779	0.01
WIMO1	306	2.40E-02	5.89E-03	0.01
WIMO1	364	1.67E-02	1.26E-02	0.01
WIMO1	167	2.87E-02	2.96E-05	0.01
WIMO1	254	2.81E-02	4.32E-05	0.01
WIMO1	60	0.0220048	4.42E-03	0.01
WIMO1	272	2.60E-02	8.46E-05	0.01
WIMO1	294	2.38E-02	1.36E-03	0.01
WIMO1	295	2.41E-02	9.69E-04	0.01
WIMO1	113	0.0243216	4.66E-05	0.01
WIMO1	22	0.0164938	7.30E-03	0.01
WIMO1	81	1.74E-02	6.25E-03	0.01
WIMO1	304	1.88E-02	4.60E-03	0.01
WIMO1	66	0.0221696	9.46E-04	0.01
WIMO1	16	1.47E-02	8.10E-03	0.01
WIMO1	57	6.72E-03	1.54E-02	0.01
WIMO1	146	0.0215539	0.000192141	0.01
WIMO1	23	1.57E-02	5.86E-03	0.01
WIMO1	305	1.80E-02	3.27E-03	0.01
WIMO1	267	2.04E-02	7.18E-04	0.01
WIMO1	291	2.00E-02	1.05E-03	0.01
WIMO1	143	0.0209209	2.65E-11	0.01
WIMO1	331	8.50E-03	1.24E-02	0.01
WIMO1	142	0.0207853	1.88E-05	0.01
WIMO1	115	2.01E-02	2.24E-04	0.01
WIMO1	36	9.66E-03	1.06E-02	0.01
WIMO1	141	1.99E-02	3.29E-04	0.01
WIMO1	46	0.0124858	7.62E-03	0.01
WIMO1	100	0.0192421	4.53E-04	0.01
WIMO1	65	0.019339	2.31E-04	0.01
WIMO1	55	0.0187865	5.55E-04	0.01
WIMO1	129	0.0190447	6.13E-05	0.01
WIMO1	17	0.00802911	1.09E-02	0.01

WIMO1	145	1.88E-02	1.10E-04	0.01
WIMO1	290	1.47E-02	4.12E-03	0.01
WIMO1	262	1.85E-02	2.13E-04	0.01
WIMO1	28	1.67E-02	1.92E-03	0.01
WIMO1	99	1.78E-02	6.73E-04	0.01
WIMO1	125	1.71E-02	2.61E-05	0.01
WIMO1	313	1.69E-02	1.78E-06	0.01
WIMO1	29	0.0123987	4.46E-03	0.01
WIMO1	151	1.68E-02	1.12E-05	0.01
WIMO1	118	0.016809	1.82E-05	0.01
WIMO1	281	1.61E-02	6.65E-04	0.01
WIMO1	53	6.79E-03	9.65E-03	0.01
WIMO1	91	1.31E-02	3.25E-03	0.01
WIMO1	10	9.78E-03	6.52E-03	0.01
WIMO1	273	1.62E-02	3.54E-05	0.01
WIMO1	339	1.03E-02	5.41E-03	0.01
WIMO1	85	0.0126213	2.97E-03	0.01
WIMO1	133	0.0153149	1.28E-04	0.01
WIMO1	130	0.0154166	1.47E-06	0.01
WIMO1	269	1.47E-02	4.81E-04	0.01
WIMO1	92	1.42E-02	0.000951285	0.01
WIMO1	266	1.44E-02	6.69E-04	0.01
WIMO1	296	1.39E-02	8.57E-04	0.01
WIMO1	75	0.0119524	2.33E-03	0.01
WIMO1	69	8.23E-03	6.01E-03	0.01
WIMO1	64	0.0113998	1.77E-03	0.01
WIMO1	238	1.28E-02	9.02E-05	0.01
WIMO1	268	1.26E-02	1.36E-04	0.01
WIMO1	102	1.21E-02	5.32E-04	0.01
WIMO1	18	6.38E-03	5.99E-03	0.01
WIMO1	169	1.21E-02	4.71E-11	0.01
WIMO1	89	0.0108085	1.02E-03	0.01
WIMO1	134	1.17E-02	1.45E-04	0.01
WIMO1	76	0.0104789	1.21E-03	0.01
WIMO1	293	9.81E-03	1.74E-03	0.01
WIMO1	144	1.15E-02	5.14E-06	0.01
WIMO1	259	1.14E-02	4.35E-05	0.01
WIMO1	357	0.00366501	7.67E-03	0.01
WIMO1	226	1.09E-02	2.06E-04	0.01
WIMO1	237	1.10E-02	2.61E-05	0.01
WIMO1	358	0.00369368	0.00724161	0.01
WIMO1	150	0.0107905	5.78E-05	0.01
WIMO1	260	1.03E-02	9.56E-05	0.01
WIMO1	288	7.43E-03	2.96E-03	0.01
WIMO1	120	0.0101881	1.17E-04	0.00
WIMO1	90	8.27E-03	1.77E-03	0.00
WIMO1	96	0.00979069	1.98E-04	0.00
WIMO1	136	0.00996768	2.86E-07	0.00
WIMO1	77	0.00939034	0.000493468	0.00
WIMO1	158	9.62E-03	1.62E-04	0.00

