**Final Report**

# ENHANCEMENT OF GLOBEIS

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# EXECUTIVE SUMMARY

## ES.1 OVERVIEW

GloBEIS, one of the primary biogenic emissions modeling systems used for ozone air quality planning, is a biogenic emissions modeling system developed by NCAR and Environ International Corporation, based on the BEIS emission factors and algorithms but with an easier-to-use interface and compatibility with a wider range of input data sources (Yarwood, 1999). GloBEIS has been continually improved over the past decade. Due to the clumsiness and over expanded memory in multiple-day calculation in previous GloBEIS and the lack of direct SQT emission estimation, our goals are to improve multiple day calculation and implement SQT emission estimation in GloBEIS. For this project, we, ENVIRON and Dr. Alex Guenther, developed the new user interface and implemented SQT emission estimation in GloBEIS version 3.5. In addition, we update GloBEIS to account the latest sciences and technologies as available. The new land cover definitions for a satellite-derived land use dataset in GloBEIS version 3.1 CSR is included in GloBEIS version 3.5 as well.

To improve GloBEIS functionality, we developed a new user interface based on the pervious GloBEIS version. We chose Microsoft Access - macro/dos batch process over Microsoft Visual Basic (VB) for simplicity and avoid incompatibility in Microsoft libraries, e.g. .NET, among Windows OS computers. The interface is designed to proceed on each calculation day and generate batch program at the end of the calculation day. The interface closes MS Access and cleans the reserved memory when the calculation is completed and the batch program will restart GloBEIS for the next day. The updated interface was tested alone in order to repeat the outputs from TCEQ AQS2 study using GloBEIS v3.1 CSR. The testing shows that the new interface does not interfere the emission estimations. The new design for the user interface is more suitable for batch process and the new algorithm is able to clean the reserved memory at the end of each day calculation. With the new user interface, GloBEIS v3.5 is more robust. The model is more convenient to setup which preventing setup error, requires less attention and time in running model, and prevents program crashes from over-expanded memory.

To implement SQT emission estimation in GloBEIS, Dr. Guenther has based the SQT emission factors (Table 2.1) on many recent studies including Karl et al., in preparation, Bouvier-Brown et al., 2009, Kim et al., 2009, Sakulyanontvittaya et al., 2008, and Arnts, 2008, for this updates. The GloBEIS 3.5 emission factors also consider recent advances in whole canopy sesquiterpene fluxes based on ambient air measurement (Kim et al., 2009, Bouvier-Brown et al., 2009, and Arnts, 2008), while sesquiterpene emission factors have previously been derived solely from branch enclosure and gas chromatography techniques. Dr. Guenther has implemented the most up-to-date emission activity algorithm for SQT (Guenther et al., in preparation) to adjust emission rates for variations in light, LAI, leaf age, canopy losses, and temperature in the model. The SQT emission methodology performs reasonably well. It is comparable to other biogenic emission models and estimates emissions that are in agreement with the few observations of canopy scale sesquiterpene emissions. However, we recommend further research on SQT emission and its impact, e.g. evaluating secondary organic aerosol formation from SQT.

Although GloBEIS and MEGAN are generally based on the same observations and approaches there are significant differences in their emission estimates and it is important to understand the characteristics of GloBEIS and MEGAN and how they differ. This study compared the emission

estimates from GloBEIS v3.5 and MEGAN v2.04a using several input configurations based on land cover data and emission factors used for the two models. Moreover, this study presents model performance evaluation for the Texas 2006 AQS2 episode by comparing to the NOAA WP-3 aircraft measurements conducted in East Texas and the Gulf of Mexico areas during the Texas Air Quality Study in September and October of 2006 (TexAQS2006) campaigns. The base case emissions from the two models were used in a regional scale photochemical gridded model (CAMx version 4.53). We compared the 3-D 15-min outputs to isoprene, and total monoterpenes, oxygenates, ozone, CO airborne measurements. It should be noted that a comparison of model and observed concentrations evaluates the combined influence of emissions, chemistry and transport and dispersion.

## GloBEIS and MEGAN Configurations

In summary, there are total of 4 GloBEIS-MEGAN configurations for the 36 km and 12 km domains and 6 GloBEIS-MEGAN configurations for the 4 km domain. These cases are described in Table E.1 – E.2. For the 36 km and 12km domains, GloBEIS configurations are; 1) G_Gef_Clai - GloBEIS emission factors and land cover, and constant LAI, and 2) G_Gef_Mlai – GloBEIS emission factors and land cover, and variable (MEGAN) LAI. For the 4 km domain, GloBEIS configurations are; 3) G_GefCSR_Clai – GloBEIS emission factors and CSR based land cover, and constant LAI, 4) G_GefCSR_Mlai – GloBEIS emission factors and CSR based land cover, and variable (MEGAN) LAI, 5) G_GefWIE_Clai – GloBEIS emission factors and WIED derived land cover, and constant LAI, and 6) G_GefWIE_Mlai – GloBEIS emission factors and WIED derived land cover, and variable (MEGAN) LAI.

The MEGAN configurations for the 36 km and 12km domains are; 7) M_MefMpft – MEGAN emission factors and MEGAN PFTF, and 8) M_GefGpft – GloBEIS emission factors and GloBEIS land cover. For the 4 km domain, the configurations are; 7) M_MefMpft, and 9) M_GefGpftCSR - GloBEIS emission factors and GloBEIS CSR based land cover.

**Table E.1. Summary of GloBEIS version 3.5 configurations**

| No. | Case | EF | Land Cover | LAI | Domain |
|---|---|---|---|---|---|
| 1 | G_Gef_Clai | GloBEIS | GloBEIS | Constant | 36/12 |
| 2 | G_Gef_Mlai | GloBEIS | GloBEIS | MEGAN | 36/12 |
| 3 | G_GefCSR_Clai | GloBEIS | CSR | Constant | 4 |
| 4 | G_GefCSR_Mlai | GloBEIS | CSR | MEGAN | 4 |
| 5 | G_GefWIE_Clai | GloBEIS | WIED | Constant | 4 |
| 6 | G_GefWIE_Mlai | GloBEIS | WIED | MEGAN | 4 |

**Table E.2. Summary of MEGAN version 2.04a configurations**

| No. | Case | EF | PFT | Domain |
|---|---|---|---|---|
| 7 | M_MefMpft | MEGAN | MEGAN | 36/12/4 |
| 8 | M_GefGpft | GloBEIS | GloBEIS | 36/12 |
| 9 | M_GefGpftCSR | GloBEIS | GloBEIS (CSR) | 4 |

For the model performance evaluations of the biogenic emission models using CAMx and aircraft measurements, we used 2 base emissions datasets, base GloBEIS and base MEGAN emission datasets. The base GloBEIS emission dataset consists of G_Gef_Clai for the 36 km and 12 km domain and G_GefCSR_Clai for the 4 km domain. The base MEGAN emission dataset consists of M_MefMpft for the 36 km, 12 km, and 4 km domains.

## ES.2 RESULTS

### Comparing GloBEIS version 3.5 and MEGAN version 2.04a

The emission comparisons between GloBEIS v3.5 and MEGAN v2.04a show that the emissions of isoprene, OVOC and CO from the GloBEIS base case (G_Gef_Clai) and the MEGAN base case (M_MefMpft) are very similar with less than 9% absolute difference for TCEQ's 36 km and 12 km modeling domains. For monoterpene and NO, GloBEIS produces higher emission by 23% to 35% and 49% to 72%, respectively, where the range depends upon episode day. Comparisons for the 4 km domain show that both land cover and emission factors play an important role in GloBEIS emission estimations. Using CSR land cover reduces emissions by 12% to 103% from GloBEIS compared to the WIED land cover. The use of MEGAN, instead of GloBEIS, emission factors can result in changes of about the same magnitude as the CSR vs WIED landcover and so using GloBEIS CSR landcover with MEGAN emission factors results in about the same isoprene emissions as WIED landcover with GloBEIS emission factors.

With emission factors and land cover held constant for the two models (comparison between G_Gef_Mlai and M_GefGpft), GloBEIS generally yields 5% to 23% lower emissions than MEGAN for the 36 km and 12 km domains. Comparison for the 4 km domain (G_GefCSR_Mlai and M_GefGpftCSR) shows variation in differences. This indicates that factors other than landcover and emission factors together have a minor impact on GloBEIS and MEGAN emission differences although it should be recognized that this is partly because there are compensating differences of different sign. It should also be noted that agreement between GloBEIS and MEGAN should not be taken as an indication of good model performance especially since some components of these models are based the same limited datasets. Isoprene emission response to light and temperature, especially past conditions, is an example of a model component with general agreement between MEGAN and GloBEIS but large uncertainties due to the lack of observations for evaluation.

The differences in NO emission between the two models are consistent across all domains. GloBEIS yields higher NO emissions than MEGAN by 64% to 86%. Future investigation is recommended in order to explain the variations and to evaluate these emission estimates with direct flux measurements. The variation in the 4 km domain could be from different light and temperature dependent emission activity algorithms used for the two models. This could be tested using tower flux measurements to characterize day to day variations in fluxes from a representative Texas landscape.

### Model Performance

Analysis using TexAQS2006 campaigns shows that CAMx simulations with base GloBEIS emissions and base MEGAN emissions, which use similar isoprene and CO emissions, yield

very similar CO and ozone predictions and perform very well in general. For BVOC, the two models overpredict the peak isoprene concentrations and can not represent the concentrations for isoprene or the major isoprene degradation products. This suggests that emissions and chemical reactions of isoprene may both be contributing to model/measurement differences. Model performance analysis for monoterpene shows a large variation in performance. CAMx with base GloBEIS emission performs better for September 21 and CAMx with base MEGAN emission performs better for September 27. Due to its complex chemistry and short lifetime, it is very difficult to pin point the causes of these discrepancy without further investigation.

The model performance analysis for Texas regions; South Texas (SOT), North Eastern Texas (NET), Dallas/Fort-Worth (DFW), Central Texas (CET), Deep East Texas (DET), and Houston (HOU) used the aircraft measurements below 1 km altitude to consider the concentrations within the boundary layer. The two models overpredict the isoprene concentration with MNB within 500% for most areas. CAMx_baseG performs better with lower bias and higher $R^2$. For monoterpene, the models underpredict the concentrations in the CET, DFW, SOT, and HOU areas, and overpredict in the DET and NET areas. MEGAN performs slightly better with lower error and higher $R^2$.

## ES.3 CONCLUSIONS

Based on the results of this project, we conclude that:

- We successfully updated GloBEIS to version 3.5. The major two updates are the user interface and SQT implementation. The new user interface results in easier setup with less chance of error and faster calculation time for multiple-day scenarios. The comparison to GloBEIS v3.1 CSR shows identical results for all pollutants except SQT.
- The SQT estimates are considered reasonable because they are comparable to other models and generally agree with the limited observations of canopy scale emissions. However, we recommend future evaluation, e.g. evaluating secondary organic aerosol formation from SQT.
- GloBEIS v3.5 can now account for emission changes between winter and summer by selecting either winter or summer leaf mass density (LMD). Using winter LMD shows some unexpected results with higher peak emissions in some areas. We would like to further investigate and correct this issue.
- Using TCEQ's CSR land cover causes much lower isoprene, total monoterpene and NO emissions by approximately 12%-100% compared to using the WIED land cover in GloBEIS. Using the WIED landcover in GloBEIS results in isoprene emissions that are similar to MEGAN while using the CSR database with GloBEIS results in monoteprene emission that are similar to MEGAN.
- GloBEIS v3.5 and MEGAN v2.04a generally yield similar isoprene emissions for the 36 km and 12 km domains and for the 4km domain if using the WIED landcover. For the 4 km domain, isoprene emissions from GloBEIS are lower by half when using the CSR landcover.
- GloBEIS generally produces higher monoterpene and NO emissions than MEGAN, except for the 4km domain. GloBEIS yields 12% lower monoterpene emission than MEGAN for the 4 km domain if using the CSR landcover.

- The model performance analysis using aircraft measurements shows large variation in differences between model predictions and measurements and there is insufficient evidence to determine whether GloBEIS v3.5 or MEGAN v2.04a performs better.
- The two models generally overpredict isoprene and underpredict monoterpene concentrations. The overpredictions in isoprene are found during the peak predicted concentrations.
- The model performance analysis by Texas areas shows overprediction in the isoprene concentration most areas and GloBIES performs better. For monoterpene, the models underpredict the concentrations in the CET, DFW, SOT, and HOU areas, and overpredict the concentration in the DET and NET areas. MEGAN performs slightly better in this case.
- MEGAN has improved algorithms for drought, leaf age and solar radiation that could easily be incorporated into GloBEIS. The MEGAN algorithm for isoprene response to CO2 should also be incorporated into GloBEIS if there is any interest in using GloBEIS to estimate isoprene emissions for future decades.

With the extensive testing of GloBEIS version 3.5, the new GloBEIS meets our expectations. The model is easier to use and yields the same emissions as GloBEIS v3.1CSR and similar emissions to MEGAN v2.04a. The new GloBEIS estimates SQT emissions based on SQT emission factors and SQT emission activity algorithms. We recommend further evaluation of SQT estimation.

# 1. INTRODUCTION

A number of models and modeling systems have been developed over the past several years for use in estimating biogenic emissions for a variety of applications, including ozone SIPs and PM Maintenance Plans, as well as for use in urban and regional scale air quality modeling. All of these models use the same general framework but they have somewhat different emission factors and emission activity algorithms. The Global Biosphere Emissions and Interactions System (GloBEIS) is one of the primary biogenic emissions modeling systems used for ozone air quality planning. GloBEIS has been continually improved over the past decade. Recently, to improve the emission estimation and functionality of GloBEIS3, ENVIRON and Dr. Alex Guenther have included sesquiterpene (SQT) emission estimation and have improved the multiple day calculation algorithm with updated user interface in GloBEIS version 3.5, as well as other algorithms and internal data. To understand the differences between the new GloBEIS and the GloBEIS currently used by the TCEQ (GloBEIS v3.1 CSR), we compared the two GloBEIS versions and evaluated the output native emissions for quality assurance.

The Model of Emissions of Gases and Aerosol from Nature (MEGAN) is another one of the primary biogenic emissions modeling systems, widely used for global scale and regional scale air quality modeling. Although GloBEIS and MEGAN are generally based on the same observations and approaches there are significant differences in their emission estimates and it is important to understand the characteristics of GloBEIS and MEGAN and how they differ. We compared the emission estimates from GloBEIS v3.5 and MEGAN v2.04a using several input configurations based on land cover data and emission factors used for the two models. We evaluated the model performances for the Texas 2006 AQS2 episode and compared to airborne measurements conducted during the Texas Air Quality Study in September and October of 2006 (TexAQS2006) campaigns. The emissions from the two models were used in a regional scale photochemical gridded model (CAMx version 4.53). The 3-D 15-min outputs were used to compare to airborne measurements for ozone, CO, isoprene, and total monoterpenes.

## 1.1 BACKGROUND

**GloBEIS version 3.5**

GloBEIS is a biogenic emissions modeling system developed by NCAR and Environ International Corporation, based on the BEIS emission factors and algorithms but with an easier-to-use interface and compatibility with a wider range of input data sources and enhanced algorithms including canopy environment, leaf age, variable LAI, and the influence of antecedent temperature conditions (Yarwood, 1999). GLOBEIS was developed to allow users to estimate biogenic emissions of volatile organic compounds, carbon monoxide and soil NOx emissions for any time scale and domain. It has been continually improved over the past decade. Recently, to improve the emission estimation and functionality of GloBEIS3, ENVIRON and Dr. Alex Guenther have included sesquiterpene (SQT) emission estimation and have improved the multiple day calculation algorithm with an updated user interface in GloBEIS version 3.5, as well as other algorithms and internal data (See User's Guide to GloBEIS version 3.5 for more detail).

## Computer and Software Requirements

The GloBEIS model runs under Microsoft Access on Windows-based personal computers. The minimum hardware requirements are 1 GB memory and 10 GB hard drive space (depending on the application). GloBEIS version 3.5 was developed in Microsoft Access 2003 and we recommend using Access 2000 or 2003. GloBEIS can be used with Access 2007 if macros are enabled. The new user interface in GloBEIS version 3.5 requires "sleep.exe" to be located in the GloBEIS directory. The "sleep.exe" is available in the GloBEIS package and in most Windows operating systems.

## Input Data Requirements

GloBEIS requires at least domain definition, land use data, PAR data or cloud cover data, and temperature data in order to estimate emissions. Other inputs, e.g. wind speed, LAI (Leaf Area Index), humidity, drought index, antecedent temperature data, are optional. Brief descriptions for GloBEIS minimum inputs are described below. Additional details are explained in GloBEIS version 3.5 USER'S GUIDE.

- Domain definition: The domain definition specifies a geographic area for which emissions are to be calculated.
- Land use: The land use (or land cover) provides information on how the area of each cell is assigned to different land cover categories. The user must define the land use for every cell listed in the domain definition file.
- PAR (Photosynthetically Active Radiation) data: The model uses this data to adjust the emission rate for light dependent emissions. It is also used to calculate the leaf energy balance used to determine leaf temperature if that option is selected. The PAR file is optional depending upon whether you have selected to directly input PAR or to input cloud cover data and have the model calculate PAR. After this file has been imported into GloBEIS, the data are stored in a table called "PAR".
- Cloud cover: The cloud cover data is optional depending upon whether you have selected to input PAR or cloud cover data. The imported cloud cover file is used to estimate PAR values which are imported to the "PAR" table.
- Temperature data: The model uses these data to adjust emission rates for temperature dependent emissions response.

## MEGAN version 2.04a

MEGAN, developed by the Biosphere-Atmosphere Interactions (BAI) group of the Atmospheric Chemistry Division (ACD) at the National Center for Atmospheric Research (NCAR), is a modeling system for estimating the net emission of gases and aerosols from terrestrial ecosystems into the atmosphere (Sakulyanontvittaya, 2008; Guenther et al., 2006). It is driven by land cover, weather, and atmospheric chemical composition. MEGAN is a global model with a base resolution of ~ 1 km that can either run as a stand-alone model for generating emission inventories or can be incorporated as an on-line component of chemistry/transport and earth system models.

Several improvements and modifications to previous versions of the MEGAN model that outputs emissions from CMAQ and CAMx have been implemented recently:

- Accounting for spatial variations in soil NOX emissions.
- Accounting for genetic variations in methanol, acetone, acetaldehyde, and formaldehyde emission capacities.
- Enabling input of temperature and solar radiation data from various sources. Previous versions of MEGAN obtained these data only from MM5 simulation outputs. ENVIRON has developed code to allow input of solar radiation from satellite data and temperature from interpolated observations
- Pre-processors have been developed to allow the use of alternative modelling grids developed in ArcGIS.
- The MEGAN code is currently capable of outputting model-ready data for CMAQ. The MEGAN code has been modified to include the option of outputting CAMx model-ready data.
- Modification of the MEGAN FORTRAN code that runs on Linux to accept observed temperature data and satellite radiation data and generate emissions for grid-definitions that are developed using ArcGIS.

## Computer and Software Requirements

The MEGAN FORTRAN version and its pre-processors are written in FORTRAN. They have been tested with Portland Group (PG) compiler on Linux OS personal computers. The minimum hardware requirement is Linux OS personal computer with 1 GB memory and 10 GB hard drive space (depending on the application). Installation requires PGI FORTRAN compiler, NetCDF library, and IOAPI library.

## Input Data Requirements

MEGAN requires at least domain projection and grid definition, land cover data, and weather data. Domain emission factor maps, which can be user generated or based on the MEGAN global 1 km data, are optional.

- Land cover data: The MEGAN land cover database has global coverage at 30 sec (~ 1 km) spatial resolution. The data is based primarily on satellite observations, such as ~1 km2 Moderate Resolution Imaging Spectroradiometer (MODIS), 30 m resolution LANDSAT data, and 1 km2 AVHRR data. MEGAN land cover variables include LAI and plant functional type (PFT) cover. These variables are available at various temporal scales and are provided in a geo-referenced gridded database in several formats (e.g., NetCDF, ESRI GRID) on the MEGAN data portal, http://acd.ucar.edu/~guenther/MEGAN/MEGAN.htm. The most up-to-date land cover inputs available from MEGAN data portal, are PFT fraction (PFTF) version 2.1 which contains fractions for 5 plant functional types: broad leaf trees, fineleaf trees, shrub/brush, cropland, and herbaceous/grass and monthly LAI version 2.0 for year 2003.
- Meteorological data: MEGAN requires solar radiation and temperature data in order to account for light and temperature dependence. With the modified MEGAN,

TPAR2IOAPI, a MEGAN pre-processor, accepts temperature from MM5CAMX, 1.5 m AG MCIP, 2.0 m AG MCIP and MM5, solar radiation from University of Maryland (UMD) satellite PAR data, MCIP solar radiation, and MM5 solar radiation.

- Domain emission factor (optional): A species-specific emission factor distribution (EFMAP) requires accurate estimates of plant species distributions. This should be accomplished using a landcover database with sufficient detail for characterizing a representative species composition type. MEGAN version 2.04 requires 20 model chemical species. The most up-to-date data is EFMAP version 2.1 containing EFMAP for 11 model species, methylbutenol, methanol, nitric oxide, 3-carene, limonene, myrcene, ocimene, alpha-pinene, beta-pinene, and sabinene. The emissions for the other 9 model chemical compound categories are estimated based on plant specific emission factors, which are built into the MEGAN model.

# 2. GLOBEIS VERSION 3.5 AND THE CHANGES

This section summarizes the new GloBEIS version 3.5 and discusses the model differences between GloBEIS version 3.5 and GloBEIS version 3.1 CSR. Later, this section presents the comparisons of the native emission outputs between the two models.

## 2.1 GLOBEIS VERSION 3.5

There are two major updates over GloBEIS version 3.4, SQT emission estimation and improved user interface. Dr. Guenther has based the SQT emission factors (Table 2.1) on many recent studies including Karl et al., in preparation, Bouvier-Brown et al., 2009, Kim et al., 2009, Sakulyanontvittaya et al., 2008, and Arnts, 2008. While sesquiterpene emission factors have previously been derived solely from branch enclosure and gas chromatography techniques, the GloBEIS 3.5 emission factors also consider recent advances in whole canopy sesquiterpene fluxes based on ambient air measurement (Kim et al., 2009, Bouvier-Brown et al., 2009, and Arnts, 2008). Dr. Guenther has implemented the most up-to-date emission activity algorithm for SQT (Guenther et al., in preparation) to adjust emission rates for variations in light, LAI, leaf age, canopy losses, and temperature in the model.

Due to the clumsiness and over expanded memory in multiple-day calculation in previous GloBEIS, ENVIRON has improved the user interface to avoid setup error and memory over expansion. We choose Microsoft Access - macro/dos batch process over Microsoft Visual Basic (VB) for simplicity and to avoid incompatibility in Microsoft libraries, e.g. .NET, among Windows OS computers. The updated interface is more suitable for batch process and able to clean the reserved memory at the end of each day calculation. This results in faster calculation and prevents program crash with multiple day runs.

Besides the two major updates, there are other improvements and programming corrections. All the changes are described below, relatively to GloBEIS version 3.1 CSR for these project objectives.

Speciation:

- Added option to speciate VOC emissions for the CB05 chemical mechanism (Yarwood et al, 2005).
- Updated the speciation algorithm and emission reports for CB05, CB4 and SAPRC99.
- Modified the speciated emissions output to include precursors to particulate matter.

Internal Data and Algorithms:

- Developed separate model versions with different leaf mass density (LMD) for winter or summer calculations.
- Added sesquiterpene (SQT) emission factors (EFs) (Karl et al., in preparation, Bouvier-Brown et al., 2009, Kim et al., 2009, Arnts, 2008, and Sakulyanontvittaya et al., 2008) and a SQT emission activity algorithm (Guenther et al., in preparation).
- Provided a consistent approach for converting between visible and total solar radiation.

Note that the new land cover definitions for a satellite-derived land use dataset in GloBEIS version 3.1 CSR is included in GloBEIS version 3.5.

User Interface:

- Updated the user interface to enable multi-day calculations.
- Added a logging feature to produce a text-file recording the input data and model options for each model run.
- Updated the user interface to allow choice of summer or winter leaf mass density (LMD).

**Table 2.1. Sesquiterpene emission factors in GloBEIS version 3.5.**

| vegib2 | Name | SQT | vegib2 | Name | SQT |
|---|---|---|---|---|---|
| Abie | Abies (fir) | 288 | Coru | Cornus (dogwood) | 288 |
| Acac | Acacia | 288 | Coti | Cotinus (smoke tree) | 288 |
| Acebar | Acer barbatum | 288 | Cott | Cotton | 46.1 |
| Acenig | Acer nigrum | 288 | Crat | Crataegus (hawthorn) | 288 |
| Acepen | Acer pensylvanicum | 288 | Cswt | Herbaceous Wetlands (AVHRR, | 144 |
| Acer | Acer (maple) | 288 | Cupr | Cupressus | 288 |
| Aesc | Aesculus (buckeye) | 288 | Desh | Desert shrub (AVHRR, Guen) | 8.9 |
| Aessp. | Aesculus (buckeye) | 288 | Dios | Diospyros (persimmon) | 288 |
| Aila | Ailanthus | 288 | Diovir | Diospyros (persimmon) | 288 |
| Alefor | Aleurites fordii | 288 | Euca | Eucalyptus | 288 |
| Aleu | Aleurites (tung-oil tree) | 288 | Fagsp. | Fagus (american beech) | 288 |
| Alfa | Alfalfa | 144 | Fagu | Fagus (american beech) | 288 |
| Alfalfa | Alfalfa | 144 | Frax | Fraxinus (ash) | 288 |
| Alnu | Alnus (European alder) | 288 | Gled | Gleditsia (honeylocust) | 288 |
| Amearb | Amelanchier arborea | 144 | Gord | Gordonia (loblolly-bay) | 288 |
| Amel | Amelanchier (serviceberry) | 144 | Gorlas | Gordonia lasianthus | 288 |
| Asim | Asimina (pawpaw) | 288 | Gras | Grass | 43.2 |
| Asitri | Asimina triloba | 288 | Grass | Grass | 43.2 |
| Avic | Avicennia (black mangrove) | 288 | Gymdio | Gymnocladus dioicus | 288 |
| Barl | Barley | 144 | Gymn | Gymnocladus (KY coffeetree) | 288 |
| Barley | Barley | 144 | Hale | Halesia (silverbell) | 288 |
| Barr | Barren | 0 | Harf | Hardwood forest (AVHRR, Guen) | 288 |
| Betsp. | Betula (birch) | 288 | Hay | Hay | 144 |
| Betu | Betula (birch) | 288 | Ilex | Ilex (holly) | 288 |
| Borf | Boreal forest (AVHRR/Guen et al | 288 | Jugl | Juglans (black walnut) | 288 |
| Bume | Bumelia (gum bumelia) | 288 | Jugsp. | Juglans spp. | 288 |
| Carp | Carpinus (hornbean) | 288 | Juni | Juniperus (east. red cedar) | 288 |
| Cary | Carya (hickory) | 288 | Lagu | Laguncularia (white mangrove) | 288 |
| Casp | Castanopsis (chinkapin) | 288 | Lari | Larix (larch) | 288 |
| Cassp. | Castanea (chestnut) | 288 | Liqu | Liquidambar (sweetgum) | 288 |
| Cast | Castanea (chestnut) | 288 | Liri | Liriodendron (yellow poplar) | 288 |
| Casu | Casuarina (Austl pine) | 288 | Macl | Maclura (osage-orange) | 288 |
| Cata | Catalpa | 288 | Magn | Magnolia | 288 |
| Cedr | Cedrus (Deodar cedar) | 288 | Magsp. | Magnolia | 288 |
| Cedsp. | Cedrus chamaecyp | 288 | Malu | Malus (apple) | 288 |
| Celsp. | Celtis (hackberry) | 288 | Meli | Melia (chinaberry) | 288 |
| Celt | Celtis (hackberry) | 288 | Mixf | Mixed forest (AVHRR, Guen) | 144 |
| Cerc | Cercis (redbud) | 288 | Morsp. | Morus spp. | 288 |
| Cersp. | Cercis (redbud) | 288 | Moru | Morus (mulberry) | 288 |
| Cham | Chamaecyparis (prt-orford cedar) | 288 | Mscp | Misc crops | 144 |
| Citr | Citrus (orange) | 288 | Mseg | Misc evergreen | 288 |
| Cnif | BEIS conifer forest | 288 | Mshw | Misc hardwood | 288 |
| Conf | Conifer forest (AVHRR, Guen) | 288 | Nmxf | Northern Mixed Forest (AVHRR, | 144 |
| Corn | Corn | 144 | Nyss | Nyssa (blackgum) | 288 |
| Corsp. | Cornus (dogwood) | 288 | Nyssp. | Nyssa (tupelo and blackgum) | 288 |

**Table 2.1 (continued). Sesquiterpene emission factors in GloBEIS version 3.5.**

| vegib2 | Name | SQT | vegib2 | Name | SQT |
|---|---|---|---|---|---|
| Oak | BEIS oak forest | 288 | Rhiz | Rhizophora (red mangrove) | 288 |
| Oats | Oats | 144 | Rice | Rice | 144 |
| Odcd | BEIS other deciduous forest | 288 | Robi | Robinia (black locust) | 288 |
| Ofor | Open forest | 26.5 | Rye | Rye | 144 |
| Oksv | Oak Savannah (AVHRR, Guen) | 186.6 | Sabl | Sabal (cabbage palmetto) | 144 |
| Ostr | Ostrya (hophornbeam) | 288 | Sali | Salix (willow) | 288 |
| Ostvir | Ostrya virginiana | 288 | Sapi | Sapium (chinese tallow tree) | 288 |
| Othe | Other (unknown, assume grass) | 43.2 | Sass | Sassafras | 288 |
| Oxyarb | Oxydendrum arboretum | 288 | Sassp. | Sassafras albidum | 288 |
| Oxyd | Oxydendrum (sourwood) | 288 | Scru | Scrub | 8.9 |
| Pacp | Pasture cropland (AVHRR, Guen) | 7.5 | Scwd | Scrub woodland (AVHRR, Guen) | 144 |
| Past | Pasture | 13.2 | Sere | Serenoa (saw palmetto) | 144 |
| Paul | Paulownia | 288 | Shrf | Southeast/Western Deciduous | 288 |
| Pautom | Paulownia | 288 | Smxf | Southeast Mixed Forest | 144 |
| Pean | Peanuts | 144 | Snow | Snow | 0 |
| Pers | Persea (redbay) | 288 | Sorb | Sorbus (mountain ash) | 288 |
| Pice | Picea (spruce) | 288 | Sorg | Sorghum | 144 |
| Pincla | Pinus clausa | 288 | Sorsp. | Sorbus (mountain ash) | 288 |
| Pingla | Pinus glabra | 288 | Soyb | Soybean | 144 |
| Pinrig | Pinus rigida | 288 | Spin | Southern pine (AVHRR, Guen) | 288 |
| Pinser | Pinus serotina | 288 | Swie | Swietenia (W. Indies mahogany) | 288 |
| Pinstr | Pinus strobiformis | 288 | Taxo | Taxodium (cypress) | 288 |
| Pinsyl | Pinus sylvestris | 288 | Thuj | Thuja (W. red cedar) | 288 |
| Pinu | Pinus (pine) | 288 | Tili | Tilia (basswood) | 288 |
| Pinvir | Pinus virginiana | 288 | Tilsp. | Tilia (basswood) | 288 |
| Plan | Planera (water elm) | 288 | Toba | Tobacco | 144 |
| Plat | Platanus (sycamore) | 288 | Torr | Torreya | 288 |
| Popu | Populus (aspen) | 288 | Tsug | Tsuga (Eastern hemlock) | 288 |
| Pota | Potato | 144 | Tsusp. | Tsuga (Eastern hemlock) | 288 |
| Pros | Prosopis (mesquite) | 288 | Tund | Tundra | 23.6 |
| Prun | Prunus (cherry) | 288 | Ufor | BEIS urban forest | 144 |
| Pseu | Pseudotsuga (douglas fir) | 288 | Ugra | BEIS urban grass | 13 |
| Quebic | Quercus bicolor | 288 | Ulmu | Ulmus (American elm) | 288 |
| Quecoc | Quercus coccinea | 288 | Uoth | BEIS2 other urban (assume 20% | 2.6 |
| Quedur | Quercus durandii | 288 | Urba | BEIS urban (.2 grass/.2 forest) | 31.1 |
| Queili | Quercus ilicifolia | 288 | Utre | Urban trees (.5 Harf/.5 Conf) | 144 |
| Queimb | Quercus imbricaria | 288 | Vacc | Vaccinium (blueberry) | 144 |
| Quelae | Quercus laevis | 288 | Wash | Washingtonia (fan palm) | 288 |
| Quelsp | Live oaks | 288 | Wate | Water | 0 |
| Quelyr | Quercus lyrata | 288 | Wcnf | W Coniferous Forest (AVHRR, | 288 |
| Quemic | Quercus michauxi | 288 | Wdcp | Woodland/cropland (AVHRR, | 288 |
| Quenut | Quercus nuttallii | 288 | Wetf | Wetland forest (AVHRR, Guen) | 288 |
| Quepri | Quercus prinus | 288 | Whea | Wheat | 144 |
| Quer | Quercus (oak) | 288 | Wmxf | Western Mixed Forest (AVHRR, | 77.2 |
| Rang | Range | 144 | Wwdl | Western Woodlands (AAVHRR, | 56.2 |

## 2.2 GLOBEIS VERSION 3.1 CSR

GloBEIS version 3.1 CSR is based on GloBEIS version 3.1 (Yarwood et al., 2010) with additional new land cover definitions for a satellite-derived land use dataset. The new land cover definitions (Table 2.2) and the plant species associated with land cover (Table 2.3) were developed by TCEQ. There are total of 18 land cover types and 102 plant species. ENVIRON has included these data in GloBEIS version 3.5 for TCEQ studies.

