Plant acclimation impacts carbon allocation to isoprene emissions: evidence from past to future CO_2 levels

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Introduction

Isoprene (C_5H_8) is produced in plant leaves as a side product of photosynthesis, whereby approximately 0.1-2.0% of the photosynthetic carbon uptake is released back into the atmosphere via isoprene emissions. Isoprene biosynthesis alleviates oxidative stress, specifically in warm, dry and high-light environments. Moreover, isoprene biosynthesis is influenced by atmospheric CO_2 concentrations in the short term (<days) via responses in the leaf interior CO_2 concentration (C_i), and in the long term (>weeks) via acclimation in photosynthetic biochemistry.

To understand the effects of CO_2-induced climate change on carbon allocation in plants it is important to quantify how isoprene biosynthesis and emissions are effected by both short-term responses and long-term acclimation to rising atmospheric CO_2 levels.

A promising development for modelling CO_2-induced changes in isoprene emissions is the Leaf-Energetic-Status (LES) model (Harrison et al., 2013 and Morfopoulos et al., 2014). This model simulates isoprene emissions based on the hypothesis that isoprene biosynthesis depends on the imbalance between the photosynthetic electron supply and the electron demands of carbon fixation (Figure 1). This imbalance is determined by environmental conditions (light, temperature and atmospheric CO_2), the photosynthetic electron transport capacity (J_{max}), and the maximum carboxylation capacity of Rubisco (V_{cmax}).

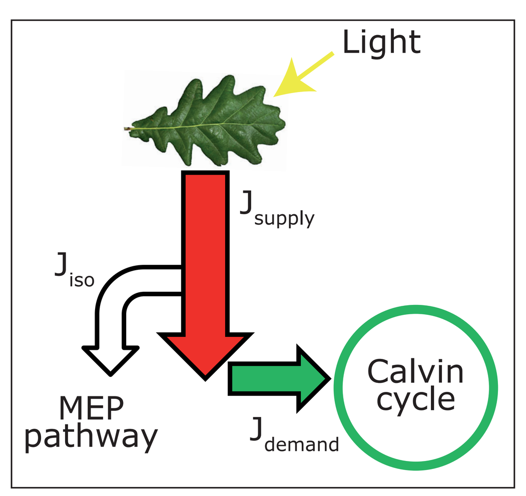


Figure 1: Schematic representation of electron fluxes (J) in the LES-model (adapted from Fig. 1 in Morfopoulos et al., 2014). J_{supply} is the primary flux of electrons through light dependent photosynthetic reactions, J_{demand} is the required electron flux for carbon fixation in the Calvin cycle. J_{iso} is the electron flux available for the synthesis of isoprene in the methylerythritol phosphate (MEP) pathway.

