Isoprene measurements in an oak-dominated forest during the 2018 heatwave in the UK

V. Ferracci[1], C.G. Bolas[2], K. Jaars[3], F. Otu-Larbi[3], T. King[3], J. Beale[1], T. W. Waine[1], R.L. Jones[2], K. Ashworth[3], N.R.P. Harris[1]

[1] Centre for Environmental and Agricultural Informatics, Cranfield University
[2] Centre for Atmospheric Science, Department of Chemistry, University of Cambridge
[3] Lancaster Environment Centre, Lancaster University

NCAS-R Met Soc Atmospheric Science Conference, Birmingham
3rd July 2019

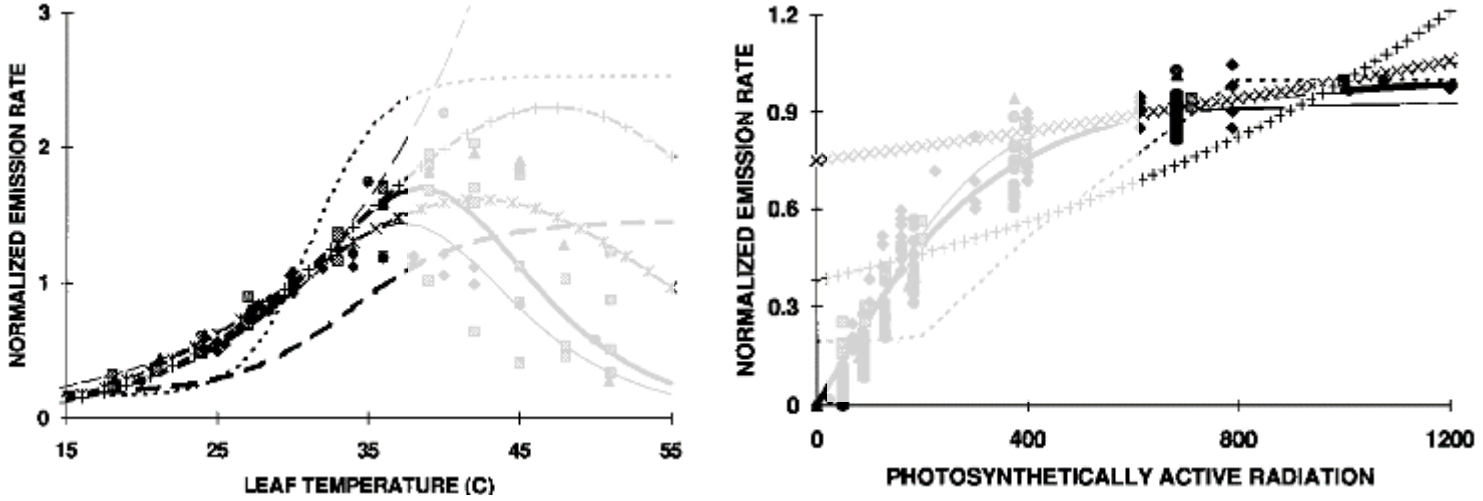
Cranfield University

Synopsis

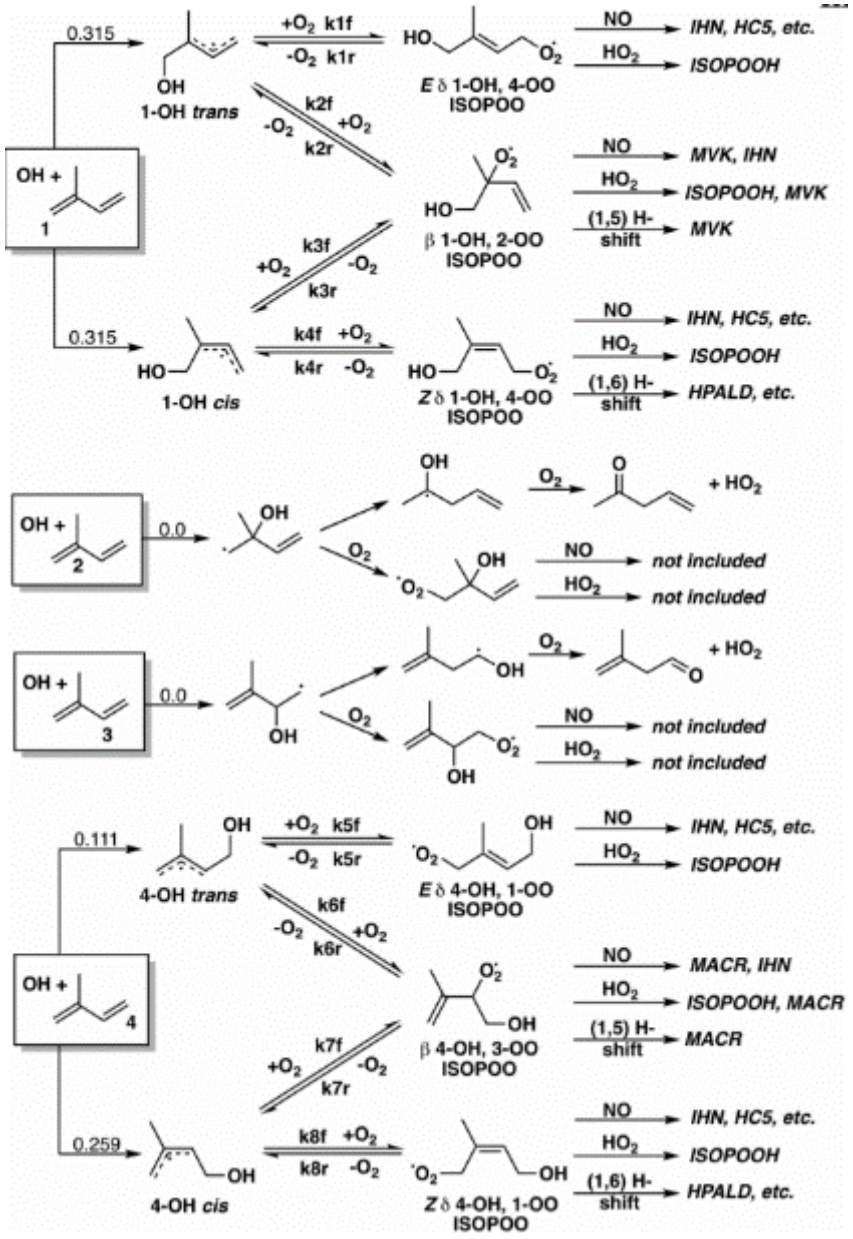
- *Introduction*: isoprene drivers, models, challenges
- *The iDirac*: instrument overview
- *Isoprene during a heatwave*: the WIsDOM campaign
- *Preliminary results from WIsDOM*
- *Conclusions and future work*

Isoprene in the atmosphere

- Isoprene (C_5H_8) is the largest biogenic emissions on the planet
- Estimated 300-700 TgC year^{-1} (*cf*. ~500 TgC year from CH_4)
- Dialkene, prone to ozonolysis as well as OH and NO_3 oxidation
- Complex oxidation chemistry, source of SOA
- Emissions mainly driven by incoming solar radiation (photosynthetically active radiation, PAR) and temperature



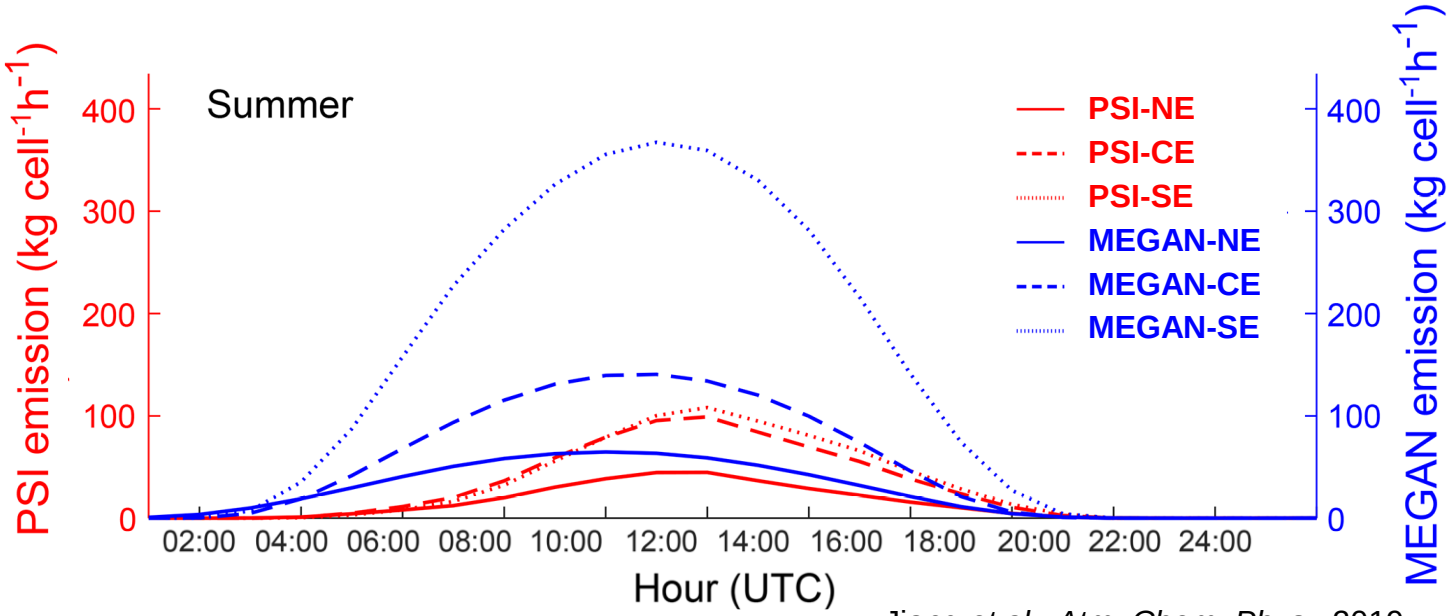
Guenther *et al.*, *J. Geophys. Res.*, 1993



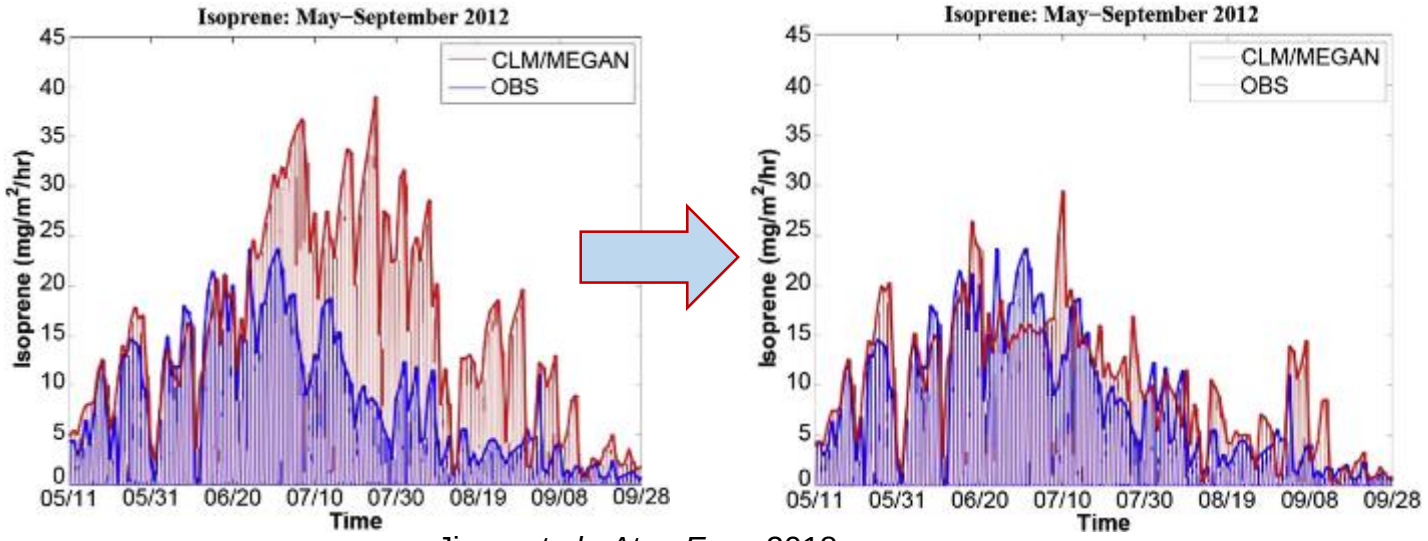
Wennberg *et al.*, *Chem. Rev.*, 2018

Current understanding and models

- Current emission estimates for isoprene vary within a factor of 2-3
- Emissions impacted by global change (increasing *T*, [CO_2], land use change), and extreme weather events (heatwaves, droughts) that will become more frequent in the near future
- Heatwaves and droughts: poorly represented by models



Jiang *et al.*, *Atm. Chem. Phys.*, 2019



Jiang *et al.*, *Atm. Env.*, 2018

Challenges in isoprene monitoring and modelling

- Measurements needed to validate our understanding of emissions in a changing environment
- Existing instrumentation requires scientific infrastructure, unsuitable for long deployments in challenging environments (often under-sampled)
- ‘Long-term’ continuous measurements are few and far apart

Aims of WIsDOM campaign:

- Profile isoprene concentrations in a temperate forest canopy over a full growth season
- Characterise isoprene transport across the canopy to inform canopy-atmosphere exchange
- How are isoprene emissions affected by leaf development, changes in temperature and soil moisture? Heatwave/drought?