**Table 2.2. Land cover definitions for the CSR satellite-derived land use data.**

| lc | Description | Canopytype | NO | NH3 |
|---|---|---|---|---|
| 50001 | Open Water, no trees/CSR | 4 | 0 | 0 |
| 50002 | Developed Open Space/CSR | 4 | 5 | 0 |
| 50003 | Developed, Low Intensity/CSR | 4 | 7 | 0 |
| 50004 | Developed, Medium Intensity/CSR | 4 | 8 | 0 |
| 50005 | Developed, High Intensity/CSR | 4 | 6 | 0 |
| 50006 | Barren Land, no trees/CSR | 4 | 5 | 0 |
| 50007 | Herbaceous, Natural/CSR | 6 | 5 | 0 |
| 50008 | Herbaceous, Cultivated/CSR | 7 | 64 | 0 |
| 50009 | Woody Wetlands (Riparian, Swamp and Shrub)/CSR | 4 | 5 | 0 |
| 50010 | Herbaceous, Natural in EPA Level IV ecoregion 34a/ | 6 | 5 | 0 |
| 50011 | Herbaceous, Cultivated in EPA Level IV ecoregion 3 | 7 | 11 | 0 |
| 50012 | Herbaceous Wetland/CSR | 6 | 5 | 0 |
| 50013 | Cold-deciduous Forest, EPA Level III ecoregion 34/ | 1 | 5 | 0 |
| 50014 | Cold-deciduous Forest, EPA Level III ecoregion 35/ | 1 | 5 | 0 |
| 50015 | Evergreen Needleleaf Forest/CSR | 3 | 5 | 0 |
| 50016 | Mixed Forest/CSR | 2 | 5 | 0 |
| 50017 | All Woodland classes/CSR | 2 | 5 | 0 |
| 50018 | All Shrub classes/CSR | 5 | 5 | 0 |

**Table 2.3. Vegetation code and LMD associated with land covers.**

| lc | lcVeg | LMD |
|---|---|---|
| 50001 | water | 0 |
| 50002 | SAPSEB | 2 |
| 50002 | ULMAME | 2 |
| 50002 | PINELL | 2 |
| 50002 | PINTAE | 1 |
| 50002 | QUENIG | 1 |
| 50002 | ULMALA | 0 |
| 50002 | COTOBO | 0 |
| 50003 | PINTAE | 17 |
| 50003 | QUENIG | 3 |
| 50003 | QUESTE | 7 |
| 50003 | SAPSEB | 4 |
| 50003 | CARILL | 5 |
| 50003 | QUEVIR | 10 |
| 50003 | LIQSTY | 1 |
| 50003 | QUEFAL | 1 |
| 50003 | ULMAME | 5 |
| 50003 | POPDEL | 5 |
| 50003 | THUOCC | 0 |
| 50003 | ACESAC | 1 |
| 50003 | CELLAE | 0 |
| 50003 | COTOBO | 0 |
| 50003 | FRAVEL | 0 |
| 50003 | JUNVIR | 7 |
| 50003 | MAGGRA | 1 |
| 50003 | QUEMAC | 4 |
| 50003 | SALNIG | 1 |
| 50003 | WASFIL | 1 |

| lc | lcVeg | LMD |
|---|---|---|
| 50004 | PINTAE | 8 |
| 50004 | SAPSEB | 4 |
| 50004 | QUENIG | 6 |
| 50004 | QUEVIR | 18 |
| 50004 | CELLAE | 5 |
| 50004 | CARILL | 2 |
| 50004 | THUORI | 1 |
| 50004 | PINELL | 4 |
| 50004 | MAGGRA | 2 |
| 50004 | CATBIG | 1 |
| 50004 | ULMAME | 2 |
| 50004 | WASFIL | 0 |
| 50004 | FRAVEL | 1 |
| 50004 | MORRUB | 0 |
| 50004 | NYSSYL | 0 |
| 50004 | QUEPHE | 1 |
| 50004 | QUESHU | 1 |
| 50004 | SALNIG | 1 |
| 50004 | ULMPAR | 2 |
| 50005 | PINTAE | 0 |
| 50005 | QUEVIR | 6 |
| 50005 | JUNVIR | 3 |
| 50005 | QUESTE | 1 |
| 50005 | SAPSEB | 1 |
| 50006 | barr | 0 |
| 50007 | QUESTE | 5 |
| 50007 | PINTAE | 10 |
| 50007 | CORFLO | 0 |
| 50007 | FRAAME | 1 |
| 50007 | FRAPEN | 1 |
| 50007 | JUGNIG | 3 |
| 50007 | JUNVIR | 7 |
| 50007 | QUEFAL | 1 |
| 50008 | SAPSEB | 2 |
| 50009 | QUELAU | 131 |
| 50009 | PINTAE | 58 |
| 50009 | SAPSEB | 24 |
| 50009 | TAXDIS | 110 |
| 50009 | LIQSTY | 23 |
| 50009 | ACESUG | 11 |
| 50009 | PLAAQU | 6 |
| 50009 | NYSSYL | 6 |
| 50009 | QUELYR | 16 |
| 50009 | ULMALA | 11 |

| lc | lcVeg | LMD |
|---|---|---|
| 50010 | SAPSEB | 2 |
| 50010 | CELLAE | 0 |
| 50010 | COTOBO | 1 |
| 50010 | QUENIG | 0 |
| 50010 | ULMAME | 1 |
| 50010 | ULMCRA | 0 |
| 50011 | PINTAE | 3 |
| 50011 | QUEVIR | 8 |
| 50012 | grass | 0 |
| 50013 | SAPSEB | 36 |
| 50013 | ULMCRA | 51 |
| 50013 | CELLAE | 36 |
| 50013 | FRAPEN | 16 |
| 50013 | BUMLAN | 12 |
| 50013 | CARILL | 14 |
| 50013 | QUENIG | 14 |
| 50013 | LIQSTY | 1 |
| 50013 | PINTAE | 5 |
| 50013 | QUEPHE | 6 |
| 50013 | QUESTE | 9 |
| 50013 | ULMALA | 5 |
| 50013 | CAROVA | 13 |
| 50013 | CRASP. | 1 |
| 50013 | ULMAME | 11 |
| 50013 | ACERUB | 1 |
| 50013 | QUEVIR | 6 |
| 50013 | SALNIG | 2 |
| 50013 | ACENEG | 3 |
| 50013 | CRATEX | 0 |
| 50013 | MELAZE | 0 |
| 50013 | MORRUB | 2 |
| 50013 | QUEFAL | 1 |
| 50013 | QUEMIC | 0 |
| 50013 | COTOBO | 2 |

## 2.3 EMISSION SUMMARY AND COMPARISON

This section presents a summary and comparison of native emissions from GloBEIS version 3.5 and GloBEIS version 3.1 CSR for a selected period, September 8-12, 2006. The model comparison was performed with input data from TCEQ, including domain definition, land cover data, temperature, and PAR for 36km, 12km, and 4km domains.

To ensure that the updated user interface would not interfere with the emission comparison, ENVIRON set up GloBEIS version 3.5 with emission factors from GloBEIS version 3.1 CSR. Table 2.4-2.7 shows identical results between GloBEIS version 3.1 CSR and GloBEIS version 3.5 with the EF from version 3.1 CSR for all domains and all species. The results demonstrate that the updated user interface does not interfere with the emission estimation.

### Comparison between GloBEIS v3.1 CSR and GloBEIS v3.5

Since GloBEIS version 3.5 can account for seasonal LMD, for this comparison purpose, we estimated the emissions for September 8 to 12, 2006 with winter and summer options. The domain total emissions are presented in Table 2.4-2.8 for NOx, ISOP, OVC, TMT, and SQT, respectively. Comparing GloBEIS version 3.1 CSR and version 3.5 with summer LMD in Table 2.4-2.7, the results are identical across domains and pollutants. The spatial plots for period total emissions (Figure 2.1-2.14) for the 4 km, 12km, and 36 km domains also show the same distribution and magnitude of emissions. This result is expected and confirms that the same LMD is used in GloBEIS version 3.1 CSR and version 3.5 with summer LMD.

The winter LMD accounts for plant shut down in cold weather. Comparisons between GloBEIS v3.5 with summer LMD and v3.5 with winter LMD are presented in Table 2.4-2.8 and Figure 2.1-2.15. The NOx emissions (Table 2.4, Figure 2.1-2.3) are the same for all cases across the domains. For organic compounds, the results (Table 2.5-2.8 and Figure 2.4-2.15) generally show reductions in emissions. Significant reduction in ISOP domain total emission ranges from 65% to almost 100%. The reduction in OVC, TMT and SQT ranges from 10% to 60%. For TMT in 36 km domain, the results show slight increases in emissions. It is necessary to investigate these unexpected results.

**Table 2.4. Domain total of native NOx emissions from September 08-12, 2006, in tons per day from GloBEIS v3.1 CSR, GloBEIS v3.5 with EF from v3.1 CSR, GloBEIS v3.5 with summer LMD, and GloBEIS v3.5 with winter LMD.**

| | | NOx (Tons/day) | | | |
|---|---|---|---|---|---|
| Domain | Date | GloBEISv3.1CSR | GloBEISv35_v31CSR | GloBEISv35_vegCode Summer | GloBEISv35_vegCode Winter |
| TCEQ_4km | Sep 08, 2006 | 25 | 25 | 25 | 25 |
| | Sep 09, 2006 | 22 | 22 | 22 | 22 |
| | Sep 10, 2006 | 24 | 24 | 24 | 24 |
| | Sep 11, 2006 | 24 | 24 | 24 | 24 |
| | Sep 12, 2006 | 24 | 24 | 24 | 24 |
| | Total (Tons/period) | 120 | 120 | 120 | 120 |
| TCEQ_12km | Sep 08, 2006 | 912 | 912 | 912 | 912 |
| | Sep 09, 2006 | 904 | 904 | 904 | 904 |
| | Sep 10, 2006 | 964 | 964 | 964 | 964 |
| | Sep 11, 2006 | 919 | 919 | 919 | 919 |
| | Sep 12, 2006 | 876 | 876 | 876 | 876 |
| | Total (Tons/period) | 4,575 | 4,575 | 4,575 | 4,575 |
| TCEQ_36km | Sep 08, 2006 | 5,823 | 5,823 | 5,823 | 5,823 |
| | Sep 09, 2006 | 5,316 | 5,316 | 5,316 | 5,316 |
| | Sep 10, 2006 | 5,290 | 5,290 | 5,290 | 5,290 |
| | Sep 11, 2006 | 5,134 | 5,134 | 5,134 | 5,134 |
| | Sep 12, 2006 | 5,007 | 5,007 | 5,007 | 5,007 |
| | Total (Tons/period) | 26,569 | 26,569 | 26,569 | 26,569 |

**Table 2.5. Domain total of native ISOP emissions from September 08-12, 2006, in tons per day from GloBEIS v3.1 CSR, GloBEIS v3.5 with EF from v3.1 CSR, GloBEIS v3.5 with summer LMD, and GloBEIS v3.5 with winter LMD.**

| | | ISOP (Tons/day) | | | |
|---|---|---|---|---|---|
| Domain | Date | GloBEISv3.1CSR | GloBEISv35_v31CSR | GloBEISv35_vegCode Summer | GloBEISv35_vegCode Winter |
| TCEQ_4km | Sep 08, 2006 | 1,046 | 1,046 | 1,046 | 3 |
| | Sep 09, 2006 | 449 | 449 | 449 | 1 |
| | Sep 10, 2006 | 896 | 896 | 896 | 3 |
| | Sep 11, 2006 | 907 | 907 | 907 | 3 |
| | Sep 12, 2006 | 833 | 833 | 833 | 3 |
| | Total (Tons/period) | 4,130 | 4,130 | 4,130 | 13 |
| TCEQ_12km | Sep 08, 2006 | 24,078 | 24,078 | 24,078 | 4,454 |
| | Sep 09, 2006 | 22,309 | 22,309 | 22,310 | 4,601 |
| | Sep 10, 2006 | 24,696 | 24,696 | 24,696 | 4,709 |
| | Sep 11, 2006 | 22,111 | 22,111 | 22,112 | 3,936 |
| | Sep 12, 2006 | 18,478 | 18,478 | 18,479 | 2,898 |
| | Total (Tons/period) | 111,674 | 111,674 | 111,674 | 20,597 |
| TCEQ_36km | Sep 08, 2006 | 77,233 | 77,233 | 77,234 | 29,470 |
| | Sep 09, 2006 | 68,897 | 68,897 | 68,898 | 25,598 |
| | Sep 10, 2006 | 70,923 | 70,923 | 70,923 | 24,876 |
| | Sep 11, 2006 | 61,631 | 61,631 | 61,631 | 20,523 |
| | Sep 12, 2006 | 42,361 | 42,361 | 42,361 | 14,486 |
| | Total (Tons/period) | 321,045 | 321,045 | 321,047 | 114,952 |

**Table 2.6. Domain total of native OVC emissions from September 08-12, 2006, in tons per day from GloBEIS v3.1 CSR, GloBEIS v3.5 with EF from v3.1 CSR, GloBEIS v3.5 with summer LMD, and GloBEIS v3.5 with winter LMD.**

| | | OVC (Tons/day) | | | |
|---|---|---|---|---|---|
| Domain | Date | GloBEISv3.1CSR | GloBEISv35_v31CSR | GloBEISv35_vegCode Summer | GloBEISv35_vegCode Winter |
| TCEQ_4km | Sep 08, 2006 | 9 | 9 | 9 | 5 |
| | Sep 09, 2006 | 7 | 7 | 7 | 4 |
| | Sep 10, 2006 | 8 | 8 | 8 | 5 |
| | Sep 11, 2006 | 8 | 8 | 8 | 5 |
| | Sep 12, 2006 | 8 | 8 | 8 | 5 |
| | Total (Tons/period) | 41 | 41 | 41 | 22 |
| TCEQ_12km | Sep 08, 2006 | 227 | 227 | 227 | 161 |
| | Sep 09, 2006 | 231 | 231 | 231 | 167 |
| | Sep 10, 2006 | 247 | 247 | 247 | 177 |
| | Sep 11, 2006 | 236 | 236 | 236 | 169 |
| | Sep 12, 2006 | 220 | 220 | 220 | 157 |
| | Total (Tons/period) | 1,160 | 1,160 | 1,160 | 831 |
| TCEQ_36km | Sep 08, 2006 | 852 | 852 | 852 | 735 |
| | Sep 09, 2006 | 823 | 823 | 823 | 704 |
| | Sep 10, 2006 | 826 | 826 | 826 | 701 |
| | Sep 11, 2006 | 802 | 802 | 802 | 682 |
| | Sep 12, 2006 | 724 | 724 | 724 | 627 |
| | Total (Tons/period) | 4,028 | 4,028 | 4,028 | 3,449 |

**Table 2.7. Domain total of native TMT emissions from September 08-12, 2006, in tons per day from GloBEIS v3.1 CSR, GloBEIS v3.5 with EF from v3.1 CSR, GloBEIS v3.5 with summer LMD, and GloBEIS v3.5 with winter LMD.**

| | | TMT (Tons/day) | | | |
|---|---|---|---|---|---|
| Domain | Date | GloBEISv3.1CSR | GloBEISv35_v31CSR | GloBEISv35_vegCode Summer | GloBEISv35_vegCode Winter |
| TCEQ_4km | Sep 08, 2006 | 31 | 31 | 31 | 25 |
| | Sep 09, 2006 | 27 | 27 | 27 | 21 |
| | Sep 10, 2006 | 30 | 30 | 30 | 24 |
| | Sep 11, 2006 | 31 | 31 | 31 | 25 |
| | Sep 12, 2006 | 31 | 31 | 31 | 25 |
| | Total (Tons/period) | 150 | 150 | 150 | 121 |
| TCEQ_12km | Sep 08, 2006 | 681 | 681 | 681 | 614 |
| | Sep 09, 2006 | 690 | 690 | 690 | 627 |
| | Sep 10, 2006 | 725 | 725 | 725 | 656 |
| | Sep 11, 2006 | 708 | 708 | 708 | 640 |
| | Sep 12, 2006 | 663 | 663 | 663 | 597 |
| | Total (Tons/period) | 3,467 | 3,467 | 3,467 | 3,135 |
| TCEQ_36km | Sep 08, 2006 | 2,377 | 2,377 | 2,377 | 2,422 |
| | Sep 09, 2006 | 2,327 | 2,327 | 2,327 | 2,343 |
| | Sep 10, 2006 | 2,370 | 2,370 | 2,370 | 2,380 |
| | Sep 11, 2006 | 2,307 | 2,307 | 2,307 | 2,312 |
| | Sep 12, 2006 | 2,088 | 2,088 | 2,088 | 2,115 |
| | Total (Tons/period) | 11,470 | 11,470 | 11,470 | 11,572 |

**Table 2.8. Domain total of native SQT emissions from September 08-12, 2006, in tons per day from GloBEIS v3.1 CSR, GloBEIS v3.5 with EF from v3.1 CSR, GloBEIS v3.5 with summer LMD, and GloBEIS v3.5 with winter LMD.**

| Domain | Date | SQT (Tons/day) | | | |
|---|---|---|---|---|---|
| | | GloBEISv3.1CSR | GloBEISv35_v31CSR | GloBEISv35_vegCode Summer | GloBEISv35_vegCode Winter |
| TCEQ_4km | Sep 08, 2006 | N/A | N/A | 8 | 3 |
| | Sep 09, 2006 | N/A | N/A | 5 | 2 |
| | Sep 10, 2006 | N/A | N/A | 7 | 3 |
| | Sep 11, 2006 | N/A | N/A | 7 | 3 |
| | Sep 12, 2006 | N/A | N/A | 7 | 3 |
| | Total (Tons/period) | N/A | N/A | 33 | 13 |
| TCEQ_12km | Sep 08, 2006 | N/A | N/A | 203 | 124 |
| | Sep 09, 2006 | N/A | N/A | 197 | 125 |
| | Sep 10, 2006 | N/A | N/A | 223 | 137 |
| | Sep 11, 2006 | N/A | N/A | 200 | 123 |
| | Sep 12, 2006 | N/A | N/A | 170 | 103 |
| | Total (Tons/period) | N/A | N/A | 993 | 612 |
| TCEQ_36km | Sep 08, 2006 | N/A | N/A | 616 | 421 |
| | Sep 09, 2006 | N/A | N/A | 576 | 401 |
| | Sep 10, 2006 | N/A | N/A | 595 | 414 |
| | Sep 11, 2006 | N/A | N/A | 541 | 375 |
| | Sep 12, 2006 | N/A | N/A | 413 | 295 |
| | Total (Tons/period) | N/A | N/A | 2,741 | 1,906 |

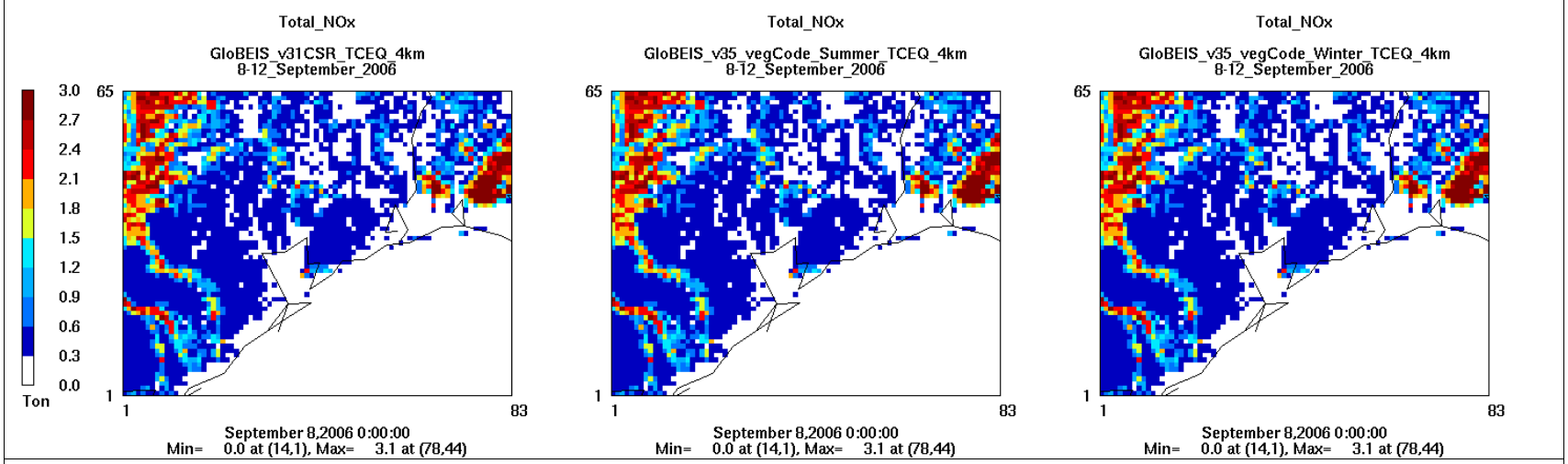



**Figure 2.1. Period total NOx (Tons) from GloBEIS v3.1 CSR, v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 4km domain.**

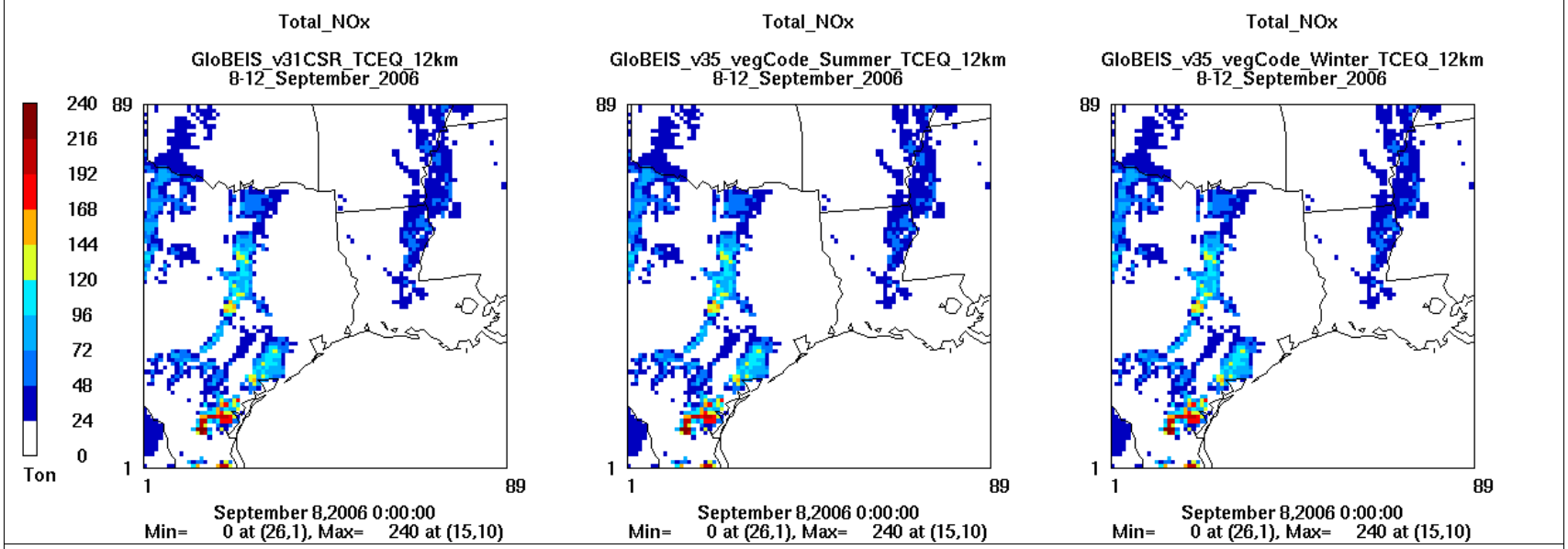



**Figure 2.2. Period total NOx (Tons) from GloBEIS v3.1 CSR, v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 12km domain.**

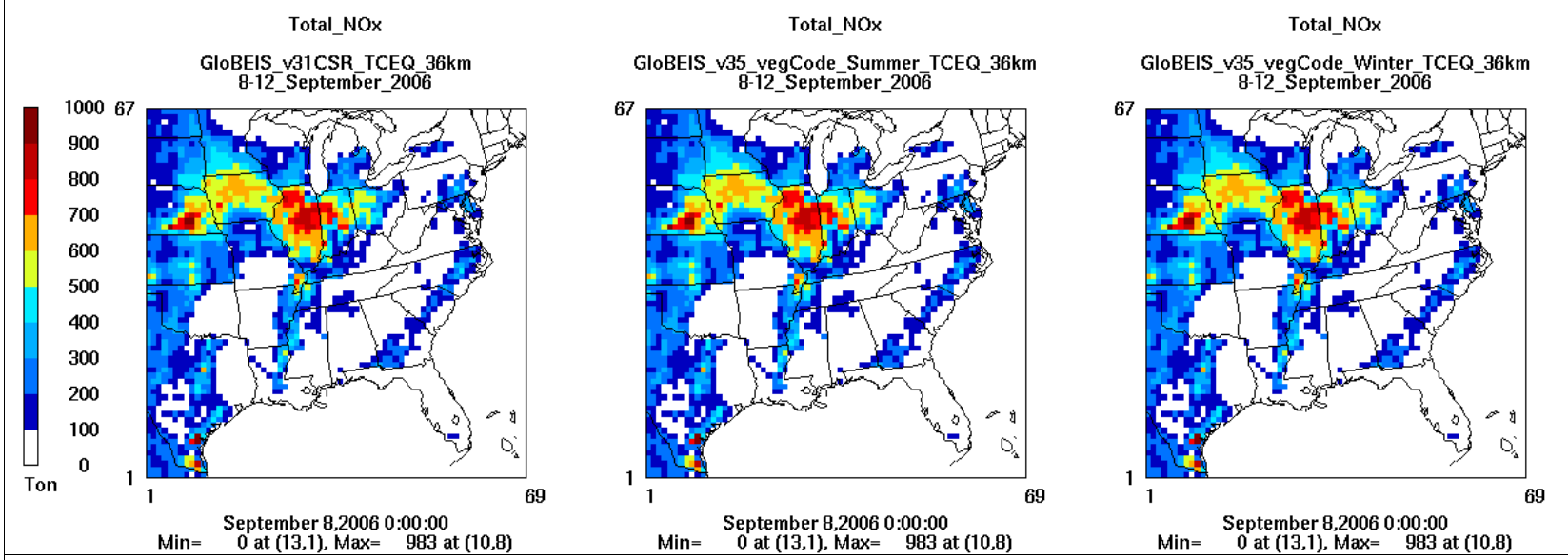



**Figure 2.3. Period total NOx (Tons) from GloBEIS v3.1 CSR, v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 36km domain.**

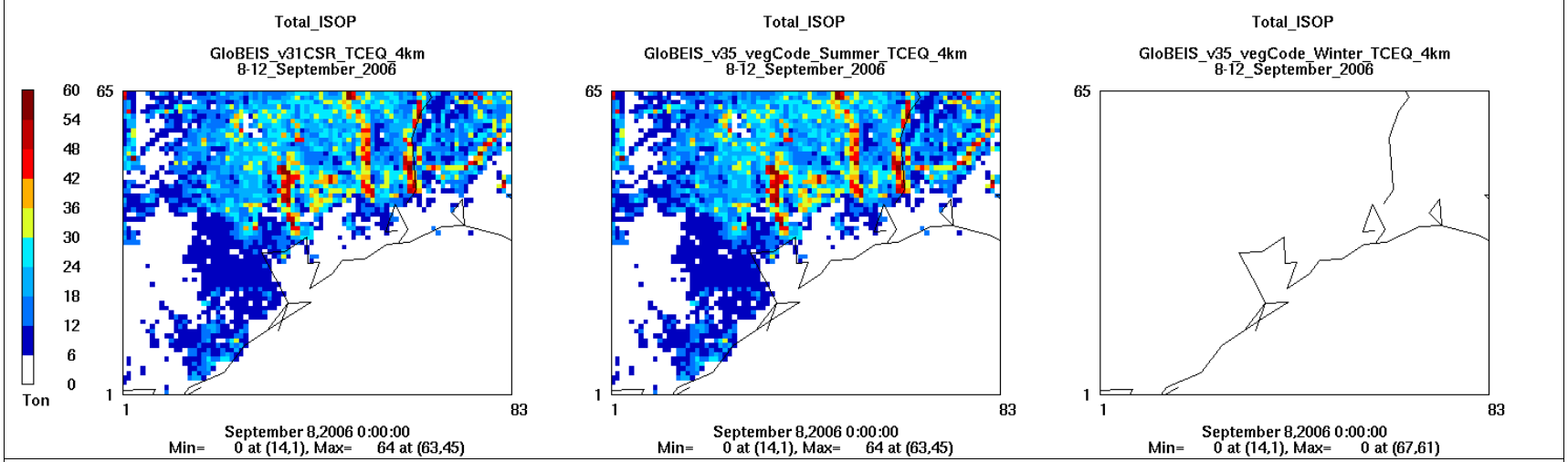



**Figure 2.4. Period total ISOP (Tons) from GloBEIS v3.1 CSR, v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 4km domain.**

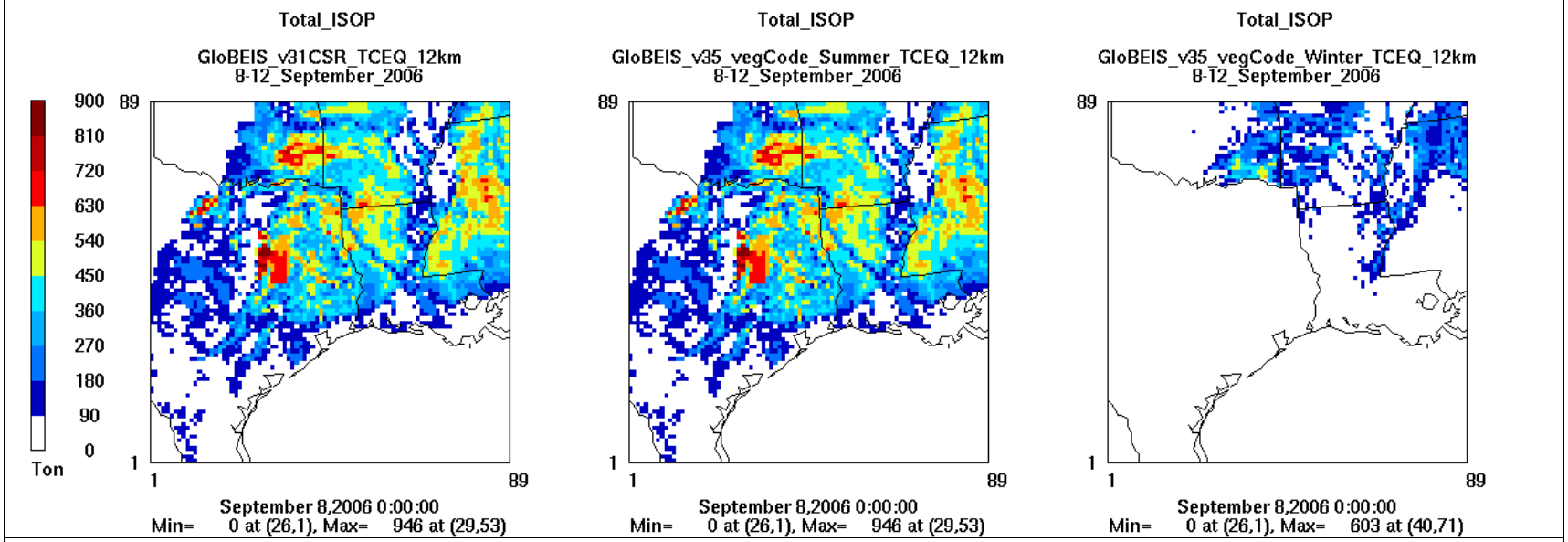



**Figure 2.5. Period total ISOP (Tons) from GloBEIS v3.1 CSR, v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 12km domain.**

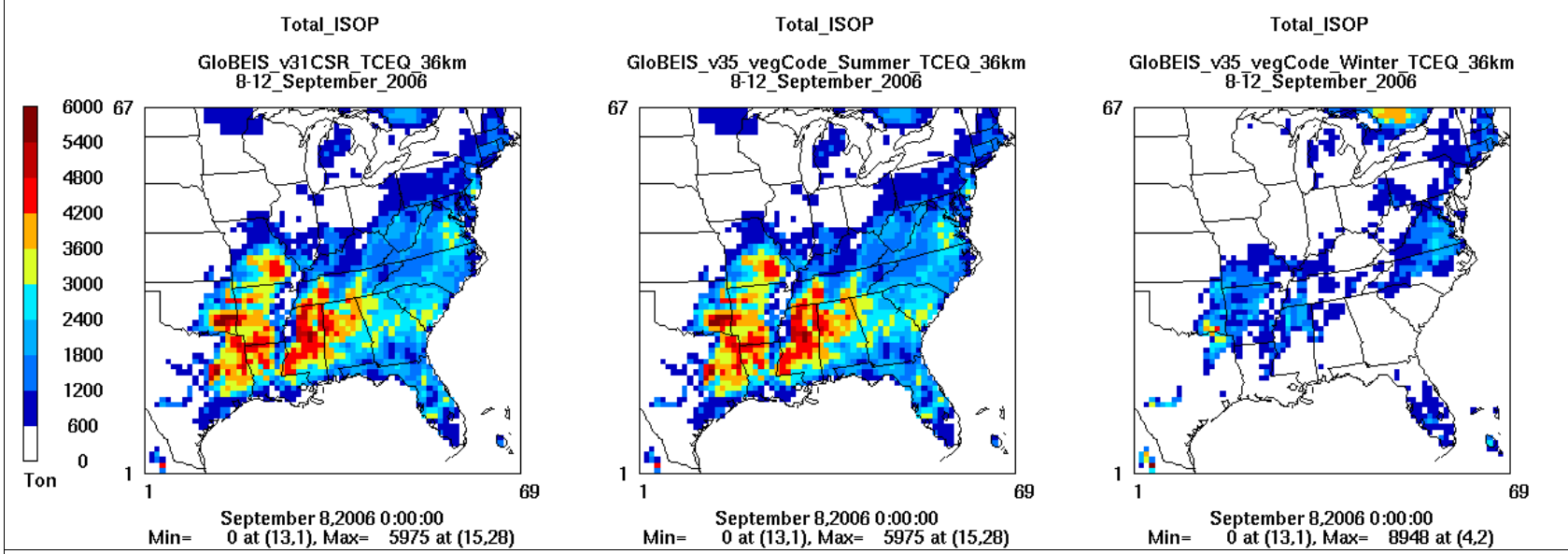



**Figure 2.6. Period total ISOP (Tons) from GloBEIS v3.1 CSR, v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 36km domain.**

