TECHNICAL MEMORANDUM

TECHNICAL JUSTIFICATION FOR CALGRID AS AN ALTERNATIVE TO THE UAM-IV MODEL IN THE NEW ENGLAND DOMAIN

Prepared for
NESCAUM

Prepared by
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1. Introduction

EARTH TECH has been retained by NESCAUM, on behalf of a consortium of New England states and industries, to conduct base case photochemical modeling simulations for four high ozone episodes with the CALGRID model. Task 1 of the workplan for this project is to compare the performance of the CALGRID model (version 1.7) with the EPA-recommended Carbon Bond IV Urban Airshed Model (UAM-IV) for the 7-8 July 1988 episode and to present the results in a technical memorandum. CALGRID must be shown to perform better than UAM-IV before it can be used as an alternative model for the New England domain ozone attainment demonstration.

The project workplan specifies the statistical measures and scoring scheme to be used in the performance evaluations. The protocol followed is based upon EPA guidance (EPA, 1991) and parallels the approach developed for the Greater Atlanta ozone nonattainment area (Georgia DNR,1994) where an alternative model was approved for use. This technical memorandum describes how the evaluation methodology was applied to the New England photochemical modeling domain and presents results demonstrating the acceptability of CALGRID as an alternative photochemical grid model for the New England domain.

In section 2 of this memorandum, several technical features of the CALGRID and UAM-IV models are described and contrasted. Section 3 presents the model inputs used to drive UAM-IV and CALGRID during the 7-8 July 1988 ozone episode. Sensitivity analyses of CALGRID to the model inputs are explored in section 4. The model performance protocol is presented in section 5. Section 6 presents and interprets the model evaluation products.

2. Comparison of CALGRID and UAM-IV Technical Features

The CALGRID photochemical model is peer-reviewed (Yamartino et al., 1992), documented (Yamartino et al., 1989; Scire et al., 1989), and publicly available. It was developed by Sigma Research Corporation (now part of EARTH TECH) scientists as an upgrade and modernization of UAM-IV. CALGRID represents a fully second-generation photochemical model for regulatory application. Modeling features to make the model backward compatible with UAM-IV were retained; however, CALGRID's more compact and streamlined preprocessor and input file style make it easier than UAM-IV to apply.

CALGRID contains state-of-the-science model improvements including:

- A vertical transport and diffusion scheme that incorporates the latest boundary layer formulations, permits several vertical level spacing approaches including dynamic, semi-logarithmic, and arbitrary level spacing, and accounts for all vertical flux components when employing either dynamic or fixed levels.

- A full resistance-based model for the computation of dry deposition rates as a function of geophysical parameters, meteorological conditions, and pollutant species.

- A chemical integration solver based on an adaptive time-step implementation of the quasi-steady state method of Hesstvedt et al. (1978) and Lamb (1983). This solver can efficiently and accurately handle the stiffest of modern schemes.

- Incorporation of more modern photochemical reaction schemes, such as the SAPRC mechanisms, that can more accurately address the roles of biogenic emissions and intermediate chemical products formed over multi-day episodes. In the current version of the model, the user can select between the SAPRC-90 and Carbon Bond IV chemical mechanisms.

- A horizontal advection scheme based on spectrally-constrained cubics (Yamartino, 1993) that conserves mass exactly, prohibits negative concentrations, and exhibits a level of numerical diffusion that is intermediate between class E and F (PGT class) dispersion.

CALGRID essentially uses the same dynamical equations as UAM-IV but, importantly, accounts for density variation with height to ensure exact mass conservation during all transport and diffusion operations. UAM-IV does not include density variation with height. Other improvements over UAM-IV include: (1) use of operator reversal to ensure second-order temporal accuracy, (2) use of three-dimensional space- and time-varying values of meteorological parameters such as photolysis coefficients, humidity, diffusivity, pressure, and temperature, and (3) on-the-fly computation of plume rise and entrainment for more precise initial vertical distribution of plume material.

There are good scientific reasons why CALGRID should perform more accurately than UAM-IV in the New England modeling domain. The Boston urban "plume" originates over land and, during the high ozone episodes, moves northeastward over the ocean, hugging the New Hampshire-Maine coastline. The land-sea difference in the thermal and turbulent structure of the planetary boundary layer results in large changes in temperature, wind direction and mixing profiles with distance from the shore. In this environment, UAM-IV is plagued by two limitations. The first is a lack of vertical resolution, which causes wind shears and temperature profile information to be lost to vertical averaging This leads to spurious instantaneous vertical transport via cell dilution as the UAM-IV layers expand. The second is that the numerical solution of the model equations is strained by the rapidly varying thickness of model layers along the coast. Errors in the estimate of fluxes across cell faces are larger, resulting in unrealistically large transport between land and marine environment along the sloping cell interfaces.

In its fixed layer mode, CALGRID is considerably less prone to several classes of numerical biases. The CALGRID model, in the New England domain application, was operated with all of the 14 layers provided by the CALMET meteorological model (Scire et al., 1995). This means there was no additional vertical averaging of the wind and temperature fields, as in UAM-IV. The CALGRID model has a 20 m thick first layer which is important for modeling thin polluted marine layers. The minimum UAM-IV first layer, on the other hand, is 50 meters, or more. The result is that CALGRID does considerably better than UAM-IV under conditions where ozone precursors from a coastal city such as Boston are transported out over water.

Another distinct advantage that CALGRID has over UAM-IV is the presence of a more realistic deposition algorithm that tracks the changes in plant uptake of ozone and other pollutants more closely. Diurnal and environmental changes in vegetation are not tracked with UAM-IV, except via changes in the aerodynamic resistance. This makes it possible for CALGRID to better track the dynamic range of the diurnal ozone variation. This is especially evident when coupled with a 20 m thick surface layer where predicted surface concentrations are quite responsive to changes in deposition velocity.

3. Description of Model Input Data

Both photochemical models use the same types of input data, although UAM-IV tends to aggregate/average the data more. The basic types of input data used by the models are:

- time-independent data on terrain and surface cover,
- time-independent data on chemistry parameters,
- time-dependent boundary and initial concentration data,
- time-dependent information on emissions, and
- time-dependent information on meteorological conditions.