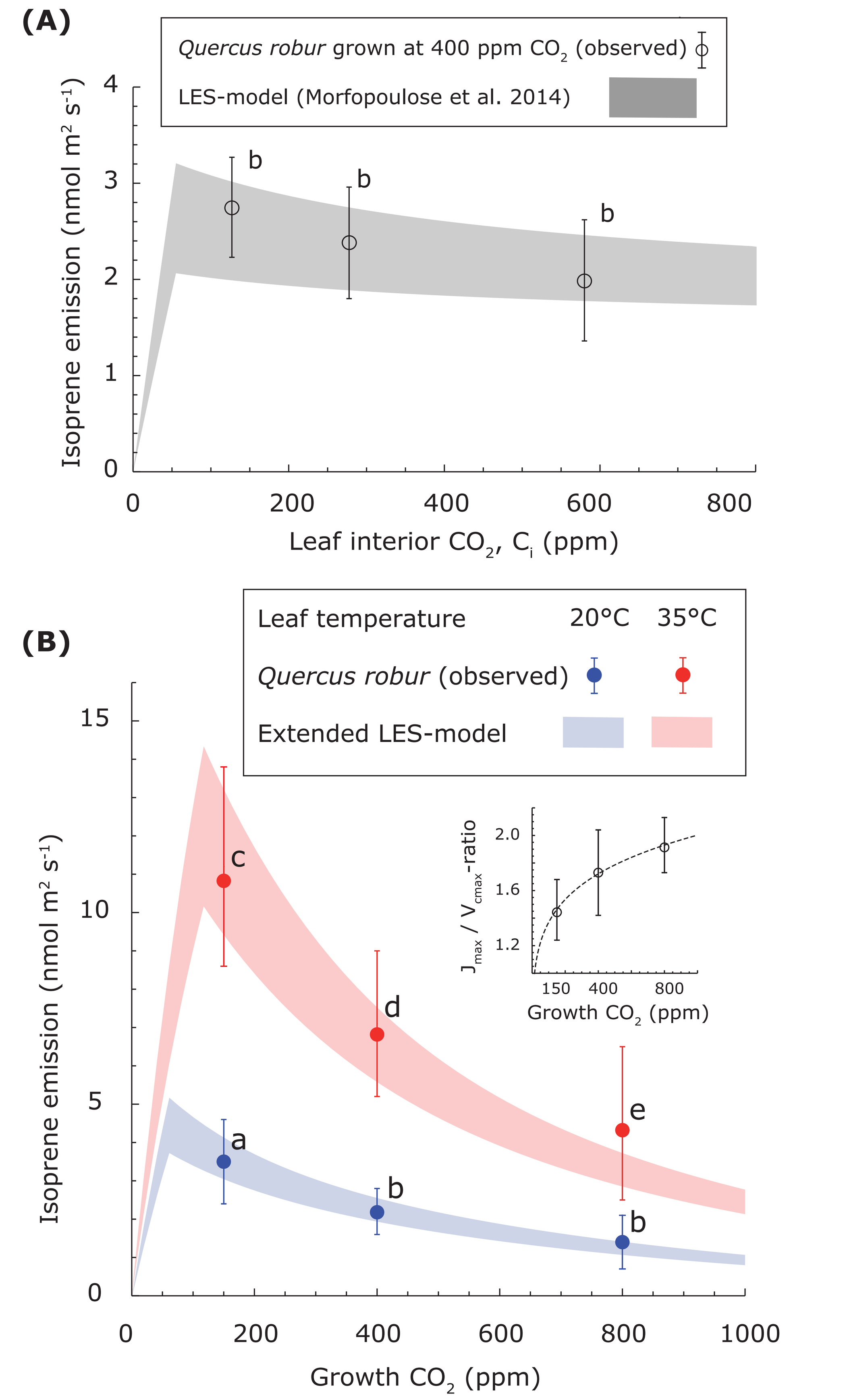


Figure 2: CO_2-induced short-term (**A**) and long-term (**B**) changes of isoprene emissions. Down-regulation of V_{cmax} and J_{max} is incorporated in the extended LES-model. Model results are indicated by shaded areas and constrained by one standard deviation of the measured V_{cmax} and J_{max} values. Data points and error bars reflect the May measurements. Error bars indicate one standard deviation around the mean.

Results

Predictions of the LES-model are supported by our emperical results that show a decrease in isoprene emissions in response to growth under higher CO_2 (Figure 2). In the short term (<days), an increase in CO_2 stimulates photosynthesis through an increase in C_i and marginally decreases isoprene production by increasing the electron demand. In the long-term, acclimation to rising CO_2 leads to down regulation of J_{max} and V_{cmax} (Figure 3), which modulates electron supply and demand. These adaptations lead to a decrease in the fractional allocation of carbon to isoprene biosynthesis with rising CO_2 (Figure 4). This effect appears most pronounced in the summer measurements.