WIMO1	70	0.00943396	1.98E-05	0.00
WIMO1	363	8.88E-03	0.000545031	0.00
WIMO1	97	9.01E-03	2.95E-04	0.00
WIMO1	274	9.10E-03	1.09E-06	0.00
WIMO1	95	8.42E-03	6.55E-04	0.00
WIMO1	135	9.04E-03	1.33E-11	0.00
WIMO1	140	0.00829716	3.09E-04	0.00
WIMO1	255	8.34E-03	2.37E-04	0.00
WIMO1	61	4.98E-03	3.26E-03	0.00
WIMO1	253	8.07E-03	1.06E-04	0.00
WIMO1	352	0.00203777	5.95E-03	0.00
WIMO1	110	7.51E-03	3.98E-04	0.00
WIMO1	298	6.16E-03	1.42E-03	0.00
WIMO1	256	7.26E-03	3.06E-05	0.00
WIMO1	283	7.05E-03	2.00E-04	0.00
WIMO1	338	2.67E-03	4.35E-03	0.00
WIMO1	292	6.69E-03	2.73E-04	0.00
WIMO1	204	6.88E-03	2.92E-05	0.00
WIMO1	170	0.0068107	1.50E-06	0.00
WIMO1	67	6.54E-03	5.78E-05	0.00
WIMO1	138	0.00641982	1.81E-05	0.00
WIMO1	194	0.00632437	4.46E-05	0.00
WIMO1	284	5.86E-03	2.26E-04	0.00
WIMO1	286	5.04E-03	1.04E-03	0.00
WIMO1	101	0.00588023	5.34E-05	0.00
WIMO1	289	4.39E-03	1.41E-03	0.00
WIMO1	103	5.55E-03	2.20E-04	0.00
WIMO1	137	0.00562978	9.86E-07	0.00
WIMO1	329	4.04E-03	1.38E-03	0.00
WIMO1	227	5.39E-03	1.32E-05	0.00
WIMO1	45	3.58E-03	1.60E-03	0.00
WIMO1	239	5.08E-03	1.95E-06	0.00
WIMO1	159	0.00488904	1.04E-05	0.00
WIMO1	282	4.68E-03	2.18E-04	0.00
WIMO1	362	2.79E-03	0.00207318	0.00
WIMO1	132	0.00424183	9.09E-05	0.00
WIMO1	349	2.31E-03	1.90E-03	0.00
WIMO1	157	0.00410733	4.06E-05	0.00
WIMO1	93	0.00343256	5.35E-04	0.00
WIMO1	147	3.84E-03	4.79E-06	0.00
WIMO1	261	3.77E-03	2.37E-06	0.00
WIMO1	78	3.08E-03	4.53E-04	0.00
WIMO1	139	3.35E-03	3.42E-06	0.00
WIMO1	104	0.00301669	5.69E-05	0.00
WIMO1	94	2.75E-03	2.93E-04	0.00
WIMO1	98	0.00299343	5.17E-05	0.00
WIMO1	205	0.0030129	1.09E-05	0.00
WIMO1	240	2.93E-03	1.10E-05	0.00
WIMO1	171	0.0029239	7.93E-07	0.00
WIMO1	44	0.00105503	1.75E-03	0.00

WIMO1	152	0.00259465	1.23E-06	0.00
WIMO1	220	2.56E-03	8.90E-06	0.00
WIMO1	116	0.00233135	0.000152969	0.00
WIMO1	252	2.40E-03	6.37E-06	0.00
WIMO1	109	0.00220533	1.10E-04	0.00
WIMO1	9	1.97E-03	3.01E-04	0.00
WIMO1	275	2.14E-03	1.81E-06	0.00
WIMO1	166	2.07E-03	1.18E-11	0.00
WIMO1	250	2.07E-03	9.29E-06	0.00
WIMO1	241	2.03E-03	1.43E-05	0.00
WIMO1	335	8.07E-04	1.16E-03	0.00
WIMO1	297	1.60E-03	2.94E-04	0.00
WIMO1	193	1.82E-03	6.11E-06	0.00
WIMO1	165	1.77E-03	1.49E-05	0.00
WIMO1	247	1.70E-03	1.17E-05	0.00
WIMO1	221	1.65E-03	5.18E-05	0.00
WIMO1	105	0.00167217	6.02E-06	0.00
WIMO1	149	0.0015993	4.60E-06	0.00
WIMO1	222	0.00136085	1.35E-05	0.00
WIMO1	225	1.36E-03	4.25E-12	0.00
WIMO1	148	0.001319	7.41E-06	0.00
WIMO1	218	1.26E-03	2.35E-07	0.00
WIMO1	242	1.17E-03	7.42E-06	0.00
WIMO1	117	1.18E-03	1.64E-06	0.00
WIMO1	219	0.0011536	1.47E-06	0.00
WIMO1	131	0.00102966	6.23E-06	0.00
WIMO1	243	9.34E-04	9.12E-06	0.00
WIMO1	217	0.000853467	1.18E-05	0.00
WIMO1	249	8.56E-04	7.77E-06	0.00
WIMO1	276	8.43E-04	8.72E-06	0.00
WIMO1	248	8.40E-04	4.85E-06	0.00
WIMO1	156	0.000839482	8.57E-07	0.00
WIMO1	172	0.000790509	6.36E-07	0.00
WIMO1	228	7.86E-04	7.93E-08	0.00
WIMO1	154	0.000749197	1.51E-07	0.00
WIMO1	106	6.83E-04	9.44E-07	0.00
WIMO1	287	5.68E-04	4.60E-05	0.00
WIMO1	244	5.61E-04	4.59E-06	0.00
WIMO1	246	5.47E-04	4.05E-12	0.00
WIMO1	155	0.000493253	2.96E-07	0.00
WIMO1	153	4.50E-04	8.50E-08	0.00
WIMO1	224	0.000450294	2.17E-12	0.00
WIMO1	160	0.000435479	7.54E-07	0.00
WIMO1	207	4.32E-04	1.46E-08	0.00
WIMO1	126	4.29E-04	1.37E-06	0.00
WIMO1	197	0.000385688	8.34E-06	0.00
WIMO1	192	3.69E-04	5.18E-07	0.00
WIMO1	121	0.000356368	9.53E-08	0.00
WIMO1	216	3.56E-04	1.97E-07	0.00
WIMO1	179	0.000342295	4.56E-07	0.00

WIMO1	245	3.17E-04	1.05E-06	0.00
WIMO1	196	0.000282868	8.68E-06	0.00
WIMO1	206	0.000274247	1.56E-06	0.00
WIMO1	195	0.000254826	2.07E-06	0.00
WIMO1	229	2.56E-04	8.10E-08	0.00
WIMO1	174	0.000233891	8.64E-06	0.00
WIMO1	175	2.14E-04	7.55E-06	0.00
WIMO1	191	0.000198289	7.81E-07	0.00
WIMO1	211	0.000184313	7.54E-06	0.00
WIMO1	223	0.000187117	1.47E-06	0.00
WIMO1	164	0.000181398	4.45E-07	0.00
WIMO1	173	1.77E-04	6.43E-07	0.00
WIMO1	178	0.00016711	3.13E-07	0.00
WIMO1	251	1.55E-04	1.74E-07	0.00
WIMO1	208	1.53E-04	4.28E-09	0.00
WIMO1	190	0.000149375	5.07E-07	0.00
WIMO1	163	0.000133667	5.03E-08	0.00
WIMO1	214	1.17E-04	4.68E-08	0.00
WIMO1	176	1.11E-04	1.52E-07	0.00
WIMO1	107	9.31E-05	2.28E-07	0.00
WIMO1	177	9.37E-05	3.84E-07	0.00
WIMO1	108	8.59E-05	6.97E-07	0.00
WIMO1	189	8.19E-05	2.96E-06	0.00
WIMO1	203	8.49E-05	1.12E-09	0.00
WIMO1	230	8.28E-05	6.27E-07	0.00
WIMO1	215	7.68E-05	1.11E-07	0.00
WIMO1	127	7.22E-05	2.04E-07	0.00
WIMO1	180	6.48E-05	2.88E-07	0.00
WIMO1	188	5.98E-05	1.47E-06	0.00
WIMO1	236	4.82E-05	2.17E-13	0.00
WIMO1	231	4.68E-05	1.53E-07	0.00
WIMO1	234	3.93E-05	1.37E-13	0.00
WIMO1	235	3.88E-05	2.14E-09	0.00
WIMO1	162	3.65E-05	7.11E-09	0.00
WIMO1	209	3.73E-05	8.54E-10	0.00
WIMO1	232	3.51E-05	3.90E-09	0.00
WIMO1	210	3.08E-05	5.57E-08	0.00
WIMO1	233	3.22E-05	6.59E-11	0.00
WIMO1	200	2.42E-05	9.72E-09	0.00
WIMO1	202	2.37E-05	1.56E-09	0.00
WIMO1	213	2.50E-05	3.05E-10	0.00
WIMO1	199	1.89E-05	3.45E-09	0.00
WIMO1	161	1.38E-05	3.86E-10	0.00
WIMO1	201	1.33E-05	1.27E-08	0.00
WIMO1	187	7.74E-06	1.04E-07	0.00
WIMO1	198	7.95E-06	4.86E-09	0.00
WIMO1	212	7.42E-06	2.66E-08	0.00
WIMO1	128	4.27E-06	3.55E-07	0.00
WIMO1	183	5.40E-06	4.62E-08	0.00
WIMO1	185	5.07E-06	1.29E-07	0.00