The information on terrain data for UAM-IV includes cell-average roughness lengths and a vegetation factor used to determine the deposition velocities of various pollutants. CALGRID uses all of the geographical data present in the CALMET output meteorological file, including terrain elevation, roughness length, albedo, leaf area index, and land cover type. Both models read in the rate coefficient information for Carbon Bond IV version 6.21 (CB4). The chemical parameters in the UAM-IV CHEMPARAM file were directly translated, number by number, to update the CALGRID CARBON4.MOD input file to match the latest EPA version.

The sources of the time-dependent input data used by CALGRID and UAM-IV in the model evaluation and comparison are summarized in Table 3-1. More details are presented in the subsections that follow.

Table 3-1. Sources of the data used to exercise UAM-IV and CALGRID for 7-8 July 1988 in the New England photochemical modeling domain.

Data Type	UAM-IV Input File	Data Origin	CALGRID Input File	Data Origin
Geophysical	TERRAIN	U.S. Geological Survey (USGS) gridded land use/land cover (LULC) data	CALMET.DAT	CALMET GEO.DAT input file prepared from USGS LULC and Digital Elevation Mapping (DEM) data
Emissions	EMISSIONS (surface)	Emissions Processing System (EPS2.0) output using state inventory data - UAM-BEIS, UAM-BEIS2 biogenic emissions processor	AREM.DAT (surface)	Same as UAM-IV
	PTSOURCE (elevated)	EPS2.0 output using state inventory data	PTEMARB.DAT (elevated)	Same as UAM-IV
Meteorology	DIFFBREAK	Extraction from hourly CALMET.DAT file using CAL2UAM extraction program	CALMET.DAT	Run CALMET3.0 with van Ulden - Holtslag PBL, 20-minute MADEP subset of Aerometric Information Retrieval System (AIRS), National Weather Service (NWS), and buoy meteorological data
	WINDS	Extraction from hourly CALMET.DAT using CAL2UAM UAMWND processor	"	"
	TEMPERATURE	Extraction from hourly CALMET.DAT file using CAL2UAM	"	"
	METSCALARS	Estimation using CALMET.DAT station information, EPA SUNFUNC routine and other UAM-IV pre-processors in CAL2UAM	"	"
	REGIONTOP	Estimated using DIFFBREAK, minimum layer thickness, and constant height top option in CAL2UAM	CALGRID.INP	Set to match UAM-IV

Table 3-1. (Continued) Sources of the data used to exercise UAM-IV and CALGRID for 7-8 July 1988 in the New England photochemical modeling domain.

Data Type	UAM-IV Input File	Data Origin	CALGRID Input File	Data Origin
Initial Concentrations	AIRQUALITY	Extracted from ROM "BASE88RR" run	ICON.DAT	Reformat of UAM-IV file
Boundary Concentrations	TOPCONC	Extracted from ROM "BASE88RR" run	TCON.DAT	Reformat of UAM-IV file
	BOUNDARY	Cutout of NY SIP UAM-IV concentrations overlaid on ROM "BASE88RR" extractions	BCON.DAT	Reformat of UAM-IV file

3.1 Emissions Data

The base year emissions data consist of daily files of gridded hourly surface and elevated point source emissions for each CB4 specie emitted. These daily UAM-IV model-ready emissions files were supplied by the Massachusetts DEP. In addition to the aggregated input files, individual files for mobile source emissions, low-level point source emissions, area source emissions, and biogenic emissions were supplied. The biogenic emission files used for the model performance evaluation were produced with version 2 of the EPA Biogenic Emissions Inventory System model (BEIS2).

CALGRID requires reformatting of the UAM-IV emissions data, but no other conversion is needed when CB4 is being used. Rather than exercising a separate plume rise model as UAM-IV does, CALGRID estimates plume rise internally. The estimates of plume rise produced by CALGRID should be more accurate since the actual temperature profile of the atmosphere is used rather than the simple two-segment fit based on the domain-wide vertical temperature gradients above and below the mixing height ("TGRADABOVE" and "TGRADBELOW") employed by the UAM-IV plume rise processor.

3.2 Meteorological Data

CALMET was used to create gridded wind, temperature, and other fields from hourly observed data provided by the Massachusetts DEP. These output data were directly mapped into CALGRID without averaging because the horizontal grid dimensions and vertical layer structures were defined identically in the CALMET and CALGRID models for this study. On the other hand, UAM-IV requires substantial processing of the CALMET output data file (or alternatively the raw observational data) in order to create the WINDS, DIFFBREAK, TEMPERATUR, METSCALARS, TERRAIN, and REGIONTOP files. The CALMET post-processing was done using the recommendations in Volume 2 of the UAM-IV user's manual (Morris et al., 1990). EARTH TECH developed a processor called CAL2UAM that uses the UAMWND and various other UAM preprocessor routines (e.g., SUNFUNC) to produce UAM-IV input files from the CALMET output file. The winds and other variables are averaged and aggregated over the domain to provide winds for the coarser UAM vertical layers and domain-wide hourly metscalars. UAMWND does a linear vertical interpolation and a momentum conservation weighting of winds in the column. No divergence minimization was applied to reduce the magnitude of the vertical winds. The temperature field and the mixing height were used to estimate the domain-wide temperature lapse rates. The station and sounding relative humidity information was directly averaged to create a domain-volume-average estimate of the water vapor concentration.

UAM-IV is a clear sky model with chemical photolysis rates estimated using a Los Angeles haze layer and a 320 Dobson Units (DU) columnar ozone depth. CALGRID also was exercised in a clear sky mode with a 320 DU columnar ozone thickness. The CALMET model outputs the PGT stability class, roughness length, Monin-Obukhov length, and a convective scaling velocity for each surface grid cell. This information is used in CAL2UAM, along with information from the UAM-IV preprocessor user's manual, in order to estimate an appropriate exposure class. Both models assumed the same fixed model top of 3300 m.

The surface winds over land during the high ozone day of 8 July 1988 were from the south-southwest. During the middle of the day, the winds were light over most of the domain except over portions of Cape Cod. The vertical winds near the surface layer were also small, with maximum vertical velocities on the order of one cm per second occurring just north of Boston. Trajectory analyses indicated that the high concentrations along the Maine coast originated in the early morning in the major source regions near Boston. The maximums that occur along the Connecticut River valley originated from the general direction of New York City and will be heavily influenced by the concentrations at the southwest boundaries of the modeling domain.