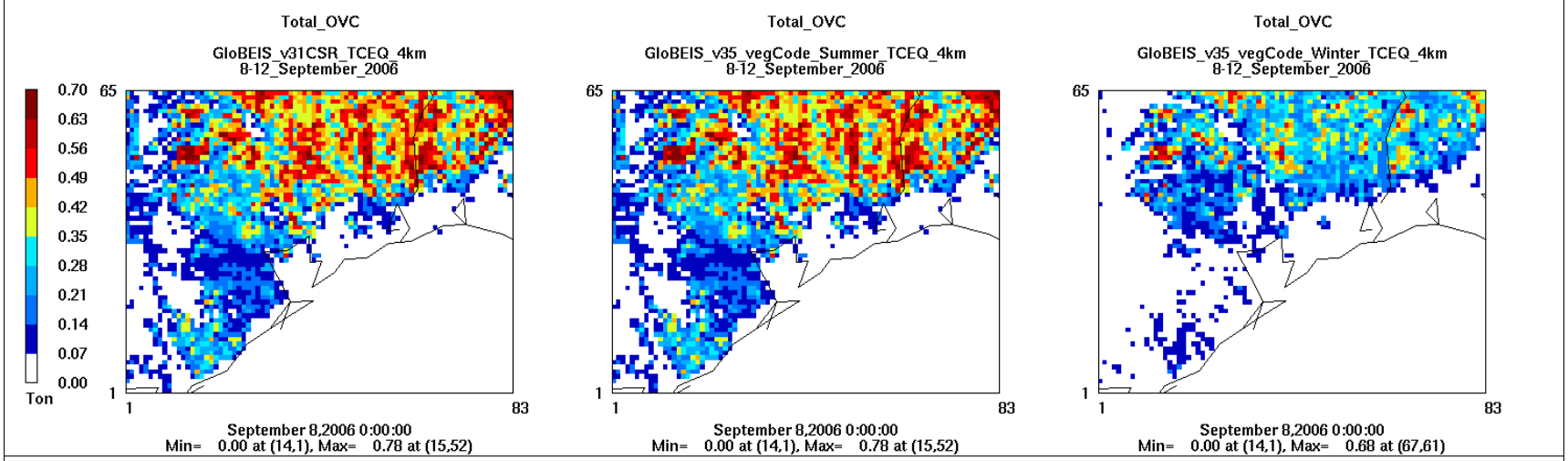



**Figure 2.7. Period total OVC (Tons) from GloBEIS v3.1 CSR, v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 4km domain.**

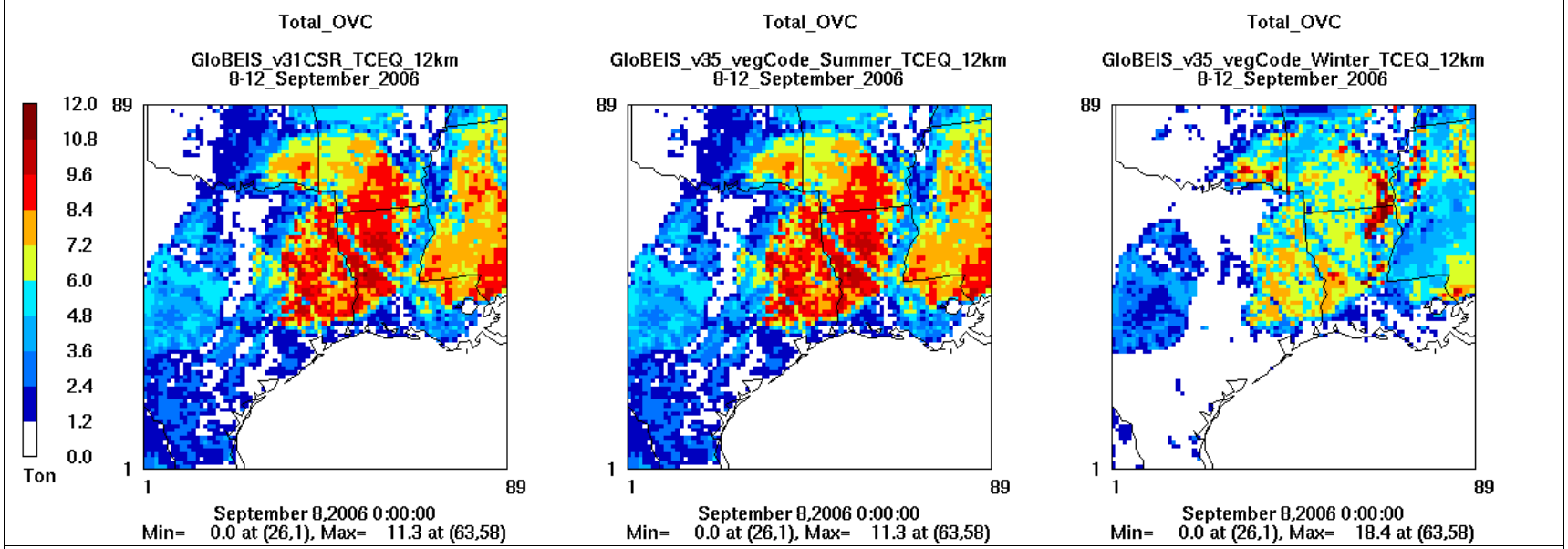



**Figure 2.8. Period total OVC (Tons) from GloBEIS v3.1 CSR, v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 12km domain.**

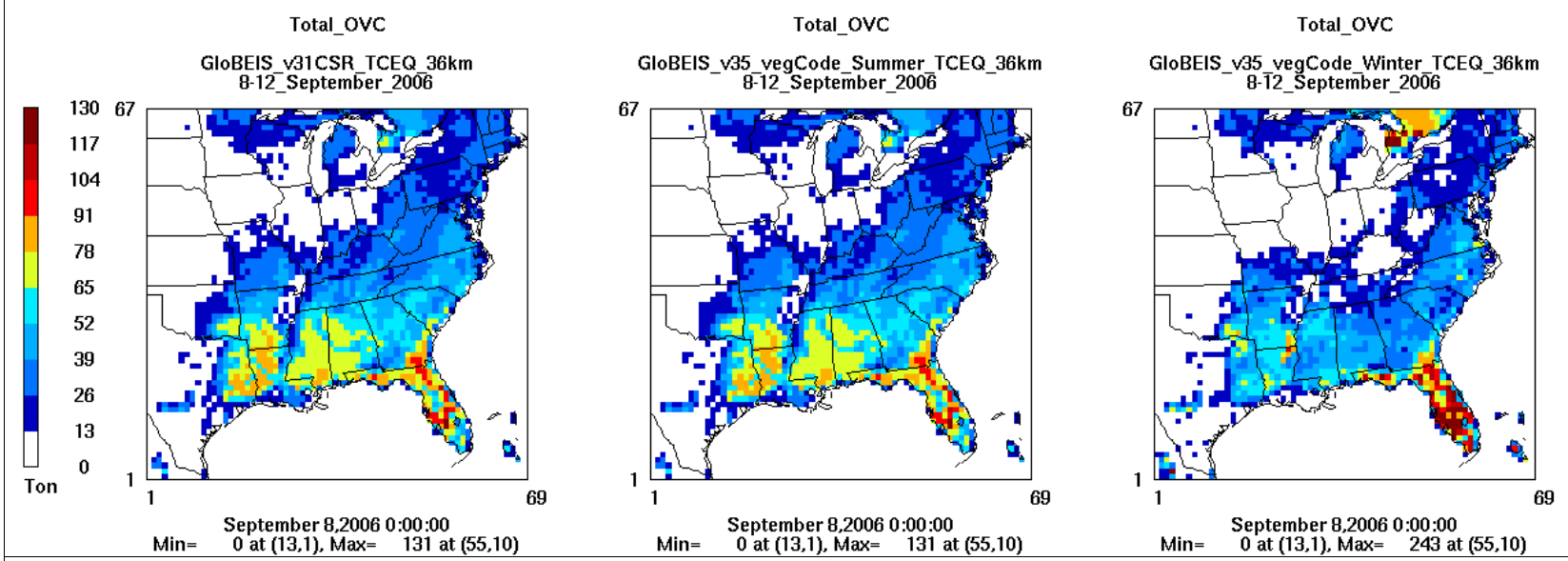



**Figure 2.9. Period total OVC (Tons) from GloBEIS v3.1 CSR, v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 36km domain.**

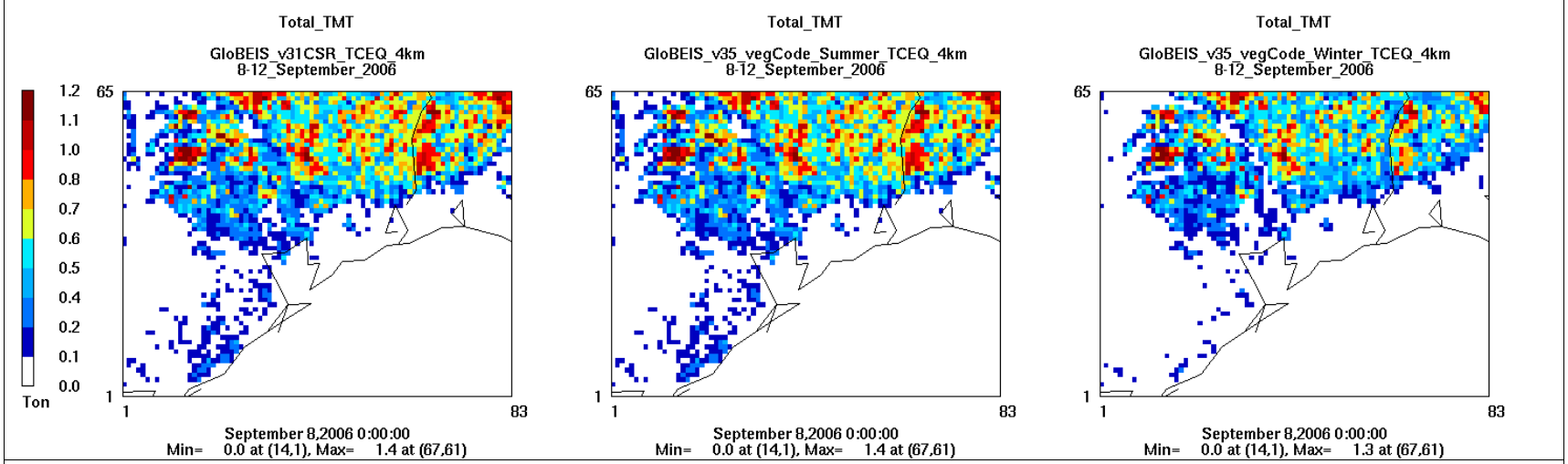



**Figure 2.10. Period total TMT (Tons) from GloBEIS v3.1 CSR, v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 4km domain.**

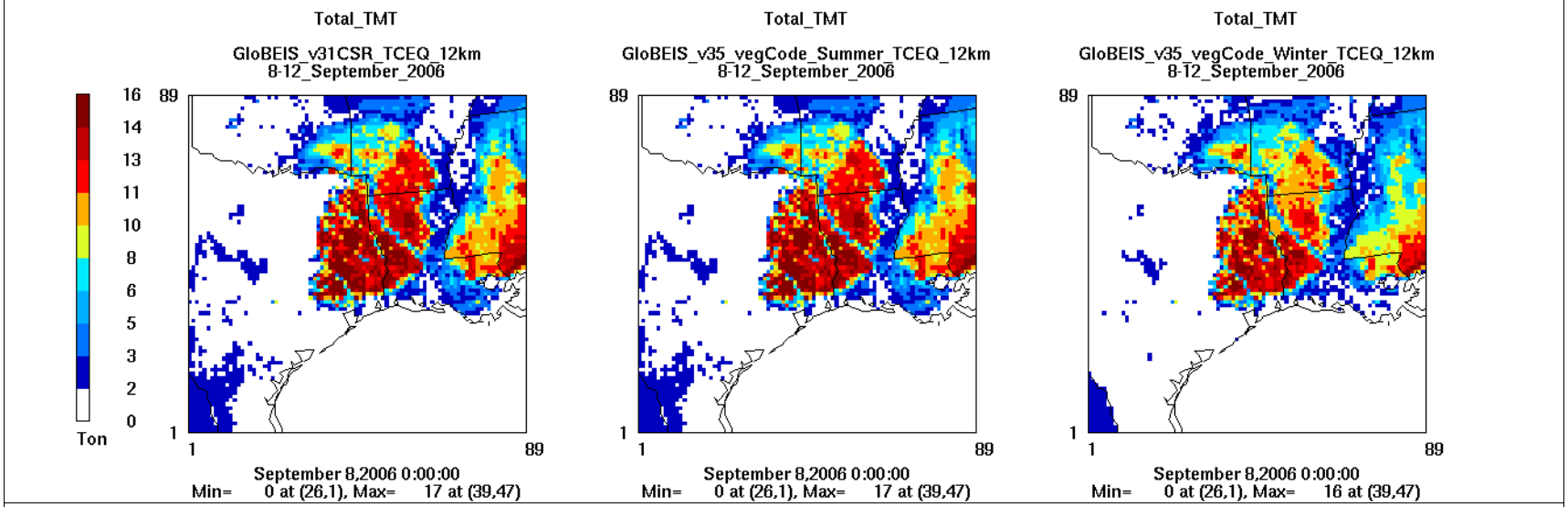



**Figure 2.11. Period total TMT (Tons) from GloBEIS v3.1 CSR, v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 12km domain.**

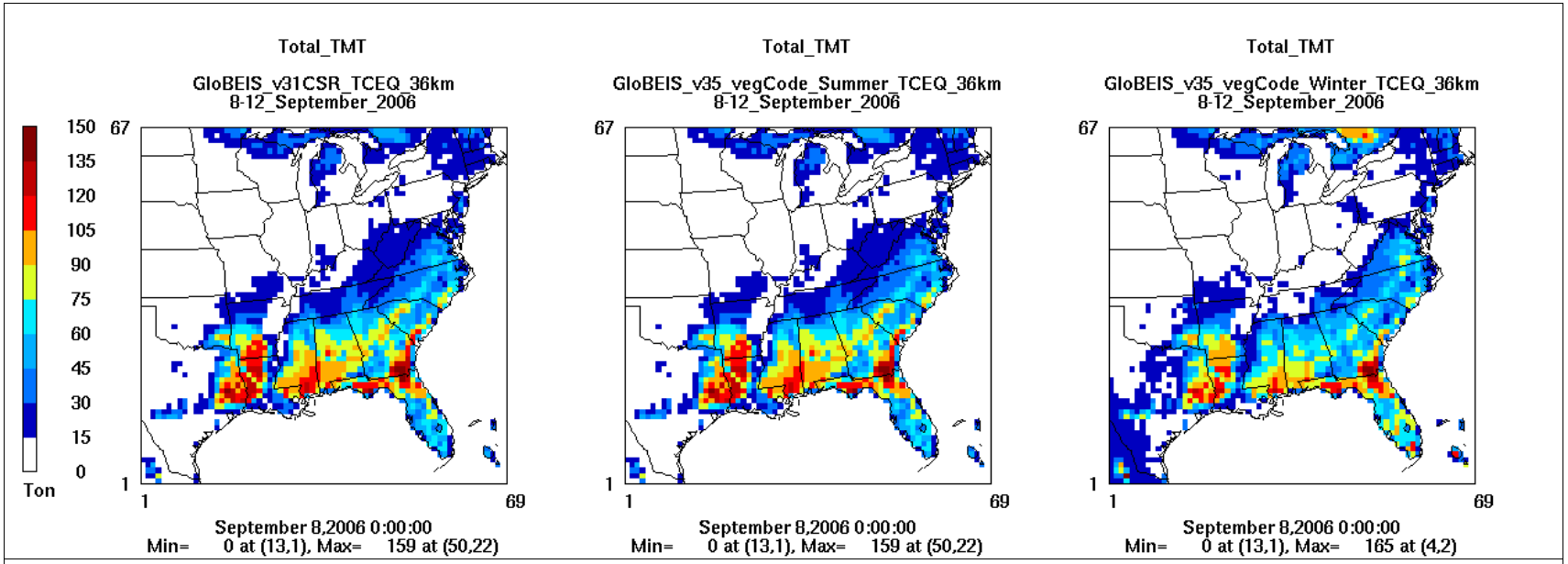



**Figure 2.12. Period total TMT (Tons) from GloBEIS v3.1 CSR, v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 36km domain.**

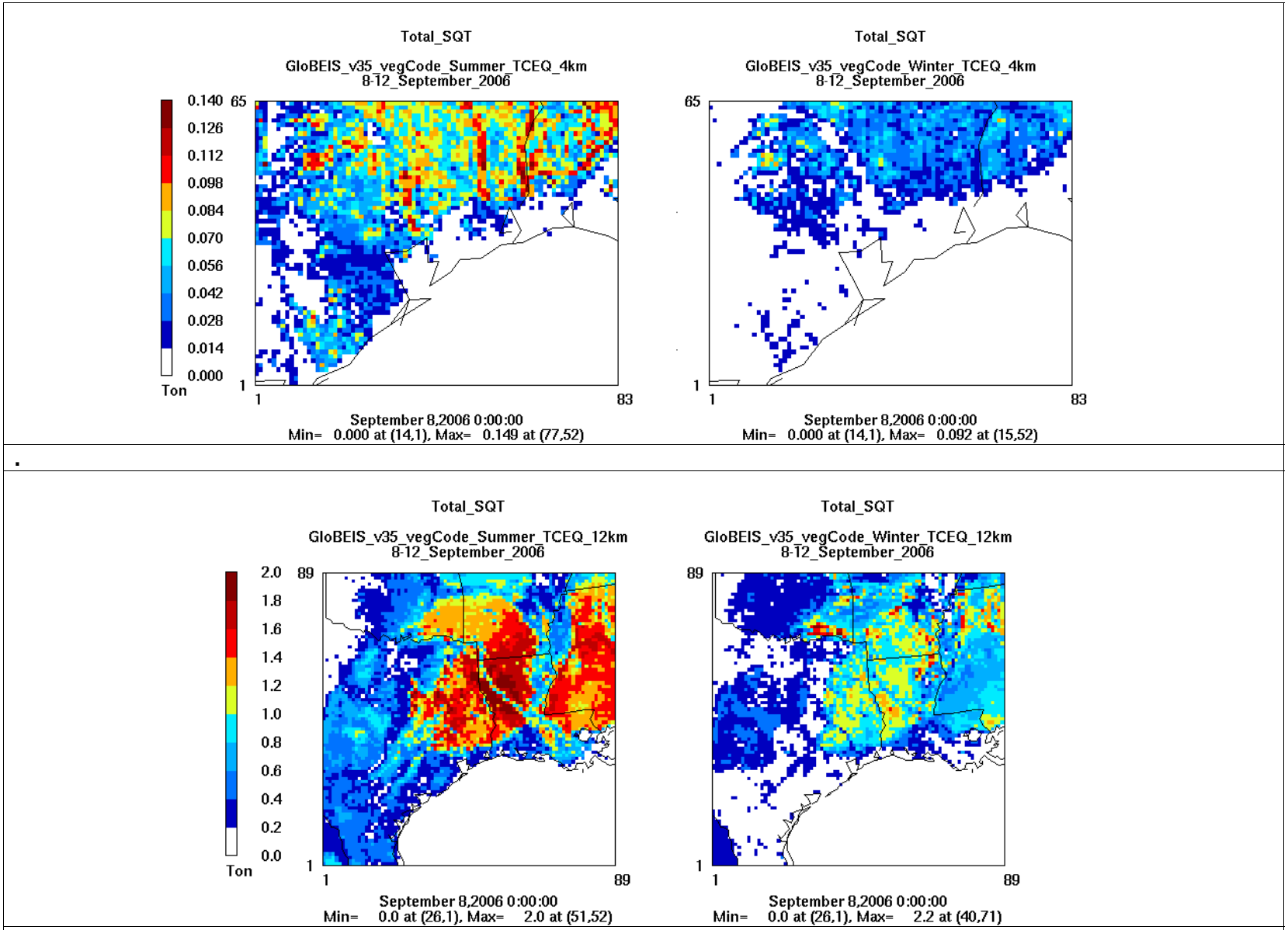



**Figure 2.14. Period total SQT (Tons) from GloBEIS v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 12km domain.**

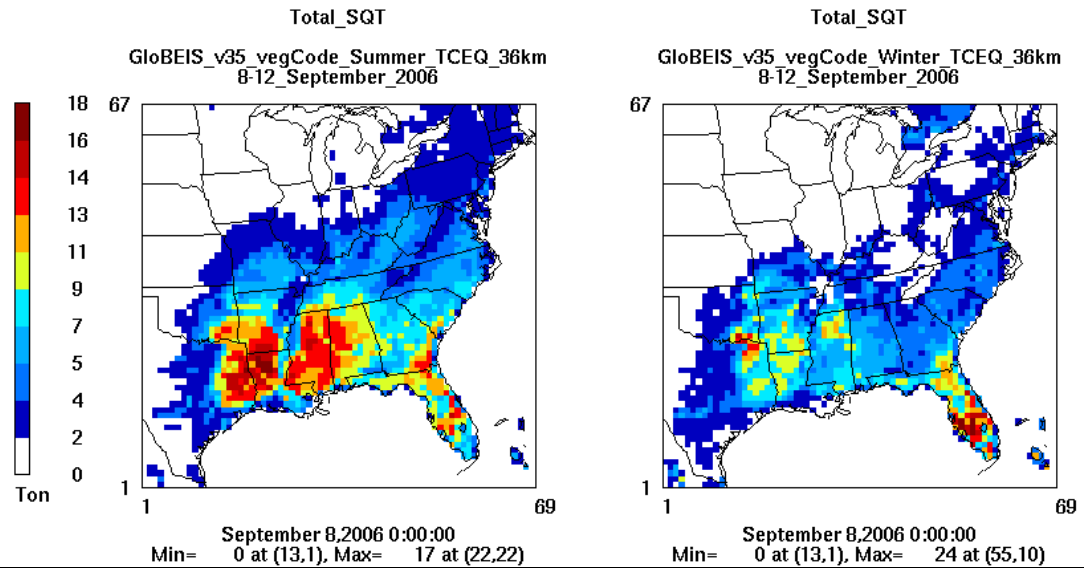



**Figure 2.15. Period total SQT (Tons) from GloBEIS v3.5 Summer LMD, and v3.5 Winter LMD for TCEQ 36km domain.**

# 3. MODEL EVALUATIONS

This section presents quantitative comparisons of biogenic emissions from GloBEIS version 3.5 and MEGAN version 2.04a using Texas 2006 AQS2 data. This was accomplished through two complementary approaches that include a comparison of model results and a detailed characterization of individual model components. We used several configurations based on land cover data and emission factors from the two models (Section 3.1) in order to understand the differences in the estimation characteristics. Section 3.2 describes differences in individual model components and provides an assessment of which components are likely to be responsible for the differences in emissions estimated by the two models. This section also includes a comparison between GloBEIS and MEGAN (Section 3.3) and a comparison of CAMx 15 min 3-D outputs based on base biogenic emissions from the two models to airborne measurements from the Texas Air Quality Study in September and October of 2006 (TexAQS2006) (Section 3.4).

## 3.1 MODEL CONFIGURATIONS AND METHODOLOGY

To understand the estimation characteristics of GloBEIS and MEGAN, we compared GloBEIS and MEGAN by using the same emission factor and land cover. This study compares GloBEIS and MEGAN using multiple configurations. Afterward, we evaluated GloBEIS and MEGAN models by using the biogenic emissions from base configurations in a regional photochemical model, CAMx, and comparing the simulation output to aircraft measurements.

### Land Cover and Emission Factor Data for GloBEIS and MEGAN

In order to compare the GloBEIS and MEGAN landcover and emission factor data, we used GloBEIS data to generate input files for MEGAN. This was accomplished for emission factors by running GloBEIS for the MEGAN standard conditions (LAI=5, Temperature = 303K, PAR=360). This causes GloBEIS to generate area average emission rates that can be used as emission factors in MEGAN. Emission factors were generated for the 4km (both CSR and WIED landcover data), 12 km and 36 km domains and were processed into the MEGAN input format. In addition, the GloBEIS data were used to generate PFT inputs for MEGAN. This was accomplished by mapping each of the 7 GloBEIS canopy types to the 5 MEGAN PFTs as shown in Table 3.1.

**Table 3.1. Plant Functional Type fractions (PFTF) for different canopy types.**

| Canopy Type | Broad Leaf Tree Fraction | Needle Leaf Tree Fraction | Shrub Fraction | Herbaceous Fraction |
|---|---|---|---|---|
| 1 | 0 | 1 | 0 | 0 |
| 2 | 0.5 | 0.5 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 |
| 4 | 0.25 | 0.25 | 0.25 | 0.25 |
| 5 | 0 | 0 | 1 | 0 |
| 6 | 0 | 0 | 0 | 1 |
| 7 | 0 | 0 | 0 | 1 |

In most cases, the GloBEIS canopy type could be directly mapped to a MEGAN PFT. For example, GloBEIS canopy type 1 (needleleaf trees) was assumed to be 100% MEGAN needleleaf tree PFT. The exceptions were that the GloBEIS Mixed forest (canopy type 2) was evenly split between MEGAN needleleaf trees and broadleaf trees and the GloBEIS mixed vegetation (canopy type 4) was evenly split among all MEGAN PFTs.

**GloBEIS and MEGAN Configurations**

Simulations ran using the GloBEIS and MEGAN land cover data and emission factors are described in Table 3.2 – 3.3. For the 36 km and 12km domains, GloBEIS configurations are; 1) G_Gef_Clai - GloBEIS emission factors and land cover, and constant LAI, and 2) G_Gef_Mlai – GloBEIS emission factors and land cover, and variable (MEGAN) LAI. For the 4 km domain, GloBEIS configurations are; 3) G_GefCSR_Clai – GloBEIS emission factors and CSR based land cover, and constant LAI, 4) G_GefCSR_Mlai – GloBEIS emission factors and CSR based land cover, and variable (MEGAN) LAI, 5) G_GefWIE_Clai – GloBEIS emission factors and WIED derived land cover, and constant LAI, and 6) G_GefWIE_Mlai – GloBEIS emission factors and WIED derived land cover, and variable (MEGAN) LAI.

The MEGAN configurations for the 36 km and 12km domains are; 7) M_MefMpft – MEGAN emission factors and MEGAN PFTF, and 8) M_GefGpft – GloBEIS emission factors and GloBEIS land cover. For the 4 km domain, the configurations are; 7) M_MefMpft, and 9) M_GefGpftCSR - GloBEIS emission factors and GloBEIS CSR based land cover.

In summary, there are total of 4 GloBEIS-MEGAN configurations for the 36 km and 12 km domains and 6 GloBEIS-MEGAN configurations for the 4 km domain.

**Table 3.2. Summary of GloBEIS version 3.5 configurations.**

| No. | Case | EF | Land Cover | LAI | Domain |
|---|---|---|---|---|---|
| 1 | G_Gef_Clai | GloBEIS | GloBEIS | Constant | 36/12 |
| 2 | G_Gef_Mlai | GloBEIS | GloBEIS | MEGAN | 36/12 |
| 3 | G_GefCSR_Clai | GloBEIS | CSR | Constant | 4 |
| 4 | G_GefCSR_Mlai | GloBEIS | CSR | MEGAN | 4 |
| 5 | G_GefWIE_Clai | GloBEIS | WIED | Constant | 4 |
| 6 | G_GefWIE_Mlai | GloBEIS | WIED | MEGAN | 4 |

**Table 3.3. Summary of MEGAN version 2.04a configurations.**

| No. | Case | EF | PFT | Domain |
|---|---|---|---|---|
| 7 | M_MefMpft | MEGAN | MEGAN | 36/12/4 |
| 8 | M_GefGpft | GloBEIS | GloBEIS | 36/12 |
| 9 | M_GefGpftCSR | GloBEIS | GloBEIS (CSR) | 4 |

For the evaluations of the biogenic emission models using CAMx and aircraft measurements, we used 2 base emissions datasets, base GloBEIS and base MEGAN emission datasets for this report. The base GloBEIS emission dataset consists of G_Gef_Clai for the 36 km and 12 km domain and G_GefCSR_Clai for the 4 km domain. The base MEGAN emission dataset consists of M_MefMpft for the 36 km, 12 km, and 4 km domains.

## GloBEIS Driving Variables and Data

For all GloBEIS configurations, we used same driving variables and data as was used for the Texas 2006 AQS2 study. The data includes 36/12/4 km domain definition, PAR data for June to October 2006, temperature data for June to October 2006, and land cover, available at ftp://ftp.tceq.state.tx.us/pub/ChiefEngineer/AIR/DA/Biogenics%20Files/CH-Bio.zip.

## MEGAN Driving Variables and Data

For all MEGAN configurations, the model is set up with temperature from MM5CAMx meteorological data and 2006 PAR observation data from UMD satellite. The MM5CAMx dataset is the same dataset used for Texas 2006 AQS2 study, September 16 to October 12, 2006, available at the link below. Emission factors and land cover data depend on the configurations selected and they are described above.

MM5CAMx Meteorological data
ftp://ftp.tceq.state.tx.us/pub/OEPAA/TAD/Modeling/HGB8H2/camx/basecase/bc06aqs2.reg10.2006ep1_eta_dbemis_fddats_newuhsst_newutcsrlulc_grell/input/met/.

PAR data from UMD satellite
http://www.atmos.umd.edu/~srb/par/03satellite.htm.

## CAMx Configuration

The Comprehensive Air quality Model with extensions (CAMx) is a regional photochemical gridded model (CAMx v4.53 User's Guide). For this study, we use CAMx version 4.53 with CB05 mechanism to be consistent with TCEQ AQS2 study. The model configurations are CAMx v.4.53

- Episode: September 16 to October 6, 2006
- Projection: Lambert with
  - Center Longitude: -100.0 degree
  - Center Latitude: 40.0 degree
  - True Latitude1: 60.0 degree
  - True Latitude2: 30.0 degree
  - Central Meridian: -100.0 degree
- Grid Definition (Figure 3.1):
  - TCEQ 36 km domain: (-108,-1584) km with 69x67x17 resolution.
  - TCEQ 12 km domain with buffer cell: (-12,-1488) km with 89x89x17 resolution.
  - TCEQ 4 km domain with buffer cell: (356,-1228) km with 83x65x28 resolution.
- Advection Solver: PPM
- Chemistry Solver: EBI
- PiG Submodel: GREASD
- Chemistry: CB05
- Dry Deposition
- Wet Deposition

- Staggered Winds
- Gridded Emissions: derived from ftp://ftp.tceq.state.tx.us/pub/OEPAA/TAD/Modeling/HGB8H2/camx/basecase/bc06aqs2.reg10.2006ep1_eta_dbemis_fddats_newuhsst_newutcsrlulc_grell/input/ei/
- Point Emissions: Obtained from ftp://ftp.tceq.state.tx.us/pub/OEPAA/TAD/Modeling/HGB8H2/camx/basecase/bc06aqs2.reg10.2006ep1_eta_dbemis_fddats_newuhsst_newutcsrlulc_grell/input/ei/
- Output: 3-D with 15 min Frequency
- MM5CAMx: Obtained from ftp://ftp.tceq.state.tx.us/pub/OEPAA/TAD/Modeling/HGB8H2/camx/basecase/bc06aqs2.reg10.2006ep1_eta_dbemis_fddats_newuhsst_newutcsrlulc_grell/input/met/
- Boundary conditions, AHOMAP data, and TUV data: obtained from ftp://ftp.tceq.state.tx.us/pub/OEPAA/TAD/Modeling/HGB8H2/camx/basecase/bc06aqs2.reg10.2006ep1_eta_dbemis_fddats_newuhsst_newutcsrlulc_grell/input/common/

The same configurations except gridded emissions are used for the 2 CAMx study cases. The two cases are: 1) CAMx – base GloBEIS (CAMx_baseG) and 2) CAMx – base MEGAN (CAMx_baseM). To obtain the gridded emission for the two cases, the biogenic emission portions in the original gridded emissions were substituted with base GloBEIS emissions (G_Gef_Clai and G_GefCSR_Clai) and base MEGAN emissions (M_MefMpft) for CAMx_baseG and CAMx_baseM, respectively. As discussed in the "Improvements to GloBEIS version 3.5" memorandum, the emissions from GloBEIS version 3.5 are equivalent to GloBEIS version 3.1 CSR. Therefore, CAMx_baseG can also represent TCEQ's base CAMx 2006 AQS2.

