March 2, 2012

## MEMORANDUM

To: Tom Moore, WGA
From: Tanarit Sakulyanontvittaya, Greg Yarwood and Alex Guenther[1]
Subject: Improved Biogenic Emissions Inventories across the West – Summary of 2008 Biogenic Emission Production (Project Task 2)

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# 1. INTRODUCTION

Emissions from vegetation, mostly from the leaves of plants, are the largest source of volatile organic compound (VOC) in the global atmosphere although VOC emissions from cars, factories and fires dominate in urban and industrial areas. In the atmosphere, the oxidation of VOC can influence aerosol particles, precipitation acidity, and regional ozone distributions (Guenther et al., 2006). Accurate predictions of biogenic VOC emissions are important for developing regulatory ozone and aerosol control strategies for at least some rural and urban areas (Karl et al. 2001). These organic carbon emissions are also a minor but potentially significant pathway for the flow of carbon between an ecosystem and the atmosphere (Guenther, 2002).

The Western Regional Air Partnership (WRAP) requires geo-gridded (model-ready) biogenic VOC and NO emission estimates for air quality modeling projects in the Western U.S. The objective of this project is to assess and improve biogenic emissions model procedures and input variables. The WRAP biogenic emission inventories are being prepared using version 2.10 of the MEGAN model which includes improvements to model input data and algorithms developed for this project.

This technical memorandum summarizes the technical descriptions and details of biogenic emission inventory modeling systems, landcover and vegetation data, and driving variables (meteorological data) in the development of 2008 biogenic emission inventories. This technical memorandum also presents comparisons with other models to provide continuity from historic biogenic emissions modeling methods used in Ozone, PM, and Regional Haze modeling and source apportionment studies.

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## 2. BIOGENIC EMISSIONS MODELING SYSTEM – MEGAN version 2.10

A number of models and modeling systems have been developed over the past several years for use in estimating biogenic emissions for use in a variety of applications, including ozone SIPs and PM Maintenance Plans, as well as for use in urban and regional scale air quality modeling.

The biogenic emissions model used for this project is the Model of Emission of Gases and Aerosol from Nature version 2.10 (MEGANv2.10) which is being developed as a community effort led by the National Center for Atmospheric Research (NCAR) and including the USEPA, NOAA, U. Colorado, Colorado State U., MIT, California Inst. Tech., U. Minnesota, Harvard U., Washington State U., U. Texas, Lancaster U., U. Edinburgh, Sun-Yat Sen University, ENVIRON and other institutions. MEGANv2.10 includes several enhancements over the previous MEGAN versions and BEIS system, including an explicit canopy environment and updated emission algorithms (see Task 1 – Technical Report, 2011). MEGAN uses the best available emission algorithms and input variables and has a structure that facilitates the use of improved input data and parameters. As part of this project, several additional improvements were incorporated into MEGANv2.1 including a soil NOx emission model (Yienger et al., 1995; SMOKE v3.0 User's Manual, 2011) that accounts for fertilizer application and precipitation and the ability to use a more frequent 8-day average Leaf Area Index (LAI) rather than monthly average LAI. This project has also improved the ability of MEGAN to accurately estimate biogenic emissions in the Western U.S. by improving Western U.S. land-use and landcover data with 1) plant functional type fractional (PFTf) coverage data based on 30 meter LANDSAT TM data, 2) emission factors based on recent emission measurements and improved U.S. species composition data, and 3) LAI based on improved satellite data products that are for a specific year and with higher (8-day) temporal resolution.

### LAND COVER AND VEGETATION DATA

Biogenic emissions depend critically upon landuse/landcover/vegetation input data. The landcover variables include total Leaf Area Index (LAI), tree fraction and plant species composition or plant functional type (PFT). These variables are determined based primarily on satellite observations. For this project, we use 2008 year specific LAI data (see Task 1 – Technical Report, 2011). The data is a set of 46 eight-day 1-km spatial resolution LAIv files for North America, which is derived from new MODIS LAI product version 5. PFT for 2008 were used in the 2008 emission estimates. A set of 9 PFT files, each at both 56-m and 1-km spatial resolution was derived from 30 meter LANDSAT-TM based landcover dataset including NCLD and CDL (see Task 1 – Technical Report, 2011). MEGAN includes a total of 17 PFTs but other types (e.g., tropical and boreal PFTs) did not occur within the domain. The high resolution LAI and PFT data were interpolated using zonal average method and reformatted from ESRI GRID format to ASCII format for modeling resolution.

### EMISSION FACTORS (EF)

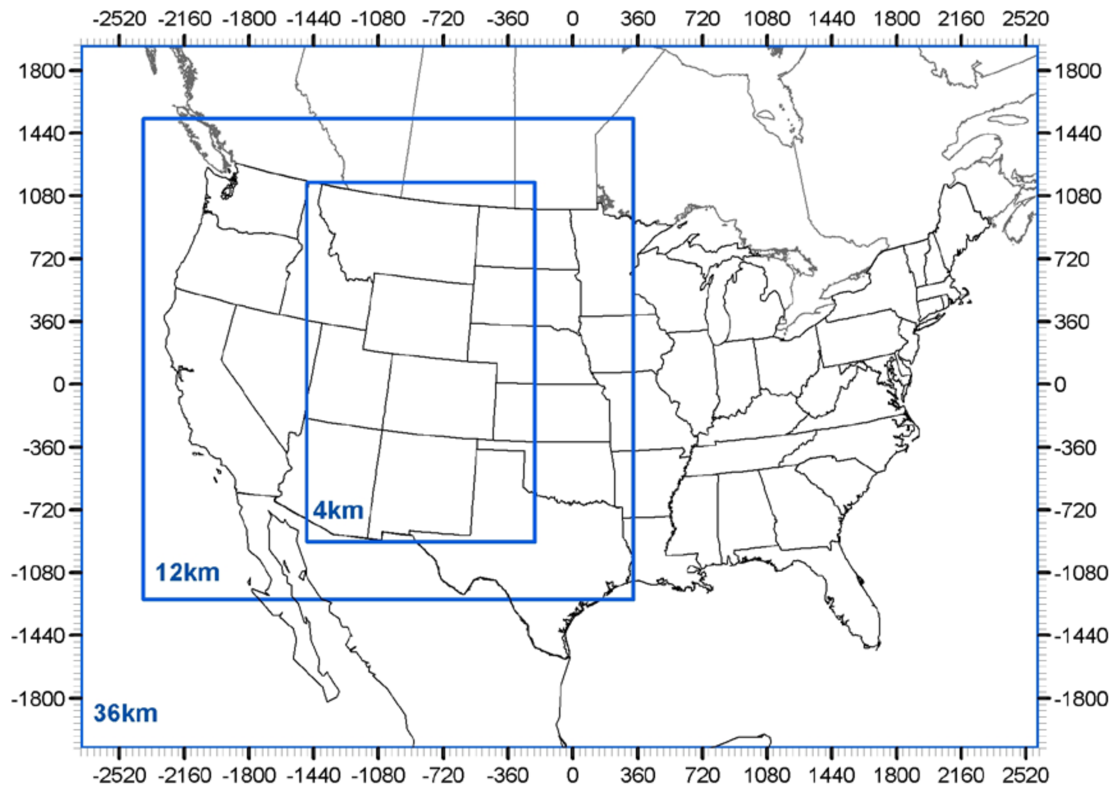
EF data was derived from the up-to-date literatures including enclosure measurements from six Western U.S. states including Arizona, presented in composition data and emission factor data in Task 1 Technical Report. The data were integrated to calculate landscape weighted average emission factors. MEGAN calculates emissions for 20 categories of biogenic compounds. Geo-gridded EF maps were calculated based on species composition and species specific emission factors for 8 biogenic compounds. PFT-average emission factors are combined with the geo-gridded PFTs for an additional 12 categories. The geo-gridded EF maps are based on the species composition distributions derived for the ~6000 vegetation types (VT) and species (or genus) specific emission factors. A weighted average is estimated for each location based on the VT fraction distribution for 2008 and the VT emission factors. As a result, the geo-gridded emission factor maps vary on an annual basis. A set of 10 EF files, each at both 56-m and 1-km spatial resolution, for the contiguous U.S. were generated for 2008. This includes files for NO and 9 VOC (isoprene, methyl butenol, alpha-pinene and 6 other monoterpenes. The data was processed using zonal average method and reformatted from ESRI GRID format to ASCII format for modeling resolution.

**MODELING DOMAINS**

A 36/12/4-km nested grid structure is used for the WestJumpAQMS meteorological, emissions and air quality modeling:

- The 36-km continental U.S. (CONUS) domain will be the same as used by the RPOs (e.g., WRAP) and most other recent modeling studies (e.g., Denver Ozone SIP).
- The 12-km western U.S. (WESTUS) domain will be larger than used in WRAP and contain all of the WRAP and adjacent states as well as extending into Canada and Mexico.
- There will be several types of 4-km domains utilized in the WestJumpAQMS study: 1) A large 4-km Inter-Mountain West Domain (IWD), 2) Detailed Source Apportionment Domains (DSAD) 4-km domains, and 3) Impact Assessment Domains (IAD).

These domains are presented in Figure 2.1.




Modeling Domain

36km: 148 x 112 (-2736, -2088) to (2592, 1944)
12km*: 227 x 230 (-2388, -1236) to (336, 1542)
04km*: 317 x 515 (-1480, -904) to (-212, 1156)

* includes buffer cells

**Figure 2.1. 36-km CONUS, 12-km WESTUS and 4-km IMWD processing domain that meteorological and emission PGM inputs will be developed for.**

**METEOROLOGICAL DATA**

The MEGAN model requires meteorological data to drive algorithms for light, temperature, canopy, and soil-NOx. For this project, 2008 meteorological data were obtained from WestJumpAQMS WRF modeling and processed through Meteorology-Chemistry Interface Processor (MCIP). The WRF meteorological model was applied for the 2008 calendar year using a 36/12/4-km domain structure. The non-hydrostatic version of the WRF model (WRF-ARW; Skamarock et al. 2008; Michalakes et al. 2001) is a three-dimensional, limited-area, primitive equation, prognostic model that has been used widely in regional air quality model applications. The WRF computational grid was designed so that it can generate CAMx/CMAQ meteorological inputs for the 36-km CONUS, 12-km WESTUS and 4-km IMWD processing. The projection is Lambert Conformal with the "national RPO" grid projection pole of $40^o$, $-97^o$ with true latitudes of $33^o$ and $45^o$. For model inputs, configurations, and evaluations, see (WestJumpAQMS Report, in preparation).

The data from WRF were processed through MCIP version 3.6 to prepare meteorological variables for MEGAN modeling. The MCIP is an interface between meteorological models such as WRF and CMAQ. MCIP deals data format translation, conversion of units of parameters, diagnostic estimations of parameters not provided, extraction of data for appropriate window domains, and reconstruction of meteorological data that is suitable for air quality modeling domains and structures. All meteorological variables used in MEGAN are available through MCIP processor, such as temperature, solar radiation, wind speed, pressure, water vapor mixing ratio, hourly rainfall, etc.

Photosynthetically Active Radiation (PAR) is an important input to MEGAN for describing how emissions respond to light intensity. Two sources of PAR data can be used in MEGAN: 1) PAR data from the ISCCP satellite (http://www.atmos.umd.edu/~srb/par/03satellite.htm), or 2) PAR calculated by a meteorological model such as WRF/MCIP. Isoprene emission depend strongly on light intensity and are useful for evaluating the consequences of using different sources of PAR data, as discussed in Section 3. The WRAP 2008 biogenic emission inventories will use satellite PAR data rather than WRF/MCIP data because the satellite data are considered more accurate, as discussed in Section 3. For dates when the satellite PAR data had gaps, solar radiation from WRF/MCIP was used. The details on using solar radiation are presented in Section 3.

## 3. ASSESSMENT OF ISOPRENE VARIATION WITH PAR DATA SOURCES

Photosynthetically Active Radiation (PAR) is an important driving variable for MEGAN and other biogenic emission models. There are two options in the MEGAN modeling system to obtain PAR data, which are solar radiation from meteorological model (MCIP processor) and PAR data from satellite observation. The solar radiation from meteorological model is always available as part of meteorological data for MEGAN and has no problems with missing data. MEGAN will internally estimate PAR from MCIP solar radiation data assuming half of the solar radiation is in the 400-700 nm spectral region (Equation 1).

$$PAR = CF \times SRAD \qquad (1)$$

Where: PAR is Photosynthetically Active Radiation ($W/m^2$)
SRAD is solar radation ($W/m^2$)
CF is conversion factor, 0.5 by default (dimensionless)

An analysis of the relationship between PAR and SRAD with latitude shows that CF can vary from 0.420 to 0.475 (See Figure 3.1). It is likely that CF also varies with solar zenith angle (time of day, season). Use of a single value for CF is a simplification that will create uncertainties. From Figure 3.1, an appropriate value for CF in this study is 0.45 and this value is used in the emission estimates from WRF/MCIP in this section if solar radiation from WRF/MCIP is required.

PAR from the ISCCP satellite[2], an alternative source, can be used within the MEGAN modeling system. The hour average PAR data is available at: http://www.atmos.umd.edu/~srb/gcip/ in monthly files from January 1996 to July 2010. It covers the United States, southern Canada, and northern Mexico. Disadvantages of PAR data are occasional data gaps and limited coverage area. Advantages of PAR data are direct linkage to actual cloud cover (as observed by the satellite) and no need to use a simple conversion fact between SRAD and PAR.

To assess the emissions variation from using satellite PAR or WRF/MCIP solar radiation, this section presents the comparison of isoprene emissions estimated from using PAR from WRF/MCIP and satellite observation. Isoprene is very sensitive to light intensity and isoprene is often a large fraction of total VOC emissions. We use MEGAN version 2.10 to estimate isoprene emissions for 36 km and 4 km domains.

[2] http://www.atmos.umd.edu/~srb/par/03satellite.htm

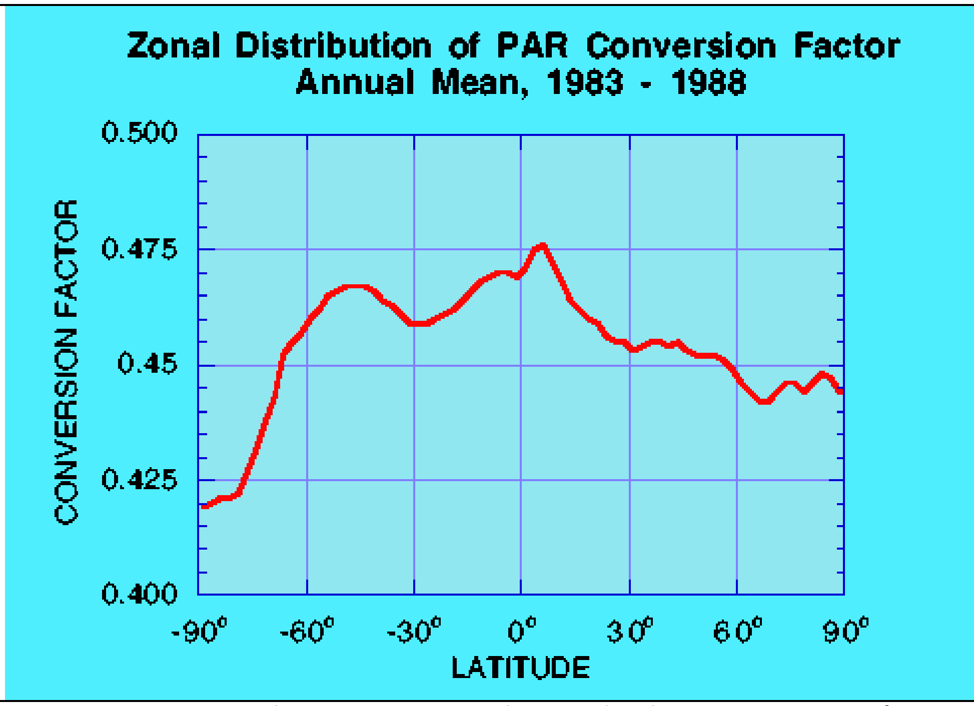



**Figure 3.1 Zonal distribution of PAR conversion factors for five year average (1983-1988). (http://www.atmos.umd.edu/~srb/par/Figure03.htm)**

**SPATIAL VARIATION**

Figures 3.3 – 3.6 show that using PAR from WRF/MCIP results in higher isoprene emission across the 36 km and 4 km domains for January 3-18 and July 3-18 periods. This is because derived PAR from WRF/MCIP is higher across the domains for the two periods. For the 36 km domain, the isoprene emissions from WRF/MCIP data are higher by 37% and 49% for July and January periods, respectively. The isoprene emissions are higher by 34% and 68% for July and January periods, respectively, for the 4 km domain. The spatial patterns of isoprene emissions are similar because they depend strongly on vegetation distributions which are common to both inventory calculations.

**TEMPORAL VARIATION**

Figure 3.7 shows that isoprene emissions using derived PAR from WRF/MCIP are noticeably higher during the peak hours.

In summary, WRF/MCIP PAR results in more than 30% higher isoprene emission than satellite PAR, especially during the peak hours. A comparison of isoprene emission under a clear sky condition was conducted to avoid having different cloudy effects in the two datasets. The results show isoprene emissions from using derived PAR from WRF/MCIP is higher across the area. This means the difference occurs under clear sky condition is not due to cloud fraction. It is rather due to the PAR calculation as a fraction of WRF Short Wave radiation. Therefore, satellite PAR data is a better data for biogenic emission estimates. The disadvantages of satellite PAR data are missing observation and limited coverage. For this project, limited satellite data coverage for Canada and Mexico is not a major shortcoming with the main focus on the United States. To fix the missing value issue, we thoroughly checked the data and replaced the data of the missing days with derived PAR from WRF/MCIP.

