Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2018-26-AC2, 2018


# *Interactive comment on* "Leaf phenology as one important driver of seasonal changes in isoprene emission in central Amazonia" *by* Eliane G. Alves et al.

**Eliane G. Alves et al.**

elianegomes.alves@gmail.com

Received and published: 18 May 2018

Reply to Referee 2 Alves et al. present a 7-month observation of isoprene flux in central Amazonia, and demonstrate the role of leaf age in controlling its seasonal variation. This study deserves documentation because it provides a long observational record of isoprene emissions and in-situ comonitored leaf phenology, which is scarce in the tropics. However, I agree with the other reviewer that this manuscript ignores a pool of previous literature. Some other issues may need to be addressed as well before accepted for publication. Author's response: We thank all the comments and suggestions made by the referee. In terms of the effect of leaf phenology on isoprene



emission, we acknowledge that this is an important factor and that has been pointed out in past studies from temperate forests. Here, we wanted to show that this could also be important in tropical forests, which was not clearly shown before because seasonal changes in leaf age and leaf biomass in tropical forests are not as strong as in temperate forests. In addition, only recently has the leaf phenology in tropical forest, especially in the Amazon forests, been shown to be one important factor on forest physiological processes (Huete et al., 2006; Lopes et al., 2016; Myneni et al., 2007; Saleska et al., 2016; Wagner et al., 2017). We understand that the main novelty of the results of this manuscript is due to our study region, a tropical forest, and we have tried to emphasize this point now. Moreover, previous literature on leaf phenology and isoprene emissions have also now been added.

Referee's comment - L64-68. What is the contribution of isoprene to total $CO_2$ emission in percentage? To my knowledge the number is very small. Author's response – According to Guenther (2002), the percentage of carbon emitted as isoprene is about 1% to 4% at optimal temperatures for plant growth, but can exceed 10% at higher temperatures. Author's changes in manuscript - Line 64. "Moreover, isoprene emissions could play an important role in the carbon balance, because it is the most emitted within BVOCs, which are regarded as highly significant for net ecosystem productivity, with their losses comparable to the magnitude of net biome productivity (Kesselmeier et al., 2002); and carbon dioxide is believed to be the fate of almost half of the carbon released in the form of BVOCs (Goldstein and Galbally, 2007).

Referee's comment - L81. "drivers of isoprene" should be "drivers of isoprene emissions". Author's response – This sentence was rewritten as suggested by the referee. Author's changes in manuscript – L79. "Some of these in situ studies indicate hat environmental factors such as solar radiation and temperature are primary drivers of isoprene emission..."

Referee's comment - L83-88. "canopy phenology could therefore be an important seasonal driver". Does the phenological control on isoprene emissions only occur through photosynthesis? Kuzma and Fall, 1993 suggested that the enzyme activity regulates the isoprene emission in response to leaf development. The authors may want to replace the sentence with a paragraph of literature review (including mid-latitude studies) on the theory and observations of isoprene emission versus leaf phenology. See review paper Harrison et al., 2013 (Table S2) and many others, Niinemets, Monson, Sharkey, etc. Author's response – We agree, and we have rewritten the paragraph giving information on how isoprene emission can be affected by leaf age and ontogeny. Author's changes in manuscript – L85. "However, besides long-term seasonal variation in light and temperature, other biological factors might act on seasonal changes of isoprene emission, as the case of canopy phenology. Previous studies with temperate species have shown that isoprene emission capacity is affected by leaf age and ontogeny (Kuzma and Fall, 1993; Mayrhofer et al., 2005; Monson et al., 1994), because: (1) isoprene synthase and other enzymes of isoprene synthesis pathway (MEP pathway) depends on the leaf ontogeny - isoprene synthase activity is low or absent in very young leaves, increasing gradually until full leaf maturation, and decreasing with leaf senescence (Schnitzler et al., 1997); (2) for species of non-senescent leaves, or with a life-span of more than one year, foliage shading and time-dependent changes of physiological activity of leaves could decrease isoprene emission capacity (Niinemets et al., 2004, 2010); and (3) leaf structure varies with leaf ontogenetic stage, indicating that seasonal isoprene emission capacity is affected by seasonal structural changes in leaves (Niinemets et al., 2004, 2010)".

