Modeling on the drought stress impact on the summertime biogenic isoprene emissions in South Korea

Jeong et al., 2024

This manuscript investigates the potential to constraining biogenic isoprene emissions under both normal and drought conditions by incorporating drought stress into the modelling with GEOSchem. The study highlights that previously implemented algorithms used for the southeastern United States are not directly applicable to the South Korean peninsula. Instead, the authors utilized the IFDMB framework to derive an empirical equation tailored to the South Korean region, significantly enhancing prediction accuracy under both normal and drought conditions. Furthermore, this approach also improved the prediction of other secondary pollutants under these conditions. Throughout the study, the methods and results convincingly highlight the scientific significance of this work, offering substantial findings that underscore its value for modeling applications. Also, this research provides valuable insights to enhance model predictions in regional air quality (AQ) contexts.

I would recommend a list of points and concerns which needs to be addressed.

→ We sincerely appreciate the reviewer who gave the constructive comments to improve the manuscript. Their comments are reproduced below followed by our responses in blue. The corresponding edits in the manuscript are highlighted with red color.

P1. Throughout the manuscript, the authors use absolute/percentage number in the text, making it difficult and complicated for readers to follow every detail. They should refine how these results are presented. For example, they could utilize the unused white space in the spatial plots (panels) to display relevant values or add more tables with columns showing results before and after implementing the algorithm. Overall, improving the readability of the manuscript would be a substantial value addition.

→ We agree with the reviewer's comment. In response, we have added values of the mean (total) isoprene emissions and mean HCHO column in each panel in the revised Figures 2-5. As the previous Table 1 contained these values, we changed Table 1 to the mean HCHO column bias of GEOS-Chem simulations for better readability. In addition, we added Table 2 presenting the differences in the biogenic isoprene emissions and the HCHO column simulated between each drought stress algorithms and the standard GEOS-Chem.

Table 1: The mean HCHO column bias (relative bias) of GEOS-Chem simulations under the normal condition and drought condition in South Korean region.

Unit: 10^{16} molec. cm^{-2}	Standard GEOS-Chem	WD	JD
Normal	0.22 (19.82 %)	0.18 (16.22 %)	0.13 (11.71 %)
Drought	0.42 (35.89 %)	0.36 (30.77 %)	0.26 (22.22 %)

Table 2: The differences (relative difference) in the biogenic isoprene emissions and the HCHO column simulated by each drought stress algorithms compared to the standard GEOS-Chem.

Drought stress algorithms	Drought	Mean flux of isoprene emissions [Unit: 10^{-10} $kgm^{-2}s^{-1}$]	Total isoprene emissions [Unit: Gg/week]	Mean HCHO column [Unit: 10^{16} molec. cm^{-2}]
WD	Normal	-0.15 (-3.9 %)	-0.95 (-3.78 %)	-0.04 (-3.00 %)
	Drought	-0.43 (-6.67 %)	-2.84 (-6.69 %)	-0.06 (-3.77 %)
JD	Normal	-0.65 (-17.29 %)	-4.36 (-17.38 %)	-0.09 (-6.77 %)
	Drought	-1.54 (-23.88 %)	-10.20 (-24.02 %)	-0.16 (-10.06 %)

P2. It is assumed that a drought index is used solely to identify drought conditions. Why were ETDI or DEDI chosen here when other drought indices are also available? Some insight on this would be valuable because DEDI is essentially an agricultural drought index best suited for short-term developing droughts, although it can also capture longer-term drying conditions (Narasimhan and Srinivasan 2005; Singh et al., 2024). Consequently, its application to vegetation---especially forests with deeply rooted trees---may not detect short-duration events. It is assumed that the developed and tested algorithm would be applicable regardless of the drought's duration and severity. Adding some discussion on this would be helpful.

→ The reviewer's point is well taken. The reason why we used DEDI in this study is that it is based on the balance of evapotranspiration between atmosphere and terrestrial ecosystem (Zhang et al., 2023), which can connect the climate system and vegetations. In addition, it has a fine gridded resolution (0.25° × 0.25°) and temporal resolution (daily). This fine spatiotemporal resolution of DEDI helped us to increase a sampling size in the limited study period (2016, 2017, and 2018 JJA) and domain (South Korea). Although we used DEDI only in this study, we compared DEDI to the Standardized Precipitation Index (SPI) in the South Korea region (Figure S1) and found that DEDI is consistent with the SPI, as reported in the Zhang et al. (2023), indicating that the overall results would be consistent when SPI is used in this study. The comparison of DEDI to SPI was already discussed in the original manuscript and we added the following sentence in the revised manuscript.

"Since DEDI data is available at fine spatial (0.25° × 0.25°) and temporal (daily) resolutions than other drought indices, we chose DEDI over other indices to help increase data sizes in the limited study period and domain."

P3. This study demonstrated that the algorithm developed and proven effective over the SE US are not equally effective over the SK region. Authors can pull some insights over the possible reasons behind this. Is it due to different types of vegetation over these regions or any other factors at play? As mentioned in P2, if the emission response is moderated by different vegetations types, then improvements claimed by the new empirical algorithm may be dependent on the types (hydrological or meteorological) and severity of drought, and thus be more region specific (e.g., algorithms over the southeastern U.S.).