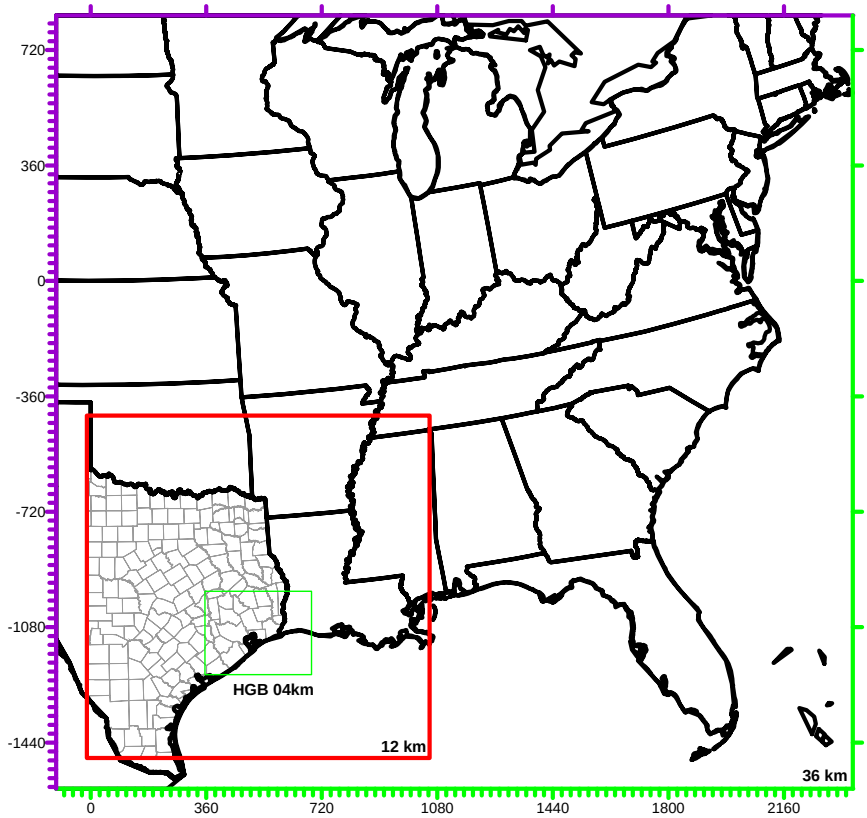
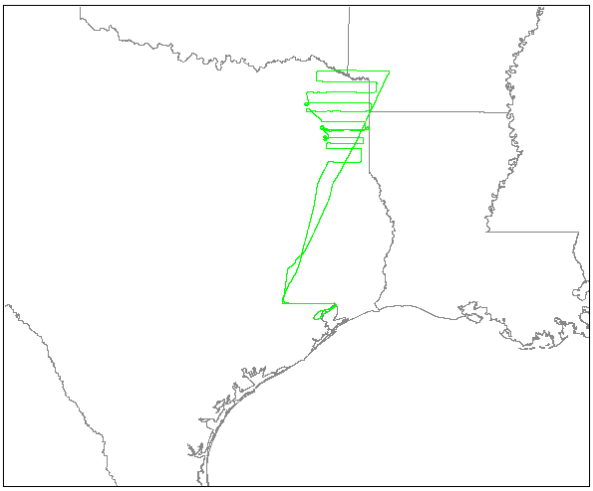


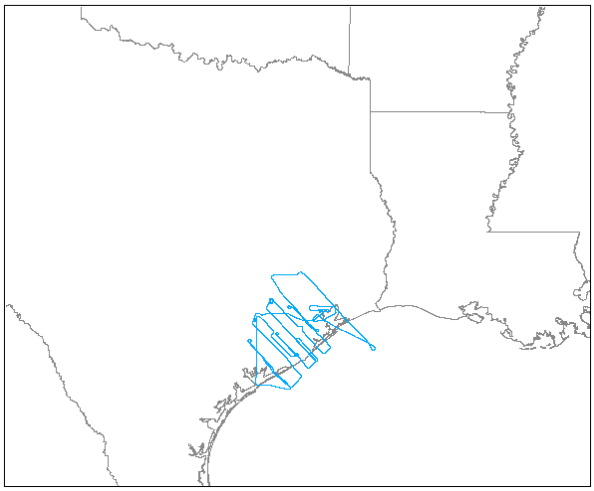

**Figure 3.1. TCEQ 36 km, 12 km, and 4 km domains.**

**Aircraft Measurements**

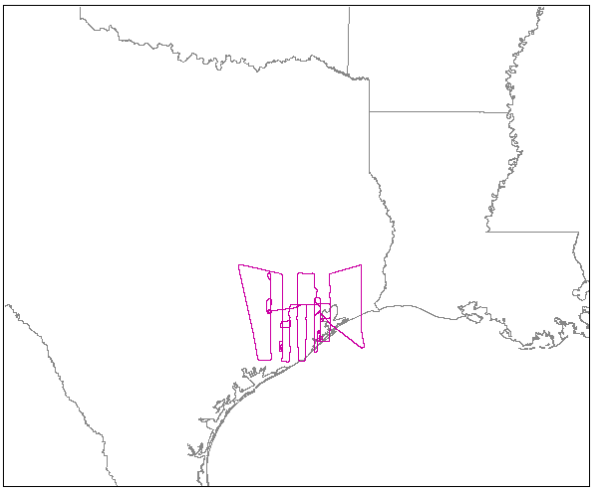
One method of evaluating biogenic emission models is comparing biogenic VOCs (BVOCs) against airborne measurements (e.g., Warneke et al., 2010). A direct flux comparison would require airborne BVOC flux measurements but since this is currently not available for Texas, we compare airborne concentration measurement data from the Texas Air Quality Study in September and October of 2006 (TexAQS2006) campaigns (Parrish et al., 2009) against CAMx 3-D concentration outputs with 15-min resolution for 12 km and 4 km domains. It should be noted that a comparison of model and observed concentrations evaluates the combined influence of emissions, chemistry and transport and dispersion. The airborne measurements were obtained by the NOAA WP-3 aircraft in East Texas and the Gulf of Mexico areas. Figure 3.2 presents the flight tracks for TexAQS2006, which were generally within the 12 km and 4-km domains. The available measurements for this study are 1-sec NO, NO2, O3, CO, HCHO, 8 to 30-sec CH3OH, 17-sec isoprene, total monoterpenes, and oxygenates. The airborne measurement data were obtained from http://www.esrl.noaa.gov/csd/tropchem/2006TexAQS/P3/.



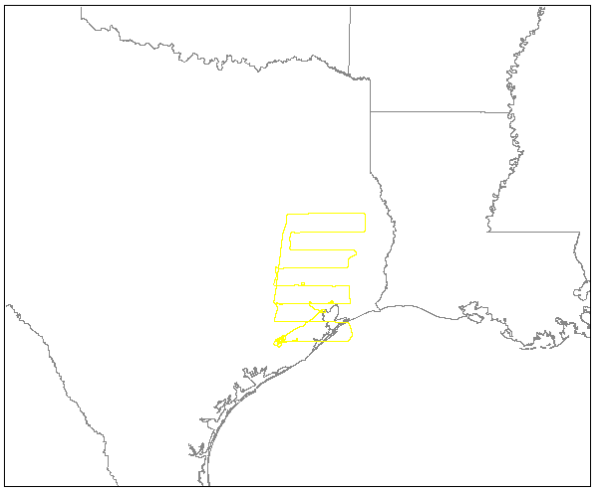
Flight track for September 16, 2006



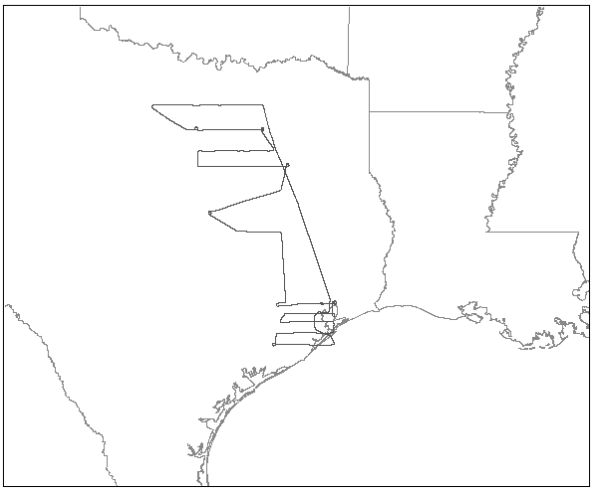
Flight track for September 19, 2006



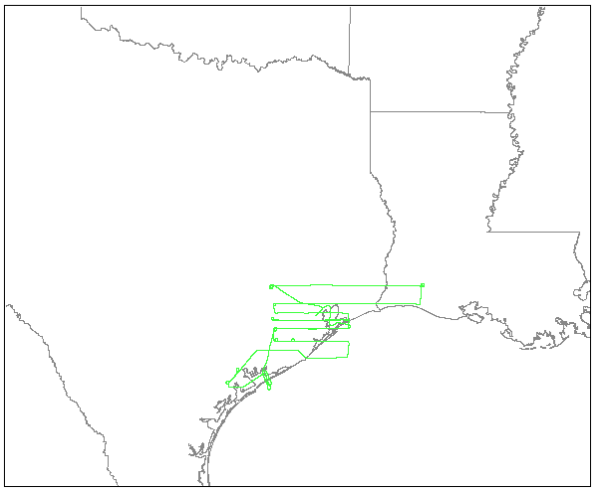
Flight track for September 20, 2006



Flight track for September 21, 2006

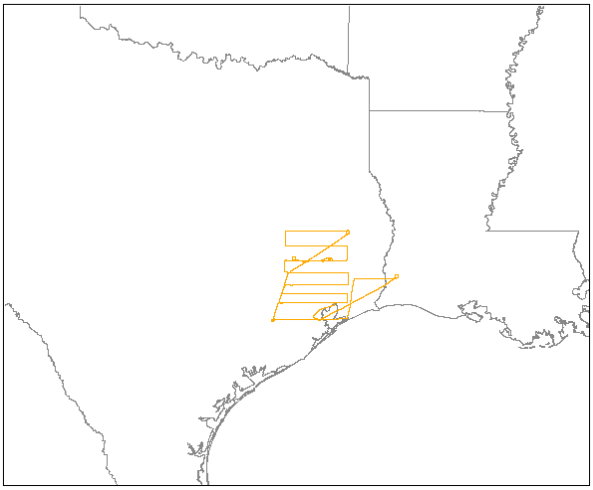


Flight track for September 25, 2006

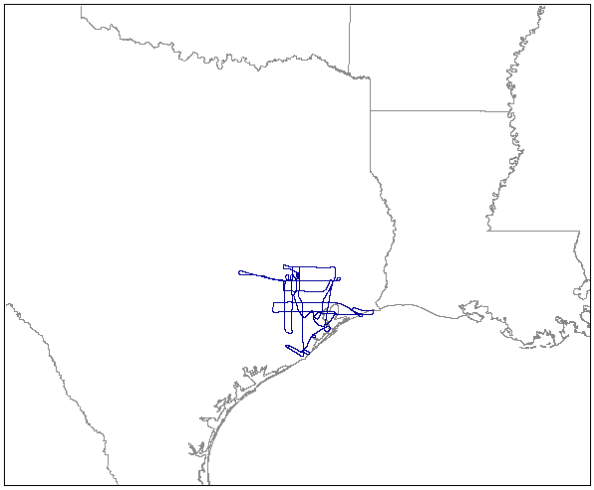


Flight track for September 26, 2006

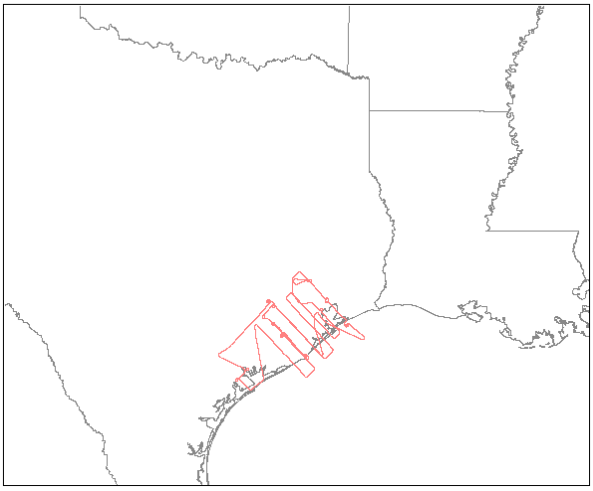
**Figure 3.2. Flight tracks for TexAQS2006 during September 16 to October 6.**



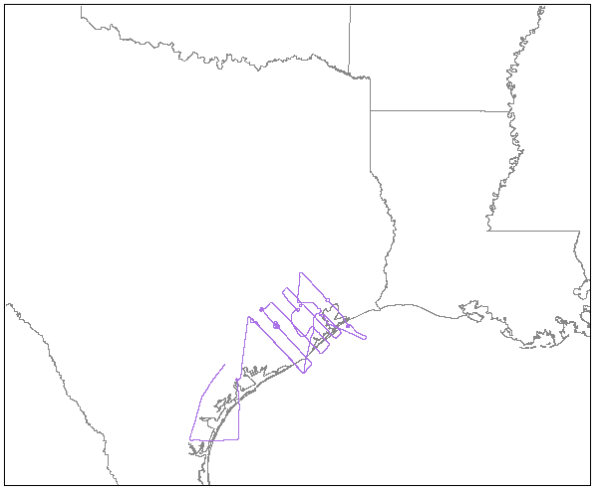
Flight track for September 27, 2006



Flight track for September 29, 2006



Flight track for October 5, 2006



Flight track for October 6, 2006

**Figure 3.2 (continued). Flight tracks for TexAQS2006 during September 16 to October 6.**

## 3.2 MODEL COMPONENT COMPARISONS

GloBEIS, BEIS, MEGAN and most other biogenic VOC emission models estimate emissions as a function of emission factors, foliage distributions, and emission activity factors that include solar radiation, temperature and other factors. Almost all of these components can be easily compared and are transferable among these models. The one exception is the procedures used to develop vegetation type distributions which is specific to each model. Table 3.4 summarizes differences in the emission factor, foliage distributions, and emission activity algorithms used in MEGAN2.04, MEGAN2.1, BEIS3.14 and GloBEIS3.5. A detailed description of the differences in model approaches for each of these categories is given in this section and the contribution to overall differences is discussed.

### Emission Factors

GloBEIS3.5 and BEIS3.14 emission factors are within a few percent for isoprene and the BEIS3.14 monoterpene emission factors are about 10% lower than GloBEIS3.5. The BEIS3.14 OVOC emission factors are an order of magnitude higher than the GloBEIS3.5 values for crops and grass, a factor of ~3 higher for broadleaf trees and ~50% higher for conifers. The BEIS3.14 sesquiterpene emission factors are more than a factor of 2 lower than the GloBEIS3.5 values for woody plants and are about the same for crops and grass. The MEGAN2.1 isoprene emission factors are ~ 37% higher than GloBEIS3.5 for most isoprene emitting species including *Quercus* (Oaks), *Populus* (Poplars) *Liquidambar* (sweetgum) and *Eucalyptus*. Exceptions include a factor of ~5 higher emission rates for *Nyssa* (Tupelo) and *Robinia* (Locust) species, a factor of ~2 higher for *Salix* (Willow) and *Platanus* (Sycamore) and a factor of ~2 lower for *Picea* (spruce). The MEGAN2.1 monoterpene emission factors tend to be ~40% lower than the GloBEIS3.5 emission factors for conifers and range from ~40% lower to more than a factor of 2 higher for broadleaf trees. MEGAN2.1 considers much of the broadleaf tree emission to be light dependent which results in much lower emissions at nighttime. The GloBEIS3.5 and MEGAN2.1 sesquiterpene emission factors are about the same.

**Table 3.4 Comparison of GloBEIS3.5 with MEGAN2.04, MEGAN 2.1, and BEIS 3.14.**

| Category | MEGAN2.04 | MEGAN2.1 | BEIS3.14 | GloBEIS3.5 | GloBEIS vs MEGAN2.1 | GloBEIS vs BEIS |
|---|---|---|---|---|---|---|
| ***Emission Factors*** | | | | | | |
| Isoprene EF | oaks=24 | oaks=24 | oaks=17.5 | oaks=17.5 | ↓↓↓ | = |
| Monoterpene EF | pine=1.45 | pine=1.45 | pine=2.1 | pine=2.38 | ↑↑ | ↑↑↑ |
| Sesquiterpene EF | pine=0.2 | pine=0.2 | pine=0.08 | pine=0.2 | ↑↑↑ | = |
| OVOC EF | oak=2 | oak=2 | oak=2.4 | oak=0.55 | ↓↓↓ | ↓↓↓ |
| ***Foliage distributions*** | | | | | | |
| Peak LAI | satellite data | satellite data | constant | both options | ↓ | ≈ |
| LAI variations | satellite data | satellite data | constant | both options | ↓ | ≈ |
| ***Solar radiation*** | | | | | | |
| Solar constant | 1367 | 1367 | 1320/1300 | 1367 | ↑ | ≈ |
| Visible fraction | f(diffuse Frac) | f(transmission) | f(diffuse Frac) | 46% of total solar | ↑ | ≈ |
| Diffuse fraction | f(transmission) | different for PPFD | f(P, zenith angle, Q) | f(transmission) | ↓ | ↓↓ |
| μmol photons per Joule | 4.55 | diffuse=4.3, direct=4.6 | 4.6 | 4.55 | ≈ | ↑ |
| Sun vs shade leaves | 40% sun | xx% sun | 37% sun | 40% sun | ↑ | ≈ |
| Canopy PPFD | 5 levels; xx% transmitted | 5 levels; xx% transmitted | 1 level; 1xx% transmitted | 5 levels; xx% transmitted | ↓ | ≈ |
| Isoprene response to light | $\alpha$, $C_L$ = f(past light) | $\alpha$, $C_L$ = f(past light) | $\alpha$=.00185, $C_L$ = 1.42 | $\alpha$, $C_L$ = f(LAI depth) | ↑↑ | ↓ |
| MT/SQT response to light | 5 to 80% light dependent | parameters vary | none | none | = | ↑ |
| OVOC response to light | 5 to 80% light dependent | parameters vary | none | 100% light dependent | ↓ | ↓ |
| ***Temperature*** | | | | | | |
| Canopy leaf temperature | energy balance | energy balance | equal to air temperature | energy balance option | ↑ | = |
| Isoprene response to T | Eopt, Topt= f(past T) | Eopt, Topt= f(past T) | Eopt=1.9, Topt= 312.5 | Eopt, Topt= f(past T) | ↑↑↑ | ↑↑ |
| MT response to T | $\beta$ = 0.09 or 0.12 | $\beta$ = 0.1 | $\beta$ = 0.09 | $\beta$ = 0.09 | = | ↓ |
| SQT response to T | $\beta$ = 0.12 0r 0.17 | $\beta$ = 0.17 | $\beta$ = 0.17 | $\beta$ = 0.17 | = | ↓ |
| OVOC response to T | $\beta$ = 0.08 to 0.13 | $\beta$ = 0.08 to 0.13 | $\beta$ = 0.09 | $\beta \approx 0.12$ | ↑ | ≈ |
| ***Other activity factors*** | | | | | | |
| Leaf age | Guenther et al. 2006 | Guenther et al. 2006 | none | Guenther et al. 1999 | ↓ | ≈ |
| Drought | =f(soil moisture) | =f(soil moisture) | none | =f(drought index) | ↓ | ≈ |
| CO2 | none | =f(ambient CO2) | none | none | ≈ | ≈ |

Comparisons are for midday conditions in Texas in August and September 2006. = indicates there is no difference; ≈ indicates GloBEIS is within 3%; ↑ (↓) GloBEIS is 3 to 7% higher (lower); ↑↑ (↓↓) GloBEIS is 8 to 15% higher (lower); ↑↑↑ (↓↓↓) GloBEIS is > 15 % higher (lower)

## Foliage Distributions

BEIS assumes a constant LAI for areas covered by vegetation while MEGAN uses satellite observations to assign the peak LAI and weekly to interannual variations. GloBEIS provides options for using either the BEIS or MEGAN approaches. The use of satellite derived foliage distributions will generally result in somewhat (~10%) lower emissions since it allows vegetation covered surfaces to have less than peak foliage. However, it is possible to have substantially (>30%) lower or higher emissions when using the satellite derived LAI in comparison to the constant peak LAI approach. The higher emissions result when the assumed peak LAI is lower than the value derived from satellite observations. Figure 3.3 illustrates that a 10% change in LAI at high LAI results in a small (~3% change in isoprene emissions while a 10% change in LAI at low LAI results in ~10% change in emissions. This figure also shows that GloBEIS3.5 and MEGAN2.04 have a similar response to changes in LAI.

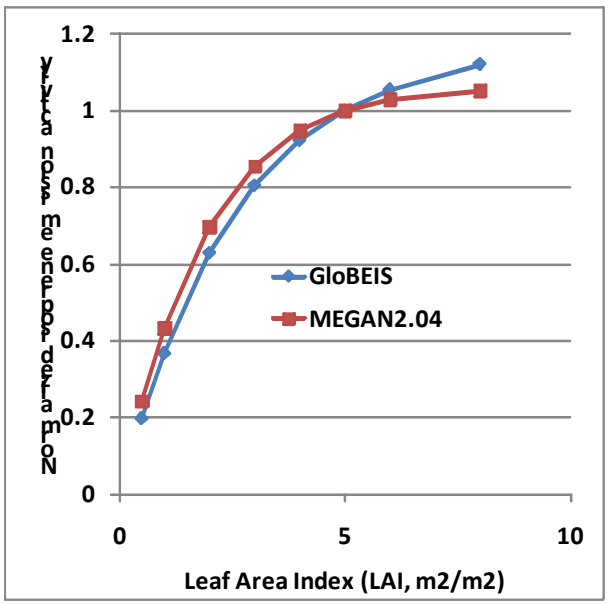



**Figure 3.3. GloBEIS3.5 and MEGAN2.04 response of normalized (to LAI=5) isoprene emission response to LAI.**

It should be noted that some of the GloBEIS landcover types (e.g. the CSR landcover types 50001 to 50018) are assigned relatively low values (~240 g/m2) of leaf mass density (variable "lmd" in table "lcCode lmd") but still have typical LAI values (e.g., 5 for broadleaf trees). This results in an unrealistic specific leaf mass of ~50 g/m2. If the variable LAI option is used then this will result in significant underestimates in emissions at low LAI because of this low specific leaf mass.

## Solar Radiation

The emission of isoprene and many other BVOC are very sensitive to photosynthetic photon flux density (PPFD) levels. In addition, solar radiation can also influence leaf temperature which is an important driver of all BVOC emissions and is discussed below. The procedures used in GloBEIS3.5 and MEGAN2.04 are very similar and are based on the approach described in Guenther et al. 1999. A number of updates to the solar decomposition and canopy environment

algorithms are being incorporated into MEGAN2.1 that are based on a recent review of the literature. These studies show that there is a substantial range in the reported values of these variables. For example, isoprene emission algorithms require solar radiation inputs in units of μmol photons $m^{-2}$ $s^{-1}$. Since atmospheric values are in units of W $m^{-2}$, models must apply a conversion factor. A value of 4.6 μmol photons per Joule is used in BEIS and 4.55 is used for GloBEIS3.5 and MEGAN2.04. Reported values for different sites and conditions range from less than 4 to greater than 5 μmol photons per Joule which could lead to differences in isoprene emissions of +/- 25%. None of these models account for the observations that show that the value for diffuse PPFD is considerably less than what is observed for direct PPFD. MEGAN2.1 accounts for this by using different values, 4.6 μmol photons per Joule for direct PPFD and 4.3 μmol photons per Joule for diffuse PPFD. Of the nine solar radiation model components listed in Table 3.4, the two that result in the largest differences between GloBEIS and the other models are 1) the decomposition of solar radiation into direct and diffuse components and 2) the algorithm that describes the response of isoprene to variations in PPFD. As shown in Figure 3.4, the diffuse PPFD estimated by MEGAN2.1 and BEIS3.14 are 10 to 50% higher than GloBEIS3.5 estimates under cloudy skies and a factor of 2 or more higher under clear sky conditions. A higher fraction of diffuse light can increase isoprene emissions by increasing light on shade leaves. However, GloBEIS shade leaves are not very responsive to increases in light and so a 25 to 50% increase in diffuse light results in only a 5 to 10% increase in isoprene emissions under cloudy skies and a factor of 2 increase in diffuse light under clear skies results in ~5% increase in emissions.

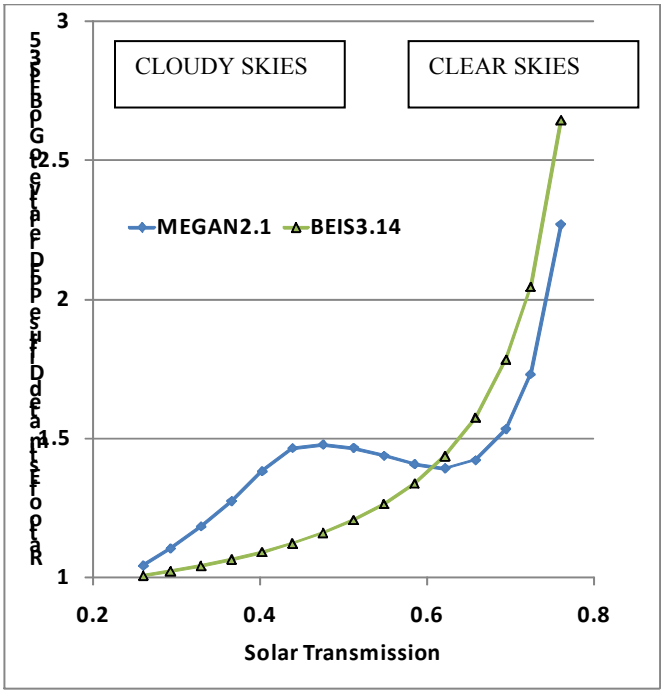



**Figure 3.4. Ratio of diffuse PPFD estimated by BEIS3.14 and MEGAN2.1 relative to diffuse PPFD values estimated for GloBEIS3.5 (which is the same as MEGAN2.04) for a range of solar transmission conditions.**

BEIS, MEGAN and GloBEIS all use the same general equation to simulate leaf level response of isoprene emission to PPFD. The only difference is in the coefficients which are kept constant in BEIS and are varied with LAI depth for GloBEIS and with past light levels for MEGAN. The BEIS values were intended to represent the response of leaves at the top of the canopy but the resulting equation is a linear increase to PPFD > 1000 which is not typically observed. The GloBEIS curves for LAI = 3 and 5 are similar to the MEGAN curves for shade leaves with past daily average PPFD of 80 and 30 μmol/m2/s. The GloBEIS curve for LAI = 1 is similar to the MEGAN curve for sun leaves with past daily average PPFD of 190 except that the MEGAN values are higher at low light. Since the MEGAN response changes with environmental conditions, MEGAN has higher emissions if the past days have been sunny and lower emissions if the past days have been cloudy. The BEIS light response curve generally results in lower emissions than GloBEIS and MEGAN because most leaves are at PPFD levels of 500 μmol/m2/s or lower.

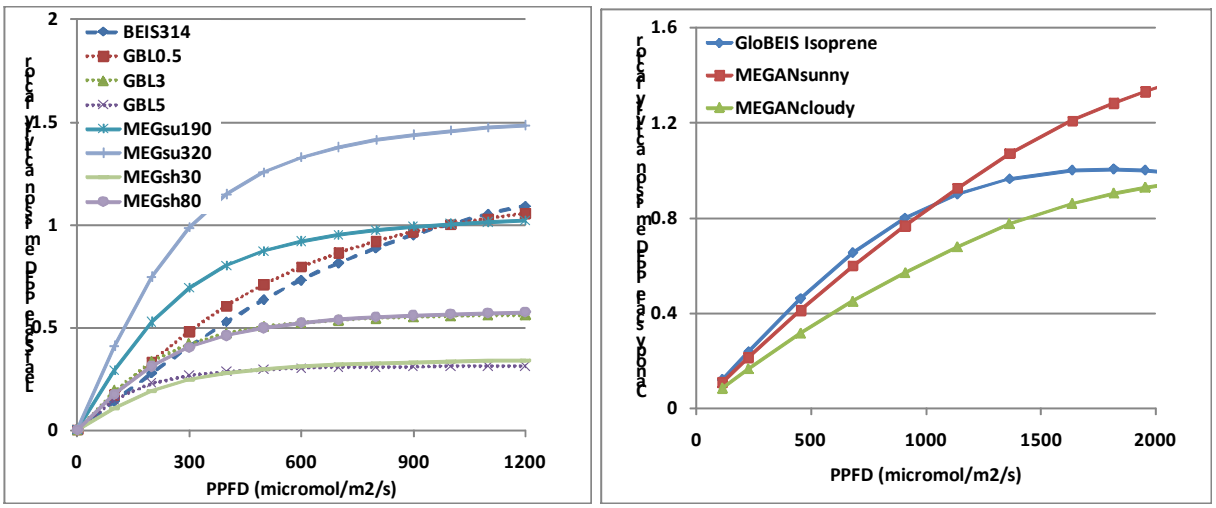



**Figure 3.5 Leaf (left panel) and canopy (right panel) scale isoprene emission response to PPFD. GloBEIS light response curves are shown for canopy LAI depths of 0.5 (GBL0.5), 3 (GBL3) and 5 (GB5). MEGAN responses are shown for sun leaves with past daily average PPFD of 190 (MEGsu190) and 320 (MEGsu320) μmol/m2/s and shade leaves with past daily average PPFD of 80 (MEGsh80) and 30 (MEGsh30) μmol/m2/s. MEGANsunny refers to a past daily average PPFD of 240 μmol/m2/s while MEGANcloudy refers to a past daily average PPFD of 120 μmol/m2/s.**

## Temperature

All BVOC emissions are very sensitive to variations in leaf temperature. MEGAN calculates leaf temperature but BEIS assumes leaf temperature is equal to ambient temperature which typically results in small underestimates in emissions. GloBEIS gives users the option to do either approach. The same general equation is used to describe BVOC emission response to leaf temperature in all of these models but different coefficients are used which can result in large differences in emissions. Isoprene emission is driven by the current temperature in BEIS and the current, past 24 hour average and past 240 hour average temperature in MEGAN. This results in large (>30%) underestimates in BEIS after periods of hot days and large overestimates after

periods of cool days. GloBEIS users have the option of using just the current temperature or using the current, past 24, past 48 and past 360 hour average temperatures. Because of different assumptions used for developing these normalized algorithms, using the past temperature option in GloBEIS results in an isoprene emission temperature activity factor that can be >20% higher than the MEGAN value for the same conditions. This is because GloBEIS assumes that emission factors were measured on plants that have a past daily average temperature of 293K while MEGAN assumes that emission factors were typically measured on plants with a past daily average temperature of 297K.

All three models use the same temperature dependence for sesquiterpene emissions while the monoterpene dependence is slightly higher in MEGAN2.1. The BEIS3.14 OVOC temperature dependence is considerably higher than the value used in GloBEIS3.5. MEGAN uses different values for various OVOC which range from lower than the GloBEIS value to higher than the BEIS value. The use of a higher temperature dependence will result in higher emissions at temperatures above the standard condition (e.g. 303K) and lower emissions at lower temperatures.

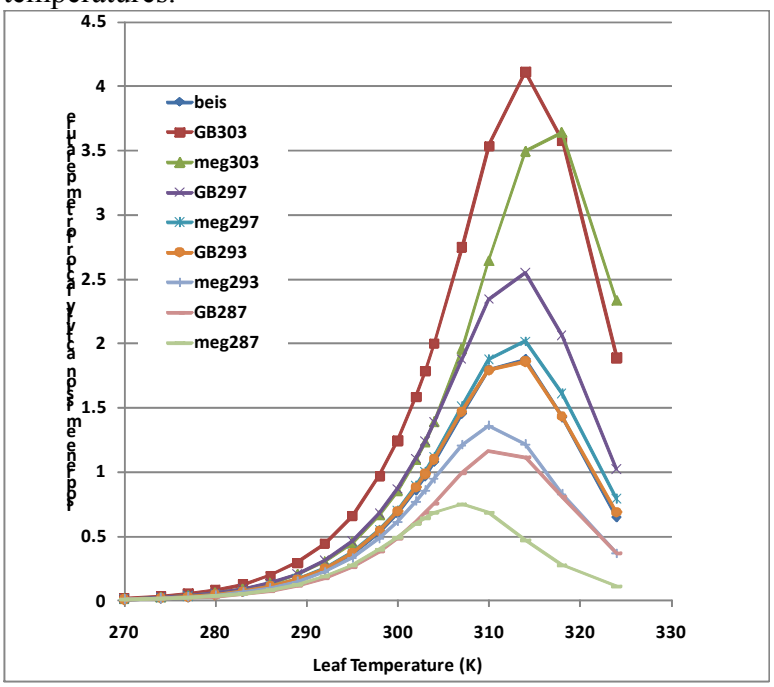



**Figure 3.6 Isoprene emission activity factors response to leaf temperature. Values shown include BEIS, GloBEIS with past temperatures of 303K (GB303) 297K (GB297), 293K (GB293) and 287 (GB287) and MEGAN with past temperatures of 303K (meg 303) 297K (meg 297), 293K (meg 293) and 287 (meg287).**

## Other Activity Factors

GloEBIS3.5, MEGAN2.04, and MEGAN2.1 all include algorithms to account for seasonal variations in emissions due to changes in leaf age. BEIS3.14 does not account for emission changes associated with leaf age which generally causes BEIS to overestimate isoprene emission in the early and late growing season. The leaf age algorithm used in GloBEIS3.15 was updated for MEGAN and extended from one compound (isoprene) to include other compounds such as monoterpenes, sesquiterpenes and methanol.

Both GloBEIS and MEGAN include algorithms that decrease isoprene emissions during drought conditions. BEIS does not consider this and so will greatly overestimate isoprene emissions during severe drought. GloBEIS uses drought index to drive emissions while MEGAN uses soil moisture. Two advantages of using soil moisture are 1) it can be observed in field and laboratory studies and so used to develop quantitative relationships, 2) it is an output of some regional and global weather models and so may be more readily available.