Referee's comment - L132: How did you choose the 5 or 6 days every month for measurement? What are the cloud conditions? Author's response – Days were chosen between 20th and 30th of each month. When possible, measurements were carried out on very sunny days and without rain. But, a few days in June and October were a little cloudy. Cloud conditions can change very quickly in the Amazon. Therefore, to really characterize differences in isoprene emissions between sunny and cloudy days, more long-term measurements are needed.



Referee's comment - In 2013, the monthly variation of satellite-derived isoprene emission is totally wrong compared to in-situ measurement. Is it because you only have a few days' measurement each month? I suggest to include the 2013 satellite isoprene curve in Figure 3 for a direct comparison. Include both monthly average and the REA period average. Author's response – We think part of the differences between satellite-derived isoprene emission and in situ isoprene emission is due to the smaller number of days of in situ measurements. But, differences due to the spatial resolution should also be considered. Satellite-derived isoprene emission resolution is 50 km, whereas in situ measurements have a much smaller footprint. This might suggest that in situ measurements have more impact from local effects, which could be diminished when lower spatial resolution is being analyzed. Author's changes in manuscript - Satellite-derived isoprene flux was added to Figure 3.

Text in the manuscript: L378. "The reasons why satellite-derived isoprene fluxes are weakly correlated to ground-based isoprene fluxes can be attributed to either the difference in the studied scales (e.g. local effects could have major influences on ground-based isoprene fluxes) and/or the uncertainties associated with the methodologies used to estimate or calculate fluxes. The high correlation between satellite-based fluxes and air temperature or PAR is not unexpected, because higher temperatures and solar radiation fluxes favor isoprene emissions. Note however that the satellite-derived fluxes might also be subject to inherent uncertainties, due to the existence of other HCHO sources, in particular biomass burning (during the dry season) and methane oxidation. Since these latter contributions are favored by high temperature and radiation levels, they could possibly contribute to the high correlation found between satellite-based isoprene and meteorological variables".

Referee's comment - L333: Does Table 2 show R or R2? "Explaining 59% of variations" usually refers to R2 values. The abstract should be consistent, too. Author's response – Table 2 shows R2 values. The corresponding sentences in the abstract are written with R2 values inside brackets, for example in L44 "...the highest correlation with observed isoprene flux seasonality (R2=0.59, p<0.05)", and L50 "...significantly improved simulations in terms of seasonal variations of isoprene fluxes (R2=0.52, p<0.05)".

Referee's comment - L342: "Regression" should be "Correlation". Author's response – In this case, it is really regression, because this is what is shown in Table 2.

Referee's comment - L352-362, Figure 6: No matter with EAF changes or not, the MEGAN monthly variations look more similar to the satellite-derived isoprene emissions. Again, is this because the in-situ observation only includes a few days every month? I wonder whether these days can represent emissions during the whole month. Is MEGAN run at a day- by-day basis? If so, the authors may try take out the MEGAN simulations during the same days as the REA measurement to see whether the correlations are improved. Author's response – The reason why MEGAN estimates and in situ observations have low correlation is, probably, in part due to the small number of in situ observations. However, when comparing results of MEGAN estimates with the same days of in situ observations, we did not improve the correlations. One issue is that, for a few days in July and December, there were gaps in the PAR and temperature datasets, which prevented us from simulating isoprene flux for those days. Therefore, a correlation between MEGAN estimates and in situ observations for the same days of REA measurements is not possible. For verification, the bellow figure shows an inset panel with MEGAN estimates of the same days of in situ observations:

