NORMBEIS3 (version 3.12)

Normbeis3 reads gridded land use data and emissions factors and produces gridded normalized biogenic emissions. The gridded land use includes 230 different land use types. Emission factors are provided for each land use type. The output gridded domain is the same as the input domain for the land use data. Emission fluxes are normalized to 30 degrees Centigrade and isoprene, methyl-butenol and methanol, are also normalized to a photosynthetic active radiation of 1000 micro moles per square meter-second. Normbeis3 computes normalized emissions for winter months. Normbeis3 outputs winter and summer normalized emissions for these species/compounds (isoprene, methyl-butenol,14 terpenes ,methanol, ethane, propene, ethanol, acetone, hexanal, hexonal, hexenylacetate, formaldehyde, acetaldehyde, butane, ethane, formic acid, acetic acid,3-buten-2-one (MVK), carbon monoxide, other reactive VOCs) as well as winter and summer leaf area indices (LAI). The output units for all species/compounds are in grams of carbon per hour. For NO, there is no distinction between summer and winter. Instead, normalized emissions are computed for three categories: growing season for agricultural grid cells, non-growing season for agricultural grid cells, and non-agricultural grid cells. For non-agricultural areas, the normalized emissions are the same all year long. For agricultural regions, the normalized emissions are based on the grassland factor during the non-growing season and on the appropriate agricultural type during the growing season. Agricultural regions include USGS types of crop-grassland, crop-woodland, dry cropland, and irrigated cropland, and the land use types of alfalfa, barley, corn, cotton, grass, hay, miscellaneous crop, oats, pasture, peanuts, potatoes, rice, rye, sorghum, soybeans, tobacco, and wheat. For the USGS types of crop-grassland, and crop-woodland, the normalized NO factor is multiplied by a factor of a half to account for the fact that these regions contain mixed agricultural and non-agricultural components.

BEIS3 (version 3.12)

Tmpbeis3 uses version 3.12 of the BEIS3 model. Tmpbeis3 reads the gridded, normalized emissions file B3GRD and meteorological data from MET_FILE1 and optionally MET_FILE2 (these files may be either MET_CRO_2D or MET_CRO_3D). Note that Tmpbeis3 uses temperature, surface pressure, convective and nonconvective rainfall data that must be in MET_FILE1, and radiation/cloud data that may be in MET_FILE1 or MET_FILE2. If the Pleim-Xue Land Surface model (PX version) of MM5 was used, then Tmpbeis3 can use the Soil temperature, soil type, and soil moisture fields in MET_FILE1 in the calculation of NO soil emissions. However, if the PX version is not used, Tmpbeis3 will still compute NO soil emissions using the rainfall information.

Within Tmpbeis3, speciation profiles are used to speciate biogenic pollutants for appropriate chemical mechanisms. The speciation profiles used in SMOKE-BEIS3 are different than those used in SMOKE-BEIS2 modeling, and speciation profiles for the CB-IV, RADM2, and SAPRC99 mechanisms are available for BEIS3 modeling. The normalized emissions and meteorological data are used to produce gridded, speciated, hourly biogenic emissions. Additionally, an optional seasonal switch file, BIOSEASON, can be used to determine when and where to use summer or winter normalized emissions data on a daily basis.

In Tmpbeis312, a leaf shading algorithm has been added for estimating methanol emissions from non-forested areas.

The Soil NO algorithm has been completely revised in version 3.12. Based on the work of Yienger and Levy (1995), the soil NO emission flux is based on the normalized factor computed in normbeis312, a temperature adjustment factor, and precipitation adjustment factor, a fertilizer adjustment factor, and a canopy adjustment factor. For the PX Version, the Temperature adjustment factor accounts for wet and dry soils and the precipitation adjustment factor accounts for saturated soils. For the non-PX version, the basic algorithm remains with a temperature adjustment factor (dry soil) and no adjustment for saturated soils.

