Local impact model : Biogenic emissions in a changing climate

Introduction

Vegetation is the dominant source of volatile organic compounds (VOCs) in the atmosphere, accounting for about 1000 Tg globally on a yearly basis (Guenther et al. 2012), and representing about 90% of the estimated total VOC emission. Isoprene accounts for almost half of the total biogenic VOC emission (400-600 Tg, Guenther et al. 2006) and plays a key role in the atmospheric composition because of its influence on tropospheric ozone formation in polluted environments and its contribution to particulate matter. Isoprene emissions depend on the type and abundance of plants, and are modulated by meteorological parameters, in particular temperature and solar radiation. Climate changes therefore affect the spatiotemporal and interannual variation of these emissions. Increases in surface temperature and/or solar radiation are expected to lead to enhanced biogenic emissions, and thereby to higher ozone concentrations.

State of the art and objectives

The question of how biogenic emissions will evolve in future warming climate has been addressed in several studies. The most recent studies conclude that global warming will lead to stronger global isoprene emissions (Meleux et al., 2007; Wiedinmyer et al., 2006), but that the inhibitory effect of CO_2 on isoprene production is likely to counteract this effect (Arneth et al., 2007; Young et al., 2009). Moreover, rising CO_2 levels are likely to induce an increase in biomass, which will also lead to stronger biogenic emissions (Arneth et al., 2007), even though human-induced land use changes such as deforestation and urbanization could counteract this effect (Heald et al., 2009; Wu et al., 2012). Overall, the uncertainties on future isoprene emission are quite large, with isoprene emissions over Europe estimated to decrease by 30% (Arneth et al., 2007) or to increase by 100% (Katragkou et al., 2011) by the end of the century. Our objective is to estimate the evolution of isoprene emissions over the EURO-CORDEX domain (with focus on Belgium) at high resolution (0.1°x0.1°) for past and future climate conditions. To this purpose, we use the MEGAN-MOHYCAN coupled emission-canopy environment model (Müller et al., 2008, Stavrakou et al. 2014) driven by meteorological fields provided by CORDEX.be simulations.

Methodology : The MEGAN-MOHYCAN model

Here we estimate the isoprene fluxes emitted by vegetation in past and future climate over the European (EURO-CORDEX) domain using the MEGAN-MOHYCAN model (Müller et al., 2008, Stavrakou et al. 2014). The model is based on the widely used MEGAN model for biogenic emissions (Guenther et al., 2006, 2012), coupled with the multi-layer canopy environment model MOHYCAN (Müller et al., 2008). The MEGAN algorithm (Eq.1) includes the specification of a standard emission factor ε (mg m^{-2} h^{-1}), representing the biogenic emission at standard conditions (Guenther et al. 2006) for each plant functional type (PFT). The activity factors ɣ account for the response of the emission to solar radiation, temperature, leaf age, soil moisture, and CO_2 levels. The γ_{CO2} activity factor is not applied for past simulations, and for the future runs two different parameterizations are tested, W2009 and PH2011, based on Wilkinson et al. (2009), and Possell and Hewitt (2011), respectively. LAI in Eq. (1) denotes the leaf area index (LAI).

$$Flux = \varepsilon * \gamma_T * \gamma_{PAR} * \gamma_{age} * \gamma_{SM} * \text{LAI} * \gamma_{co_2} \qquad (1)$$