The iDirac: instrument overview

ograph with

run

https://doi.org/10.5194/amt-2019-219
Preprint. Discussion started: 1 July 2019

Atmospheric Measurement Techniques Discussions

iDirac: a field-portable instrument for long-term autonomous measurements of isoprene and selected VOCs

Conor G. Bolas[1], Valerio Ferracci[2], Andrew D. Robinson[3], Mohamed I. Mead[2], Mohd Shahrul Mohd Nadzir,[4] John A. Pyle[1,5], Roderic L. Jones[1] and Neil R.P. Harris[1,2]

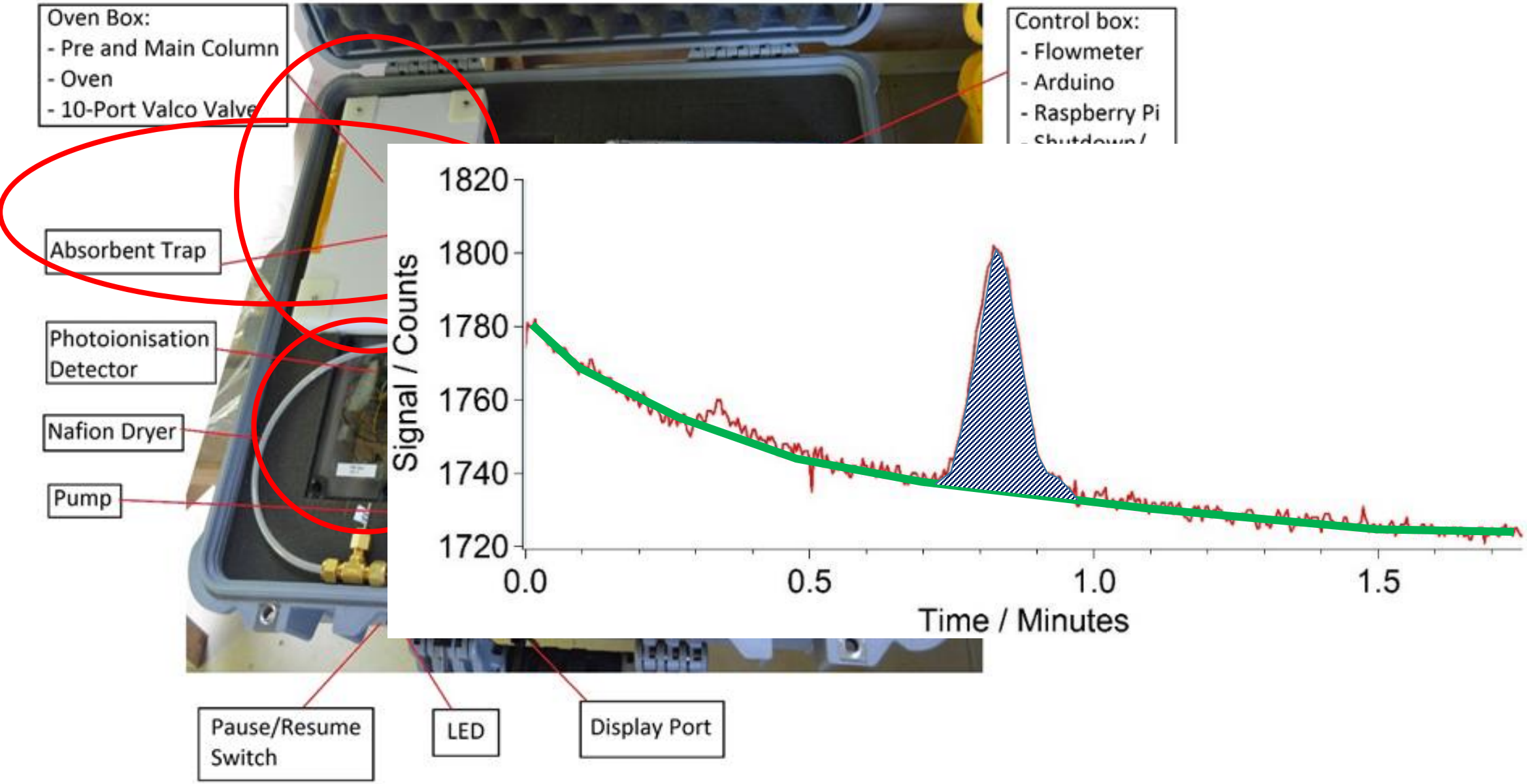
[1]Department of Chemistry, University of Cambridge, Lensfield Road, Cambridge, CB2 1EW, UK
[2]Centre for Environmental and Agricultural Informatics, Cranfield University, College Road, Cranfield, MK43 0AL, UK
[3]Schlumberger Cambridge Research, Madingley Rd, Cambridge, CB3 0EL, UK
[4]School of Environmental and Natural Resource Sciences, Universiti Kebangsaan Malaysia, 43600, Bangi, Selangor, Malaysia
[5]National Centre for Atmospheric Science, NCAS, UK

Correspondence to: Neil R.P. Harris (neil.harris@cranfield.ac.uk)

- Limit of detection of ~40 ppt (3:1 S/N)
- Precision ~5-10%
- 3-15 min time resolution

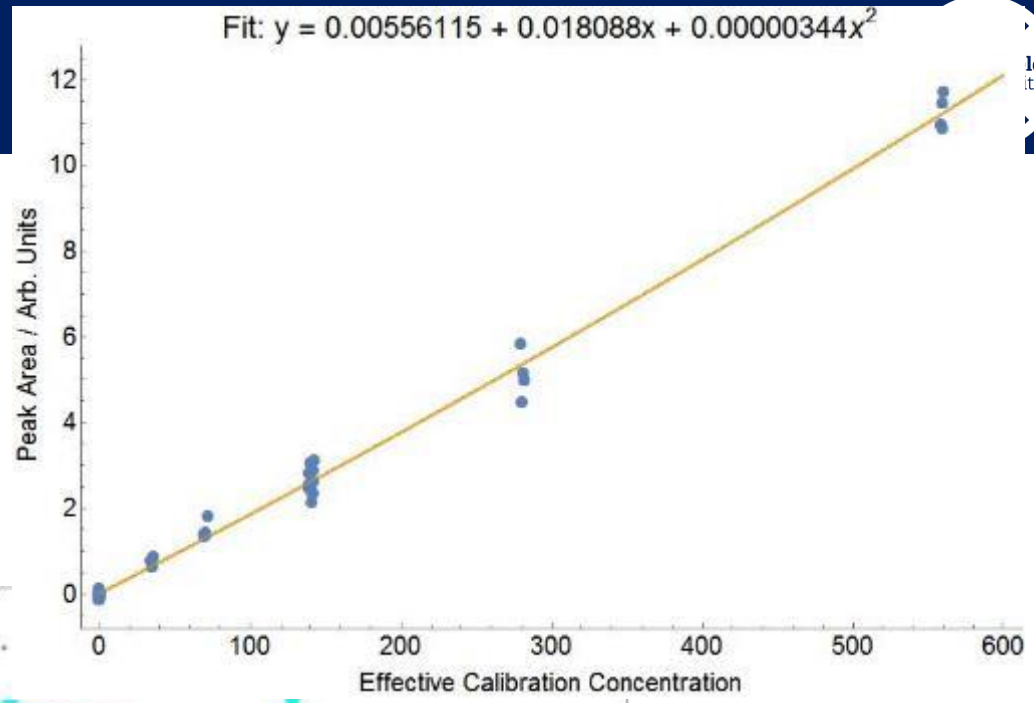
Bolas *et al.*, *Atm. Meas. Tech. Discuss.*, 2019
Visakorpi *et al.*, *New Phytologist*, 2018

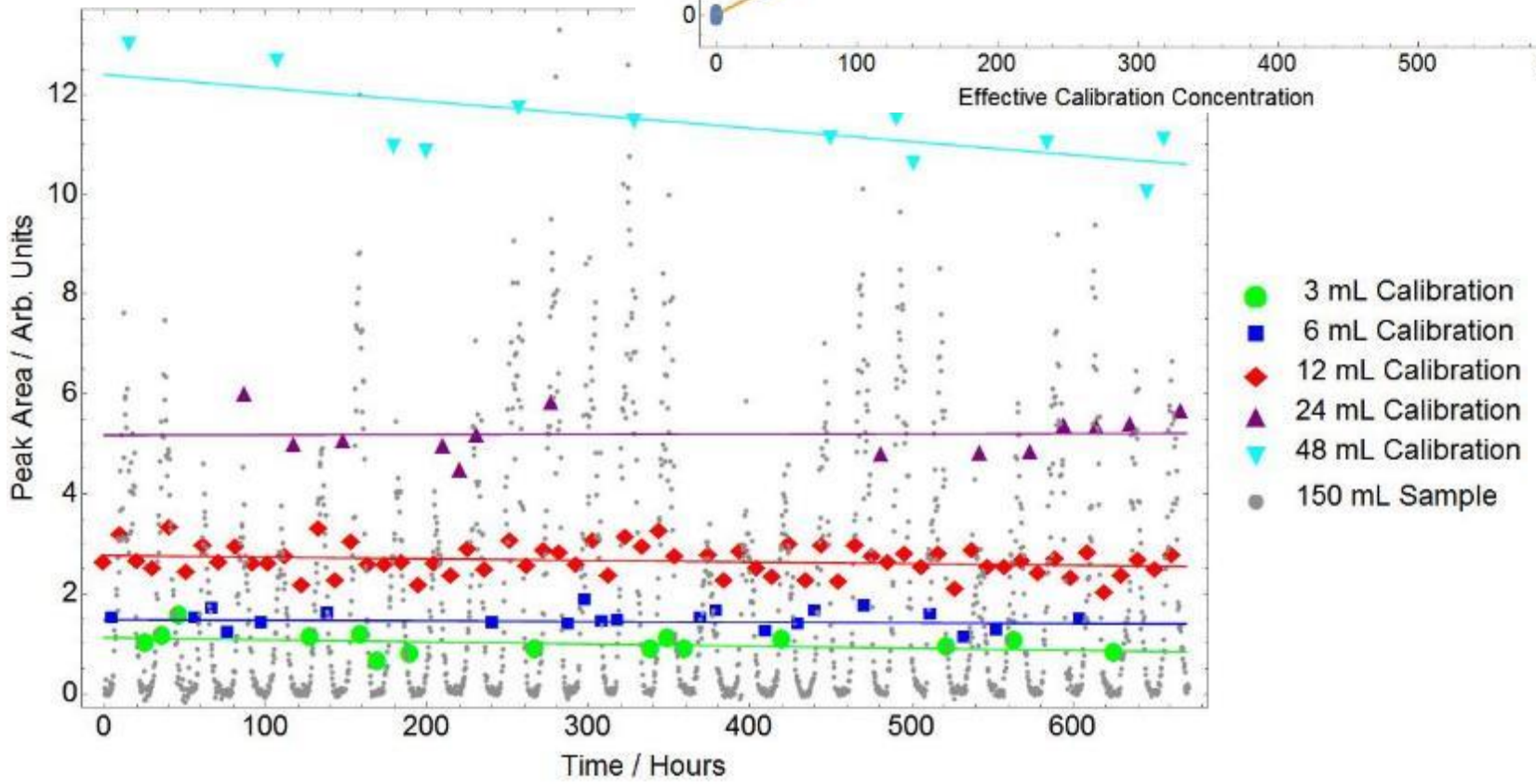
The i-Dirac: operation



The i-Dirac: calibration

- One gas standard needed
- Routinely calibrated with different volumes of cal gas
- Allows to test detector linearity
- Good stability over weeks