WIMO1	186	6.05E-06	7.24E-08	0.00
WIMO1	182	2.56E-06	4.84E-09	0.00
WIMO1	184	2.23E-06	9.13E-08	0.00
WIMO1	181	1.12E-06	6.10E-09	0.00
WIMO1	365	0	0	0.00

These results indicate that sulfate impacts are about twice that of nitrate for the majority of the days that have higher del-dv impacts. These higher modeled days generally occurred in the winter months when the weather patterns take the plume toward the Wichita Mountains. On the day with maximum modeled del-dv (0.47), Julian day 342 (December 8, 2002), the sulfate impact was 2.24 times that of the nitrate. This is to be expected as the emissions rate for sulfate is higher than nitrate for Sunflowers proposed expansion, and during this time of year sulfate is the dominant pollutant impacting visibility in the Wichita Mountains Class I area, as Figure 1 shows.

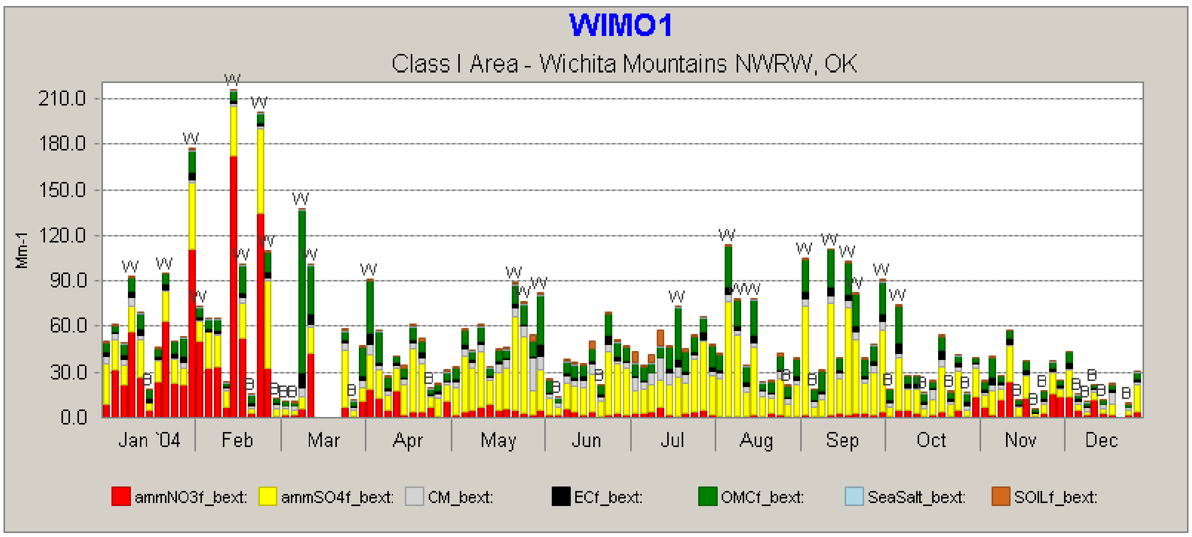


Figure 1. Monthly monitored visibility species impacts in 2004 for Wichita Mountains.

Appendix A contains graphics of the sulfate plume location for the five highest del-dv days.

Conclusion

The proposed Sunflower Holcomb expansion has been evaluated for visibility impacts using the alternative CAMx model utilizing PSAT and PiG. The results indicate that for the year modeled the maximum visibility attributed to the proposed expansion would be 0.47 del-dv. This maximum modeled del-dv occurred on December 8, 2002. Based on this level of maximum visibility impacts under worst case normal operating conditions, the modeling indicates the proposed Sunflower expansion does not adversely impact visibility in the Wichita Mountains Class I area in Oklahoma. KDHE believes this analysis is more representative than the CALPUFF analysis because of the large source receptor distance from Sunflower to surrounding Class I areas (~400 km).

References

EPA. 2003. Guidance for Estimating Natural Visibility Conditions under the Regional Haze Rule. EPA-454/B-03-005. U.S. ENVIRONmental Protection Agency, Research Triangle Park, NC.

