Mapping the effects of ozone pollution and mixing on floral odour plumes and their impact on plant-pollinator interactions

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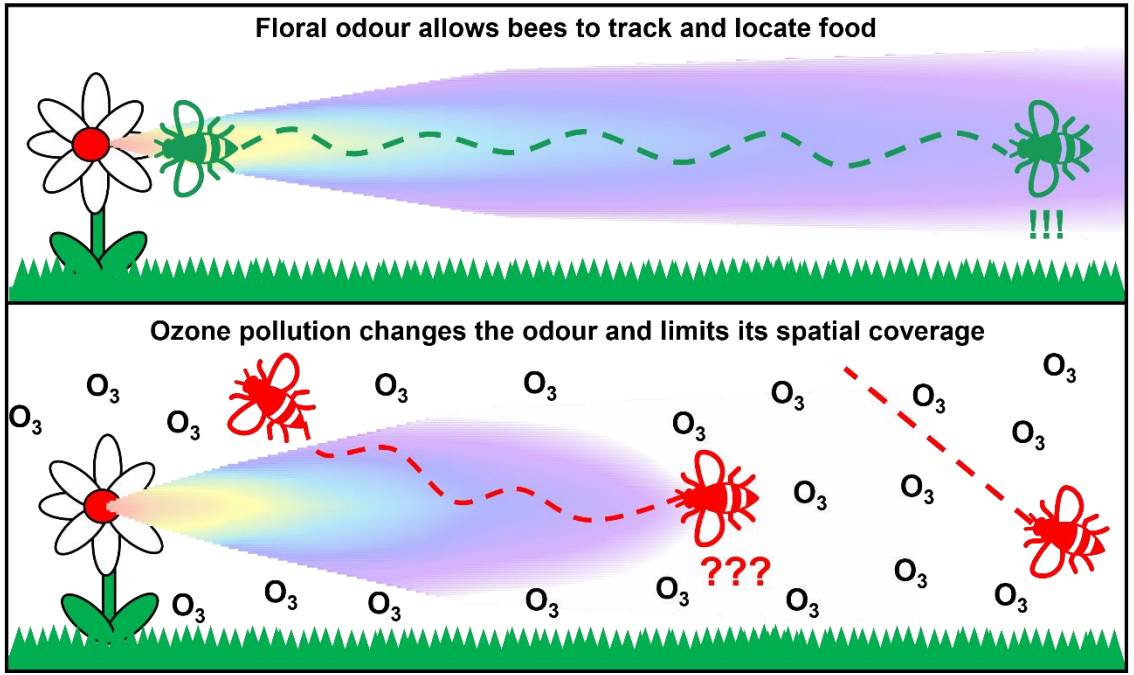
DOMINO

NERC funded project
2017 to 2020
led by the University of Reading and CEH Edinburgh.

Oxidising air pollution degrades important VOC plumes → disrupts chemical communication between plants and insects.

(VOC: Volatile Organic Compound)



