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Drought effect on urban plane tree ecophysiology and its isoprene emissions

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1. Introduction

- ✓ Trees emits a wide range of biogenic Volatile Organic Compounds (bVOC), impacting both air quality and climate.
- ✓ BVOC like isoprene can react with atmospheric oxidants to form secondary compounds impacting both air quality and climate.
- ✓ Isoprene emissions are strongly influenced by environmental factors, but little is known about how stressful urban environments modulate bVOC emissions from urban trees and the consequences on air quality.

2. Experimental site and methods

- Semi-controlled experiment installed in an urban area, in February 2020 (Figure 1).
- Drought treatment was applied to half of the trees in 2021 (58 days long) and 2022 (29 days long), by water withholding.

Figure 1 In situ experiment (a) Map localization of the experimental site in an urban area near Paris (yard of the IUT of Créteil-Vitry; 48.776376, 2.375333) (b) Picture of the semi-controlled experiment composed of fourteen young plane trees (*Platanus x hispanica*, known as a strong isoprene emitter), grown in 500 L containers equipped with total rainfall exclusion system to control water supply.

Photosynthetic CO_2/H_2O gas exchange (CIRAS-3, PP System)

- Parameters: 25°C temperature (T), 1000 $\mu mol_{photons}$ m^{-2} s^{-1} light (PAR), 1.2 kPa relative water vapor concentration and 410 ppm CO_2 concentration.

BVOC sampling (Custom leaf cuvette, see picture →)

- Leaf acclimated at ambient CO_2 and relative water vapor concentration, at a T of 30°C, and PAR of 1000 $\mu mol_{photons}$ m^{-2} s^{-1}, using a custom Parkinson-type leaf cuvette (air flow: 400 ml min^{-1})
- Air leaving the cuvette sampled during **10 min at a rate of 4 ml min^{-1}** using a Custodion **Neddle Trap** (**NT**; tri-bed: Tenax TA, Carboxen 1016 and 1003) with a Clairion pump system (Perkin Elmer)

BVOC Analysis (Torion T-9 Portable GC-MS, Perkin-Elmer , see picture →)

- Direct thermal desorption (270°C) of **NT** inside Torion T-9 GC injector
- **Three minutes run** (2°C s^{-1} ramp with an initial and final temperature of 50°C and 290°C, respectively)
- Detection and quantification of bVOC using ion-trap mass spectrometer
- Data for isoprene emission factor was calculated using calibration curves obtained with a 1ppmv gaseous standard (diluted at 39, 70, 90 and 140 ppbv) and normalized for temperature and light intensity[1]