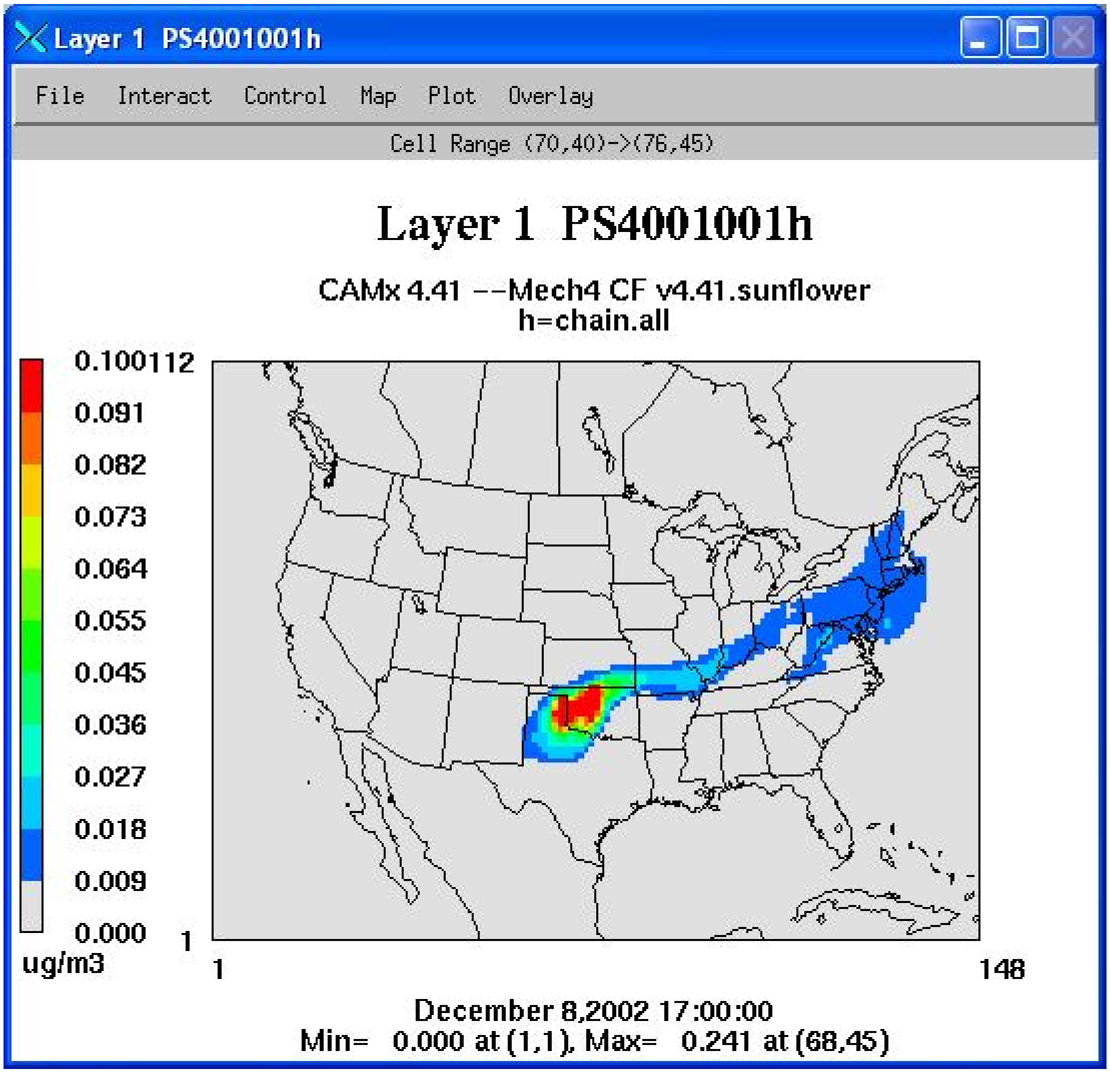
ENVIRON. 2006a. “User’s Guide – Comprehensive Air-quality Model with extensions, Version 4.40.” ENVIRON International Corporation, Novato, California. (Available at http://www.camx.com). September 2006

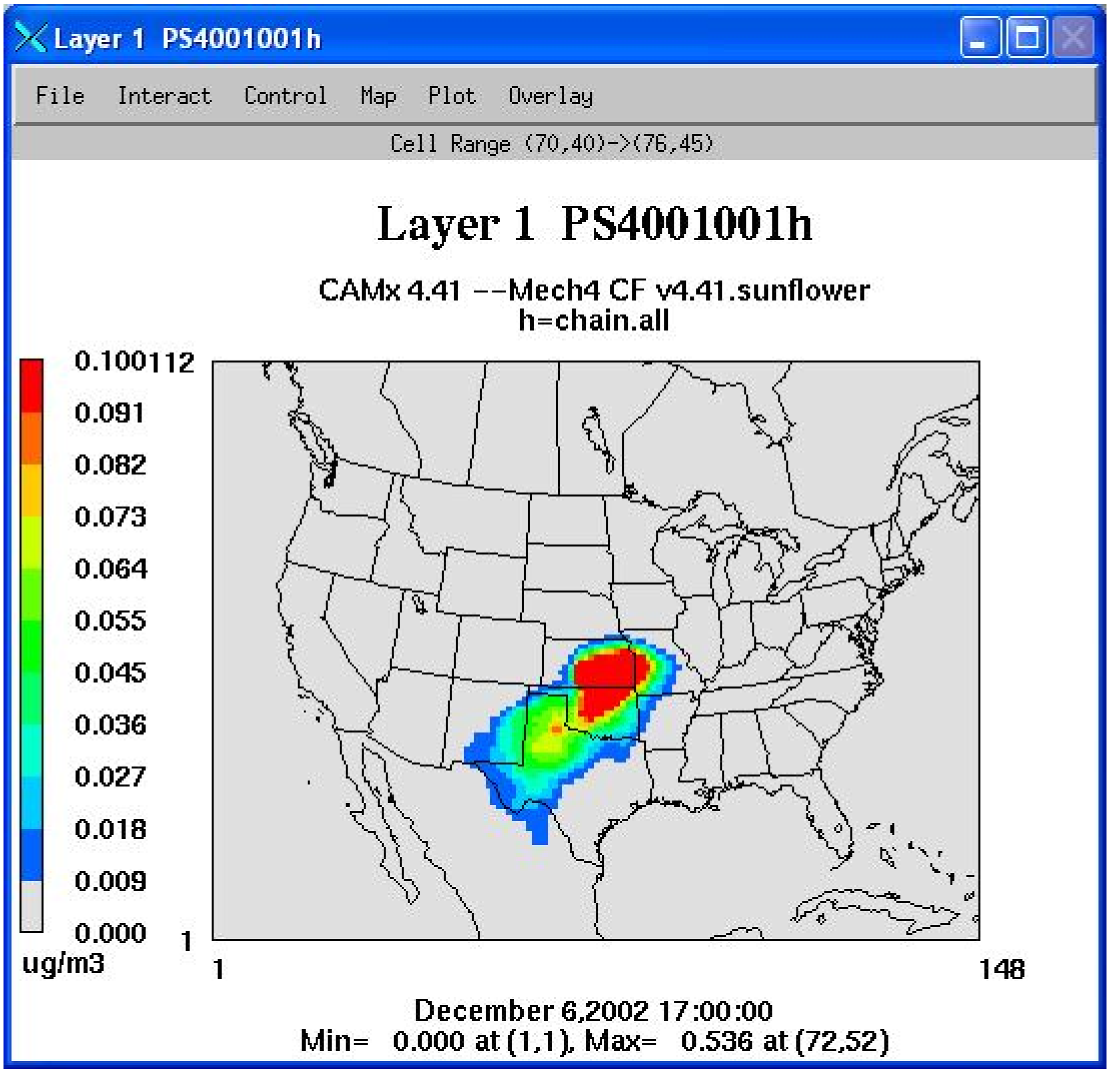
ENVIRON. 2006b. Guidance for the Application of the CAMx Hybrid Photochemical Grid Model to Assess Visibility Impacts of Texas BART Sources at Class I Areas. Prepared for Texas Commission of ENVIRONmental Quality, Austin Texas. Prepared by ENVIRON International Corporation, Novato, CA. September 27.