**Vegetation Type Distributions, Species Composition Data and Foliar Density**

BEIS3 uses county average NASS crop statistics and county average FIA tree statistics for counties where FIA data is available and does not consider shrubs and grass for those counties (which are dominated by forests). For other U.S. counties, which include most grass and shrubland regions, BEIS uses 1km USGS landcover data and assigns emission factors to each of 11 USGS landcover types. MEGAN uses the same FIA tree species composition statistics and NASS crop statistics but averages over ecoregions rather than counties. MEGAN also uses NRCS data to quantify grass and shrub species composition. MEGAN uses an ecoregion approach with 867 level 3 ecoregions covering the earth's surface. Within the North America, Australia, Europe, and parts of Africa, Asia, and South America, more highly resolved ecoregions (level 4) are used. The twelve level 3 ecoregions that occur in Texas, for example, are subdivided into fifty-six level 4 ecoregions. Remotely sensed data products (RSDP) are then used to characterize distributions of plant functional types (PFTs: broadleaf trees, needleleaf trees, shrubs, crops/grass) within each ecoregion and a unique plant species composition is assigned to each ecoregion PFT.

GloBEIS enables users to develop their own landcover data. Feldman et al (2010) described and compared two GloBEIS landcover databases developed for the TCEQ 4km HGBPA domain. The WIED-LULC data has over 600 landcover classes based on satellite and ground observation derived vegetation maps that are highly resolved in urban areas. The CSR-LULC data base uses satellite observations to assign broad landcover types to each 30m X 30m location and uses several ecoregions (34a, 34, and 35) to further differentiate resulting in 18 landcover types in the HGBPA 4km domain. Feldman et al. (2010) found that CSR-LULC resulted in 40% lower isoprene emission than the WIED-LULC database. Feldman noted that the general spatial patterns were the same and attributed the lower emissions to differences in both the classification and biomass of key emitting species. However, an analysis performed for this study shows that the CSR-LULC database actually has much higher (63%) fraction of high isoprene emitting biomass with an average isoprene emission factor of 13 $\mu g\ g^{-1}\ h^{-1}$ in comparison to 8 $\mu g\ g^{-1}\ h^{-1}$ for the WIED-LULC database. The lower isoprene emission of the CSR-LULC database is due to the lower estimate of foliage for the HGBPA domain, 7 Tg in comparison to 17.4 Tg estimated by WIED-LULC. The CSR-LULC foliar density values used for deciduous and mixed forests, the major source of isoprene, range from 247 to 277 g m-2 which is much lower than the values used for the WIED-LULC database and in other models such as MEGAN or BEIS. The average emission factor for monoterpenes, sesquiterpenes and other VOC is similar for the CSR-LULC and WIED-LULC which results in overall emissions for CSR-LULC that are about 60% lower than WIED-LULC for those compounds.
MEGAN includes 20 ecoregions in the HGBPA domain which, combined with the 4 MEGAN RSDPs, results in 80 PFTs in the HGBPA domain.

## 3.3 EMISSION SUMMARY AND COMPARISIONS

This section quantitatively compares and discusses the emissions (Table 3.5-3.14) from the GloBEIS and MEGAN models. Table 3.5-3.6 show the domain total emissions for ISOP for the 36 km, 12 km and 4 km domains. Table 3.7-3.8, 3.9-3.10, 3.11-3.12, and 3.13-3.14 show the same analysis for TERP, PAR, CO, and NO, respectively. Note that the missing MEGAN emissions for September 29-30 and October 1 in the 4 km domain are due the incomplete MM5CAMx meteorological data.

### Comparison between GloBEIS and MEGAN

This sub-section is the comparison between GloBEIS with constant LAI (G_Gef_Clai, G_GefCSR_Clai, and G_GefWIE_Clai) and base MEGAN (M_MefMpft). The comparisons for isoprene, PAR, and CO emissions show that GloBEIS and MEGAN produce similar total estimates for the 36 km and 12km domains with less than 9% absolute difference (Table 3.15). For the 4 km domain, ISOP emission from G_GefCSR_Clai is less than MEGAN by 57% and G_GefWIE_Clai is similar to MEGAN. PAR emission from G_GefCSR_Clai is almost a factor of 2 less than MEGAN and G_GefWIE_Clai is higher than MEGAN by 21%. CO emission from G_GefCSR_Clai is a factor of 2 less than MEGAN and G_GefWIE_Clai is higher than MEGAN by 9%.

Monoterpene emission from GloBEIS generally higher than emissions estimated with MEGAN. G_Gef_Clai and G_GefWIE_Clai are higher than MEGAN by 23% to 55% (Table 3.15), while G_GefCSR_Clai is lower by 12%. For NO, GloBEIS and MEGAN are quite different. Generally GloBEIS results in higher emission by 43% to 72%, except G_GefCSR_Clai that is less than MEGAN by 30%.

The 4km results demonstrate that both emission factors and land cover data can play important roles in GloBEIS emission estimations. The differences between the GloBEIS and MEGAN emission factors can be offset by the differences in the WIED and CSR landcover. GloBEIS isoprene emission factors are higher than those used in MEGAN but the WIED land cover apparently has a higher abundance of isoprene emitters which means that using GloBEIS with the WIED landcover results in isoprene emissions that are about the same as those estimated with MEGAN. Conversely, the GloBEIS monoterpene emission factors are lower than those used in MEGAN but the CSR land cover apparently has a lower abundance of emitters which means that using GloBEIS with the CSR landcover results in monoterpene emissions that are about the same as those estimated with MEGAN. In summary, both emission factors and landcover are important drivers of GloBEIS isoprene and monoterpene emissions and accurate distributions of both are needed to calculate accurate emission estimates

### Comparison between GloBEIS with Constant LAI and Variable (MEGAN) LAI

For ISOP, TERP, PAR, and CO, using variable MEGAN LAI reduces emissions. Emission is reduced by 7%-18% for ISOP, 2%-18% for TERP, 8%-28% for PAR, and10%-30% for CO (Table 3.16). This is within the expected range based on our understanding of the model algorithms. However, the model algorithms suggest that compounds that are more light dependent (e.g., isoprene) should have a smaller response to the LAI change which was not the

case. Further analysis is required to determine why this was the case. NO emissions are from soil microbes and so do not depend on LAI. As a result, NO emissions are the same for both cases.

**Comparison between GloBEIS and MEGAN with the Same EF and Land Cover**

To understand the estimation characteristics of the two models, we compare GloBEIS using variable LAI (G_Gef_Mlai) to MEGAN using GloBEIS EF and GloBEIS land cover (M_GefGpft). The comparison for ISOP, TERP, PAR, and CO show consistently lower emission in GloBEIS for the 36 km and 12 km domains for most days. GloBEIS yields lower emissions by 10% to 16% for ISOP, 13% to 15% for TERP, 7% to 23% for PAR, and 5% to 15% for CO (Table 3.17). For the 4 km domain (G_GefCSR_Mlai VS M_GefGpftCSR), ISOP emissions from GloBEIS are higher or lower depending on the day. On average the total emissions are similar. TERP and PAR emissions from GloBEIS are generally higher than MEGAN by 10% and 14%, respectively. The comparisons of daily CO emissions from the two models vary from day to day (Table 3.12), GloBEIS emission is higher than MEGAN emission by 12%.

The differences in NO emission between the two models are consistent across all domains. GloBIES yields higher emission than MEGAN by 86% for the 36 km domain, 83% for the 12 km domain, and 64% for the 4 km domain (Table 3.17).

In summary, GloBEIS yields 5 to 23% lower emissions for the 36 km and 12km domains. For the 4km domain, quantitative comparison varies from day to day and across pollutants. The variation in ISOP emissions in the 4 km domain could be from different light and temperature dependent emission activity algorithms used for the two models. To explain the variation in the 4 km domain, we recommend future investigation.

**Table 3.5. Isoprene emission summary for 36 km and 12 km domains.**

| Date | Domain Total Emission (Ton/Day) for ISOP, TCEQ36KM | | | | Domain Total Emission (Ton/Day) for ISOP, TCEQ12KM | | | |
|---|---|---|---|---|---|---|---|---|
| | G_Gef_Clai | G_Gef_Mlai | M_MefMpft | M_GefGpft | G_Gef_Clai | G_Gef_Mlai | M_MefMpft | M_GefGpft |
| 9/15/2006 | 70,759 | 64,657 | 79,126 | 80,234 | 25,534 | 21,063 | 28,584 | 28,332 |
| 9/16/2006 | 82,262 | 75,138 | 88,357 | 87,736 | 30,159 | 25,166 | 30,576 | 30,482 |
| 9/17/2006 | 68,625 | 65,577 | 71,468 | 73,720 | 18,587 | 16,180 | 16,911 | 16,821 |
| 9/18/2006 | 50,891 | 49,018 | 55,958 | 55,566 | 11,107 | 9,111 | 10,593 | 10,173 |
| 9/19/2006 | 45,212 | 42,839 | 52,406 | 52,030 | 16,308 | 13,540 | 19,475 | 19,191 |
| 9/20/2006 | 39,148 | 36,306 | 48,388 | 48,638 | 16,037 | 12,938 | 18,210 | 17,762 |
| 9/21/2006 | 38,154 | 35,528 | 41,411 | 41,218 | 14,829 | 11,599 | 11,738 | 11,249 |
| 9/22/2006 | 57,696 | 53,084 | 45,131 | 43,426 | 28,765 | 23,795 | 18,145 | 17,400 |
| 9/23/2006 | 56,536 | 53,434 | 51,869 | 52,204 | 18,802 | 15,733 | 14,501 | 13,774 |
| 9/24/2006 | 42,145 | 40,168 | 40,114 | 43,023 | 9,891 | 8,400 | 9,461 | 9,420 |
| 9/25/2006 | 40,604 | 37,647 | 48,446 | 48,935 | 12,184 | 10,069 | 14,449 | 14,007 |
| 9/26/2006 | 48,593 | 44,562 | 54,185 | 54,149 | 16,933 | 13,963 | 18,088 | 17,677 |
| 9/27/2006 | 50,813 | 47,379 | 53,003 | 51,350 | 20,049 | 16,399 | 18,260 | 17,634 |
| 9/28/2006 | 36,235 | 34,122 | 39,782 | 40,275 | 12,537 | 10,414 | 13,372 | 12,833 |
| 9/29/2006 | 29,267 | 26,566 | 34,849 | 34,677 | 12,495 | 9,938 | 12,945 | 12,500 |
| 9/30/2006 | 46,922 | 42,279 | 46,232 | 45,117 | 22,307 | 18,296 | 19,771 | 19,552 |
| 10/1/2006 | 65,305 | 58,767 | 61,323 | 60,406 | 24,558 | 20,624 | 24,328 | 23,968 |
| 10/2/2006 | 69,585 | 63,429 | 61,822 | 60,790 | 23,933 | 18,833 | 22,477 | 22,038 |
| 10/3/2006 | 73,116 | 66,954 | 67,381 | 66,120 | 24,939 | 19,875 | 24,630 | 24,291 |
| 10/4/2006 | 67,342 | 63,169 | 66,641 | 65,279 | 24,835 | 19,870 | 24,729 | 24,512 |
| 10/5/2006 | 52,254 | 48,500 | 52,687 | 52,558 | 21,940 | 17,571 | 21,473 | 21,089 |
| 10/6/2006 | 34,262 | 30,936 | 32,117 | 31,596 | 14,298 | 10,817 | 13,979 | 13,321 |
| Total | 1,165,725 | 1,080,061 | 1,192,698 | 1,189,048 | 421,026 | 344,191 | 406,694 | 398,025 |

**Table 3.6. Isoprene emission summary for 4 km domain.**

| Date | Domain Total Emission (Ton/Day) for ISOP, TCEQ04KM | | | | | |
|---|---|---|---|---|---|---|
| | G_GefCSR_Clai | G_GefCSR_Mlai | G_GefWIE_Clai | G_GefWIE_Mlai | M_MefMpft | M_GefGpftCSR |
| 9/15/2006 | 1,111 | 1,012 | 1,803 | 1,627 | 2,024 | 1,220 |
| 9/16/2006 | 1,243 | 1,127 | 2,010 | 1,807 | 1,658 | 974 |
| 9/17/2006 | 1,059 | 968 | 1,715 | 1,540 | 1,543 | 919 |
| 9/18/2006 | 535 | 493 | 844 | 760 | 646 | 383 |
| 9/19/2006 | 863 | 790 | 1,390 | 1,264 | 1,776 | 1,064 |
| 9/20/2006 | 854 | 776 | 1,385 | 1,250 | 1,707 | 1,013 |
| 9/21/2006 | 840 | 741 | 1,387 | 1,222 | 978 | 556 |
| 9/22/2006 | 1,275 | 1,164 | 2,055 | 1,862 | 1,489 | 884 |
| 9/23/2006 | 1,231 | 1,124 | 1,972 | 1,783 | 1,482 | 885 |
| 9/24/2006 | 447 | 409 | 715 | 644 | 503 | 299 |
| 9/25/2006 | 546 | 499 | 886 | 800 | 1,202 | 719 |
| 9/26/2006 | 699 | 639 | 1,134 | 1,027 | 1,312 | 787 |
| 9/27/2006 | 852 | 775 | 1,381 | 1,248 | 1,463 | 876 |
| 9/28/2006 | 717 | 659 | 1,145 | 1,031 | 1,026 | 618 |
| 9/29/2006 | 597 | 542 | 967 | 867 | | |
| 9/30/2006 | 1,068 | 976 | 1,719 | 1,558 | | |
| 10/1/2006 | 1,000 | 918 | 1,605 | 1,454 | | |
| 10/2/2006 | 871 | 776 | 1,389 | 1,218 | 1,267 | 767 |
| 10/3/2006 | 964 | 865 | 1,556 | 1,380 | 1,522 | 932 |
| 10/4/2006 | 953 | 856 | 1,527 | 1,352 | 1,465 | 903 |
| 10/5/2006 | 1,134 | 1,022 | 1,822 | 1,624 | 1,965 | 1,190 |
| 10/6/2006 | 873 | 773 | 1,418 | 1,242 | 1,688 | 993 |
| Total | 17,066 | 15,469 | 27,535 | 24,681 | 26,716 | 15,982 |

**Table 3.7. Monoterpene emission summary for 36 km and 12 km domains.**

| Date | Domain Total Emission (Ton/Day) for TERP, TCEQ36KM | | | | Domain Total Emission (Ton/Day) for TERP, TCEQ12KM | | | |
|---|---|---|---|---|---|---|---|---|
| | G_Gef_Clai | G_Gef_Mlai | M_MefMpft | M_GefGpft | G_Gef_Clai | G_Gef_Mlai | M_MefMpft | M_GefGpft |
| 9/15/2006 | 21,195 | 18,456 | 17,760 | 22,081 | 6,238 | 5,181 | 4,539 | 6,456 |
| 9/16/2006 | 23,497 | 20,371 | 19,861 | 23,947 | 7,595 | 6,339 | 5,405 | 7,700 |
| 9/17/2006 | 22,863 | 20,570 | 18,483 | 23,521 | 6,753 | 5,793 | 4,245 | 6,501 |
| 9/18/2006 | 20,144 | 18,274 | 16,091 | 20,957 | 4,933 | 4,177 | 3,132 | 4,618 |
| 9/19/2006 | 17,771 | 16,018 | 13,528 | 18,167 | 4,540 | 3,830 | 3,108 | 4,443 |
| 9/20/2006 | 14,375 | 12,645 | 11,286 | 14,773 | 4,153 | 3,429 | 2,931 | 4,062 |
| 9/21/2006 | 15,354 | 13,351 | 11,775 | 15,217 | 4,863 | 4,005 | 3,018 | 4,265 |
| 9/22/2006 | 22,093 | 19,199 | 15,084 | 19,649 | 8,228 | 6,964 | 4,162 | 5,982 |
| 9/23/2006 | 23,267 | 20,747 | 16,949 | 22,355 | 6,823 | 5,778 | 3,857 | 5,815 |
| 9/24/2006 | 18,998 | 17,245 | 14,360 | 19,566 | 4,249 | 3,615 | 2,590 | 3,889 |
| 9/25/2006 | 15,302 | 13,621 | 12,418 | 16,307 | 3,651 | 3,045 | 2,516 | 3,506 |
| 9/26/2006 | 15,333 | 13,435 | 12,856 | 16,058 | 4,239 | 3,514 | 3,094 | 4,223 |
| 9/27/2006 | 16,530 | 14,481 | 13,349 | 16,800 | 5,035 | 4,160 | 3,404 | 4,724 |
| 9/28/2006 | 14,978 | 13,300 | 11,520 | 15,523 | 4,156 | 3,474 | 2,579 | 3,756 |
| 9/29/2006 | 12,100 | 10,483 | 9,735 | 12,706 | 3,651 | 2,980 | 2,505 | 3,496 |
| 9/30/2006 | 15,822 | 13,539 | 12,613 | 15,868 | 5,778 | 4,824 | 3,978 | 5,652 |
| 10/1/2006 | 19,420 | 16,638 | 14,714 | 18,677 | 6,495 | 5,447 | 4,382 | 6,385 |
| 10/2/2006 | 20,379 | 17,617 | 15,123 | 18,869 | 6,323 | 4,795 | 4,165 | 5,976 |
| 10/3/2006 | 20,905 | 18,162 | 15,993 | 19,563 | 6,448 | 4,930 | 4,341 | 6,284 |
| 10/4/2006 | 20,245 | 17,838 | 15,705 | 19,548 | 6,378 | 4,890 | 4,483 | 6,530 |
| 10/5/2006 | 18,482 | 16,145 | 13,560 | 18,250 | 6,196 | 4,843 | 3,949 | 6,010 |
| 10/6/2006 | 14,804 | 12,765 | 9,714 | 13,357 | 4,426 | 3,385 | 2,601 | 3,677 |
| Total | 403,856 | 354,901 | 312,478 | 401,760 | 121,151 | 99,399 | 78,986 | 113,951 |

**Table 3.8. Monoterpene emission summary for 4 km domain.**

| Date | Domain Total Emission (Ton/Day) for TERP, TCEQ04KM | | | | | |
|---|---|---|---|---|---|---|
| | G_GefCSR_Clai | G_GefCSR_Mlai | G_GefWIE_Clai | G_GefWIE_Mlai | M_MefMpft | M_GefGpftCSR |
| 9/15/2006 | 298 | 265 | 745 | 733 | 377 | 266 |
| 9/16/2006 | 337 | 299 | 844 | 830 | 353 | 253 |
| 9/17/2006 | 326 | 291 | 816 | 804 | 362 | 261 |
| 9/18/2006 | 227 | 202 | 561 | 550 | 239 | 175 |
| 9/19/2006 | 222 | 198 | 553 | 544 | 271 | 190 |
| 9/20/2006 | 207 | 184 | 518 | 509 | 261 | 180 |
| 9/21/2006 | 248 | 218 | 624 | 612 | 262 | 186 |
| 9/22/2006 | 367 | 328 | 920 | 909 | 343 | 246 |
| 9/23/2006 | 333 | 296 | 832 | 817 | 332 | 240 |
| 9/24/2006 | 200 | 179 | 498 | 489 | 192 | 140 |
| 9/25/2006 | 164 | 146 | 408 | 400 | 207 | 145 |
| 9/26/2006 | 181 | 161 | 452 | 443 | 226 | 159 |
| 9/27/2006 | 215 | 191 | 539 | 530 | 270 | 189 |
| 9/28/2006 | 215 | 191 | 535 | 523 | 242 | 173 |
| 9/29/2006 | 186 | 164 | 462 | 452 | | |
| 9/30/2006 | 279 | 248 | 698 | 686 | | |
| 10/1/2006 | 278 | 248 | 694 | 683 | | |
| 10/2/2006 | 259 | 226 | 643 | 622 | 297 | 217 |
| 10/3/2006 | 270 | 236 | 674 | 653 | 301 | 220 |
| 10/4/2006 | 265 | 233 | 661 | 640 | 295 | 216 |
| 10/5/2006 | 292 | 257 | 728 | 707 | 345 | 249 |
| 10/6/2006 | 245 | 213 | 612 | 591 | 270 | 190 |
| Total | 4,871 | 4,313 | 12,164 | 11,905 | 5,446 | 3,895 |

**Table 3.9. PAR emission summary for 36 km and 12 km domains.**

| Date | Domain Total Emission (Ton/Day) for PAR, TCEQ36KM | | | | Domain Total Emission (Ton/Day) for PAR, TCEQ12KM | | | |
|---|---|---|---|---|---|---|---|---|
| | G_Gef_Clai | G_Gef_Mlai | M_MefMpft | M_GefGpft | G_Gef_Clai | G_Gef_Mlai | M_MefMpft | M_GefGpft |
| 9/15/2006 | 5,256 | 4,455 | 5,886 | 5,260 | 1,520 | 1,095 | 1,704 | 1,533 |
| 9/16/2006 | 5,863 | 4,945 | 6,603 | 5,856 | 1,841 | 1,346 | 1,987 | 1,805 |
| 9/17/2006 | 5,621 | 4,956 | 5,804 | 5,305 | 1,567 | 1,203 | 1,441 | 1,333 |
| 9/18/2006 | 4,933 | 4,409 | 4,961 | 4,616 | 1,152 | 870 | 1,069 | 956 |
| 9/19/2006 | 4,236 | 3,766 | 4,190 | 3,913 | 1,067 | 794 | 1,135 | 1,016 |
| 9/20/2006 | 3,458 | 2,983 | 3,638 | 3,321 | 1,017 | 726 | 1,101 | 970 |
| 9/21/2006 | 3,704 | 3,154 | 3,731 | 3,416 | 1,200 | 850 | 1,079 | 935 |
| 9/22/2006 | 5,295 | 4,504 | 4,726 | 4,352 | 1,958 | 1,460 | 1,500 | 1,317 |
| 9/23/2006 | 5,569 | 4,881 | 5,198 | 4,836 | 1,605 | 1,201 | 1,321 | 1,192 |
| 9/24/2006 | 4,571 | 4,073 | 4,293 | 3,956 | 985 | 749 | 860 | 790 |
| 9/25/2006 | 3,742 | 3,250 | 3,902 | 3,516 | 878 | 643 | 909 | 811 |
| 9/26/2006 | 3,821 | 3,257 | 4,202 | 3,718 | 1,038 | 751 | 1,138 | 1,012 |
| 9/27/2006 | 4,089 | 3,512 | 4,293 | 3,900 | 1,245 | 891 | 1,245 | 1,103 |
| 9/28/2006 | 3,534 | 3,091 | 3,536 | 3,293 | 986 | 722 | 924 | 816 |
| 9/29/2006 | 2,957 | 2,503 | 3,144 | 2,829 | 907 | 634 | 927 | 805 |
| 9/30/2006 | 3,864 | 3,223 | 4,131 | 3,717 | 1,403 | 1,019 | 1,463 | 1,300 |
| 10/1/2006 | 4,775 | 3,965 | 4,744 | 4,345 | 1,560 | 1,152 | 1,587 | 1,455 |
| 10/2/2006 | 5,092 | 4,265 | 4,861 | 4,389 | 1,533 | 1,011 | 1,513 | 1,374 |
| 10/3/2006 | 5,285 | 4,457 | 5,177 | 4,666 | 1,544 | 1,032 | 1,570 | 1,447 |
| 10/4/2006 | 5,036 | 4,344 | 5,004 | 4,632 | 1,523 | 1,023 | 1,606 | 1,486 |
| 10/5/2006 | 4,339 | 3,709 | 4,211 | 3,995 | 1,444 | 988 | 1,414 | 1,300 |
| 10/6/2006 | 3,515 | 2,952 | 3,045 | 2,827 | 1,082 | 704 | 986 | 848 |
| Total | 98,556 | 84,652 | 99,278 | 90,658 | 29,057 | 20,864 | 28,478 | 25,602 |

**Table 3.10. PAR emission summary for 4 km domain.**

| Date | Domain Total Emission (Ton/Day) for PAR, TCEQ04KM | | | | | |
|---|---|---|---|---|---|---|
| | G_GefCSR_Clai | G_GefCSR_Mlai | G_GefWIE_Clai | G_GefWIE_Mlai | M_MefMpft | M_GefGpftCSR |
| 9/15/2006 | 60 | 51 | 138 | 128 | 126 | 51 |
| 9/16/2006 | 68 | 58 | 157 | 144 | 116 | 47 |
| 9/17/2006 | 66 | 56 | 151 | 139 | 117 | 47 |
| 9/18/2006 | 46 | 39 | 104 | 96 | 74 | 30 |
| 9/19/2006 | 45 | 38 | 102 | 94 | 91 | 37 |
| 9/20/2006 | 42 | 36 | 96 | 89 | 88 | 36 |
| 9/21/2006 | 51 | 43 | 117 | 107 | 84 | 34 |
| 9/22/2006 | 74 | 63 | 170 | 157 | 112 | 45 |
| 9/23/2006 | 67 | 58 | 154 | 142 | 109 | 44 |
| 9/24/2006 | 40 | 35 | 92 | 85 | 58 | 23 |
| 9/25/2006 | 33 | 28 | 76 | 70 | 67 | 27 |
| 9/26/2006 | 37 | 31 | 84 | 77 | 74 | 30 |
| 9/27/2006 | 44 | 37 | 100 | 92 | 88 | 36 |
| 9/28/2006 | 44 | 37 | 100 | 91 | 77 | 31 |
| 9/29/2006 | 38 | 32 | 87 | 79 | | |
| 9/30/2006 | 56 | 48 | 129 | 119 | | |
| 10/1/2006 | 56 | 48 | 128 | 119 | | |
| 10/2/2006 | 52 | 44 | 120 | 108 | 96 | 39 |
| 10/3/2006 | 54 | 45 | 125 | 113 | 99 | 40 |
| 10/4/2006 | 54 | 45 | 122 | 111 | 97 | 39 |
| 10/5/2006 | 59 | 49 | 134 | 122 | 116 | 47 |
| 10/6/2006 | 50 | 41 | 114 | 102 | 93 | 37 |
| Total | 986 | 835 | 2,255 | 2,067 | 1,782 | 720 |

**Table 3.11. CO emission summary for 36 km and 12 km domains.**

| Date | Domain Total Emission (Ton/Day) for CO, TCEQ36KM | | | | Domain Total Emission (Ton/Day) for CO, TCEQ12KM | | | |
|---|---|---|---|---|---|---|---|---|
| | G_Gef_Clai | G_Gef_Mlai | M_MefMpft | M_GefGpft | G_Gef_Clai | G_Gef_Mlai | M_MefMpft | M_GefGpft |
| 9/15/2006 | 12,648 | 10,666 | 15,241 | 12,323 | 3,645 | 2,548 | 4,498 | 3,328 |
| 9/16/2006 | 14,128 | 11,850 | 16,791 | 13,464 | 4,412 | 3,135 | 5,046 | 3,782 |
| 9/17/2006 | 13,506 | 11,859 | 14,321 | 12,096 | 3,722 | 2,788 | 3,605 | 2,768 |
| 9/18/2006 | 11,843 | 10,553 | 12,246 | 10,550 | 2,740 | 2,017 | 2,849 | 2,084 |
| 9/19/2006 | 10,114 | 8,968 | 10,752 | 9,237 | 2,541 | 1,838 | 3,170 | 2,338 |
| 9/20/2006 | 8,271 | 7,109 | 9,878 | 8,215 | 2,442 | 1,691 | 3,123 | 2,254 |
| 9/21/2006 | 8,867 | 7,517 | 9,908 | 8,278 | 2,886 | 1,978 | 2,947 | 2,076 |
| 9/22/2006 | 12,658 | 10,721 | 11,929 | 9,944 | 4,674 | 3,390 | 3,952 | 2,818 |
| 9/23/2006 | 13,310 | 11,625 | 12,632 | 10,814 | 3,821 | 2,783 | 3,405 | 2,528 |
| 9/24/2006 | 10,937 | 9,707 | 10,653 | 9,089 | 2,340 | 1,734 | 2,327 | 1,781 |
| 9/25/2006 | 8,982 | 7,761 | 10,425 | 8,589 | 2,099 | 1,495 | 2,601 | 1,922 |
| 9/26/2006 | 9,206 | 7,803 | 11,361 | 9,138 | 2,491 | 1,750 | 3,178 | 2,329 |
| 9/27/2006 | 9,837 | 8,416 | 11,211 | 9,308 | 2,994 | 2,078 | 3,398 | 2,474 |
| 9/28/2006 | 8,420 | 7,343 | 9,214 | 7,873 | 2,353 | 1,673 | 2,599 | 1,891 |
| 9/29/2006 | 7,095 | 5,978 | 8,654 | 7,044 | 2,185 | 1,477 | 2,648 | 1,880 |
| 9/30/2006 | 9,273 | 7,693 | 10,890 | 8,828 | 3,362 | 2,370 | 3,868 | 2,800 |
| 10/1/2006 | 11,471 | 9,466 | 12,001 | 10,013 | 3,730 | 2,682 | 4,060 | 3,075 |
| 10/2/2006 | 12,273 | 10,216 | 12,303 | 10,133 | 3,674 | 2,350 | 3,897 | 2,915 |
| 10/3/2006 | 12,767 | 10,704 | 12,981 | 10,706 | 3,692 | 2,396 | 4,018 | 3,070 |
| 10/4/2006 | 12,127 | 10,417 | 12,241 | 10,504 | 3,638 | 2,375 | 4,068 | 3,125 |
| 10/5/2006 | 10,329 | 8,790 | 10,358 | 9,080 | 3,433 | 2,279 | 3,637 | 2,757 |
| 10/6/2006 | 8,387 | 7,004 | 8,032 | 6,768 | 2,597 | 1,631 | 2,752 | 1,915 |
| Total | 236,447 | 202,166 | 254,020 | 211,995 | 69,471 | 48,457 | 75,645 | 55,911 |

**Table 3.12. CO emission summary for 4 km domain.**

| Date | Domain Total Emission (Ton/Day) for CO, TCEQ04KM | | | | | |
|---|---|---|---|---|---|---|
| | G_GefCSR_Clai | G_GefCSR_Mlai | G_GefWIE_Clai | G_GefWIE_Mlai | M_MefMpft | M_GefGpftCSR |
| 9/15/2006 | 139 | 117 | 312 | 282 | 315 | 115 |
| 9/16/2006 | 157 | 132 | 352 | 319 | 292 | 106 |
| 9/17/2006 | 151 | 128 | 338 | 308 | 292 | 106 |
| 9/18/2006 | 105 | 90 | 234 | 211 | 192 | 69 |
| 9/19/2006 | 103 | 87 | 229 | 208 | 244 | 89 |
| 9/20/2006 | 97 | 81 | 217 | 196 | 240 | 87 |
| 9/21/2006 | 118 | 98 | 265 | 237 | 221 | 79 |
| 9/22/2006 | 170 | 144 | 381 | 347 | 284 | 102 |
| 9/23/2006 | 155 | 131 | 346 | 313 | 276 | 100 |
| 9/24/2006 | 93 | 79 | 207 | 188 | 155 | 56 |
| 9/25/2006 | 77 | 64 | 171 | 154 | 188 | 69 |
| 9/26/2006 | 84 | 71 | 189 | 171 | 204 | 74 |
| 9/27/2006 | 100 | 84 | 225 | 203 | 235 | 86 |
| 9/28/2006 | 101 | 85 | 224 | 202 | 205 | 74 |
| 9/29/2006 | 88 | 73 | 195 | 175 | | |
| 9/30/2006 | 130 | 109 | 291 | 263 | | |
| 10/1/2006 | 129 | 109 | 289 | 262 | | |
| 10/2/2006 | 121 | 99 | 269 | 237 | 240 | 88 |
| 10/3/2006 | 125 | 103 | 280 | 248 | 247 | 92 |
| 10/4/2006 | 123 | 102 | 275 | 244 | 243 | 90 |
| 10/5/2006 | 135 | 112 | 302 | 268 | 288 | 107 |
| 10/6/2006 | 115 | 94 | 257 | 226 | 241 | 88 |
| Total | 2,269 | 1,902 | 5,075 | 4,563 | 4,599 | 1,676 |

**Table 3.13. NO emission summary for 36 km and 12 km domains.**

| Date | Domain Total Emission (Ton/Day) for NO, TCEQ36KM | | | | Domain Total Emission (Ton/Day) for NO, TCEQ12KM | | | |
|---|---|---|---|---|---|---|---|---|
| | G_Gef_Clai | G_Gef_Mlai | M_MefMpft | M_GefGpft | G_Gef_Clai | G_Gef_Mlai | M_MefMpft | M_GefGpft |
| 9/15/2006 | 6,103 | 6,103 | 1,874 | 887 | 1,007 | 1,007 | 580 | 188 |
| 9/16/2006 | 6,639 | 6,639 | 2,137 | 997 | 1,113 | 1,113 | 696 | 236 |
| 9/17/2006 | 5,298 | 5,298 | 1,735 | 867 | 931 | 931 | 517 | 183 |
| 9/18/2006 | 4,385 | 4,385 | 1,431 | 744 | 777 | 777 | 394 | 138 |
| 9/19/2006 | 3,986 | 3,986 | 1,182 | 613 | 763 | 763 | 363 | 122 |
| 9/20/2006 | 4,097 | 4,097 | 1,071 | 527 | 794 | 794 | 365 | 116 |
| 9/21/2006 | 4,387 | 4,387 | 1,159 | 568 | 890 | 890 | 404 | 129 |
| 9/22/2006 | 5,124 | 5,124 | 1,538 | 755 | 1,095 | 1,095 | 569 | 187 |
| 9/23/2006 | 4,963 | 4,963 | 1,597 | 814 | 974 | 974 | 491 | 172 |
| 9/24/2006 | 4,384 | 4,384 | 1,259 | 656 | 703 | 703 | 297 | 108 |
| 9/25/2006 | 4,418 | 4,418 | 1,161 | 577 | 691 | 691 | 292 | 98 |
| 9/26/2006 | 4,889 | 4,889 | 1,299 | 617 | 775 | 775 | 373 | 122 |
| 9/27/2006 | 4,545 | 4,545 | 1,305 | 638 | 872 | 872 | 428 | 140 |
| 9/28/2006 | 3,747 | 3,747 | 1,024 | 523 | 750 | 750 | 318 | 104 |
| 9/29/2006 | 4,171 | 4,171 | 1,009 | 481 | 766 | 766 | 328 | 101 |
| 9/30/2006 | 4,881 | 4,881 | 1,343 | 633 | 940 | 940 | 519 | 167 |
| 10/1/2006 | 5,877 | 5,877 | 1,462 | 705 | 976 | 976 | 538 | 183 |
| 10/2/2006 | 6,249 | 6,249 | 1,544 | 735 | 981 | 981 | 527 | 178 |
| 10/3/2006 | 6,385 | 6,385 | 1,616 | 774 | 961 | 961 | 522 | 182 |
| 10/4/2006 | 5,110 | 5,110 | 1,444 | 725 | 938 | 938 | 530 | 187 |
| 10/5/2006 | 4,362 | 4,362 | 1,185 | 609 | 889 | 889 | 470 | 159 |
| 10/6/2006 | 4,532 | 4,532 | 959 | 474 | 837 | 837 | 367 | 109 |
| Total | 108,533 | 108,533 | 30,335 | 14,920 | 19,422 | 19,422 | 9,887 | 3,307 |