The MOHYCAN model (Müller et al. 2008) calculates the leaf temperature and the attenuation of light as a function of the height inside the canopy, using visible and near-infrared solar radiation values at the canopy top, together with air temperature, relative humidity, wind speed and cloud cover. More precisely, the meteorological input fields driving MEGAN-MOHYCAN are: the downward solar radiation, the cloud cover fraction, the volumetric soil moisture (at four soil layers), the air temperature above the surface, the dew point temperature, and the wind speed directly above the canopy. The emissions are calculated with a time step of 1h at a horizontal resolution of $0.1^{o}x0.1^{o}$, or about 11 km. Here we first calculate isoprene emissions over 1979-2005 based on the ECMWF ERA-Interim reanalysis data, and investigate the sensitivity to solar radiation changes observed at European stations. Next, we perform simulations using the output of the CORDEX.be ALARO-0 regional climate model (Giot et al., 2016) forced by the RCP2.6, RCP4.5 and RCP8.5 scenarios over 2071-2099, and compare with the historical emissions over 1976-2005 derived by the same model. The ALARO fields used are temperature, wind, cloud cover fraction, solar radiation downward flux and specific humidity. Furthermore, we incorporate the inhibition effect of isoprene emissions to the enhanced CO_2 levels of the climate projections.

Scientific results: High-resolution inventory of past and future isoprene emissions over Europe

Two simulations were performed to calculate past isoprene emissions over the period 1979-2005, both driven by ERA-Interim ECMWF reanalysis meteorological fields (Dee et al., 2011). Because these fields are constrained by meteorological observations, the derived isoprene emissions constitute our 'best' estimate. Moreover, to better account for the effects of solar radiation changes over Europe that might not be captured by the ECMWF solar radiation fields, in the SSR simulation we have corrected the modelled short-wave radiation by using ground-based solar radiation observations over 1979-2005 (Sanchez-Lorenzo et al., 2013). Four simulations were conducted using the meteorology of the CORDEX.be ALARO model, one over 1976-2005 (ALARO-HIST) and three over 2071-2099 forced by the RCP2.6, RCP4.5 and RCP8.5 climate projections. The simulations are summarized in Table 1.

Table 1. Performed simulations using the MEGAN-MOHYCAN model driven by either ECMWF or ALARO meteorology. The mean fluxes over Europe and over Belgium are given in Tg/yr and in Gg/yr, respectively. The percentual changes (in *italics*) are calculated with respect to the standard simulations.

Performed simulations		Flux over Europe (Tg/yr)	Flux over Europe accounting for CO_2 inhibition		Flux over Belgium (Gg/yr)	Flux over Belgium accounting for CO_2 inhibition	
			W2009	PH2011		W2009	PH2011
ECMWF	1979-2005	6.2	-	-	14.0	-	-
SSR	1979-2005	6.2	-	-	14.3	-	-
ALARO-HIST	1976-2005	4.6	-	-	10.1	-	-
ALARO-RCP2.6	2071-2099	5.0	4.8 *(-4%)*	4.3 *(-14%)*	10.5	10.1	9.0
ALARO-RCP4.5	2071-2099	6.1	5.4 *(-11%)*	4.4 *(-28%)*	11.6	10.3	8.4
ALARO-RCP8.5	2071-2099	8.4	5.8 *(-31%)*	4.1 *(-51%)*	15.3	10.5	7.5

The distribution of the isoprene emissions is similar for the ECMWF, SSR and ALARO simulations (Figure 1), with higher isoprene emissions in Southern Europe and over central Russia. Compared to the ECMWF simulation, the use of observed solar radiation fields results in only slightly higher emission over the entire domain, but leads to up to 10% higher emission in eastern Europe, due to stronger brightening suggested by the observations. The use of ALARO-0 climate data results in lower mean emission flux over Europe (by 23%), due to the negative temperature bias in ALARO (Giot et al. 2016) with respect to ECMWF temperature fields, except over Ukraine, Poland and Belarus.