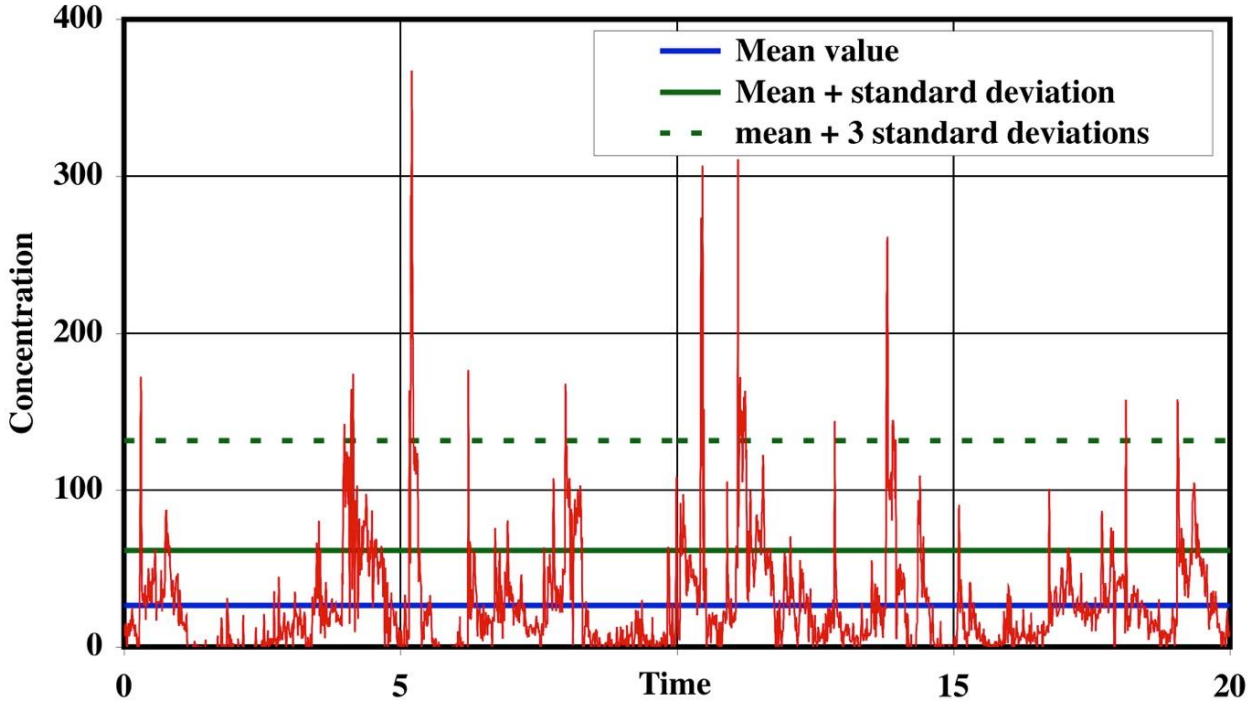
Concentration fluctuations in a plume

Signal from a small, elevated source in a turbulent boundary layer

→ highly skewed

→ very large deviations from the mean

→ intermittent (periods of zero concentration).



Experiment design

The reaction with ozone as the oxidant:

$$\frac{\P[VOC]}{\P t} = - k\left([O_3][VOC]\right)$$

$$\frac{1}{T} = -\frac{1}{[VOC]}\frac{\partial[VOC]}{\partial t} = k[O_3]$$

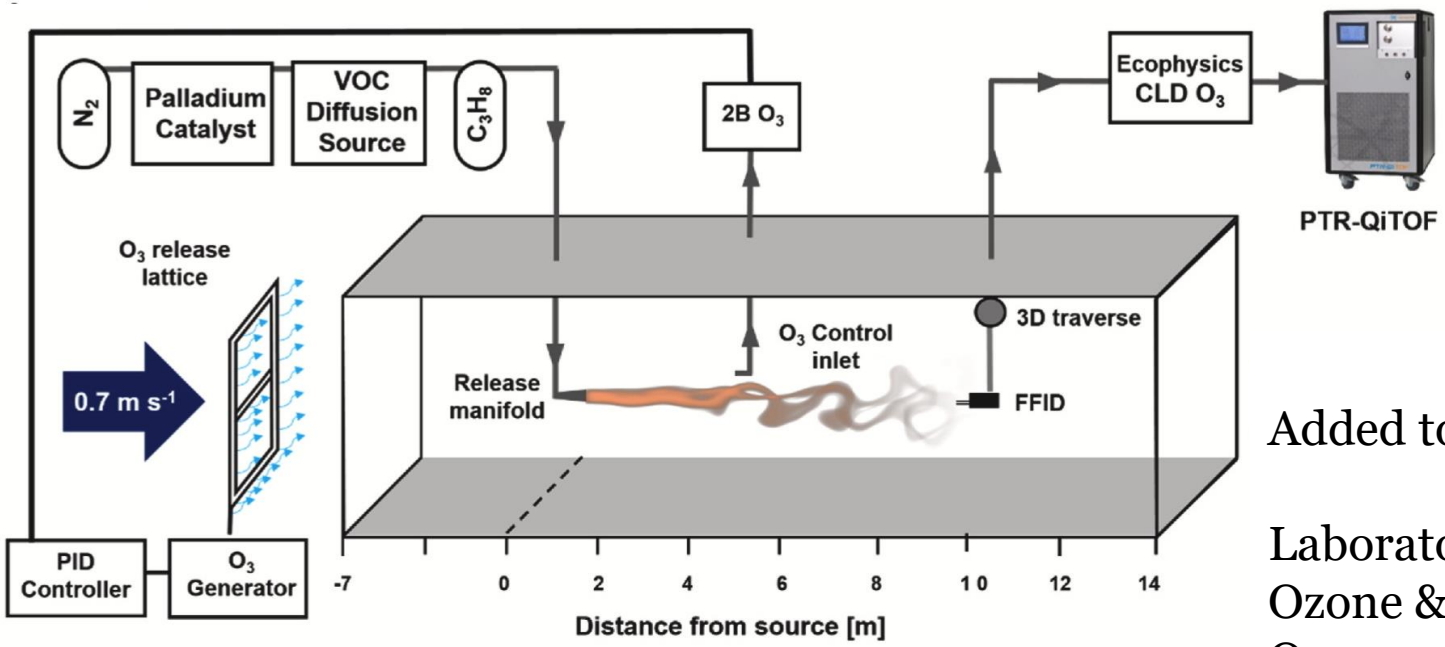
T is the time scale, k the reaction rate.