During the afternoon of 8 July the mixing heights reached heights of 2400 m. Near the coast, the mixing heights rapidly decrease to a marine mechanical mixing height that is on the order of 200 m. Pollutant material moving across a shoreline experiences a dramatic change in the profile of vertical mixing. Within the boundary layer, the winds were generally from the south-southwest. The winds veered to the west with elevation, and were northwest at the top of the modeling domain. The afternoon surface temperatures and humidity were high and skies were fair. The average columnar ozone was about 320 DU. The only attenuation of solar radiation occurs in the first few hundred meters, which could result in an actual increase in UV-B due to forward Mie scattering.

Meteorological data for CALGRID was interpolated to 20 minute intervals. CALMET created the 20 minute data from the hourly average observations (like AIRS) and the National Weather Service one minute average observations. The solar angle, which is critical for mixing height estimation, was calculated at the center of each 20-minute period. CALMET uses the van Ulden and Holtslag (1985) scheme to interpolate winds in the boundary layer. At the shoreline where onshore flow occurs, an advective averaging scheme in CALMET creates an approximate thermal internal boundary layer.

3.3 Boundary and Initial Conditions

UAM-IV was initially exercised with lateral and top boundary conditions that were extracted using the EPA ROM-UAM interface software. Due to biases in the ROM predicted concentration estimates, the predicted UAM-IV boundary ozone concentrations along the Connecticut coastline during 8 July showed poor agreement with observations. Since the New York modeling domain overlaps Connecticut, UAM-IV runs conducted by the New York DEC were used to estimate boundary conditions on the southern border of the New England domain, with ROM boundary conditions for the nonoverlapping borders. Direct mapping from UTM zone 18 to UTM zone 19 was conducted. The mixing heights in both cases were obtained using CALMET on a 5 km grid. When intercompared, the mixing height differences were small. As a result, direct layer-to-layer mapping of the concentrations was used, rather than doing mass adjustments. This second set of boundary conditions resulted in high ozone concentrations moving up the Hudson River Valley. Both the UAM-IV and CALGRID simulations for 8 July 1988 for the performance evaluation used the UAM-IV/ROM boundary conditions.

In this study, the top boundary conditions remain the same as the set extracted from the ROM-UAM interface processor by MADEP. The initial conditions were developed by exercising the UAM-IV for the 7 July period and using the concentrations estimated at the end of the day as initial concentrations at the beginning of the day. The same sets of top and initial conditions are used for CALGRID and the UAM-IV simulation, except for reformatting and redistributing vertically to conserve mass.

4. Sensitivity Analyses

CALGRID has several user-specified input parameters not used in UAM-IV, including the following:

- surface emissions vertical weighting profile,
- minimum surface resistances for various canopy and surface removal pathways, and
- minimum eddy diffusivity at the PBL top.

In addition, CALGRID uses all of the meteorological information present in the CALMET output file, including sub-hourly information on solar radiation and meteorological conditions. CALGRID is affected by changes in the meteorological fields in the 20 m thick surface layer, which are minimized in UAM-IV due to vertical averaging. The CALMET meteorological fields in the 20 m surface layer also are affected by different choices in some of the parameters such as the sphere of influence (SOI) and the number of sites used within the SOI. Settings of other parameters such as the minimum mixing height are overridden in UAM-IV, but not in CALGRID.

In an initial CALGRID simulation for 8 July 1988, the area source emissions were placed into the first two layers (0-20 m, and 20-50 m) with a 75/25 percent weighting. UAM-IV puts all of the area source emissions in the first layer. A sensitivity run was conducted which placed all of the area source emissions into the first layer. Difference plots of maximum daily one-hour predicted ozone concentrations indicated a small effect.

A second parameter varied was the default minimum vertical eddy diffusivity at the top of the boundary layer. The UAM-IV has a very small value of 0.02 m^2/s at the diffusion break, effectively placing a lid on the vertical mixing. The default value used by CALGRID is a much larger value of 1 m^2/s, which is more in line with estimates of other researchers. A CALGRID simulation made with a value of 0.2 m^2/s showed little change.

There is some indication that when leaf surfaces are wetted by dew the cuticle resistance for ozone declines and leaves may take up more ozone than when dry. The cuticle resistance was reduced by a factor of three to account for such a change. While there was some noticeable reduction in CALGRID predicted daily maximum surface ozone concentrations in northern Massachusetts and southern New Hampshire, the resulting differences were also small.

5. Description of the Model Evaluation and Comparison Methodology

The model evaluation methodology was based on four EPA-recommended (EPA, 1991) statistics. The New England domain was divided into five subdomains by the Massachusetts DEP to capture different influences and transport processes. A scoring scheme was devised by the DEP to compare the performance of UAM-IV and CALGRID. This scheme uses estimates of the statistical measures in the domain and each subdomain to develop a single composite measure.

5.1 Statistical Performance Measures

The four statistics are defined in equations 5-1 through 5-4 and have the following percentage evaluation targets:

- A_U - unpaired highest prediction accuracy 20%,
- D - normalized bias for $C_O > 60$ ppb 15%
- E_d - gross error for $C_O > 60$ ppb 30%
- A - average station peak prediction accuracy 30%

where C_O is the observed concentration. Note that since the convention for residual concentrations of observed minus predicted is used, a positive value is an underprediction.