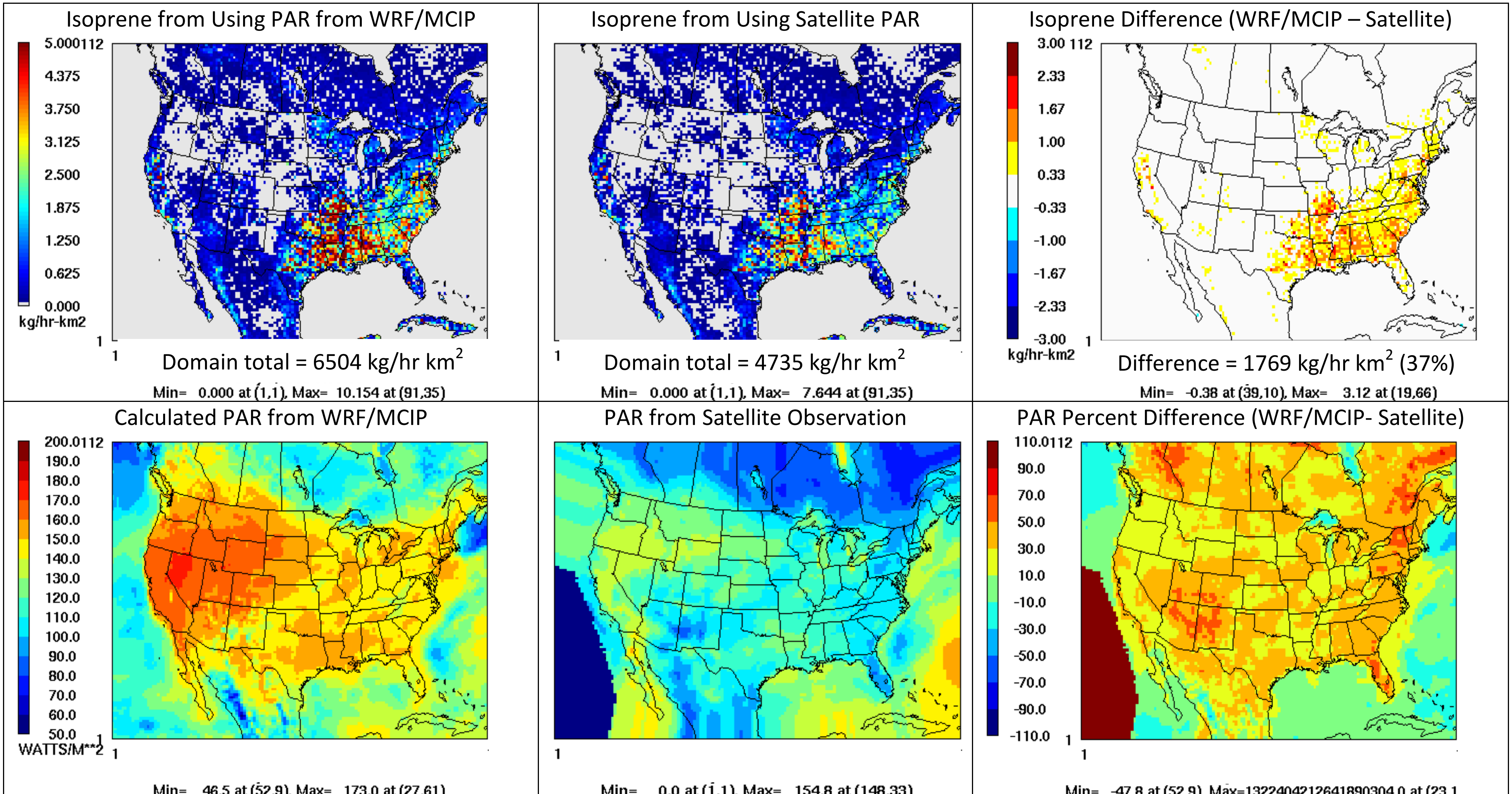



**Figure 3.3. July 3-18, 2008, period average of isoprene emission (top row) and PAR (bottom row) from using WRF/MCIP and satellite PAR, and the difference for 36 km domain.**

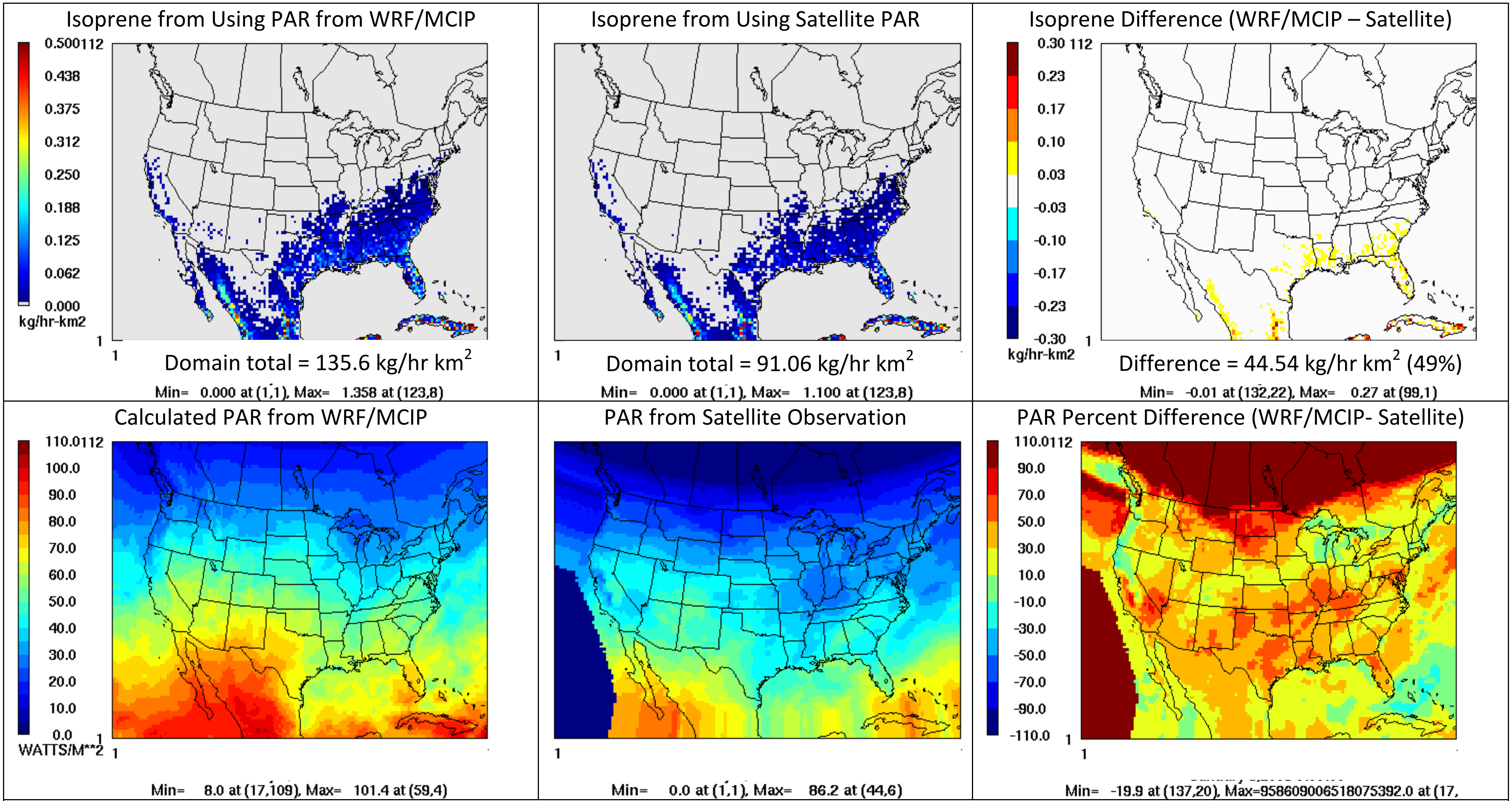



**Figure 3.4. January 3-18, 2008, period average of isoprene emission (top row) and PAR (bottom row) from using WRF/MCIP and satellite PAR, and the difference for 36 km domain.**

Isoprene from Using PAR from WRF/MCIP | Isoprene from Using Satellite PAR | Isoprene Difference (WRF/MCIP – Satellite)

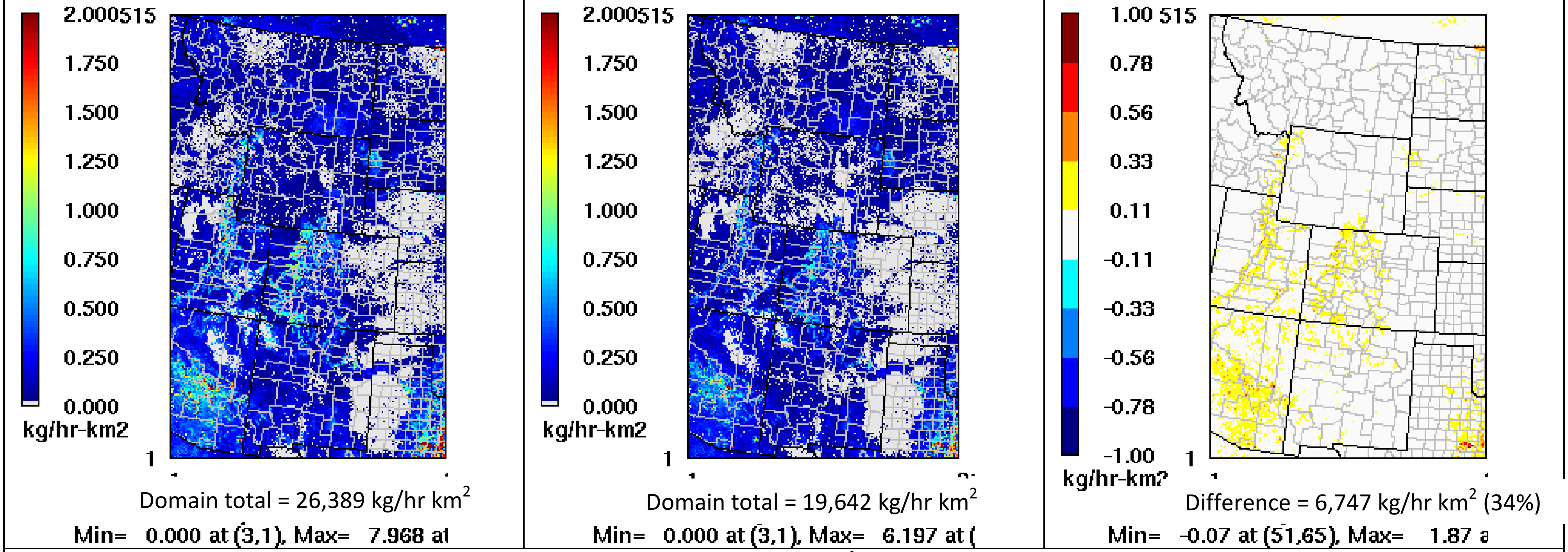



**Figure 3.5. July 3-18, 2008, period average of isoprene emission from using WRF/MCIP and satellite PAR, and the difference for 4 km domain.**

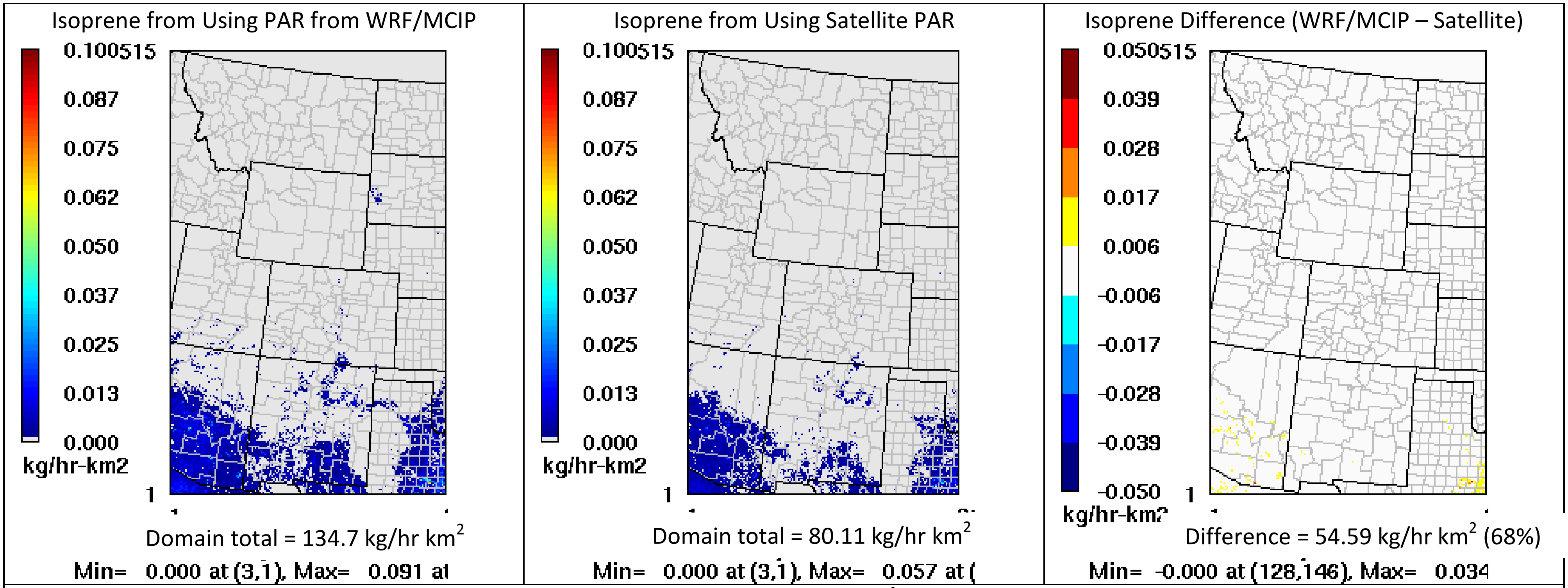
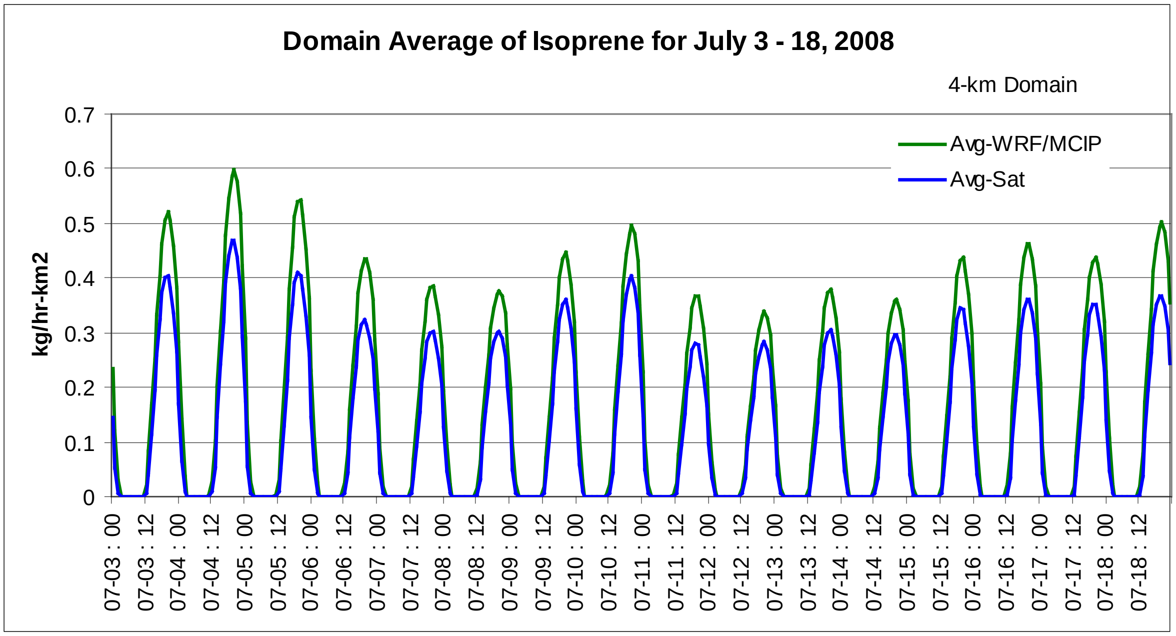



**Figure 3.6. January 3-18, 2008, period average of isoprene emission from using WRF/MCIP and satellite PAR, and the difference for 4 km domain.**



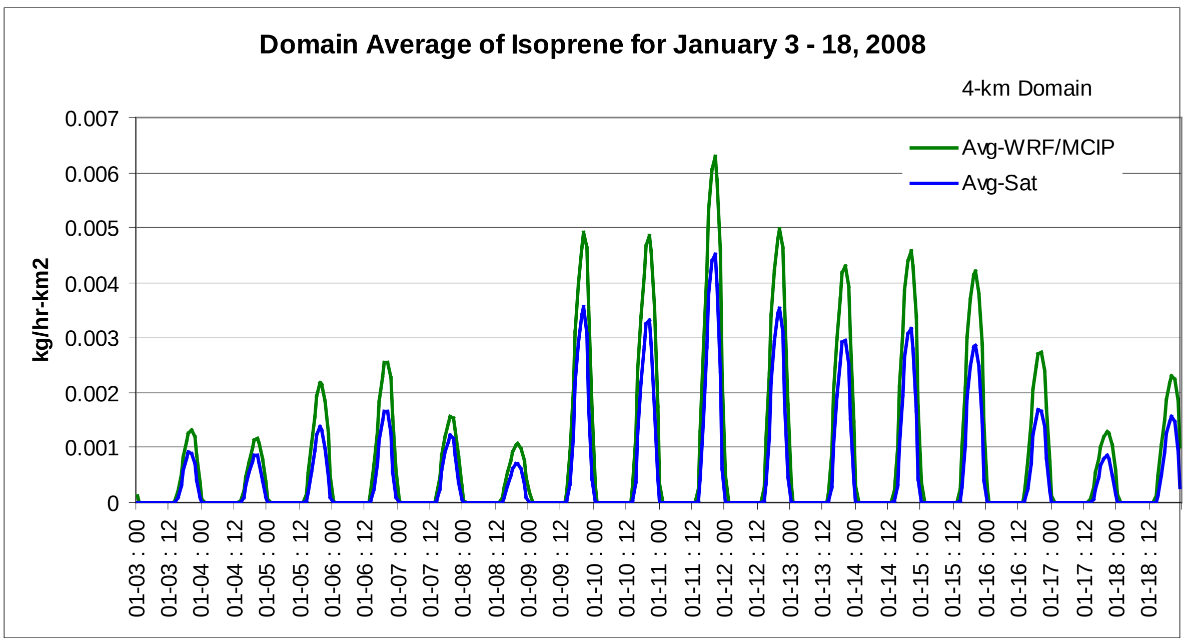




**Figure 3.7. Domain average of isoprene for July 3-18, 2008 (top), and January 3-18, 2008 (bottom) for 4 km domain.**

# 4. SUMMARY AND COMPARISON OF BIOGENIC EMISSION INVENTORIES

This section presents graphical and tabular summaries of biogenic emission inventories from MEGAN version 2.10, MEGAN version 2.04, and SMOKE-BEIS version 3.14. Summary of biogenic emission inventories presents tabular summaries at county level that were derived from the inventories for the 4 km domain. The comparison among the three models presents the quantitative comparisons for 36, 12, and 4 km domains, and the period-averaged spatial plots of biogenic emissions for the 36 and 4 km domains. The deliverable model-ready biogenic emission for 36, 12, and 4 km domains for different modeling systems, listed in this section, will be provided in an external hard drive.

**SMOKE-BEIS**

SMOKE BEIS is the Biogenic Emission Inventory System (BEIS) built into the SMOKE emission modeling framework. The BEIS family of models estimates VOC emissions from biological activity of land-based vegetation and NO emissions from microbial activity in soil. The EPA's third version of the BEIS has been incorporated within the SMOKE emissions modeling system with various modifications and updates from previous versions.

The types of input data used in BEISv3.14 are similar to those used in earlier versions of the BEIS model. The seven primary inputs to BEIS3 models are:

- Meteorological data, spatially and temporally resolved meteorological data including temperatures, solar radiation and surface pressures
- BELD3 landcover, spatially resolved, species-specific vegetation
- BELD3 emission factors, species-specific biogenic emissions factors (including a winter adjustment)
- Species-specific leaf area indices (LAI)
- Chemical speciation profiles

The model SMOKE-BEIS can make use of any meteorological data as long as it is in Network Common Data Format (NetCDF). For this project, we use WRF/MCIP meteorological data to drive the model. SMOKE-BEISv3.14 uses the incoming shortwave radiation to estimate the amount of PAR available in the plant canopy. SMOKE BEIS is unable to use satellite derived PAR data.

One of the most important changes included in the BEIS3 modeling system is the use of the Biogenic Emissions Landcover Database version 3 (BELD3). The BELD3 consists of 1-km horizontal resolution for 230 different land use types. BELD3 combines the spatial resolution available from the U.S. Geological Survey (USGS) 1-km data with the detailed tree and crop species information available in county-level forest and agricultural datasets. The BELD3 data is aggregated and/or interpolated to the desired modeling domain and resolution and the land use data input must be in NetCDF.

Emission factors consist of isoprene, monoterpene, nitrogen oxide and other VOC factors for all BELD3 land use types. The emissions factors are the flux-rate that each species emits under standard environmental conditions (i.e. $30^oC$ and 1000 umol• $m^{-2}$• $s^{-1}$ PAR for isoprene and $30^oC$ for monoterpenes, other VOCs, and NO). The emissions factors are stored in an ASCII file.

