



Supplement of

Regional to global distributions, trends, and drivers of biogenic volatile organic compound emission from 2001 to 2020

Hao Wang et al.

Correspondence to: Xiaohong Liu (xiaohong.liu@tamu.edu)

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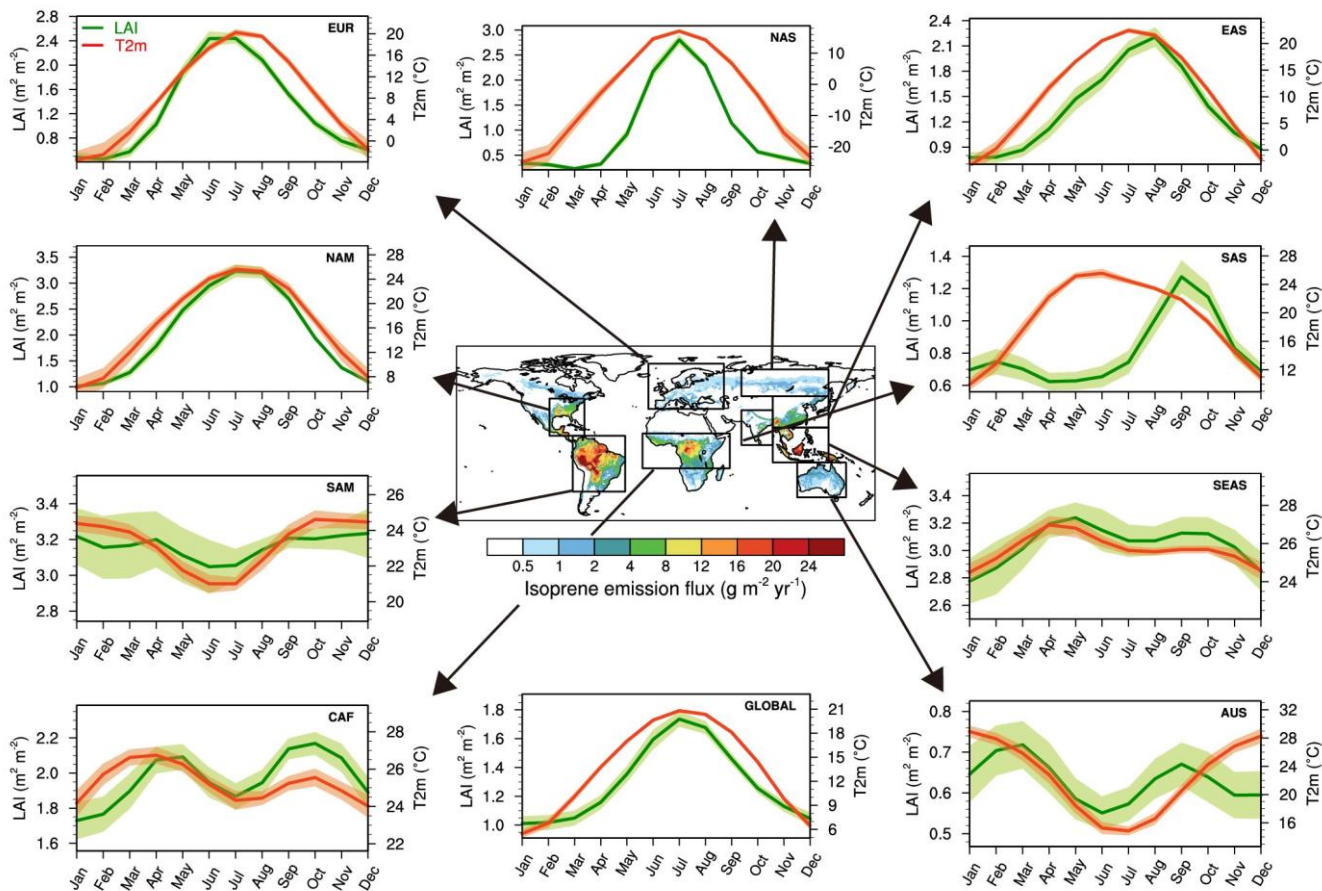
Table S1: Summary of isoprene emission site observations collected from the literature (mg C m⁻² day⁻¹).