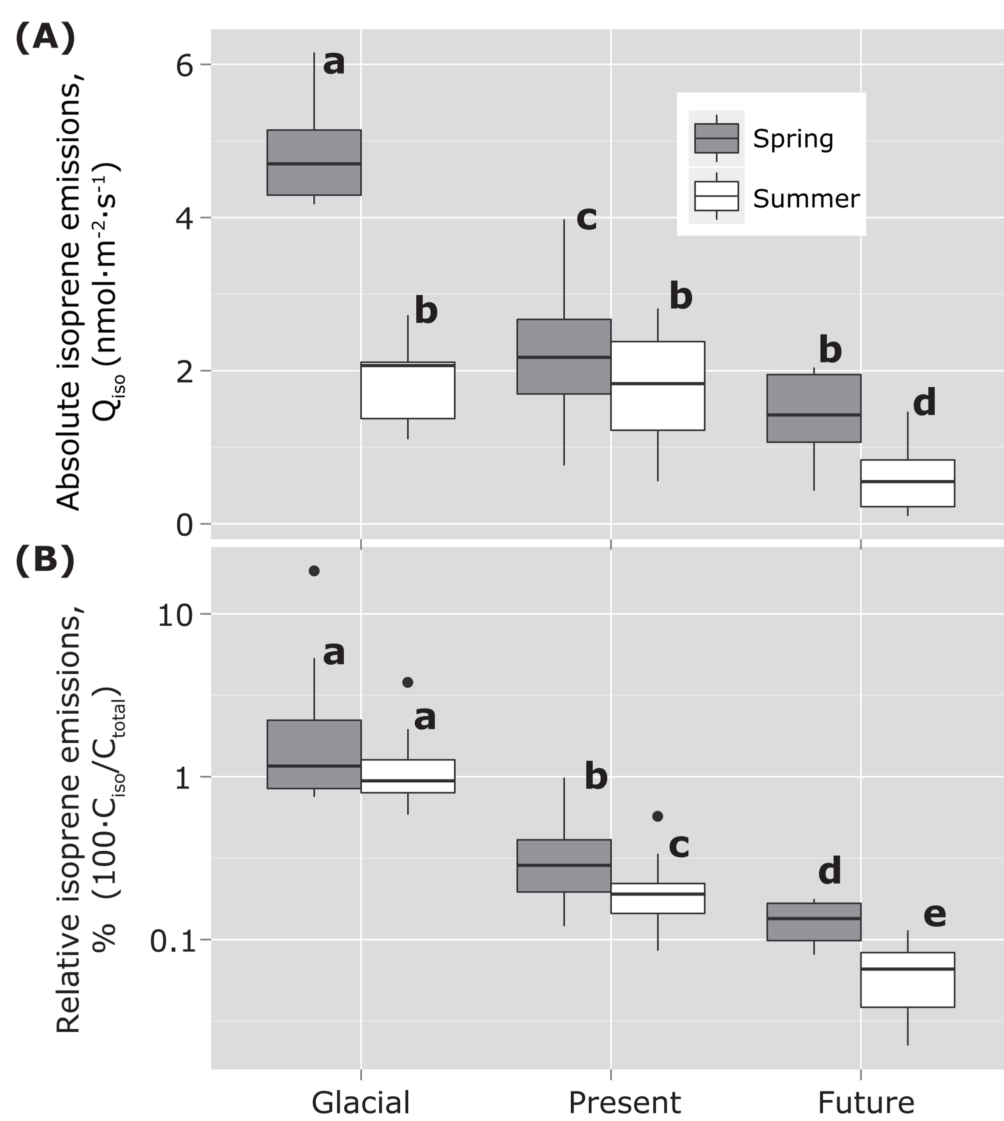


Figure 4: Leaf-level isoprene emissions (Q_{iso}) by *Quercus robur*, expressed as absolute fluxes (**A**) and as percentages (%) of total carbon (C) uptake (**B**). Measurements were taken at average growth CO_2.