3. Seasonal and drought effects on canopy development

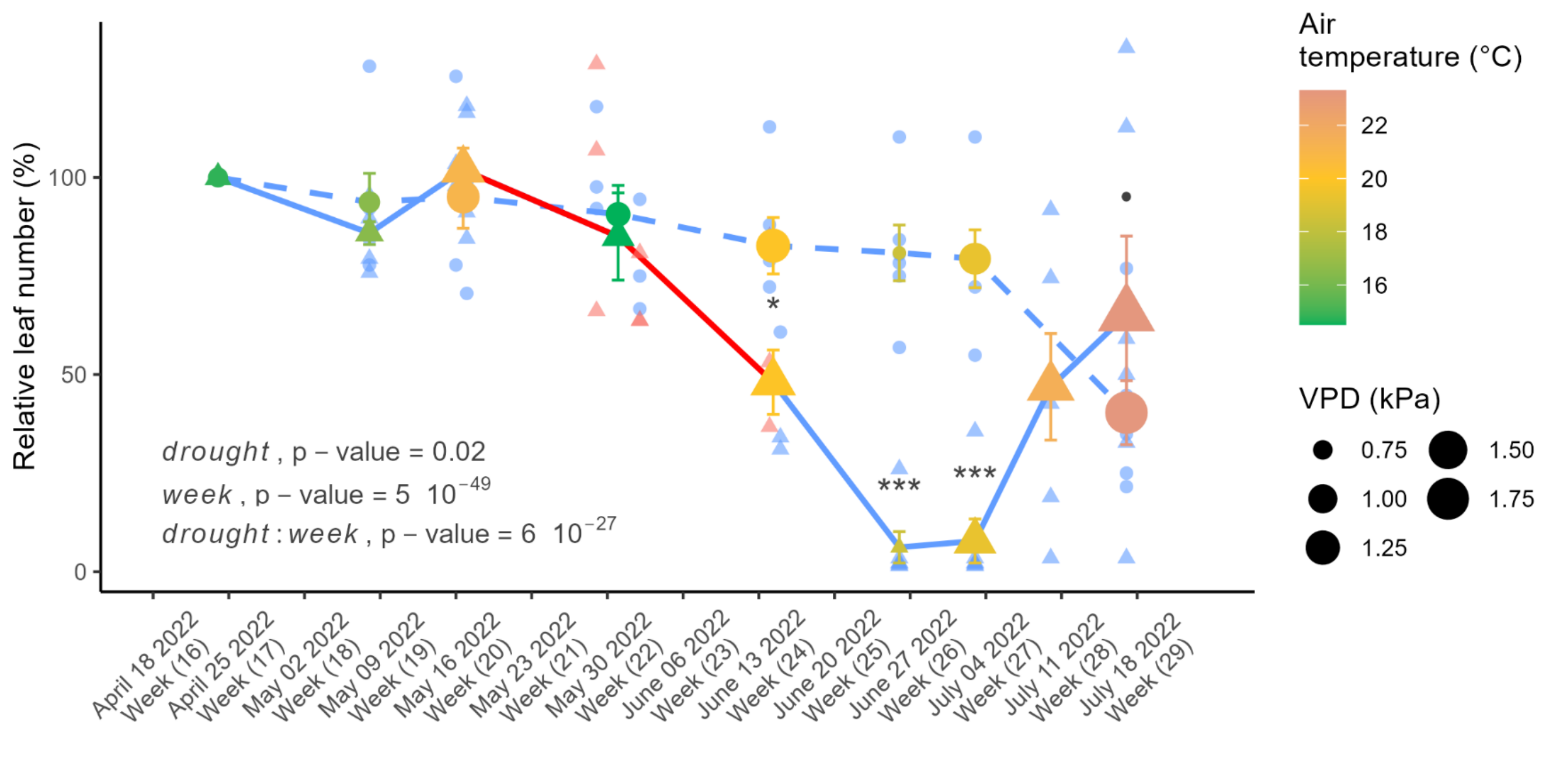

Figure 2 Canopy development and meteorological parameters Leaves on selected branches located at equivalent height were counted every second week. Relative leaf number was expressed as the % of remaining leaves relative to the initial leaf number (100 %) determined on week 16. Filled triangles (▲) with solid line and circles (●) with dashed line represent droughted trees and control trees, respectively. Small symbols correspond to individual trees and larger ones represent the weekly means of relative leaf number, with the color and size of the symbols representing, respectively the mean of the last three days air temperature and water vapor pressure deficit (VPD), according the scales on the right. Blue and red line indicates period without or with water withholding, respectively. Significance of variations between weeks, in response to drought or the interaction of both factors are presented on the left bottom side (linear mixed model followed by a type II ANOVA). Asterisks indicates significance differences between drought and control trees in the week (Tukey HSD post-hoc test, *** p-value < 0.001, ** p-value < 0.01, * p-value < 0.05, ● p-value < 0.1).

