Eddy covariance fluxes in support of canopy exchange modelling

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1. **Stomatal sink.** Stomatal opening regulate carbon uptake and largely contribute to pollutant removal in the atmosphere.

2. **Surface deposition on cuticles and soil.** Adsorption processes

3. **Chemistry in the gas phase.** Reactions between BVOC and ozone
Ozone in low troposphere: an increasing threat for plants

Ozone in the stratosphere is GOOD!

*protects life on Earth from the sun's harmful ultraviolet (UV) rays*

Ozone in the troposphere is BAD!

*Damages humans and plants, greenhouse gas*

EPA (2010)
Ozone formation in the troposphere

O$_3$ formation is caused by photolytic reactions in which NO$_2$, VOC, and OH radicals take part.

NO$_x$ + VOC + Heat & Sunlight = Ozone

Ground-level or “bad” ozone is not emitted directly into the air, but is created by chemical reactions between NO$_x$ and VOCs in the presence of heat & sunlight.

Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of oxides of nitrogen (NO$_x$) and volatile organic compounds (VOC).
Plants interact with the ecosystem using BVOC

- Key component in the biosphere-atmosphere interactions.
- Affect other plants and organism
- Favour the ecosystem perturbation
- Play an additional or alternative role in plant defences

Atmosphere

Ecosystem

Plant
Types of Biogenic VOC

- **Hemiterpenoids** $\rightarrow \text{C}_5$, only a few produced naturally
  - Isoprene ($\text{C}_5\text{H}_8$, alkene)
  - Methylbutenol ($\text{C}_5\text{H}_{10}\text{O}$, alcohol)

- **Monoterpenoids** $\rightarrow \text{C}_{10}$, thousands of different structures
  - Limonene
  - myrcene (alkene)
  - α-pinene (alkene)
  - linalool (alcohols)

- **Sesquiterpenoids** $\rightarrow \text{C}_{15}$, most varied class of terpenoids
  - β-caryophyllene
  - farnesene

Amount Known

- Isoprene ($\text{C}_5\text{H}_8$)
- Monoterpenes ($\text{C}_{10}\text{H}_{16}$)
- Oxygenated VOC
- Sesquiterpenes ($\text{C}_{15}\text{H}_{24}$)
Biogenic emission of VOC is about 10 times higher than anthropogenic emissions globally!

AVOC
Industrial processes
Biomass burning
Animal husbandry
Vehicular traffic
Mining, energy production

BVOC
Isoprene $C_5H_8$
Monoterpene $C_{10}H_{16}$
Sesquiterpenes $C_{15}H_{24}$
A canopy-scale approach: Eddy Covariance flux measurements

Fluxes are measured from the eddy covariance (EC) between vertical wind speed and gas concentration (ozone, VOC, CO₂, H₂O), with observations 10 times per second.

CO₂ flux: Subtracting modelled ecosystem respiration to the Net Ecosystem Exchange (NEE), Gross Primary Productivity (GPP) is calculated.

Water flux: Stomatal conductance is calculated from measured transpiration by inversion of Monteith equation, therefore an estimate of stomatal ozone fluxes is possible.

Ozone fluxes: sum of stomatal and non-stomatal components.
Case studies: the Holm oak urban forest in Castelporziano, Rome

Above the canopies of Mediterranean oaks and pines a complex photochemistry takes place with concurrent phenomena of ozone formation and ozone deposition.

https://www.icos-cp.eu/icoscapes/castelporziano
Wet years in Castelporziano = higher GPP

Circa 600 g CO2 m-2 per anno rimossi dal bosco in anni con scarsa precipitazione, quasi il doppio nel 2014!

- Tot. GPP in 2013: 1793 g (C) m-2 (665 mm precip.)
- Tot. GPP in 2014: 2242 g (C) m-2 (900 mm precip.)
- Tot. GPP in 2019: 1870 g (C) m-2 (694 mm precip.)
field measurements in Exeter (Central valley, CA)
Long term field measurements in Blodgett Forest

Through a multiyear analysis (2001-2006), we observed different sinks of ozone uptake, elucidating their dependence on plant physiology and environmental conditions.
The Hom Oak is a relevant O3 sink

Ozone fluxes are higher during late spring, when stomatal conductance is high. Up to 8 g O3 m-2 are sequestrated every year!