J.J. Yienger and H. Levy II, Journal of Geophysical Research, vol 100,11447-11464,1995

New Input Environment Variables:

PX_VERSION (Y./N) Y indicate the PX version of the met model was run and MET_FILE1 contains soil temperature, soil moisture, and soil type fields. N indicates these fields are not present or not used in the NO calculation. Default: N

SOILT_VAR: name of soil temperature variable if PX_VERSION = Y: Default SOIT1
ISLYTP_VAR: name of soil type variable if PX_VERSION=Y: Default SLTYP
SOILM_VAR: name of soil moisture variable if PX_VERSION=Y Default: SOIM1

INTIAL_RUN: set to Y for the first day of a sequence of runs. Set to N for subsequent days. If set to N, TmpBeis3 will look for a SOILINP file to restart the soil NO calculation. When set to Y, the Soil NO calculation will not have a rainfall dependence. Default: N

NEW INPUT/OUTPUT files:
SOILINP: contains rainfall data for the past 24 hrs (from a previous run of Tmpbeis3) This file must exist if INITIAL_RUN is set to N

SOILOUT: created at the end of Ttmpbeis3 run for restarting the soil NO algorithm. The user must include in the script some way of renaming or moving the SOILOUT file to a SOILINP file at the end of each run.

A leaf shading algorithm is added for estimating methanol emissions from non-forested areas

Recent changes to the emission factor file include

The emission factors for spruce and fir had been revised. It is Geron's opinion that the monoterpene emission factor for these tree types should reflect a moderate instead of a high monoterpene emission factor. The emission factor has been lowered from ~2.6 ugC/g-hr to ~1.5 ugC/g-hr. In some of the high-emitting counties in the western U.S. (such as Lassen County, California which is near the Lassen Volcanic Park IMPROVE site), this change should lower monoterpene emissions by ~20%.

A white paper describing the 2001 changes to the shrubland factors is included at the end of this document.

Reconsideration of the Emission Factors assumed in BEIS3 for Three USGS Vegetation Categories: Shrubland, Coniferous Forest, and Deciduous Forest

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Background—

This technical memorandum is in response to concerns raised about the emission factors assumed in BEIS3v0.9 for the shrubland and coniferous forest categories. Earlier in 2001, the Atmospheric Modeling Division released a prototype version of the Biogenic Emissions Inventory System (BEIS3v0.9) for preliminary testing. OAQPS has been actively examining results from SMOKE/BEIS3v0.9, including a CMAQ model grid domain that extends to the Pacific Ocean. This is one of the first – if the not the first – applications of CMAQ/BEIS to the western U.S. However, the resulting isoprene emissions estimated for this region have raised questions about the rather substantial emissions arising from "desert" areas. Further inspection revealed that these emissions were almost all attributable to the USGS shrubland category, a prominent vegetation category in the BELD3 database.

Shrubland is one of nineteen USGS categories in the Biogenic Emissions Landuse Database (BELD3). USGS categories are assigned to portions of the modeling domain lacking vegetation coverage from the US Forest Service and the US Department of Agriculture datasets. It was hoped in developing BELD3 that the USGS categories would not contribute significantly to the biogenic emissions estimates across the United States, because of the uncertainties in assigning vegetation species distributions, leaf biomass, and emission factors to these rather broad categories. Indeed, one of the primary motivations for developing BELD3 was to estimate, where possible, species-specific biomass distributions so that more accurate biogenic emission inventories could be constructed. It has now become painfully obvious, however, that the USGS categories demand more attention because of their prevalence in BELD3 over many parts of the U.S., particularly in the west. We will examine the distribution of three important USGS categories and reconsider their assumed emission factors for use in BEIS3.

BELD3 vegetation data—

To assess the prevalence of the USGS shrubland category, the BELD3 data have been summarized and sorted for the contiguous U.S. and for four southwestern states in Table 1.