FLAG. 2000. “Federal Land Managers’ Air Quality Related Values Workgroup (FLAG)”: Phase I Report. USDI – National Park Service, Air Resources Division, Denver, CO.

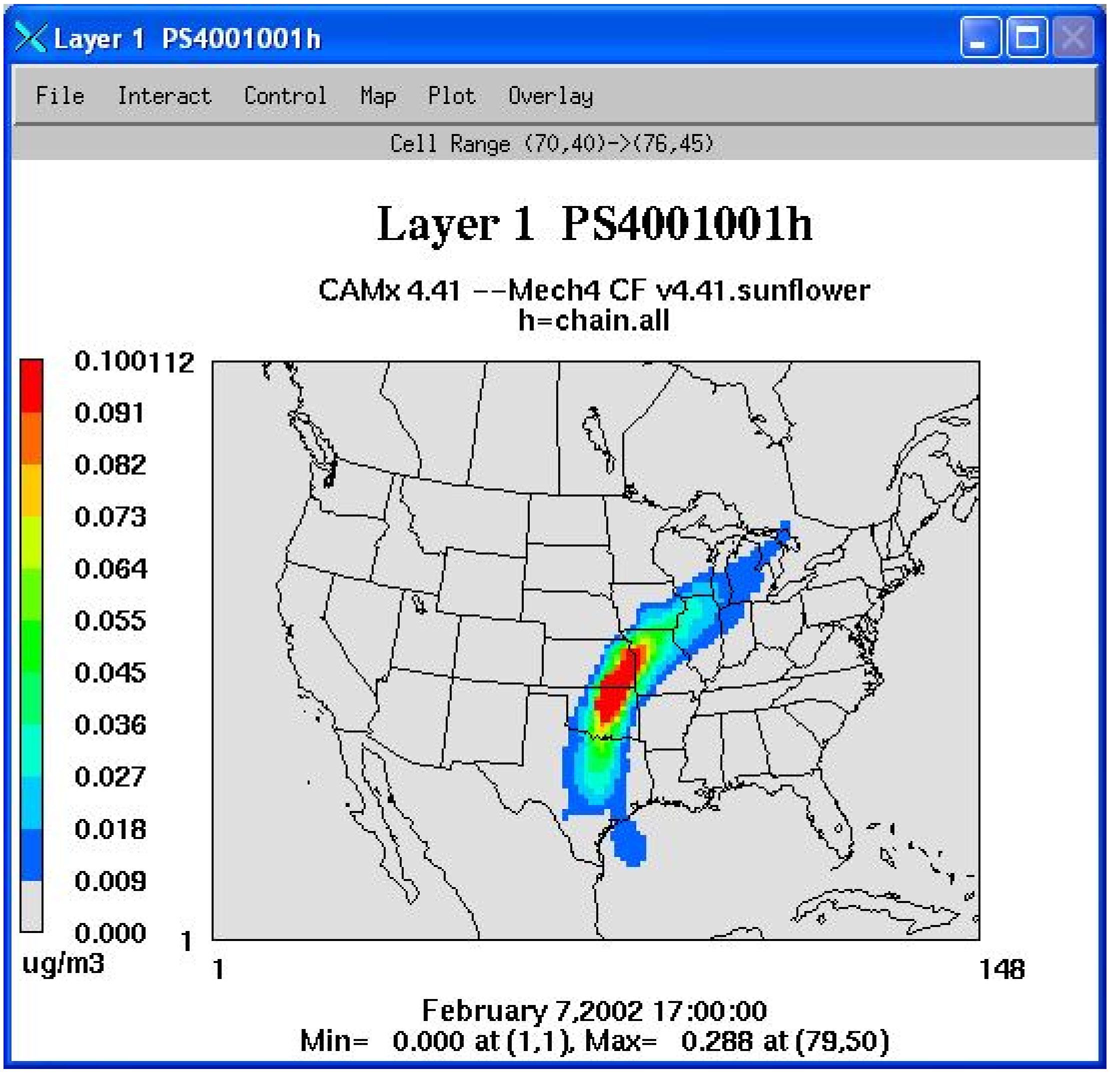
Sunflower Electric Power Corporation. 2006. Holcomb Expansion Project Visibility Impact on Class I areas and PM2.5 Impact in Northeast Kansas. Prepared by HDR Engineering, Inc. November 2006.

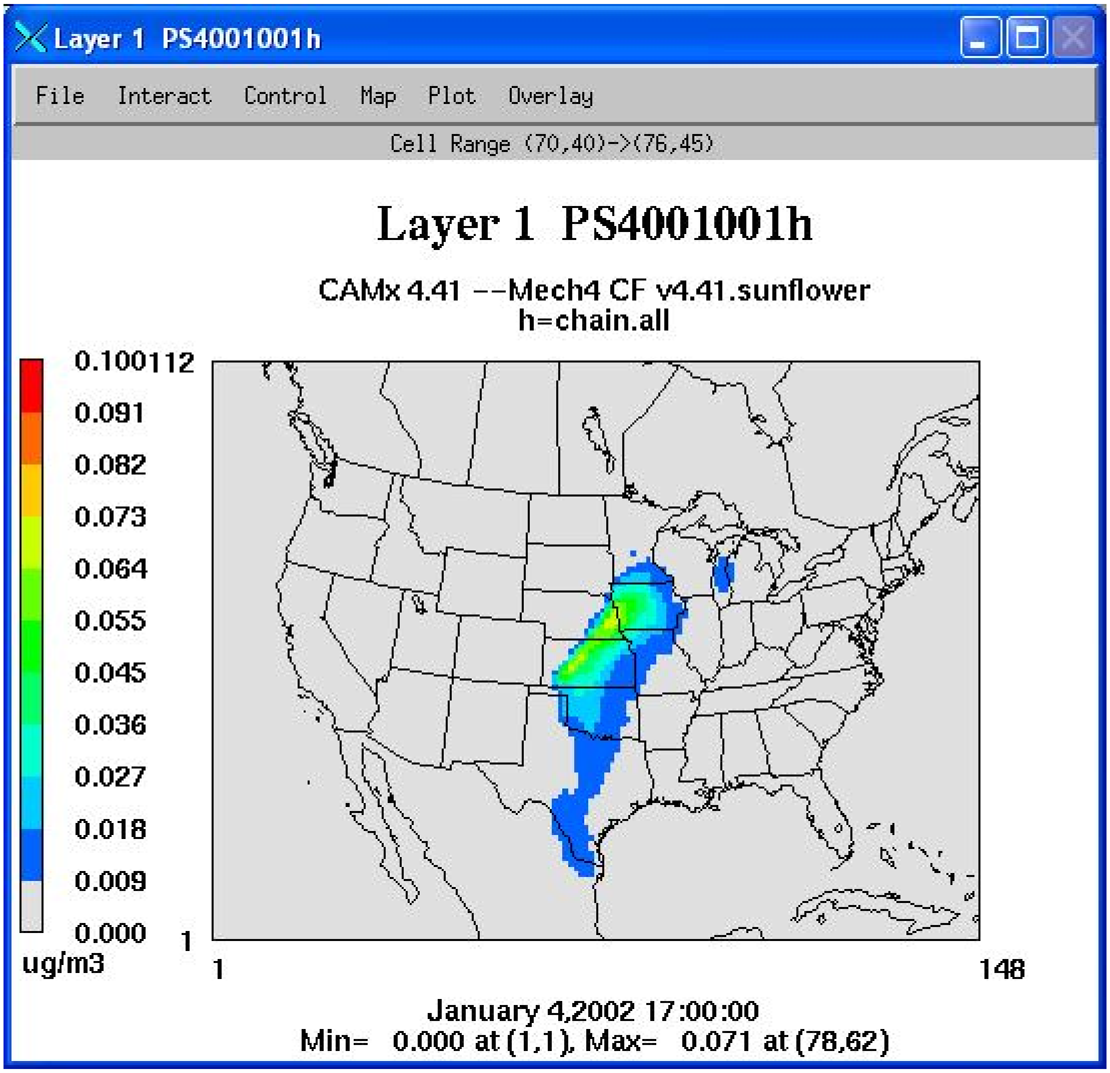
Appendix A Sulfate Plume (ug/m3) Location During High del-dv Impacts.