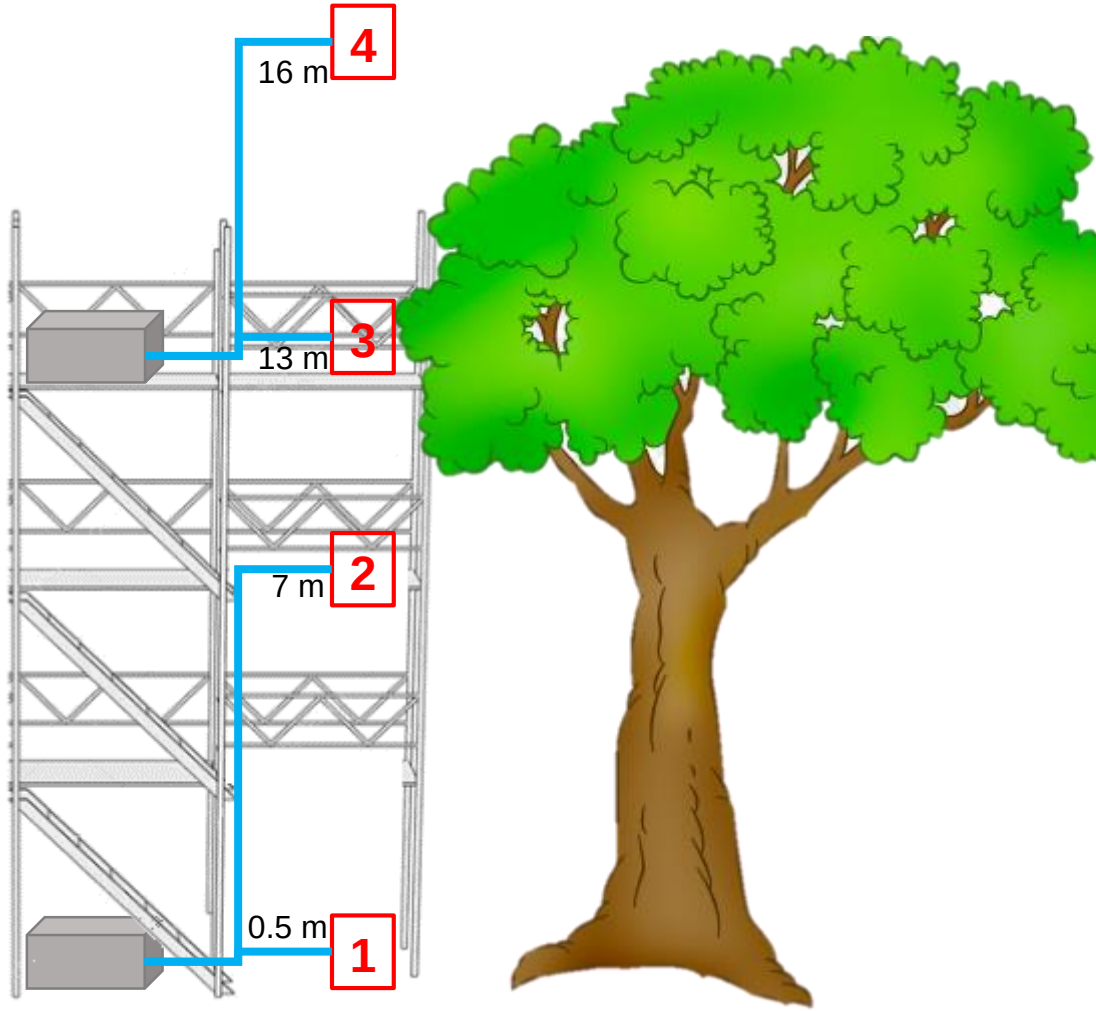


Wytham Woods – Site overview

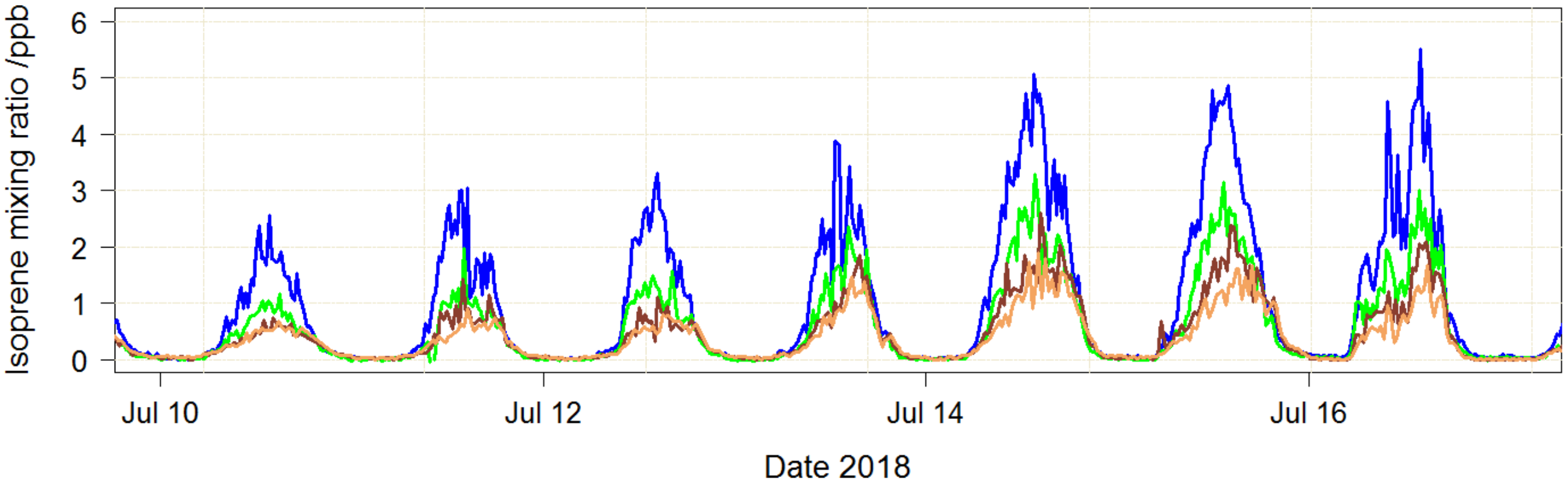
- Wytham Woods (Oxfordshire) is a mixed temperate woodland
- *Quercus robur* (common oak) dominant isoprene emitter
- Canopy walkway allows sampling at different heights
- Run on solar power for 5+ months

WIsDOM measurement set-up

- **W**ytham **Is**oprene i**D**irac **O**ak tree **M**easurements (WIsDOM)
- Isoprene, *T* and PAR measured at 4 heights
- Nearby *T*, PAR, wind and soil moisture from met station (400 m from walkway) – all summer
- Periodic leaf gas exchange, foliage VOC emissions and whole air samples
- Satellite retrievals of normalised difference vegetation index (NDVI)
- Monitor for a complete growing season (May – Nov 2018)

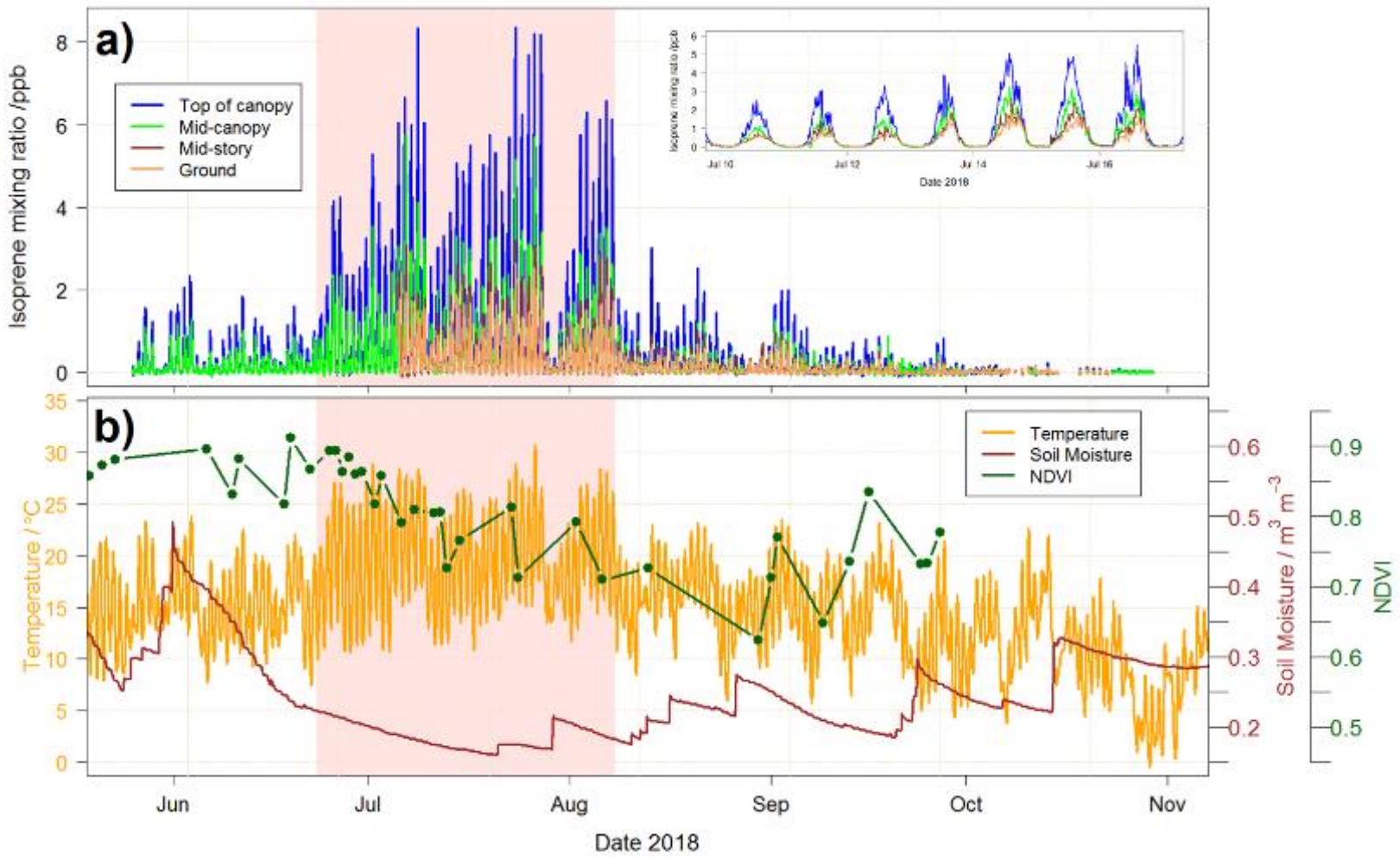


Results: isoprene time series



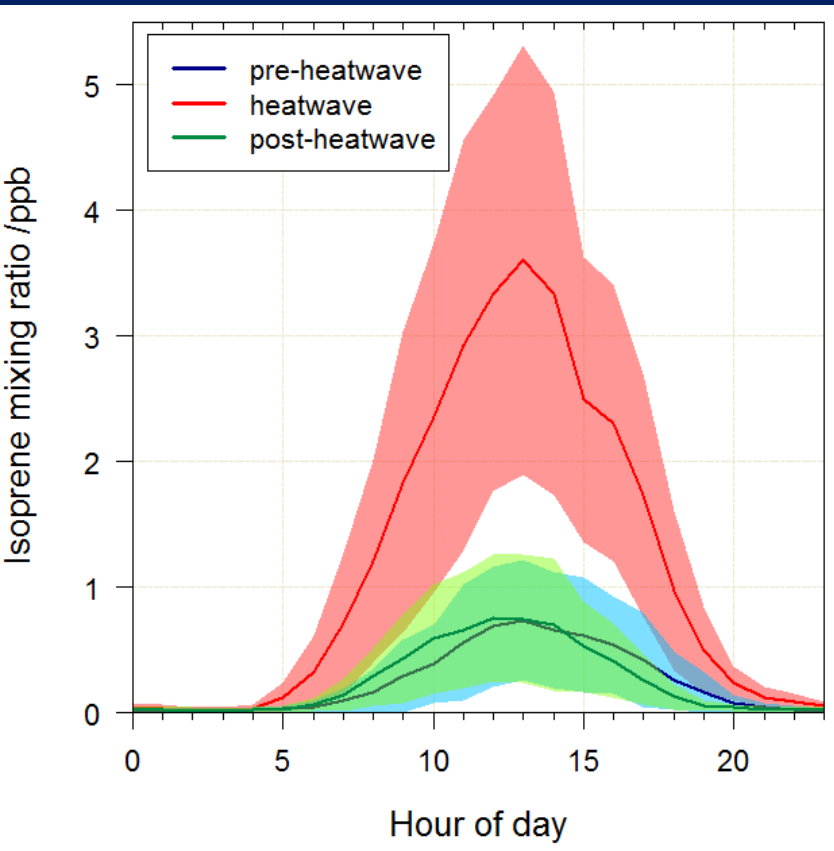
- (almost) uninterrupted time series from May to October 2018 (5+ months)
- Peak values ~8 ppb
  cf. tropical forests!
- Vertical gradient

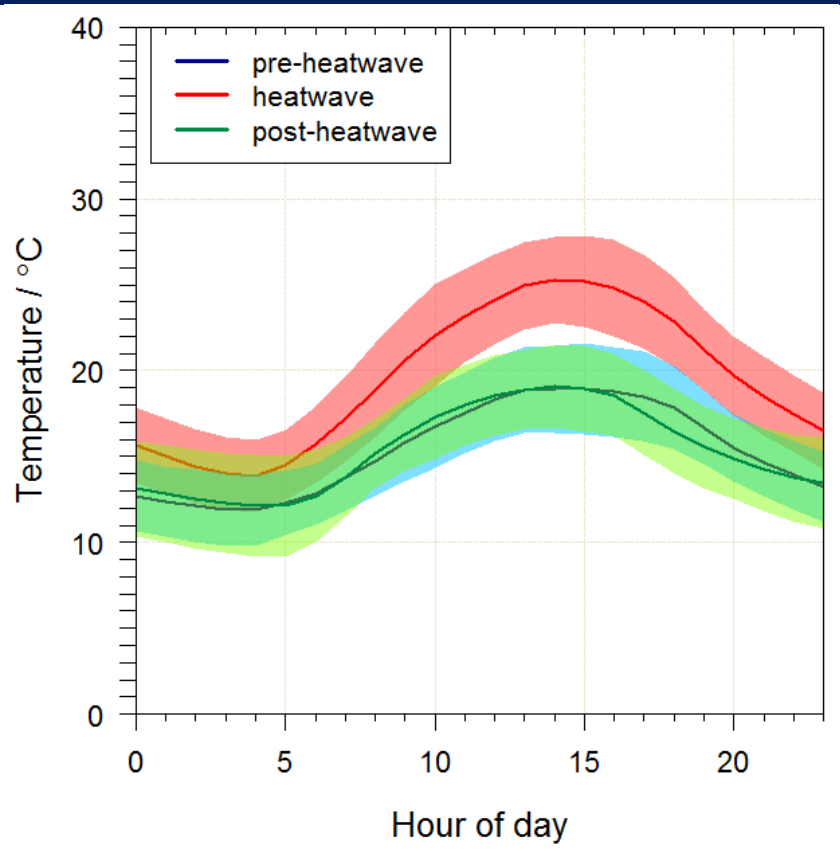
Isoprene during the ‘Great Heatwave of 2018’ (1)

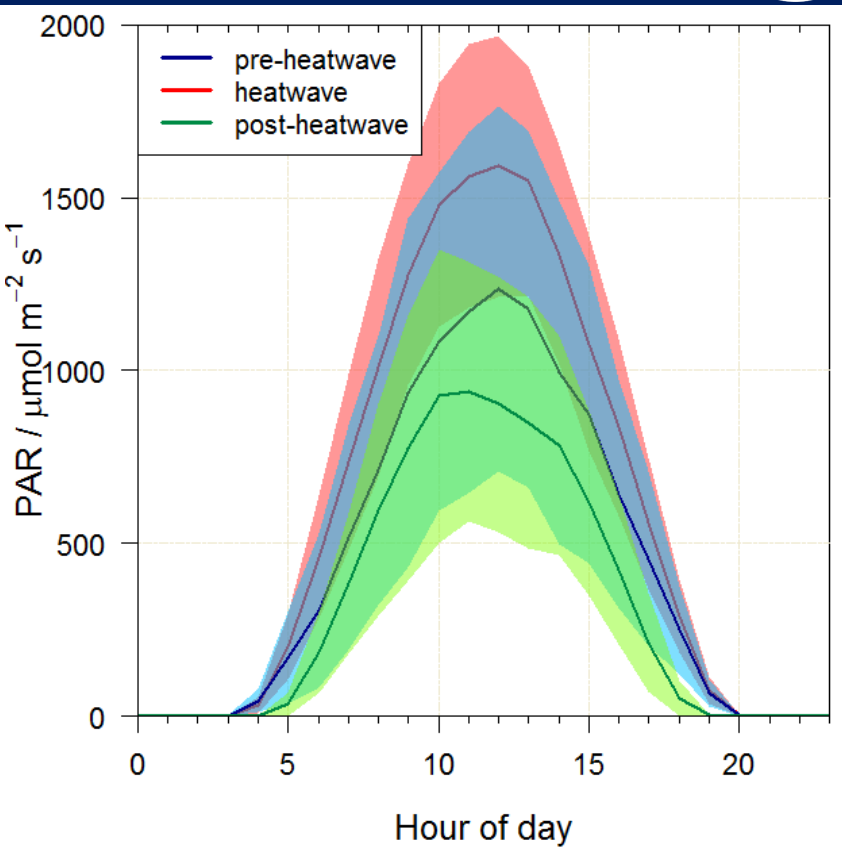


- Heatwave (22 Jun-08 Aug 2018): one of the hottest summers on record, combined with prolonged drought
- Mean temperature during the heatwave 4°C higher than before or after; 3°C higher than the 1992-2017 mean over the same period
- Soil moisture decreased significantly through heatwave/drought
- NDVI shows drought stress increased through heatwave/drought