Unpaired Highest-Prediction Accuracy

$$A_u = \frac{C_o(.,.) - C_p(.,.)}{C_o(.,.)} \times 100\% \qquad (5\text{-}1)$$

where

A_U = unpaired highest-prediction accuracy (quantifies the difference between the magnitude of the highest 1-hour observed value and the highest 1-hour predicted value, regardless of location

$C_O(.,.)$ = maximum 1-hour observed concentration over all hours and monitoring stations

$C_P(.,.)$ = maximum 1-hour predicted concentration over all hours and surface grid squares

Normalized Bias

$$D = \frac{1}{N_T} \sum_{i=1}^{N} \sum_{j=1}^{H_i} \frac{C_O(i,j) - C_P(i,j)}{C_O(i,j)} \times 100\% \qquad (5\text{-}2)$$

where

D = normalized bias obtained from all hourly prediction-observation pairs with hourly observed values > 60 ppb

N = number of monitoring stations

H_i = number of hourly prediction-observation pairs for monitoring station i

N_T = total number of station-hours

$C_O(i, j)$ = observed value at monitoring station i for hour j

$C_P(i, j)$ = predicted value at monitoring station i for hour j

Gross Error of All Pairs >60 ppb

$$E_d = \frac{1}{N_T} \sum_{i=1}^{N} \sum_{j=1}^{H_i} \frac{|C_O(i,j) - C_P(i,j)|}{C_O(i,j)} \times 100\% \qquad (5\text{-}3)$$

where

E_d	=	normalized gross error for all hourly prediction-observation pairs for hourly observed values >60 ppb
N_T	=	total number of station hours (defined previously)
N	=	number of monitoring stations
H_i	=	number of hourly prediction-observation pairs for monitoring station i
C_O (i, j)	=	observed value >60 ppb at monitoring station i for hour j
C_P (i, j)	=	predicted value at monitoring station i for hour j

5-4. *Average Station Peak Prediction Accuracy*

$$A = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{C_O(i,t_i) - C_P(i,t_i)}{C_O(i,t_i)} \right| \text{ x } 100\% \qquad (5\text{-}4)$$

where

A	=	mean paired peak prediction accuracies averaged over all monitoring stations
N	=	number of monitoring stations
C_O (i, t_i)	=	peak observed value at monitoring station i for hour t_i
C_P (i, t_i)	=	predicted value at monitoring station i for hour t_i

The pairing in time at sites provides a valuable indication of the match in timing between the observed and predicted maximum concentrations.

5.2 Model Subdomains

To examine local performance, the Massachusetts DEP divided the modeling domain into five subdomains. These five subdomains are shown in Figure 5-1. They are descriptively noted as:

- Subdomain A - Maine, coastal New Hampshire, northern coastal Massachusetts,
- Subdomain B - northeast Massachusetts, Merrimack Valley,
- Subdomain C - southeast Massachusetts and Rhode Island,
- Subdomain D - central Massachusetts, and
- Subdomain E - Connecticut and Vermont.

Subdomain E, at the request of the DEP, was excluded from the performance evaluation because most of the monitors in this region are in the New York SIP modeling domain. There are nine monitors in subdomain A, seven in subdomain B, six in subdomain C, and seven in subdomain D.

5.3 Model Performance Scoring

The scoring scheme developed by the Massachusetts DEP is based on the four statistical measures and their targets. A maximum of one point is awarded for each measure for the whole domain and for each of the four subdomains, or a maximum of twenty points. No points are awarded if the value of the performance measure is outside of the target. The maximum of one point is awarded if the performance is perfect (0% for the statistical measure). For performance between perfect and outside of the target value, a linear interpolation is used. For example, if the bias is plus or minus 10% for a given subdomain, then 0.3333 points are awarded (1 - 10%/15%).

5.4 Graphical Measures

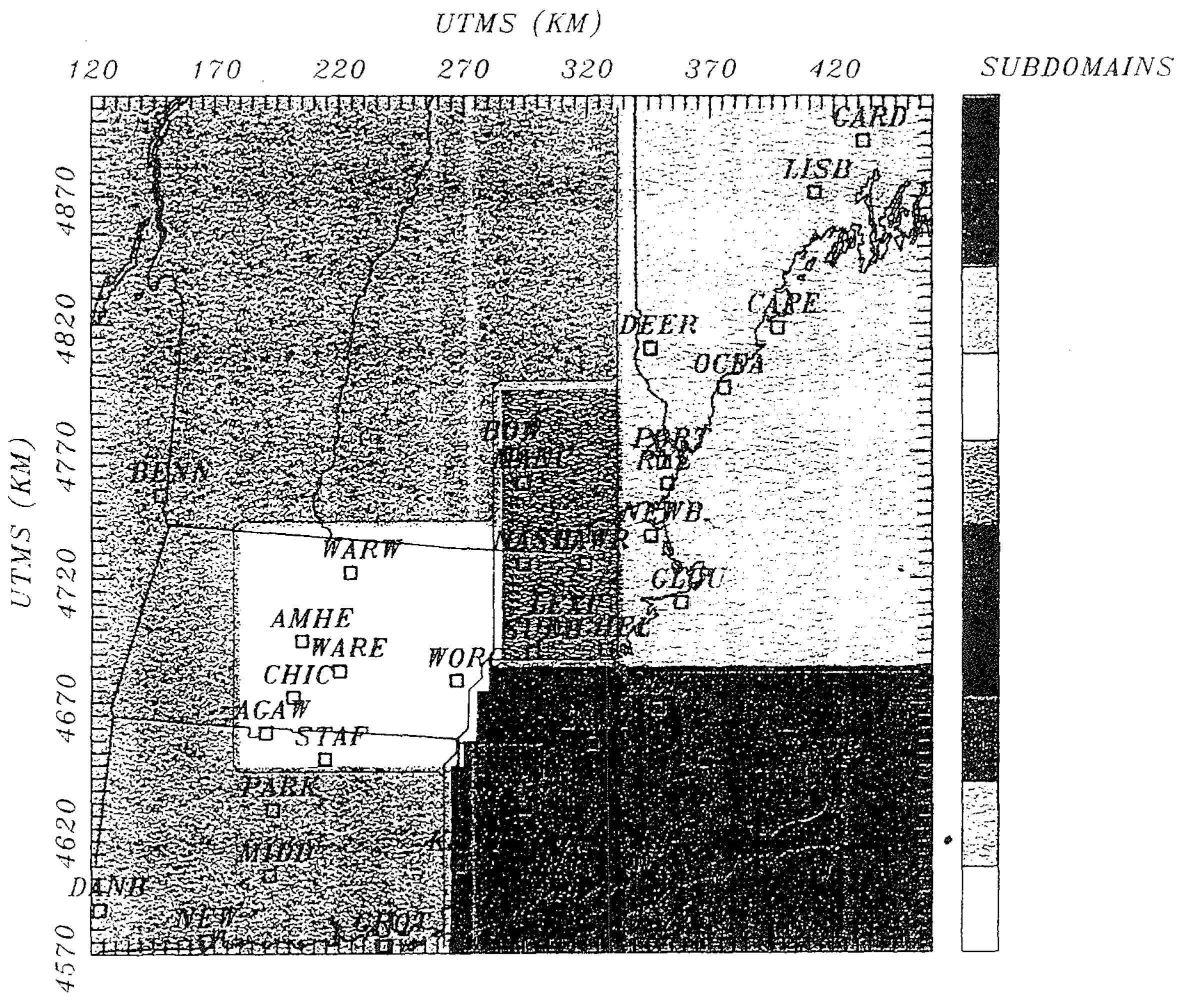
Several graphical products were generated to assist in model interpretation. These included plots of the maximum hourly ozone concentrations, scatter plots of observation-prediction pairs, and time series plots at monitor sites.

