CHANGES TO THE BIOGENIC EMISSIONS INVENTORY SYSTEM VERSION 3 (BEIS3)

Donna Schwede*[+], George Pouliot[+], and Thomas Pierce[+]
Atmospheric Sciences Modeling Division, Air Resources Laboratory, NOAA,
Research Triangle Park, NC, USA

1. INTRODUCTION

A new version of the Biogenic Emissions Inventory System (BEIS3.13) has been created for the 2005 release of CMAQ (v 4.5). Development of BEIS3.13 was prompted by a recommendation from Environment Canada to update the isoprene emission factor for spruce and an in-depth examination of the treatment of the light correction factor for isoprene. BEIS3.13 also includes updated monoterpene emission factors for Douglas fir and hemlock. This extended abstract summarizes the changes in BEIS3.13 compared to BEIS3.12 and briefly describes the sensitivity of CMAQ predictions to these changes.

2.0 EMISSIONS MODEL

Biogenic emissions of isoprene and monoterpenes are calculated in BEIS3 from a standardized emission rate that assumes a leaf temperature of 30°C and photosynthetically active radiation (PAR) of 1000 μmol m^{-2} s^{-1}. The standardized emission rate is then adjusted for actual temperature and radiation conditions using empirical algorithms.

2.1 Standardized Emission Factors

In earlier versions of BEIS3, standardized isoprene emission factors for black spruce, blue spruce, white spruce, and Englemann spruce were assumed to be 14 μgC g^{-1} h^{-1}. With BEIS3.13, this emission factor has been lowered to 7 μgC g^{-1} h^{-1}, based on more detailed measurements of spruce by Isebrands et al. (1999), Pattey et al. (1999), and Westberg et al. (2000) who report emission factors for spruce ranging from 6-8 μgC g^{-1} h^{-1}. Assuming a leaf biomass of 1500 g m^{-2}, this translates into an area flux of 10,500 gC km^{-2} h^{-1}. The reduction in the emission factor for all spruce species has consequently resulted in reductions in the emission fluxes for USGS-defined coniferous forests (from 11,383 gC km^{-2} hr^{-1}to 7,918 gC km^{-2} h^{-1}) and for USGS-defined deciduous forests (from 8,232 gC km^{-2} h^{-1} to 6,707 gC km^{-2} h^{-1}). The main effect of these changes is to reduce isoprene emissions in Canada as shown in Figure 1.

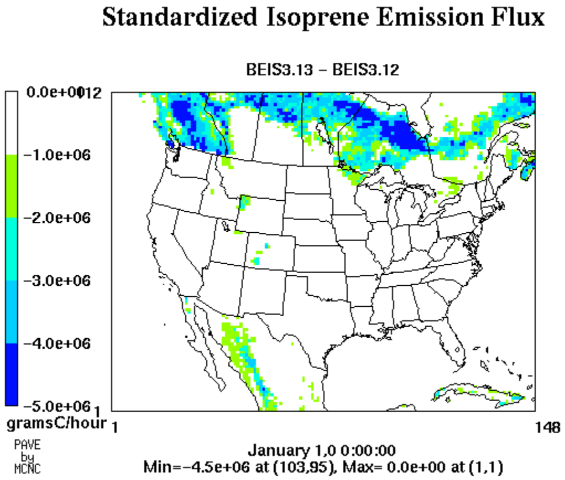
Standardized Isoprene Emission Flux

Figure 1. Difference in standardized isoprene emission flux calculated by BEIS3.13 compared to BEIS3.12 for the RPO North American domain (grid size = 36 km).