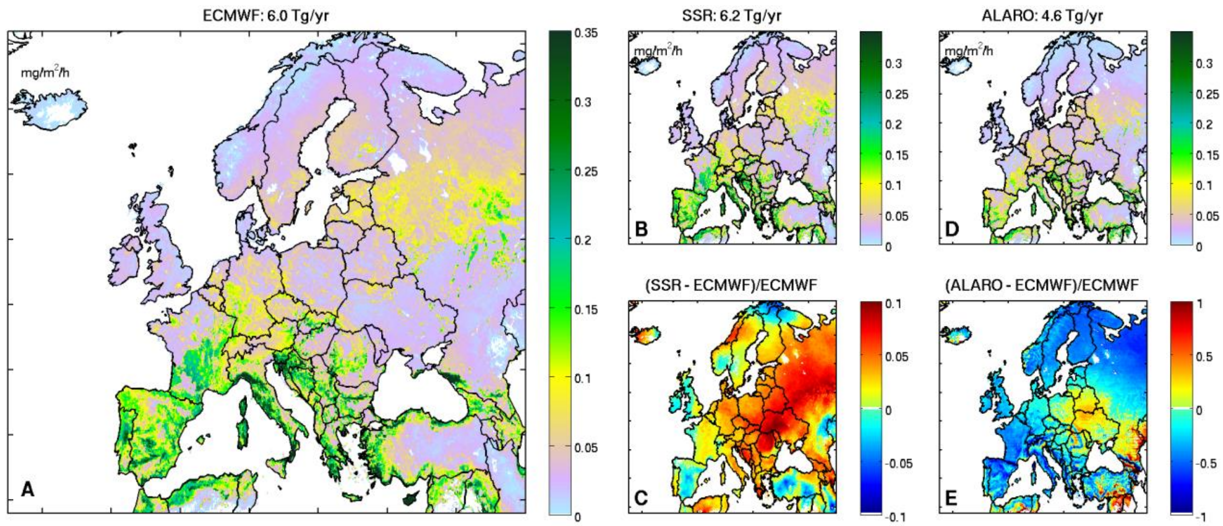

Figure 1: Mean isoprene emission flux (in mg/m^2/h) calculated by ECMWF (A), SSR (B) and ALARO (D) simulations. The relative difference between the SSR and ALARO simulations with respect to the ECMWF results is illustrated in panels C and E, respectively.

The isoprene emission trends over 1979-2005 based on ECMWF, SSR and ALARO simulations are shown in Figure 2. The isoprene emissions increased almost uniformly during this period. Although the emission trend is weaker using the ALARO climate input, the patterns are similar in the three simulations. The strongest emission trends (up to 3%/yr) are calculated over northern France, southern Belgium, and southern Turkey, and the weakest trends (less than 1%/yr) over Spain, Turkey, Sweden, and central European Russia.

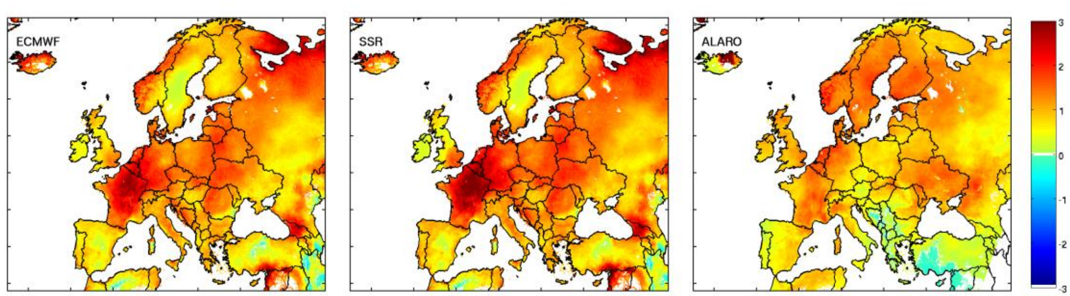

Figure 2: Isoprene emission trend (in % per year) between 1979 and 2005 according to 3 historical runs, ECMWF (left), SSR (middle) and ALARO (right).