Calculations using rate constants from literature showed practical options with ozone concentrations ~ 100ppb or more.

Top three VOCs: α-terpinene, β-caryophyllene, α-humulene.

Experiment arrangement - 20 x 3.5 x 1.5 m working section

EnFlo software controls all aspects of operation of the tunnel and its instrumentation.



Added to this:

Laboratory as a whole
Ozone & VOC emissions
Ozone sensors
Mass spectrometer

Health and safety → the operating regime

Ozone standards

- Air quality → 60 ppb
- Workplace → 200 ppb

Strategy

→ demonstrate online control of ventilation in the EnFlo laboratory

Time scales for natural ventilation ~ 1hr, forced ~ 10 mins

→ work to air quality standard during working day, say 7am to 8pm

→ operate at workplace limit overnight, with nobody present in the laboratory

→ make full use of unmanned operation

Programme

VOC plumes with and without ozone background; mixtures (4 components)

Source mid boundary layer
Vary ozone and VOC levels

Standard 1 m boundary layer with U_{ref} ~ 0.7 ms^{-1} ; ~ 20 s flight time.

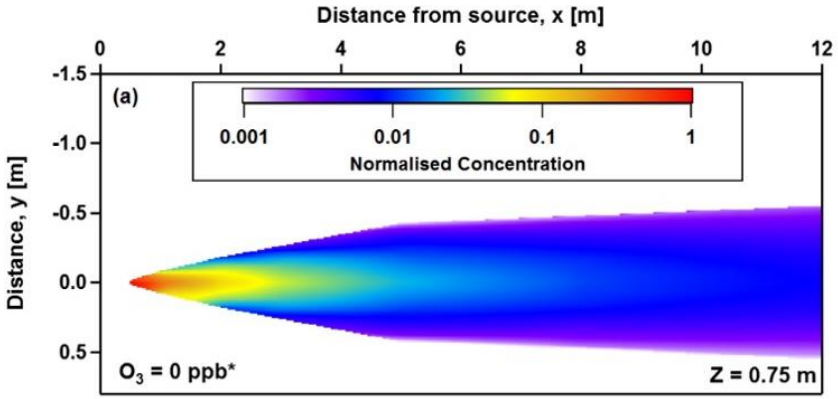
Map plumes in → 35 measurements per run, averaging time ~ 10 minutes per point.

Background subtracted and concentrations adjusted to compensate for changes in VOC source strength.