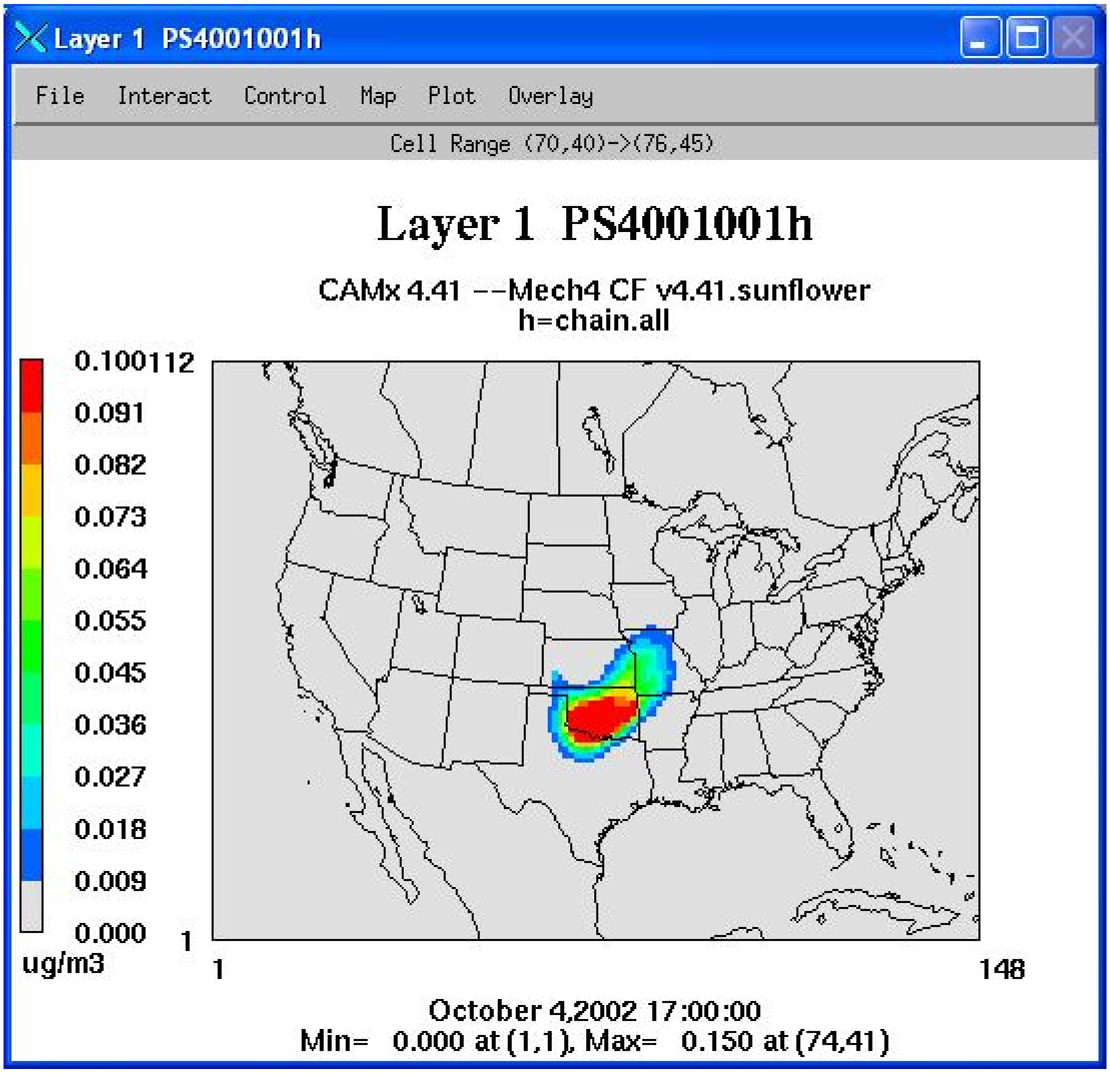




Layer 1 PS4001001h
File
Interact
Control
Map
Plot
Overlay
Cell Range (70,40)->(76,45)
Layer 1 PS4001001h
CAMx 4.41 --Mech4 CF v4.41.sunflower
h=chain.all
0.100112
0.091
0.082
0.073
0.064
0.055
0.045
0.036
0.027
0.018
0.009
0.000
ug/m3
1
1
148
December 6,2002 17:00:00
Min= 0.000 at (1,1), Max= 0.536 at (72,52)


Layer 1 PS4001001h
File Interact Control Map Plot Overlay
Cell Range (70,40)->(76,45)
Layer 1 PS4001001h
CAMx 4.41 --Mech4 CF v4.41.sunflower
h=chain.all
0.100112
0.091
0.082
0.073
0.064
0.055
0.045
0.036
0.027
0.018
0.009
0.000
ug/m3
1
1
148
February 7,2002 17:00:00
Min= 0.000 at (1,1), Max= 0.288 at (79,50)