The isoprene emission distribution over Europe and over Belgium calculated based on ALARO-0 meteorological fields is illustrated in Figure 3. All climate scenarios suggest a flux increase over the European domain with respect to the historical simulation, which amounts to 6% in RCP2.6, 33% in RCP4.5, and 82% in the RCP8.5 simulation. Similar but somewhat weaker increases are found over Belgium, 4% in RCP2.6, 15% in RCP4.5 and 51% in RCP8.5. The highest emission in Belgium are found over the Ardenne and Campine forests (Figure 3), whereas central and eastern Belgium stays a low isoprene emitting region due to the dominance of urban centers, pasture and croplands. The distribution of the relative change in the future scenario emissions with respect to the historical run is shown in Figure 4 (upper panels).

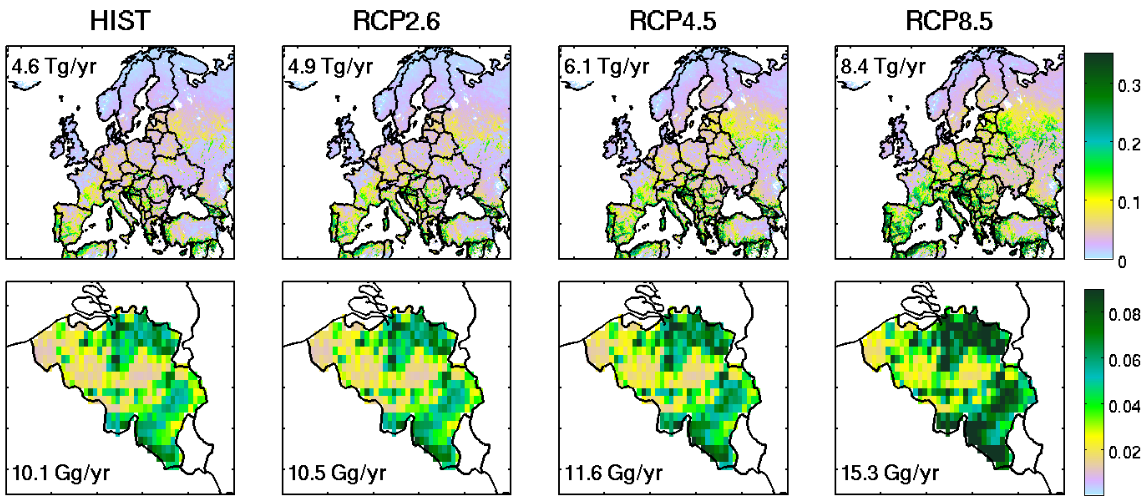

Figure 3: Isoprene fluxes over Europe and Belgium for the historical run ALARO-HIST and for the 3 RCP scenarios (calculation without accounting for CO_2 inhibition effects), and are thus only influenced by the changes in future climate as predicted by the ALARO model.

Whereas the RCP2.6 simulation suggests weakly higher isoprene emissions (up to 20%), the RCP4.5 and RCP8.5 simulations suggest isoprene emission increases that locally reach 40% and 110%, respectively. The enhanced future isoprene emissions in the central Russian region are mainly a result of strongly increasing temperatures, somewhat counteracted by decreasing insolation. In the Mediterranean region, similar isoprene emission increases are the result of a combination of less strong temperature increases, solar brightening and increased soil moisture stress due to the dryer future climate in this region, which slightly reduces the isoprene flux.