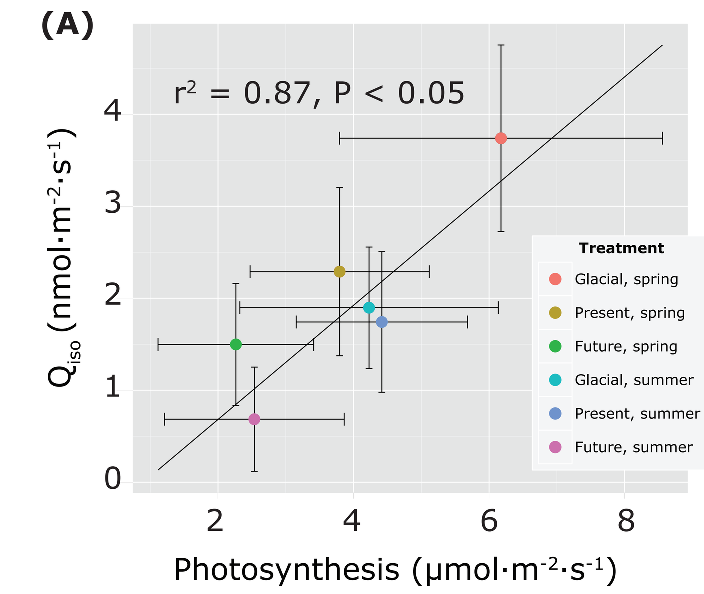
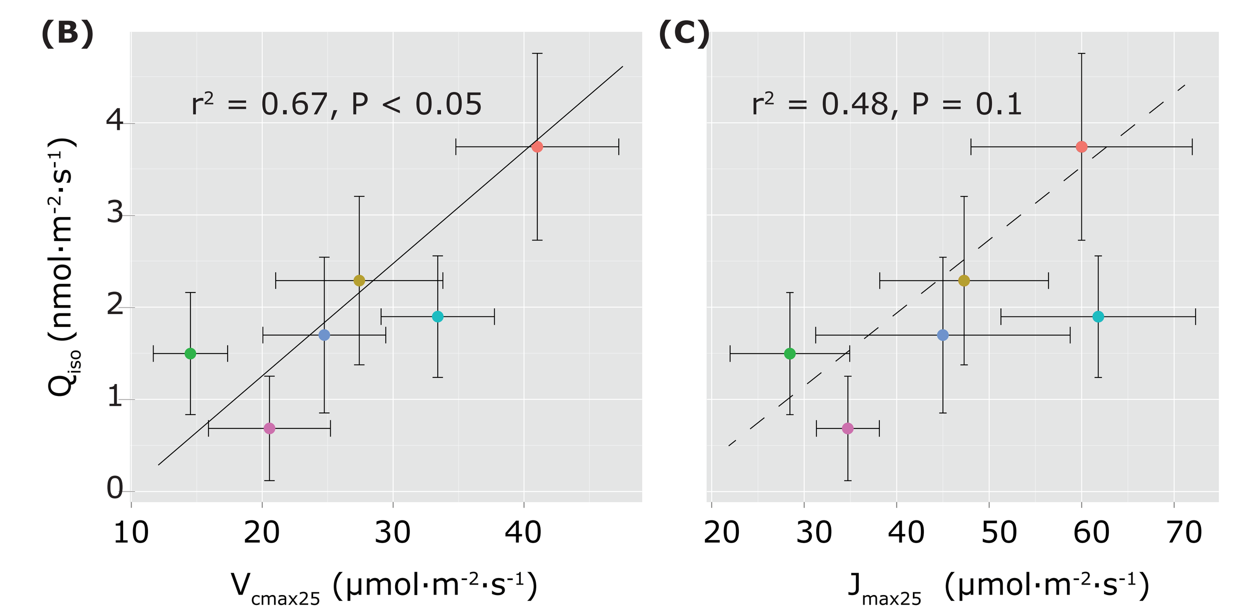


Figure 3: Observed relations between leaf-level isoprene emissions (Q_{iso}) and photosynthesis (**A**), the temperature adjusted maximum carboxylation capacity of Rubisco (V_{cmax25}) (**B**), and the photosynthetic electron transport capacity (J_{max25}) (**C**). Measurements of photosynthesis and Q_{iso} were taken under a reference CO_2 concentration of 400 ppm. Correlation r^2 reflects population averages.



Discussion & conclusion

Allocation of photosynthetic carbon to isoprene emissions by *Quercus robur* saplings is reduced in response to rising atmospheric CO_2 levels.

CO_2-induced down-regulation of isoprene emissions occurs through acclimation of photosynthetic biochemistry.

The ability of the LES-model to simulate CO_2-induced changes in isoprene emissions critically depends on parameterisations of V_{cmax} and J_{max}.