Isoprene during the ‘Great Heatwave of 2018’ (2)

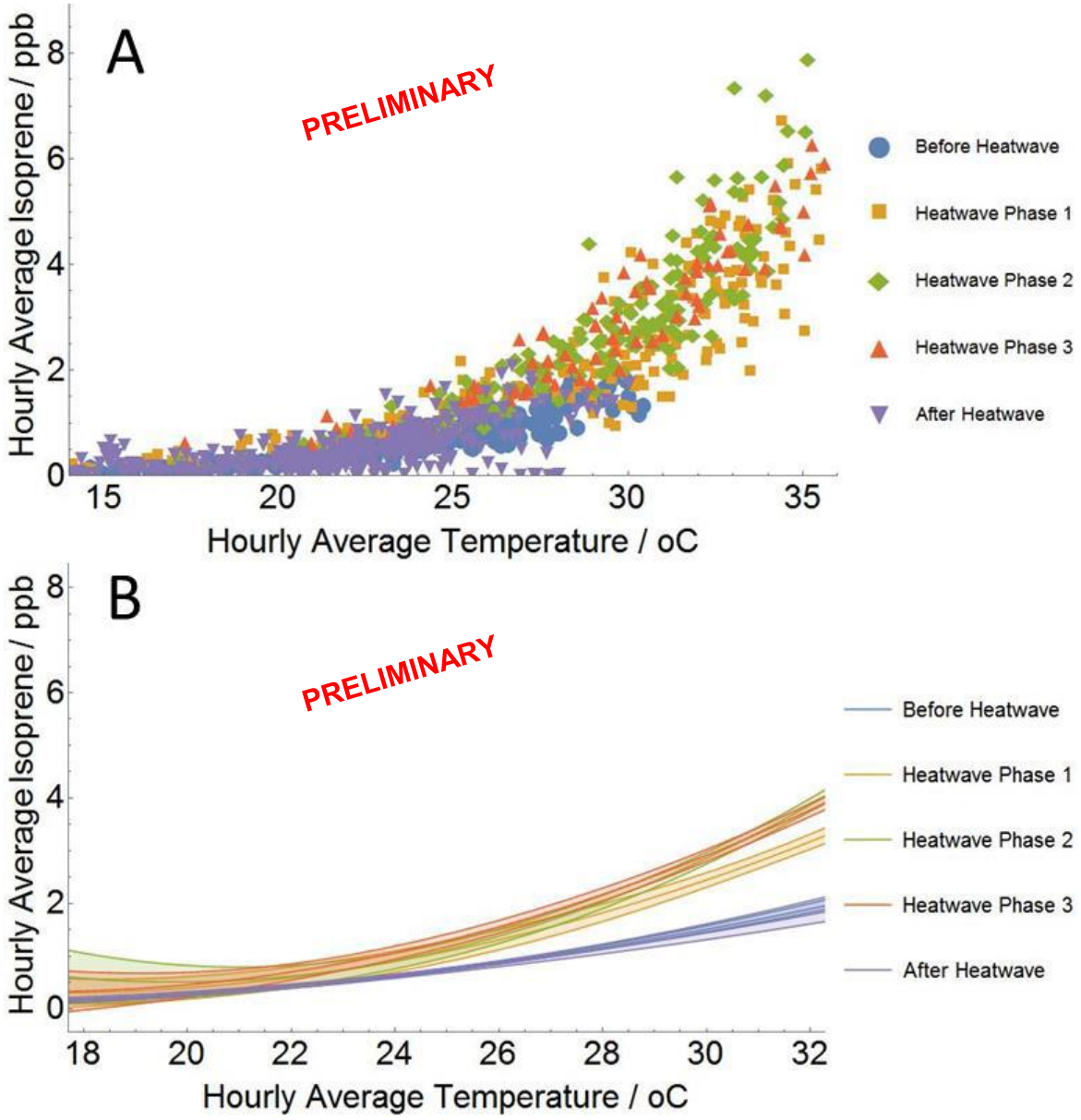






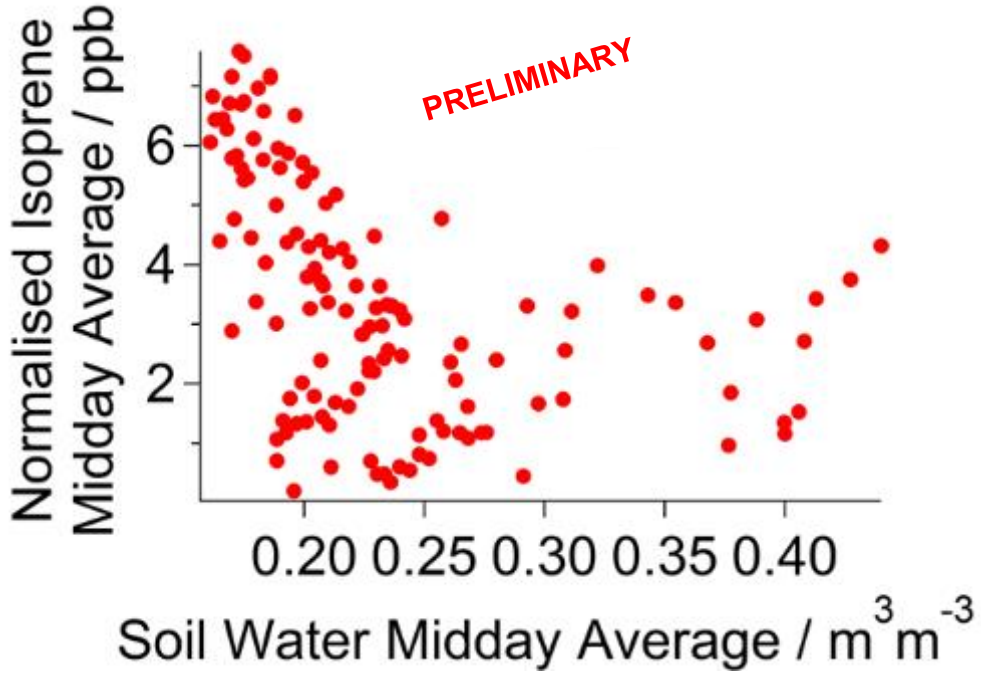
- Diurnal mean isoprene during heatwave up to 4-5 times greater than non-heatwave
- PAR goes with season
- Only temperature driven?

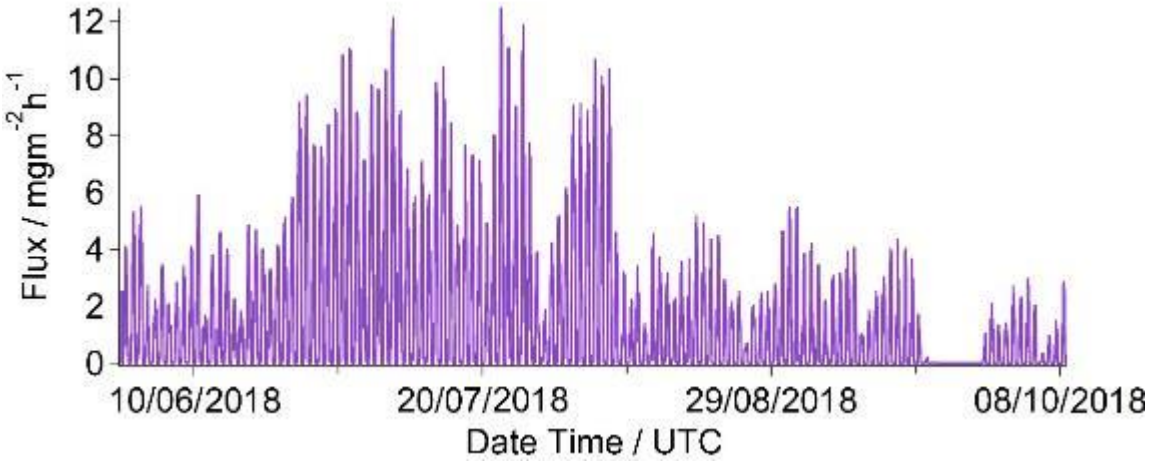
Isoprene during the ‘Great Heatwave of 2018’ (3)



- Expected response of isoprene to temperature seen in early part of summer and after the heatwave
- Unexpected enhancement in response to temperature during the heatwave
- Pre-and post-heatwave response curves overlap

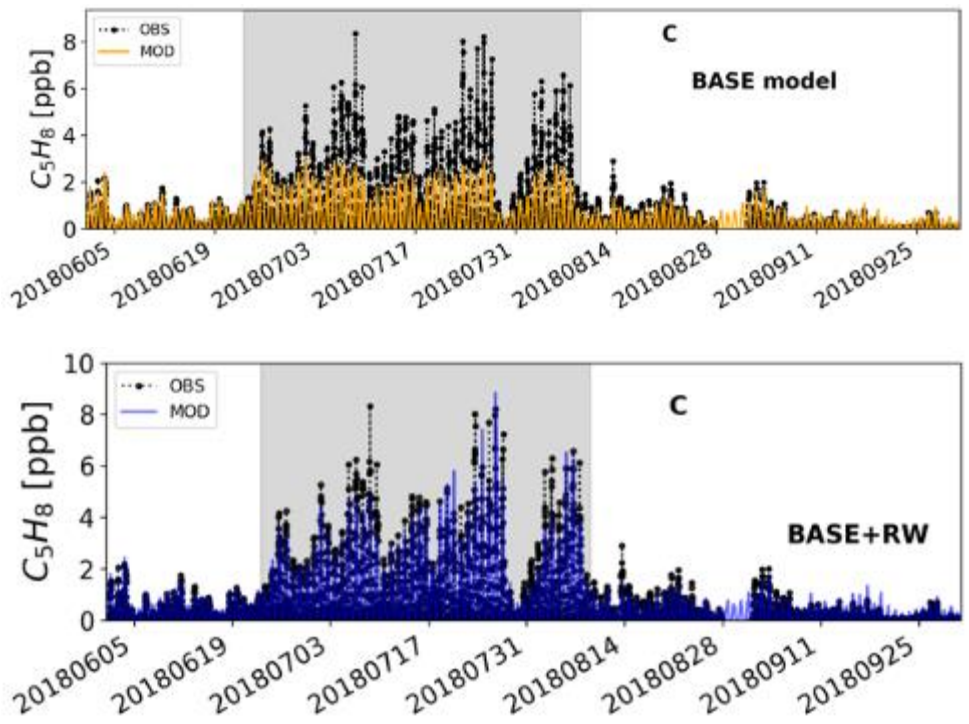
Isoprene during the ‘Great Heatwave of 2018’ (4)



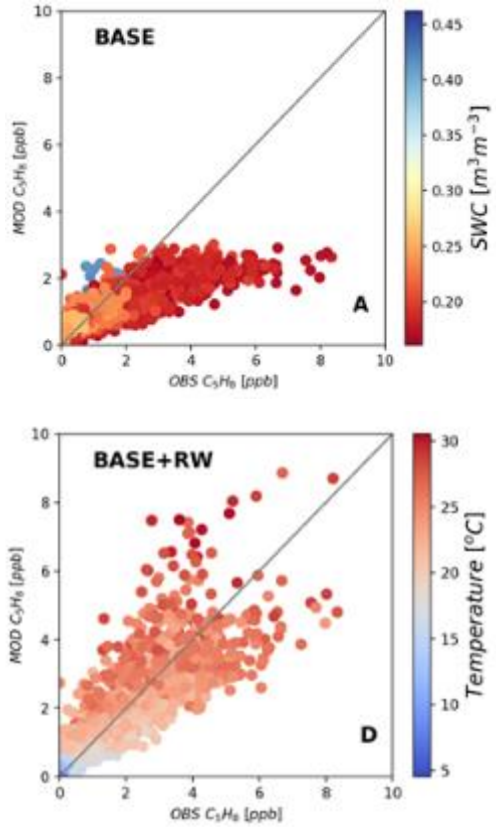


- Normalising isoprene concentrations (with respect to *T* and PAR) shows a clear correlation between soil moisture and enhanced isoprene during drought stress
- No isoprene shutdown observed following drought stress – soil moisture remained above wilting point (~0.15 m^3m^{-3})
- Tightly constrained canopy models show isoprene flux into boundary layer is ~4 times higher during heatwave

FORCAsT modelling



Otu-Larbi *et al.*, in preparation



- FORest Canopy Atmosphere Transfer (**FORCAsT**): 1-D model of biosphere-atmosphere exchange simulating biogenic emissions, chemical production and loss, vertical mixing, advection and deposition within and above the canopy

- Current isoprene emissions algorithms reproduce isoprene concentrations before and after the heatwave **BUT** not during the heatwave-drought period
- Model outputs were significantly improved when stress-induced emissions were included within the emissions algorithms

Conclusions and Future work

- iDirac ran autonomously in a logistically difficult environment
- 5 months of uninterrupted isoprene concentration measurements across the canopy before, during and after heatwave
- Response of isoprene to temperature enhanced during heatwave apparently as a result of drought stress
- Our data in combination with canopy models provide an alternative method to derive forest VOC fluxes into the lower atmosphere

- Exceptionally hot summer, expected to be typical around 2050
- Need to establish impact of greater isoprene emissions on tropospheric oxidising capacity, ozone and SOA production in future climate scenarios
- Further development of iDirac: DMS, ethylene, monoterpenes
- WIsDOM 2 currently underway…