Ozone flux partitioned between stomatal and non-stomatal sinks

A RESISTANCE is the inverse of a CONDUCTANCE. A FLUX is driven by concentration differences between the canopies and the atmosphere.

A series of resistances (e.g. aerodynamic, boundary layer, stomata, cuticles, trace gases) reduce flux magnitude from the atmosphere to the ground, obeying Ohm`s law.

\[
F_{O_3} = F_{O_3 \text{sto}} + F_{O_3 \text{nsto}} = \frac{[O_3]}{R_{\text{sto}}} + \frac{[O_3]}{\Sigma R_{\text{nsto}}}
\]

\[
F_{O_3 \text{sto}} = G_{\text{sto}} *[O_3]
\]
O₃ sink partitioning: stomata are the main sink

- Evaporative/resistive method for the stomatal component:
  \[
  O_{3\,sto} = [O_3] \text{canopy} \cdot 0.61 \cdot G_{sto,H_2O}
  \]

\[
\lambda E = \frac{\rho c_p [e_s(T_0) - e(z_m)]}{\gamma (R_a + R_b + R_{sto})}
\]

- Soil sink:
  \[
  R_{ac} = \frac{14 \times \text{LAI} \times z_c}{u^*}
  \]
  \[
  R_g = R_{g1} + R_{g2} \cdot \frac{\text{SWC10}}{\text{SWCfc}}
  \]

Validated with EC measurements below canopy (Fares et al. Agr For Met 2014)

- Cuticoles:
  \[
  R_{cut(dry)} = \frac{R_{cut(dry)_0}}{e^{0.03RH} \times \text{LAI}^{1/4} \times u^*}
  \]
  \[
  R_{cut(wet)} = \frac{R_{cut(wet)_0}}{\text{LAI}^{1/2} \times u^*}
  \]

(Zhang et al., 2002)
Dramatic levels of tropospheric ozone concentrations in the central valley

Fares et al. Atm. Env. 2012
The daily ozone concentrations showed maximum diurnal peaks above 90 ppb!

Stomata represented a significant sink of ozone for this ecosystem, but not the major sink, similarly to Citrus site!

Fares et al. Agr. For. Met. 2010
Evidence of non-stomatal ozone removal at Blodgett:

Non-stomatal ozone fluxes peak during the day in coincidence with monoterpene fluxes and the fluxes of the oxidation products of monoterpenes (m113)!

We calculated that up to 40% of ozone uptake is due to BVOC!

*(Fares et al. 2010 Agr. For. Mt.)*
VOC emission: Fluxes at Castelporziano peak during the day because primary emitted BVOC depend on light and temperature.

Holm Oak is a predominant Monoterpene emitter.

Deployment of PTRMS to the field site.
Back in 2007 in a dune ecosystem: Clear diurnal fluxes of isoprene, monoterpenes and of Methyl Vinyl Chetone (MVK), one of the main oxidation products of isoprene.
Evidences of Ozone – scavenging by VOC

Norm. concentrations and meteor. variables

- T
- Sesquiterpenes
- O₃ conc.
- O₃ flux (non stom.)

Monoterp. conc. gradient

- T
- MVK & MACR
- O₃ conc.
- O₃ flux (non stom.)

SQT >> Isoprene >> Acetone
BVOC concentration in the Orchard:  

This compounds is the major BVOC released from the orchard.

Flowering event!  
Harvesting & trimming  
Fertilizer application  

Fares et al.  
ACP 2012
Large fluxes during the flowering period...
We believe that the model underestimates $F_{voc}$ during flowering, because not fully accounting for the burst of BVOCs coming from flowers.