The standardized emission factors for monoterpenes were also updated. In earlier versions of BEIS3 the emission factor for Douglas fir was 1.41 μgC g^{-1} h^{-1}. Based on extensive measurements by Pressley et al (2004), this factor was reduced to 0.39 μgC g^{-1} h^{-1} in BEIS3.13. Assuming a leaf biomass of 1500 g m^{-2}, this translates into an area flux of 585 gC km^{-2} h^{-1}. This change mainly affects the emissions in the Pacific Northwest as shown by the decrease in α-pinene emissions in Figure 2. The emission factor for hemlock was also changed in BEIS3.13 based on Pressley et al (2004) from 0.18 μgC g^{-1} h^{-1} to 0.95 μgC g^{-1} h^{-1}. Assuming a leaf biomass of 700 g m^{-2}, this translates into an area flux of 665 gC km^{-2} h^{-1}. This change mainly affects the monoterpene emissions in the Northeast as shown in Figure 2.

---

[*] *Corresponding author:* Donna Schwede, USEPA, MD E-243-04), RTP,NC 27711; schwede.donna@epa.gov
[+] In partnershjp with the National Exposure Research Laboratory, U.S. Environmental Protection Agency.

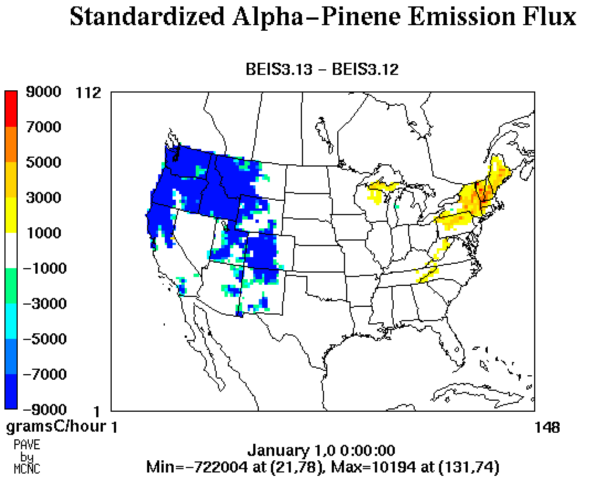

Figure 2. Difference in standardized alpha-pinene emission flux calculated by BEIS3.13 compared to BEIS3.12 for the RPO North American domain (grid size = 36 km).

2.2 Effect Of Temperature

BEIS uses the ambient temperature as a surrogate for leaf temperature. BEIS3.12 uses the 10 m temperature from the Meteorology-Chemistry Interface Processor (MCIP) meteorological file, which is a rediagnosed variable. MCIP version 3 also provides the 2 m temperature, which is passed directly from MM5. BEIS3.13 can use either of these temperatures. Figure 3 shows a comparison of domain total isoprene and monoterpene emissions calculated using the different temperatures for July 7-9, 2001. Using the 2 m temperature results in 12% higher isoprene emissions during the daytime. Monoterpene emissions are 10% higher during the day and up to 7% lower at night using the 2 m temperature. Arguments can be made for using either the 2 m or the 10 m temperature. Future work will examine the use of vegetation-type dependent temperatures.

2.3 Effects of Radiation

Visible solar radiation (PAR) strongly influences isoprene emissions from leaves. The partitioning of radiation into its components is typically modeled using empirical relationships that rely on global radiation as input. In BEIS, PAR is separated into its direct and diffuse components based on the global radiation at the top of the canopy. The canopy can then be treated as a big-leaf or a multi-layer canopy in modeling the transmission of direct and diffuse PAR through the canopy.

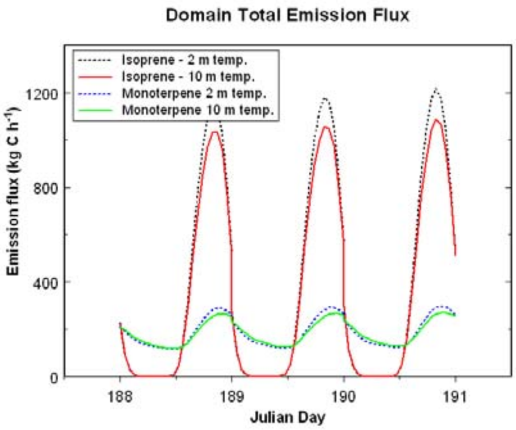

Figure 3. Domain total emissions of isoprene and monoterpene from BEIS3.13 using the MCIP 2 m and 10 m temperatures.