Date	Location	PFTs	Emissions	References
2001/02	[25 °S, 31.5 °E]	EBF	1.5	(Harley et al., 2003)
2002/08/13-2002/08/31	[42.0 °N, 116.3 °E]	Grass	6.4	(Bai et al., 2003)
2003/04/16-2003/05/05	[10.4 °N, 84.0 °W]	EBF	6.0	(Karl et al., 2004)
2001/08/02-2001/08/12	[61.9 °N, 24.3 °E]	ENF	0.6	(Spirig et al., 2004)
2002/07/08-2002/07/18	[21.9 °N, 101.3 °E]	DBF	10.0	(Baker et al., 2005)
2002/06/06-2002/09/21	[45.5 °N, 84.7 °W]	DBF	26.4	(Pressley et al., 2005)
2003/07/13-2003/07/24	[50 °N, 6 °E]	DBF	26.9	(Spirig et al., 2005)
2004/9/14-2004/9/29	[2.6 °S, 60.2 °W]	EBF	20.6	(Karl et al., 2007)
2007/12/15-2007/12/19	[3 °N, 102.3 °E]	EBF	7.4	(Saito et al., 2008)
2006/08/01-2006/09/19	[68.3 °N, 19.1 °E]	Grass	2.9	(Holst et al., 2010)
2008/06/20-2008/07/20	[5.0 °N, 117.8 °E]	EBF	11.4	(Langford et al., 2010)
2007/06-2007/08	[42.9 °N, 72.2 °W]	DBF	19.4	(McKinney et al., 2011)
2008/05/30-2008/06/11	[5.2 °N, 118.5 °E]	EBF	42.8	(Miształ et al., 2011)
2002/06/26-2002/06/28	[43.7 °N, 116.6 °E]	Grass	7.0	(Bai, 2015)
2010/06/19-2010/06/30	[42.4 °N, 128.1 °E]	DBF	5.6	(Bai et al., 2015)
2010/09/02-2011/01/27	[2.6 °S, 60.1 °W]	EBF	5.1	(Alves et al., 2016)
2012/07/07-2012/07/13	[30.3 °N, 119.57 °E]	EBF	12.4	(Bai et al., 2016)
2005/07/15-2005/08/16	[51.17 °N, 0.85 °W]	DBF	16.8	(Langford et al., 2017)
2011/09/13-2011/10/01	[41.74 °N, 12.4 °E]	DBF	0.7	(Langford et al., 2017)
2012/06/13-2012/07/12	[45.2 °N, 10.74 °E]	DBF	15.0	(Langford et al., 2017)
2012/06/09-2012/06/11	[43.94 °N, 5.71 °E]	DBF	20.8	(Langford et al., 2017)
2012/07-2012/08	[38.74 °N, 92.2 °W]	DBF	47.3	(Zheng et al., 2017)
2013/06-2013/12	[2.6 °S, 60.2 °W]	EBF	50.0	(Alves et al., 2018)
2013/06/11-2013/06/26	[45.81 °N, 8.63 °E]	DBF	27.0	(Jensen et al., 2018)

2015/05/08-2015/05/25	[39.32 °N, 86.42 °W]	DBF	29.2	(Stoy et al., 2021)
2013/09-2014/07	[2.59 °S, 8.60.21 °W]	EBF	17.9	(Langford et al., 2022)

Table S2. Summary of monoterpenes emission site observations collected from the literature (mg C m⁻² day⁻¹).

