Summary of the EQUATOR project

Tropospheric chemistry is strongly influenced by land-atmosphere interactions. Because of their high reactivity and ubiquity, volatile organic compounds (VOCs) have a significant impact on the atmospheric oxidation, ozone and particulate matter production. VOCs readily react with hydroxyl radicals (OH), the primary atmospheric detergent, that plays a central role in atmospheric chemistry. Isoprene (C_5H_8) is the most abundantly emitted biogenic volatile organic compound (BVOC) emitted by terrestrial vegetation. The global budget of BVOC is dominated by the Tropics, largely due to high emissions of BVOCs resulting from their high productivity through broadleaf rainforests and favourable climatic conditions. Despite their importance, isoprene emissions remain highly uncertain, especially in tropical regions, due to complex biosphere–atmosphere interactions, limited observational constraints, and poorly constrained NO_X (= NO + NO_2) levels. Indeed, tropical regions are among the most poorly monitored and understood ecosystems. Low levels of NO_X prevail in most tropical regions, leading to VOCs oxidation pathways differing from those occurring in better monitored areas at mid-latitudes. Natural NO_X emissions from soil and lightning play a key role in the Tropics, but their appraisal is highly uncertain. Understanding and quantifying the magnitude, trends and impacts of BVOCs on atmospheric chemistry represents a major scientific challenge that requires the integrated use of global satellite observations complemented by ground-based, in situ measurements and state-of-the-art atmospheric modelling tools. Spaceborne formaldehyde (HCHO), a key product of isoprene oxidation, can provide valuable information on VOCs when coupled with atmospheric chemistry-transport models and inverse modelling tools allowing to improve the emissions appraisal.

The EQUATOR (Emission Quantification of Atmospheric tracers in the Tropics using ObseRvations from satellites) project focuses on the determination of the emissions of trace gases, in particular, isoprene, soil NO_X and lightning in the Tropics. The work consists in (i) the study of the impact of land cover (LC) distributions on global isoprene emission and trends, including the identification of factors leading to uncertainties in the emission appraisal, (ii) the bias characterisation of OMI HCHO satellite retrievals using independent ground-based and airborne observations, (iii) the satellite-based estimation of isoprene and natural NO_X emissions obtained using a two-species inversion from spaceborne TROPOMI HCHO and NO_2 concentrations over Africa and South America. The project combines bottom-up and top-down modelling approaches. The bottom-up methodology is based on the BVOCs emission model, MEGAN-MOHYCAN, whereas the top-down approach integrates a chemistry-transport model (CTM) and inverse modelling techniques. We use the in-house CTM of the troposphere, MAGRITTEv1.1, and its adjoint-based tool for emission optimization.

The first study investigates the distribution and trends of tree cover in various land cover datasets. Substantial discrepancies were found among the different datasets, with global tree cover area

estimates ranging from 30 to 50 million km², and trend estimates varying from -0.26% to +0.03% per year over 2001-2016. Correspondingly, annual isoprene emission estimates based on those land use datasets ranged from 350 to 520 Tg. Changes in land cover were found to mitigate the overall positive trend in isoprene emissions, driven mainly by increasing temperature and solar radiation, by 0.04% to 0.33% per year. This mitigation effect is largely attributed to tree cover loss in tropical regions. As a result of this study, the ALBERI dataset was developed: a long-term, bottom-up inventory of global monthly isoprene emissions at 0.5°×0.5° spatial resolution for the period 2001-2018, incorporating satellite-based vegetation distributions. The associated land cover dataset (GFWMOD) represents annual tree cover distributions from 2001 to 2018 and is based on the MODIS land cover dataset, adjusted to align with tree cover estimates from the very high-resolution (30-m) Global Forest Watch database.

The characterisation of OMI HCHO retrievals using both Fourier-transform infrared (FTIR) and aircraft measurements reveals a systematic bias: OMI tends to underestimate the high HCHO columns and overestimate the low ones. To address this, we derived linear regression-based corrections to adjust OMI HCHO column densities. Applying these bias corrections results in global top-down isoprene emission estimates that are approximately by 25% higher than those obtained using uncorrected data, highlighting the substantial impact of this adjustment. The effect is particularly pronounced over South Asia (+43%) and Africa (nearly +30%). The updated emission estimates also show good consistency with recent values derived from spaceborne isoprene columns retrieved by the CrIS sensor. These findings support the integration of bias-corrected satellite HCHO observations into inverse modelling frameworks to improve the accuracy of VOC emission estimates.

A novel inversion framework was developed based on the chemistry-transport model MAGRITTEv1.1, enabling the simultaneous inversion of two species, VOCs and NO_x, using satellite (TROPOMI) observations of HCHO and NO_2. Over Africa, the inversion results indicate that bottom-up emission inventories underestimate emissions significantly: biogenic isoprene by approximately 30%, soil NO_x by 25%, and lightning NO_x by as much as 300%. Evaluation against surface NO_2 concentrations at rural locations, as well as cloud-sliced upper-tropospheric NO_2, used as a proxy for lightning NO emissions, supports further increases in the optimised soil and lightning NO_x emissions. Top-down emissions derived from the two-species inversion show clear improvements in the representation of isoprene columns, both in magnitude and spatial distribution, when evaluated against independent CrIS satellite observations over Africa. Notably, CrIS data corroborates the emergence of a previously unidentified hotspot over Angola that is absent from the bottom-up inventory. The improved performance of the joint NO_2-HCHO inversion compared to single-species inversions using HCHO alone underscores the added value of including satellite NO_2 constraints. This study resulted in high-resolution (0.5°×0.5°) monthly top-down emission estimates for isoprene, soil NO_x, and lightning NO_x over Africa for a complete year (2019).

We adopted this inversion approach to estimate top-down VOC and NO_x emissions over South America, using satellite observations of HCHO and NO_2 columns. The optimisation resulted in a 60% increase in lightning NO_x emissions and in a small increase in soil NO_x emissions relative to bottom-up inventories. As for Africa, the evaluation of soil and lightning NO_x emissions indicate a remaining underestimation in top-down inventories. For isoprene, the top-down estimates are approximately 20% lower than bottom-up values. The inversion indicates substantial reductions (up to 80%) in high-emission regions of Western and Southern Amazonia, leading to improved agreement with CrIS-derived isoprene column densities and their spatial distribution. However, local FTIR measurements of isoprene columns at Porto Velho do not confirm the pronounced reductions observed during the dry season, highlighting the need for further investigation.

Keywords: isoprene, land cover changes, NO_X, soil, lightning, inversion, bias, TROPOMI.