Analytical Estimation of Uncertainties in Biogenic Emissions Calculated by BEIS3 due to Uncertainties in Model Inputs and Parameters

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BIES3 – Biogenics Emissions Inventory System, Version 3

- Used to estimate emissions of biogenic emissions of isoprene, monoterpenes, oxygenated volatile organic compounds OVOCs),and biogenic nitric oxide (BNO)
- Input to Chemical Transport Models (CTMs) for calculating regional concentrations of air pollutants such as ozone
- Biogenic emissions are of the same order of magnitude as man-made emissions of these pollutants in many parts of the U.S.

Study sponsored by EPRI to determine the uncertainties in BEIS3 emissions estimates and their effect on the uncertainties in CTM predictions

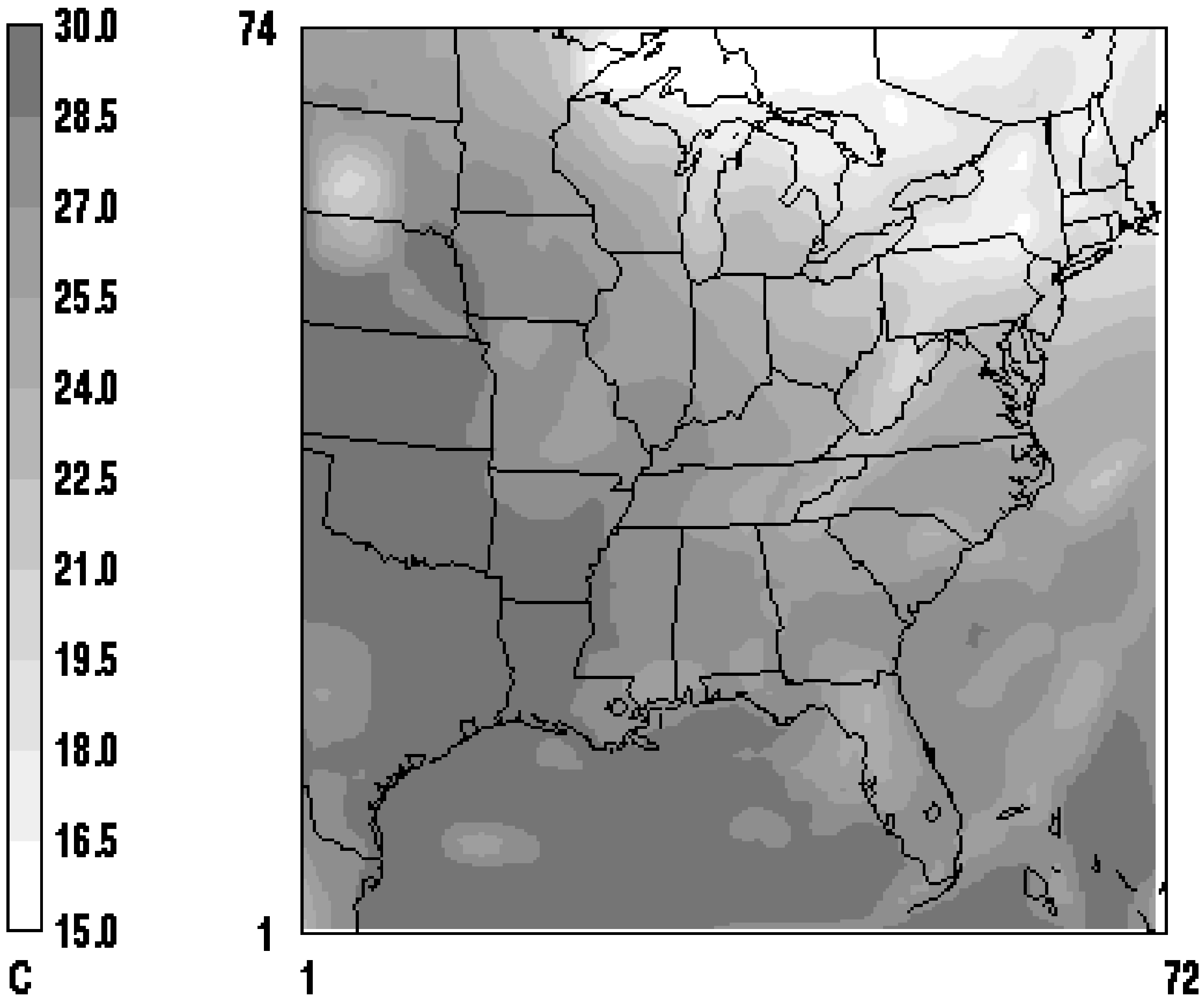
- The primary methodology is the Monte Carlo probabilistic approach
- Besides the authors, other study participants are Ted Russell of GIT, Jeff Vukovich of UNC, Alan Hansen of EPRI, and Chris Frey of NCSU.
- MC study involves random and independent variation of 17 BEIS3 inputs and model parameters
- Results are given in two project reports and in an article just submitted to JGR