Hundreds of unexplored reactive VOC


Park et al. Science 2013
Eddy covariance fluxes to test and validate canopy models
AIRTREE- Aggregated Interpretation of the Energy balance and water dynamics for Ecosystem services assessment

Proximally sensed data

Radiative transfers:
- Leaf temperature and solar irradiation

Photosynthesis & stomatal conductances

BVOC emission

Air pollutants deposition, carbon fluxes and ecosystem services

Measurements on site

Pollutant concentrations, meteorological parameters, vegetation type

Literature

Photosynthetic parameters, e.g.- Vcmax, Basal Emisison Factors for BVOC, LAI

Canopy profile

Turbulent transport

Soil processes

Leaf
Model sensitivity: major effects of soil properties and drought on photosynthetic parameters

Optimization routines by PEST (Doherty, 2016). PEST is a nonlinear parameter estimation and optimization package based on the Gauss-Marquardt-Levenberg algorithm.

- Unrealistic predictions when soil water content is not included among the parameters driving stomatal regulation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensitivity</th>
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<tr>
<td>scat_veg</td>
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<tr>
<td>qteta</td>
<td>0.01</td>
</tr>
<tr>
<td>cluster</td>
<td>0.02</td>
</tr>
<tr>
<td>lw_emiss</td>
<td>0.02</td>
</tr>
<tr>
<td>scat_nir</td>
<td>0.03</td>
</tr>
<tr>
<td>tsmir_nir</td>
<td>0.03</td>
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<tr>
<td>b</td>
<td>0.06</td>
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<tr>
<td>scat_vis</td>
<td>0.08</td>
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<td>t_delta_max</td>
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<td>tetaw</td>
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<tr>
<td>leafwidth</td>
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<td>phi</td>
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<td>bprime</td>
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<td>tetac</td>
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</tr>
<tr>
<td>k</td>
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Soil porosity

Velocity of carboxilation changing over the vegetative season
Photosynthetic performances change in time and along the vertical canopy profile

\[ V_{c_{\text{max}}} \] extinction

\[ V_{c_{\text{max}}}^{25}(x) = V_{c_{\text{max}}^{25}}(0)e^{-K_n x} \]

\( V_{c_{\text{max}}} \) values scaled at each canopy layer from the top of the canopy (layer 1) to the ground (layers 5)

<table>
<thead>
<tr>
<th>Layer</th>
<th>LAI cumulated</th>
<th>( V_{c_{\text{max}}} )</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>0.43</td>
<td>73</td>
</tr>
<tr>
<td>2</td>
<td>1.32</td>
<td>64</td>
</tr>
<tr>
<td>3</td>
<td>2.37</td>
<td>54</td>
</tr>
<tr>
<td>4</td>
<td>3.25</td>
<td>48</td>
</tr>
<tr>
<td>5</td>
<td>3.69</td>
<td>45</td>
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</tbody>
</table>

Velocity of carboxilation changing over the vegetative season

Fares et al. Sci. Tot. Env. 2019
Measured vs simulated ozone fluxes

Multi-level deposition affected by the proportion of leaf biomass at each level

Underestimated gas phase chemistry
AIRTREE performances: The Castel di Guido periurban forest, Rome

1 ton carbon/ha
8.1 kg ozone and PM/ha

Table 1. NPP, Tropospheric Ozone (O₃), and Particle (PM₁₀ and PM₂.₅) Dry Deposition Simulated by the AIRTREE Model for the Year 2018 at Castel di Guido Natural Reserve