Acknowledgements










UNIVERSITY OF CAMBRIDGE

NERC SCIENCE OF THE ENVIRONMENT

Lancaster University

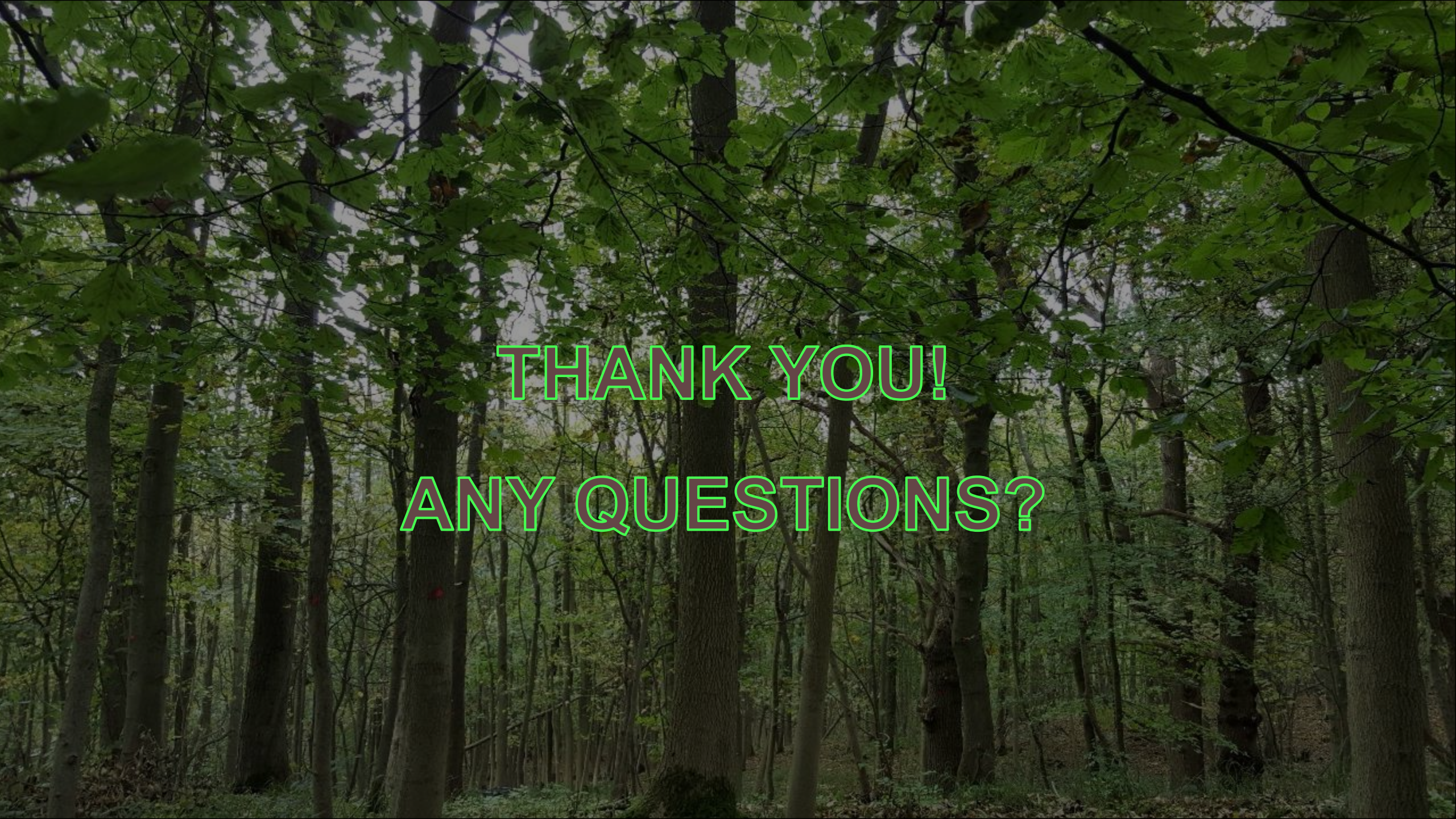
BALI
Biodiversity And Land-use Impacts on Tropical Ecosystem Function

Wytham Woods 75 Years of Science

CEH Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF OXFORD

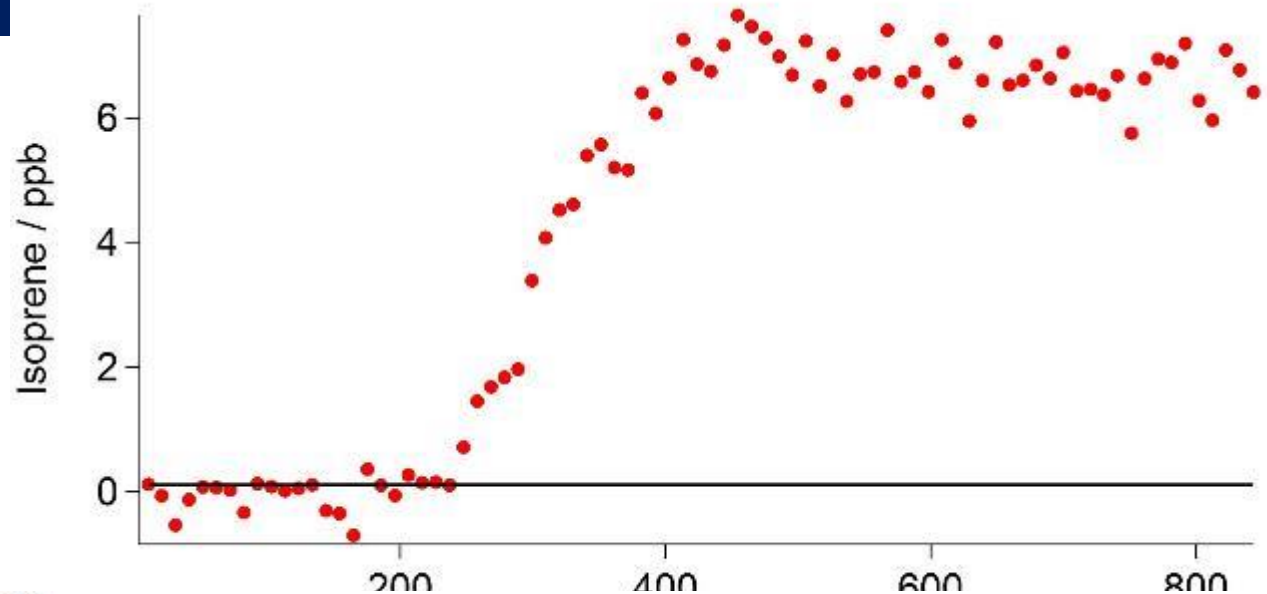
UK Environmental Change Network


THANK YOU!
ANY QUESTIONS?

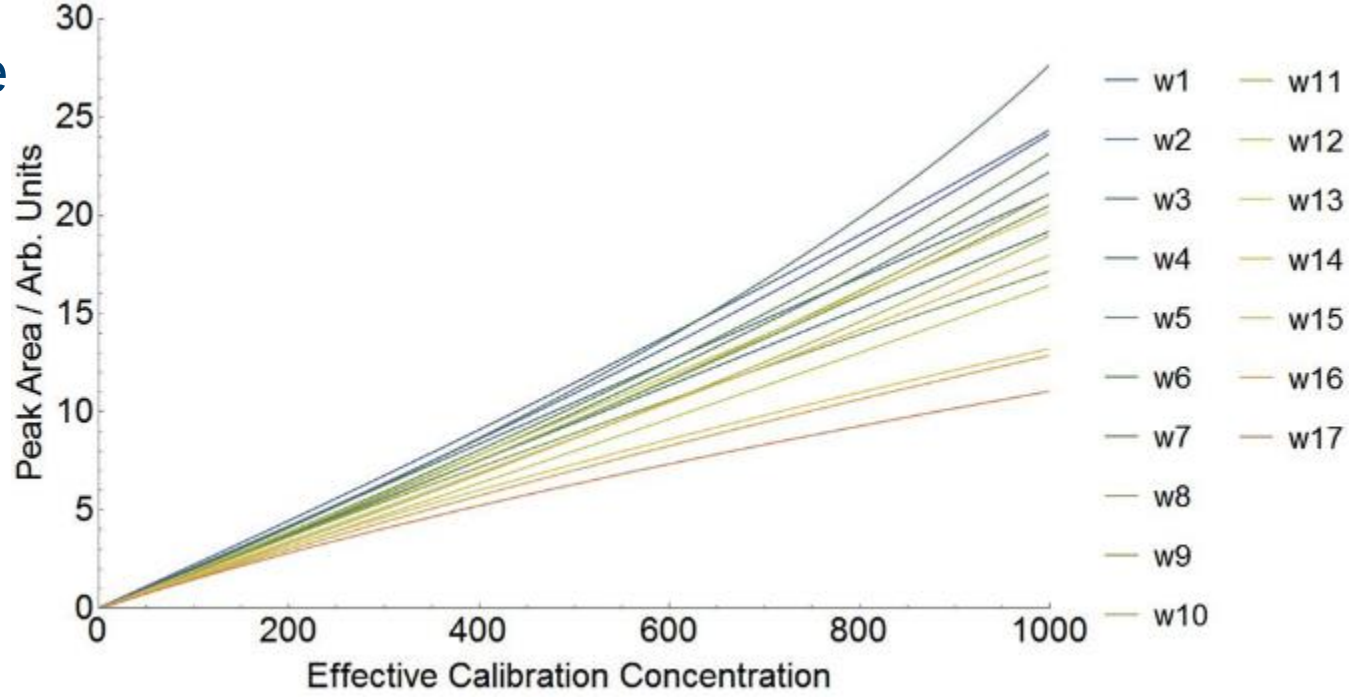
The i-Dirac: trap performance

- Breakthrough volume: 250 mL
- Max sampled volume = 200 mL

  → LOD ~ 40 ppt

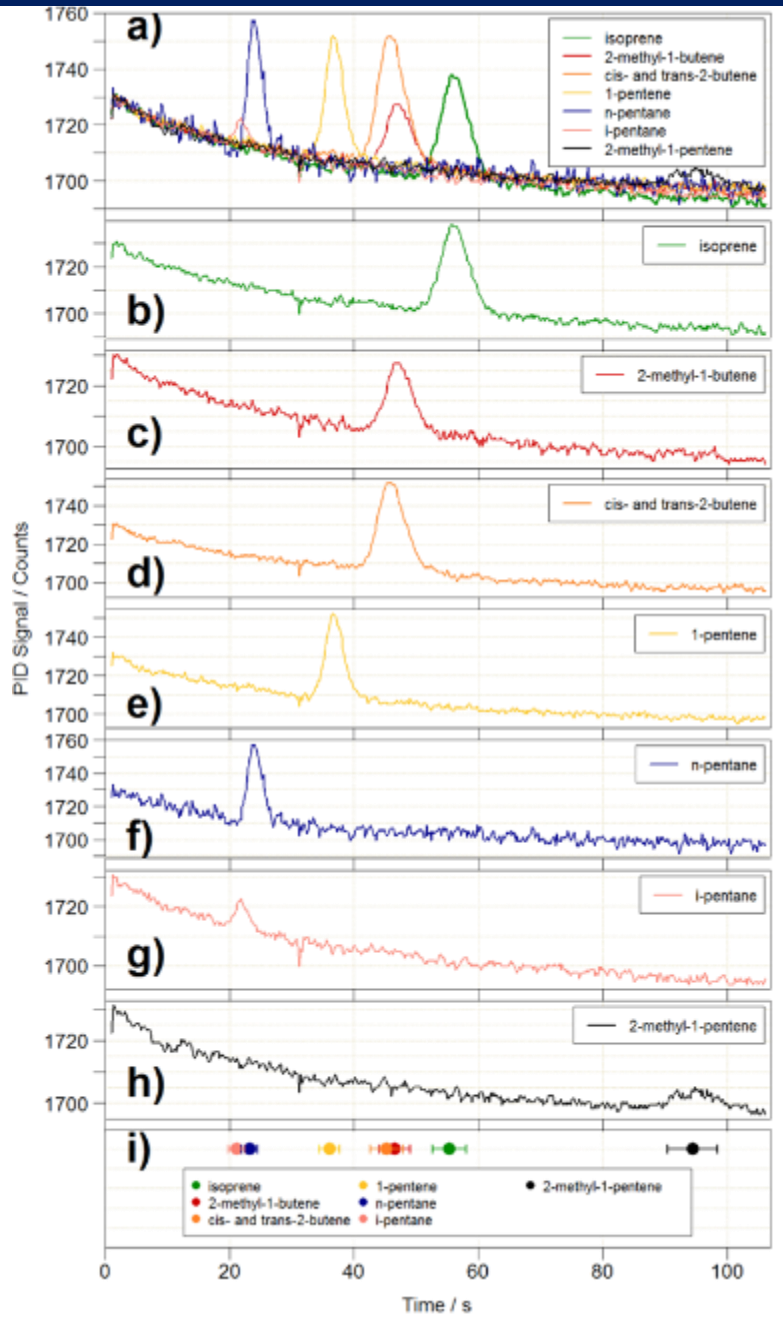


- Response factor decreases with time
- Attributed to trap ‘poisoning’
- Replace trap periodically



The i-Dirac: co-elution tests

- Tested for co-elution with other C4-C5 alkanes and alkenes
- Isoprene peak well-separated
- Peak fitting routine can account for additional peaks in the chromatograms
- Additional peaks seen in sample runs provide additional info once identified
- Work in progress



The i-Dirac: design requirements (2)

• Robust (able to operate in harsh environments) - ant and elephant-proof - Tropical forest (high *T*, *RH*)	• Pelicase (rugged and durable)
• Lightweight (carry to off-road location)	• 10 kg without power or gas
• Low power (needs to run off-grid)	• 12 W (4 W or less on standby)
• Minimal reliance on cylinders of carrier gas	• 1 full N_2 cylinder → ~2 months
• Autonomous	• Arduino control/Raspberry Pi interface
• Remote data collection	• Ad-hoc wifi network
• Easy to use, suitable for non-specialists	• *Potentially*

Guenther MEGAN equations

$$I = I_S C_L C_T \qquad \textit{Equation 3}$$

$$C_L = \frac{\alpha C_{L1} L}{\sqrt{1 + \alpha^2 L^2}} \qquad \textit{Equation 4}$$

$$C_T = \frac{exp\,\frac{C_{T1}(T - T_S)}{R T_S T}}{1 + exp\,\frac{C_{T2}(T - T_M)}{R T_S T}} \qquad \textit{Equation 5}$$

FORCAsT drought model

BASE+SW: Isoprene activity factor, γSWC iso was calculated from soil water content as follows:

$\gamma SWC\ iso = 1$ for $\theta \geq \theta_c$ (7a)

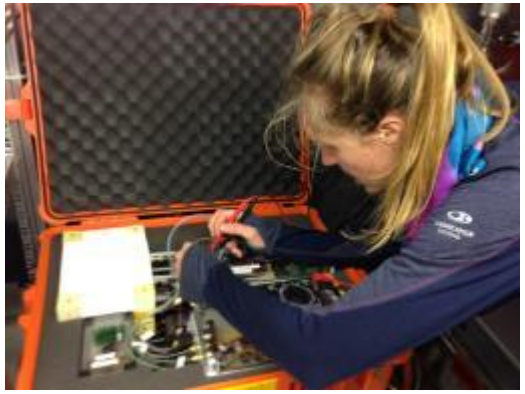
$\gamma SWC\ iso = [(\theta - \theta w)/(\theta c - \theta w)]^q$ for $\theta_w < \theta < \theta_c$ (7b)

$\gamma SWC\ iso = 0$ for $\theta < \theta_w$ (7c)

where θ ($m^3\ m^{-3}$) is the volumetric soil moisture, θ_w (0.15 $m^3 m^{-3}$) is the wilting point, θ_c (0.22 $m^3 m^{-3}$) is a critical soil moisture content above which water stress does not affect isoprene emissions and q (0.40) is a site-specific empirical factor describing the non-linearity of the effects of soil water stress on tree physiological processes.