**Table 3.14. NO emission summary for 4 km domain.**

| Date | Domain Total Emission (Ton/Day) for NO, TCEQ04KM | | | | | |
|---|---|---|---|---|---|---|
| | G_GefCSR_Clai | G_GefCSR_Mlai | G_GefWIE_Clai | G_GefWIE_Mlai | M_MefMpft | M_GefGpftCSR |
| 9/15/2006 | 26 | 26 | 59 | 59 | 40 | 11 |
| 9/16/2006 | 28 | 28 | 64 | 64 | 40 | 11 |
| 9/17/2006 | 27 | 27 | 61 | 61 | 41 | 11 |
| 9/18/2006 | 21 | 21 | 48 | 48 | 27 | 7 |
| 9/19/2006 | 21 | 21 | 47 | 47 | 26 | 7 |
| 9/20/2006 | 20 | 20 | 47 | 47 | 25 | 7 |
| 9/21/2006 | 24 | 24 | 56 | 56 | 30 | 8 |
| 9/22/2006 | 29 | 29 | 65 | 65 | 39 | 11 |
| 9/23/2006 | 28 | 28 | 63 | 63 | 38 | 10 |
| 9/24/2006 | 20 | 20 | 44 | 44 | 21 | 6 |
| 9/25/2006 | 18 | 18 | 41 | 41 | 20 | 5 |
| 9/26/2006 | 19 | 19 | 43 | 43 | 21 | 6 |
| 9/27/2006 | 21 | 21 | 48 | 48 | 27 | 7 |
| 9/28/2006 | 21 | 21 | 49 | 49 | 26 | 7 |
| 9/29/2006 | 19 | 19 | 46 | 46 | | |
| 9/30/2006 | 25 | 25 | 56 | 56 | | |
| 10/1/2006 | 24 | 24 | 55 | 55 | | |
| 10/2/2006 | 24 | 24 | 54 | 54 | 32 | 9 |
| 10/3/2006 | 24 | 24 | 54 | 54 | 30 | 9 |
| 10/4/2006 | 24 | 24 | 53 | 53 | 30 | 9 |
| 10/5/2006 | 25 | 25 | 55 | 55 | 35 | 10 |
| 10/6/2006 | 23 | 23 | 54 | 54 | 29 | 8 |
| Total | 442 | 442 | 1,005 | 1,005 | 576 | 161 |

**Table 3.15 Summary of domain-period total emissions and the differences for GloBEIS and MEGAN base cases.**

| Pollutant | TCEQ 36km Domain | | | TCEQ 12km Domain | | |
|---|---|---|---|---|---|---|
| | G_Gef_Clai | M_MefMpft | G_Gef_Clai - M_MefMpft | G_Gef_Clai | M_MefMpft | G_Gef_Clai - M_MefMpft |
| ISOP | 1,165,725 | 1,192,698 | -26,972 (-2.3%) | 421,026 | 406,694 | 14,332 (3.4%) |
| TERP | 403,856 | 312,478 | 91,378 (22.6%) | 121,151 | 78,986 | 42,166 (34.8%) |
| PAR | 98,556 | 99,278 | -721 (-.7%) | 29,057 | 28,478 | 579 (2.0%) |
| CO | 236,447 | 254,020 | -17,574 (-7.4%) | 69,471 | 75,645 | -6,174 (-8.9%) |
| NO | 108,533 | 30,335 | 78,198 (72.1%) | 19,422 | 9,887 | 9,535 (49.1%) |

| Pollutant | TCEQ 4 km Domain | | | | |
|---|---|---|---|---|---|
| | G_GefCSR_Clai | G_GefWIE_Clai | M_MefMpft | G_GefCSR_Clai - M_MefMpft | G_GefWIE_Clai - M_MefMpft |
| ISOP | 17,066 | 27,535 | 26,716 | -9,650 (-56.5%) | 819 (3.0%) |
| TERP | 4,871 | 12,164 | 5,446 | -576 (-11.8%) | 6,718 (55.2%) |
| PAR | 986 | 2,255 | 1,782 | -796 (-80.8%) | 473 (21.0%) |
| CO | 2,269 | 5,075 | 4,599 | -2,330 (-102.7%) | 476 (9.4%) |
| NO | 442 | 1,005 | 576 | -134 (-30.2%) | 429 (42.7%) |

**Table 3.16. Summary of domain-period total emissions and the differences for GloBEIS with constant LAI and GloBEIS with variable (MEGAN) LAI.**

| Pollutant | TCEQ 36km Domain | | | TCEQ 12km Domain | | |
|---|---|---|---|---|---|---|
| | G_Gef_Clai | G_Gef_Mlai | G_Gef_Clai - G_Gef_Mlai | G_Gef_Clai | G_Gef_Mlai | G_Gef_Clai - G_Gef_Mlai |
| ISOP | 1,165,725 | 1,080,061 | 85,665 (7.3%) | 421,026 | 344,191 | 76,835 (18.2%) |
| TERP | 403,856 | 354,901 | 48,955 (12.1%) | 121,151 | 99,399 | 21,752 (18.0%) |
| PAR | 98,556 | 84,652 | 13,904 (14.1%) | 29,057 | 20,864 | 8,193 (28.2%) |
| CO | 236,447 | 202,166 | 34,280 (14.5%) | 69,471 | 48,457 | 21,014 (30.2%) |
| NO | 108,533 | 108,533 | (0.0%) | 19,422 | 19,422 | (0.0%) |

| Pollutant | TCEQ 4 km Domain | | | | | |
|---|---|---|---|---|---|---|
| | G_GefCSR_Clai | G_GefCSR_Mlai | G_GefCSR_Clai - G_GefCSR_Mlai | G_GefWIE_Clai | G_GefWIE_Mlai | G_GefWIE_Clai - G_GefWIE_Mlai |
| ISOP | 17,066 | 15,469 | 1,597 (9.4%) | 27,535 | 24,681 | 2,853 (10.4%) |
| TERP | 4,871 | 4,313 | 558 (11.5%) | 12,164 | 11,905 | 259 (2.1%) |
| PAR | 986 | 835 | 150 (15.3%) | 2,255 | 2,067 | 189 (8.4%) |
| CO | 2,269 | 1,902 | 367 (16.2%) | 5,075 | 4,563 | 512 (10.1%) |
| NO | 442 | 442 | (0.0%) | 1,005 | 1,005 | (0.0%) |

**Table 3.17. Summary of domain-period total emissions and the differences for GloBEIS with variable (MEGAN) LAI and MEGAN with GloBEIS EF and PFTF.**

| Pollutant | TCEQ 36km Domain | | | TCEQ 12km Domain | | |
|---|---|---|---|---|---|---|
| | G_Gef_Mlai | M_GefGpft | G_Gef_Mlai - M_GefGpft | G_Gef_Mlai | M_GefGpft | G_Gef_Mlai - M_GefGpft |
| ISOP | 1,080,061 | 1,189,048 | -108,987 (-10.1%) | 344,191 | 398,025 | -53,834 (-15.6%) |
| TERP | 354,901 | 401,760 | -46,859 (-13.2%) | 99,399 | 113,951 | -14,552 (-14.6%) |
| PAR | 84,652 | 90,658 | -6,006 (-7.1%) | 20,864 | 25,602 | -4,738 (-22.7%) |
| CO | 202,166 | 211,995 | -9,829 (-4.9%) | 48,457 | 55,911 | -7,453 (-15.4%) |
| NO | 108,533 | 14,920 | 93,613 (86.3%) | 19,422 | 3,307 | 16,114 (83.0%) |

| Pollutant | TCEQ 4 km Domain | | | | |
|---|---|---|---|---|---|
| | G_GefCSR_Mlai | G_GefWIE_Mlai | M_GefGpftCSR | G_GefCSR_Mlai - M_GefGpftCSR | G_GefWIE_Mlai - M_GefGpftCSR |
| ISOP | 15,469 | 24,681 | 15,982 | -513 (-3.3%) | 8,699 (35.2%) |
| TERP | 4,313 | 11,905 | 3,895 | 417 (9.7%) | 8,010 (67.3%) |
| PAR | 835 | 2,067 | 720 | 116 (13.8%) | 1,347 (65.2%) |
| CO | 1,902 | 4,563 | 1,676 | 226 (11.9%) | 2,887 (63.3%) |
| NO | 442 | 1,005 | 161 | 282 (63.7%) | 845 (84.0%) |

## 3.4 MODEL PERFORMANCE

This section presents the comparisons between CAMx_baseG and CAMx_baseM simulations against aircraft measurements. Figures 3.7 to 3.11 show scatter plots for September 16, 20, 21, 25, 27, and October 6, 2006, for Ozone, CO, isoprene, isoprene products (ISPD) and monoterpene. The 3-D 15-min CAMx outputs in the 12-km domain represent the predictions in this analysis. In general, CAMx_baseG and CAMx_baseM perform equally well for ozone and CO, especially for September 25, 27, and October 6. The models overpredict ozone and CO for September 16 and 21, and slightly underpredict the ozone for September 20. These results suggest that transport and the chemistry perform well and CAMx configurations and the total emissions were set up correctly. Therefore, it is reasonable to compare other predicted chemical compounds to the aircraft measurements.

In general, the two models overpredict isoprene concentrations. However, the predictions from CAMx_baseG significantly differ from CAMx_baseM. CAMx_baseG predicts higher concentrations than CAMx_baseM for September 21 and 25. The concentrations for these days are not consistent with the daily total emissions in Table 3.5. The daily total emissions from G_Gef_Clai are higher for September 21, 27, and October 6. On the other hand, isoprene product predictions (Figure 3.10) from the two models are very similar. This suggests that isoprene reactions could be the limit while the isoprene concentration is abundant or that the concentrations of isoprene products are dominated more by the regional, rather than local, emissions.

The two models generally underpredict monoterpene concentrations (Figure 3.11), except during September 27 when the two models perform relatively well. The inconsistency in estimated emissions and concentrations can be found for September 20, 25, 27, and October 6, when CAMx_baseG predicts lower concentrations while the daily total TERP emissions (Table 3.7) for G_Gef_Clai are higher. However, the uncertainty in prediction could be large due to fast reaction rates, multiple-compounds, and spatial variations.

We recommend further analysis, e.g. direct comparison to airborne BVOC flux measurements, to improve emission estimates. Further more, it could be worthwhile to include weather conditions, and reaction rates in the parallel analysis of emissions, concentrations, and airborne measurements in order to understand the correlation between emission estimates and atmospheric processes.

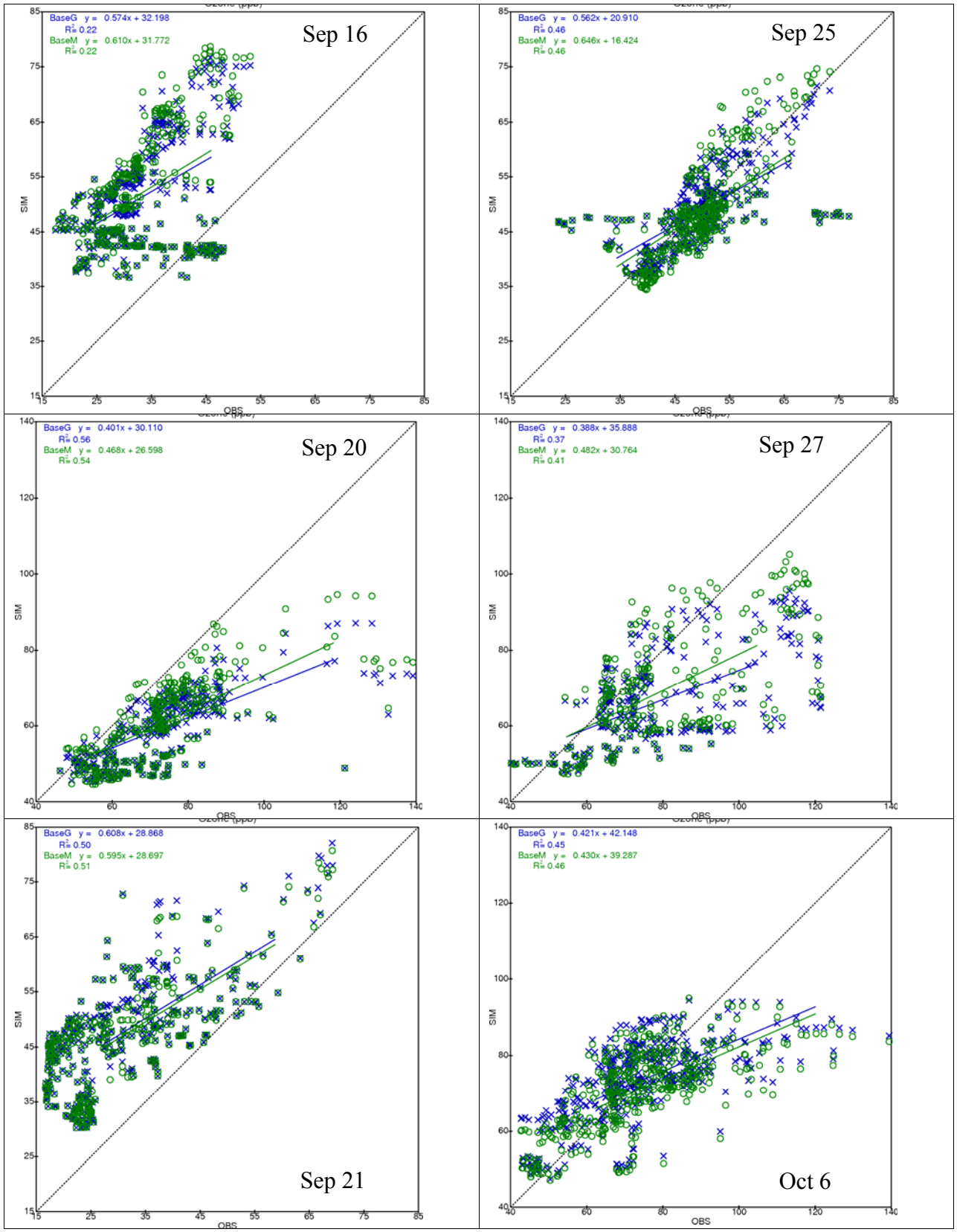



**Figure 3.7. Ozone scatter plots of predictions in 12 km domain against aircraft measurement.**

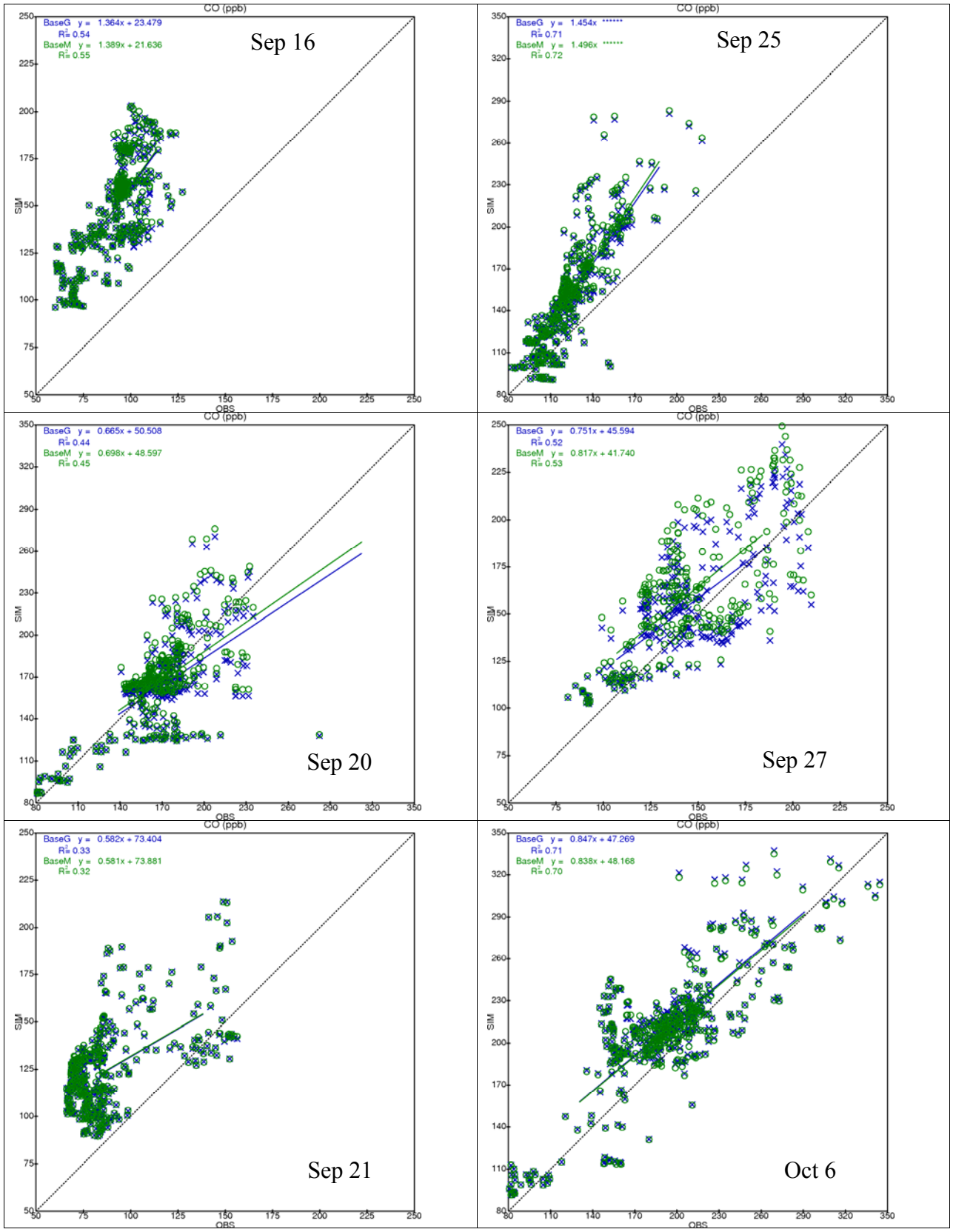



**Figure 3.8. CO scatter plots of predictions in 12 km domain against aircraft measurement.**

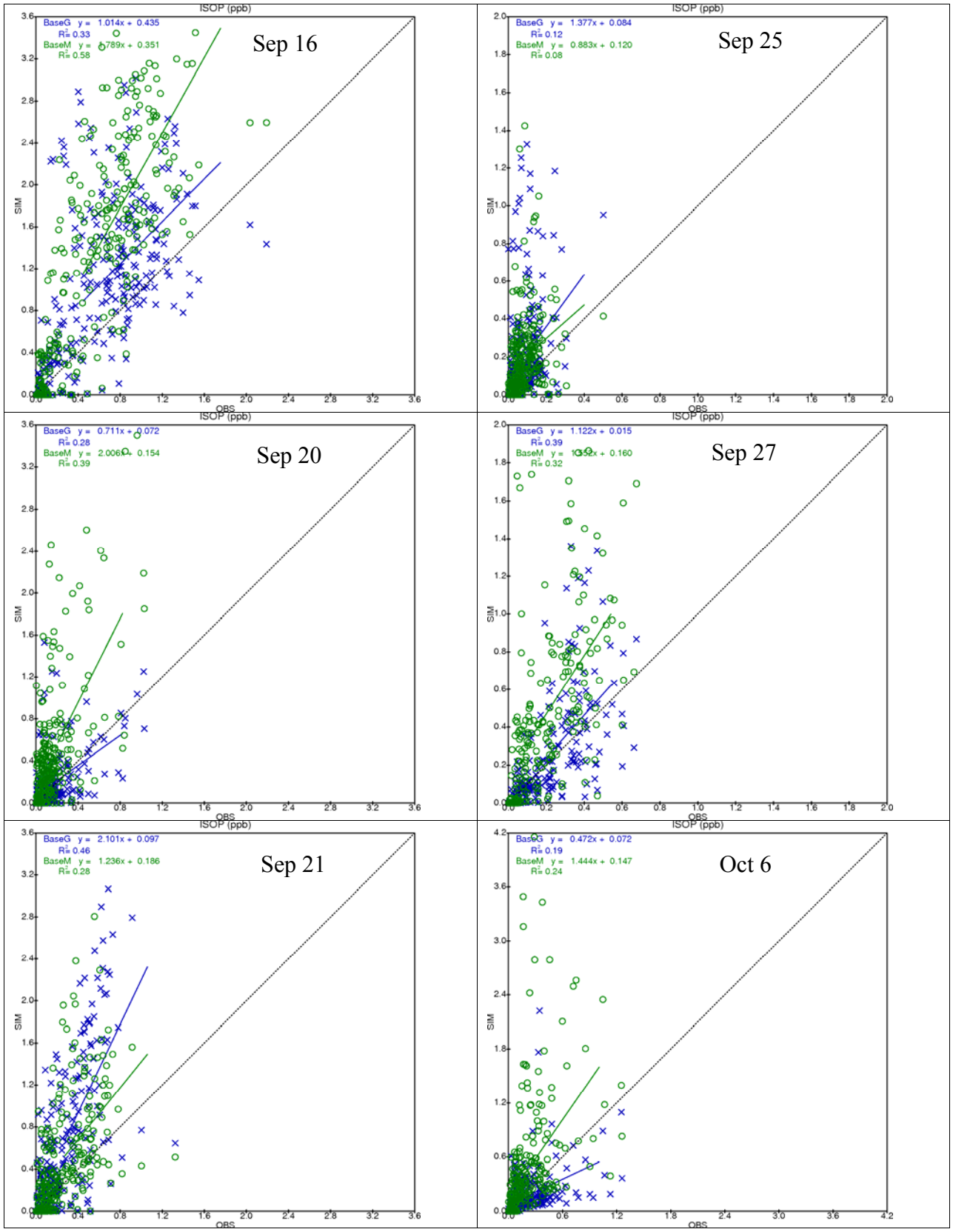



**Figure 3.9. ISOP scatter plots of predictions in 12 km domain against aircraft measurement.**

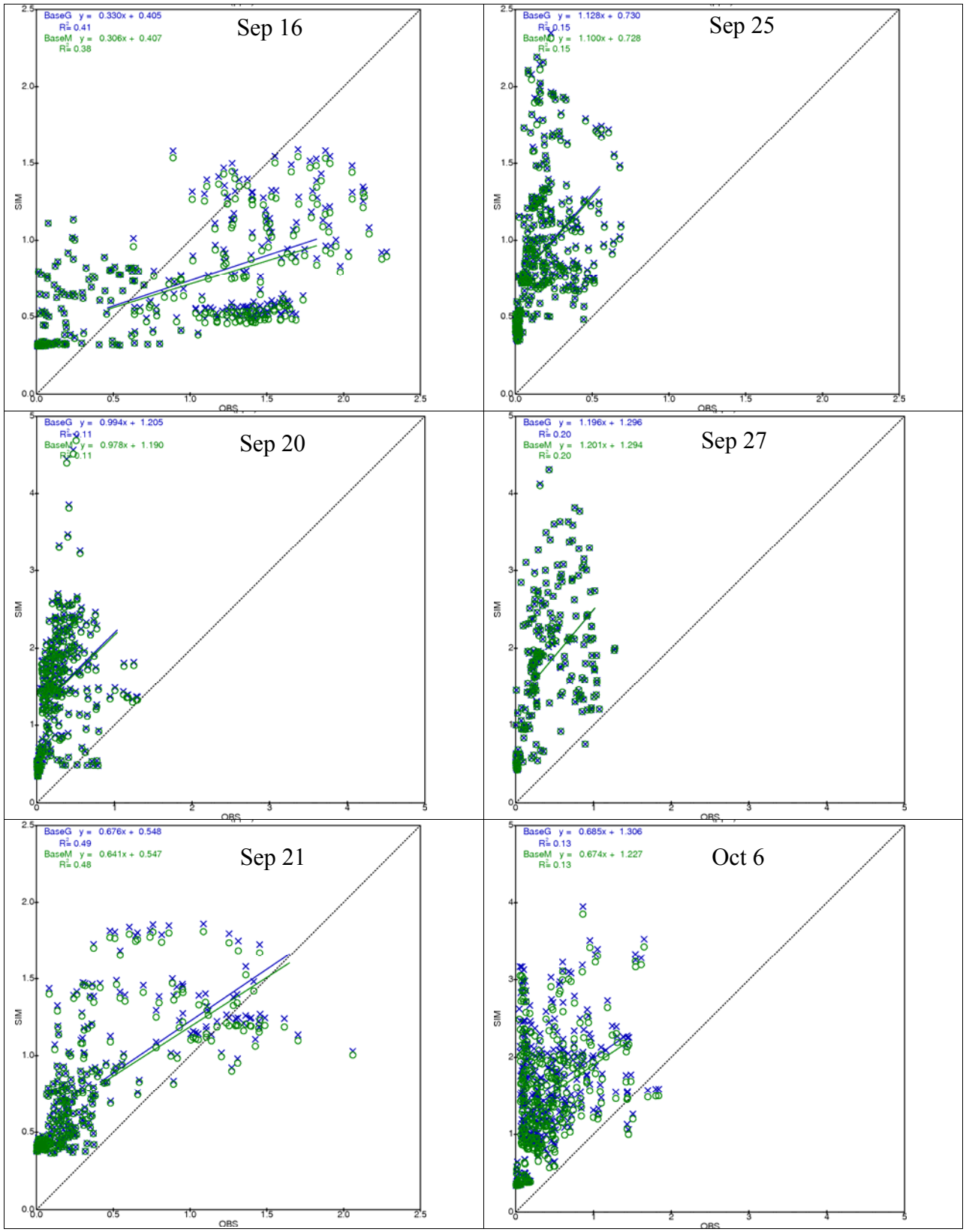



**Figure 3.10. ISPD scatter plots of predictions in 12 km domain against aircraft measurement.**

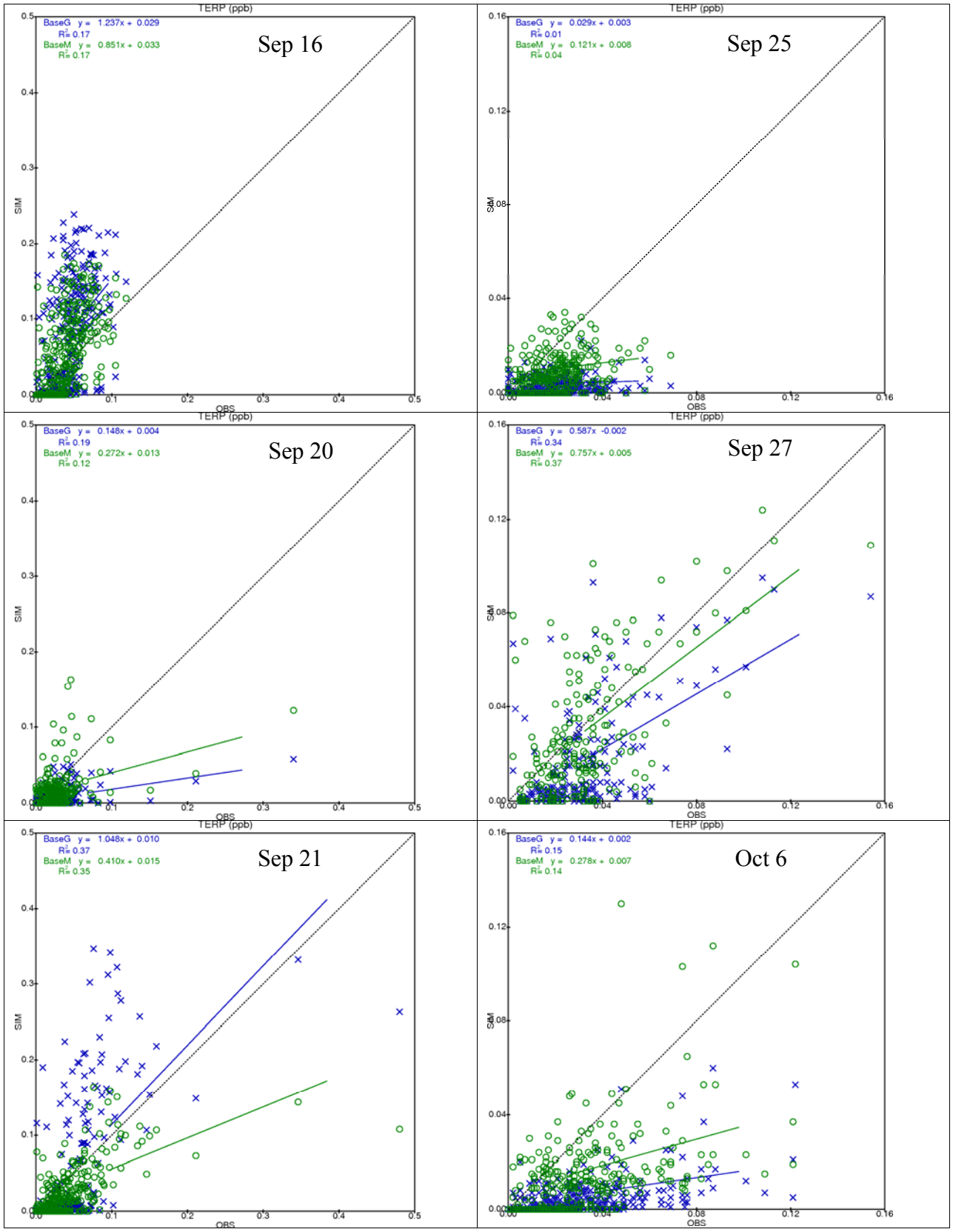



**Figure 3.11. TERP scatter plots of predictions in 12 km domain against aircraft measurement.**

Figure 3.12 – 3.17 presents time series of isoprene, isoprene product, monoterpene, CO, and ozone for September 16, 20, 21, 25, 27, and October 6, respectively, along with aircraft altitude. The plots for September 20 and 27 are based on the 4km CAMx outputs, while the plots for the other days are based on the 12 km CAMx outputs. The ozone and CO prediction from the two models are very similar though the days. The models perform very well for September 27 and October 6 and constantly overpredict for September 16 and 21.

For the isoprene predictions, the two models can generally represent the variations and have good correlations with the measurements. In most cases, the models overpredict the peak concentrations, especially CAMx_baseM. On the contrary, CAMx_baseG overpredict the peak concentrations and the predictions are higher than the predictions from CAMx_baseM during September 21 and 25. As the results from isoprene product which the models do not perform very well, regardless of the estimated amount of emissions, the chemical reactions of isoprene could be the cause. The reaction rates and schemes for isoprene and monoterpenes are obtained from smog chamber experiments and they might not be able to represent the reactions in the real atmosphere. To understand the differences between predictions and measurements for the peak concentrations, we suggest field investigations of the oxidation of isoprene and its impact on ozone and other oxidants. This could lead to both better estimates of isoprene emission and a better understanding of the impact of isoprene on ozone.

The variation of the differences between monoterpene predictions and measurements are relatively random and larger when compared to the isoprene differences. The two models perform quite well for September 27. CAMx_baseM performs well while CAMx_baseG considerably overpredicts the peak concentrations for September 21. Due to its complex chemistry and fast reactions, it is very difficult to pin point the causes of these discrepancy without further investigation.