<table>
<thead>
<tr>
<th>Species</th>
<th>dbh (cm)</th>
<th>NPP (g m⁻²)</th>
<th>NPP class</th>
<th>O₃ (g m⁻²)</th>
<th>O₃ class</th>
<th>PM₁₀ (g m⁻²)</th>
<th>PM₂.₅ (g m⁻²)</th>
<th>PM₁₀ class</th>
<th>PM₂.₅ class</th>
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<tbody>
<tr>
<td>A. campestris</td>
<td>35</td>
<td>354.23 ± 38.76</td>
<td>IV</td>
<td>2.97 ± 0.82</td>
<td>V</td>
<td>1.01 ± 0.048</td>
<td>II</td>
<td>0.09 ± 0.0041</td>
<td>I</td>
</tr>
<tr>
<td>Acer negundo</td>
<td>15</td>
<td>48.6</td>
<td>I</td>
<td>2.75</td>
<td>V</td>
<td>0.77</td>
<td>I</td>
<td>0.06</td>
<td>I</td>
</tr>
<tr>
<td>A. cordata</td>
<td>35</td>
<td>438.59 ± 39.9</td>
<td>V</td>
<td>3.27 ± 0.05</td>
<td>VI</td>
<td>1 ± 0.0045</td>
<td>II</td>
<td>0.08 ± 0.0034</td>
<td>I</td>
</tr>
<tr>
<td>C. atlantica</td>
<td>35</td>
<td>938.24 ± 128.36</td>
<td>X</td>
<td>5.67 ± 0.33</td>
<td>X</td>
<td>7.39 ± 1.272</td>
<td>VIII</td>
<td>3.01 ± 0.1739</td>
<td>X</td>
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<tr>
<td>C. australis</td>
<td>35</td>
<td>392.79</td>
<td>IV</td>
<td>2.8</td>
<td>X</td>
<td>0.93</td>
<td>I</td>
<td>0.08</td>
<td>I</td>
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<tr>
<td>C. sempervirens</td>
<td>55</td>
<td>1084.6</td>
<td>X</td>
<td>7.4</td>
<td>X</td>
<td>16.23</td>
<td>II</td>
<td>2.27</td>
<td>X</td>
</tr>
<tr>
<td>Eschscholzia sp</td>
<td>55</td>
<td>490.78</td>
<td>V</td>
<td>3.34</td>
<td>VI</td>
<td>1.44</td>
<td>II</td>
<td>0.12</td>
<td>I</td>
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<tr>
<td>Fraxinus angustifolia</td>
<td>15</td>
<td>253.71 ± 79.24</td>
<td>III</td>
<td>2.19 ± 0.69</td>
<td>IV</td>
<td>0.83 ± 0.1507</td>
<td>I</td>
<td>0.07 ± 0.0125</td>
<td>I</td>
</tr>
<tr>
<td>F. ornus</td>
<td>35</td>
<td>562.24 ± 95.6</td>
<td>VI</td>
<td>2.88 ± 0.26</td>
<td>V</td>
<td>1.42 ± 0.1802</td>
<td>II</td>
<td>0.12 ± 0.0155</td>
<td>I</td>
</tr>
<tr>
<td>Juglans regia</td>
<td>35</td>
<td>140.48 ± 126.39</td>
<td>II</td>
<td>2.17 ± 0.69</td>
<td>IV</td>
<td>0.82 ± 0.1714</td>
<td>I</td>
<td>0.07 ± 0.0143</td>
<td>I</td>
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<tr>
<td>Juglans regia</td>
<td>35</td>
<td>370.26</td>
<td>IV</td>
<td>2.51</td>
<td>IV</td>
<td>1.05</td>
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<td>Malus sylvestris</td>
<td>35</td>
<td>225.31</td>
<td>II</td>
<td>3.02</td>
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<td>Ostrya carpinifolia</td>
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<td>528.65 ± 91.68</td>
<td>II</td>
<td>2.85 ± 0.25</td>
<td>V</td>
<td>1.32 ± 0.1603</td>
<td>II</td>
<td>0.11 ± 0.0138</td>
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<td>Pinus sylvestris</td>
<td>35</td>
<td>704.89 ± 97.32</td>
<td>VIII</td>
<td>6.19 ± 0.61</td>
<td>V</td>
<td>9.58 ± 2.196</td>
<td>X</td>
<td>3.11 ± 0.333</td>
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<tr>
<td>Pinus halepensis</td>
<td>55</td>
<td>894.96</td>
<td>IX</td>
<td>6.67</td>
<td>X</td>
<td>13.73</td>
<td>X</td>
<td>1.88</td>
<td>X</td>
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<td>Pinus pinaster</td>