Another possibility is soil-moisture dependence. Quite a few studies showed the importance of water availability, e.g. Pegoraro et al., 2004-2006, Zheng et al., 2015, 2017, etc. In Figure 3, observed isoprene flux shows a similar monthly pattern as the TRMM precipitation in dry and dry-to-wet seasons (when water is limited). The authors may want to do a MEGAN sensitivity test that includes soil moisture dependence or at least discuss the role of soil moisture in Section 4.1. Author's response – We do not have soil moisture data simultaneous to our REA measurements. For this experimental site, a previous study showed that during the dry season there is only a small reduction (∼10 %) in soil moisture compared to the wet season (Cuartas et al., 2012);



this reduction does not induce water stress to this forest region (Wagner et al., 2017). Moreover, based on the dataset of soil moisture shown from 2002 to 2006 (Cuartas et al., 2012), the soil moisture always exceeds the threshold for the isoprene drought response in MEGAN 2.1 (Guenther et al., 2012), which means that MEGAN would predict that there are no variations in isoprene emissions due to these observed changes in soil moisture. Therefore, we feel justified in having kept the soil moisture constant in model simulations.

Referee's comment - L434: The wording "during leaf phenology" is strange. Author's response – This sentence was rewritten to "...isoprene emission during leaf ageing". However, after doing some revisions based on the comments from the other referee, we removed this paragraph and wrote a new one with more relevant information from previous studies of temperate forests. Author's changes in manuscript – "However, besides long-term seasonal variation in light and temperature, other biological factors might act on seasonal changes of isoprene emission, as the case of canopy phenology. Previous studies with temperate species have shown that isoprene emission capacity is affected by leaf age and ontogeny (Kuzma and Fall, 1993; Mayrhofer et al., 2005; Monson et al., 1994), because: (1) isoprene synthase and other enzymes of isoprene synthesis pathway (MEP pathway) depends on the leaf ontogeny - isoprene synthase activity is low or absent in very young leaves, it increases gradually until full leaf maturation, and decreases with leaf senescence (Schnitzler et al., 1997); (2) for species of non-senescent leaves, or with life-span of more than one year, foliage shading and time-dependent changes of physiological activity of leaves could decrease isoprene emission capacity (Niinemets et al., 2004, 2010); (3) and leaf structure varies with leaf ontogenetic stage, indicating that seasonal isoprene emission capacity is affected by seasonal structural changes in leaves (Niinemets et al., 2004, 2010)".

Referee's comment - Figure 2, 3, 6: As a convention, the panel numbers (a)(b)(c) are usually placed in front of description. Author's response – Suggestion accepted. The panel numbers are now placed in front of the description for each of these figures. Author's changes in manuscript - Figure 2. (a) Monthly averages of photosynthetic active radiation (PAR) and (b) air temperature from 2005 to 2013 at the K34 tower site (measured every 30 min during -6:00-18:00h, local time). (c) OMI satellite-derived isoprene flux in a resolution of 0.5° centered on K34 tower site from 2005 to 2013. Monthly averages of isoprene flux were scaled to 10:00-14:00, local time. Error bars represent one standard error of the mean. Figure 3. (a) Monthly cumulative precipitation given by the Tropical Rainfall Measuring Mission (TRMM) for the K34 tower domain in 2013. (b) Monthly averages of PAR and (c) air temperature, both measured every 30 minutes during 6:00-18:00h, local time, at the K34 tower site in 2013. (d) Isoprene flux measured with the REA system at the K34 tower site in 2013. Figure 6. (a) Emission activity factor (EAF) of isoprene for each leaf age class assigned in the default mode of MEGAN 2.1 proportional to leaf age class distribution derived from field observations (CAMERA-LAI). (b) Isoprene EAF for each leaf age class, obtained from leaf level measurements of the tree species E. coriacea, proportional to leaf age class distribution derived from field observations (CAMERA-LAI). Observations of the tree species E. coriacea (Alves et al., 2014) and CAMERA-LAI are both from the K34 site.