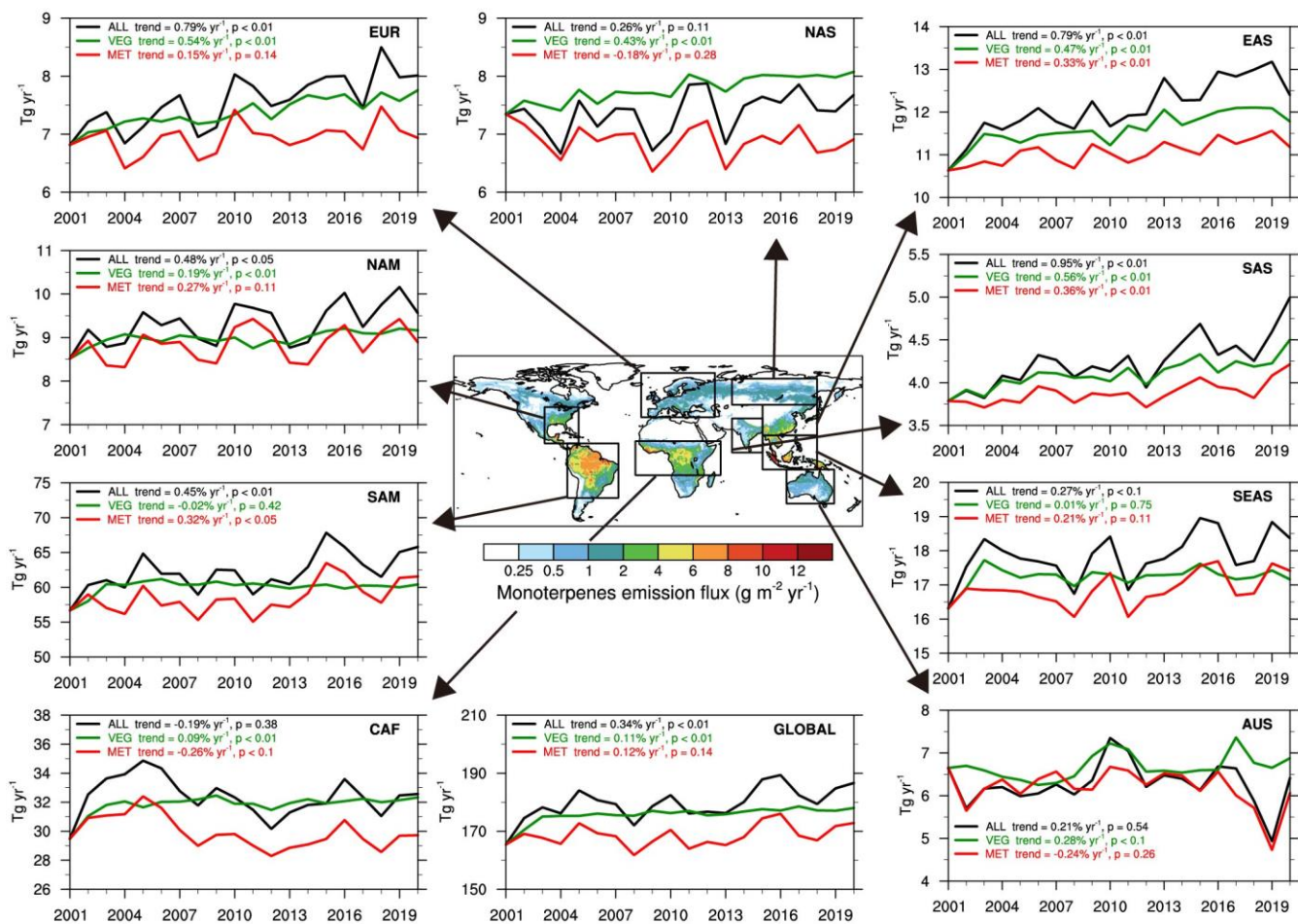
Date	Location	PFTs	Emissions	References
2003/04/16-2003/05/05	[10.4 °N, 84.0 °W]	EBF	0.44	(Karl et al., 2004)
2001/08/02-2001/08/12	[61.9 °N, 24.3 °E]	ENF	2.12	(Spirig et al., 2004)
2003/07/13-2003/07/24	[50 °N, 6 °E]	DBF	8.60	(Spirig et al., 2005)
2004/9/14-2004/9/29	[2.6 °S, 60.2 °W]	EBF	3.20	(Karl et al., 2007)
2000/04/20-2008/05/07	[5.0 °N, 117.8 °E]	EBF	1.50	(Langford et al., 2010)
2008/06/20-2008/07/20	[5.0 °N, 117.8 °E]	EBF	2.80	(Langford et al., 2010)
2007/06-2007/08	[42.9 °N, 72.2 °W]	DBF	0.66	(McKinney et al., 2011)
2010/06/19-2010/06/30	[42.4 °N, 128.1 °E]	DBF	0.86	(Bai et al., 2015)
2010/09/02-2011/01/27	[2.6 °S, 60.1 °W]	EBF	4.80	(Alves et al., 2016)
2012/07/07-2012/07/13	[30.3 °N, 119.57 °E]	EBF	0.05	(Bai et al., 2016)
2013/06/11-2013/06/26	[45.81 °N, 8.63 °E]	DBF	0.83	(Jensen et al., 2018)