2.3.1 Top of canopy radiation

To estimate the partitioning of radiation at the top of the canopy, BEIS uses the model of Weis and Norman (1985). An alternative approach is the model of Spitters et al. (1986) which is used in the Global Biosphere Emissions and Interactions System (GLOBEIS) (Yarwood et al., 2003), another biogenic emissions model. We ran each of these radiation models using global radiation from the SURFRAD network (Augustine et al., 2000) as input and compared the estimated direct and diffuse radiation against the measurements at the SURFRAD site. Figures 4 and 5 show a comparison of the estimates of direct and diffuse radiation from these models with the measured values from the SURFRAD site in Bondville, IL. We see that the models estimate the direct radiation fairly well, but show significant errors for the diffuse radiation. We performed similar comparisons at a number of SURFRAD sites. Because the estimates from the Weis and Norman model more closely matched the observations, we have retained this model in BEIS3.13.

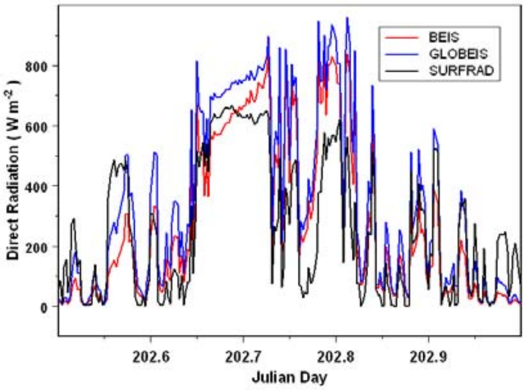

Figure 4. Comparison of direct radiation estimated by BEIS and GLOBEIS radiation modules with measurements from the SURFRAD site in Bondville, IL for 20 July 2004.

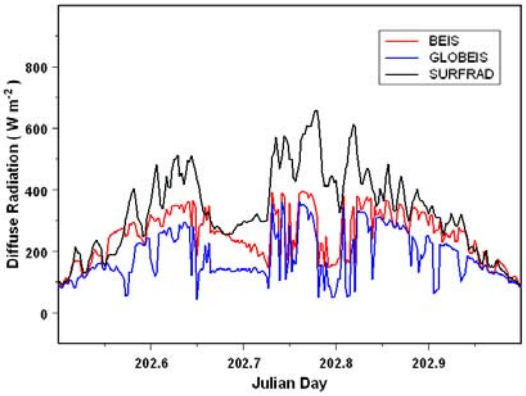

Figure 5. Comparison of diffuse radiation estimated by BEIS and GLOBEIS radiation modules with measurements from the SURFRAD site in Bondville, IL for 20 July 2004.

2.3.3 PAR Adjustment factor

For isoprene, the adjustment factor for the effects of PAR (γ_p) is calculated as in Guenther et al. (1993)

$$\gamma_p = (\alpha C_L Q)/[(1+\alpha^2 Q^2)^{0.5}] \quad (1)$$

where α and C_L are coefficients and Q is the photosynthetic photon flux density (µmol m^{-2} s^{-1}). BEIS3.12 uses α = 0.0027 and C_L = 1.066 as in Guenther et al. (1993). More recent work by Guenther et al. (1999) describes an approach with updated coefficients and with α and C_L varying with canopy depth. Values for α and C_L are calculated as follows

$$\alpha = 0.001 + 0.0085 LAI \quad (2)$$

$$C_L = 1.42\exp(-0.3 LAI) \quad (3)$$

where LAI is the cumulative leaf area index above the leaf. The PAR adjustment factor is calculated at each level in the canopy, using Q at that level, and then integrated to get a whole canopy value.