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<td>847.47</td>
<td>IX</td>
<td>6.46</td>
<td>X</td>
<td>12.01</td>
<td>X</td>
<td>1.65</td>
<td>X</td>
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<tr>
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<td>794.22 ± 30.13</td>
<td>VIII</td>
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<td>X</td>
<td>10.86 ± 0.7685</td>
<td>X</td>
<td>1.49 ± 0.1055</td>
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<td>I</td>
<td>2.01</td>
<td>IV</td>
<td>0.69</td>
<td>I</td>
<td>0.06</td>
<td>I</td>
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<td>2.76</td>
<td>IV</td>
<td>1.12</td>
<td>II</td>
<td>0.1</td>
<td>I</td>
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<td>27.91</td>
<td>I</td>
<td>2.15</td>
<td>IV</td>
<td>0.66</td>
<td>I</td>
<td>0.06</td>
<td>I</td>
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<td>Pyrus pyraster</td>
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<td>2.57</td>
<td>V</td>
<td>1.08</td>
<td>I</td>
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<td>Q. cerris</td>
<td>35</td>
<td>412.27 ± 51.97</td>
<td>V</td>
<td>2.89 ± 0.21</td>
<td>V</td>
<td>1.21 ± 0.192</td>
<td>II</td>
<td>0.1 ± 0.0103</td>
<td>I</td>
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<tr>
<td>Quercus faginea</td>
<td>35</td>
<td>332.5</td>
<td>IV</td>
<td>2.54</td>
<td>IV</td>
<td>1.12 ± 0.0045</td>
<td>I</td>
<td>0.1 ± 0.0035</td>
<td>I</td>
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<tr>
<td>Q. ilex</td>
<td>35</td>
<td>656.6 ± 162.43</td>
<td>VII</td>
<td>3.43 ± 0.48</td>
<td>VI</td>
<td>2.79 ± 0.179</td>
<td>III</td>
<td>0.31 ± 0.0083</td>
<td>IV</td>
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<tr>
<td>Q. pubescens</td>
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<td>480.99 ± 61.35</td>
<td>V</td>
<td>2.98 ± 0.22</td>
<td>V</td>
<td>1.21 ± 0.192</td>
<td>II</td>
<td>0.1 ± 0.0103</td>
<td>I</td>
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<tr>
<td>Q. robur</td>
<td>15</td>
<td>260.37 ± 76.66</td>
<td>V</td>
<td>2.45 ± 0.12</td>
<td>IV</td>
<td>0.7 ± 0.171</td>
<td>I</td>
<td>0.06 ± 0.001</td>
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<td>Quercus suber</td>
<td>35</td>
<td>854.12 ± 87.2</td>
<td>IX</td>
<td>5.52 ± 0.62</td>
<td>V</td>
<td>2.09 ± 0.1795</td>
<td>III</td>
<td>0.23 ± 0.0201</td>
<td>I</td>
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<tr>
<td>Quercus trojana</td>
<td>15</td>
<td>159.36 ± 80.58</td>
<td>II</td>
<td>2.24 ± 0.08</td>
<td>IV</td>
<td>0.56 ± 0.1356</td>
<td>I</td>
<td>0.05 ± 0.0115</td>
<td>I</td>
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<tr>
<td>R. pseudoacacia</td>
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<td>474.66</td>
<td>V</td>
<td>2.65</td>
<td>V</td>
<td>1.16</td>
<td>I</td>
<td>0.1</td>
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<tr>
<td>Sorbus domestica</td>
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<td>189.59</td>
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<td>2.07</td>
<td>IV</td>
<td>1.01</td>
<td>I</td>
<td>0.09</td>
<td>I</td>
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</tbody>
</table>