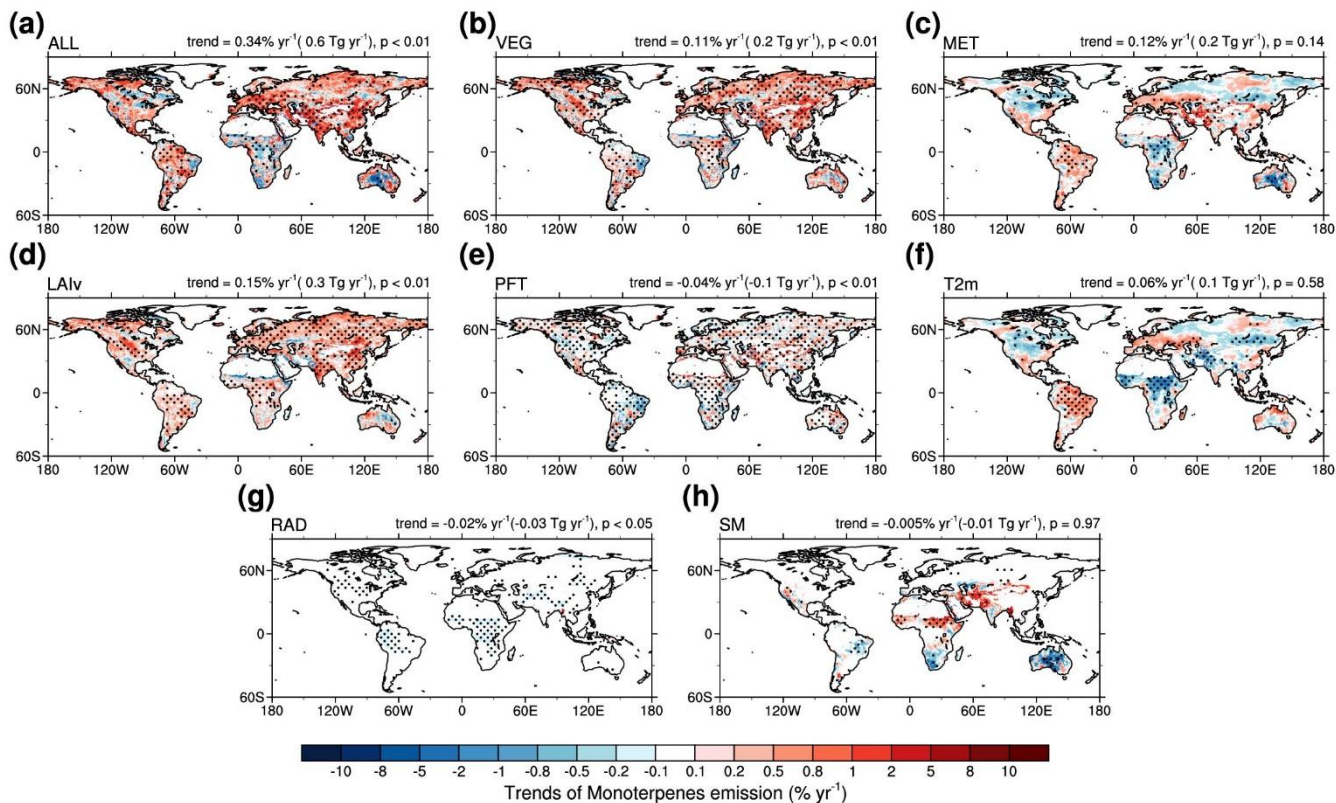
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Figure S1: The seasonal variation of leaf area index (LAI) and surface 2 m temperature (T2m) for each region outlined in black on the map during 2001-2020. The shaded area represents one standard deviation. The nine regions are listed below: NAM: North America; EUR: Europe; NAS: North Asia; EAS: East Asia; SAS: South Asia; SEAS: Southeast Asia; SAM: South America; CAF: Central Africa; AUS: Australia.