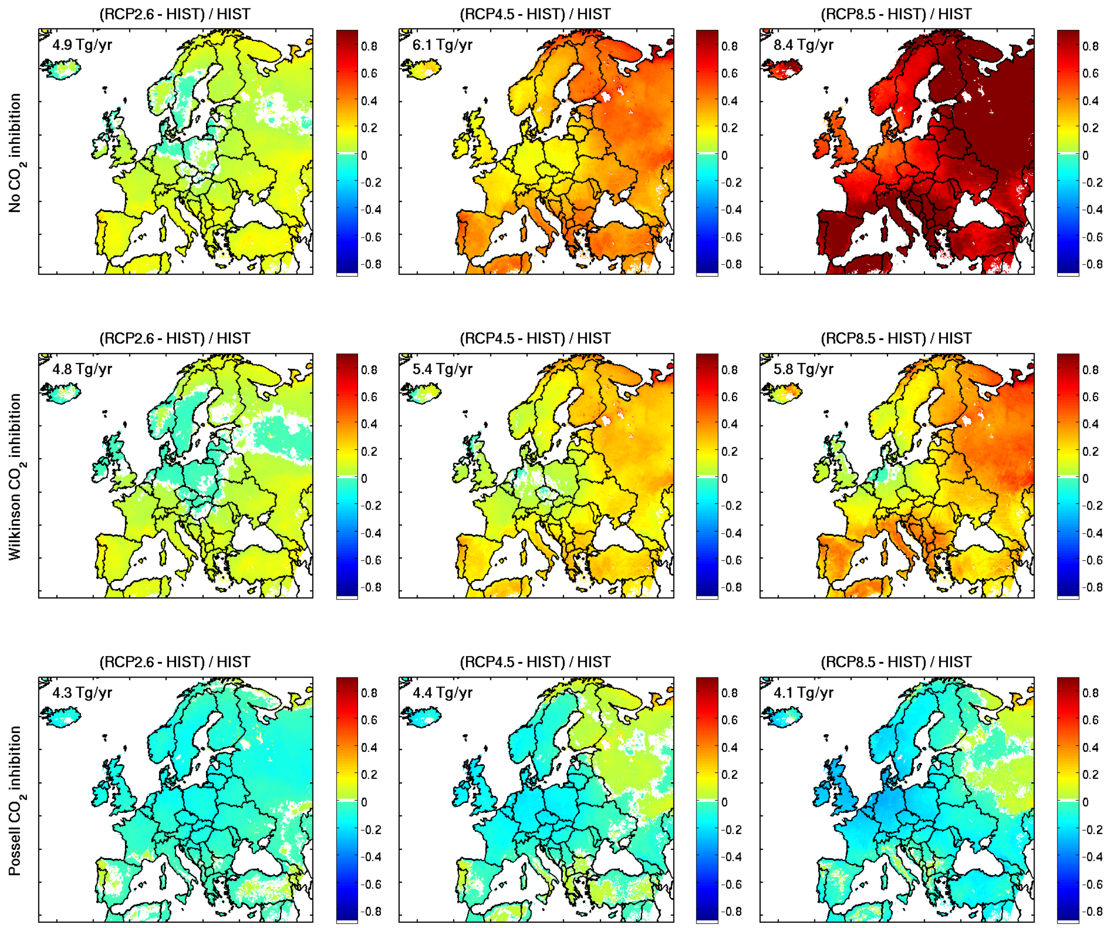

Figure 4: Relative isoprene emission increments compared to the Historical ALARO run for 3 RCP scenarios considering no CO_2 inhibition (top row), considering moderate CO_2 inhibition according the parametrization of Wilkinson et a. (2009) (middle row) or considering strong CO_2 inhibition according to the parameterization of Possell and Hewitt (2011) (bottom row). The average annual isoprene emission for each run is given on the left upper corner of every map.

When accounting for the inhibitory effect of future CO_2 levels on isoprene production the estimated isoprene fluxes are found to be lower than in the standard future simulations (Table 1 and Figure 4). Because CO_2 is uniformly distributed, the spatial patterns of the emission changes are not influenced by including the CO_2 inhibition parameterization. Relative to the standard future simulations (in which the CO_2 inhibition effect is neglected), the future isoprene emission decreases by 4%, 11% and 31% in RCP2.6, RCP4.5 and RCP8.5, respectively, when applying the Wilkinson et al. (2009) parameterization, whereas the decrease is stronger when the Possell and Hewitt (2011) parameterization is used (-14%, -28%, -51%). It should be acknowledged, however, that due to the limited amount of measurements, both parameterizations bear large uncertainties. By the end of the century, the isoprene emissions in Belgium will remain very close to the present value, ranging between +4% and -26%, depending on the used parameterization (Table 1, Figure 5).