This emission factors file also includes a winter adjustment factor and a leaf area index (LAI) for each land use type. Leaf area index (LAI) is defined as the total one-sided, or one half of the total all-sided, green leaf area per unit ground surface area. In BEIS3, LAI is used to adjust the isoprene emissions for the effects of PAR penetrating through the leaf canopy.

**MEGAN VERSION 2.04**

MEGAN version 2.04 is the version prior to MEGAN version 2.10. The model uses landuse/landcover and LAI data, derived from 2001 1-km resolution MODIS data and 2003 1-km resolution MODIS LAI data, respectively. The updates for MEGAN 2.10 are described in Section 2.

**SUMMARY OF BIOGENIC EMISSION INVENTORIES**

Tables 4.1 – 4.8 present county-level biogenic emissions and percent differences for SMOKE-BEIS, MEGAN v2.04, and MEGAN v2.10 for selected counties in the WestJumpAQMS 4 km domain. The selected counties are important to oil and gas development projects and have different major vegetation types. Tables 4.1 – 4.4 are for the July 3-18, 2008, summer period and Tables 4.5 – 4.6 are for the January 3 – 18, 2008, winter period. The emission pollutants in the tables are isoprene, monoterpene, CO, and NOx, which are major biogenic emission pollutants and important to atmospheric chemistry and air quality. By convention, the mass of NOx emissions is reported using the molecular weight of $NO_2$. The emission estimates using SMOKE-BEIS were conducted using the configurations and inputs described above and were configured to use winter and summer EFs for January and July period, respectively. For MEGAN v2.04 and MEGAN v2.10, the emission estimates were conducted using configurations described above, and using satellite PAR data. During the two periods, there were no data gaps in the PAR data.

The complete county-level biogenic emission summary will be provided in spreadsheet format due to the size of the data. The summary is based on the 4 km domain and includes only the counties in the 4 km domain. The deliverable products, the model-ready biogenic emission data generated for the 36 km, 12 km, and 4 km domains, are listed below.

List of deliverable model-ready files for different modeling systems.

For January 3-18 and July 3-18, 2008:

- MEGAN v2.04 for CAMx with CB05 mechanism
- MEGAN v2.04 for CMAQ with CB05 mechanism
- BEIS3.14 for CAMx with CB05 mechanism
- BEIS3.14 for CMAQ with CB05 mechanism
- MEGAN v2.10 for CAMx with CB05 mechanism
- MEGAN v2.10 for CMAQ with CB05 mechanism

For annual 2008:

- MEGAN v2.10 for CAMx with CB6 mechanism
- MEGAN v2.10 for CMAQ with CB6 mechanism

**Table 4.1. Table summary of isoprene emissions for July 3-18 period for the 4 km domain.**

| State | County | Isoprene (tpd) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SMKBEIS | MEGANV2.04 | MEGANV2.10 | % Difference (M2.04-SMKB) | % Difference (M2.10-SMKB) | % Difference (M2.10-M2.04) |
| AZ | Pima | 123.2 | 146.5 | 171.3 | 18.9 | 39.0 | 16.9 |
| AZ | Maricopa | 110.1 | 230.7 | 237.3 | 109.5 | 115.6 | 2.9 |
| CO | Boulder | 6.9 | 16.6 | 11.4 | 141.6 | 66.2 | -31.2 |
| CO | Denver | 3.4 | 3.3 | 0.8 | -4.5 | -75.5 | -74.4 |
| CO | El Paso | 22.3 | 31.2 | 11.4 | 39.6 | -48.8 | -63.3 |
| CO | Teller | 11.2 | 9.2 | 5.5 | -17.7 | -51.0 | -40.5 |
| NM | Bernalillo | 7.7 | 10.6 | 7.3 | 37.7 | -5.3 | -31.2 |
| ID | Bear Lake | 26.2 | 18.5 | 13.6 | -29.5 | -48.0 | -26.3 |
| ID | Bingham | 72.1 | 30.1 | 9.3 | -58.3 | -87.0 | -68.9 |
| ID | Boise | 2.5 | 11.9 | 3.6 | 370.0 | 40.6 | -70.1 |
| UT | Box Elder | 53.1 | 57.5 | 23.8 | 8.3 | -55.2 | -58.6 |
| UT | Davis | 8.3 | 11.0 | 5.3 | 32.6 | -35.6 | -51.5 |
| UT | Salt Lake | 18.3 | 24.7 | 15.8 | 34.8 | -13.8 | -36.0 |
| UT | Weber | 23.2 | 26.9 | 15.7 | 15.7 | -32.4 | -41.6 |
| UT | Duchesne | 32.5 | 39.6 | 26.4 | 22.1 | -18.6 | -33.3 |
| UT | Uintah | 45.2 | 49.4 | 32.7 | 9.2 | -27.7 | -33.8 |
| WY | Carbon | 93.5 | 88.8 | 48.5 | -5.0 | -48.1 | -45.4 |
| WY | Teton | 223.3 | 87.7 | 54.6 | -60.7 | -75.6 | -37.8 |
| WY | Laramie | 6.2 | 46.7 | 8.6 | 651.4 | 37.7 | -81.7 |
| WY | Sublette | 60.0 | 62.5 | 18.4 | 4.2 | -69.3 | -70.5 |
| WY | Lincoln | 88.3 | 75.2 | 21.2 | -14.9 | -76.0 | -71.8 |
| WY | Sweetwater | 74.1 | 43.3 | 23.3 | -41.5 | -68.5 | -46.2 |
| WY | Uinta | 22.3 | 24.0 | 8.6 | 7.5 | -61.5 | -64.2 |
| Domain Total | | 9,185.7 | 12,885.2 | 7,814.0 | 40.3 | -14.9 | -39.4 |

**Table 4.2. Table summary of monoterpene emissions for July 3-18 period for the 4 km domain.**

| State | County | Monoterpene (tpd) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SMKBEIS | MEGANV2.04 | MEGANV2.10 | % Difference (M2.04-SMKB) | % Difference (M2.10-SMKB) | % Difference (M2.10-M2.04) |
| AZ | Pima | 126.7 | 32.5 | 47.1 | -74.4 | -62.8 | 45.0 |
| AZ | Maricopa | 149.4 | 49.3 | 60.4 | -67.0 | -59.6 | 22.3 |
| CO | Boulder | 17.9 | 8.2 | 5.3 | -54.1 | -70.1 | -34.8 |
| CO | Denver | 0.7 | 0.7 | 0.2 | -11.4 | -70.2 | -66.3 |
| CO | El Paso | 17.3 | 7.9 | 6.3 | -54.4 | -63.3 | -19.7 |
| CO | Teller | 7.6 | 4.5 | 3.6 | -39.8 | -52.3 | -20.7 |
| NM | Bernalillo | 13.5 | 4.9 | 7.7 | -63.8 | -43.1 | 57.2 |
| ID | Bear Lake | 14.5 | 5.1 | 6.6 | -64.9 | -54.8 | 29.0 |
| ID | Bingham | 18.5 | 6.6 | 12.1 | -64.4 | -34.5 | 84.0 |
| ID | Boise | 19.6 | 6.6 | 7.3 | -66.2 | -62.8 | 10.0 |
| UT | Box Elder | 60.8 | 12.4 | 21.2 | -79.7 | -65.0 | 71.8 |
| UT | Davis | 3.0 | 2.3 | 1.9 | -23.5 | -37.6 | -18.4 |
| UT | Salt Lake | 11.9 | 6.9 | 5.9 | -42.1 | -50.7 | -14.9 |
| UT | Weber | 5.9 | 4.8 | 4.7 | -18.3 | -20.5 | -2.8 |
| UT | Duchesne | 47.2 | 15.1 | 20.7 | -68.0 | -56.1 | 37.3 |
| UT | Uintah | 65.7 | 17.9 | 35.1 | -72.8 | -46.5 | 96.8 |
| WY | Carbon | 93.7 | 29.9 | 41.9 | -68.1 | -55.3 | 40.4 |
| WY | Teton | 50.2 | 41.9 | 31.3 | -16.6 | -37.7 | -25.2 |
| WY | Laramie | 8.6 | 6.5 | 4.1 | -24.3 | -52.2 | -36.8 |
| WY | Sublette | 56.0 | 23.9 | 29.0 | -57.3 | -48.2 | 21.4 |
| WY | Lincoln | 52.2 | 22.2 | 27.1 | -57.5 | -48.1 | 21.9 |
| WY | Sweetwater | 98.6 | 9.2 | 54.8 | -90.6 | -44.4 | 494.0 |
| WY | Uinta | 17.3 | 6.0 | 10.0 | -65.4 | -41.9 | 67.9 |
| Domain Total | | 9,583.9 | 4,144.4 | 5,022.6 | -56.8 | -47.6 | 21.2 |

**Table 4.3. Table summary of CO emissions for July 3-18 period for the 4 km domain.**

| State | County | CO (tpd) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SMKBEIS | MEGANV2.04 | MEGANV2.10 | % Difference (M2.04-SMKB) | % Difference (M2.10-SMKB) | % Difference (M2.10-M2.04) |
| AZ | Pima | 145.6 | 38.9 | 37.6 | -73.3 | -74.2 | -3.2 |
| AZ | Maricopa | 174.9 | 53.8 | 56.3 | -69.2 | -67.8 | 4.5 |
| CO | Boulder | 8.6 | 6.7 | 2.5 | -22.2 | -71.1 | -62.8 |
| CO | Denver | 1.3 | 1.2 | 0.2 | -14.0 | -85.8 | -83.4 |
| CO | El Paso | 18.7 | 11.5 | 2.2 | -38.3 | -88.0 | -80.5 |
| CO | Teller | 4.8 | 3.2 | 1.0 | -33.6 | -79.8 | -69.5 |
| NM | Bernalillo | 12.2 | 4.6 | 3.1 | -62.6 | -74.6 | -32.1 |
| ID | Bear Lake | 11.8 | 6.6 | 3.5 | -44.2 | -70.5 | -47.2 |
| ID | Bingham | 22.9 | 15.3 | 8.7 | -33.0 | -62.0 | -43.3 |
| ID | Boise | 11.6 | 5.4 | 3.4 | -53.1 | -70.4 | -36.9 |
| UT | Box Elder | 69.4 | 20.9 | 14.6 | -69.9 | -79.0 | -30.4 |
| UT | Davis | 3.7 | 2.7 | 1.3 | -26.2 | -63.5 | -50.5 |
| UT | Salt Lake | 10.7 | 7.5 | 3.5 | -29.3 | -66.8 | -53.1 |
| UT | Weber | 6.6 | 6.5 | 3.0 | -1.1 | -54.9 | -54.4 |
| UT | Duchesne | 35.2 | 16.7 | 9.8 | -52.4 | -72.1 | -41.3 |
| UT | Uintah | 59.0 | 19.6 | 15.8 | -66.8 | -73.2 | -19.4 |
| WY | Carbon | 73.4 | 34.2 | 19.8 | -53.3 | -73.0 | -42.2 |
| WY | Teton | 33.8 | 27.3 | 12.7 | -19.3 | -62.5 | -53.6 |
| WY | Laramie | 21.8 | 16.2 | 3.7 | -25.7 | -82.9 | -77.0 |
| WY | Sublette | 41.8 | 21.8 | 14.0 | -47.8 | -66.6 | -35.9 |
| WY | Lincoln | 39.6 | 21.8 | 13.6 | -45.0 | -65.7 | -37.5 |
| WY | Sweetwater | 99.9 | 19.4 | 27.2 | -80.6 | -72.8 | 40.3 |
| WY | Uinta | 17.9 | 9.3 | 5.8 | -47.9 | -67.3 | -37.2 |
| Domain Total | | 10,833.6 | 5,817.8 | 3,047.4 | -46.3 | -71.9 | -47.6 |

**Table 4.4. Table summary of NOx[3] emissions for July 3-18 period for the 4 km domain.**

| State | County | NOx (tpd) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SMKBEIS | MEGANV2.04 | MEGANV2.10 | % Difference (M2.04-SMKB) | % Difference (M2.10-SMKB) | % Difference (M2.10-M2.04) |
| AZ | Pima | 8.5 | 3.9 | 8.0 | -54.8 | -6.8 | 106.2 |
| AZ | Maricopa | 7.0 | 6.2 | 10.9 | -12.5 | 54.7 | 76.8 |
| CO | Boulder | 0.9 | 0.6 | 0.4 | -32.6 | -57.1 | -36.3 |
| CO | Denver | 0.4 | 0.1 | 0.1 | -58.3 | -76.7 | -44.2 |
| CO | El Paso | 4.3 | 1.1 | 1.4 | -74.8 | -67.9 | 27.6 |
| CO | Teller | 0.2 | 0.2 | 0.2 | -22.7 | -31.7 | -11.7 |
| NM | Bernalillo | 0.8 | 0.4 | 1.0 | -52.4 | 19.8 | 151.7 |
| ID | Bear Lake | 0.9 | 0.6 | 0.6 | -40.7 | -32.8 | 13.3 |
| ID | Bingham | 5.2 | 2.2 | 1.3 | -58.5 | -75.3 | -40.5 |
| ID | Boise | 0.2 | 0.3 | 0.4 | 47.9 | 86.2 | 25.9 |
| UT | Box Elder | 5.9 | 2.2 | 3.0 | -62.9 | -48.8 | 38.1 |
| UT | Davis | 0.6 | 0.3 | 0.2 | -47.1 | -71.2 | -45.6 |
| UT | Salt Lake | 1.4 | 0.7 | 0.5 | -48.9 | -65.5 | -32.5 |
| UT | Weber | 0.7 | 0.7 | 0.4 | -3.7 | -49.3 | -47.4 |
| UT | Duchesne | 2.8 | 1.4 | 1.7 | -49.8 | -40.5 | 18.6 |
| UT | Uintah | 3.9 | 1.8 | 3.5 | -54.7 | -11.6 | 94.9 |
| WY | Carbon | 5.0 | 2.8 | 3.8 | -43.3 | -23.6 | 34.8 |
| WY | Teton | 1.0 | 1.4 | 1.2 | 34.8 | 15.2 | -14.5 |
| WY | Laramie | 9.2 | 1.8 | 3.1 | -80.6 | -65.8 | 76.3 |
| WY | Sublette | 2.2 | 1.5 | 1.9 | -29.8 | -11.2 | 26.5 |
| WY | Lincoln | 2.4 | 1.6 | 1.9 | -35.4 | -23.3 | 18.7 |
| WY | Sweetwater | 4.3 | 2.0 | 6.3 | -53.5 | 47.0 | 216.1 |
| WY | Uinta | 1.9 | 0.9 | 1.0 | -53.2 | -45.8 | 15.8 |
| Domain Total | | 2,208.5 | 650.4 | 1,029.1 | -70.5 | -53.4 | 58.2 |

[3] NOx emission was estimated from NO emission using molecular weight of 46 g/mole ($NO_2$ molecular weight).

**Table 4.5. Table summary of isoprene emissions for January 3-18 period for the 4 km domain.**

| State | County | Isoprene (tpd) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SMKBEIS | MEGANV2.04 | MEGANV2.10 | % Difference (M2.04-SMKB) | % Difference (M2.10-SMKB) | % Difference (M2.10-M2.04) |
| AZ | Pima | 4.9 | 4.7 | 2.4 | -2.3 | -51.3 | -50.1 |
| AZ | Maricopa | 3.0 | 4.2 | 2.3 | 41.2 | -23.6 | -45.9 |
| CO | Boulder | 0.0 | 0.1 | 0.0 | 342.5 | 0.3 | -77.3 |
| CO | Denver | 0.0 | 0.0 | 0.0 | 494.5 | -47.8 | -91.2 |
| CO | El Paso | 0.1 | 0.2 | 0.0 | 226.1 | -53.4 | -85.7 |
| CO | Teller | 0.0 | 0.1 | 0.0 | 632.1 | 3.9 | -85.8 |
| NM | Bernalillo | 0.1 | 0.1 | 0.0 | 58.7 | -60.1 | -74.8 |
| ID | Bear Lake | 0.0 | 0.0 | 0.0 | -43.3 | -86.8 | -76.8 |
| ID | Bingham | 0.0 | 0.0 | 0.0 | 25.2 | -99.6 | -99.7 |
| ID | Boise | 0.0 | 0.0 | 0.0 | -60.0 | -96.2 | -90.5 |
| UT | Box Elder | 0.1 | 0.1 | 0.0 | 6.2 | -96.3 | -96.5 |
| UT | Davis | 0.0 | 0.0 | 0.0 | 103.4 | -96.7 | -98.4 |
| UT | Salt Lake | 0.0 | 0.0 | 0.0 | 239.4 | -76.9 | -93.2 |
| UT | Weber | 0.0 | 0.0 | 0.0 | 73.9 | -92.9 | -95.9 |
| UT | Duchesne | 0.1 | 0.1 | 0.0 | -21.2 | -85.9 | -82.1 |
| UT | Uintah | 0.1 | 0.1 | 0.0 | -19.8 | -91.1 | -89.0 |
| WY | Carbon | 0.1 | 0.1 | 0.0 | -43.1 | -92.3 | -86.5 |
| WY | Teton | 0.2 | 0.0 | 0.0 | -85.8 | -96.7 | -76.8 |
| WY | Laramie | 0.0 | 0.1 | 0.0 | 280.0 | -86.5 | -96.4 |
| WY | Sublette | 0.0 | 0.0 | 0.0 | -57.1 | -94.8 | -87.9 |
| WY | Lincoln | 0.0 | 0.0 | 0.0 | -42.3 | -96.0 | -93.1 |
| WY | Sweetwater | 0.2 | 0.1 | 0.0 | -63.8 | -99.6 | -99.0 |
| WY | Uinta | 0.0 | 0.0 | 0.0 | -32.6 | -94.0 | -91.0 |
| Domain Total | | 79.9 | 97.6 | 31.4 | 22.2 | -60.7 | -67.8 |

**Table 4.6. Table summary of monoterpene emissions for January 3-18 period for the 4 km domain.**

| State | County | Monoterpene (tpd) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SMKBEIS | MEGANV2.04 | MEGANV2.10 | % Difference (M2.04-SMKB) | % Difference (M2.10-SMKB) | % Difference (M2.10-M2.04) |
| AZ | Pima | 10.9 | 4.6 | 6.2 | -57.5 | -42.7 | 34.8 |
| AZ | Maricopa | 12.3 | 5.3 | 7.0 | -56.9 | -42.5 | 33.4 |
| CO | Boulder | 2.1 | 0.5 | 0.4 | -76.9 | -82.6 | -24.8 |
| CO | Denver | 0.1 | 0.0 | 0.0 | -64.5 | -87.4 | -64.4 |
| CO | El Paso | 1.7 | 0.4 | 0.5 | -74.3 | -70.9 | 13.1 |
| CO | Teller | 0.9 | 0.3 | 0.2 | -67.2 | -77.4 | -31.1 |
| NM | Bernalillo | 1.3 | 0.5 | 0.7 | -62.9 | -46.1 | 45.3 |
| ID | Bear Lake | 1.1 | 0.1 | 0.0 | -94.3 | -95.9 | -28.7 |
| ID | Bingham | 1.0 | 0.1 | 0.0 | -89.6 | -99.3 | -93.2 |
| ID | Boise | 2.1 | 0.2 | 0.1 | -91.8 | -96.1 | -52.3 |
| UT | Box Elder | 2.3 | 0.5 | 0.2 | -78.8 | -90.9 | -56.8 |
| UT | Davis | 0.2 | 0.1 | 0.0 | -73.4 | -98.4 | -93.9 |
| UT | Salt Lake | 0.9 | 0.2 | 0.0 | -79.7 | -95.6 | -78.4 |
| UT | Weber | 0.3 | 0.0 | 0.0 | -86.4 | -96.8 | -76.5 |
| UT | Duchesne | 3.2 | 0.4 | 0.3 | -86.6 | -90.2 | -26.6 |
| UT | Uintah | 2.9 | 0.5 | 0.3 | -82.2 | -88.6 | -36.0 |
| WY | Carbon | 5.8 | 1.0 | 0.5 | -83.2 | -91.9 | -51.7 |
| WY | Teton | 4.8 | 0.7 | 0.5 | -84.9 | -90.3 | -35.6 |
| WY | Laramie | 0.6 | 0.2 | 0.1 | -67.0 | -88.4 | -64.7 |
| WY | Sublette | 3.8 | 0.4 | 0.3 | -90.2 | -93.3 | -31.4 |
| WY | Lincoln | 3.8 | 0.3 | 0.2 | -92.7 | -95.3 | -35.8 |
| WY | Sweetwater | 3.2 | 0.2 | 0.1 | -92.3 | -97.0 | -60.2 |
| WY | Uinta | 1.0 | 0.2 | 0.1 | -83.0 | -94.5 | -67.5 |
| Domain Total | | 910.5 | 269.3 | 262.7 | -70.4 | -71.1 | -2.5 |