BEIS uses a big-leaf canopy model rather than a multilayer model so we implemented equations 2 and 3 assuming a cumulative LAI of zero (i.e. top of canopy). To assess the effect of this simplification, we developed a multilayer version of BEIS to be able to use the full equations. We used the multilayer approach from the Multilayer Model (MLM) (Meyers et al, 1998) and the Multilayer Biochemical Model (MLBC) (Wu et al, 2003) which allows plant specific vertical profiles of leaf area index. The LAI profiles are then used to calculate the Q at each level. We found that comparable values of γ_p could be obtained using a uniform vertical LAI profile with the multilayer model and the big-leaf model. We also extracted the code for calculating γ_p from the GLOBEIS model and compared the results from the big-leaf model with those from GLOBEIS. For consistency, we modified the GLOBEIS code to initialize it with the Weis and Norman model at the top of the canopy. As shown in Figure 6, BEIS3.13 is in good agreement with the GLOBEIS values.

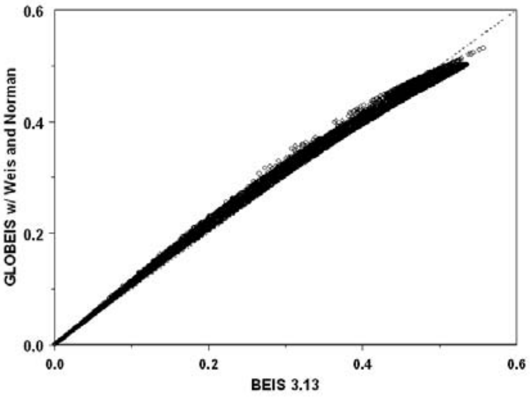

Figure 6. Comparison of the PAR adjustment factor calculated by the BEIS3.13 and GLOBEIS radiation modules for each valid SURFRAD observation at the Bondville site for July 2004.

Given the results of these comparisons and the need to minimize computational time, BEIS3.13 contains equation 1 as in BEIS3.12, but uses α =

0.001 and $C_L = 1.42$ for the values of the empirical constants. Figure 7 shows a comparison of the isoprene adjustment factors from BEIS3.12 and BEIS3.13. The γ computed by BEIS3.13 is lower than the factor computed by BEIS3.12 for most PAR values. Figure 8 shows the temporal pattern of γ using the results from the SURFRAD station at Bondville. We see a large effect of changing the coefficients during peak radiation periods.

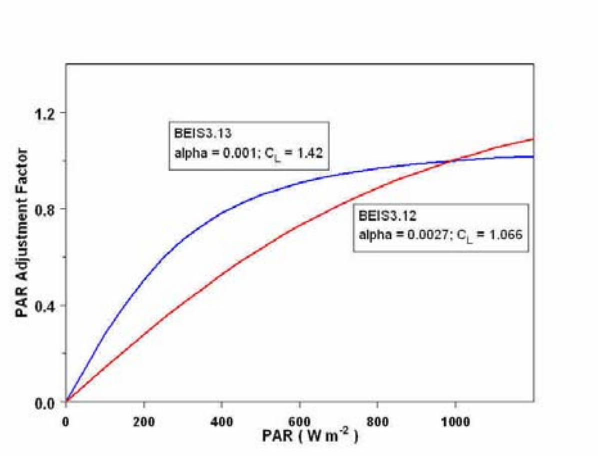

Figure 7. Comparison of PAR adjustment factors for BEIS3.13 and BEIS3.12.