- ✓ Soil drought combined with atmospheric drought, induces near total defoliation (***week 26***)
- ✓ Re-watering allows canopy to replenish (***week 28***)
- ✓ Late intense atmospheric drought impacts control trees while trees acclimatized to drought continue to restore their canopy (***week 29***)

4. Seasonal and drought effects on gas exchanges

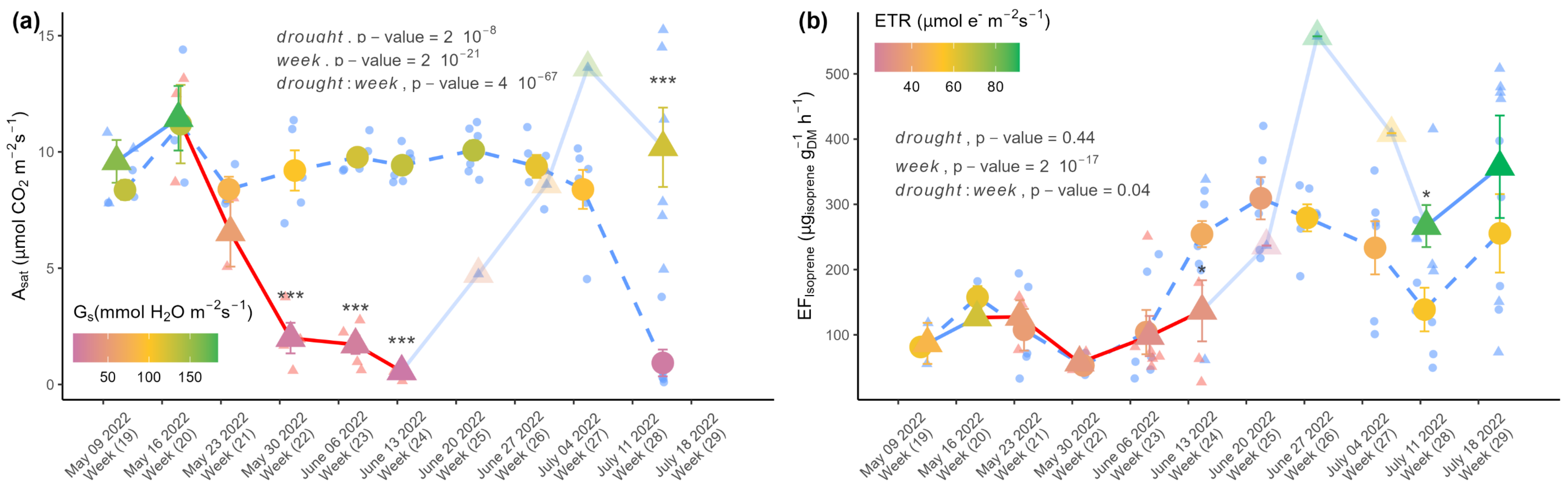

Figure 3 Leaf gas exchange (a) Light saturated net CO_2 assimilation rate (A_{sat}) and stomatal conductance to water vapor (G_s) and (b) Isoprene emission factor (EF) and Electron Transport Rate (ETR). Filled triangles (▲) with solid line and circles (●) with dashed line represent droughted trees and control trees, respectively. Small symbols represent individual trees while larger ones represent the weekly A_{sat} and EF means, with the color corresponding to the weekly mean value of G_s and ETR (according to the scale) for A_{sat} and EF, respectively. Blue and red lines indicate periods without or with water withholding, respectively. Light lines and symbols indicate values obtained from a unique tree as a result of the total defoliation of the other (Figure 2). Significance of variations between weeks, in response to drought or the interaction of both factors are presented on the left bottom side (linear mixed model followed by a type II ANOVA). Asterisks indicates significance differences between drought and control trees in the week (Tukey HSD post-hoc test, *** p-value < 0.001, ** p-value < 0.01, * p-value < 0.05).