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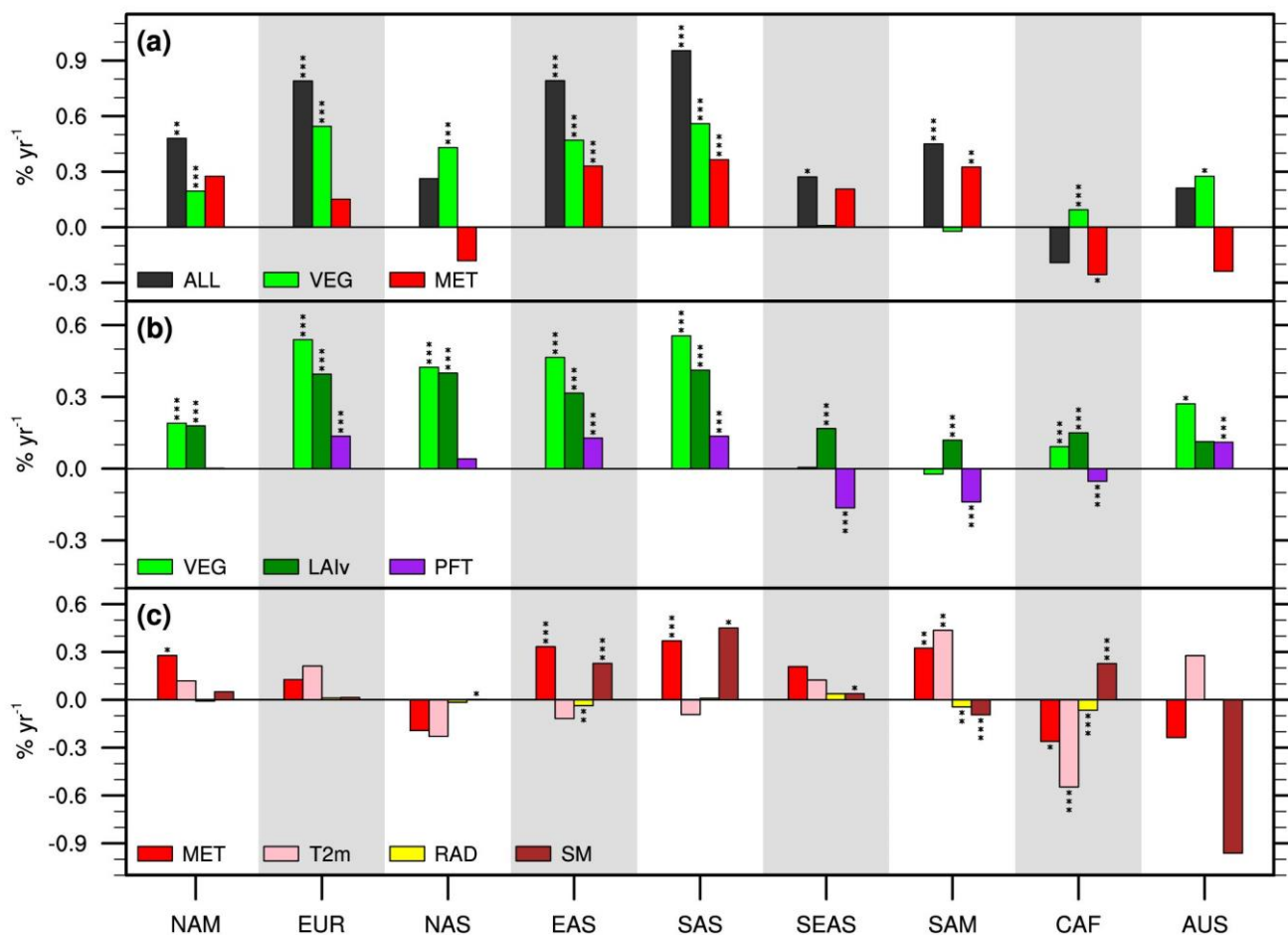
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25 **Figure S3: Spatial distribution of monoterpene emission trends from 2001 to 2020.** (a) ALL represents simulated results considering interannual variability of all drivers. (b, c) VEG and MET represent simulated trends when considering only interannual variability of vegetation and meteorology, respectively. (d, e) Contributions from individual vegetation parameters including LAIv (leaf area index of vegetation covered surfaces) and PFT (plant functional types). (f, g, and h) Contributions from individual meteorological factors including T2m (surface 2 m temperature), RAD (surface solar radiation), and SM (soil moisture). Stippling denotes regions where the trend is statistically significant ($p < 0.1$) using the Mann-Kendall test. Trends are expressed by the relative change in percentage (i.e., the linear change during 2001-2020 divided by the mean value) and absolute change. p-values represent statistically significant levels using the Mann-Kendall test.