The current paper concerns an analytical approach that is an alternate to the MC methodology for estimating uncertainty

- Chapter 6 in first project report published by EPRI
- Uses the same assumptions for uncertainties (standard deviations) in BEIS3 inputs and parameters assumed for MC study
- Three ozone episodes in 1995 (24-29 May, 11-15 July, 4-8 September)
- Compare analytical results with MC results

Observed mean daily temper-atures (in C) for 11 July 1995

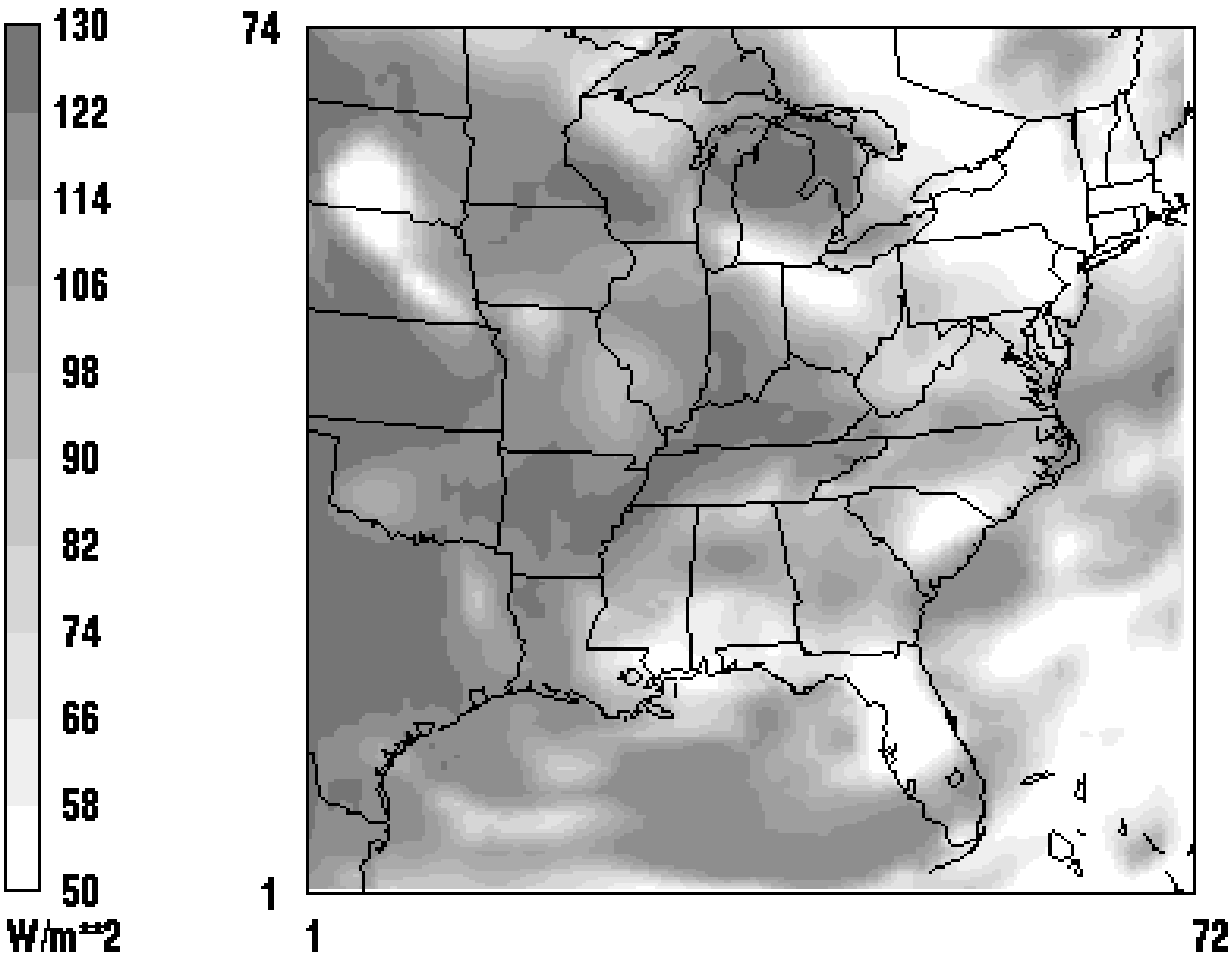
Values represent averages over a 36 km by 36 km grid.