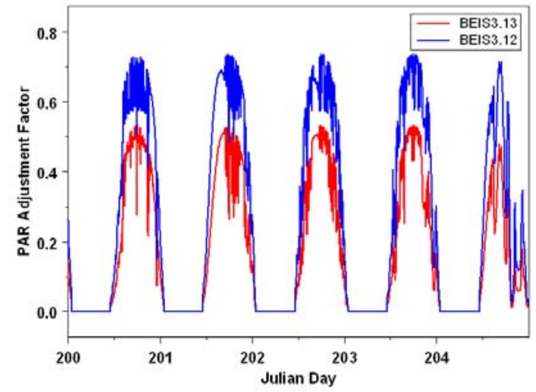

Figure 8. Diurnal variation of PAR adjustment factor using data from the Bondville, IL SURFRAD site for July 2004.

3. CMAQ MODEL RESULTS

A pre-release build of CMAQ v4.5 was run for July 2001 for the RPO North American domain (36 km grid size) using emissions calculated from BEIS3.12 and BEIS3.13. BEIS3.13 was run using the 2 m temperature from MCIP. Comparisons of the input emissions and CMAQ model predictions are presented below.

Figure 9 shows the difference in isoprene emission calculated by BEIS3.12 and BEIS3.13 for 23 UTC on 8 July 2001. Across the modeling domain, isoprene emissions decreased by 44% during the July 2001 simulation. This decrease was expected because of the reduction in the standardized emission factor and the decrease in the PAR adjustment factor. These reductions in emissions lead to lower isoprene concentrations (not shown) and slightly lower ozone concentrations as shown for 01 UTC on 7 July 2001 (Figure 10).

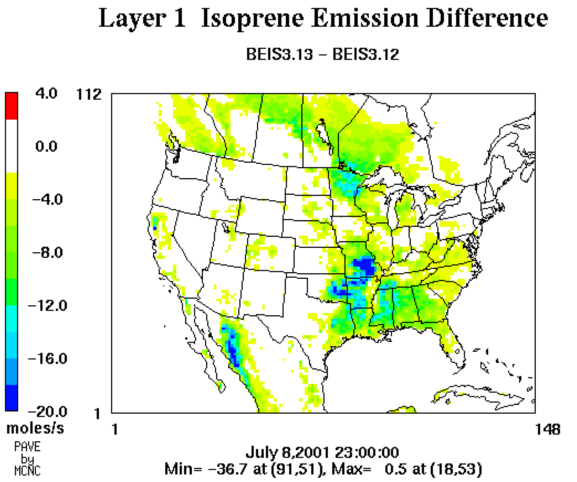

Figure 9. Difference in isoprene emissions from BEIS3.13 and BEIS3.12 for 23 UTC on 8 July 2001.

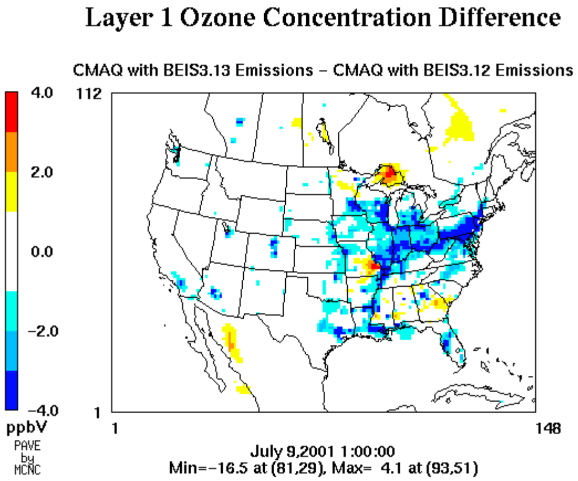

Figure 10. Difference in CMAQ predicted ozone concentrations using emissions from BEIS3.13 and BEIS3.12 for 1 UTC on 9 July 2001.

The differences in monoterpene emissions are shown in Figure 11 for 23 UTC on 6 July 2001. Domain total emissions were reduced by about 1%, but larger reductions can be seen in the

Pacific Northwest due to the reduction in the standardized emission factors. However, minor increases in emissions are noted in other areas due to the change from the 10 m (used with BEIS3.12) to the 2 m (used with BEIS3.13) temperature. Changes in monoterpene emissions affect the modeled concentrations of secondary organic aerosols. Figure 12 shows the organic carbon (OC) concentrations for 12 UTC on 7 July 2001. The concentration of OC generally decreases, most noticeably in the Pacific Northwest.