Table 1. Areal coverage of the top five vegetation categories from BELD3 for four southwestern states and the contiguous United States

Arizona (total = 28.6 million ha)	
Shrubland	64%
Grassland	14%
Juniper	6%
Conifer forest	4%
Mesquite	2%
California (total = 40.0 million ha)	
Shrubland	26%
Savanna	12%
Shrub/grassland	7%
Misc_crop	6%
Conifer forest	6%
Nevada (total = 27.0 million ha)	
Shrubland	68%
Shrub/grassland	11%
Juniper	8%
Pine_pinyon	5%
Sparse/barren	3%
Utah (total = 20.7 million ha)	
Shrubland	53%
Grassland	6%
Juniper	6%
Shrub/grassland	5%
Conifer forest	5%
US-48 states (total = 731.5 million ha)	
Shrubland	13%
Grassland	11%
Misc_crop	8%
Conifer forest	4%
Corn	4%

Table 1 confirms the concern raised by Mr. Brian Timin of OAQPS that the USGS shrubland category predominates in the southwestern U.S. and thus deserves careful scrutiny for CMAQ modeling applications. It is also clear that the USGS coniferous forest category deserves attention as it comprises 4% of the land area in the contiguous U.S. and is among the top five categories for three of the four southwestern states shown above.

Emissions Potential—

To further investigate the emissions significance of the shrubland category and the other poorly characterized USGS vegetation categories, we multiplied the BEIS3 isoprene emission factors by the vegetation cover area for each BELD3 vegetation category across the contiguous United States. As seen in Table 2, the top five potential contributors are oak, populus (e.g., aspen), and three USGS categories.

Table 2. Isoprene emissions potential for the top five categories estimated across the contiguous United States, based on normalized BEIS3v0.9 emission factors and vegetation coverage from BELD3

BELD3 vegetation category(s)	Isoprene emissions potential
Oak (summed over all species)	43%
Conifer forests	14%
Shrubland	10%
Populus	10%
Deciduous forests	8%

Although (as expected) the contribution to isoprene by oaks dominates across the continental U.S., nearly one-third of the emissions potential may be attributed to the USGS categories conifer forests, shrubland, and deciduous forests.

Basis and Recommendation for Selected USGS Emission Factors—

The basis for the isoprene emission factors currently assumed in BEIS3v0.9 for each of these three categories is given below.

$$\text{Conifer forests} = 11{,}383\ \text{gC/km}^2\text{-hr}$$

Our initial thinking was to construct an emission factor that would be applicable to Canada, since we were assuming that the US Forest Service data would account for any tree coverage information in the United States. The SMOKE/BEIS3 system currently accounts for this “on-the-fly” and applies a grassland (or “open forest”) emission factor anytime a USGS tree category is encountered in a U.S. grid cell and there is US Forest Service information. This assumption avoids the problem of double-counting trees. According to the Ontario Forestry Association (www.oforest.on.ca), boreal or evergreen needleleaf forests are dominated by white spruce, black spruce, jack pine, balsam fir, poplars, and white birch. Using this tree distribution and the BEIS3 emission factors, we have computed the emission factor to be the following:

$$11{,}383 = (2*21{,}000 + 70 + 150 + 26{,}250 + 38)/6$$

where genus-level emission factors for the six tree “categories” were applied evenly to arrive at a rate of 11,383. Thus, three very high isoprene emitters – two species of spruce and poplar – result in a high isoprene emission factor.

The major limitation with this emission factor is that the assumed tree distribution applies everywhere across the modeling domain. As stated earlier, this may not seriously affect calculations for the U.S. (except with the existing SMOKE/BEIS2 code), but tree distributions in the western portion of Canada are likely to be different. Thus, for applications involving British Columbia, this assumption needs to be revisited. I recommend that we sift through the database and determine to what extent conifer forests are actually producing significant emissions. For certain geographical areas, we may need to revisit the calculation of the emission factor and perhaps generate geographic specific emission factors. Logical geographical separations might be western Canada/northwestern U.S. conifer, southeastern U.S. conifer, northeastern U.S./eastern Canada conifer, southwestern U.S./Mexican conifer. If Chris Geron could provide a preliminary “one-size-fits-all” interim solution, I will gladly incorporate it into the emission factor database.