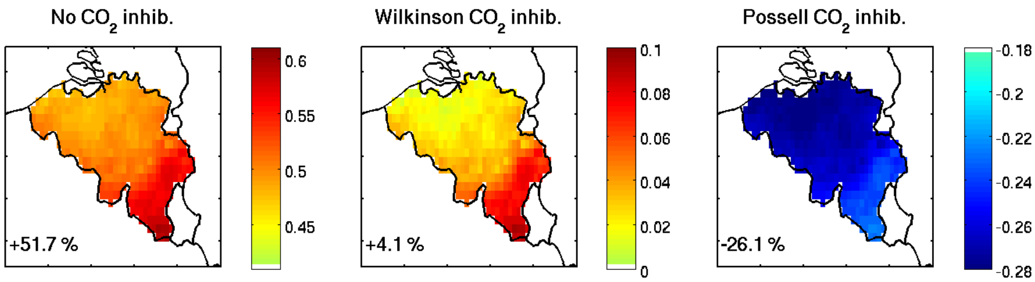

Figure 5: Same as Figure 4 for Belgium. Relative isoprene emission increments compared to the historical ALARO run for the RCP8.5 scenario, considering no CO_2 inhibition, moderate CO_2 inhibition (Wilkinson et al. 2009), or strong CO_2 inhibition (Possell and Hewitt (2011).

Conclusions

We have calculated the isoprene emissions from vegetation over the EURO-CORDEX domain based on reanalysis data and on the output of a regional climate model. The estimated emission fluxes over Europe are found to increase by up to 83% in the RCP8.5 projection, and moderate increases are calculated in the RCP2.6 and RCP4.5 cases. In Belgium, the emission increase relative to the present day emissions due to the climate change is estimated at 51% in the extreme RCP8.5 scenario, but is much lower in the RCP2.6 (4%) and RCP4.5 (15%) simulations. The inclusion of the CO_2 inhibition results in an overall decrease in the estimated fluxes, which counteracts the increase due to climate change. It should be acknowledged however that the present study does not account for the potentially non-negligible effects of land use changes and CO_2 fertilization on the estimated emissions. Furthermore, the role of isoprene emissions on the atmospheric composition in a future climate depends also on the evolution of other emission sources (e.g. NOx) with which isoprene interacts, leading to ozone formation. The non-linearity of tropospheric ozone chemistry and the strong decline of anthropogenic emissions over Europe expected to occur during the 21st century, as a result of regulations, is expected to modify in the future the relationship between surface ozone and meteorological parameters. To assess these effects, simulations of the atmospheric composition using a high-resolution atmospheric model would be necessary.

Dissemination and valorisation

The results of this study are presented at the EGU General assembly in 2016 and 2017 and will be the subject of a peer-review publication to be submitted soon.

- "High resolution isoprene emission over Europe in past and future climate"**,** T. Stavrakou, J.-F. Müller, M. Bauwens, J. Berckmans, S. Caluwaerts, R. De Troch, L. De Cruz, O. Giot, R. Hamdi, P. Termonia, and B. Schaeybroeck, EGU General Assembly, Vienna, 17-22 April, 2016.
- **"**Effect of climate change and CO_2 inhibition on isoprene emissions in Europe calculated using the ALARO-0 regional climate model", M. Bauwens, T. Stavrakou, J.-F. Müller, J. Berckmans, R. De Troch, L. De Cruz, O. Giot, R. Hamdi, P. Termonia, and B. Schaeybroeck, EGU General Assembly, Vienna, 23–28 April 2017.
- Bauwens M., Stavrakou T., Müller J.-F., De Cruz L., Giot O., Hamdi R., Termonia P., and Schaeybroeck B."How will future climate and atmospheric composition influence isoprene emissions over Europe?" (in preparation).

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