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Trends of Monoterpenes emission during 2001-2020



35 **Figure S4: Trends of monoterpenes emissions and associated influencing factors from 2001–2020 in nine regions. (a) ALL**
represents simulated results considering interannual variability of all drivers, while VEG and MET represent simulated results
considering only interannual variability of vegetation and meteorology, respectively. (b) Contributions from individual vegetation
parameters including LAIv (leaf area index of vegetation covered surfaces) and PFT (plant functional types). (c) Contributions
from individual meteorological factors including T2m (surface 2 m temperature), RAD (surface solar radiation), and SM (soil
moisture). (d) Trends of individual influencing factors including vegetation parameters and meteorological factors. Tree, shrub,
grass, and crop represent the four plant functional types (PFTs). The single, double, and triple asterisks denote 90%, 95%, and 99%
confidence levels (CI) using the Mann-Kendall test, respectively.

References

Alves, E. G., Jardine, K., Tota, J., Jardine, A., Yáñez-Serrano, A. M., Karl, T., Tavares, J., Nelson, B., Gu, D., Stavrakou, T.,
 Martin, S., Artaxo, P., Manzi, A., and Guenther, A.: Seasonality of isoprenoid emissions from a primary rainforest
 in central Amazonia, *Atmos. Chem. Phys.*, 16, 3903-3925, <https://doi.org/10.5194/acp-16-3903-2016>, 2016.