Deciduous forests = 8,232 gC/km^2-hr

The logic for this USGS category is analogous to the conifer forest emission factor and applies primarily to eastern Canadian forests. Using information given on the Ontario Forestry Association web site, the following tree distributions were assumed: 44% USGS coniferous forest (tree distribution given above) and approximately even proportions of maple, red pine, white pine, white oak, red oak, birch, tulip poplar, sassafras, and hickory.

Shrublands = 2,859 gC/km^2-hr

The basis for this emission factor is very weak, but closely follows that given by Guenther et al. (1995) in a global model of natural VOC emissions for the categories grass/shrub-hot, mediterranean, and semi-desert. In the Guenther et al. article, normalized emission factors for these three categories ranged from 2000 – 3000 gC/km2-hr.

Review of the Guenther et al. paper indicates that the basis for these three emission factors is scanty, with citations only available for work performed by Zimmerman (1979) and Arey et al. (1995). Given the prevalence of shrubland in the western U.S. and its contribution to isoprene emissions, a quick review of available U.S. emission factor data has been attempted with the goal of proposing a revised shrubland emission factor.

Information provided by Arey et al. (1995), Diem and Comric (1998), Guenther et al. (1995, 1999), Knowlton et al. (1999) and Geron (personal communication, 2001) allows us to propose the following revised emission factors for shrubland:

Isoprene = 600 gC/km^2-hr (range: 200 – 3000 gC/km^2-hr)
Monoterpenes = 250 gC/km^2-hr (range: 100 – 2000 gC/km^2-hr)

This revision represents nearly a factor of five decrease in the isoprene emission factor currently assumed in BEIS3v0.9. However, it should be duly noted that because of the absence of emission factor measurements, uncertainties in characterizing shrubland vegetation species composition and biomass, the range of uncertainty for these assumed emission factors spans an order of magnitude!

In addition, it is recommended that the shrub/grassland category in BEIS3 be recalculated to reflect a mosaic of the USGS shrubland and grassland categories.

Summary—

- In the BEIS3/BELD3 system, the USGS shrubland category is prominent, especially in the western U.S. where it dominates in areal coverage and potential isoprene emissions.

- The emission factors for the USGS vegetation categories are based on very sketchy information.

- The emission factors proposed for the USGS coniferous forest and deciduous categories were based on vegetation distributions from Canada.

- The current BEIS3 system treats most (but not all) coniferous and deciduous forest areas in the U.S. as "open forest". We are not, at the moment, proposing changes to these emission factors.

- Revised shrubland and shrubland/grassland emission factors for isoprene and monoterpenes have been proposed, based on a few citations in the literature and on measurements performed (but not yet published) by NRMRL.

- The technical basis for the BEIS3 emission factors assumed for the USGS categories should continue to be closely evaluated and modified as new information becomes available.

References—

Arey, J., D. Crowley, M. Crowley, M. Resketo, and J. Lester (1995) Hydrocarbon emissions from natural vegetation in California's South Coast Air Basin, *Atmospheric Environment*, **29**, pp. 2977-2988. (One of two U.S. shrubland studies cited by

Guenther et al. [1995]. Enclosure measurements reported for ten native plant species. Some plants emitted a significant amount of terpenes, including sequiterpenes. Emissions showed significant plant-to-plant and seasonal variability. Also, indications were strong that herbivory and other “disturbances” elevated the emissions of terpenes and other VOCs. Emissions from oak averaged <25 ug/g/hr, significantly less than NCAR measurements even after considering cuvette vs. enclosure effects. Am assuming that the emission factor measurements were assimilated by Guenther et al. [1995].)