Referee's comment - Some references: Kuzma, Jennifer, and Ray Fall. "Leaf isoprene emission rate is dependent on leaf development and the level of isoprene synthase." Plant physiol- ogy 101.2 (1993): 435-440. Harrison, Sandy P., et al. "Volatile isoprenoid emissions from plastid to planet." New Phytologist 197.1 (2013): 49-57. Niinemets, Ülo, et al. "The emission factor of volatile isoprenoids: stress, acclimation, and developmental responses." Biogeosciences 7.7 (2010): 2203. Pegoraro, E., et al. "Effect of drought on isoprene emission rates from leaves of Quercus virginiana Mill." Atmospheric Environment 38.36 (2004): 6149-6156. Pegoraro, Emiliano, et al. "The interacting effects of elevated atmospheric CO 2 concentration, drought and leaf-to-air vapour pressure deficit on ecosystem isoprene fluxes." Oecologia 146.1 (2005): 120-129. Pegoraro, Emiliano, et al. "Drought effect on isoprene production and consumption in Biosphere 2 tropical rainforest." Global Change Biology 12.3 (2006): 456-469. Zheng, Yiqi, et al. "Relationships between photosynthesis and formaldehyde as a probe of isoprene emis-



sion." Atmospheric Chemistry and Physics 15.15 (2015): 8559-8576. Zheng, Yiqi, et al. "Drought impacts on photosynthesis, isoprene emission and atmospheric formaldehyde in a mid-latitude forest." Atmospheric Environment 167 (2017): 190-201. Author's response: We thank the suggestion of the above references, and we have added some to the manuscript. References Alves, E. G., Harley, P., Gonçalves, J. F. C., Moura, C. E. S. and Jardine, K.: Effects of light and temperature on isoprene emission at different leaf developmental stages of eschweilera coriacea in central amazon, Acta Amaz., 44(1), 9–18, doi:10.1590/S0044-59672014000100002, 2014.

Cuartas, L. A., Tomasella, J., Nobre, A. D., Nobre, C. A., Hodnett, M. G., Waterloo, M. J., Oliveira, S. M. De, Randow, R. D. C. Von, Trancoso, R. and Ferreira, M.: Distributed hydrological modeling of a micro-scale rainforest watershed in Amazonia: Model evaluation and advances in calibration using the new HAND terrain model, J. Hydrol., 462–463, 15–27, doi:10.1016/j.jhydrol.2011.12.047, 2012.

Goldstein, A. H. and Galbally, I. E.: Known and Unexplored Organic Constituents in the Earth's Atmosphere, Environ. Sci. Technol., 41(5), 1514–1521, doi:10.1021/es072476p, 2007.

Guenther, A.: The contribution of reactive carbon emissions from vegetation to the carbon balance of terrestrial ecosystems., Chemosphere, 49(8), 837–44, 2002.

Guenther, A. B., Jiang, X., Heald, C. L., Sakulyanontvittaya, T., Duhl, T., Emmons, L. K. and Wang, X.: The Model of Emissions of Gases and Aerosols from Nature version 2.1 (MEGAN2.1): an extended and updated framework for modeling biogenic emissions, Geosci. Model Dev., 5(2), 1503–1560, doi:10.5194/gmdd-5-1503-2012, 2012.

Huete, A. R., Didan, K., Shimabukuro, Y. E., Ratana, P., Saleska, S. R., Hutyra, L. R., Yang, W., Nemani, R. R. and Myneni, R.: Amazon rainforests green-up with sunlight in dry season, Geophys. Res. Lett., 33, 2–5, doi:10.1029/2005GL025583, 2006.

Kesselmeier, J., Ciccioli, P., Kuhn, U., Stefani, P., Biesenthal, T., Rottenberger, S., Wolf, A., Vitullo, M., Valentini, R., Nobre, A., Kabat, P. and Andreae, M. O.: Volatile organic compound emissions in relation to plant carbon fixation and the terrestrial carbon budget, Global Biogeochem. Cycles, 16(4), 73-1-73–9, doi:10.1029/2001GB001813, 2002.