PAR = Photosynthetically Active Radiation

Observed mean daily PAR values (in W/m2) for 11 July 1995

Values represent averages over a 36 km by 36 km grid.



Analytical Uncertainty Method

Assume a simple equation: $Y = AB$

$$\frac{(\Delta Y)^2}{Y^2} = \frac{(\Delta A)^2}{A^2} + \frac{(\Delta B)^2}{B^2}$$

Assuming that $(\Delta Y)^2 = \sigma_Y^2$

$$\left(\frac{\sigma_Y}{Y}\right)^2 = \left(\frac{\sigma_A}{A}\right)^2 + \left(\frac{\sigma_B}{B}\right)^2$$

Example for Biogenic Nitric Oxide Emissions Equation in BEIS3

- BNO $$\frac{E}{A} = E_A = E_S \exp\left[T_3\left(T_1\left(T - 273.15\,\mathrm{K}\right) + T_2 - 30\,\mathrm{C}\right)\right]$$

$$T_{soil} = T_1\left(T - 273.15\,\mathrm{K}\right) + T_2$$

- E_S is BNO emissions factor and varies with plant species
- T is ambient temperature
- T_1 is an inverse temperature scale
- T_2 is a temperature parameter
- T_3 is an inverse temperature scale

Assumed uncertainties (standard deviations) for BNO parameters

- E_S: 26% of median value
- T_1: Median = 0.72 C^{-1} and σ = 0.36 C^{-1}
- T_2: Median = 5.8 C and σ = 2.9 C
- T_3: Median = 0.071 C^{-1} and σ = 0.0071 C^{-1}
- T: Median = ambient T in K and σ = 1.9 C

Analytical equation for BNO emissions uncertainty

$$\left(\frac{\sigma_{EA}}{E_A}\right)^2 = \left(\frac{\sigma_{ES}}{E_S}\right)^2 + \left(\frac{\sigma_{T3}}{T_3}\right)^2 \left(\left(0.051\ \mathrm{C}^{-1}\right)T_A + 0.41 - 2.73\right)^2 +$$

$$\left(\frac{\sigma_{T2}}{T_2}\right)^2 (0.41)^2 + \left(\frac{\sigma_{T1}}{T_1}\right)^2 \left(\left(0.051\ \mathrm{C}^{-1}\right)T_A\right)^2 +$$