The i-Dirac - Conclusions & Future work

- Developed a portable GC-PID for long-term isoprene measurements
- Data shows long-term linearity and stability
- Field measurements capture different isoprene abundances in different forest environments
- Successful deployment for 5+ months with minimal maintenance

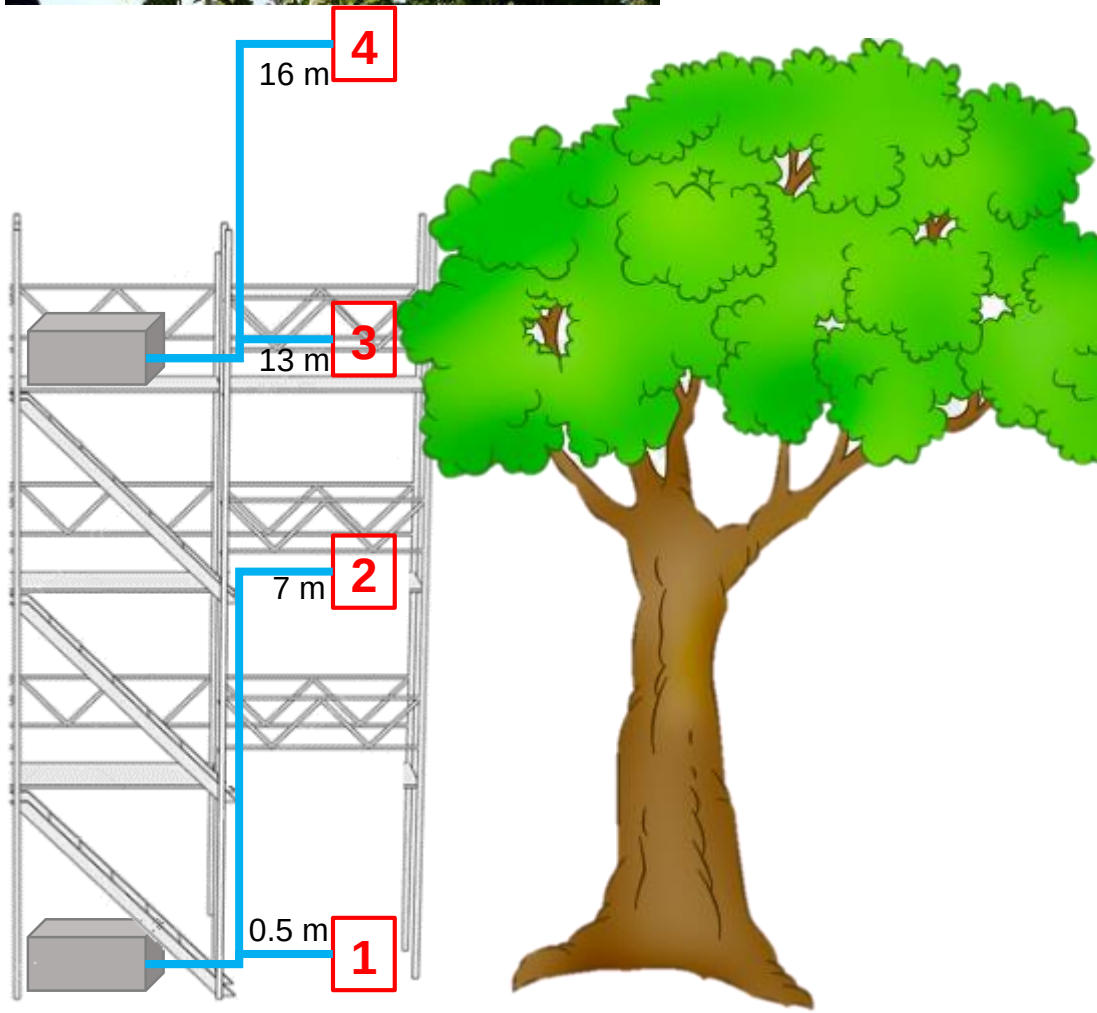


Future work

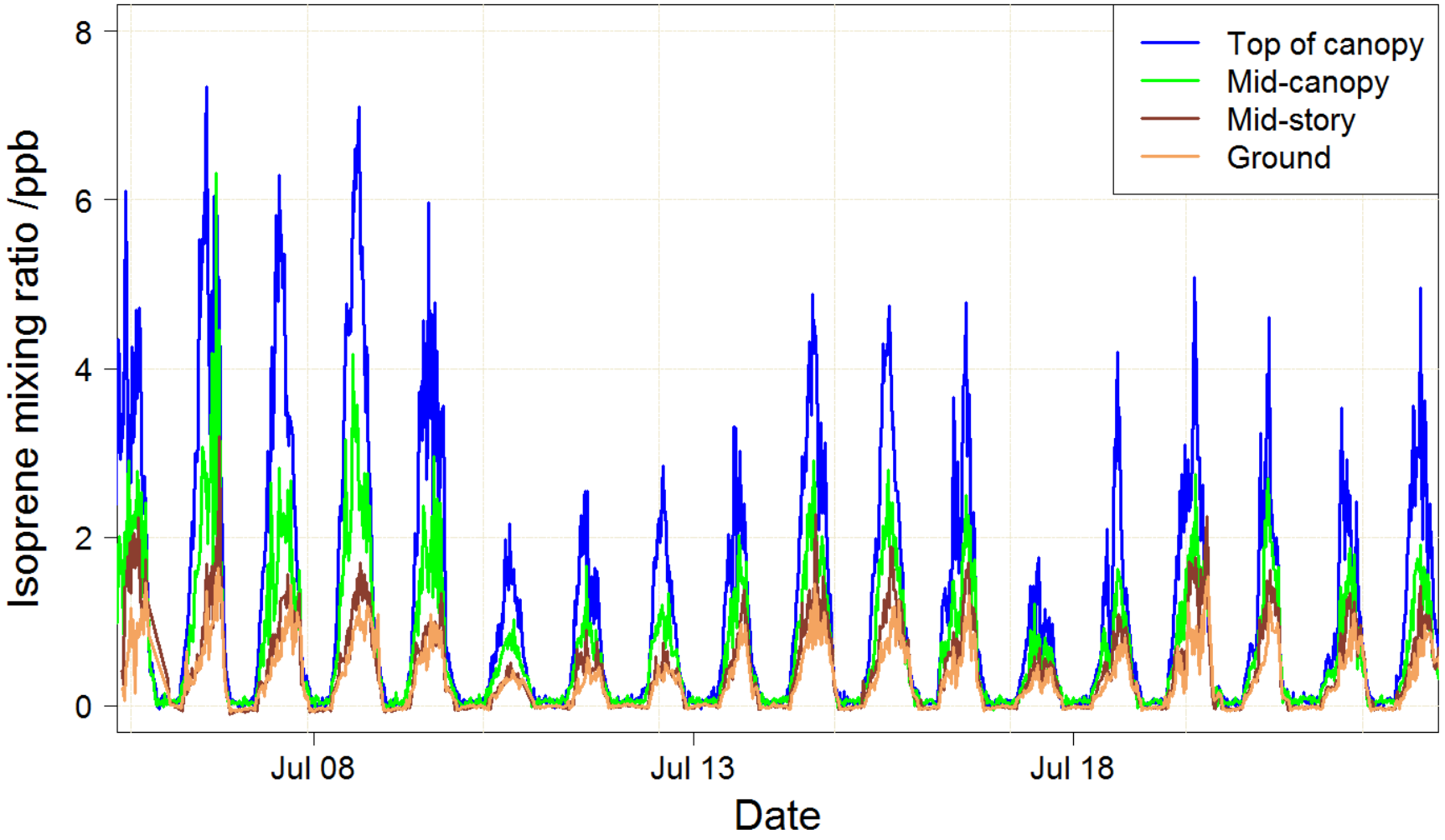
- New target species (methacrolein, MVK, DMS, ethylene, *etc*.)
- Further develop automated analysis software for real-time analysis of chromatograms
- Model emissions from field data and estimate forest fluxes

Measurement set-up

- Isoprene measured at 4 heights – inside, below and above the canopy
- Range of other parameters (*T*, RH, PAR, [CO_2]) at each inlet
- 3D anemometer at the top of the canopy
- Long-term, low-power, unmanned deployment - unsuitable for traditional instrumentation
- Monitor for a complete growing season (May 2018 – ongoing)



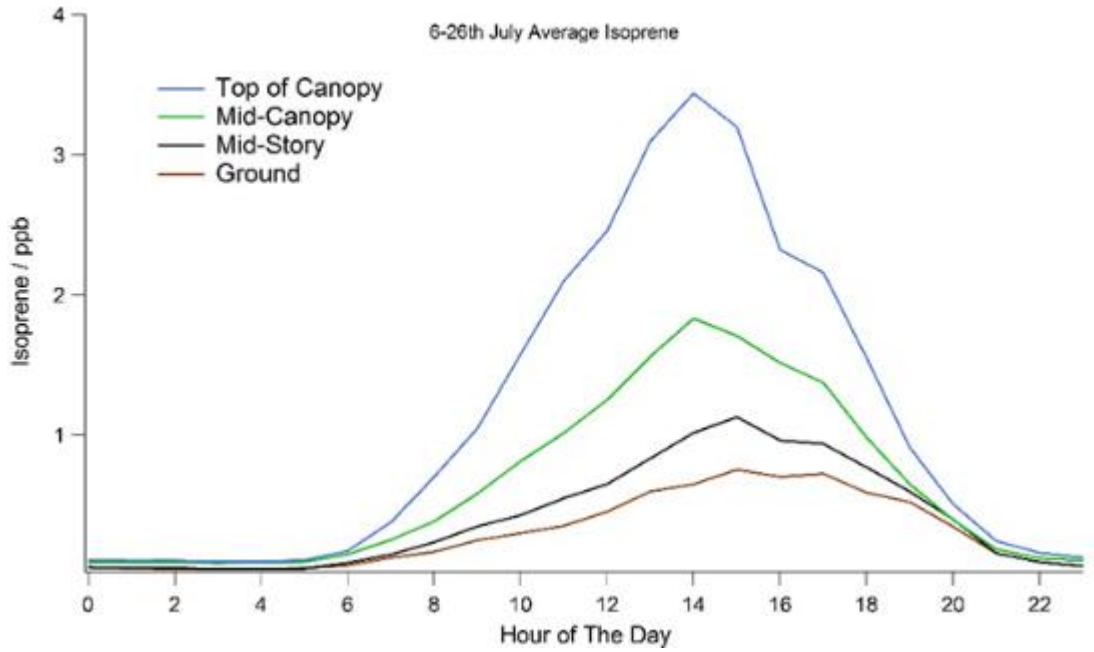
Results: isoprene time series

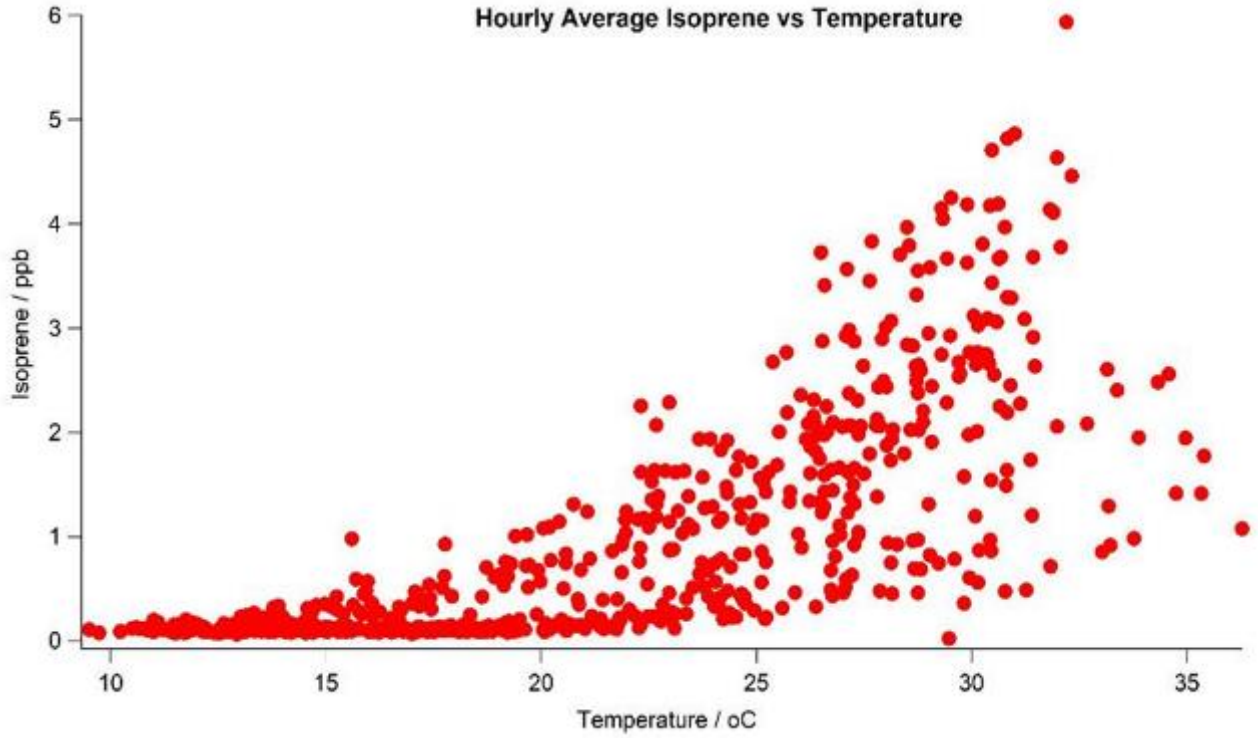


- (almost) uninterrupted time series from May 2018
- Peak values ~7 ppb *cf*. Borneo!
- Vertical gradient