Kuzma, J. and Fall, R.: Leaf Isoprene Emission Rate Is Dependent on Leaf Development and the Level of Isoprene Synthase., Plant Physiol., 101(2), 435–440, 1993.

Lopes, A. P., Nelson, B. W., Wu, J., Graça, P. M. L. de A., Tavares, J. V., Prohaska, N., Martins, G. A. and Saleska, S. R.: Leaf flush drives dry season green-up of the Central Amazon, Remote Sens. Environ., 182, 90–98, doi:10.1016/j.rse.2016.05.009, 2016.

Mayrhofer, S., Teuber, M., Zimmer, I., Louis, S., Fischbach, R. J. and Schnitzler, J.-P.: Diurnal and seasonal variation of isoprene biosynthesis-related genes in grey poplar leaves., Plant Physiol., 139(1), 474–484, doi:10.1104/pp.105.066373, 2005.

Monson, R. K., Harley, P. C., Litvak, M. E., Wildermuth, M., Guenther, A. B., Zimmerman, P. R. and Fall, R.: Environmental and developmental controls over the seasonal pattern of isoprene emission from aspen leaves, Oecologia, 99(3–4), 260–270, doi:10.1007/BF00627738, 1994.

Myneni, R. B., Yang, W., Nemani, R. R., Huete, A. R., Dickinson, R. E., Knyazikhin, Y., Didan, K., Fu, R., Negrón Juárez, R. I., Saatchi, S. S., Hashimoto, H., Ichii, K., Shabanov, N. V, Tan, B., Ratana, P., Privette, J. L., Morisette, J. T., Vermote, E. F., Roy, D. P., Wolfe, R. E., Friedl, M. A., Running, S. W., Votava, P., El-Saleous, N., Devadiga, S., Su, Y. and Salomonson, V. V: Large seasonal swings in leaf area of Amazon rainforests, Proc. Natl. Acad. Sci. U. S. A., 104(12), 4820–4823, doi:10.1073/pnas.0611338104, 2007.

Niinemets, U., Arneth, A., Kuhn, U., Monson, R. K., Penuelas, J. and Staudt, M.: The emission factor of volatile isoprenoids: stress, acclimation, and developmental responses, Biogeosciences, 7(7), 2203–2223, doi:10.5194/bg-7-2203-2010, 2010.



Niinemets, U., Loreto, F. and Reichstein, M.: Physiological and physicochemical controls on foliar volatile organic compound emissions., Trends Plant Sci., 9(4), 180–6, doi:10.1016/j.tplants.2004.02.006, 2004.

Saleska, S. R., Wu, J., Guan, K., Araujo, A. C., Huete, A., Nobre, A. D. and Restrepo-Coupe, N.: Dry-season greening of Amazon forests, Nature, 531(7594), doi:10.1038/nature16457, 2016.

Schnitzler, J.-P., Lehning, A. and Steinbrecher, R.: Seasonal Pattern of Isoprene Synthase Activity in Quercus robur Leaves and its Significance or Modeling Isoprene Emission Rates, Bot. Acta, 110, 240–243, 1997.

Wagner, F. H., Hérault, B., Rossi, V., Hilker, T., Maeda, E. E., Sanchez, A., Lyapustin, A. I., Galvão, L. S., Wang, Y. and Aragão, L. E. O. C.: Climate drivers of the Amazon forest greening, PLoS One, 12(7), 1–15, doi:10.1371/journal.pone.0180932, 2017.

Figures

Figure 3: (a) Monthly cumulative precipitation given by the Tropical Rainfall Measuring Mission (TRMM) for the K34 tower domain in 2013. (b) Monthly averages of PAR and (c) air temperature, both measured every 30 minutes during 6:00-18:00h, local time, at the K34 tower site in 2013. (d) Isoprene flux measured with the REA system at the K34 tower site in 2013; and OMI satellite-derived isoprene flux for the K34 tower region.