Layer 1 PS4001001h
File
Interact
Control
Map
Plot
Overlay
Cell Range (70,40)->(76,45)
Layer 1 PS4001001h
CAMx 4.41 --Mech4 CF v4.41.sunflower
h=chain.all
0.100112
0.091
0.082
0.073
0.064
0.055
0.045
0.036
0.027
0.018
0.009
0.000
ug/m3
1
1
148
January 4,2002 17:00:00
Min= 0.000 at (1,1), Max= 0.071 at (78,62)



Layer 1 PS4001001h
File Interact Control Map Plot Overlay
Cell Range (70,40)->(76,45)
Layer 1 PS4001001h
CAMx 4.41 --Mech4 CF v4.41.sunflower
h=chain.all
0.100112
0.091
0.082
0.073
0.064
0.055
0.045
0.036
0.027
0.018
0.009
0.000
ug/m3
1
1
148
October 4,2002 17:00:00
Min= 0.000 at (1,1), Max= 0.150 at (74,41)

Appendix B - CAMx Script Used for Sunflower PSAT Analysis Using the SO_4 and NO_3 PSAT Tracers

```
#!/bin/csh
#
# CAMx 4.31
#
setenv NCPUS 4
setenv MPSTKZ 128M
limit stacksize unlimited
set EXEC      = "/modeling/cenrap_psat/src.fixed/CAMx.sunflower.pg_linuxomp"
#

set run = revised_psat.Q1
set STARTDATE = 2001356
set ENDDATE   = 2002365
set JDATE = 2001356
#
set RUN     = "v4.42.sunflower"
set CHEM    = "/mnt/usb2/modeling/inputs/inputs"
set LUSE    = "/mnt/usb2/modeling/inputs/landuse"
set AHOMAP  = "/mnt/usb2/modeling/inputs/ahomap"
set PHOT    = "/mnt/usb2/modeling/inputs/tuv"
set ICBC    = "/mnt/usb2/modeling/inputs/icbctc"
set MET     = "/mnt/usb2/modeling/inputs/met_new/36"
set EMIS    = "/modeling/cenrap_psat/merged"
set EMIS2   = "/mnt/usb2/modeling/cenrap02f/area_uam"
set OUTPUT  = "/modeling/cenrap_psat/outputs/$run"
#
mkdir -p $OUTPUT $run
#
#  --- set the dates and times ----
#
while ( $JDATE <= $ENDDATE )

set RESTART = "true"
if ( $JDATE == $STARTDATE ) set RESTART = "false"

@ YESTERDAY = $JDATE - 1
if ( $YESTERDAY == 2002000 ) set YESTERDAY = 2001365
set YYYY = `./j2g $JDATE | awk '{print $1}'`
set Y2 = `echo $YYYY | awk '{printf("%2.2d",$1-2000)}'`
set MM = `./j2g $JDATE | awk '{print $2}'`
set DD = `./j2g $JDATE | awk '{print $3}'`
```

```
echo '---- Copying Files -----'

cp -v $EMIS/final.${YYYY}${MM}${DD}.RPO_US36.Base02f.pt.revised.bin
$EMIS/final.${YYYY}${MM}${DD}.RPO_US36.Base02f.pt
.revised.bin.copy >> & $OUTPUT/CAMx.$RUN.$JDATE.stdout
cp -v $EMIS2/camx.ar.bart.36km.$JDATE.bin
$EMIS2/camx.ar.bart.36km.$JDATE.bin.copy >> &
$OUTPUT/CAMx.$RUN.$JDATE.stdo
ut


#
#  --- Create the input file (always called CAMx.in)
#
cat << ieof > CAMx.in

 &CAMx_Control

 Run_Message      = 'CAMx 4.41 --Mech4 CF $RUN',

!--- Model clock control ---

 Time_Zone        = 0,                 ! (0=UTC,5=EST,6=CST,7=MST,8=PST)
 Restart          = .${RESTART}.,
 Start_Date_Hour  = ${YYYY},${MM},${DD},0000,   ! (YYYY,MM,DD,HHHH)
 End_Date_Hour    = ${YYYY},${MM},${DD},2400,   ! (YYYY,MM,DD,HHHH)

 Maximum_Timestep    = 15.,            ! minutes
 Met_Input_Frequency = 60.,            ! minutes
 Ems_Input_Frequency = 60.,            ! minutes
 Output_Frequency    = 60.,            ! minutes

!--- Map projection parameters ---

 Map_Projection           = 'LAMBERT',  ! (LAMBERT,POLAR,UTM,LATLON)
 UTM_Zone                 = 0,
 POLAR_Longitude_Pole     = 0.,        ! deg (west<0,south<0)
 POLAR_Latitude_Pole      = 0.,        ! deg (west<0,south<0)
 LAMBERT_Central_Meridian = -97.,      ! deg (west<0,south<0)
 LAMBERT_Center_Longitude = -97.,      ! deg (west<0,south<0)
 LAMBERT_Center_Latitude  =  40.,      ! deg (west<0,south<0)
 LAMBERT_True_Latitude1   =  45.,      ! deg (west<0,south<0)
 LAMBERT_True_Latitude2   =  33.,      ! deg (west<0,south<0)

!--- Parameters for the master (first) grid ---
```

```
 Number_of_Grids      = 1,
 Master_Origin_XCoord = -2736.,        ! km or deg, SW corner of cell(1,1)
 Master_Origin_YCoord = -2088.,        ! km or deg, SW corner of cell (1,1)
 Master_Cell_XSize    = 36.,           ! km or deg
 Master_Cell_YSize    = 36.,           ! km or deg
 Master_Grid_Columns  = 148,
 Master_Grid_Rows     = 112,
 Number_of_Layers(1)  = 19,

!--- Parameters for the second grid ---

 Nest_Meshing_Factor(2) = 3,           ! Relative to master grid
 Nest_Beg_I_Index(2)    = 31,          ! Relative to master grid
 Nest_End_I_Index(2)    = 69,          ! Relative to master grid
 Nest_Beg_J_Index(2)    = 29,          ! Relative to master grid
 Nest_End_J_Index(2)    = 72,          ! Relative to master grid
 Number_of_Layers(2)    = 14,

!--- Model options ---

 Diagnostic_Error_Check = .false.,      ! True = will stop after 1st timestep
 Advection_Solver       = 'PPM',        ! (PPM,BOTT)
 Chemistry_Solver       = 'CMC',        ! (CMC,IEH)
 PiG_Submodel           = 'GREASD',       ! (None,GREASD,IRON)
 Probing_Tool           = 'PSAT',       ! (None,OSAT,GOAT,APCA,DDM,PA,RTRAC)