**Table 4.7. Table summary of CO emissions for January 3-18 period for the 4 km domain.**

| State | County | CO (tpd) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SMKBEIS | MEGANV2.04 | MEGANV2.10 | % Difference (M2.04-SMKB) | % Difference (M2.10-SMKB) | % Difference (M2.10-M2.04) |
| AZ | Pima | 12.3 | 5.4 | 1.0 | -55.8 | -92.1 | -82.2 |
| AZ | Maricopa | 13.3 | 5.6 | 1.0 | -58.3 | -92.4 | -81.8 |
| CO | Boulder | 0.8 | 0.3 | 0.0 | -62.7 | -98.5 | -95.9 |
| CO | Denver | 0.1 | 0.0 | 0.0 | -52.4 | -99.1 | -98.1 |
| CO | El Paso | 1.4 | 0.5 | 0.0 | -66.3 | -98.7 | -96.1 |
| CO | Teller | 0.5 | 0.2 | 0.0 | -59.6 | -98.8 | -97.0 |
| NM | Bernalillo | 1.0 | 0.4 | 0.0 | -60.6 | -96.5 | -91.2 |
| ID | Bear Lake | 0.8 | 0.1 | 0.0 | -92.9 | -99.8 | -97.8 |
| ID | Bingham | 0.9 | 0.2 | 0.0 | -73.4 | -100.0 | -99.9 |
| ID | Boise | 1.2 | 0.1 | 0.0 | -93.8 | -99.8 | -97.4 |
| UT | Box Elder | 2.5 | 0.8 | 0.0 | -69.7 | -99.7 | -98.8 |
| UT | Davis | 0.2 | 0.1 | 0.0 | -66.5 | -99.9 | -99.8 |
| UT | Salt Lake | 0.6 | 0.2 | 0.0 | -69.0 | -99.7 | -99.1 |
| UT | Weber | 0.3 | 0.1 | 0.0 | -77.3 | -99.9 | -99.6 |
| UT | Duchesne | 1.9 | 0.4 | 0.0 | -81.7 | -99.6 | -97.6 |
| UT | Uintah | 2.2 | 0.4 | 0.0 | -82.1 | -99.6 | -97.5 |
| WY | Carbon | 3.6 | 0.7 | 0.0 | -80.6 | -99.7 | -98.6 |
| WY | Teton | 2.3 | 0.3 | 0.0 | -87.1 | -99.7 | -97.3 |
| WY | Laramie | 1.2 | 0.4 | 0.0 | -65.5 | -99.6 | -98.9 |
| WY | Sublette | 2.3 | 0.2 | 0.0 | -91.0 | -99.8 | -97.9 |
| WY | Lincoln | 2.3 | 0.2 | 0.0 | -90.0 | -99.8 | -98.4 |
| WY | Sweetwater | 3.2 | 0.5 | 0.0 | -85.4 | -99.9 | -99.4 |
| WY | Uinta | 0.9 | 0.2 | 0.0 | -79.1 | -99.9 | -99.3 |
| Domain Total | | 803.4 | 274.2 | 20.2 | -65.9 | -97.5 | -92.6 |

**Table 4.8. Table summary of NOx[4] emissions for January 3-18 period for the 4 km domain.**

| State | County | NOx (tpd) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SMKBEIS | MEGANV2.04 | MEGANV2.10 | % Difference (M2.04-SMKB) | % Difference (M2.10-SMKB) | % Difference (M2.10-M2.04) |
| AZ | Pima | 3.8 | 0.5 | 0.4 | -87.8 | -88.2 | -3.8 |
| AZ | Maricopa | 3.1 | 0.6 | 0.6 | -81.9 | -81.0 | 5.3 |
| CO | Boulder | 0.2 | 0.0 | 0.0 | -92.0 | -97.6 | -69.4 |
| CO | Denver | 0.1 | 0.0 | 0.0 | -96.5 | -99.1 | -75.2 |
| CO | El Paso | 1.1 | 0.0 | 0.0 | -97.1 | -98.1 | -35.6 |
| CO | Teller | 0.0 | 0.0 | 0.0 | -71.0 | -95.6 | -84.9 |
| NM | Bernalillo | 0.2 | 0.0 | 0.0 | -89.3 | -90.1 | -7.5 |
| ID | Bear Lake | 0.1 | 0.0 | 0.0 | -95.8 | -99.6 | -91.6 |
| ID | Bingham | 0.7 | 0.0 | 0.0 | -95.8 | -100.0 | -99.4 |
| ID | Boise | 0.0 | 0.0 | 0.0 | -85.9 | -98.6 | -89.8 |
| UT | Box Elder | 0.8 | 0.1 | 0.0 | -92.5 | -99.4 | -91.5 |
| UT | Davis | 0.1 | 0.0 | 0.0 | -94.4 | -100.0 | -99.2 |
| UT | Salt Lake | 0.3 | 0.0 | 0.0 | -94.2 | -99.8 | -95.9 |
| UT | Weber | 0.1 | 0.0 | 0.0 | -94.2 | -99.9 | -99.0 |
| UT | Duchesne | 0.2 | 0.0 | 0.0 | -90.3 | -99.3 | -93.0 |
| UT | Uintah | 0.3 | 0.0 | 0.0 | -92.3 | -99.2 | -89.0 |
| WY | Carbon | 0.5 | 0.0 | 0.0 | -90.3 | -99.4 | -94.2 |
| WY | Teton | 0.1 | 0.0 | 0.0 | -79.7 | -97.7 | -88.8 |
| WY | Laramie | 2.3 | 0.0 | 0.0 | -98.2 | -99.6 | -75.6 |
| WY | Sublette | 0.1 | 0.0 | 0.0 | -84.9 | -99.6 | -97.4 |
| WY | Lincoln | 0.2 | 0.0 | 0.0 | -91.6 | -99.7 | -96.1 |
| WY | Sweetwater | 0.3 | 0.0 | 0.0 | -86.7 | -99.5 | -96.3 |
| WY | Uinta | 0.2 | 0.0 | 0.0 | -93.3 | -99.9 | -98.1 |
| Domain Total | | 550.8 | 24.2 | 15.4 | -95.6 | -97.2 | -36.3 |

[4] NOx emission was estimated from NO emission using molecular weight of 46 g/mole ($NO_2$ molecular weight).

**COMPARISONS OF EMISSION INVENTORIES FROM DIFFERENT MODELS**

In general, MEGAN v2.04 and 2.10 estimate lower monoterpene, NOx, and CO emissions and similar isoprene emissions compared to SMOKE-BEIS (Table 4.9). MEGAN v2.10 estimates lower isoprene and lower CO emissions than MEGAN v2.04 for all domains in both January and July. Monoterpene emissions from MEGAN v2.10 are lower than MEGAN v2.04 except for the 12 km and 4 km domains in July. NOx emissions from MEGAN v2.10 are higher than MEGAN v2.04 in July but lower in January.

*Isoprene Emissions*

Figures 4.1 - 4.4 show spatial comparisons of period average isoprene emissions for the 36 km and 4 km domains for both periods. The spatial distributions of isoprene emissions from all three models are similar. During the January period, isoprene emissions from the three models can be noticed in only the southern U.S. MEGAN v2.04 and MEGAN v2.10 estimate higher isoprene emissions than SMOKE-BEIS in the southeastern U.S. for the July period. A comment on the isoprene emission from SMOKE-BEIS is that SMOKE-BEIS may use county average plant distribution leading to county boundaries being noticeable in the isoprene emission distribution from SMOKE-BEIS (Figure 4.2). MEGAN does not have this issue. Comparing between the two versions of MEGAN model, MEGAN v2.10 estimates lower isoprene emissions across the 4 km domain for the two periods.

*Monoterpene Emissions*

Figures 4.5 - 4.8 show spatial comparisons of period average monoterpene emissions for the 36 km and 4 km domains for both periods. The spatial distributions of monoterpene emissions from all three models have similarities but there are some differences between BEIS and both versions of MEGAN. MEGAN v2.04 and MEGAN v2.10 estimate lower monoterpene emissions than SMOKE-BEIS for most areas in the western U.S. and Canada and MEGAN v2.04 and MEGAN v2.10 estimate higher monoterpene emissions than SMOKE-BEIS in the south eastern U.S. The two versions of MEGAN model estimate very similar emissions across the domains for the two periods. SMOKE-BEIS estimates higher monoterpene emissions than MEGAN in western Arizona and Sothern Nevada, which are regions with sparse vegetation cover and the MEGAN emission estimates are more reasonable.

*NOx Emissions*

Figures 4.9 - 4.12 show spatial comparisons of period average NOx emissions for the 36 km and 4 km domains for both periods. The NO emissions from the three models were converted to NOx emissions using molecular weight of 46 g per mole. SMOKE-BEIS estimates much higher NOx emissions in agricultural regions in the middle part of the U.S. and in the Central valley of California. In January, NOx emissions from the two version of MEGAN are noticeable (> 1g/h/km2) in only the southern U.S., whereas NOx emissions from SMOKE-BEIS are noticeable in most areas. In July, NOx emissions from MEGAN v2.10 are higher than MEGAN v2.04 in the Central U.S., Mexico and Florida while MEGAN 2.04 is higher than v2.10 in other regions. In January, NOx emissions from the two versions of MEGAN are very similar.

The NOx emission factors in MEGAN and SMOKE-BEIS are similar so the large differences between MEGAN and SMOKE-BEIS are likely due to the different landuse data and how adjustment factors were applied to different environmental drivers in the two models. MEGAN and BEIS landuse and landcover are based on different databases with different methodologies. BEIS landcover are from the previous decade and use county average statistics. MEGAN v2.10 landcover is representative of specific years, e.g. values for 2008 were used for this comparison, and have a 30 meter spatial resolution. Both SMOKE-BEIS and MEGANv2.10 use the NOx emission adjustments, including adjustments from precipitation, heterogeneity in soil, and fertilizer, developed by Yienger and Levy. However, there are differences in NOx estimations in the two models. For example, MEGAN applies the adjustment factors according to landuse type, e.g. grass land or agricultural land, and period of growing season. In contrast, SMOKE-BEIS uses the maximum adjustment between non-growing and growing seasons during the growing season period.

*CO Emissions*

Figures 4.13 - 4.16 show spatial comparisons of period average CO emissions for the 36 km and 4 km domains for both periods. In July, CO emission spatial distributions from all three models are different, especially in the western U.S. SMOKE estimates significant emissions along the California-Arizona border. These areas are desert with sparse vegetation and therefore low emissions are expected. In January, SMOKE-BEIS and MEGAN v2.04 estimate similar CO emissions. CO emission spatial distributions from MEGAN v2.10 are different and noticeable only in the southern U.S. and Mexico. The CO emissions from MEGAN v2.10 are lower than MEGAN v2.04 across all domains, especially in the southeastern U.S.

**Table 4.9 Domain total summary Table of period average biogenic emissions from SMOKE-BEIS (SBEIS), MEGAN v2.04 (Mv2.04), and MEGAN v2.10 (Mv2.10). ISOP is isoprene, TERP is monoterpene, NOx[5] is mono-nitrogen oxides, and CO is carbon monoxide.**

| Period | Domain | Pollutant | Emission (kg/hr-km$^2$) | | | Percent Difference | | |
|---|---|---|---|---|---|---|---|---|
| | | | SBEIS | Mv2.04 | Mv2.10 | (Mv2.04 - SBEIS) | (Mv2.10 - SBEIS) | (Mv2.10 - Mv2.04) |
| 3-18 July, 2008 | 36 km | ISOP | 4,212.4 | 5,474.2 | 4,735.0 | 30.0 | 12.4 | -13.5 |
| | | TERP | 2,019.2 | 1,537.1 | 1,388.8 | -23.9 | -31.2 | -9.6 |
| | | NOx | 298.5 | 140.6 | 176.4 | -52.9 | -40.9 | 25.5 |
| | | CO | 1,610.1 | 1,377.9 | 817.4 | -14.4 | -49.2 | -40.7 |
| | 12 km | ISOP | 12,289.0 | 15,585.8 | 12,921.8 | 26.8 | 5.1 | -17.1 |
| | | TERP | 7,426.1 | 4,243.4 | 4,388.9 | -42.9 | -40.9 | 3.4 |
| | | NOx | 1,594.7 | 637.8 | 833.6 | -60.0 | -47.7 | 30.7 |
| | | CO | 7,862.2 | 5,293.9 | 3,112.6 | -32.7 | -60.4 | -41.2 |
| | 4 km | ISOP | 22,395.1 | 31,603.5 | 19,641.9 | 41.1 | -12.3 | -37.8 |
| | | TERP | 23,244.7 | 10,143.2 | 12,293.1 | -56.4 | -47.1 | 21.2 |
| | | NOx | 5,698.6 | 1,649.2 | 2,597.7 | -71.1 | -54.4 | 57.5 |
| | | CO | 26,749.3 | 14,513.8 | 7,636.0 | -45.7 | -71.5 | -47.4 |
| 3-18 January, 2008 | 36 km | ISOP | 87.2 | 152.7 | 91.1 | 75.1 | 4.4 | -40.4 |
| | | TERP | 283.2 | 173.6 | 155.8 | -38.7 | -45.0 | -10.3 |
| | | NOx | 86.1 | 11.6 | 9.8 | -86.5 | -88.7 | -16.0 |
| | | CO | 163.6 | 125.9 | 22.5 | -23.1 | -86.2 | -82.1 |
| | 12 km | ISOP | 145.5 | 200.0 | 101.8 | 37.5 | -30.0 | -49.1 |
| | | TERP | 860.0 | 404.5 | 340.3 | -53.0 | -60.4 | -15.9 |
| | | NOx | 398.6 | 29.8 | 18.0 | -92.5 | -95.5 | -39.7 |
| | | CO | 663.3 | 333.1 | 30.8 | -49.8 | -95.4 | -90.8 |
| | 4 km | ISOP | 203.8 | 241.6 | 80.1 | 18.5 | -60.7 | -66.8 |
| | | TERP | 2,219.4 | 662.3 | 645.8 | -70.2 | -70.9 | -2.5 |
| | | NOx | 1,379.8 | 61.0 | 38.3 | -95.6 | -97.2 | -37.2 |
| | | CO | 1,982.2 | 683.4 | 50.8 | -65.5 | -97.4 | -92.6 |

[5] NOx emission was estimated from NO emission using molecular weight of 46 g/mole ($NO_2$ molecular weight).

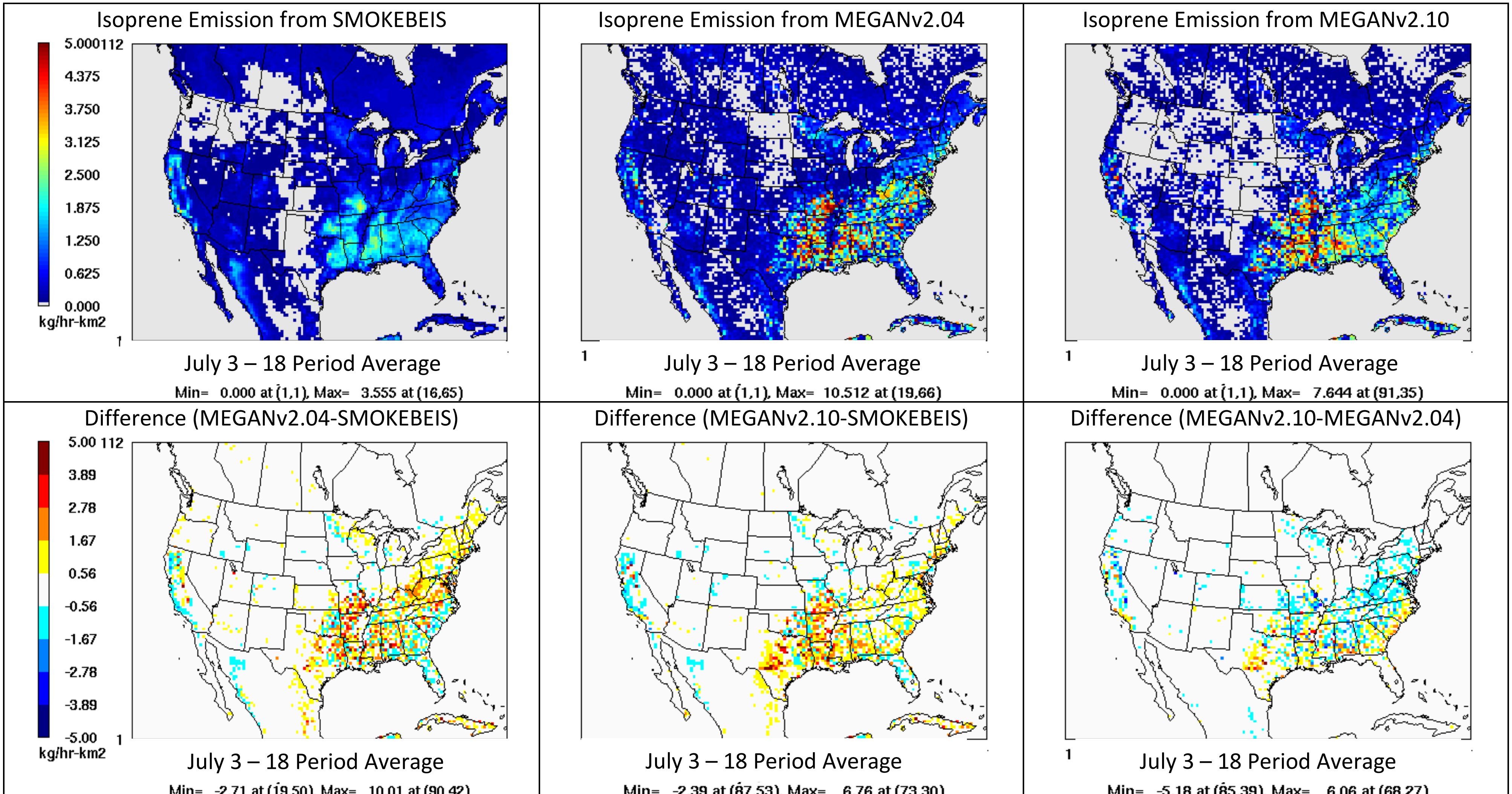
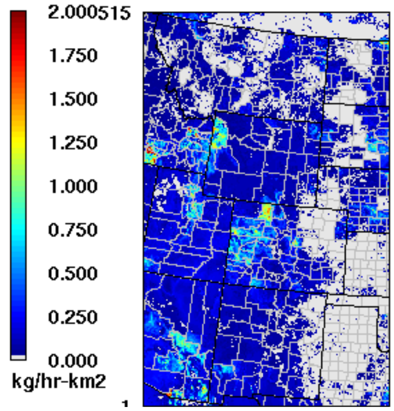