Photosynthetic CO_2/H_2O gas exchange

- ✓ Drought induces stomatal limitation of net photosynthesis leading to nearly zero gas exchange (***week 24***)
- ✓ Re-watering restores gas exchange to levels equivalent to control trees (***week 28-29***)
- ✓ Late intense atmospheric drought impacts control trees while trees acclimatized to drought maintain their gas exchanges (***week 29***)

Isoprene emission factor

- ✓ Strongly varies with seasonality (***week 22 vs. 25***)
- ✓ Weakly impacted by drought (***week 24***)
- ✓ Bursts after re-watering (***week 26-27***)
- ✓ Highly dependent on photosynthetic energy conversion of light (***ETR***)[2]

5. Implication for emission modelling

In air quality models, BVOC emissions are usually computed based on an empirical approach (Guenther et al., 1995 and 2012):

$$ER = EF \cdot DB \text{ or } LA \cdot \gamma_T \cdot \gamma_P \cdot \gamma_A \cdot \gamma_{SM}$$

Emission Rate = Emission Factor x Dry Biomass or Leaf Area x activity factors

- EF is assumed to be constant over time and is only BVOC and tree species dependent
- γ represent the effects of temperature (T), light (P), age (A) and soil moisture (SM) on emissions

Different empirical parameterizations are proposed in the literature and measurements can support the choice between them

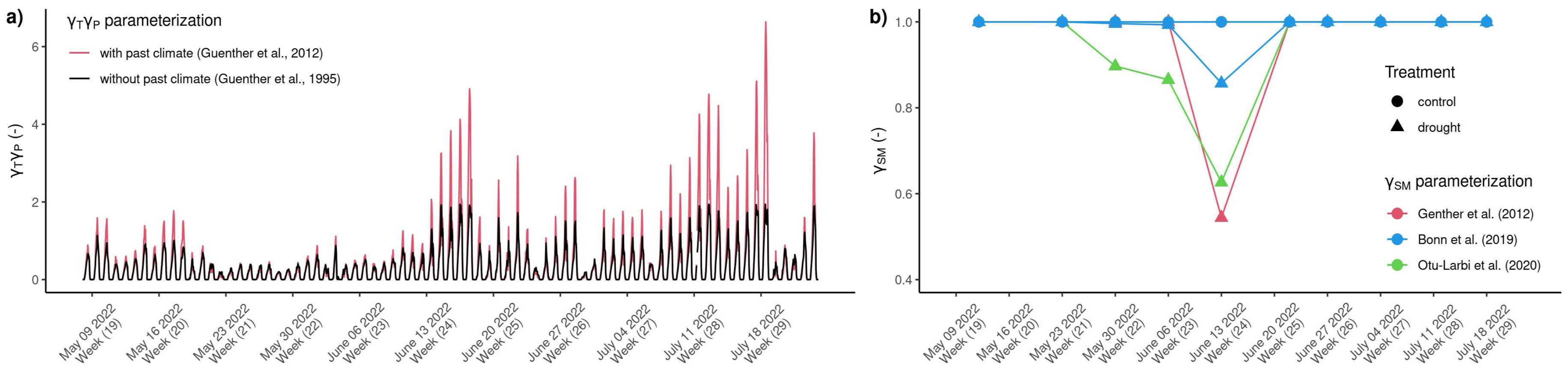

Figure 4 Activity factors parameterizations (a) Temporal variation of the activity factors for leaf temperature (γ_T) and light (γ_P) with a dependency or not to the climate of the past days and (b) of the activity factor for soil moisture (γ_{SM}) computed for the drought and control trees.

- ✓ EF of controls are not constants → impact of the past few days temperature and radiation conditions (Fig. 4a)[1,3]
- ✓ EF of the drought trees are significantly lower than the controls on ***week 24*** (÷2) → soil is water-limited: introduction of γ_{SM} is necessary (Fig. 4b)[3-5]
- ✓ Early senescence can be taken into account in the γ_A
- ✓ At the tree scale, de/re-foliation are directly included in the DB or LA

6. Conclusions and perspectives

- ✓ Isoprene emission factor highly varies with season but less with drought
- ✓ Drought-induced defoliation (Leaf Area Index) should be parameterized in air quality models
- ✓ Burst effect on isoprene emissions after re-watering should be investigated

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