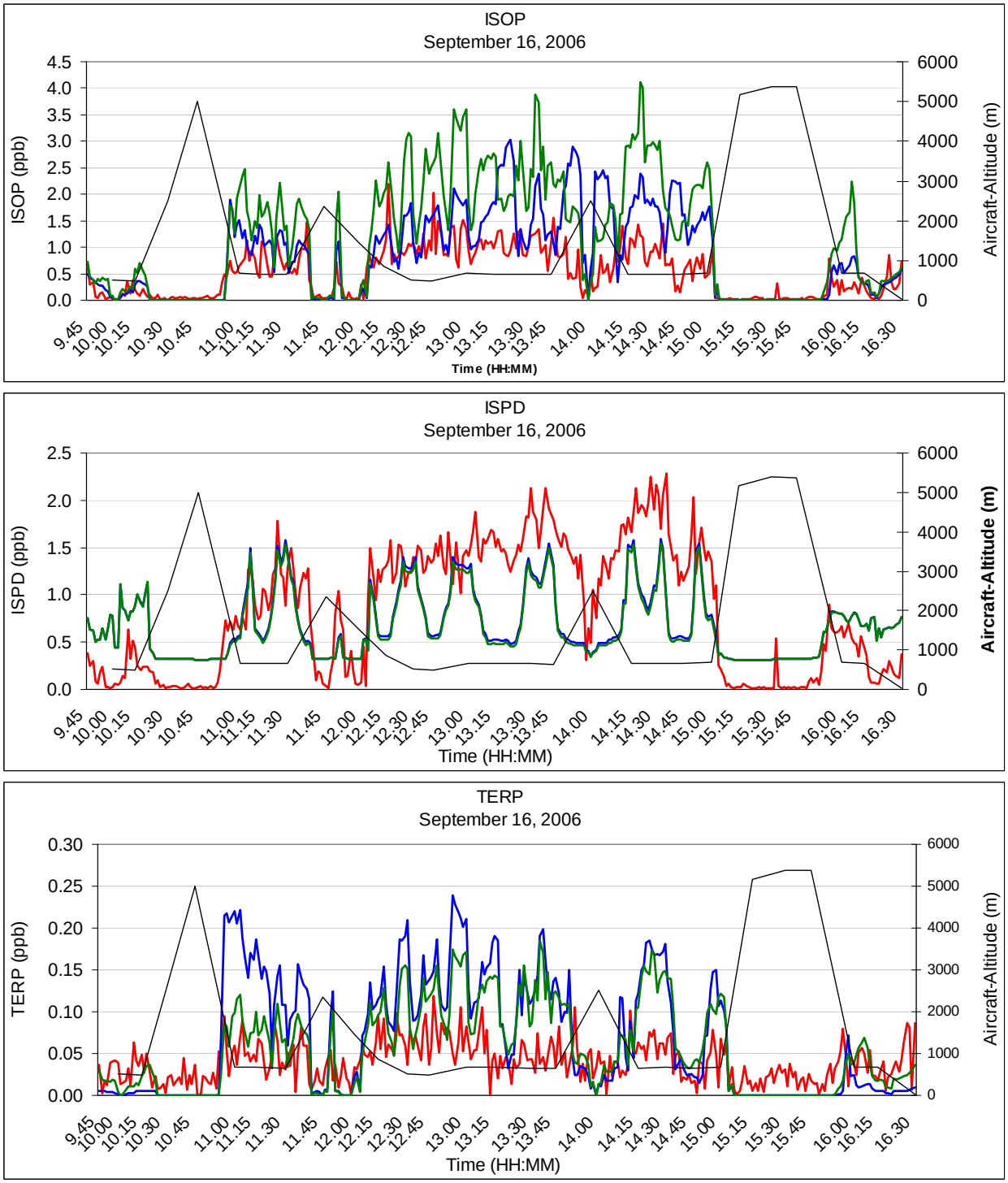



**Figure 3.12. Time series of the concentrations from aircraft (red), CAMx_baseG (blue), CAMx_baseM (green), and altitude (black) for September 16, 2006.**

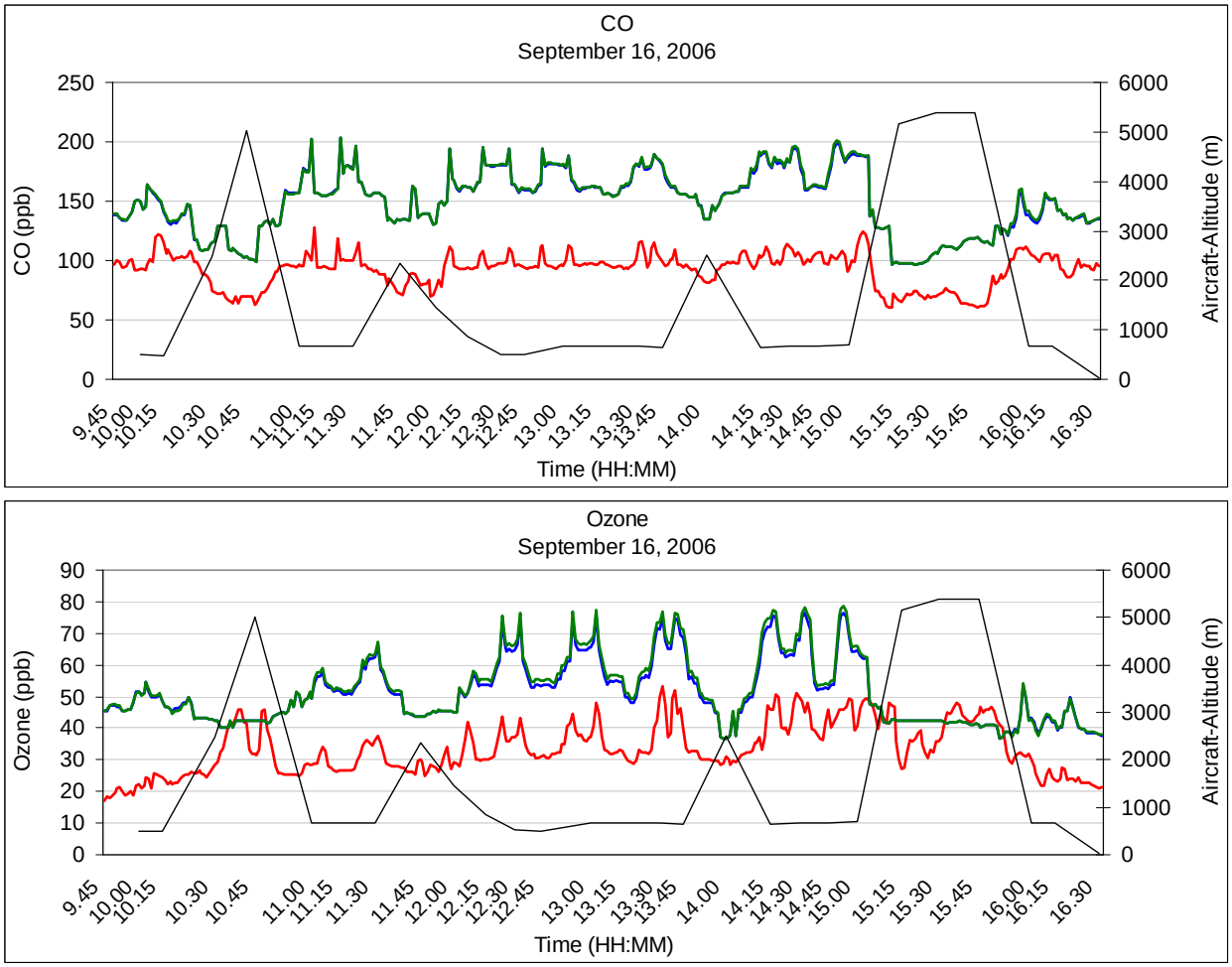



**Figure 3.12 (continued). Time series of the concentrations from aircraft (red), CAMx_baseG (blue), CAMx_baseM (green), and altitude (black) for September 16, 2006.**

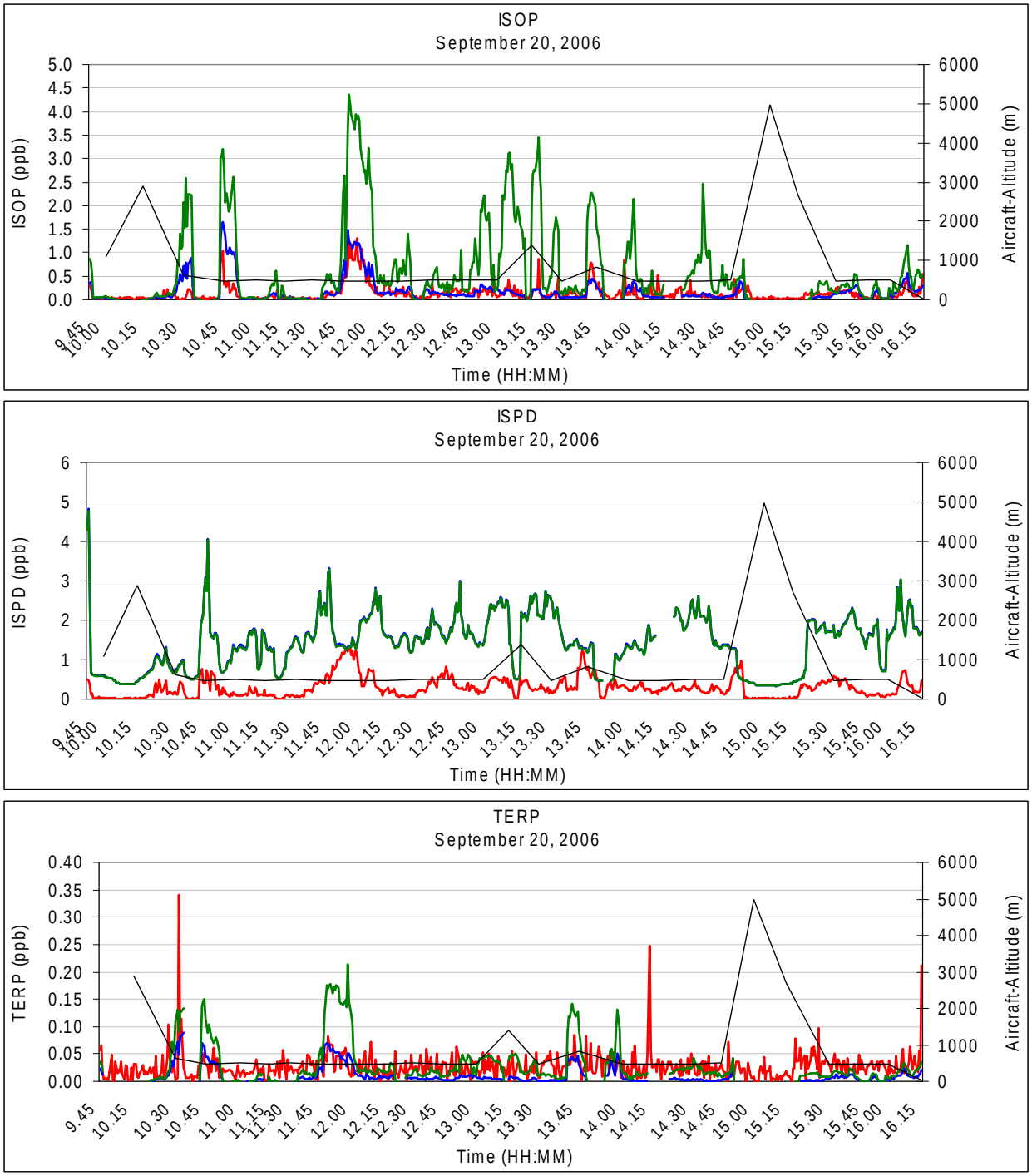



**Figure 3.13. Time series of the concentrations from aircraft (red), CAMx_baseG (blue), CAMx_baseM (green), and altitude (black) for September 20, 2006.**

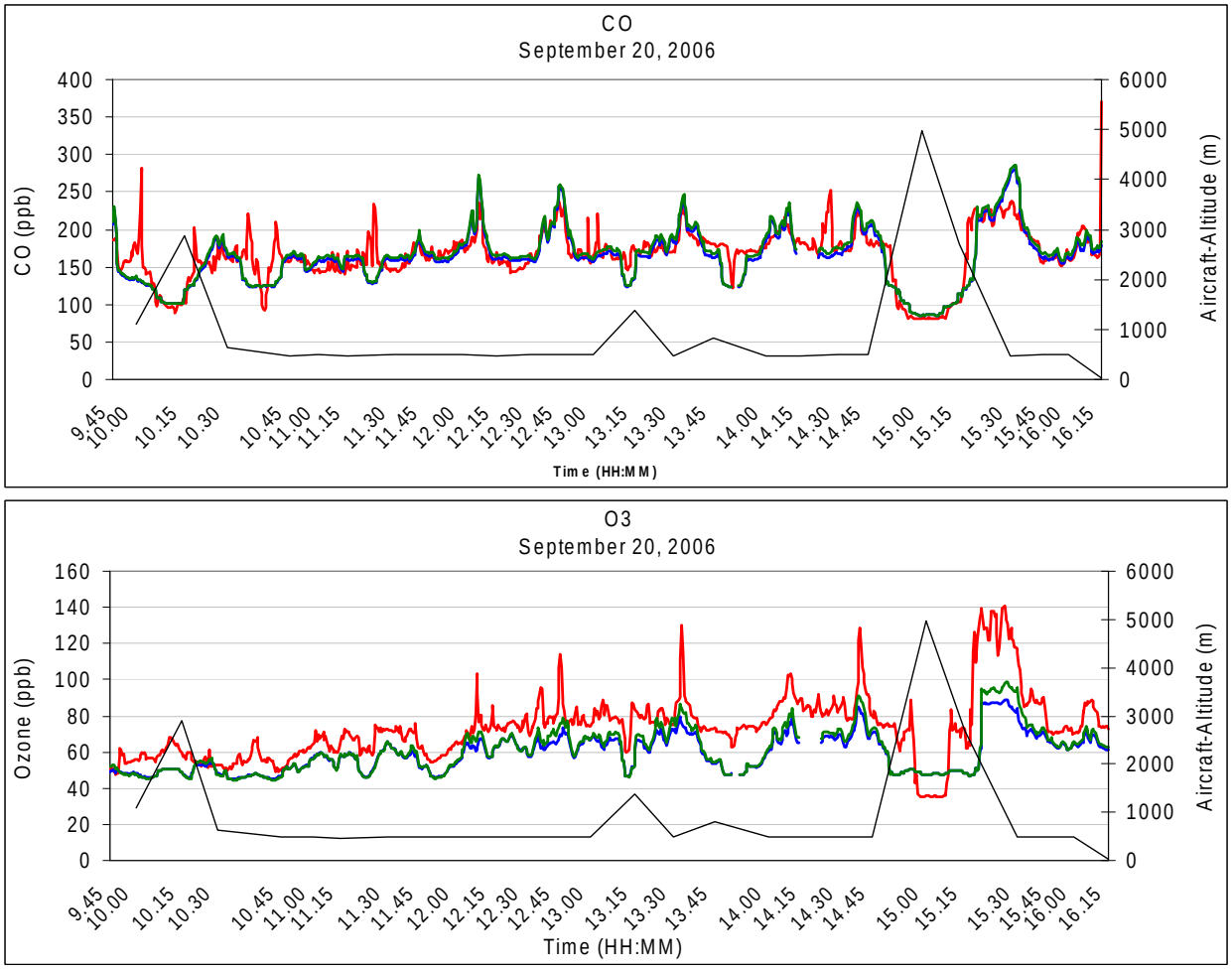



**Figure 3.13 (continued). Time series of the concentrations from aircraft (red), CAMx_baseG (blue), CAMx_baseM (green), and altitude (black) for September 20, 2006.**

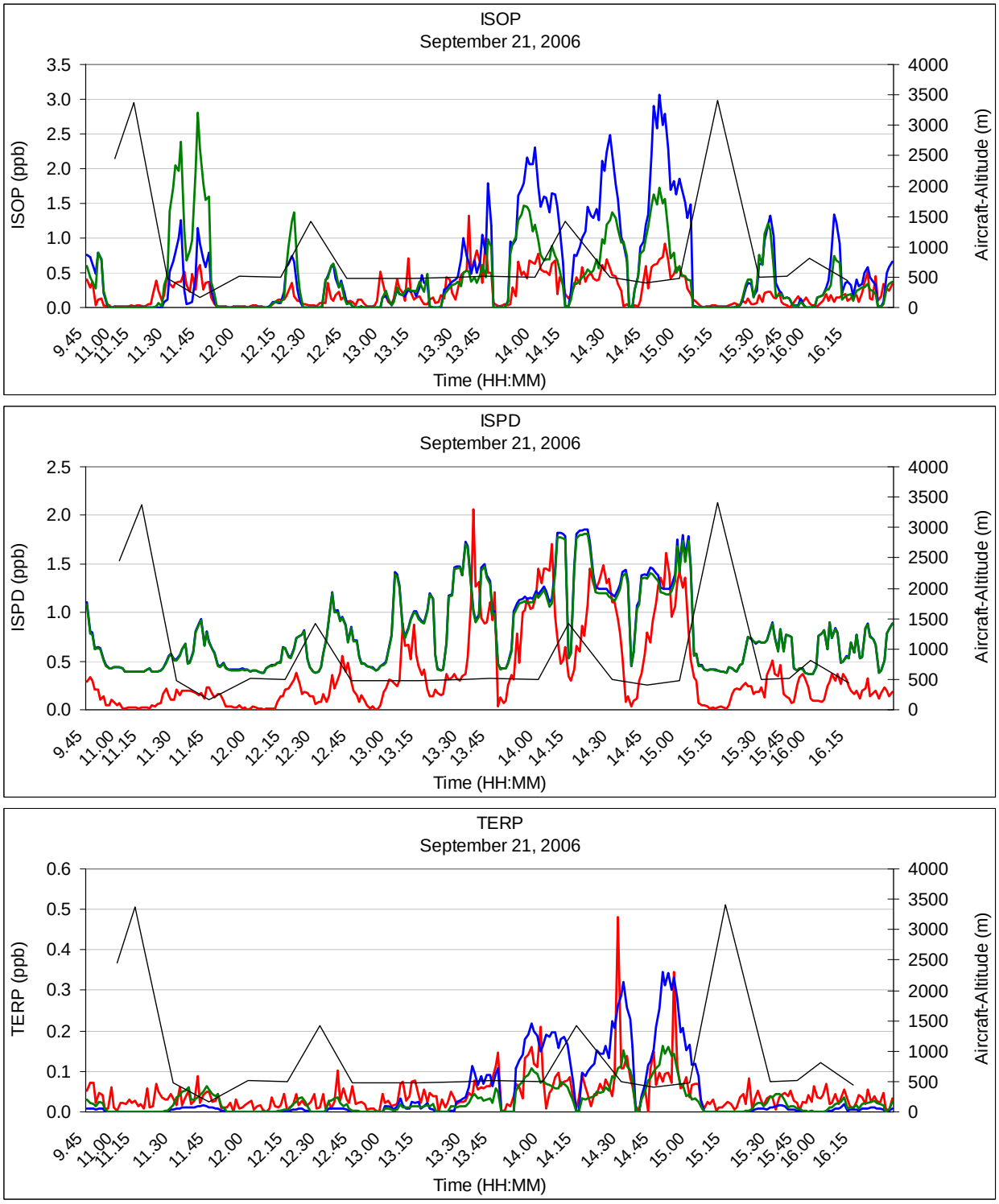



**Figure 3.14. Time series of the concentrations from aircraft (red), CAMx_baseG (blue), CAMx_baseM (green), and altitude (black) for September 21, 2006.**

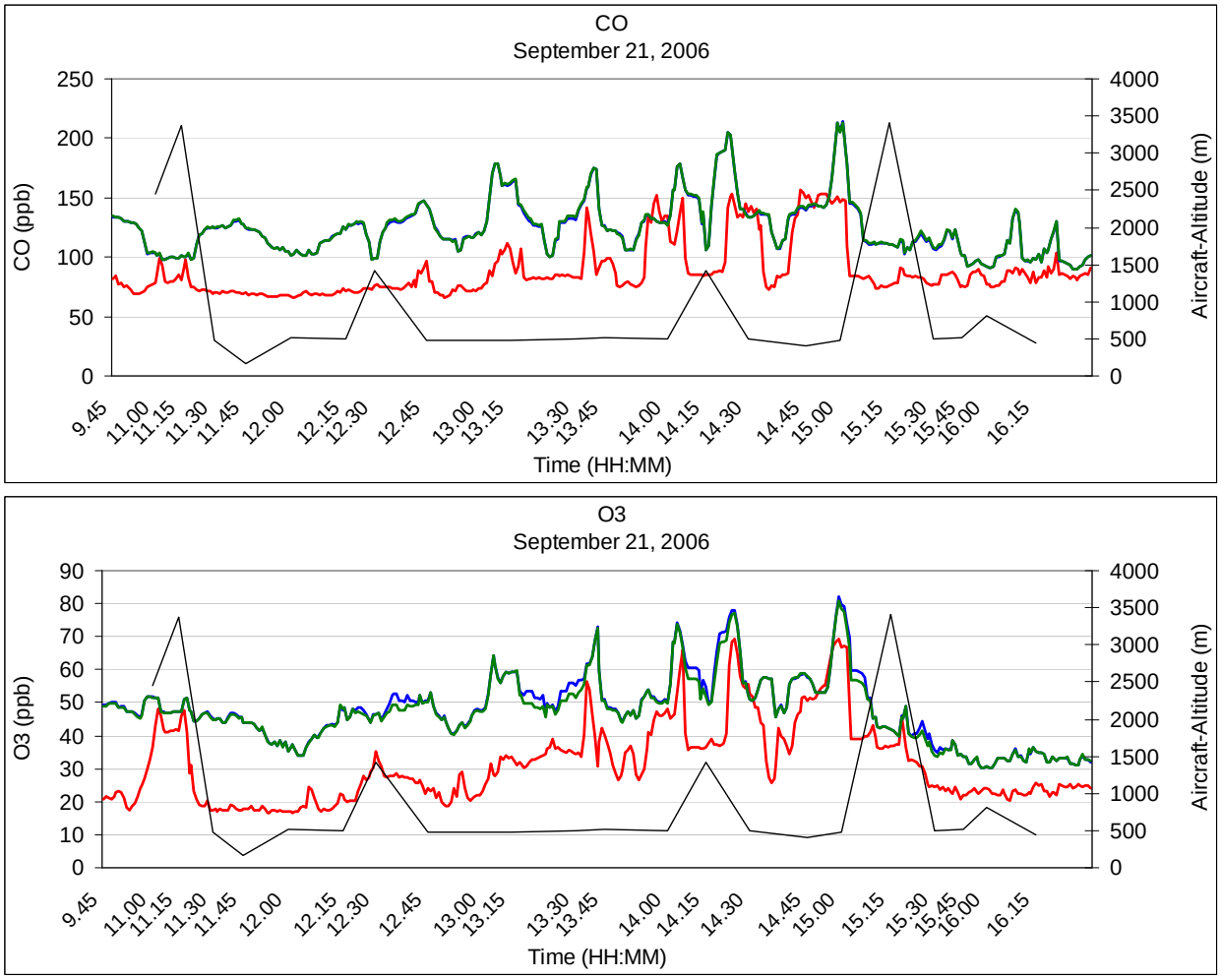



**Figure 3.14 (continued). Time series of the concentrations from aircraft (red), CAMx_baseG (blue), CAMx_baseM (green), and altitude (black) for September 21, 2006.**

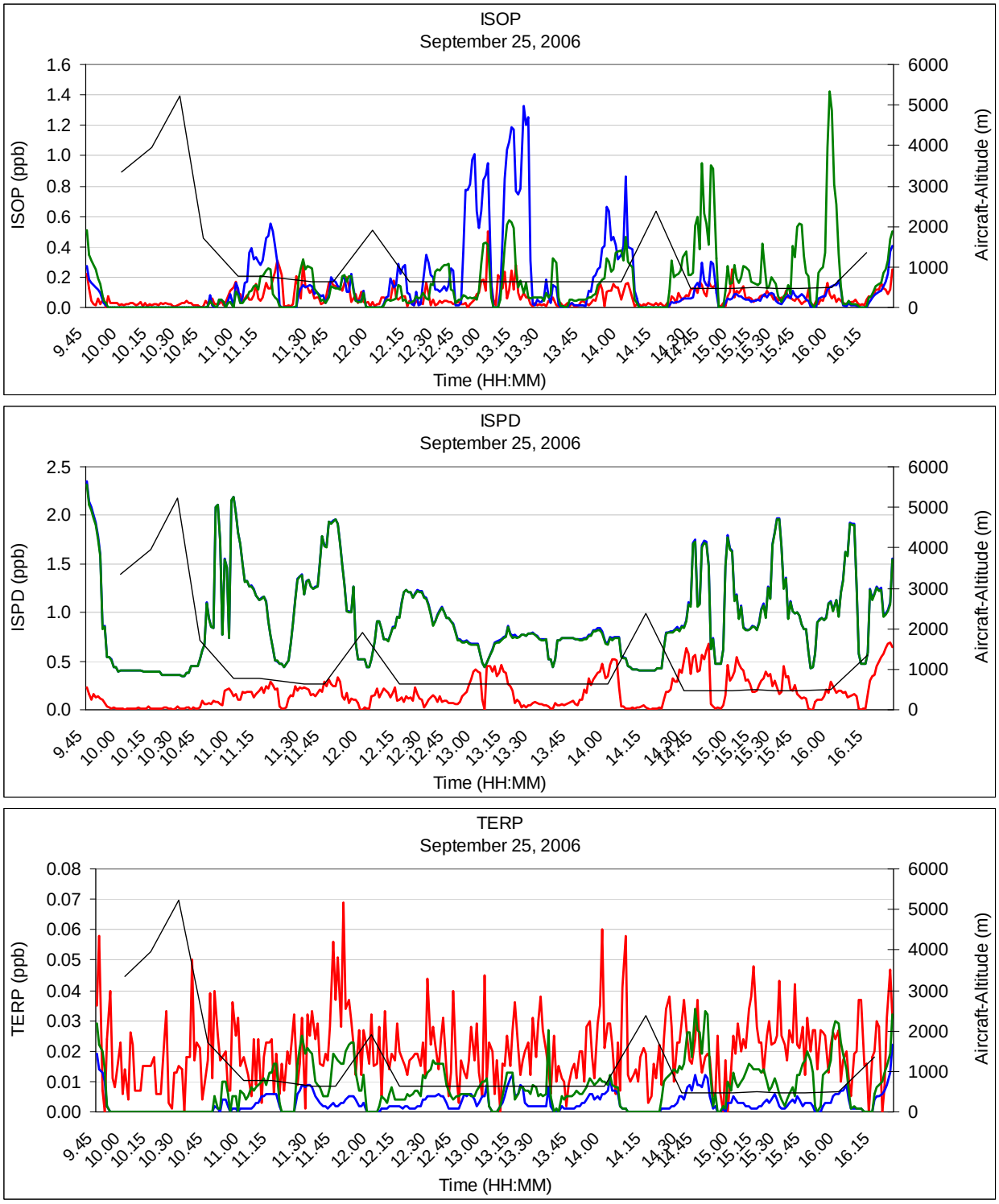



**Figure 3.15. Time series of the concentrations from aircraft (red), CAMx_baseG (blue), CAMx_baseM (green), and altitude (black) for September 25, 2006.**

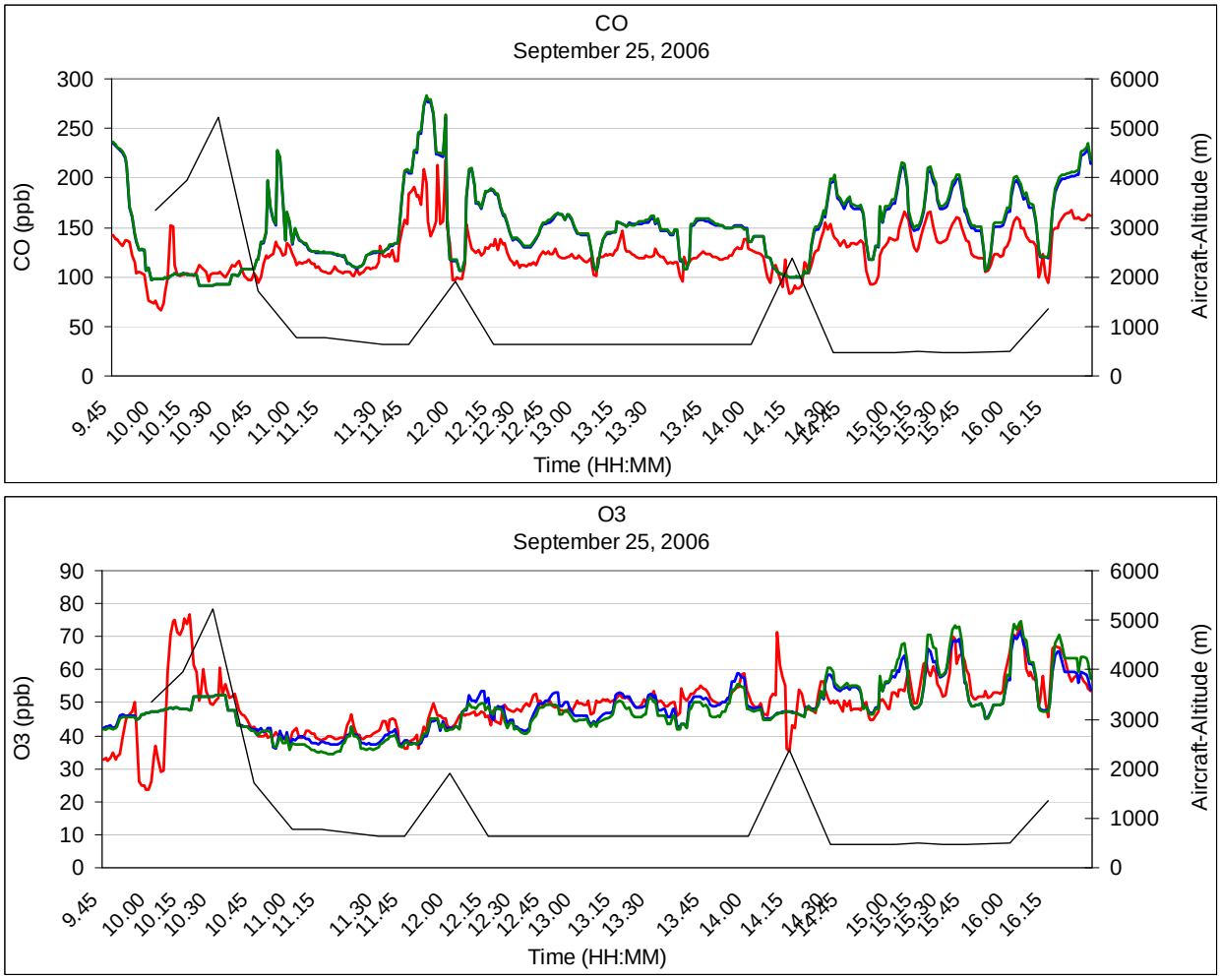



**Figure 3.15 (continued). Time series of the concentrations from aircraft (red), CAMx_baseG (blue), CAMx_baseM (green), and altitude (black) for September 25, 2006.**

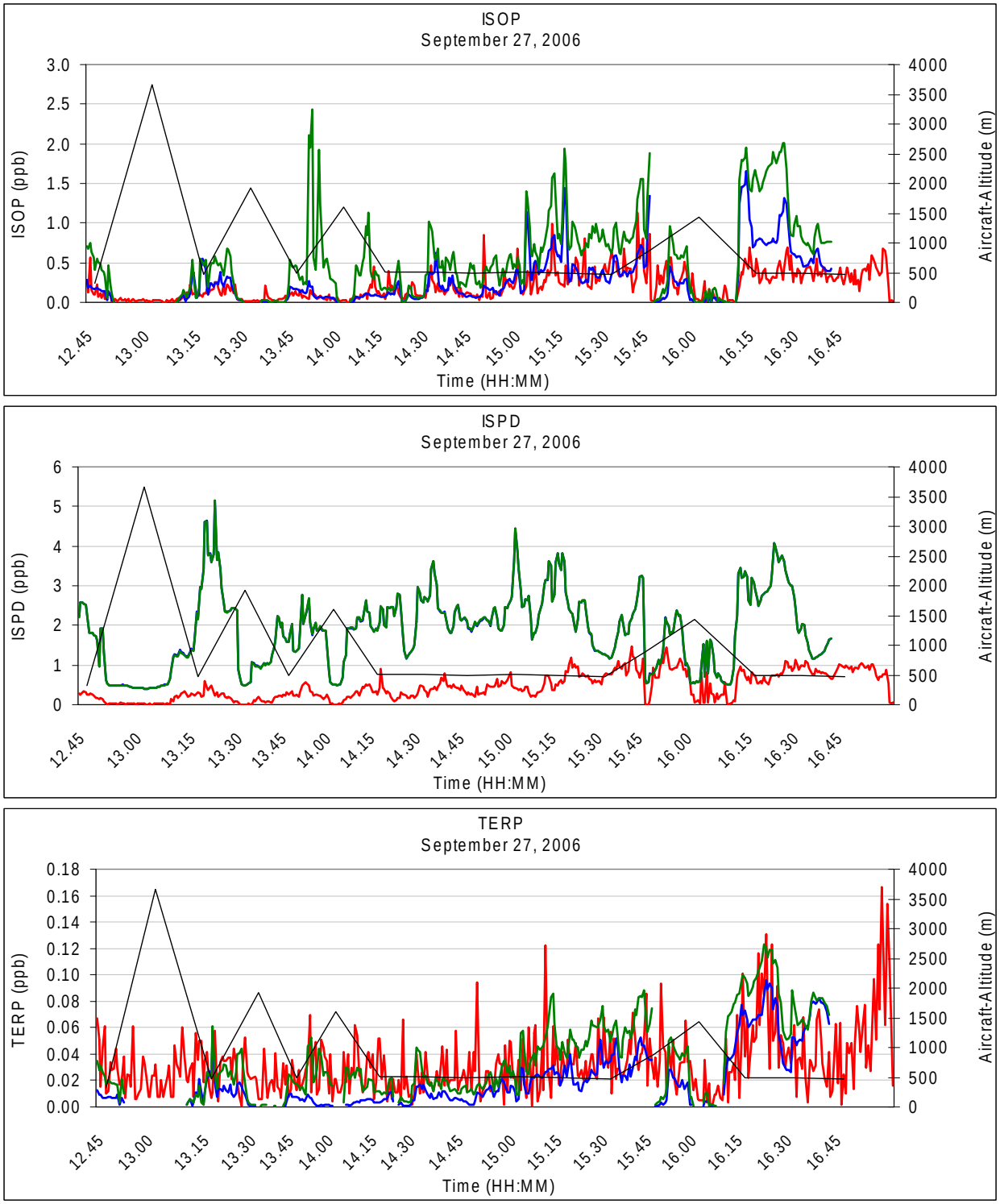



**Figure 3.16. Time series of the concentrations from aircraft (red), CAMx_baseG (blue), CAMx_baseM (green), and altitude (black) for September 27, 2006.**