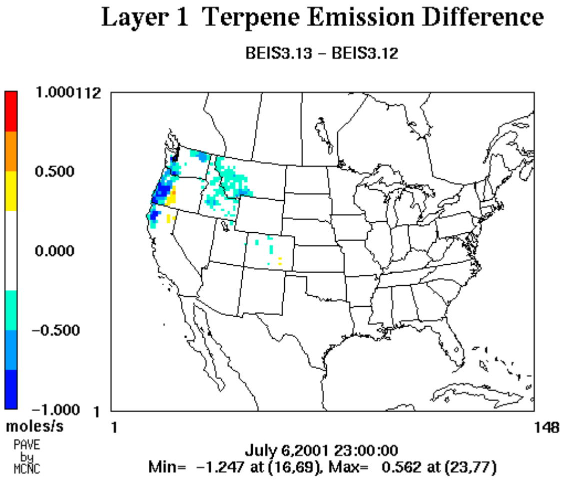

Figure 11. Difference in monoterpene emissions for 23 UTC on 6 July 2001.

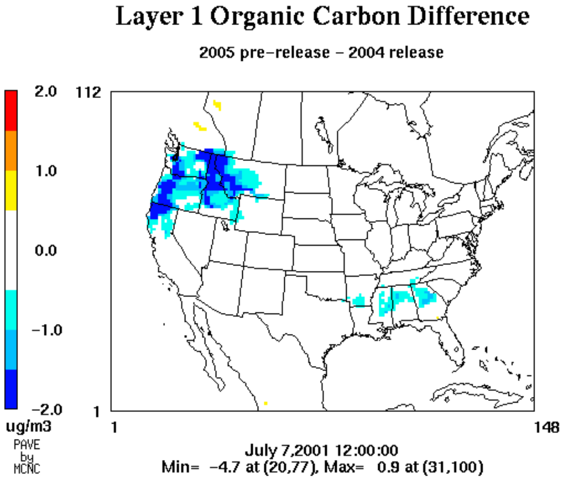

Figure 12. Difference in CMAQ predicted organic carbon concentrations using emissions from BEIS3.13 and BEIS3.12 for 12 UTC on 7 July 2001.

We also did a preliminary analysis of CMAQ model performance using the two sets of emissions by comparing model predictions of organic carbon, PM 2.5, and 8-hour maximum ozone with observations from the AIRS and IMPROVE monitoring networks. As noted above, these species are affected by changes in isoprene and monoterpene emissions. The model performance statistics including root mean square error (RMSE), normalized mean bias (NMB), and normalized mean error (NME) are given in Table 1. For O_3, there was little difference in the RMSE between the two model runs, while the NMB and the NME both decreased when the emissions from BEIS3.13 were used. For PM 2.5, there was little difference in the performance statistics for the two model runs. In contrast, the performance statistics for OC showed a marked decrease in the NMB and NME when the BEIS3.13 emissions were used.

Table 1. Performance statistics for CMAQ using emissions from BEIS3.13 and BEIS3.12 for the IMPROVE and AIRS monitoring networks

		BEIS3.12	BEIS3.13
8 hr O_3	RMSE (ppmV)	0.02	0.01
	NMB	16.71	14.20
	NME	37.78	36.97
PM 2.5	RMSE (μg m^{-3})	5.42	5.34
	NMB	-35.70	-37.65
	NME	47.80	46.89
OC	RMSE (μg m^{-3})	1.25	1.07
	NMB	10.35	0.38
	NME	72.65	63.51

7. SUMMARY

Based on a review of current literature and suggestions from the user community, a new version of the Biogenic Emissions Inventory System (BEIS3.13) has been developed. This new version of BEIS results in reductions in isoprene emissions, primarily in the Eastern U.S and Canada. Monoterpene emissions calculated by BEIS3.13 are generally lower in the Pacific Northwest and slightly higher in the Northeastern U.S. when compared to those from BEIS3.12. The sensitivity of CMAQ to these changes was explored and slight changes in model predictions of ozone and PM 2.5 occurred as a result of varying the biogenic emissions. There was a notable improvement in model performance for organic carbon when emissions from BEIS3.13 were used.