→ This is a good point. As the response of the isoprene emissions to the drought can be different by vegetation types (mainly deciduous-leaf trees), the empirical drought stress algorithms based on the southeastern US may not work in South Korea. For example, in South Korea, the main deciduous-leaf trees are *Quercus mongolica*, *Quercus variabilis*, and *Quercus acutissima* (Lee et al., 2025). While in southeastern US, the main deciduous-leaf trees are *Quercus stellata, Quercus alba*, and *Quercus prinus* (Perry et al., 2022). These difference in main deciduous-leaf tree species between the southeastern US and South Korea can make drought stress algorithms based on the southeastern US not effective in South Korea. Responding to the reviewer's comment, we added the following sentences in the revised manuscript.

"The two regions have different main deciduous-leaf tree species. South Korea has mainly *Quercus mongolica*, *Quercus variabilis*, and *Quercus acutissima* (Lee et al., 2025), while the SE US has *Quercus stellata*, *Quercus alba*, and *Quercus prinus* (Perry et. al., 2022). This fundamental difference may cause ineffectiveness of WD and JD in South Korea."

P4. Authors have reported the results % change across the manuscript. Authors should also provide some estimate of uncertainties over the region. I.e sensitivity of new approach.

→ To provide statistical information, the mean, standard deviation, and p-value based on Student's *t*-test were added in each figure (Figures 2-5).

P5: The authors should verify the calculations for the percentage change in emissions reported in Table 1 (e.g., isoprene emissions for the standard case, and HCHO). It appears that the percentage change between normal and drought conditions was computed using values with more decimal precision than those shown in Table 1, which only displays two decimal places. Consequently, the percentage changes in Table 1 differ by about 1–2% from the values one would obtain using the tabulated data. The authors should ensure consistency and revise these figures throughout the manuscript after cross-checking.

→ Corrected. Revised values were added in Figures 2-5 and Tables 1-2.

P6. Figure 5 and its description (section 4.2) is really confusing and hard to keep track when previous figures are referred. I assume in figure 5, row 1, panel 2 (drought) should have the IFDMB? Also, Fig 5c shows the box-whiskers for HCHO different approaches for all GEOSchem simulations. how many? What would be the significance of these bar/statistics? This needs some efforts to make it more explanatory.

→ We added a caption for each panel in Figure 5 for clarity in Section 4.2. The box in boxplot extends from the first quartile (Q1) to the third quartile (Q3) with a line at the median value and a dot at a mean value. The inter-quartile range (IQR) is from Q1 to Q3, and the whisker in boxplot extends from the Q1-1.5×IQR to the Q3+1.5×IQR. We added this explanation in the caption for Figure 5.

P7: Line 418: "presented in table 2." Table 2 is missing in manuscript. This is vital.

→ The original Table 2 was removed in response to a comment by Reviewer #1. There is a new Table 2 in the revised manuscript as shown above (P1).

Specifics:

1. Line 10: - I suggest authors to rephrase this sentence to frame the importance of reducing the uncertainties in these emission context to SK region instead of directly stating the effort has not been made in SK region. This will better abstract the requirement and gap in knowledge in context to the region.

→ Agreed. We revised the sentence as below:

"This study aims at constraining drought stress on biogenic isoprene emissions in South Korea using satellite formaldehyde (HCHO) column"

2. Line 40: - "some studies" sounds vague here, better cite them here. Also, in line 43 if "some previous studies" refers to the cited in the end of sentences (line 46), author can rephrase this like "recent studies…."

→ Yes, we revised those sentences in the revised manuscript as below:

"…, some studies (Wang et al., 2022b; Wasti and Wang, 2022) have used the tropospheric formaldehyde (HCHO) column retrievals from the satellite to estimate isoprene emissions response to drought."

"Recent studies (Li et al., 2022; Naimark et al., 2021) showed that the tropospheric HCHO column from the Ozone Monitoring Instrument (OMI) on the Aura satellite increased by 6.5–22 % in the southeastern United States (US) region during the summertime drought, which is indicative of the increase of isoprene emissions during drought."

3. Line 112: "factor of 1.28*.. "sounds like a sudden introduction of something important. Presumably this comes from the Shen et al., 2019; Wang et al 2022b. I suggest a rephrasing of this sentence for better connectivity and explanation.

→ The sentence was revised in the revised manuscript as below:

"To correct this underestimation, we applied a constant factor of 1.28 (1 / (1–0.22)) to the OMHCHOd data as in the previous studies (Shen et al., 2019; Wang et al., 2022b)."

4. Line 326: "fig 3.c". please check figure 3 if "c" is marked there?

→ Yes, Figure 3c shows the biogenic isoprene emissions under the drought condition in the standard GEOS-Chem.

5. Line 324" "geographical characteristics over the South Korean" please elaborate the context of geographical condition here. It is related to vegetation or climatic features.

→ We used the term of "geographical characteristics" here to state that the spatial distribution of isoprene emissions estimated by the IFDMB was consistent with the mountain ranges where the sources of biogenic isoprene were highly populated. Responding to the reviewer's comment, we revised the sentence as below:

"In both normal and drought conditions, therefore, the spatial distribution of isoprene emissions estimated by the IFDMB could represent higher isoprene emissions over the mountain ranges with large density of broadleaf trees."

References:

Narasimhan, B. and Srinivasan, R.: Development and evaluation of Soil Moisture Deficit Index (SMDI) and Evapotranspiration Deficit Index (ETDI) for agricultural drought monitoring, Agricultural and Forest Meteorology, 133, 69–88, https://doi.org/10.1016/j.agrformet.2005.07.012, 2005.

Singh, R., Tsigaridis, K., Bull, D., Swiler, L. P., Wagman, B. M., and Marvel, K.: Mount Pinatubo's effect on the moisture-based drivers of plant productivity, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-2280, 2024.