**Figure 4.1. Isoprene emission for July 3 – 18 period average for the 36 km domain from different models, and the emission difference.**

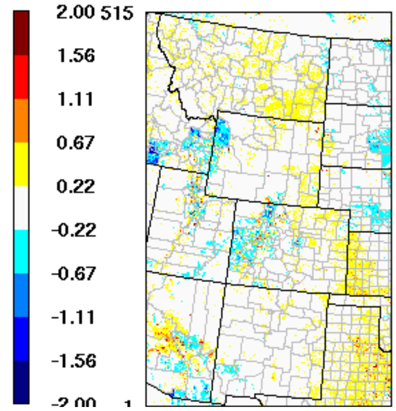
Isoprene Emission from SMOKEBEIS




July 3 – 18 Period Average

Min= 0.000 at (152,39), Max= 3.137 a

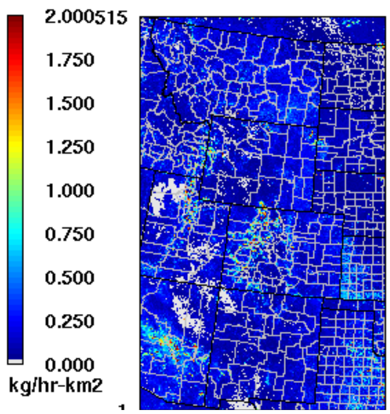
Difference (MEGANv2.04-SMOKEBEIS)




July 3 – 18 Period Average

Min= -3.04 at (11,335), Max= 6.06

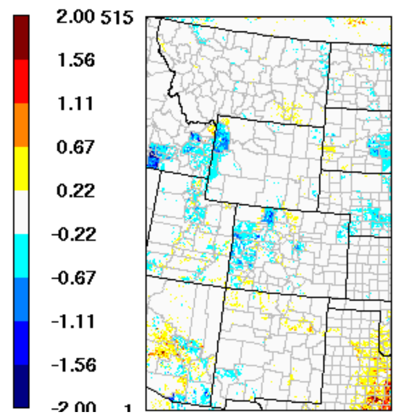
Isoprene Emission from MEGANv2.04




July 3 – 18 Period Average

Min= 0.000 at (114,1), Max= 6.066

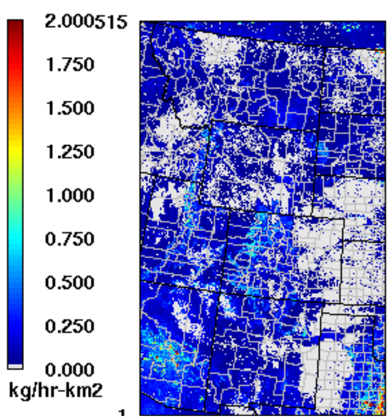
Difference (MEGANv2.10-SMOKEBEIS)




July 3 – 18 Period Average

Min= -3.07 at (11,335), Max= 6.14

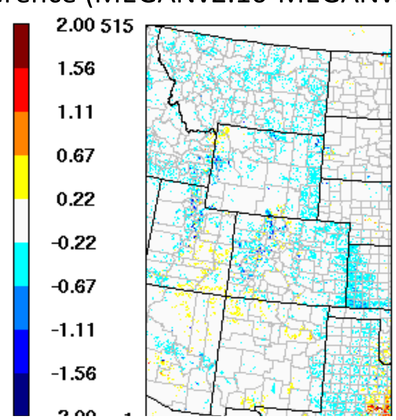
Isoprene Emission from MEGANv2.10




July 3 – 18 Period Average

Min= 0.000 at (3,1), Max= 6.197 at

Difference (MEGANv2.10-MEGANv2.04)




July 3 – 18 Period Average

Min= -4.30 at (3,65), Max= 4.82 at

**Figure 4.2. Isoprene emission for July 3 – 18 period average for the 4 km domain from different models, and the emission difference.**

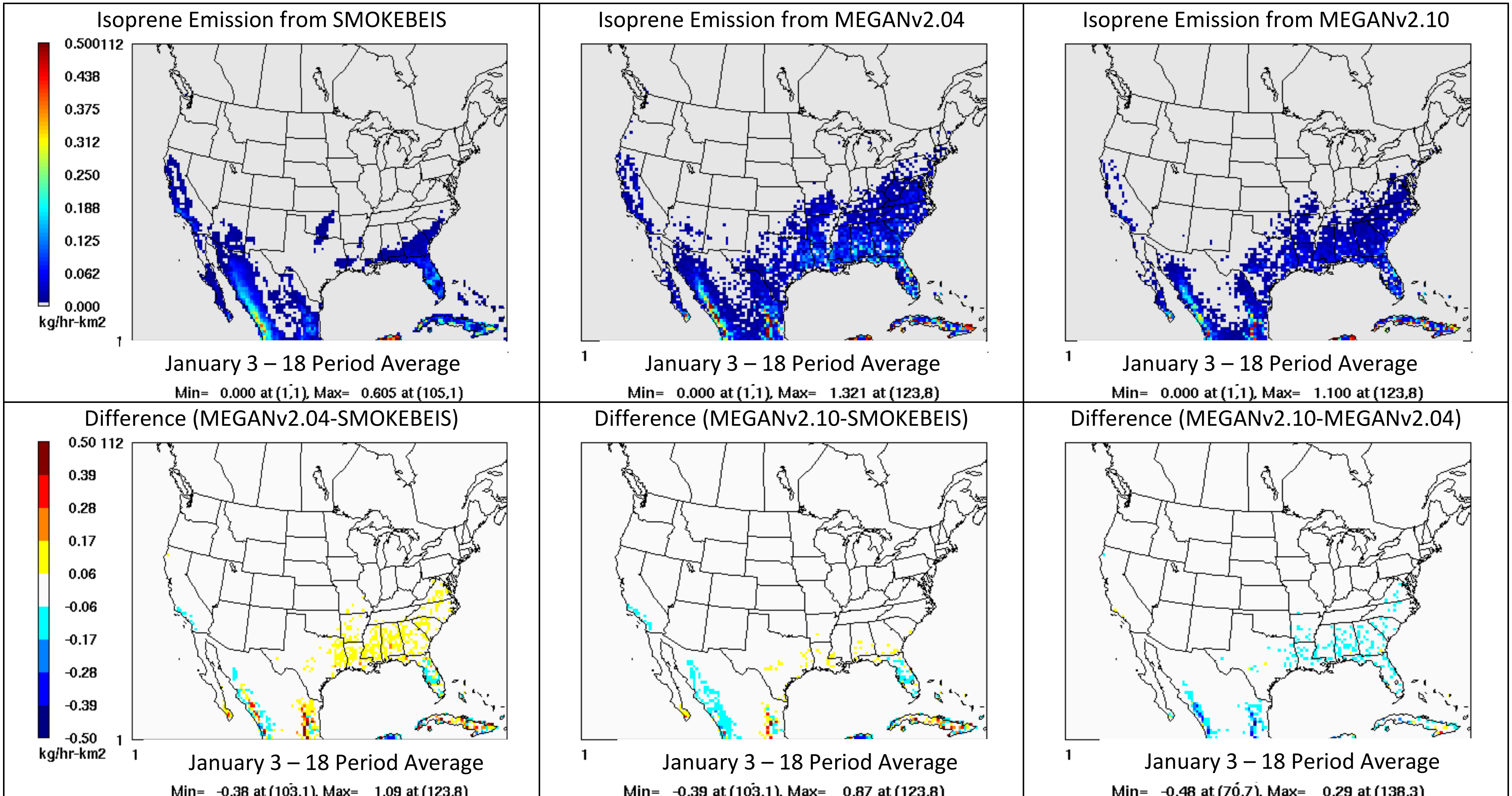



**Figure 4.3. Isoprene emission for January 3 – 18 period average for the 36 km domain from different models, and the emission difference.**

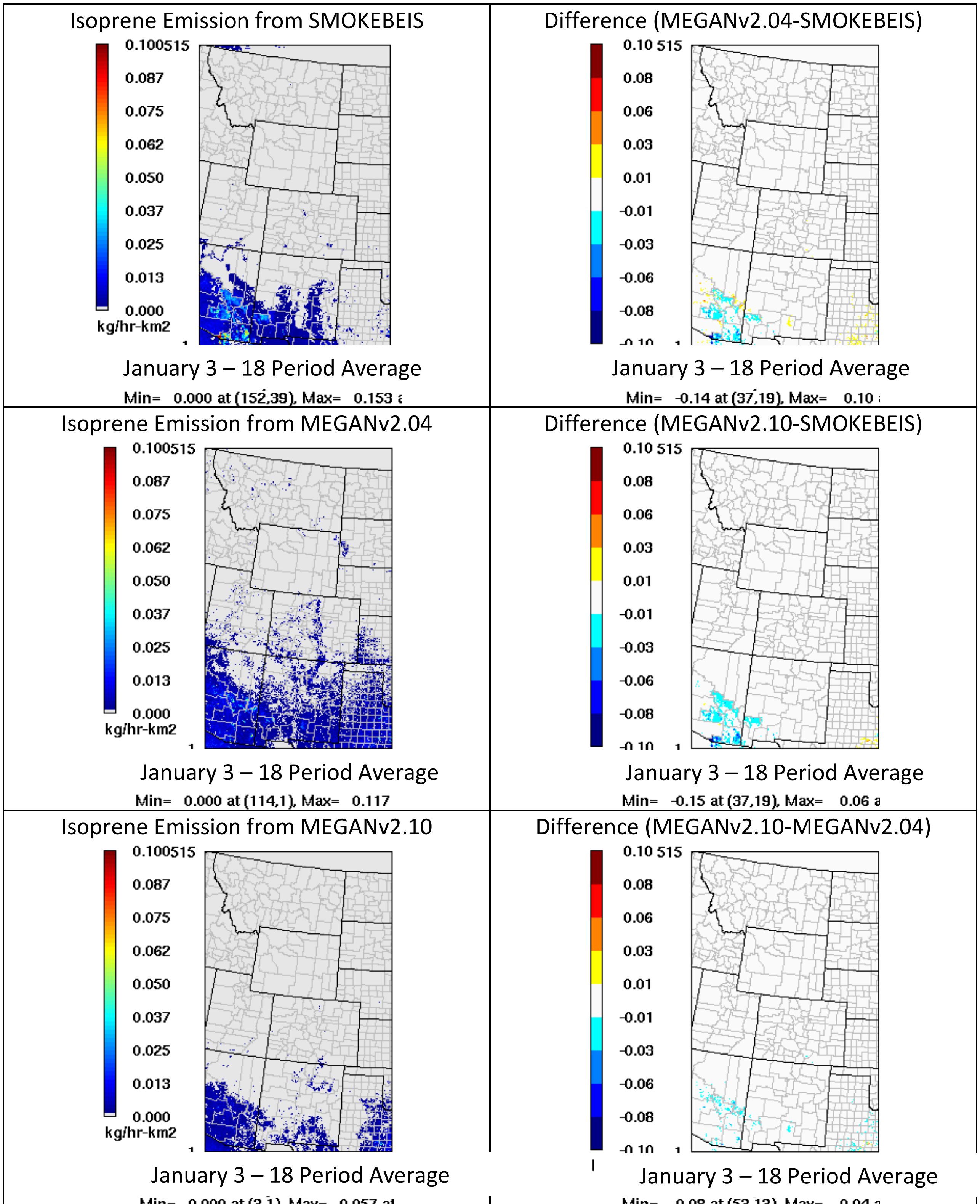



**Figure 4.4. Isoprene emission for January 3 – 18 period average for the 4 km domain from different models, and the emission difference.**

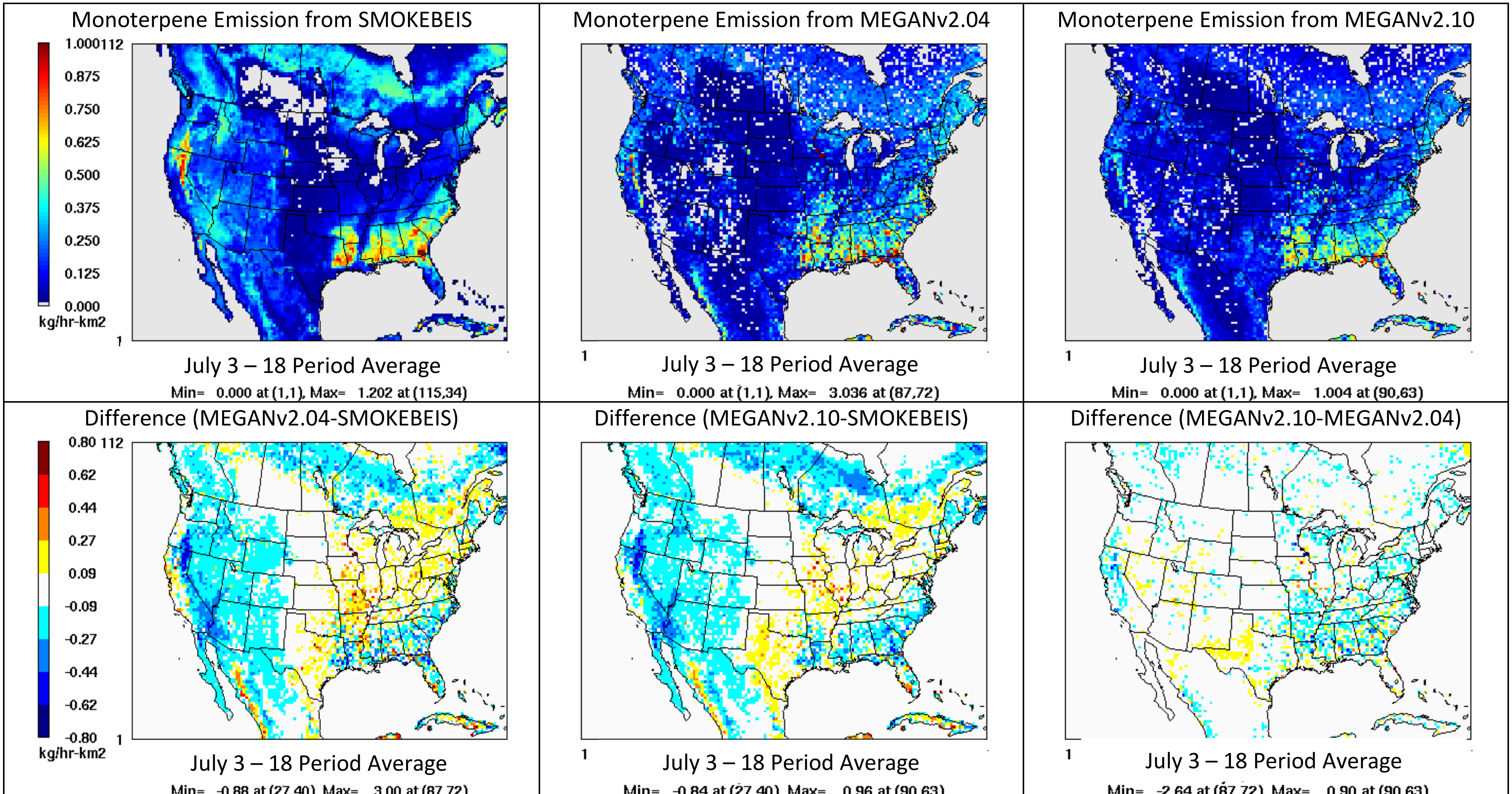



**Figure 4.5. Monoterpene emission for July 3 – 18 period average for the 36 km domain from different models, and the emission difference.**

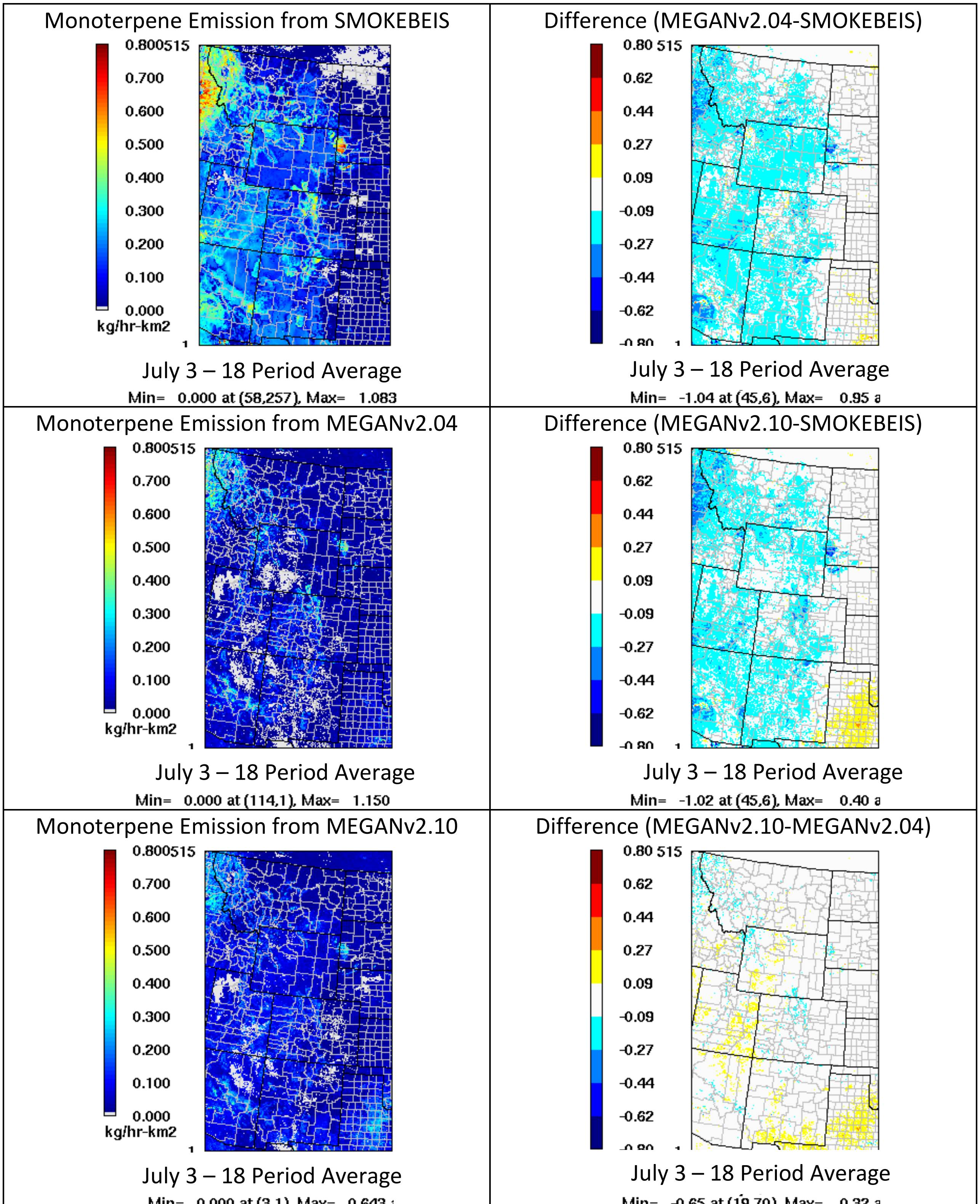



**Figure 4.6. Monoterpene emission for July 3 – 18 period average for the 4 km domain from different models, and the emission difference.**