Results: isoprene daily averages and *T* correlation

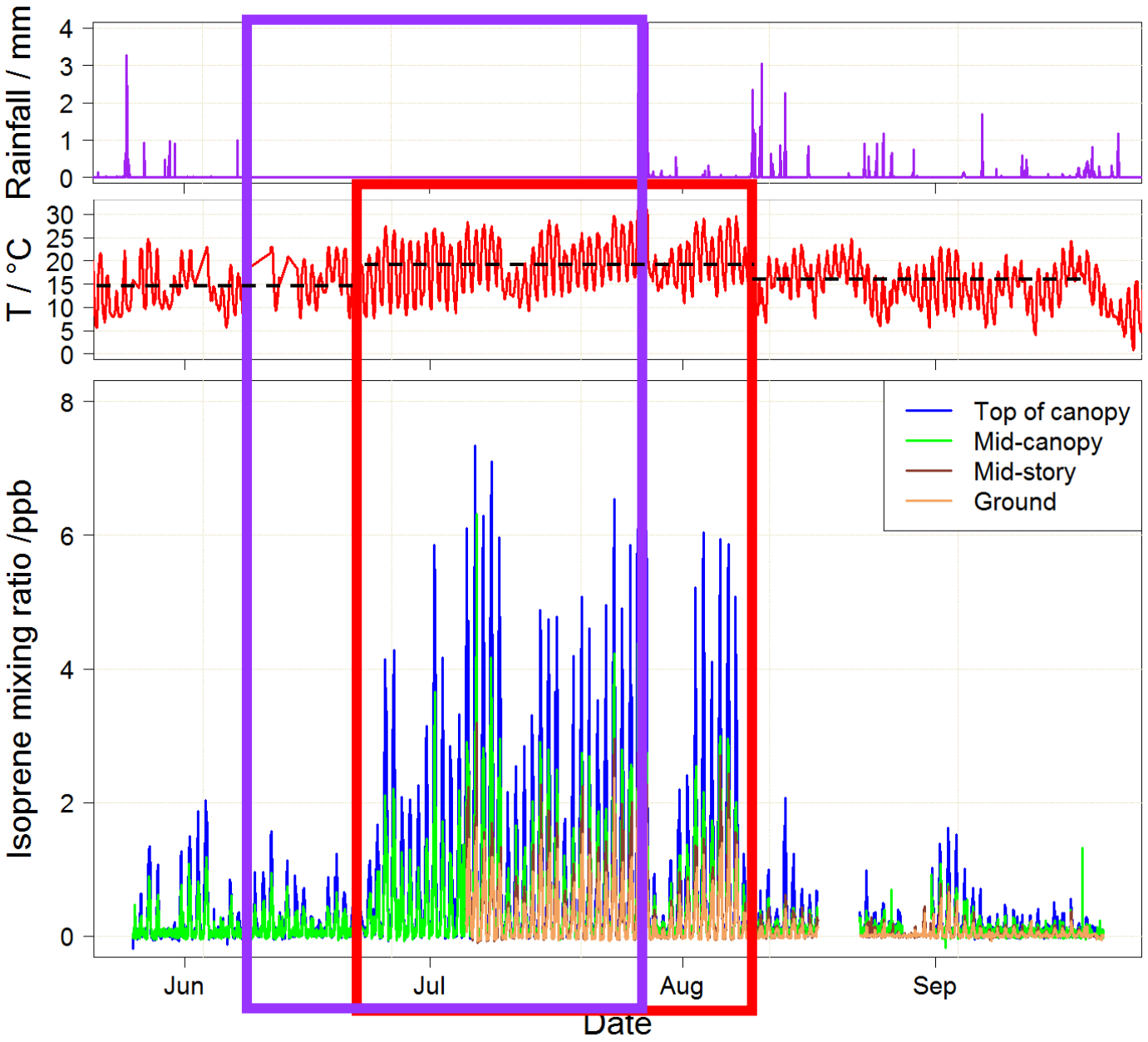
- Daily averages
- Peak below canopy lags ~1 h behind top → advected from canopy





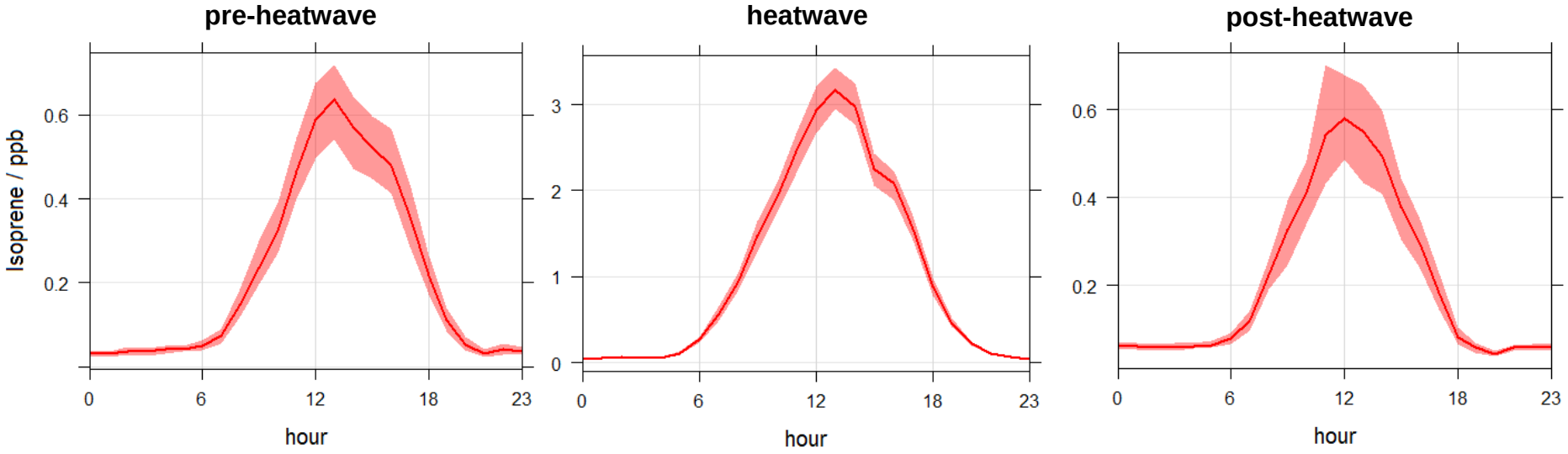
- Isoprene *vs T* at top of canopy
- Hourly average values (day *and* night)
- Increased temperature → increased isoprene (non-linear, exponential)
- 2018 heatwave: shall we talk about the weather?

Isoprene during the ‘Great Heatwave of 2018’ (1)

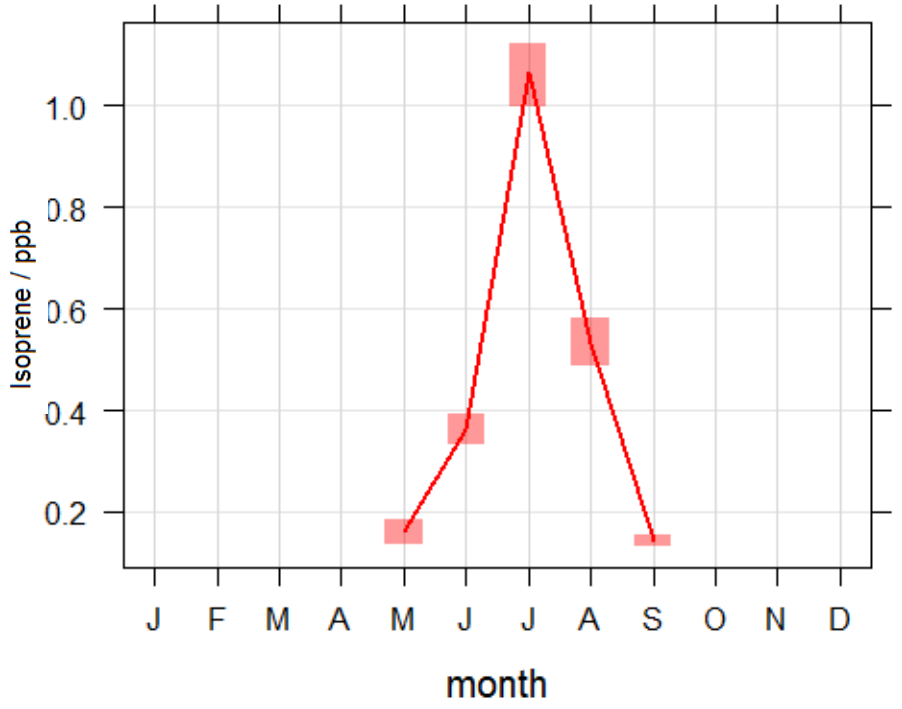


- One of the hottest summers on record in the UK
- Widespread drought, hosepipe bans, crop failures, and a number of wildfires
- T_{mean} during heatwave: 19.2 °C
- T_{mean} before heatwave: 14.7 °C
- T_{mean} after heatwave: 15.3 °C
- ΔT ~ +4-5 °C → isoprene increases by up to a factor of 5
- *T* is not the full story: PAR needs to be taken into account
- Effect of drought on isoprene (look at soil moisture, *etc*.)

Isoprene during the ‘Great Heatwave of 2018’ (2)

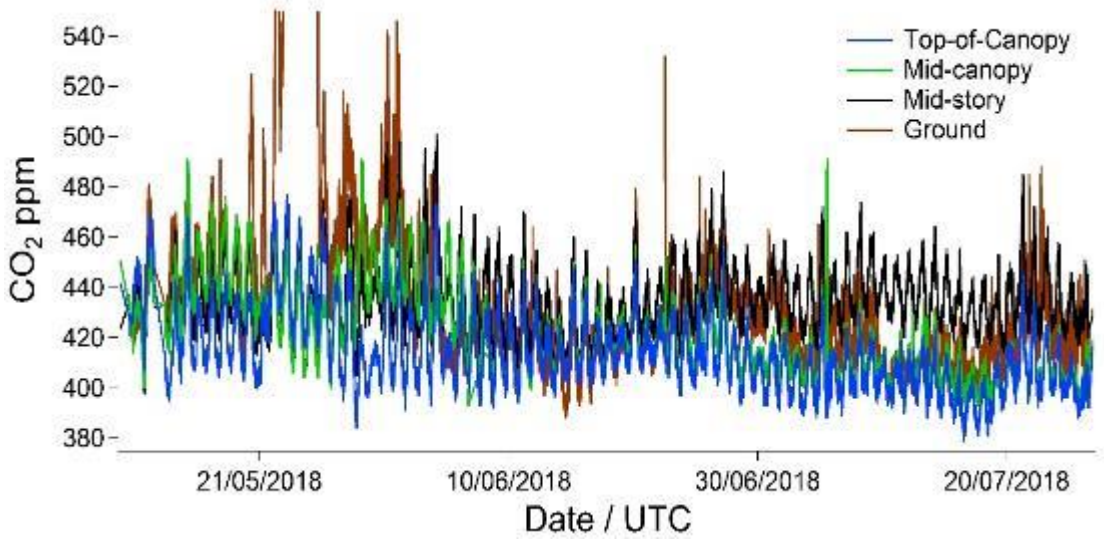


- Mean isoprene diurnal peak 5 times higher during the heatwave
- Monthly average 2-3 times higher during heatwave
- Effects of local air quality? O_3 production? Oxidising capacity? → Modelling needed
- Preliminary results; further rigorous analysis needed

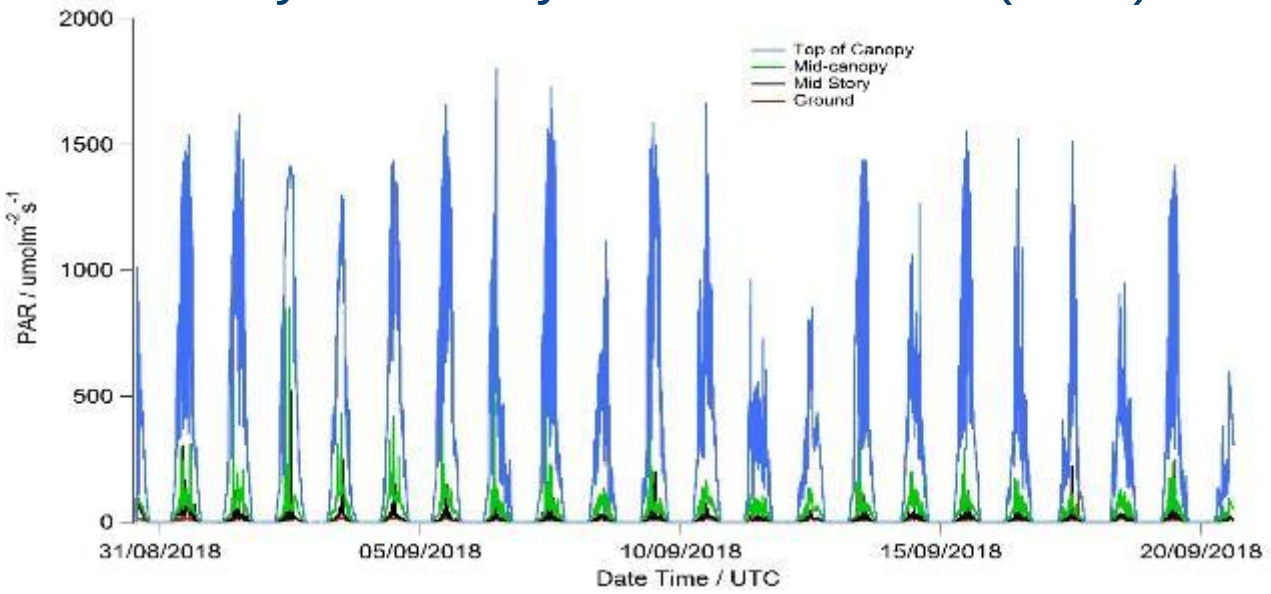


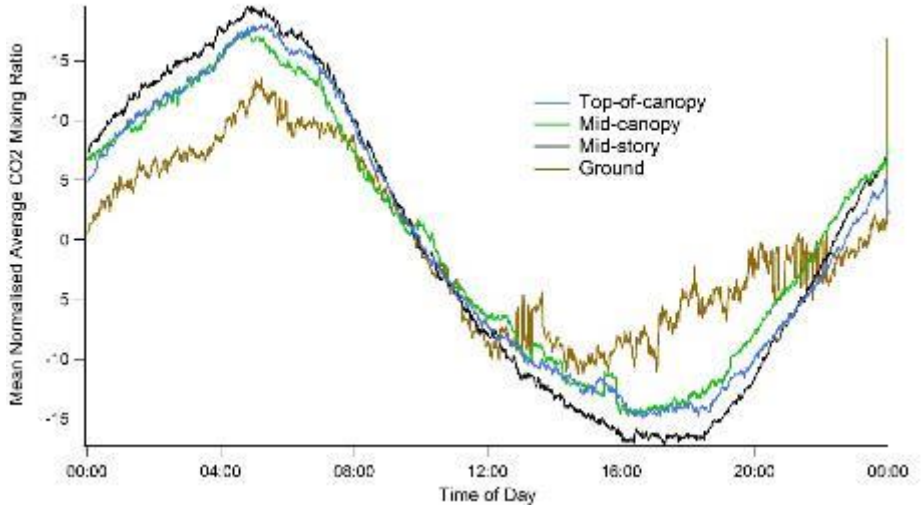
Ancillary measurements

CO_2



Photosynthetically active radiation (PAR)