6.0 Results of Model Performance Evaluation

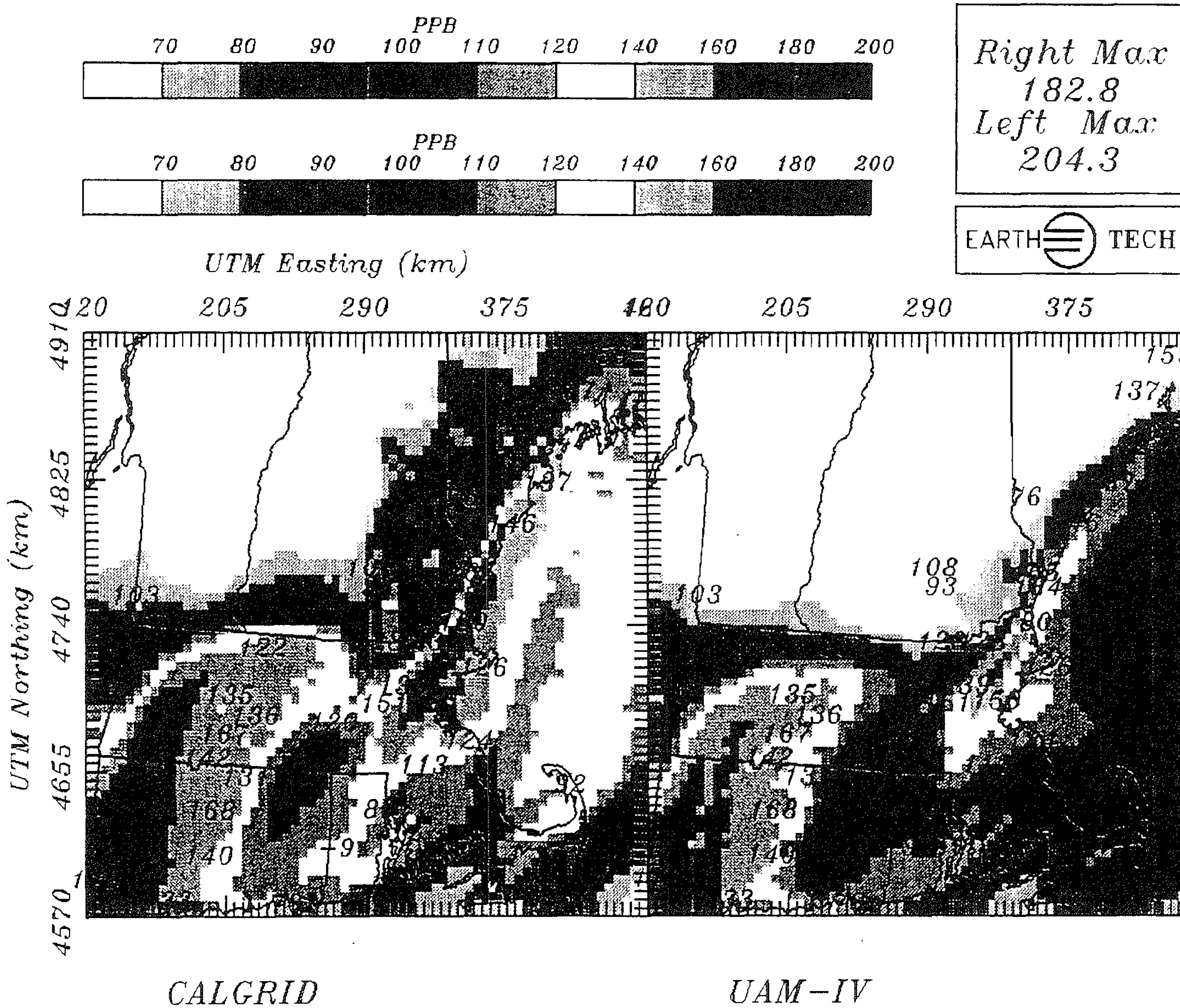
6.1 Graphical Results

Figure 6-1 presents the maximum predicted ozone concentrations for 8 July for both CALGRID and UAM-IV, along with the observed concentrations. CALGRID predicts much higher concentrations of ozone along the coastline north of Boston, and into the Connecticut River valley

MODEL EVALUATION SUBDOMAINS IN NEW ENGLAND



Predicted Surface Ozone for July 8, 1988.



than UAM-IV. This agrees better with the high observed concentrations along the coast and into Maine, and provides more reasonable concentrations into New Hampshire. Differences in western Massachusetts are more difficult to interpret since the boundary conditions in the southwestern corner of the modeling domain greatly affect the maximum daily ozone concentrations in central Massachusetts.

Figure 6-2 presents the scatter plot of observed and predicted concentrations for each model. The key feature in this figure is the significant underprediction by UAM-IV in subdomain A, which covers the coastal area north of Boston. The best fit line, the triangle representing the average of all predictions paired with the average of all observations, and box representing half a standard deviation of the observed and predicted about the average are also plotted for both models. The degree of scatter is less for CALGRID than for UAM-IV.

Figures 6-3 to 6-5 present the time series plots for three monitors that recorded the transport of the ozone plume northward from the Boston metropolitan area into central Maine. The highest hourly ozone concentration in the domain of 184 ppb was observed by the Rye, NH monitor at 1400 LST. Cape Elizabeth, ME observed a peak of 137 ppb at 1500 LST and Gardiner, ME observed a peak of 159 ppb at 1900. The plots show that CALGRID performs better than UAM-IV at all these sites in matching both the peak observed concentration and the timing of the peak.