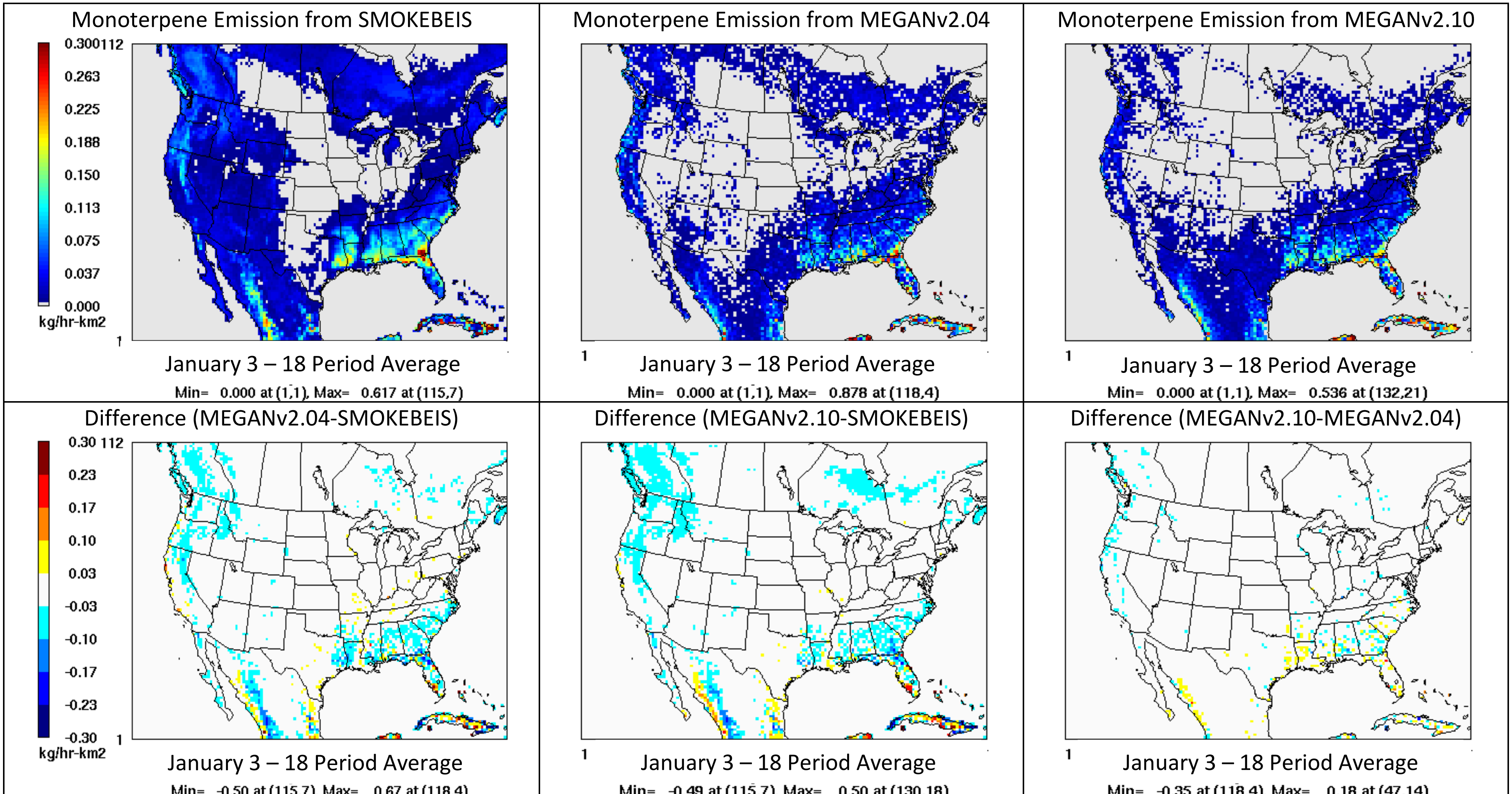



**Figure 4.7. Monoterpene emission for January 3 – 18 period average for the 36 km domain from different models, and the emission difference.**

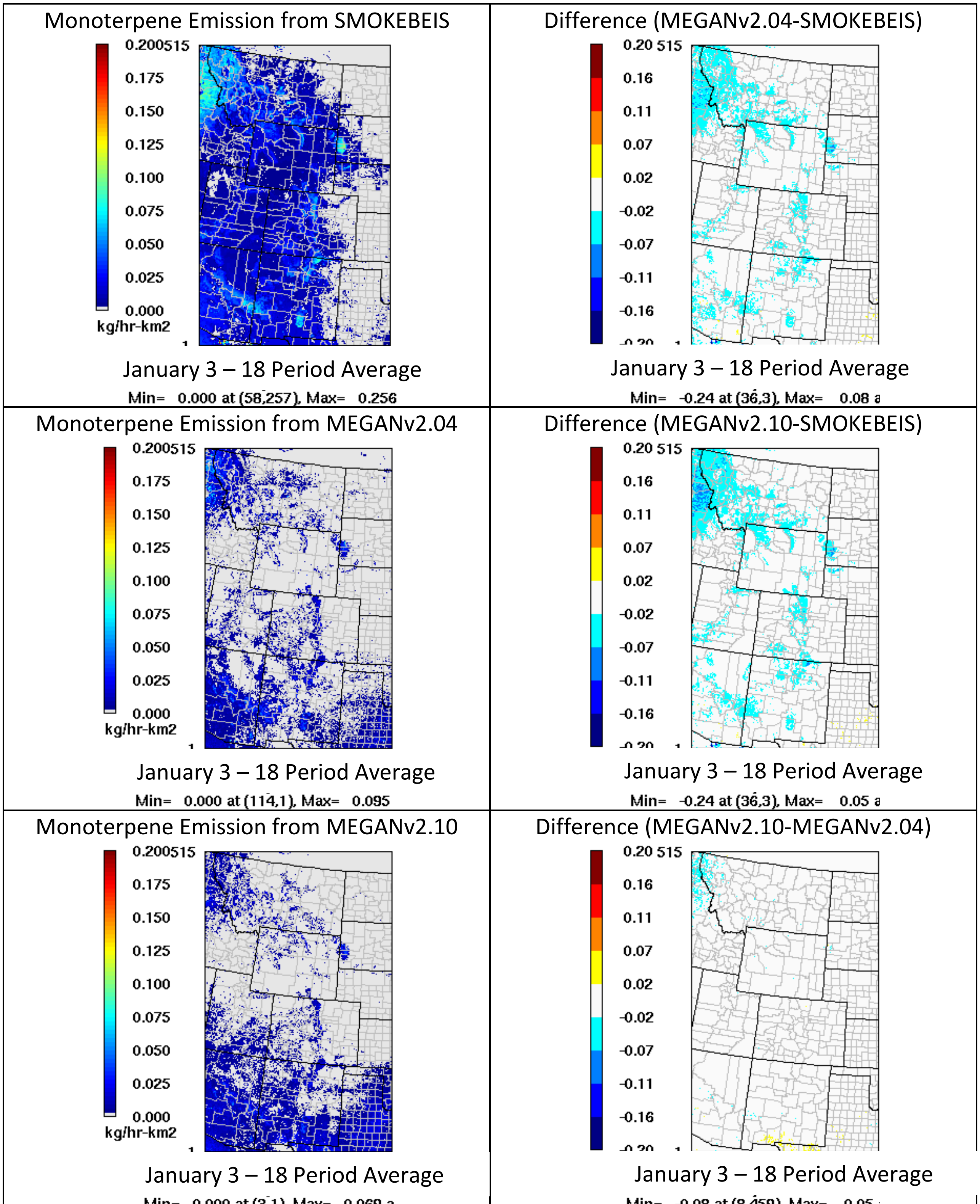



**Figure 4.8. Monoterpene emission for January 3 – 18 period average for the 4 km domain from different models, and the emission difference.**

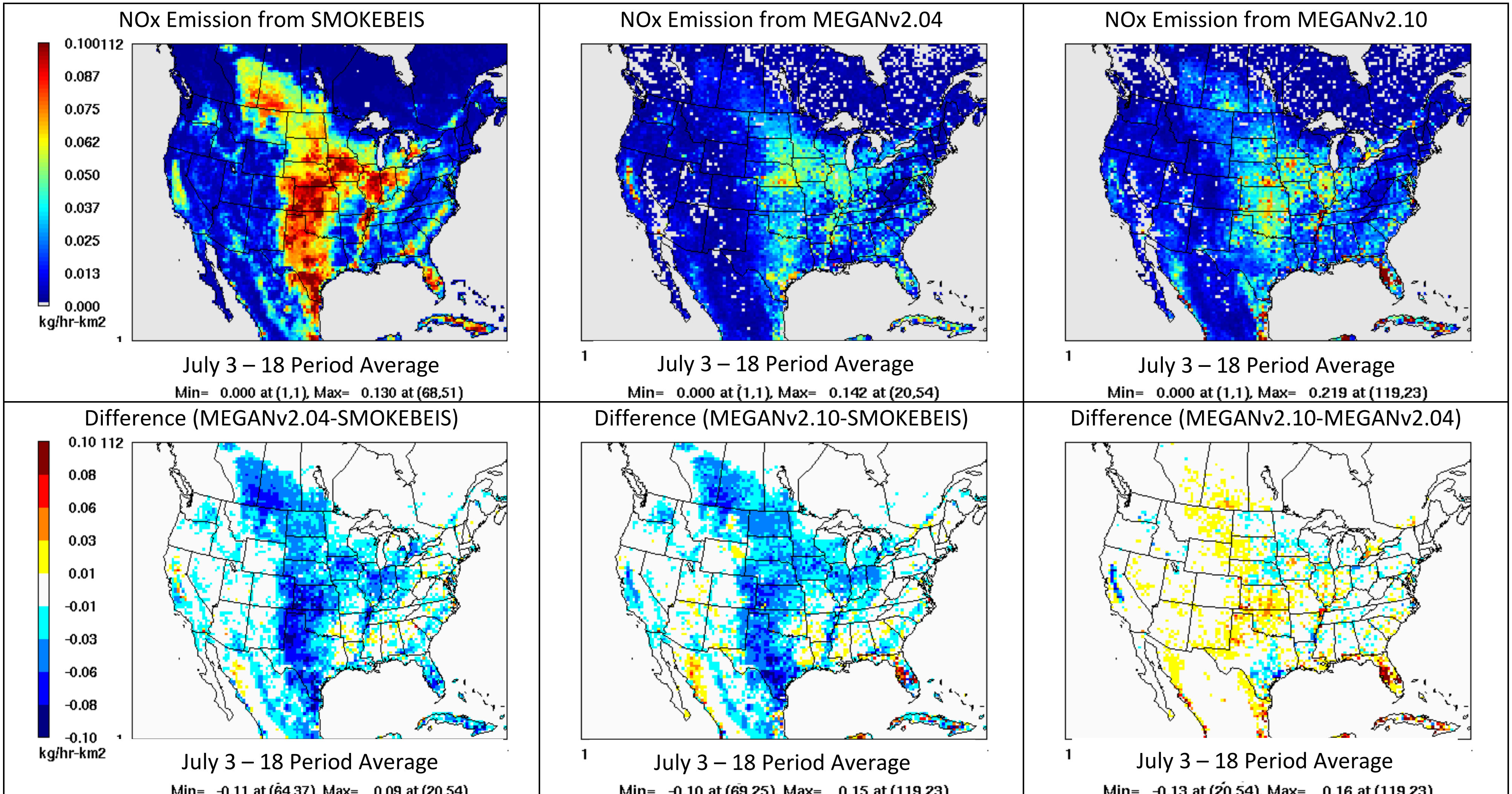



**Figure 4.9. NOx[6] emission for July 3 – 18 period average for the 36 km domain from different models, and the emission difference.**

[6] NOx emission in Figures 4.9 to 4.12 was estimated from NO emission using molecular weight of 46 g/mole ($NO_2$ molecular weight).

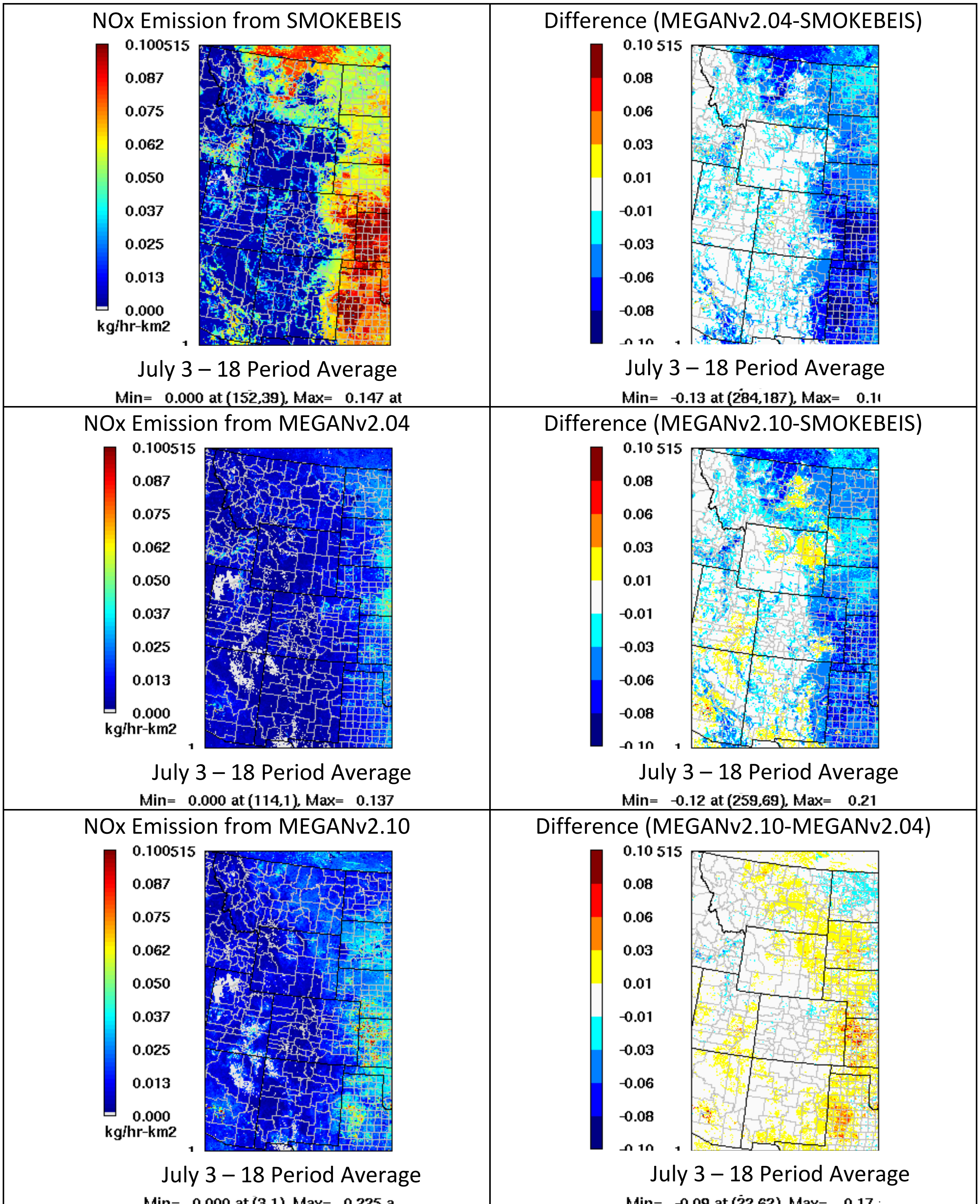



**Figure 4.10. NOx emission for July 3 – 18 period average for the 4 km domain from different models, and the emission difference.**

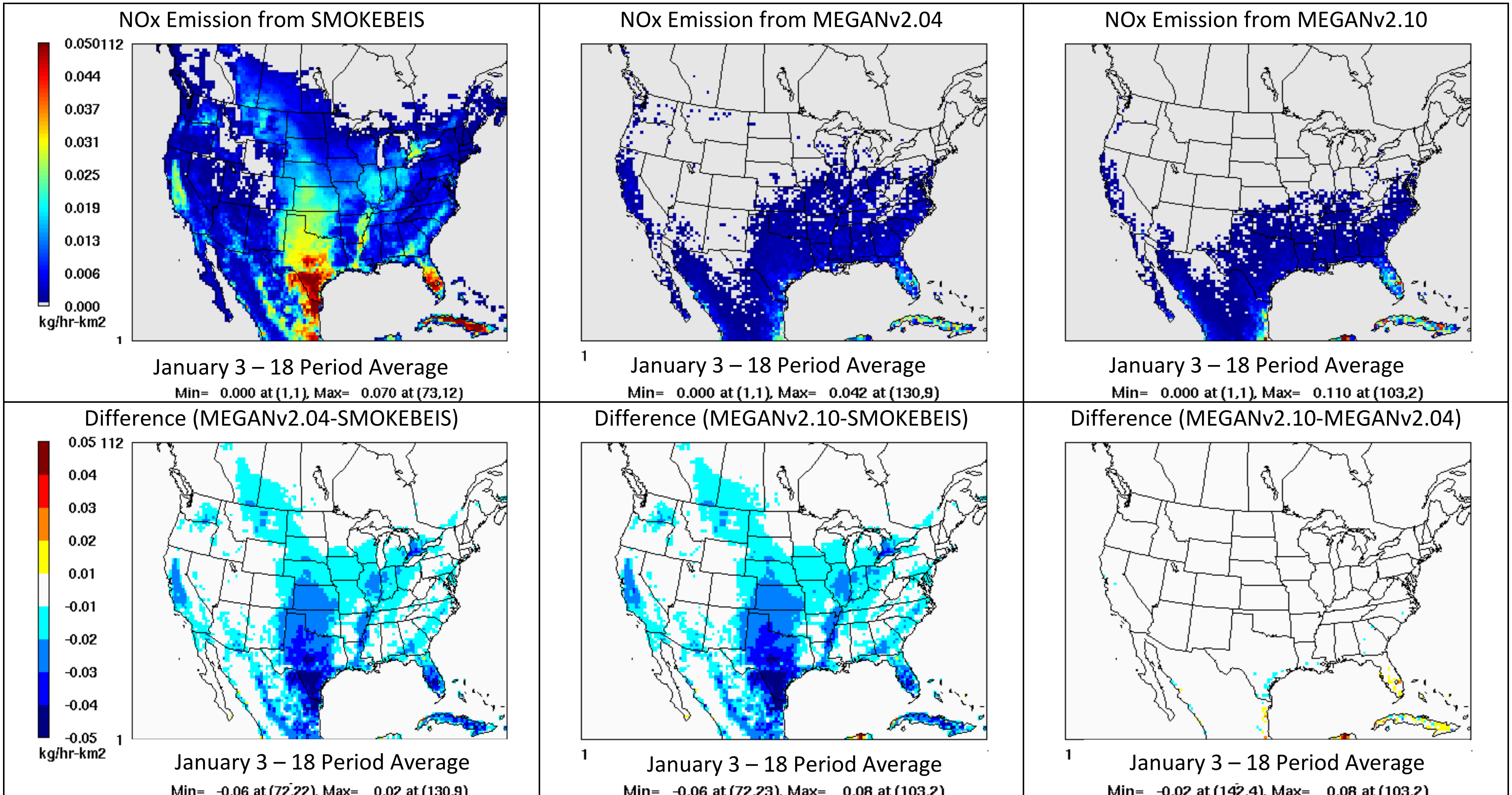



**Figure 4.11. NOx emission for January 3 – 18 period average for the 36 km domain from different models, and the emission difference.**