- 45 Alves, E. G., Tóta, J., Turnipseed, A., Guenther, A. B., Vega Bustillos, J. O. W., Santana, R. A., Cirino, G. G., Tavares, J. V.,
Lopes, A. P., Nelson, B. W., de Souza, R. A., Gu, D., Stavrakou, T., Adams, D. K., Wu, J., Saleska, S., and Manzi, A.
O.: Leaf phenology as one important driver of seasonal changes in isoprene emissions in central Amazonia,
Biogeosciences, 15, 4019-4032, <https://doi.org/10.5194/bg-15-4019-2018>, 2018.
- Bai, J.: Estimation of the isoprene emission from the Inner Mongolia grassland, *Atmos. Pollut. Res.*, 6, 406-414,
50 <https://doi.org/10.5094/APR.2015.045>, 2015.
- Bai, J., Guenther, A., Turnipseed, A., and Duhl, T.: Seasonal and interannual variations in whole-ecosystem isoprene and
monoterpene emissions from a temperate mixed forest in Northern China, *Atmos. Pollut. Res.*, 6, 696-707,
<https://doi.org/10.5094/APR.2015.078>, 2015.
- Bai, J., Guenther, A., Turnipseed, A., Duhl, T., Yu, S., and Wang, B.: Seasonal variations in whole-ecosystem BVOC
55 emissions from a subtropical bamboo plantation in China, *Atmos. Environ.*, 124, 12-21,
<https://doi.org/10.1016/j.atmosenv.2015.11.008>, 2016.
- Bai, J. H., Wang, G. C., Ren, L. X., Baker, B., Zimmerman, P., and Liang, B. S.: The emission flux of volatile organic
compounds in the Inner Mongolia Grassland, *Huan jing ke xue*, 24(6), 16-22, 2003, (In Chinese).
- Baker, B., Bai, J.-H., Johnson, C., Cai, Z.-T., Li, Q.-J., Wang, Y.-F., Guenther, A., Greenberg, J., Klinger, L., Geron, C., and
60 Rasmussen, R.: Wet and dry season ecosystem level fluxes of isoprene and monoterpenes from a southeast Asian
secondary forest and rubber tree plantation, *Atmos. Environ.*, 39, 381-390,
<https://doi.org/10.1016/j.atmosenv.2004.07.033>, 2005.
- Harley, P., Otter, L., Guenther, A., and Greenberg, J.: Micrometeorological and leaf-level measurements of isoprene
emissions from a southern African savanna, *J. Geophys. Res.-Atmos.*, 108, <https://doi.org/10.1029/2002JD002592>,
65 2003.
- Holst, T., Arneth, A., Hayward, S., Ekberg, A., Mastepanov, M., Jackowicz-Korczynski, M., Friborg, T., Crill, P. M., and
Bäckstrand, K.: BVOC ecosystem flux measurements at a high latitude wetland site, *Atmos. Chem. Phys.*, 10, 1617-
1634, <https://doi.org/10.5194/acp-10-1617-2010>, 2010.
- Jensen, N. R., Gruening, C., Goded, I., Müller, M., Hjorth, J., and Wisthaler, A.: Eddy-covariance flux measurements in an
70 Italian deciduous forest using PTR-ToF-MS, PTR-QMS and FIS, *Int. J. Environ. Anal. Chem.*, 98, 758-788,
<https://doi.org/10.1080/03067319.2018.1502758>, 2018.
- Karl, T., Guenther, A., Yokelson, R. J., Greenberg, J., Potosnak, M., Blake, D. R., and Artaxo, P.: The tropical forest and fire
emissions experiment: Emission, chemistry, and transport of biogenic volatile organic compounds in the lower
atmosphere over Amazonia, *J. Geophys. Res.-Atmos.*, 112, <https://doi.org/10.1029/2007JD008539>, 2007.
- 75 Karl, T., Potosnak, M., Guenther, A., Clark, D., Walker, J., Herrick, J. D., and Geron, C.: Exchange processes of volatile
organic compounds above a tropical rain forest: Implications for modeling tropospheric chemistry above dense
vegetation, *J. Geophys. Res.-Atmos.*, 109, <https://doi.org/10.1029/2004JD004738>, 2004.