6.2 Performance Measures Results

The results of the statistical performance measures and the scoring scheme are shown in Tables 6-1 and 6-2. CALGRID performs better than UAM-IV in every subdomain and in the entire New England domain. With the exception of the Rhode Island/Southeast MA subdomain, where neither model does very well, CALGRID has very low bias, as opposed to UAM-IV, which does poorly with this measure. The CALGRID performance is best in the Maine and coastal MA and NH subdomain.

In summary, applying the statistical measures and scoring scheme developed in the workplan to the July 8, 1988 base case, the CALGRID model was clearly shown to perform better than the UAM-IV model for the New England domain for this episode.

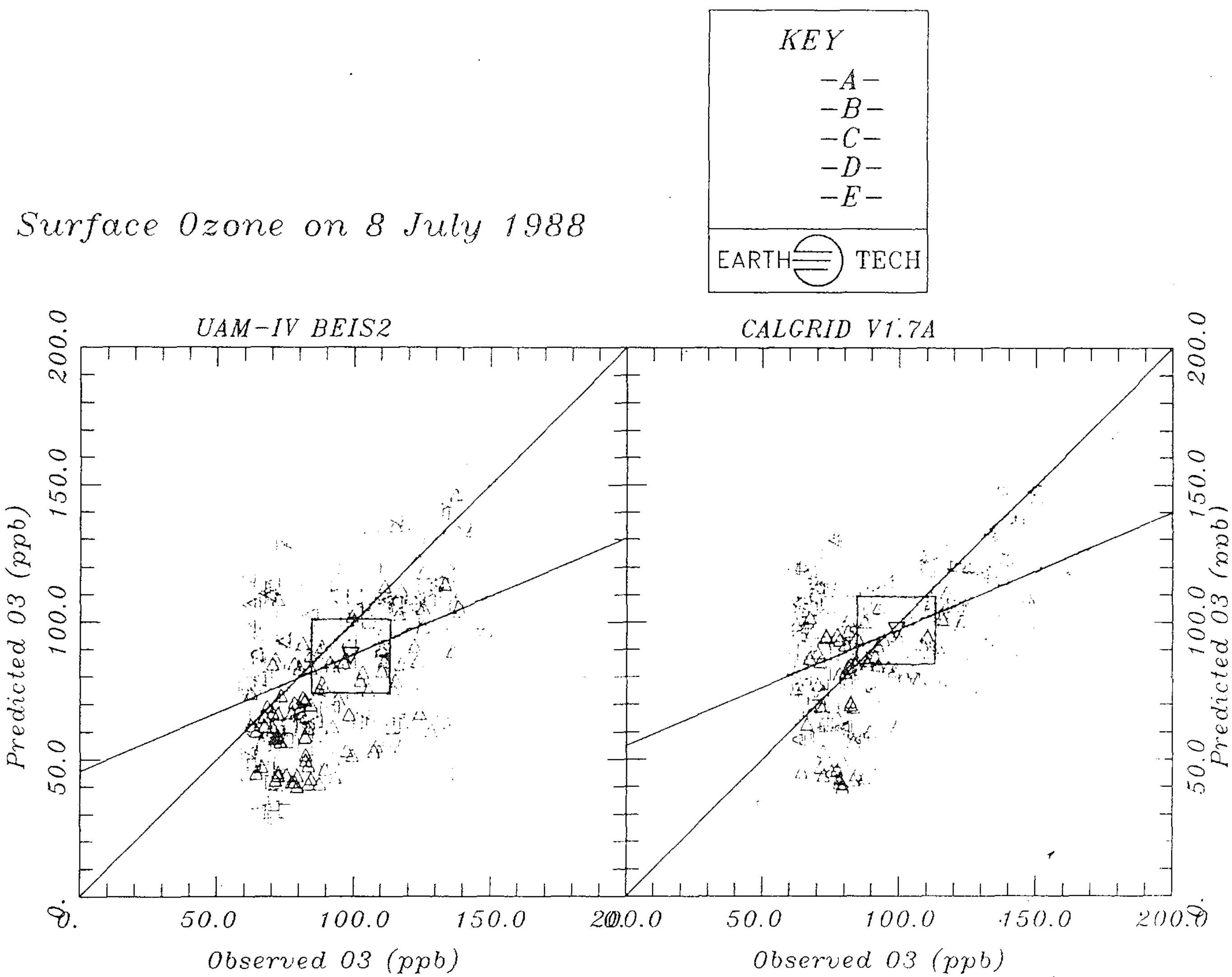
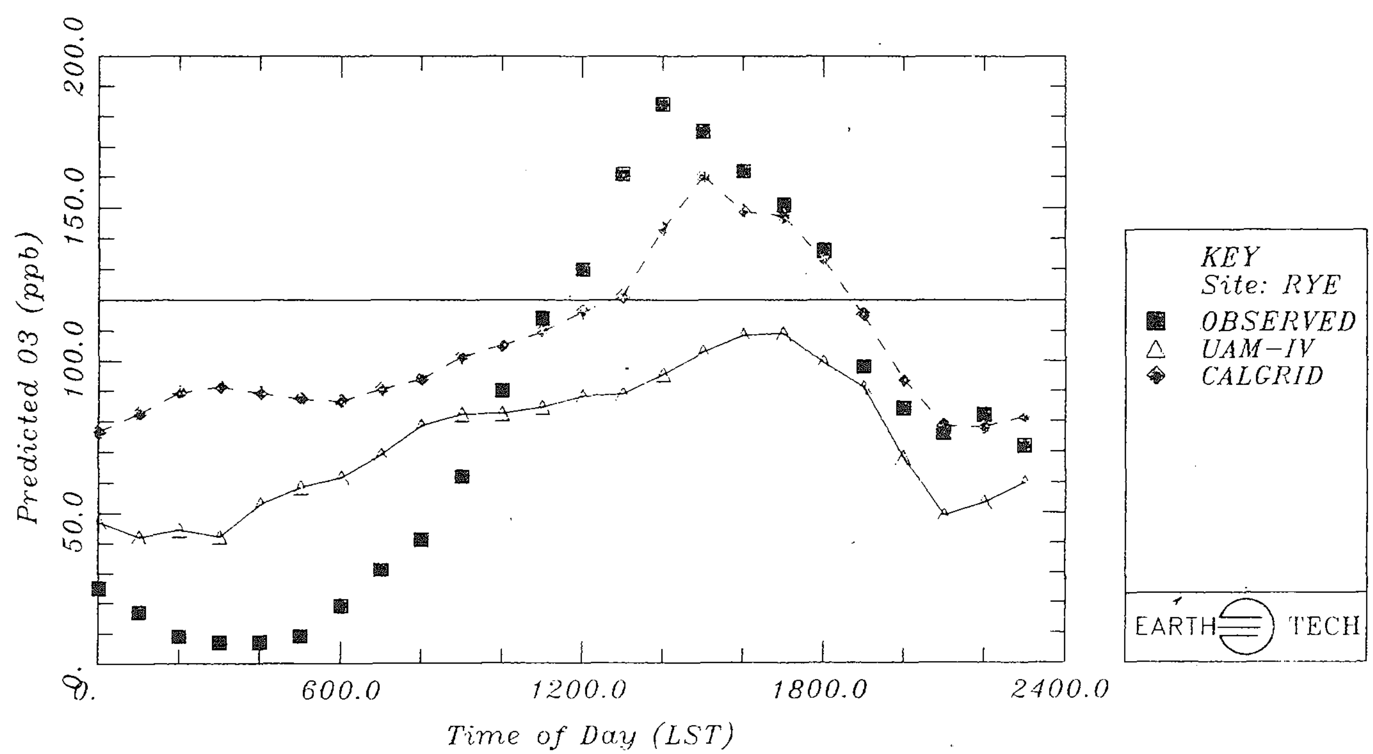
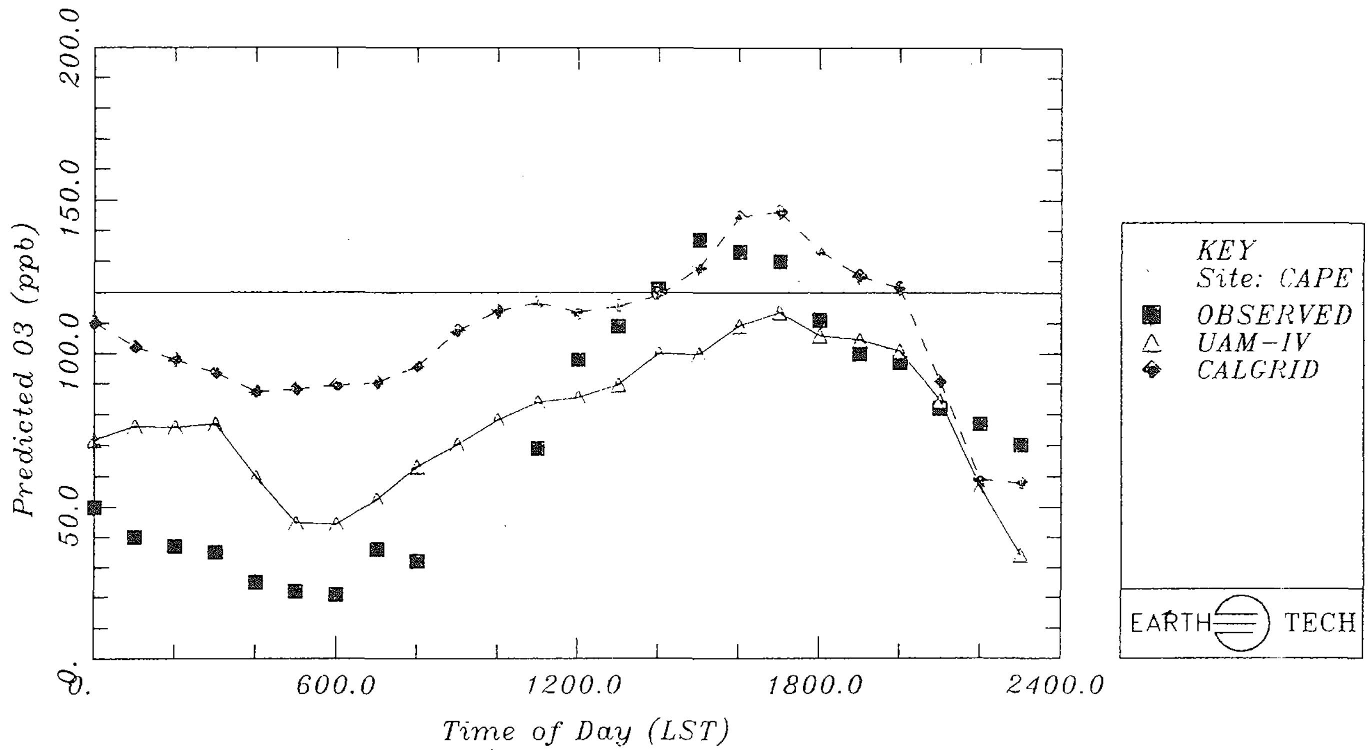