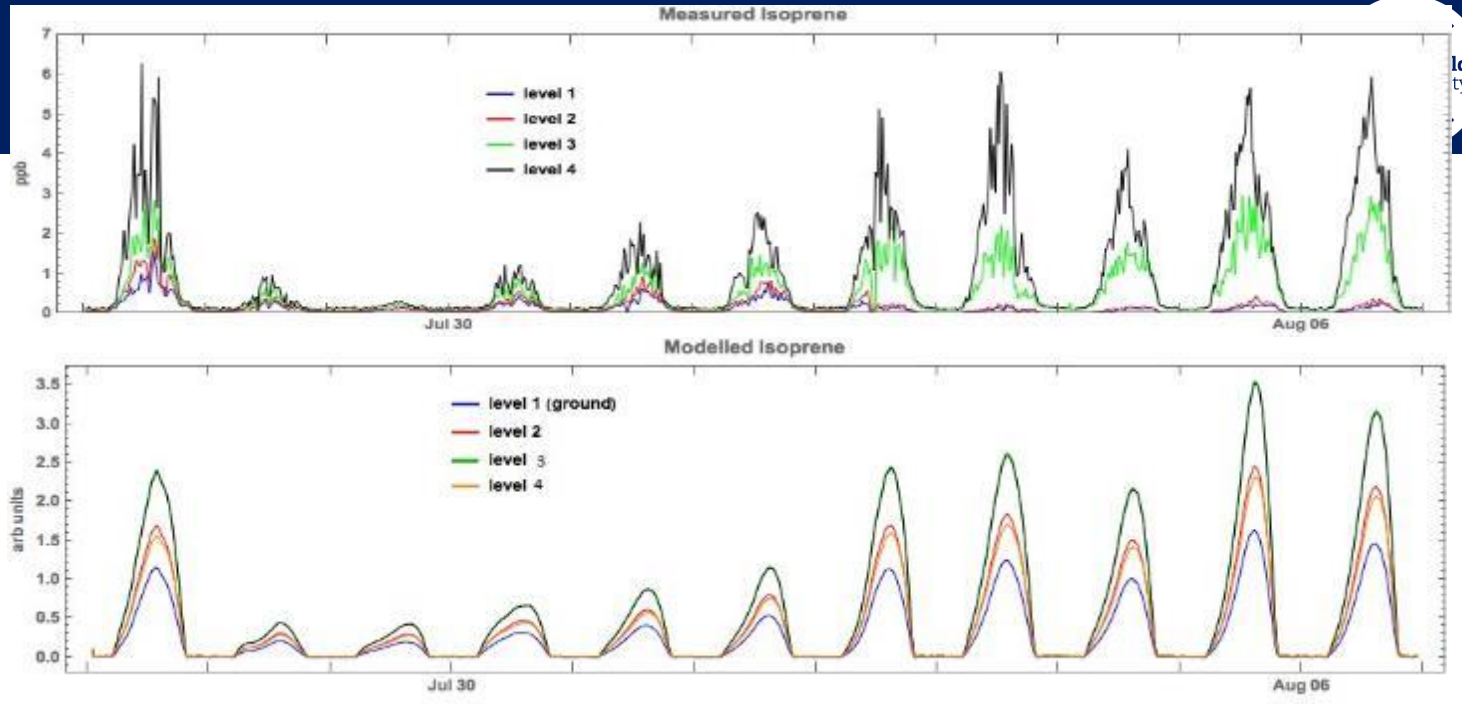


- Temperature (4 heights)
- Relative Humidity (4 heights)
- Wind direction and speed (top of canopy)

Modelling the Wytham data

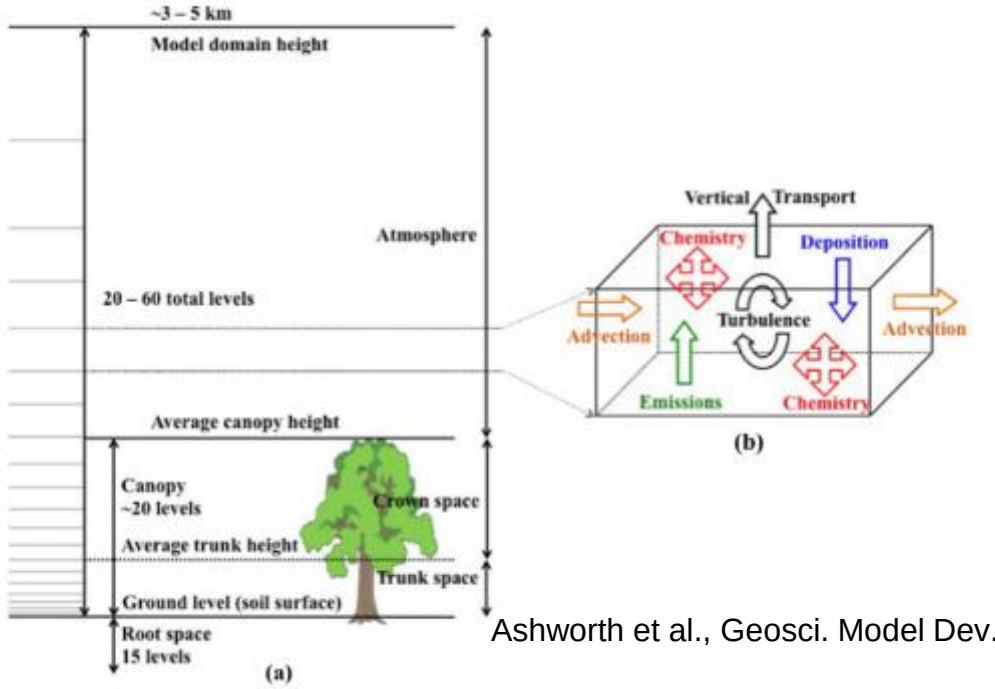
Cambridge box-model (Rod Jones)

- Uses light and temperature data to estimate isoprene emission
- [OH] estimated from SZA and assumptions of initial concentration
- Under development



FORCAsT (University of Lancaster)

- 1-D single column model predicting chemical species and aerosols from soil to above canopy
- Energy balance and radiative transfer within the canopy
- Sophisticated emission factors and chemical mechanisms
- Characterises canopy-atmosphere exchange

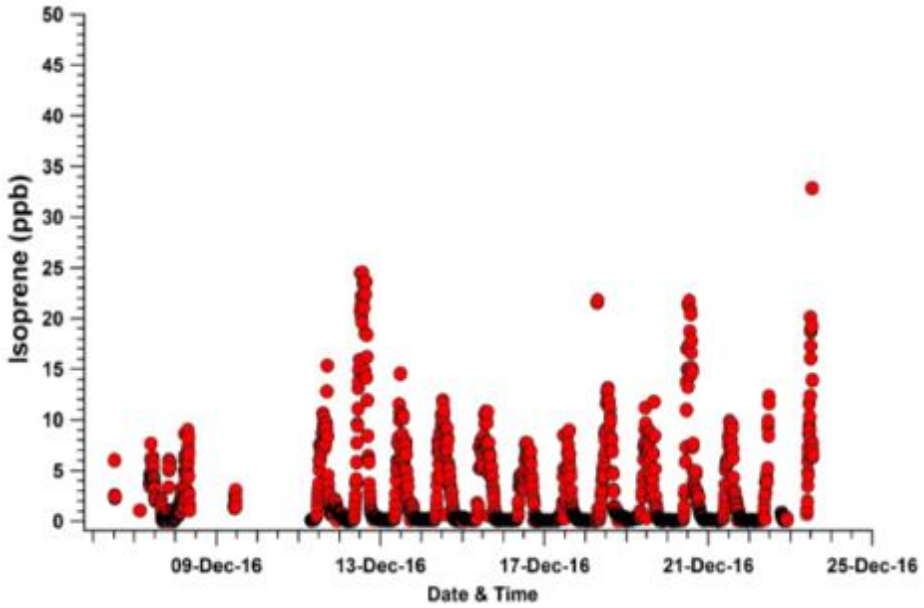


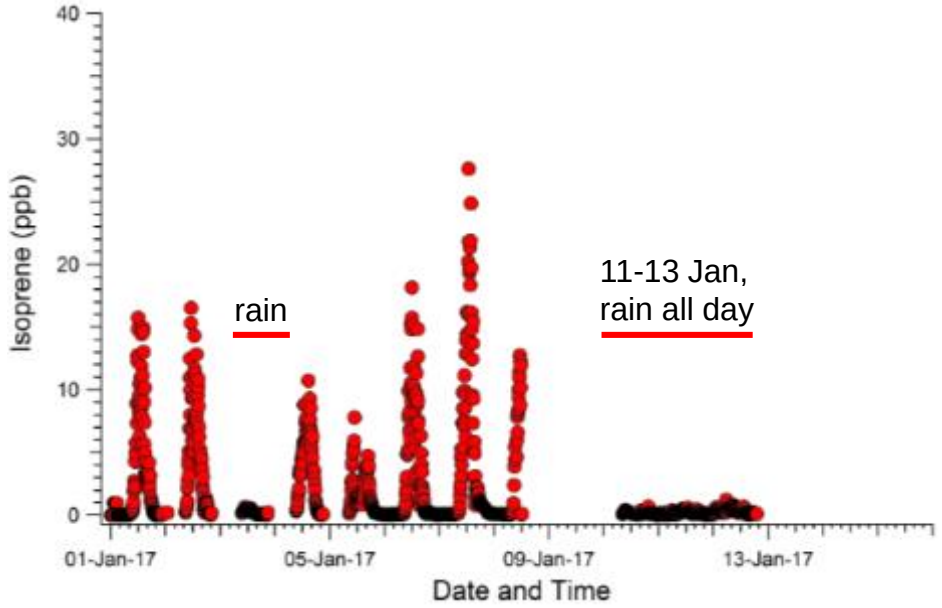
Ashworth et al., Geosci. Model Dev., 2015

Palm oil plantation in Peninsular Malaysia (1)

- Malaysia Palm Oil Board (MPOB), Pekan site
- Dec 2016 - Jan 2017

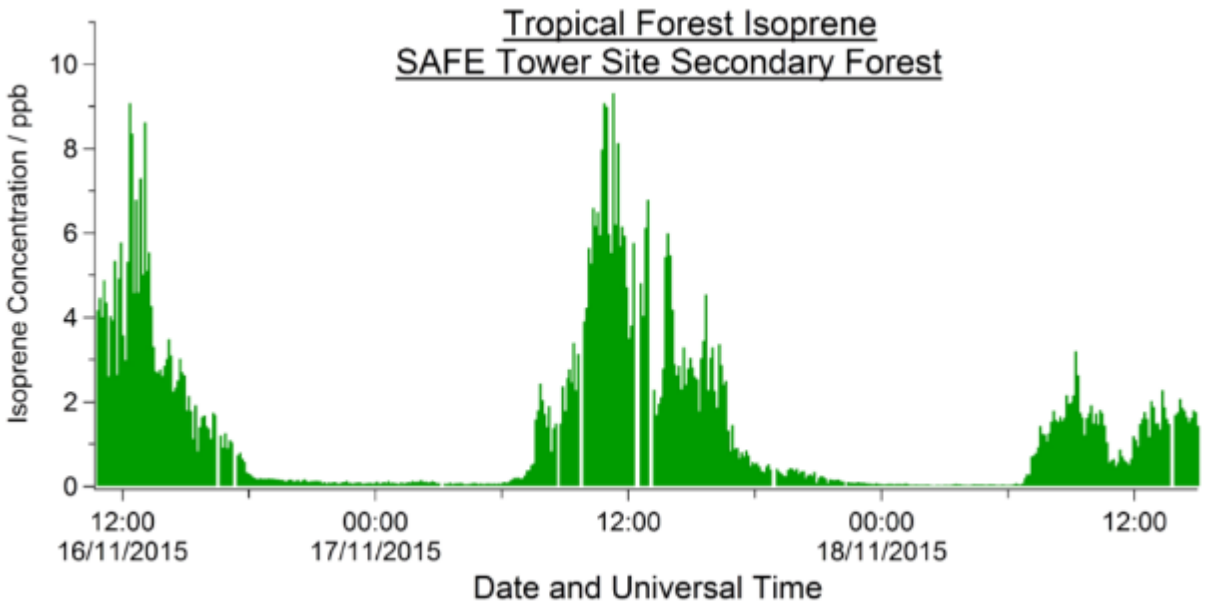
Palm oil plantation in Peninsular Malaysia (2)





- Daytime peak: maximum ~30 ppb
- Daytime peak: variable, rain affected
- Night-time minimum: < 100 ppt
- *cf*. secondary forest in Borneo

Secondary forest in Malaysian Borneo



- Daytime peak: maximum <10 ppb
- Daytime peak: variable, rain affected
- Nighttime minimum: < 100 ppt