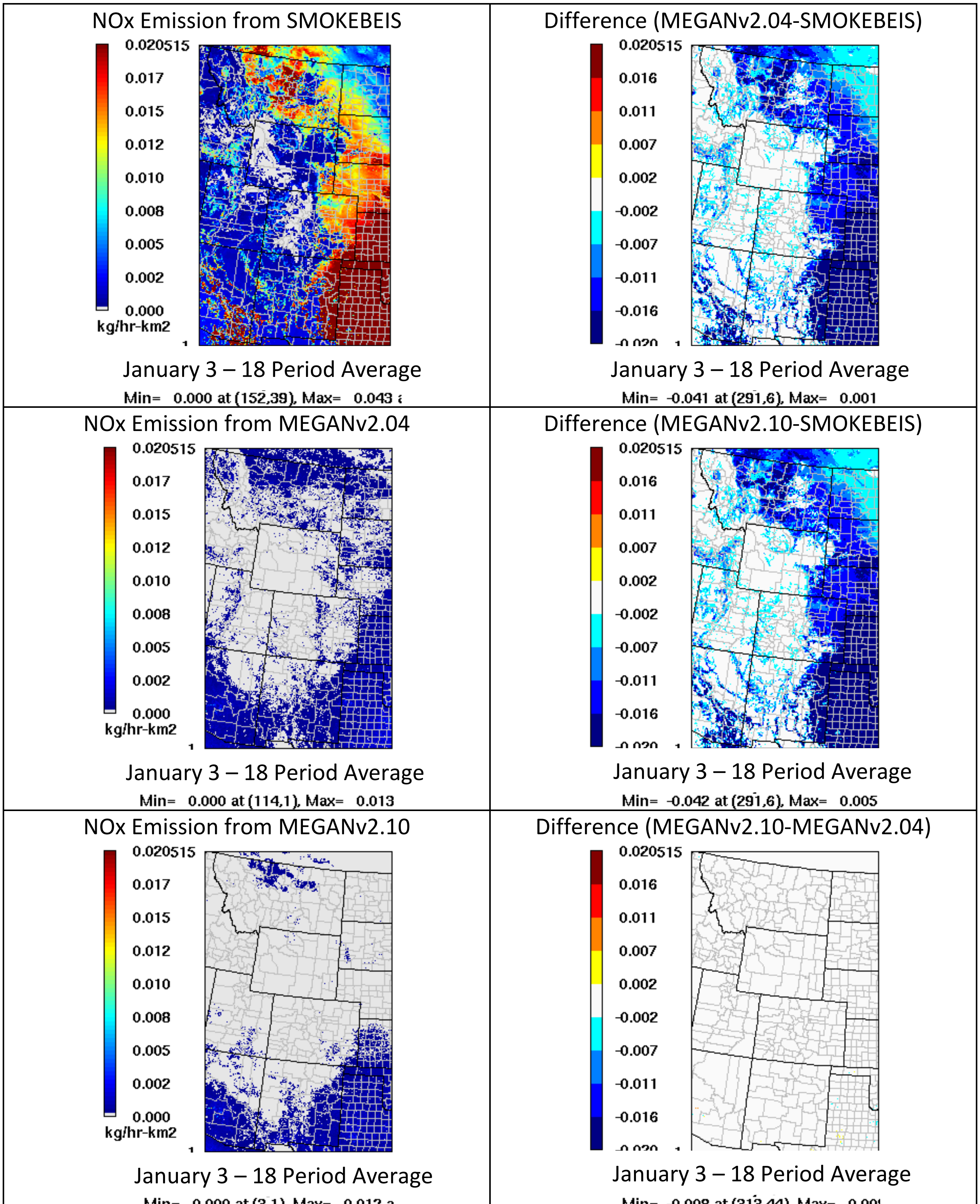



**Figure 4.12. NOx emission for January 3 – 18 period average for the 4 km domain from different models, and the emission difference.**

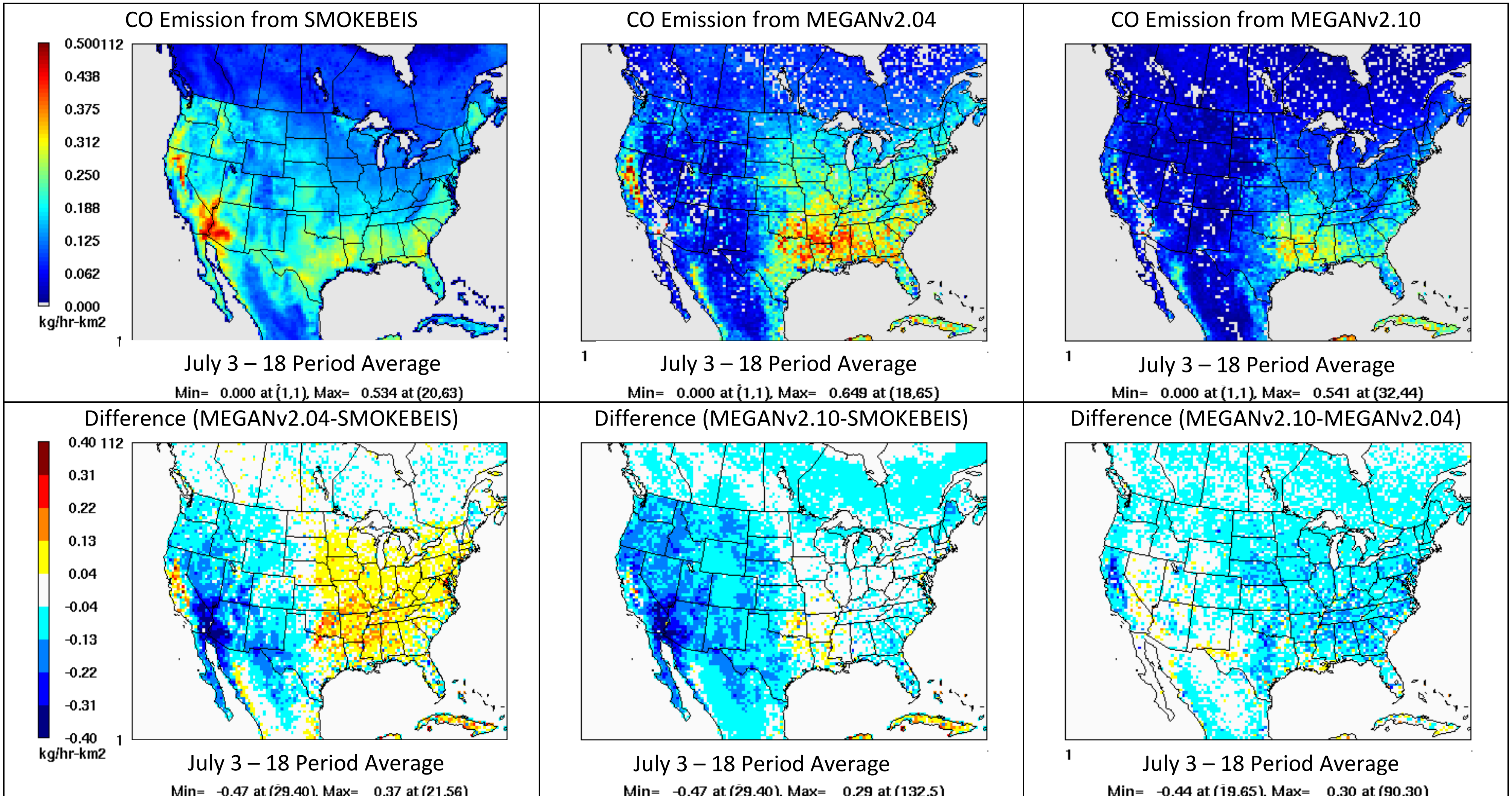



**Figure 4.13. CO emission for July 3 – 18 period average for the 36 km domain from different models, and the emission difference.**

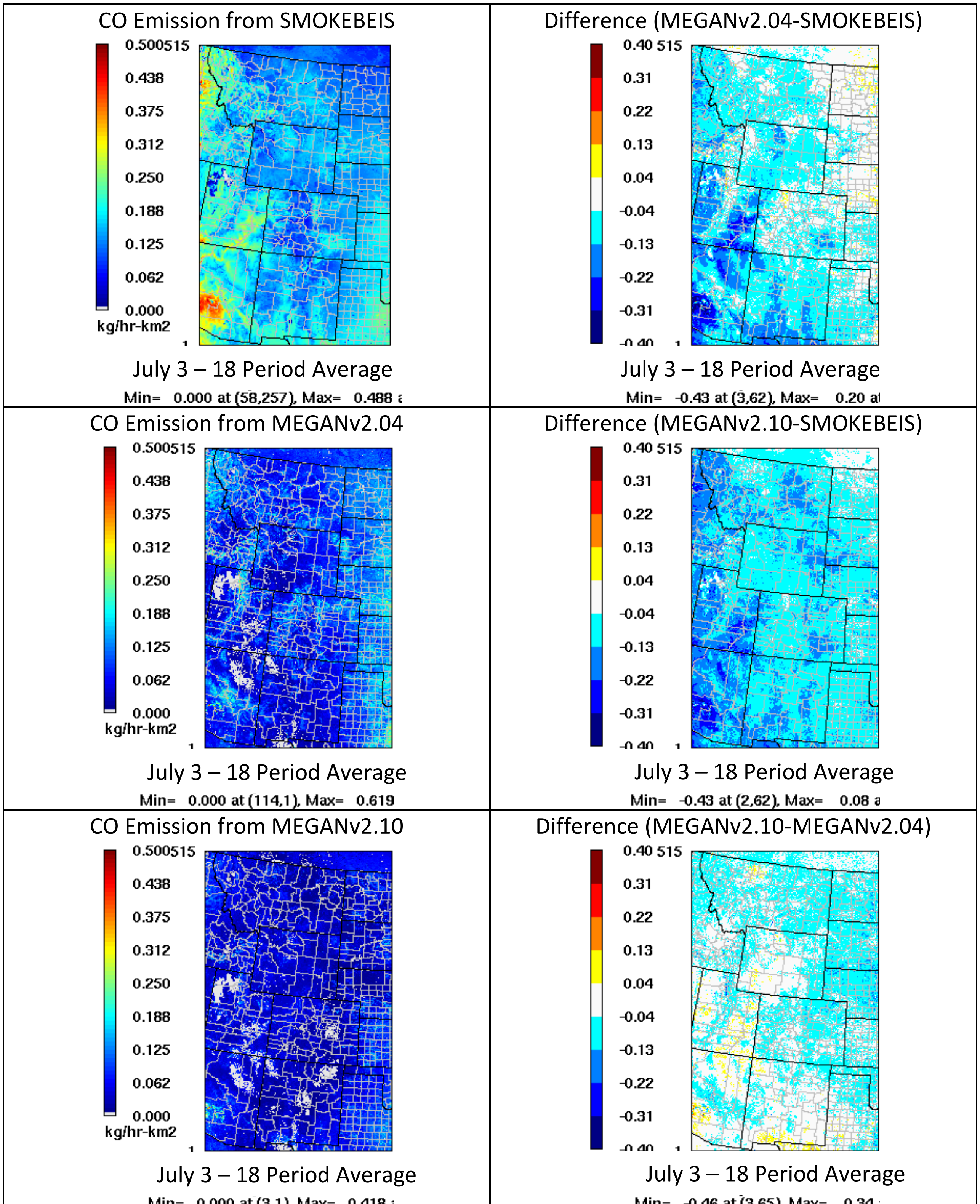



**Figure 4.14. CO emission for July 3 – 18 period average for the 4 km domain from different models, and the emission difference.**

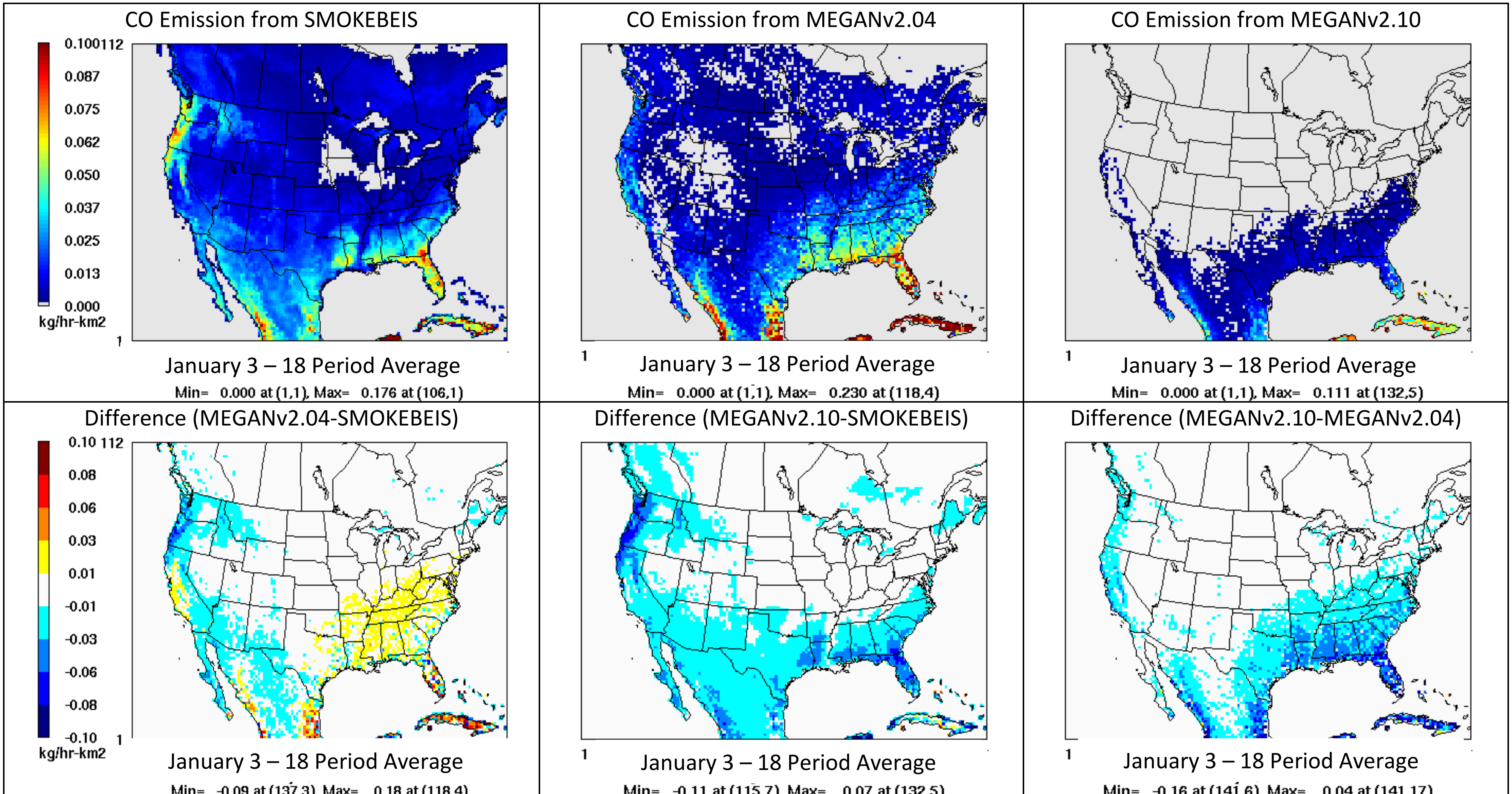



**Figure 4.15. CO emission for January 3 – 18 period average for the 36 km domain from different models, and the emission difference.**

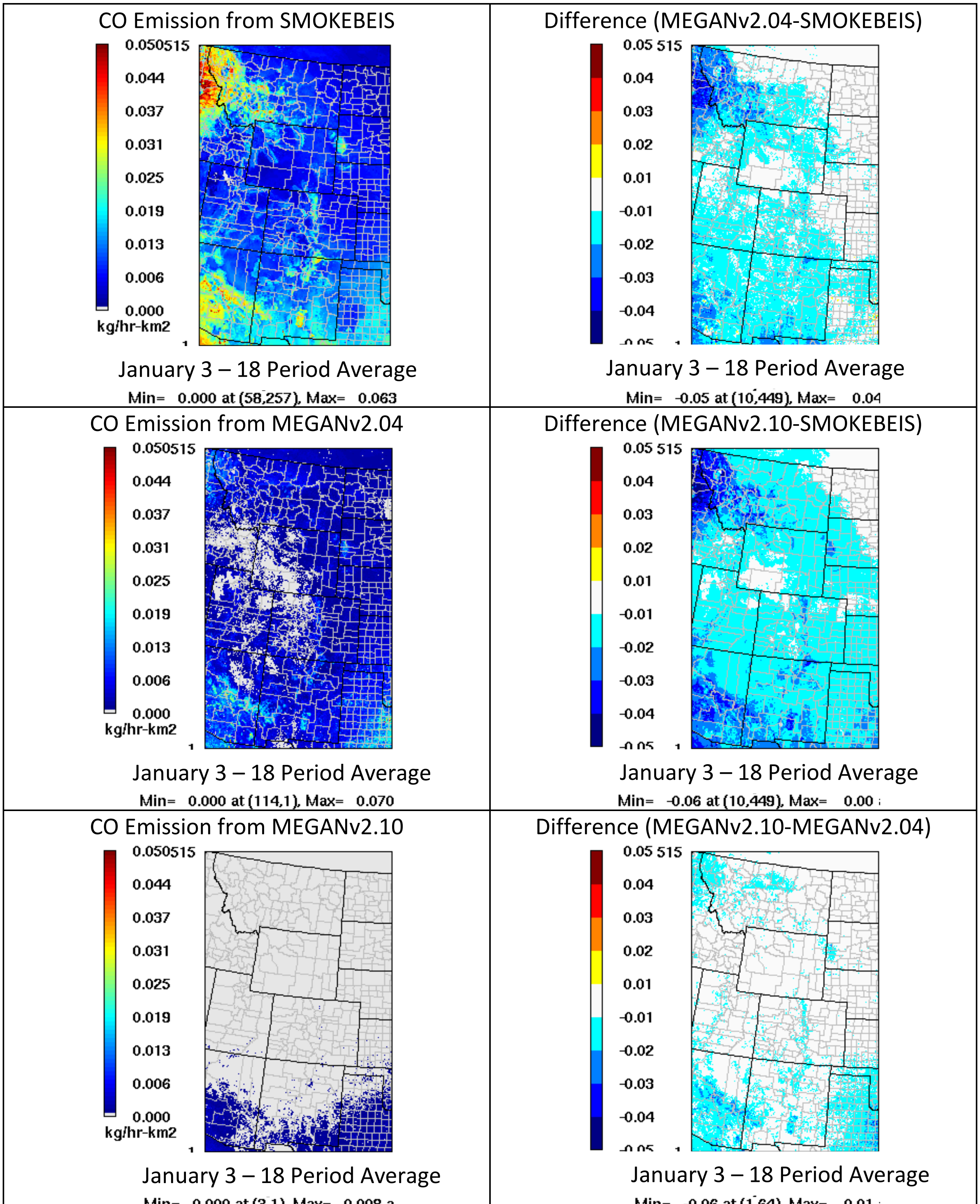



**Figure 4.16. CO emission for January 3 – 18 period average for the 4 km domain from different models, and the emission difference.**

**ISOPRENE AND MONOTERPENE EMISSIONS AND PFTS**

Isoprene and monoterpene emission distributions are compared to PFT and LAI distributions in Figures 17 and 18 to understand the distributions of emissions and their relationships to vegetation. The comparison can be used to assess the functionality of model algorithms. The results show that the emissions in the southeastern U.S. are dominated by broadleaf deciduous trees. The emissions in Canada are from needle leaf evergreen trees and isoprene emissions in the western U.S. are from shrubs. LAI also plays an important role as peak emissions are associated with peak LAI in the southeastern and eastern U.S.