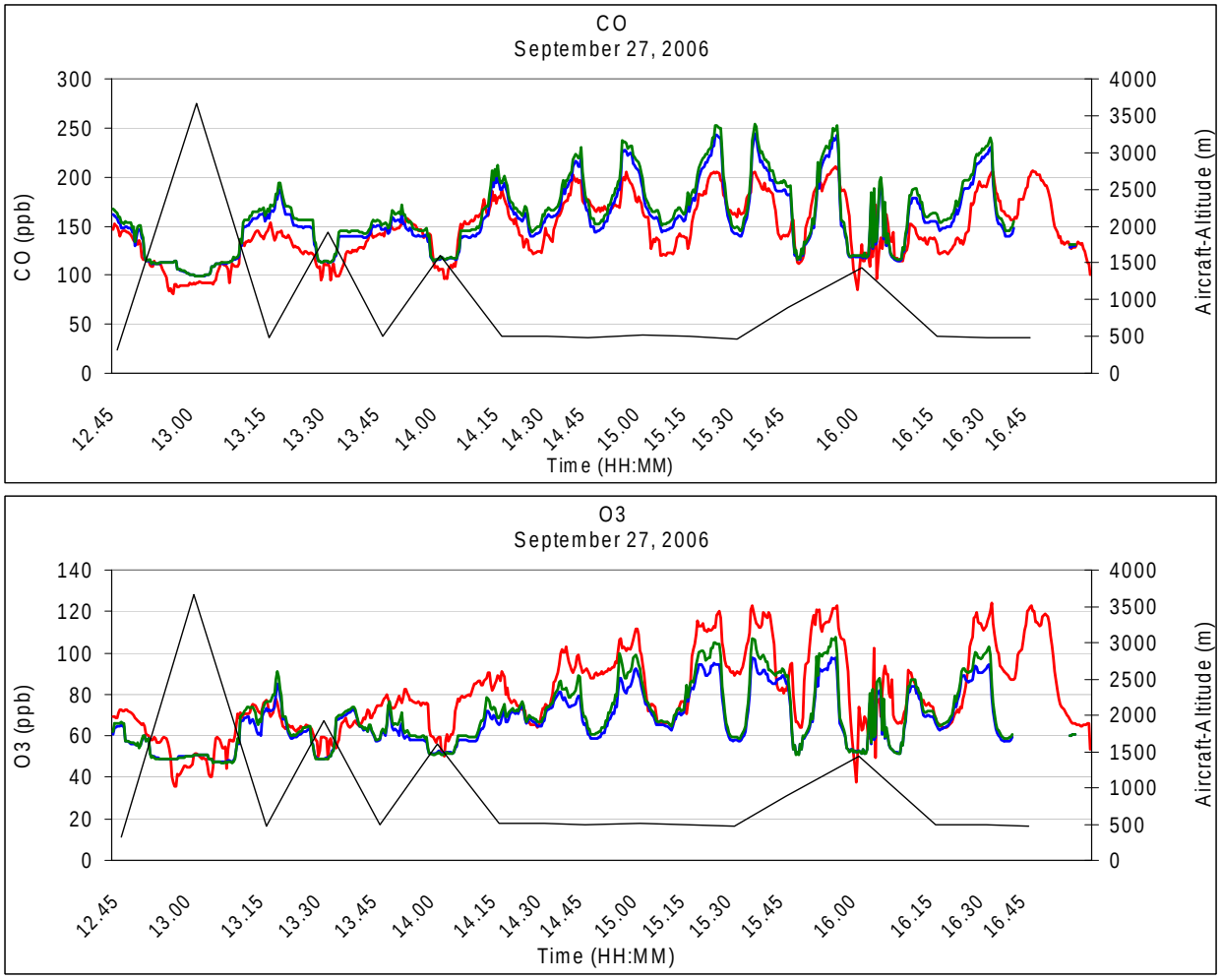



**Figure 3.16 (continued). Time series of the concentrations from aircraft (red), CAMx_baseG (blue), CAMx_baseM (green), and altitude (black) for September 27, 2006.**

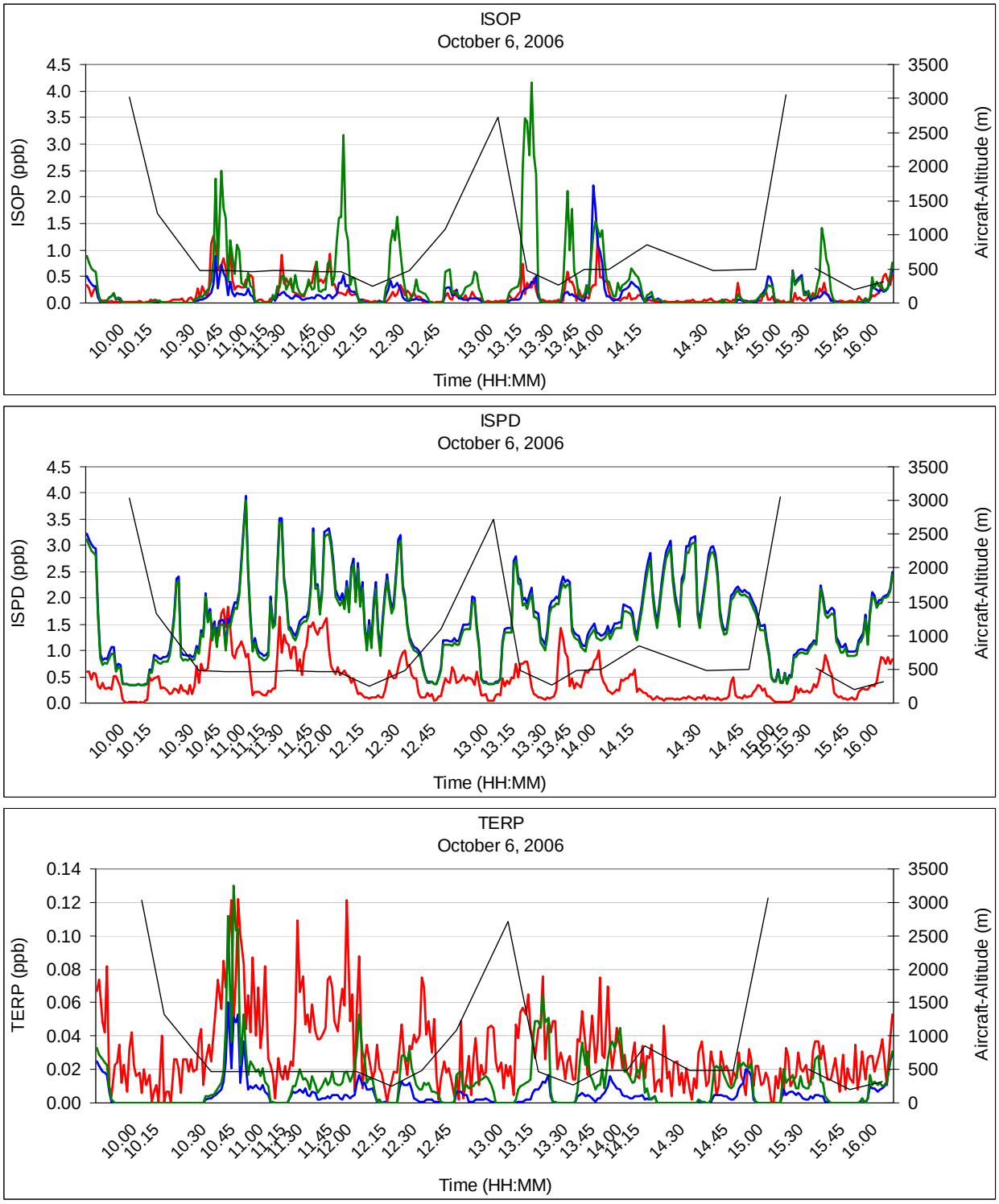



**Figure 3.17. Time series of the concentrations from aircraft (red), CAMx_baseG (blue), CAMx_baseM (green), and altitude (black) for October 6, 2006.**

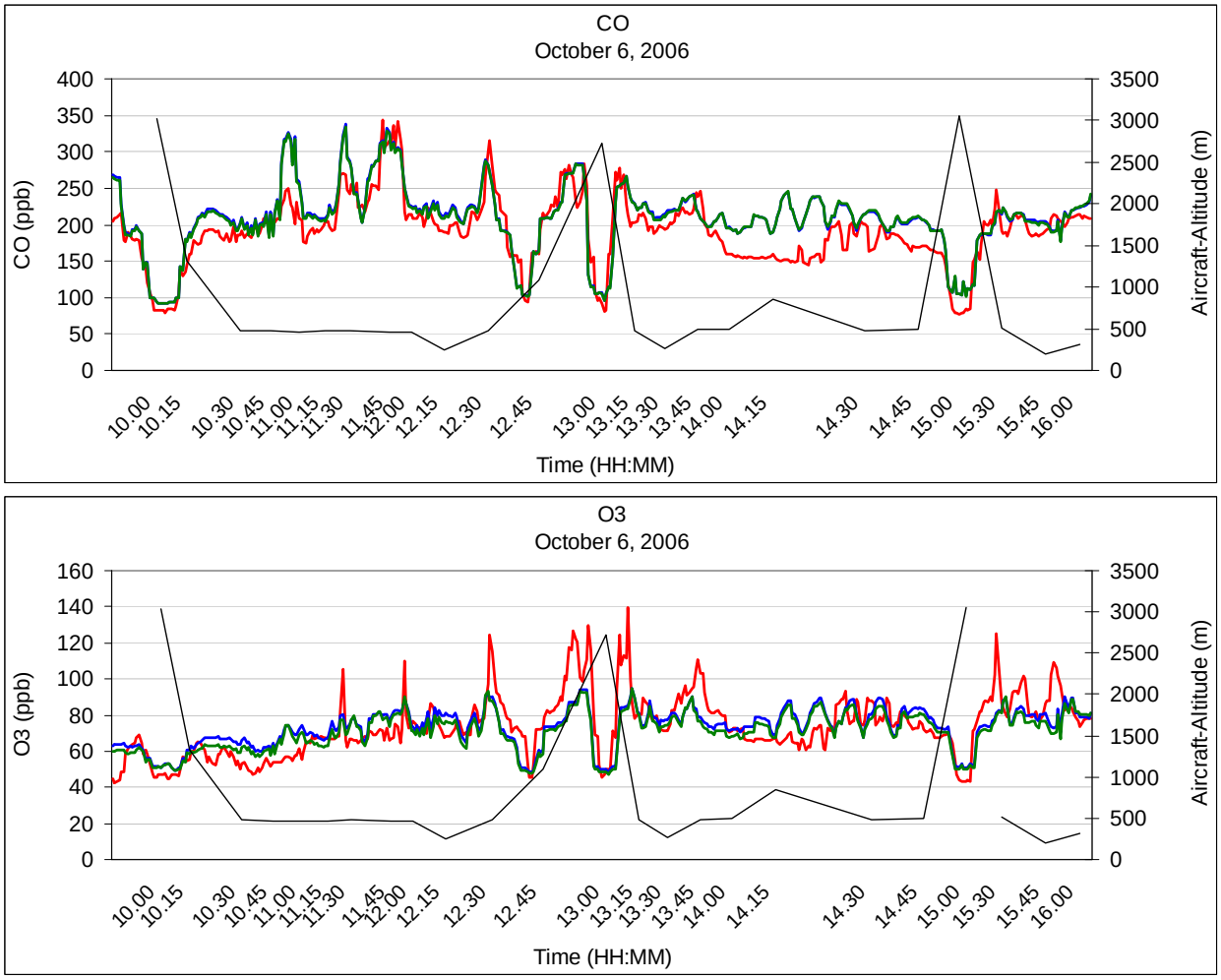



**Figure 3.17 (continued). Time series of the concentrations from aircraft (red), CAMx_baseG (blue), CAMx_baseM (green), and altitude (black) for October 6, 2006.**

**Regional Statistical Analysis**

This sub-section presents model performance analysis by Texas regions (Figure 3.18). We used the aircraft measurements below 1 km altitude to consider the concentrations within the boundary layer and statistically compared CAMx_baseG to CAMx_baseM using the measurement data. The analysis for Houston (HOU) and Deep Eastern Texas (DET) used the predictions from the 4km domain, while the analysis for other regions used the predictions from the 12km domain.

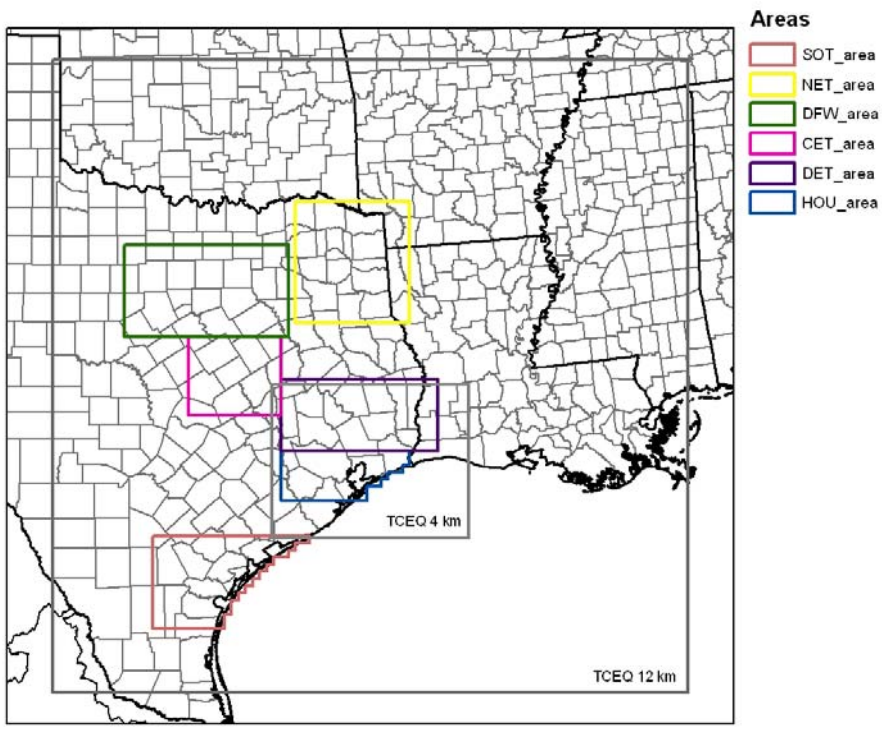
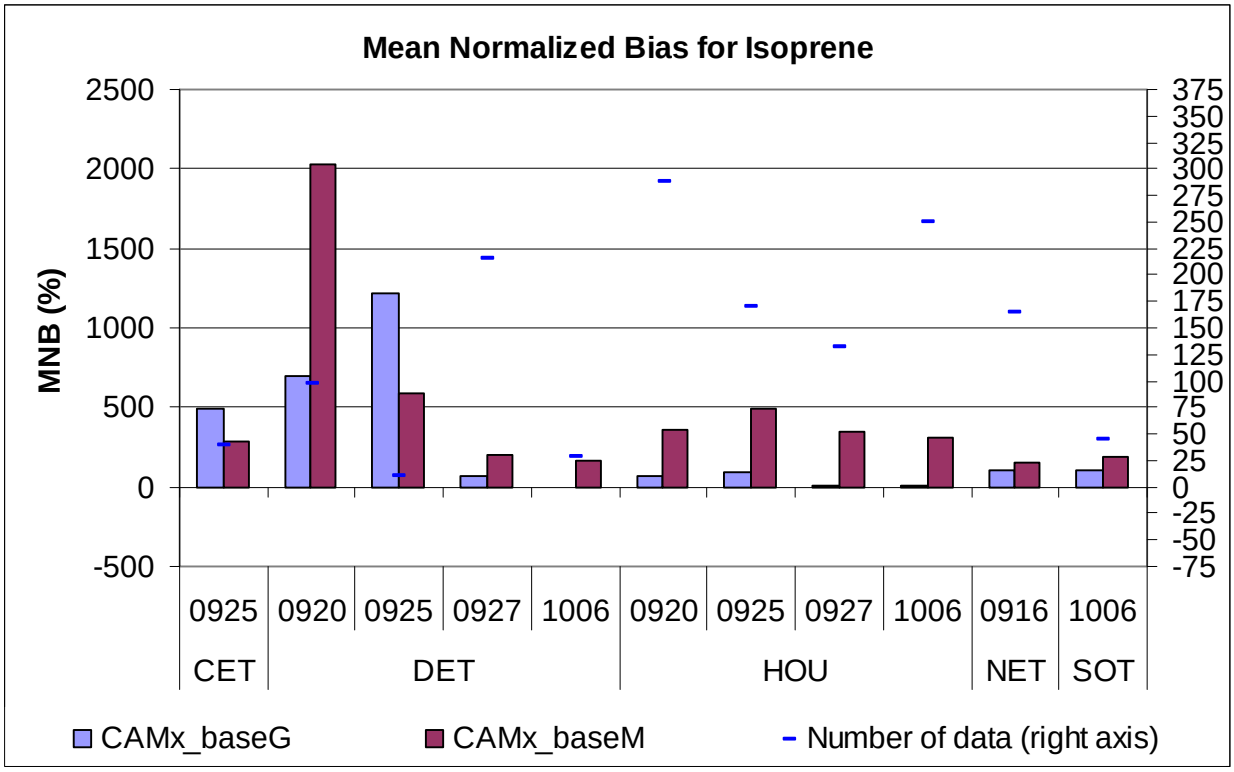



**Figure 3.18. CAMx 12 km and 4km domains, and Texas regions; SOT: South Texas, NET: North Eastern Texas, DFW: Dallas/Fort-Worth, CET: Central Texas, DET: Deep East Texas, and HOU: Houston.**

Figure 3.19 and 3.20 show Mean Normalized Bias (MNB) and coefficient of determination ($R^2$) for isoprene and monoterpene, respectively. The two models overpredict the isoprene concentration with MNB within 500% for most areas, except DET for Sep 20 and 25. In general, CAMx_baseG performs better with lower bias and higher $R^2$. For monoterpene (Figure 3.20), the models underpredict the concentrations in the CET, DFW, SOT, and HOU areas, and overpredict in the DET and NET areas. MEGAN performs slightly better with lower error and higher $R^2$, except DET for Sep 20 and 27.



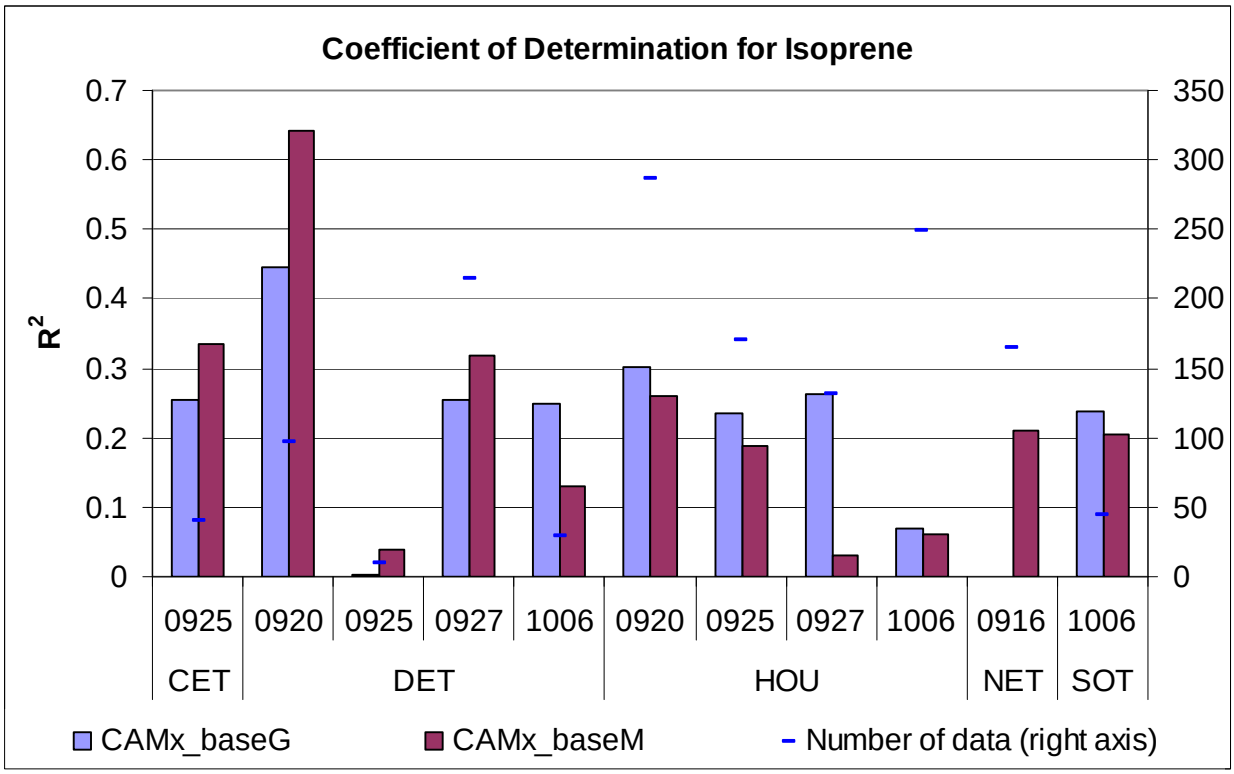
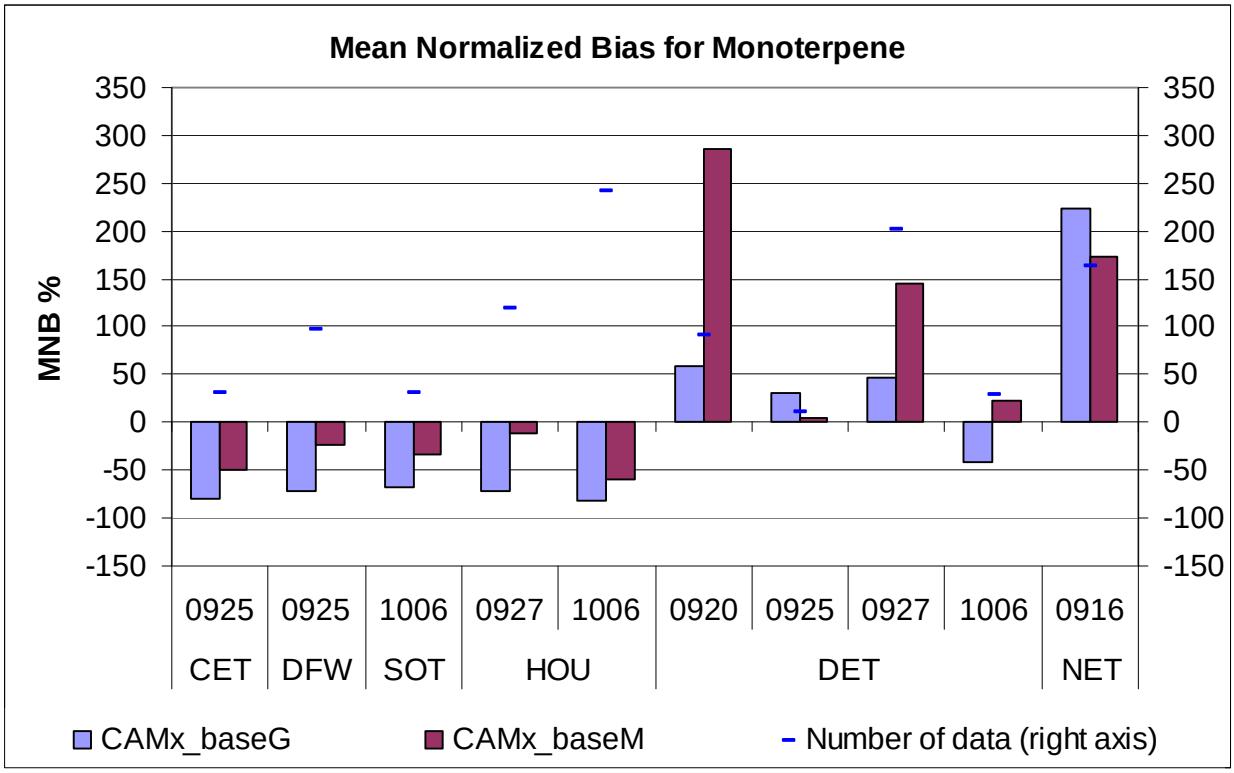




**Figure 3.19. Mean normalized bias and coefficient of determination of isoprene concentrations between predictions and observations**



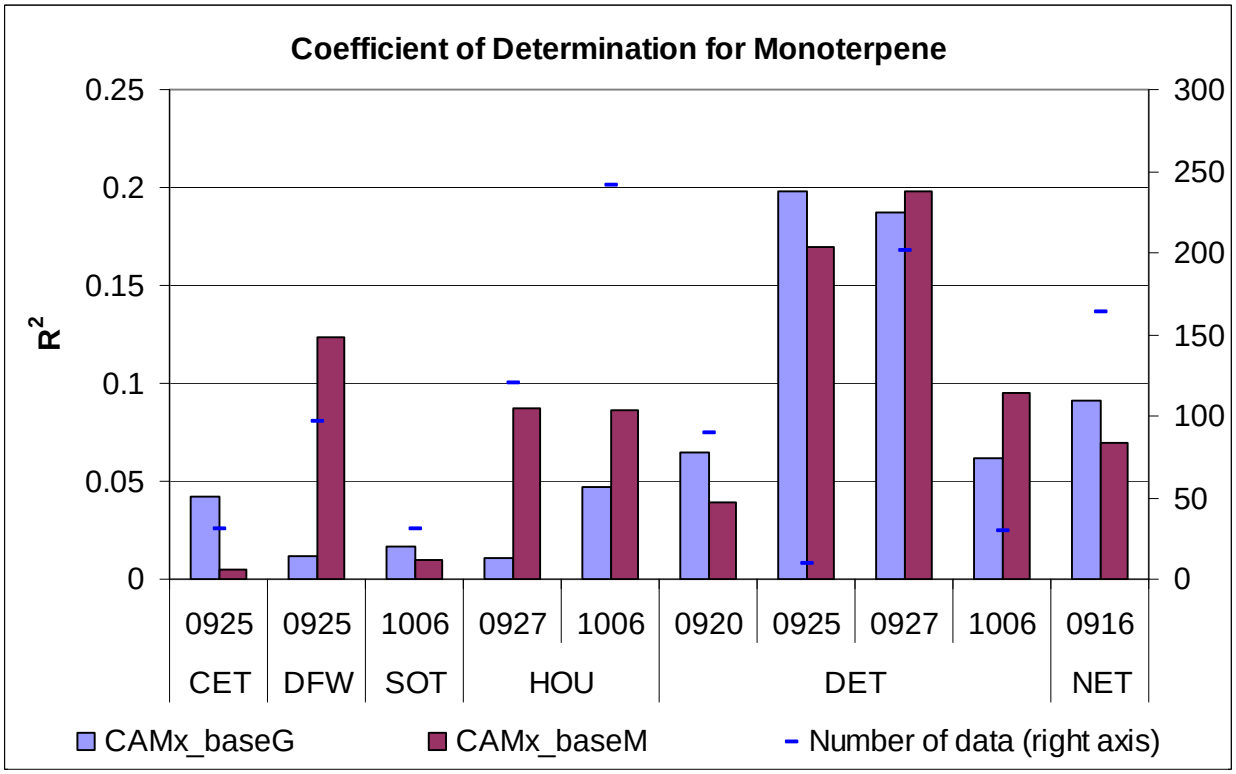




**Figure 3.20. Mean normalized bias and coefficient of determination of monoterpene concentrations between predictions and observations**

# 4. CONCLUSION

## 4.1 SUMMARY

### GloBEIS version 3.5

ENVIRON and Dr. Alex Guenther have improved the functionality of the Global Biosphere Emissions and Interactions System (GloBEIS) and implemented sesquiterpene (SQT) emission estimation in GloBEIS version 3.5. The updated user interface provides new capability to perform batch processing more efficiently with easier set up. Comparing results between GloBEIS versions 3.5 and 3.1 CSR shows identical emissions using summer emission factors but small differences for SQT with winter emission factors.

The SQT emission methodology performs reasonably well. It is comparable to other biogenic emission models and estimates emissions that are in agreement with the few observations (Karl et al.; Bouvier-Brown et al.; 2009, Kim et al., 2009; Kim et al. 2010) of canopy scale sesquiterpene emissions. However, we recommend further research on SQT emission and its impact, e.g. evaluating secondary organic aerosol formation from SQT.

### Comparing GloBEIS version 3.5 and MEGAN version 2.04a

This study compared emission estimates from GloBEIS version 3.5 and Model of Emissions of Gases and Aerosol from Nature (MEGAN) version 2.04a. Several configurations were compared varying both land cover data and emission factors from the two models for the Texas 2006 AQS2 episode in order to determine the relative importance of landcover, emission factors, and all other model components. For TCEQ's 36 km and 12 km modeling domains, emissions of isoprene, OVOC and CO from the GloBEIS base case (G_Gef_Clai) and the MEGAN base case (M_MefMpft) are very similar with less than 9% absolute difference. For monoterpene and NO, GloBEIS produces higher emission by 23% to 35% and 49% to 72%, respectively, where the range depends upon episode day. Comparisons for the 4 km domain show that both land cover and emission factors play an important role in GloBEIS emission estimations. Using CSR land cover reduces emissions by 12% to 103% from GloBEIS compared to the WIED land cover. The use of MEGAN, instead of GloBEIS, emission factors can result in changes of about the same magnitude as the CSR vs WIED landcover and so using GloBEIS CSR landcover with MEGAN emission factors results in about the same isoprene emissions as WIED landcover with GloBEIS emission factors.

With emission factors and land cover held constant (comparison between G_Gef_Mlai and M_GefGpft), GloBEIS generally yields 5% to 23% lower emissions than MEGAN for the 36 km and 12 km domains. Comparison for the 4 km domain (G_GefCSR_Mlai and M_GefGpftCSR) shows variation in differences. This indicates that factors other than landcover and emission factors together have a minor impact on GloBEIS and MEGAN emission differences although it should be recognized that this is partly because there are compensating differences of different sign. It should also be noted that agreement between GloBEIS and MEGAN should not be taken as an indication of good model performance especially since some components of these models are based the same limited datasets. Isoprene emission response to light and temperature,

especially past conditions, is an example of a model component with general agreement between MEGAn and GloBEIS but large uncertainties due to the lack of observations for evaluation.

The differences in NO emission between the two models are consistent across all domains. GloBEIS yields higher NO emissions than MEGAN by 64% to 86%. Future investigation is recommended in order to explain the variations and to evaluate these emission estimates with direct flux measurements. The variation in the 4 km domain could be from different light and temperature dependent emission activity algorithms used for the two models. This could be tested using tower flux measurements to characterize day to day variations in fluxes from a representative Texas landscape.

**Model Performance**

Analysis using TexAQS2006 campaigns shows that CAMx simulations with base GloBEIS emissions and base MEGAN emissions, which use similar isoprene and CO emissions, yield very similar CO and ozone predictions and perform very well in general. For BVOC, the two models overpredict the peak isoprene concentrations and can not represent the concentrations for isoprene or the major isoprene degradation products. This suggests that emissions and chemical reactions of isoprene may both be contributing to model/measurement differences. Model performance analysis for monoterpene shows a large variation in performance. CAMx with base GloBEIS emission performs better for September 21 and CAMx with base MEGAN emission performs better for September 27. Due to its complex chemistry and short lifetime, it is very difficult to pin point the causes of these discrepancy without further investigation.

The model performance analysis for Texas regions; South Texas (SOT), North Eastern Texas (NET), Dallas/Fort-Worth (DFW), Central Texas (CET), Deep East Texas (DET), and Houston (HOU) used the aircraft measurements below 1 km altitude to consider the concentrations within the boundary layer. The two models overpredict the isoprene concentration with MNB within 500% for most areas. CAMx_baseG performs better with lower bias and higher $R^2$. For monoterpene, the models underpredict the concentrations in the CET, DFW, SOT, and HOU areas, and overpredict in the DET and NET areas. MEGAN performs slightly better with lower error and higher $R^2$.

## 4.2 CONCLUSIONS

Based on the results of this project, we conclude that:

- We successfully updated GloBEIS to version 3.5. The major two updates are the user interface and SQT implementation. The new user interface results in easier setup with less chance of error and faster calculation time for multiple-day scenarios. The comparison to GloBEIS v3.1 CSR shows identical results for all pollutants except SQT.
- The SQT estimates are considered reasonable because they are comparable to other models and generally agree with the limited observations of canopy scale emissions. However, we recommend future evaluation, e.g. evaluating secondary organic aerosol formation from SQT.
- GloBEIS v3.5 can now account for emission changes between winter and summer by selecting either winter or summer leaf mass density (LMD). Using winter LMD shows

some unexpected results with higher peak emissions in some areas. We would like to further investigate and correct this issue.

- Using TCEQ's CSR land cover causes much lower isoprene, total monoterpene and NO emissions by approximately 12%-100% compared to using the WIED land cover in GloBEIS. Using the WIED landcover in GloBEIS results in isoprene emissions that are similar to MEGAN while using the CSR database with GloBEIS results in monoteprene emission that are similar to MEGAN.
- GloBEIS v3.5 and MEGAN v2.04a generally yield similar isoprene emissions for the 36 km and 12 km domains and for the 4km domain if using the WIED landcover. For the 4 km domain, isoprene emissions from GloBEIS are lower by half when using the CSR landcover.
- GloBEIS generally produces higher monoterpene and NO emissions than MEGAN, except for the 4km domain. GloBEIS yields 12% lower monoterpene emission than MEGAN for the 4 km domain if using the CSR landcover.
- The model performance analysis using aircraft measurements shows large variation in differences between model predictions and measurements and there is insufficient evidence to determine whether GloBEIS v3.5 or MEGAN v2.04a performs better.
- The two models generally overpredict isoprene and underpredict monoterpene concentrations. The overpredictions in isoprene are found during the peak predicted concentrations.
- The model performance analysis by Texas areas shows overprediction in the isoprene concentration most areas and GloBIES performs better. For monoterpene, the models underpredict the concentrations in the CET, DFW, SOT, and HOU areas, and overpredict the concentration in the DET and NET areas. MEGAN performs slightly better in this case.
- MEGAN has improved algorithms for drought, leaf age and solar radiation that could easily be incorporated into GloBEIS. The MEGAN algorithm for isoprene response to CO2 should also be incorporated into GloBEIS if there is any interest in using GloBEIS to estimate isoprene emissions for future decades.

With the extensive testing of GloBEIS version 3.5, the new GloBEIS meets our expectations. The model is easier to use and yields the same emissions as GloBEIS v3.1CSR and similar emissions to MEGAN v2.04a. The new GloBEIS estimates SQT emissions based on SQT emission factors and SQT emission activity algorithms. We recommend further evaluation of SQT estimation.

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