Surface Ozone on 8 July 1988
KEY
-A-
-B-
-C-
-D-
-E-
EARTH TECH
UAM-IV BEIS2
CALGRID V1.7A
Predicted O3 (ppb)
Observed O3 (ppb)
0.
50.0
100.0
150.0
200.0

Figure 6-2.

Station Surface Hourly Ozone on 8 July 1988



Station Surface Hourly Ozone on 8 July 1988



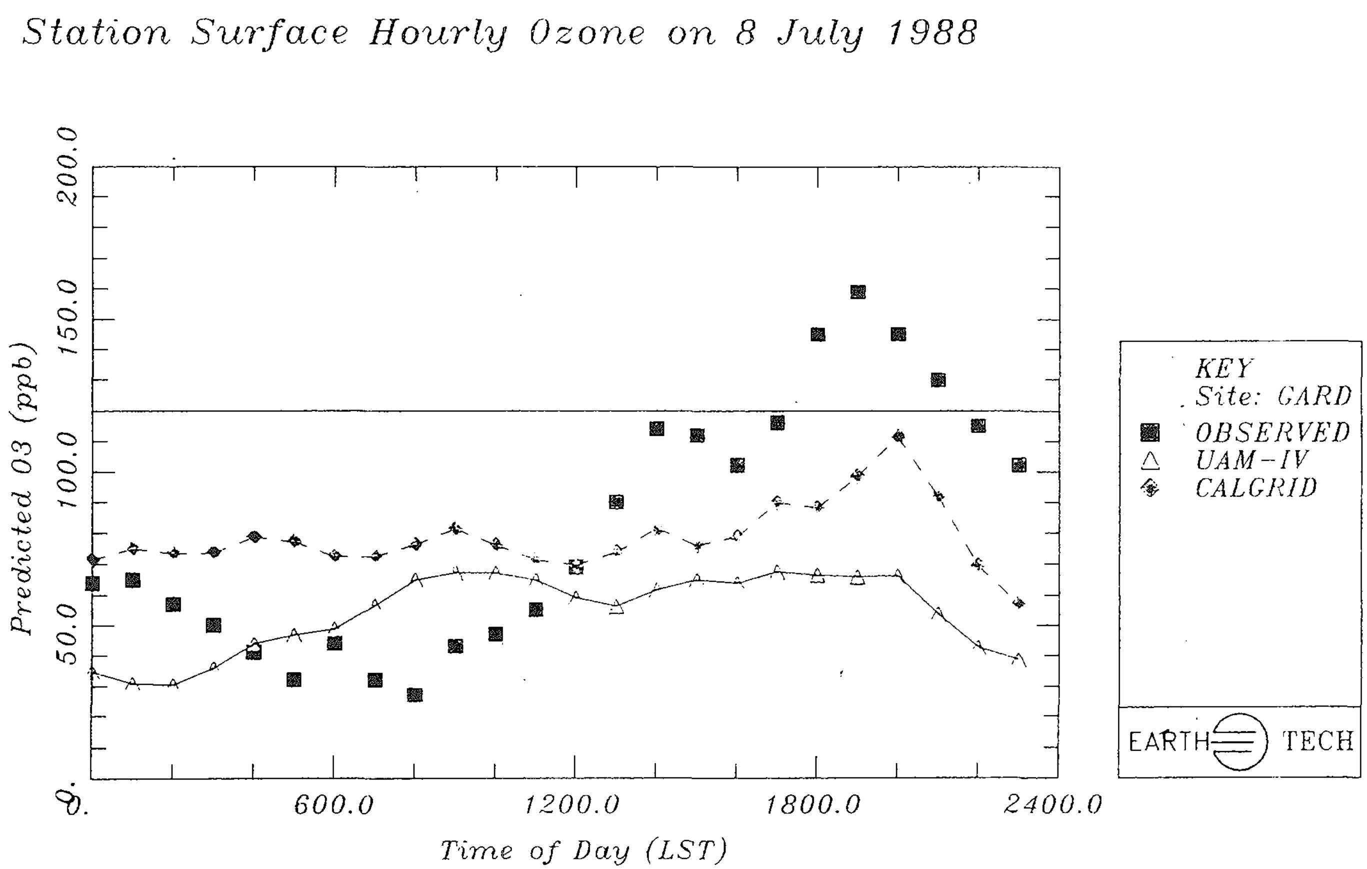

Station Surface Hourly Ozone on 8 July 1988
Predicted 03 (ppb)
0.
50.0
100.0
150.0
200.0
0.
600.0
1200.0
1800.0
2400.0
Time of Day (LST)
KEY
Site: GARD
OBSERVED
UAM-IV
CALGRID
EARTH TECH

Table 6-1

PERFORMANCE EVALUATION STATISTICS

Comparison of CALGRID and UAM-IV models

New England Domain - 8 July 1988

	ME/Coastal MA & NH	NH/N MA	RI/SE MA	Central MA	All subdomains	
CALGRID with BEIS2						EPA Target
Unpaired Peak Accuracy	3.3	-12.7	-14.5	-4.5	1.1	20%
Paired Peak Accuracy	19.9	25.0	18.4	28.7	23.1	30%
Normalized Bias	0.4	8.8	**-22.4**	2.6	-2.3	15%
Gross Error	20.8	21.1	28.3	25.3	24.1	30%
UAM-IV with BEIS2						
Unpaired Peak Accuracy	-2.1	**-23.6**	-13.3	-4.9	-2.1	20%
Paired Peak Accuracy	**35.4**	**35.6**	25.0	**32.6**	**30.7**	30%
Normalized Bias	**20.3**	**20.0**	**-17.8**	11.4	8.5	15%
Gross Error	29.3	24.6	24.0	24.2	26.1	30%

Notes:
1. Units are percent
2. Negative values - predicted exceeds observed
3. Positive values - observed exceeds predicted
4. Values in **bold face** exceed target
5. Boundary conditions for both models from UAM-IV

i:\1532\pfcaluam.xls

Table 6-2.

PERFORMANCE EVALUATION SCORES							
Comparison of CALGRID and UAM-IV models							
New England Domain - 8 July 1988							
	ME/Coastal MA & NH	NH/N MA	RI/SE MA	Central MA	All subdomains		
CALGRID with BEIS2						Total	Maximum
Unpaired Peak Accuracy	0.83	0.36	0.27	0.78	0.95	**3.19**	5.00
Paired Peak Accuracy	0.34	0.17	0.39	0.04	0.23	**1.17**	5.00
Normalized Bias	0.97	0.41	0.00	0.83	0.85	**3.06**	5.00
Gross Error	0.31	0.30	0.05	0.16	0.20	**0.71**	5.00
Total	**2.45**	**1.24**	**0.71**	**1.81**	**2.23**	**8.13**	20.00
UAM-IV with BEIS2							
Unpaired Peak Accuracy	0.89	0.00	0.33	0.76	0.89	**2.87**	5.00
Paired Peak Accuracy	0.00	0.00	0.17	0.00	0.00	**0.17**	5.00
Normalized Bias	0.00	0.00	0.00	0.24	0.43	**0.67**	5.00
Gross Error	0.02	0.18	0.20	0.19	0.13	**0.72**	5.00
Total	**0.91**	**0.18**	**0.70**	**1.19**	**1.45**	**4.43**	20.00

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References

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