8. REFERENCES

Augustine, J. A., J. DeLuisi, and C. Long, 2000: SURFRAD -- A National Surface Radiation Budget Network for Atmospheric Research. *Bulletin of the American Meteorological Society*, **81**, 2341-2357.

Guenther, A., P. Zimmerman, P. Harley, R. Monson, and R. Fall, Isoprene and monoterpene emission rate variability: Model evaluation and sensitivity analysis, *J. Geophys. Res.*, **98**, 12609-12617.

Guenther, A., B. Baugh, G. Brasseur, J. Greenberg, P. Harley, L. Klinger, D. Serca, and L. Vierling, 1999: Isoprene emission estimates and uncertainties for the Central African EXPRESSO study domain. *J. Geophys. Res.*, **104**, 30625-30639.

Isebrands, J.G., A. B. Guenther, P. Harley, D. Helmig, L. Klinger, L. Vierling, P. Zimmerman and C. Geron, 1999: Volatile organic compound emission rates from mixed deciduous and coniferous forests in Northern Wisconsin, *Atmospheric Environment*, **33**, 2527-2536.

Pattey, E., R. L. Desjardins, H. Westberg, B. Lamb and T. Zhu, 1999: Measurement of isoprene emissions over a black spruce stand using a tower-based relaxed eddy-accumulation system, *Journal of Applied Meteorology*, **28**, 870-877.

Pierce, T., C. Geron, L. Bender, R. Dennis, G. Tonnesen, and A. Guenther, 1998: Influence of increased isoprene emissions on regional ozone modeling. *J. Geophys. Res.*, **103**, 25611-25629.

Pressley, S., B. Lamb, H. Westberg, A. Guenther, J. Chen, and E. Allwine, 2004: Monoterpene emissions from a Pacific Northwest Old-Growth Forest and impact on regional biogenic VOC emission estimates. *Atmos. Environ.*, **38**, 3089-3098.

Spitters, C.J.T., H.A.J.M. Toussaint and J. Goudriaan, 1986: Separating the diffuse and direct component of global radiation and its implications for modeling canopy photosynthesis. Part 1. Components of incoming radiation. *Agric. For. Meteorol.*, **38**, 217-229.

Weiss, A. and J.M. Norman, 1985: Partitioning solar radiation into direct and diffuse, visible, and near-infrared components. *Agric. For. Meteorol.*, **34**, 205-213.

Westberg, H, B. Lamb, K. Kempf, and G. Allwine,2000: Isoprene emission inventory for the BOREAS southern study area, *Tree Physiology*, **20**, 735-743.

Yarwood, G., G. Wilson, S. Shepard, and A. Guenther, 2003: User's Guide to the Global Biosphere Emissions and Interactions System (GLOBEIS3) Version 3.1. Environ International Corporation, Novato, CA. 33 pp.

9. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the information and suggestions on the emission factors for spruce and coniferous forests provided by Dr. Veronique Bouchet, David Plummer, and Billes Morneau of Environment Canada. We also appreciate the advice and counsel of Chris Geron of the U.S. Environmental Protection Agency.

10. DISCLAIMER

The research presented here was performed under the Memorandum of Understanding between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and under agreement number DW13921548. This work constitutes a contribution to the NOAA Air Quality Program. Although it has been reviewed by EPA and NOAA and approved for publication, it does not necessarily reflect their policies or views.