Figure 5: Isoprene flux observed (REA) and estimated with MEGAN 2.1 in default mode, leaf age algorithm driven by MODIS-LAI, and with MEGAN 2.1 leaf age algorithm driven by CAMERA-LAI. EAF stands for emission activity factor, which was changed for the different leaf age classes based on emissions of E. coriacea (Alves et al., 2014). The inset panel shows the four MEGAN simulations only for the days of REA measurements.

Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2018-26, 2018.

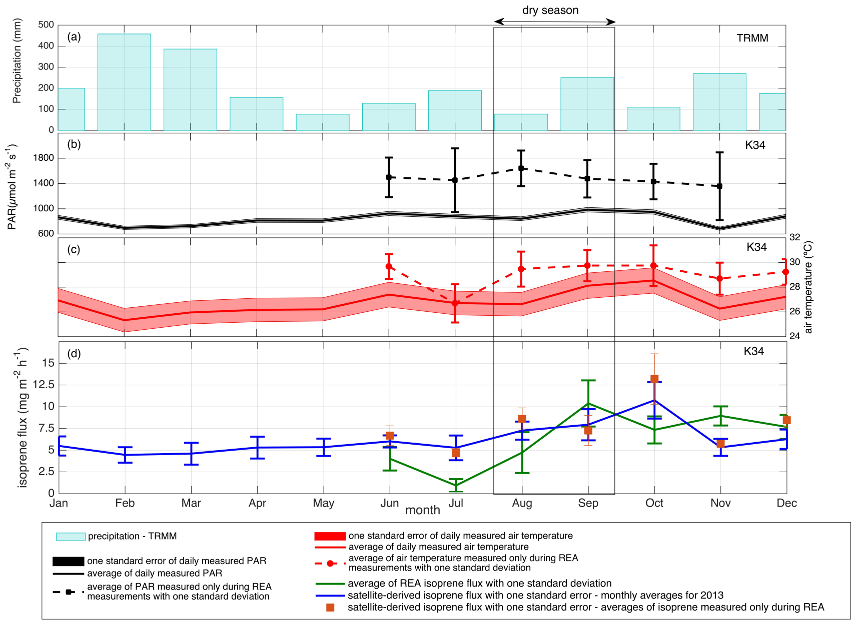


**Fig. 1.** Figure 3



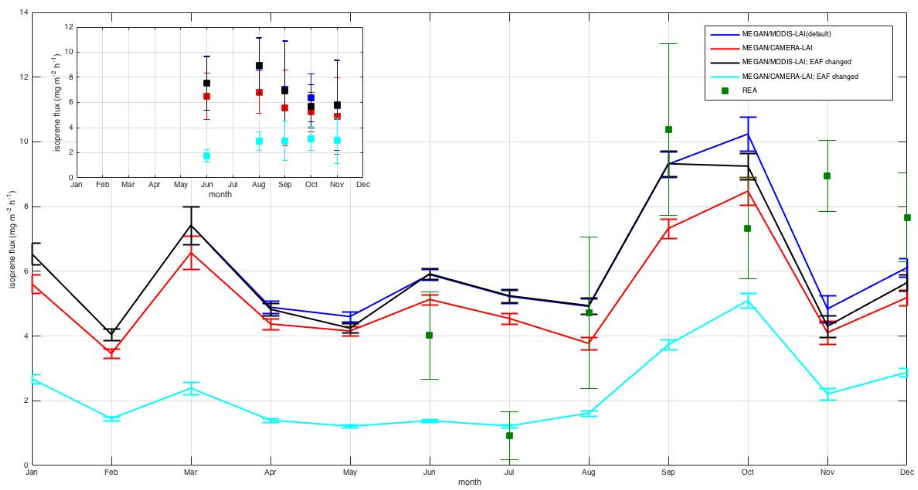


**Fig. 2.** Figure 5