CO_2-induced acclimation of isoprene emissions is confounded by changes in V_{cmax} and J_{max} with leaf age.

Table 1: Overview of the experimental treatments and growth conditions in the walk-in growth chambers.

Treatment	Month of measurement	CO_2 (ppm)	Light intensity (µmol·m⁻²·s⁻¹)	Temperature day/night (°C)	Day length (hours)
Glacial spring	May	150-200	250-300	21/17	10
Present spring	May	400-450	250-300	21/17	10
Future spring	May	750-800	250-300	21/17	10
Glacial summer	August	150-200	250-300	21/17	10
Present summer	August	400-450	250-300	21/17	10
Future summer	August	750-800	250-300	21/17	10

Methods

***Quercus robur* (pedunculate oak) saplings were grown for two growing seasons in walk-in growth chambers with tight control of light, temperature, humidity and CO_2 concentrations (Table 1) prior to measurements. The CO_2 levels in growth chambers reflect glacial, present and future conditions. Each population consisted of 10 individual trees. Photosynthesis and photosynthetic biochemical parameters V_{cmax} and J_{max} were determined with a Licor LI-6400XT photosynthesis system by measuring two leaves from five to seven plants. The relationship between photosynthesis and isoprene emissions was measured by coupling the photosynthesis system with a Proton-Transfer Reaction Time-of-Flight Mass Spectrometer (Figure 5). Measurements were taken in May, two weeks after full leaf expansion, and repeated in August.**

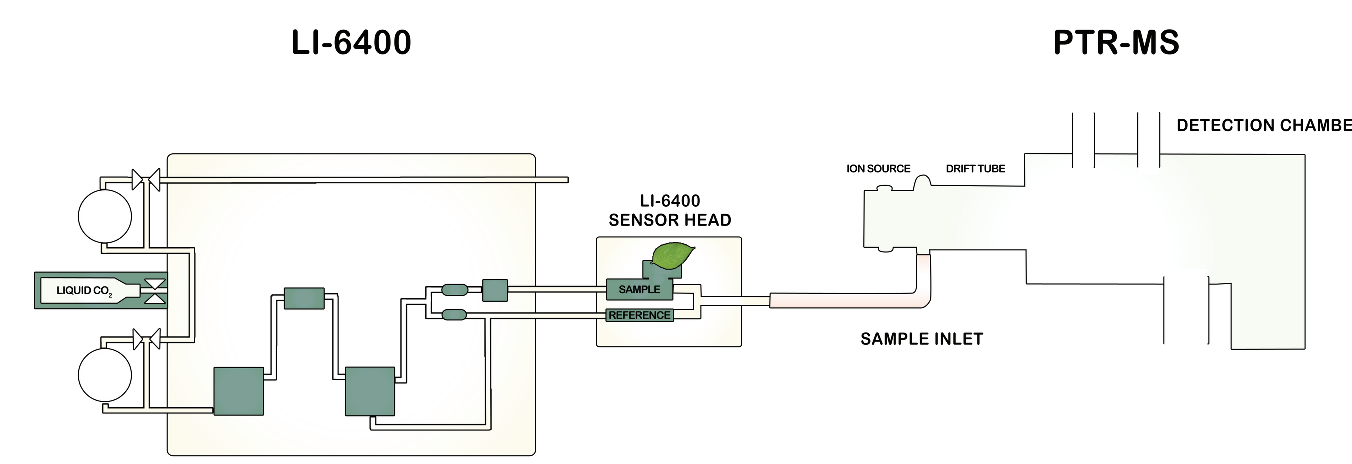


Figure 5: Schematic representation of the measurement setup. The Licor LI-6400XT photosynthesis system is directly coupled to a Proton-Transfer Reaction Time-of-Flight Mass Spectrometer. This system allows for simultaneous measurements of photosynthesis and isoprene emissions.

References

Harrison, S. P. et al: Volatile isoprenoid emissions from plastid to planet, New Phytol., 197(1), 49–57, 2013.
Morfopoulos, C. et al: A model of plant isoprene emission based on available reducing power captures responses to atmospheric CO2, New Phytol., 203(1), 125–139, 2014.