Diem, J. and A. Comric (1998) Development of a biogenic emissions inventory for a southwestern semi-arid city, *Proceedings of the American Meteorological Society Second Urban Environment Symposium*, November 2-6, 1998, Albuquerque, New Mexico, pp. 40-41. (Very short article apparently based on the first author’s PH.D. dissertation. Have been unable to locate any peer-reviewed journal material related to actual emission factor development. For the Tucson region, authors developed a biogenic inventory that relies heavily on Benjamin’s taxonomic approach. For the modeling domain, normalized isoprene = 454 ug/m2-hr and normalized monoterpenes = 248 ug/m2-hr. Also refers to a study by Chinkin for Phoenix (which also relies heavily on a taxonomic approach), where isoprene = 325 ug/m2-hr and monoterpenes = 93 ug/m2-hr.)

Geron, C., personal communication, July 3, 2001. (Assisted in measurements made in 1998 and 1999 at the FACE site in western Nevada. Ephedra and psorothamnus were found to be isoprene emitters. Suggests that a range of isoprene emissions for this region may be on the order of 400-1000 ug/m2-hr. As with the Knowlton et al. work, isoprene emissions continued to increase above 40C. Recommends that the range given above may be a good place to start for the shrubland/desert emission factors.)

Guenther, A., et al. (1995) A global model of natural volatile organic compounds, *Journal of Geophysical Research*, **100**, pp. 8873-8892. (Consensus model developed from emission factors available up to the early 1990s. Very limited information available for U.S. shrubland. Only two citations; both are considered here. Isoprene emissions for “shrubland” like categories ranged from 2000-3000 ug/m2-hr, monoterpenes ranged from 300-1000 ug/m2-hr, and other VOCs ranged from 500-1100 ug/m2-hr.)

Guenther, A., et al. (1999) Biogenic hydrocarbon emissions and landcover/climate change in a subtropical savanna, *Physics and Chemistry of the Earth – B: Hydrology, Oceans, and Atmosphere*, **24**, pp. 659-667. (Reports on enclosure and above-canopy measurements taken in a mixed savanna parkland/thorn woodland landscape. It is not exactly shrubland, but it is worth a comparison. Mean VOC emissions = 700 ug/m2-hr.)

Knowlton, J., R. Martin, and C. Popp (1999) Biogenic hydrocarbon, organic acid, and carbonyl emissions from desert shrubs, *Proceedings of the AWMA Annual Meeting*, June 20-23, 1999, St. Louis, Missouri, 14 pp. (This paper reports on enclosure measurements made over two days for seven desert shrubs in southern New Mexico: including shrub live oak, salt brush, juniper, creosote, and mesquite. Only live oak had detectable isoprene, averaging 25 ug/g-hr. All shrubs emitted other VOCs. Dominate monoterpenes were a-pinene and myrcene. Other detected compounds included acetic and formic acid, formaldehyde, and acetaldehyde. Important findings were that isoprene did not decline at temperatures above 40C, indicating a heat tolerance by desert plants. Response of monoterpenes to temperature was not as strong as other non-desert studies have shown. Assuming that desert shrub oak is $1/7^{th}$ of biomass and total leaf biomass = 100 g/m2, then normalized isoprene emissions inferred from this study is ~1000 ug/m2-hr. To my knowledge, this work has not yet been published in a peer-reviewed journal and it is based on only a few measurements.)

Zimmerman, P. (1979) *Testing of hydrocarbon emissions from vegetation, leaf litter and aquatic surfaces, and development of a methodology for compiling biogenic emission inventories*, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. (This report is a pioneering effort, from which later studies have been based. Reports on numerous enclosure measurements made in the Tampa Bay area. Light was poorly characterized, so isoprene factors are difficult to interpret. Because vegetation species do not necessarily represent western shrublands, no information from this report was used directly in determining a revised emission factor for shrubland. However, Guenther et al. [1995] may have considered information from this report.)