- Langford, B., Misztal, P. K., Nemitz, E., Davison, B., Helfter, C., Pugh, T. A. M., MacKenzie, A. R., Lim, S. F., and Hewitt, C. N.: Fluxes and concentrations of volatile organic compounds from a South-East Asian tropical rainforest, *Atmos. Chem. Phys.*, 10, 8391-8412, <https://doi.org/10.5194/acp-10-8391-2010>, 2010.
- Langford, B., Cash, J., Acton, W. J. F., Valach, A. C., Hewitt, C. N., Fares, S., Goded, I., Gruening, C., House, E., Kalogridis, A. C., Gros, V., Schafers, R., Thomas, R., Broadmeadow, M., and Nemitz, E.: Isoprene emission potentials from European oak forests derived from canopy flux measurements: an assessment of uncertainties and inter-algorithm variability, *Biogeosciences*, 14, 5571-5594, <https://doi.org/10.5194/bg-14-5571-2017>, 2017.
- Langford, B., House, E., Artaxo, P., Barkley, M., Brito, J., Davison, B., Hewitt, N., MacKenzie, R., Marais, E., Newland, M., Rickard, A., Shaw, M., Valach, A., Yañez-Serrano, A. M., and Nemitz, E.: Seasonality of isoprene oxidation chemistry in the remote Amazon is mediated by anthropogenic pollution, *Environ. Sci.: Atmos.*, 230-240, <https://doi.org/10.1039/D1EA00057H>, 2022.
- McKinney, K. A., Lee, B. H., Vasta, A., Pho, T. V., and Munger, J. W.: Emissions of isoprenoids and oxygenated biogenic volatile organic compounds from a New England mixed forest, *Atmos. Chem. Phys.*, 11, 4807-4831, <https://doi.org/10.5194/acp-11-4807-2011>, 2011.
- Misztal, P. K., Nemitz, E., Langford, B., Di Marco, C. F., Phillips, G. J., Hewitt, C. N., MacKenzie, A. R., Owen, S. M., Fowler, D., Heal, M. R., and Cape, J. N.: Direct ecosystem fluxes of volatile organic compounds from oil palms in South-East Asia, *Atmos. Chem. Phys.*, 11, 8995-9017, <https://doi.org/10.5194/acp-11-8995-2011>, 2011.
- Pressley, S., Lamb, B., Westberg, H., Flaherty, J., Chen, J., and Vogel, C.: Long-term isoprene flux measurements above a northern hardwood forest, *J. Geophys. Res.-Atmos.*, 110, <https://doi.org/10.1029/2004JD005523>, 2005.
- Saito, T., Yokouchi, Y., Kosugi, Y., Tani, M., Philip, E., and Okuda, T.: Methyl chloride and isoprene emissions from tropical rain forest in Southeast Asia, *Geophys. Res. Lett.*, 35, <https://doi.org/10.1029/2008GL035241>, 2008.
- Spirig, C., Guenther, A., Greenberg, J. P., Calanca, P., and Tarvainen, V.: Tethered balloon measurements of biogenic volatile organic compounds at a Boreal forest site, *Atmos. Chem. Phys.*, 4, 215-229, <https://doi.org/10.5194/acp-4-215-2004>, 2004.
- Spirig, C., Neftel, A., Ammann, C., Dommen, J., Grabmer, W., Thielmann, A., Schaub, A., Beauchamp, J., Wisthaler, A., and Hansel, A.: Eddy covariance flux measurements of biogenic VOCs during ECHO 2003 using proton transfer reaction mass spectrometry, *Atmos. Chem. Phys.*, 5, 465-481, <https://doi.org/10.5194/acp-5-465-2005>, 2005.
- Stoy, P. C., Trowbridge, A. M., Siqueira, M. B., Freire, L. S., Phillips, R. P., Jacobs, L., Wiesner, S., Monson, R. K., and Novick, K. A.: Vapor pressure deficit helps explain biogenic volatile organic compound fluxes from the forest floor and canopy of a temperate deciduous forest, *Oecologia*, 197(4), 971-988, <https://doi.org/10.1007/s00442-021-04891-1>, 2021.
- Zheng, Y., Unger, N., Tadić, J. M., Seco, R., Guenther, A. B., Barkley, M. P., Potosnak, M. J., Murray, L. T., Michalak, A. M., Qiu, X., Kim, S., Karl, T., Gu, L., and Pallardy, S. G.: Drought impacts on photosynthesis, isoprene emission and atmospheric formaldehyde in a mid-latitude forest, *Atmos. Environ.*, 167, 190-201, <https://doi.org/10.1016/j.atmosenv.2017.08.017>, 2017.