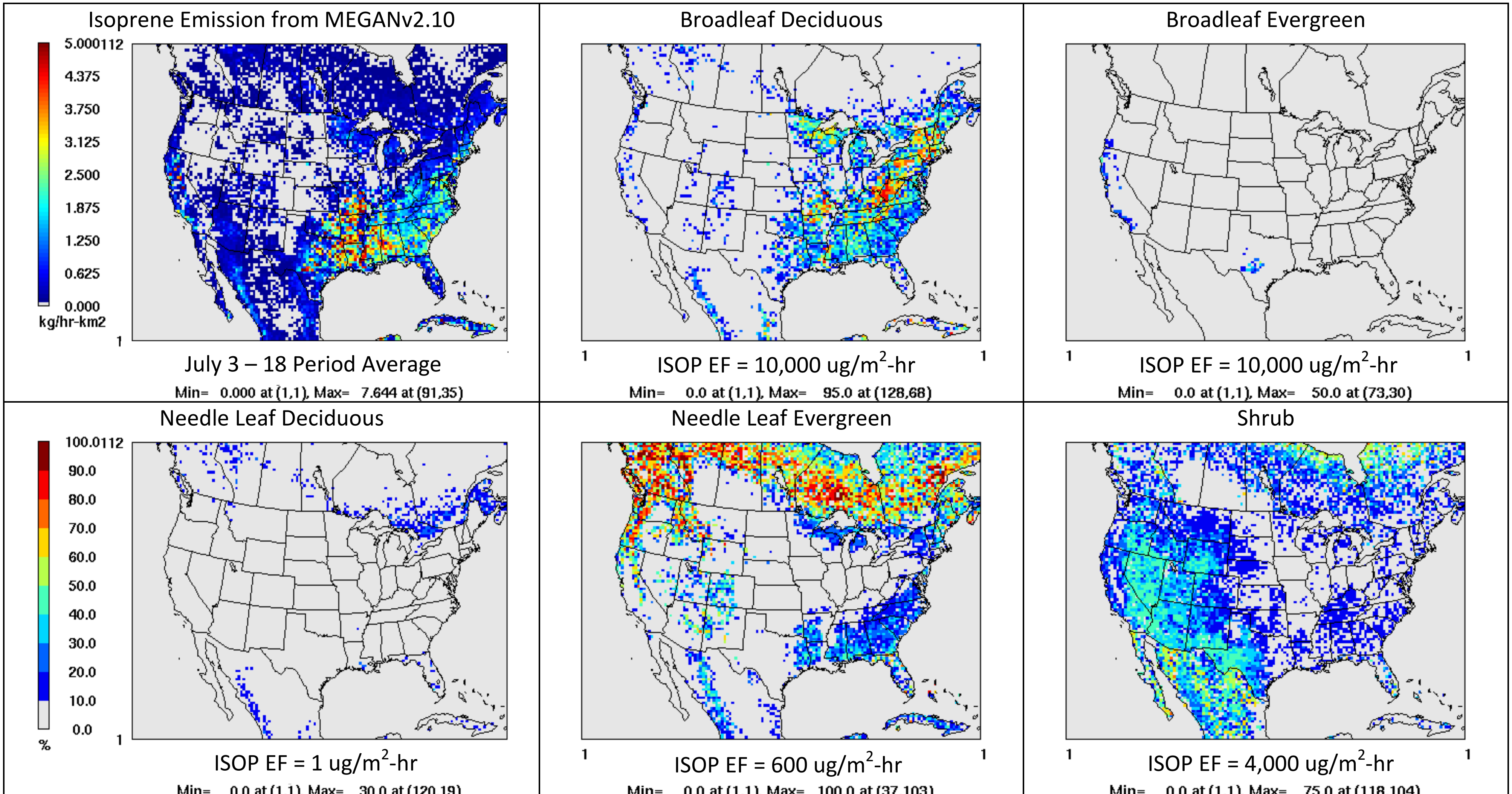



**Figure 4.17a. Isoprene emission for July 3 – 18 period average for the 36 km domain from MEGANv2.10, and PFT distribution used in MEGANv2.10 with corresponding isoprene EFs. The color range for PFT distribution plots refers to color bar in the lower left plot.**

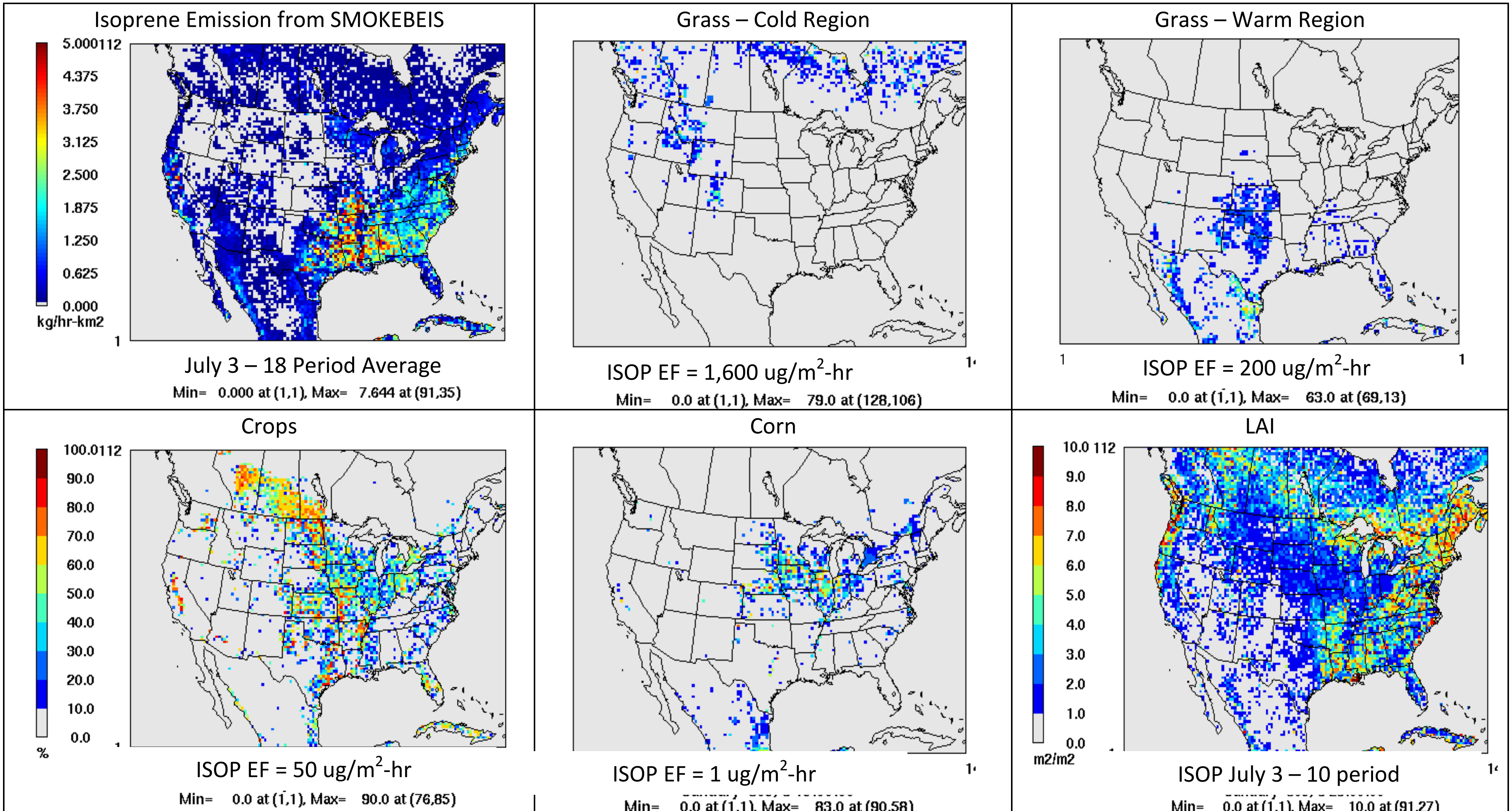



**Figure 4.17b. Isoprene emission for July 3 – 18 period average for the 36 km domain from MEGANv2.10, PFT distribution used in MEGANv2.10 with corresponding isoprene EFs, and LAI for July 3 – 10 period. The color range for PFT distribution plots refers to color bar in the lower left plot.**

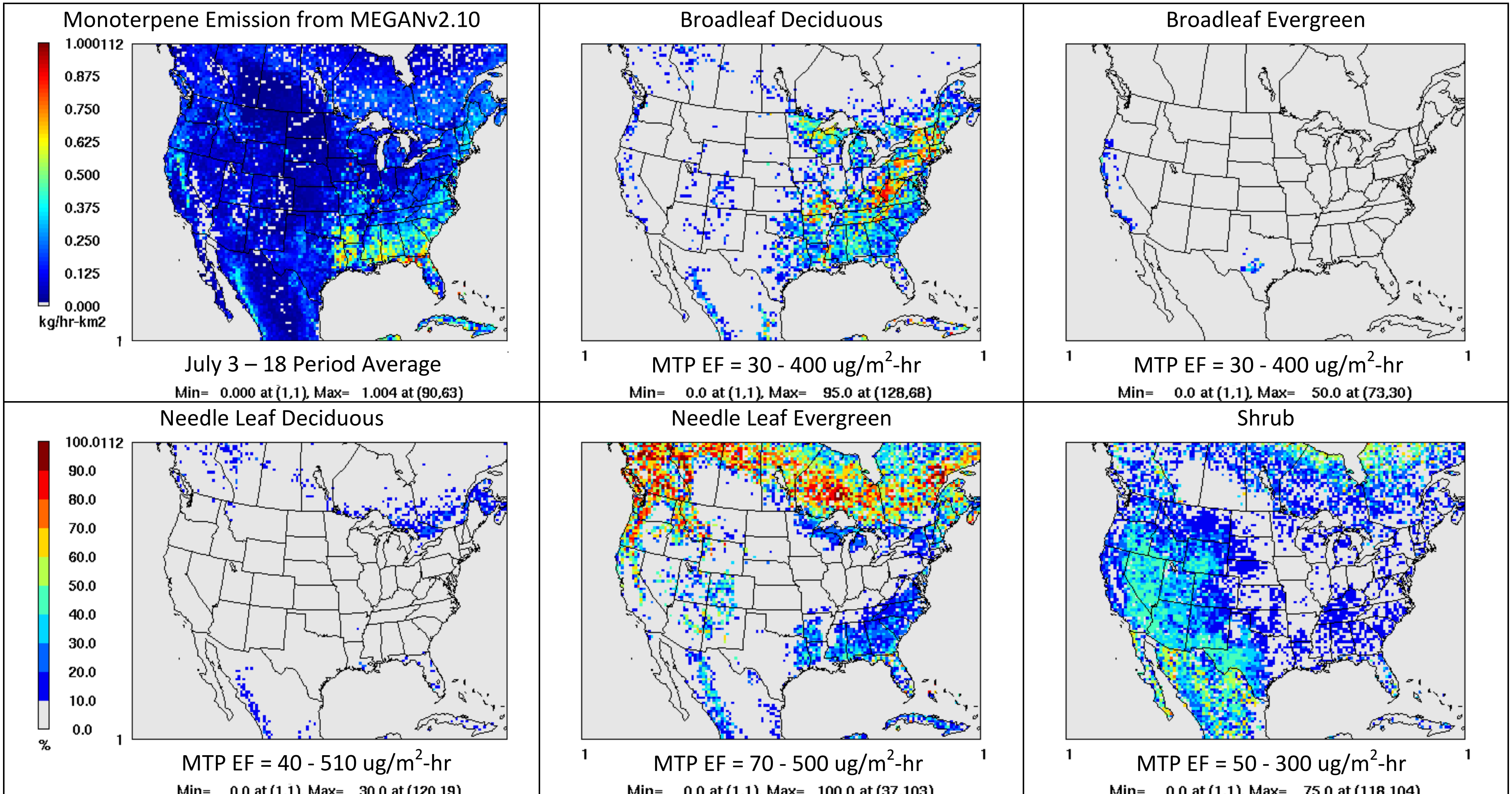



**Figure 4.18a. Monoterpene emission for July 3 – 18 period average for the 36 km domain from MEGANv2.10, and PFT distribution used in MEGANv2.10 with corresponding monoterpene EFs. The color range for PFT distribution plots refers to color bar in the lower left plot.**

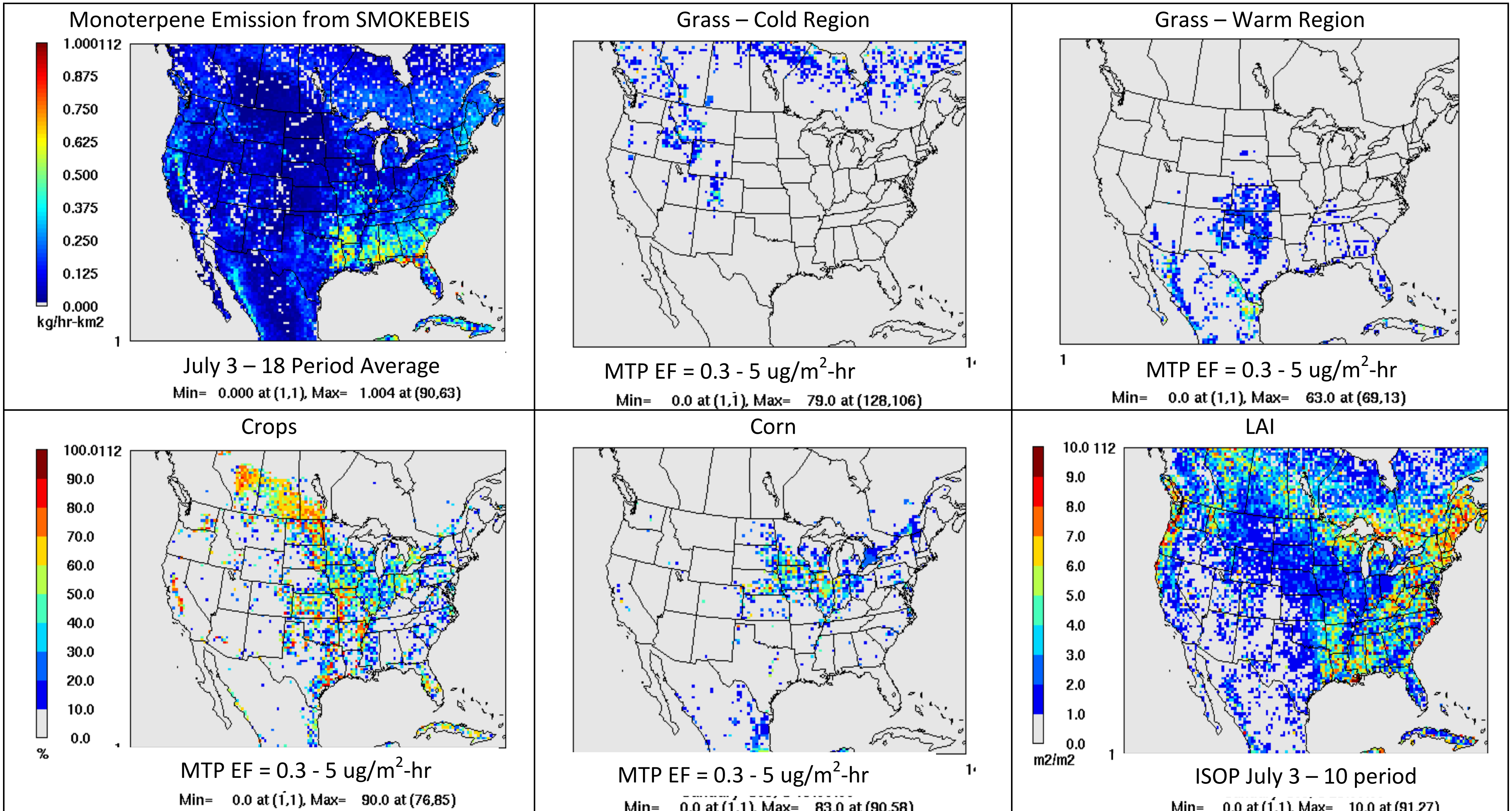



**Figure 4.18b. Monoterpene emission for July 3 – 18 period average for the 36 km domain from MEGANv2.10, PFT distribution used in MEGANv2.10 with corresponding monoterpene EFs, and LAI for July 3 – 10 period. The color range for PFT distribution plots refers to color bar in the lower left plot.**

## 5. CONCLUSION

Emissions from vegetation are the largest source of volatile organic compound (VOC) in the global atmosphere and important to air quality modeling in most regions. The Western Regional Air Partnership (WRAP) requires geo-gridded (model-ready) biogenic VOC and NO emission estimates for air quality modeling application in the Western U.S.

This project developed 2008 biogenic emission inventories using MEGAN version 2.10 which includes several enhancements over the previous version 2.04 of MEGAN and the BEIS system. The enhancements are an explicit canopy environment, updated emission algorithms, a soil NOx emission model, and the ability to use more frequent 8-day average LAI. This project has also improved the ability of MEGAN to accurately estimate biogenic emissions in the Western U.S. by improving Western U.S. land-use and landcover data with 1) 2008 year specific PFTf coverage data based on 30 meter LANDSAT TM data, 2) emission factors based on recent emission measurements and improved U.S. species composition data, and 3) 2008 year specific LAI based on improved satellite data products with higher (8-day) temporal resolution. The meteorological data used in the emission estimates are from 2008 WRF/MCIP modeling except that PAR was derived from ISCCP satellite data.

The emissions from MEGAN 2.10 were compared with the previous version of MEGAN (MEGAN v2.04) and SMOKE BEIS version 3.14 to understand how the model updates in MEGAN 2.10 influence emission estimates and to document the differences among the models. Comparisons were made for winter and summer periods (in January and July) of 2008 for three WRAP modeling domains (36, 12 and 4 km). In summary, MEGAN v2.10 estimates lower monoterpene, NOx, and CO emissions and higher isoprene emission than SMOKE-BEIS. MEGAN v2.10 estimates lower isoprene and CO emissions than MEGAN v2.04 for all domains and the two periods. Monoterpene emissions from MEGAN v2.10 are lower than MEGAN v2.04 except for the 12 km and 4 km domains in July. NOx emission from MEGAN v2.10 is higher than MEGAN v2.04 for July but lower for January. The spatial distributions of emissions from MEGAN v2.10 and MEGAN v2.04 are similar for all pollutants. Comparing to SMOKE-BEIS, MEGAN v2.10 has similar isoprene and monoterpene spatial distributions but different CO and NOx spatial distributions.

The 2008 biogenic emission inventory from MEGAN v2.10 is considered to be improved dataset and should be used for the WRAP 2008 modeling. Applications Advantages of MEGAN 2.10 are the most up-to-date scientific algorithms for emission estimates, year specific 2008 land cover/vegetation inputs with high temporal resolution (8 day LAI), and the most up-to-date emission factors. In addition, the emission distributions from MEGAN v2.10 are more reasonable than SMOKE-BEIS in that SMOKE-BEIS estimates unreasonable high emissions in some desert regions with sparse vegetation, and county boundaries are noticeable in the SMOKE-BEIS isoprene emissions. We recommend future investigation to understand the differences in CO and NOx emissions and recommend future study using biogenic emissions from different models in air quality modeling performance assessments to further evaluate MEGAN v2.10.

The deliverable products from this project are model-ready files for 36 km CONUS, 12 km WESTUS, and 4 km WestJumpAQMS domains for the following cases.

- MEGAN v2.04 for CAMx with CB05 mechanism, for January 3-18 and July 3-18, 2008.
- MEGAN v2.04 for CMAQ with CB05 mechanism, for January 3-18 and July 3-18, 2008.
- BEIS3.14 for CAMx with CB05 mechanism, for January 3-18 and July 3-18, 2008.
- BEIS3.14 for CMAQ with CB05 mechanism, for January 3-18 and July 3-18, 2008.
- MEGAN v2.10 for CAMx with CB05 mechanism, for January 3-18 and July 3-18, 2008.
- MEGAN v2.10 for CMAQ with CB05 mechanism, for January 3-18 and July 3-18, 2008.
- MEGAN v2.10 for CAMx with CB6 mechanism, for the entire 2008.
- MEGAN v2.10 for CMAQ with CB6 mechanism, for the entire 2008.

## 6. REFERENCE

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