 Chemistry              = .true.,
 Dry_Deposition         = .true.,
 Wet_Deposition         = .true.,
 Staggered_Winds        = .true.,
 Gridded_Emissions      = .true.,
 Point_Emissions        = .true.,
 Ignore_Emission_Dates  = .true.,

!--- Output specifications ---

 Root_Output_Name         = '$OUTPUT/camx.$RUN.$JDATE',
 Average_Output_3D        = .false.,
 HDF_Format_Output        = .false.,
 Number_of_Output_Species = 35,
 Output_Species_Names(1)  = 'NO',
 Output_Species_Names(2)  = 'NO2',
 Output_Species_Names(3)  = 'O3',
 Output_Species_Names(4)  = 'PAN',
 Output_Species_Names(5)  = 'NXOY',
 Output_Species_Names(6)  = 'CO',
 Output_Species_Names(7)  = 'HONO',
```

```
 Output_Species_Names(8)  = 'HNO3',
 Output_Species_Names(9)  = 'NTR',
 Output_Species_Names(10)  = 'SO2',
 Output_Species_Names(11)  = 'SULF',
 Output_Species_Names(12)  = 'NH3',
 Output_Species_Names(13)  = 'HCL',
 Output_Species_Names(14)  = 'CG1',
 Output_Species_Names(15)  = 'CG2',
 Output_Species_Names(16)  = 'CG3',
 Output_Species_Names(17)  = 'CG4',
 Output_Species_Names(18)  = 'CG5',
 Output_Species_Names(19)  = 'PNO3',
 Output_Species_Names(20)  = 'PSO4',
 Output_Species_Names(21)  = 'PNH4',
 Output_Species_Names(22)  = 'POA',
 Output_Species_Names(23)  = 'SOA1',
 Output_Species_Names(24)  = 'SOA2',
 Output_Species_Names(25)  = 'SOA3',
 Output_Species_Names(26)  = 'SOA4',
 Output_Species_Names(27)  = 'SOA5',
 Output_Species_Names(28)  = 'PEC',
 Output_Species_Names(29)  = 'FPRM',
 Output_Species_Names(30)  = 'FCRS',
 Output_Species_Names(31)  = 'CPRM',
 Output_Species_Names(32)  = 'CCRS',
 Output_Species_Names(33)  = 'NA',
 Output_Species_Names(34)  = 'PCL',
 Output_Species_Names(35)  = 'PH2O',

!--- Input files ---

 Chemistry_Parameters = '$CHEM/CAMx4.4.chemparam.4_CF',
 Photolyis_Rates      = '$PHOT/tuv.wrap36km.${YYYY}${MM}.20051013.txt',
 Initial_Conditions   = '$ICBC/ic.wrap36km.CAMx',
 Boundary_Conditions  = '$ICBC/bc.wrap36km.CAMx.$JDATE',
 Top_Concentrations   = '$ICBC/topc.wrap36km.CAMx',
 Albedo_Haze_Ozone    = '$AHOMAP/ahomap.${YYYY}${MM}.20051013.txt',
 Point_Sources        =
'$EMIS/final.${YYYY}${MM}${DD}.RPO_US36.Base02f.pt.revised.bin',
 Master_Grid_Restart  = '$OUTPUT/camx.$RUN.$YESTERDAY.inst',
 Nested_Grid_Restart  = ' ',
 PiG_Restart          = '$OUTPUT/camx.$RUN.$YESTERDAY.pig ',

 Emiss_Grid(1)   = '$EMIS2/camx.ar.bart.36km.$JDATE.bin',
 Landuse_Grid(1) = '$LUSE/CAMx.wrap36km.luse.bin',
 ZP_Grid(1)      = '$MET/camx.zp.${Y2}${MM}${DD}.36k.bin',
```

```
 Wind_Grid(1)    = '$MET/camx.uv.${Y2}${MM}${DD}.36k.bin',
 Temp_Grid(1)    = '$MET/camx.tp.${Y2}${MM}${DD}.36k.bin',
 Vapor_Grid(1)   = '$MET/camx.qa.${Y2}${MM}${DD}.36k.bin',
 Cloud_Grid(1)   = '$MET/camx.cr.${Y2}${MM}${DD}.36k.bin',
 Kv_Grid(1)      = '$MET/camx.kv.OB70.${Y2}${MM}${DD}.36k.bin',
 Emiss_Grid(2)   = ' ',
 Landuse_Grid(2) = ' ',
 ZP_Grid(2)      = ' ',
 Wind_Grid(2)    = ' ',
 Temp_Grid(2)    = ' ',
 Vapor_Grid(2)   = ' ',
 Cloud_Grid(2)   = ' ',
 Kv_Grid(2)      = ' ',

 &
!-------------------------------------------------------------------------------

 &SA_Control

 SA_File_Root                = '$OUTPUT/camx.$RUN.$run.$JDATE',
 SA_Summary_Output           = .true.,
 SA_Master_Sfc_Output        = .true.,
 SA_Stratify_Boundary        = .false.,
 SA_Number_of_Source_Regions =  2,
 SA_Number_of_Source_Groups  =  1,
 Use_Leftover_Group          = .false.,
 Number_of_Timing_Releases   =  0,
 SA_Receptor_Definitions     =
'/mnt/usb2/modeling/camx/sa/receptor.nebraska.classI.txt',
 SA_Source_Area_Map(1)       =
'/mnt/usb2/modeling/cenrap_psat/camx/srcmap/srcmap.dat',
 SA_Master_Restart           = '$OUTPUT/camx.$RUN.$run.$YESTERDAY.sa.inst',
 SA_Nested_Restart           = ' ',
 SA_Points_Group(1)          =
'$EMIS/final.${YYYY}${MM}${DD}.RPO_US36.Base02f.pt.revised.bin.copy',
 SA_Emiss_Group_Grid(1,1)    = '$EMIS2/camx.ar.bart.36km.$JDATE.bin.copy',
 PSAT_Treat_SULFATE_Class    = .true.,
 PSAT_Treat_NITRATE_Class    = .true.,
 PSAT_Treat_SOA_Class        = .false.,
 PSAT_Treat_PRIMARY_Class    = .true.,
 PSAT_Treat_MERCURY_Class    = .false.,
 PSAT_Treat_OZONE_Class      = .false.,

  &

ieof
```

```
#
#  --- Execute the model ---
#

echo '---- Running for Date ',$JDATE

cp CAMx.in $run/camx.$RUN.$run.$JDATE.in
/usr/bin/time $EXEC >& $run/camx.$RUN.$run.$JDATE.stdout

rm -fv $EMIS/final.${YYYY}${MM}${DD}.RPO_US36.Base02f.pt.revised.bin.copy
>> & $OUTPUT/camx.$RUN.$JDATE.stdout
rm -fv $EMIS2/camx.ar.bart.36km.$JDATE.bin.copy >> &
$OUTPUT/camx.$RUN.$JDATE.stdout

@ JDATE++
if ( $JDATE == 2001366 ) set JDATE = 2002001

end
```