$$\left(\sigma_{TA}\right)^2 \left(0.051\ \mathrm{C}^{-1}\right)^2$$

$$\left(\frac{\sigma_{ES}}{E_S}\right)^2 = 0.26^2 = 0.0676$$

$$\left(\frac{\sigma_{T3}}{T_3}\right)^2 = \left(\frac{0.007\ \mathrm{C}^{-1}}{0.071\ \mathrm{C}^{-1}}\right)^2 = 0.00972 \approx 0.01$$

$$\left(\frac{\sigma_{T2}}{T_2}\right)^2 = \left(\frac{2.9\ \mathrm{C}}{5.8\ \mathrm{C}}\right)^2 = 0.25$$

$$\left(\frac{\sigma_{T1}}{T_1}\right)^2 = \left(\frac{0.36\ \mathrm{C}^{-1}}{0.72\ \mathrm{C}^{-1}}\right)^2 = 0.25$$

$$\sigma_{Ta} = 1.9\ \mathrm{C}$$

Table 2. Summary of analytical uncertainty estimate in BNO emissions.

T_A (C)	E_S Term	T_3 Term	T_2 Term	T_1 Term	T_A Term	$(\sigma_{EA} / E_A)^2$
30	0.068	0.006	0.042	0.585	0.009	0.71
20	0.068	0.017	0.042	0.260	0.009	0.40
10	0.068	0.033	0.042	0.065	0.009	0.22

σ_{EA}/E_A = about 0.45 to 0.85

- The T_1 uncertainty term dominates the total uncertainty in BNO emissions at higher T_A. This same result was found in the Monte Carlo (MC) uncertainty runs.

- At lower T_A, the E_S uncertainty term becomes more important, and this result was also found from the MC runs, since the correlation between E_A and E_S for BNO was found to be near zero in the southern U.S. but as high as 0.9 in colder parts of the domain.

- The contribution of T_A, uncertainty is very small.

- It is concluded that the analytical results are similar to the MC results, as would be expected for this relatively simple emissions equation.

For OVOC and monoterpenes, which have the same basic equation, the following results are obtained

T **(K)**	E_S **Term**	***β*** **Term**	***T*** **Term**	$(\sigma_{EA}/E_A)^2$
303	0.068	0.0	0.030	0.10
293	0.068	0.040	0.030	0.14
283	0.068	0.160	0.030	0.26

For T = 293 K (typical of domain), $\sigma_{EA}/E_A = (0.14)^{1/2} = 0.37$

Summary of analytical uncertainty estimate in the isoprene emissions due to temperature terms.

***T* (K)**	c_{T1}	***T***	c_{T2}	***T***	T_M	$(\sigma_{CT}/C_T)^2$
314	0.077	0.048	0.0	0.076	0.190	0.39
303	0.0	0.056	0.006	0.0	0.001	0.06
293	0.073	0.064	0.0	0.0	0.0	0.14
283	0.315	0.073	0.0	0.0	0.0	0.39

σ_{CT}/C_T = 0.25 to 0.63

Summary of analytical uncertainty estimate in the isoprene emissions due to solar radiation terms.

$$\left(\frac{\sigma_{C_L}}{C_L}\right)^2 = 0.036 + \frac{0.3086 + 0.0169}{\left(1 + \alpha^2 L^2\right)^2}$$

L (μmol·m^{-2}·s^{-1})	c_{L1} **Term**	α **Term**	L **Term**	$\left(\frac{\sigma_{CL}}{C_L}\right)^2$
100	0.036	0.268	0.015	0.32
300	0.036	0.113	0.006	0.16
600	0.036	0.024	0.001	0.06

Conclusions

- For fairly simple analytical emissions equations, the uncertainties can be estimated by mathematical analysis
- When the same uncertainties are assumed for model inputs and parameters, then the Monte Carlo method and the analytical method agree approximately in their estimated biogenic emissions uncertainties
- Typical uncertainties in biogenics emissions estimates are in the range from ± 20 % to ± 80 %