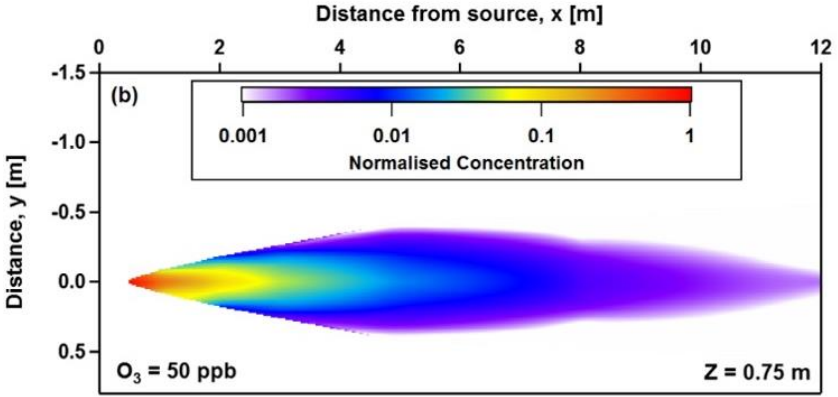
Data normalised to 1 at reference point, x=500 mm, y = 0, z = z_s.

Example - normalised concentrations, α-terpinene experiments

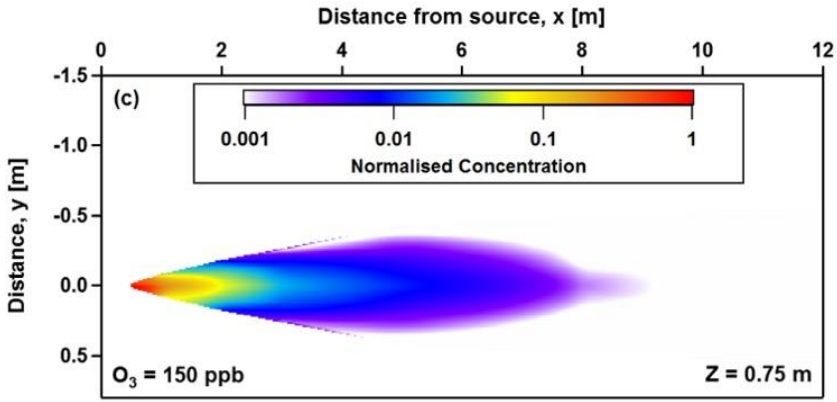
Reference case,
0 ppb ozone



50 ppb ozone



150 ppb ozone



Mixing in a turbulent flow

Expect apparent reaction rate to depart from standard values due to incomplete mixing/turbulence effects.

$$\frac{\P[VOC]}{\P t} = - k\left([O_3][VOC] + [O_3'VOC']\right)$$

→ second term generally negative.

Rate equation with effective rate constant written as:

$$\frac{\P[VOC]}{\P t} = - k_{eff}\left([O_3][VOC]\right)$$

Conclusions from the experiments

… conclusions were mixed …

Cases of slower decay - $k_{eff} < k$
Cases of faster decay - $k_{eff} > k$

$$\frac{1}{T} = k[O_3]$$

Plumes decayed much faster at the edges; reaction rates slower in the centre.

Analysis of correlation between concentrations of α-terpinene and ozone revealed the effective rate constant reduced by up to 10% in first 2 m following release.

Ozone also found to increase plume intermittency and decrease odour filament width, two properties used by insects for navigation.

What happened after that?

Working with bees …

- Honeybees trained to learn a four VOC blend as released in the wind tunnel.
- When presented with odour blend representative of that at the plume centre, 6 m from the source, 52% recognised the odour, falling to 38% at 12 m.
- … with the more degraded blend from the plume edge, recognition decreased to 32% and 10% at 6 and 12 m respectively.
- Findings showed rapid decline in honeybees' ability to recognise floral odour.
- Likely impact on other odour-mediated behaviours, e.g. mate attraction.

Reference

Langford, B, et al., 2023

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Environmental Pollution 336 (2023) 122336

Next – investigation of the intensity of segregation

High frequency measurements are feasible using two FFIDs and one tracer.

Exp 1: Tracer in background → measure concentrations in plume
Exp 2: Tracer in source → measure concentrations in plume
Exp 3: Tracer in source & background → measure concentrations in plume

$$2\overline{c_1 c_2} = \overline{c_3^2} - \overline{c_1^2} - \overline{c_2^2}$$