Legend:
- **Boundaries-Temita**
  - Castel di Guido
  - Acer campestre
  - Acer negundo
  - Alnus cordifolia
  - Cerasus atlantica
  - Celtis australis
  - Ceratonia siliosa
  - Cercis siliquastrum
  - Carpinus sylvatica
  - Capparis sylvestris
  - Escallonia spp.
  - Fothergilla angustifolia
  - Fothergilla virgata
  - Juglans regia
  - Juglans nigra
  - Malus sylvestris
  - Pinus sylvestris
  - Pinus halepensis
  - Pinus pinaster
  - Populus nigra
  - Prunus avium
  - Pyrus amygdaliformis
  - Pyrus pyraster
  - Quercus cerris
  - Quercus faginea
  - Quercus ilex
  - Quercus pubescens
  - Quercus robur
  - Quercus suber
  - Quercus trojana
  - Robinia pseudoacacia
  - Sorbus domesitica
  - Sorbus torminalis

**Figure 1.** Map of the vegetation surveyed at the park of Castel di Guido, Rome. Map data 2020 Google.

Fares et al. ES&T 2020
Can we appreciate moderate drought effects on Monoterpene emissions from canopies?

Drought impact the energy balance: an increase in leaf temperatures lead to an emission of monoterpenes higher up to 20% in warm summer days.
EC VOC fluxes to determine canopy emission factors

Algorithms used in MEGAN: Model of Emissions of Gases and Aerosols from Nature

\[ F_{\text{gas}} = \text{BEF} \cdot b_1 \cdot \exp\left( b_2 \cdot (P_{24} - P_o) \right) \cdot (P_{24})^{0.6} \cdot \frac{[b_1 - b_2 \cdot \ln(P_{24})] \cdot \text{PAR}}{[1 + b_1 - b_2 \cdot \ln(P_{24})]^2 \cdot \text{PAR}^2} \cdot b_3 \cdot \exp\left( b_4 \cdot (T_{24} - 297) \right) \cdot b_5 \cdot \exp\left( b_6 \cdot (T_{24} - 297) \right) \cdot \exp\left( b_7 \cdot (T_{24} - 297) \right) \]

- New Basal Emission factors calculated for key Mediterranean ecosystems in Castelporziano were used to run MEGAN for estimating BVOC emissions in central Italy form the main plant functional types coupled with a Comunity Land Model developed at the NCAR

- The global model run with realistic BEF from prevailing MT emitting species predicted lower concentrations of tropospheric ozone compared with an isoprene emitting scenario used in the previous MEGAN version.
Integration of vegetation maps & national forest inventories: Emission Factor attribution for a realistic estimate

Do we have enough information on BEF? Is it still worth measuring BEF at leaf/ecosystem scale?

**Emissions in Italy**
Can we estimate ozone damage to vegetation using continuous EC field measurements?

Case studies on Pinus ponderosa forest, an orange orchard, and a mixed Mediterranean forest
Stomatal ozone fluxes (green line) correlate with GPP better than total ozone fluxes (blue line)
At increasing ground levels of ozone, the slope between GPP and stomatal ozone deposition decreases.

Blodgett

Lindcove

Photosynthesis uncoupling from stomatal conductance ay high levels of O3 concentrations

The FREQUENCY domain: Usage of Wavelet coherence analysis to highlight regions of significant temporal correlations in a pine forest

Temporal correlation between GPP (residuals), ozone concentration and stomatal ozone flux exists

High correlation at daily scale (period ~ 1) was observed

At the higher GPP we often do not reach the highest covariance between GPP and stomatal ozone deposition...

Correlations between ozone concentration and GPP

Correlations between stomatal ozone deposition and GPP

Fares et al. GCB 2013
Can we predict GPP using multiple regression linear and non-linear models?

Multiple regression linear model:  \( \text{GPP} = b_1P + b_2Q + b_3R + \ldots + b_nN \)

### Case 1

<table>
<thead>
<tr>
<th>Predicators</th>
<th>Beta</th>
<th>multiple R&lt;sup&gt;2&lt;/sup&gt;</th>
<th>F</th>
<th>Total Beta</th>
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<tbody>
<tr>
<td>PAR (umol m&lt;sup&gt;-2&lt;/sup&gt; s&lt;sup&gt;-1&lt;/sup&gt;)</td>
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<td>0.489</td>
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<tr>
<td>VPD (kpa)</td>
<td>0.457</td>
<td>0.492</td>
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<td>0.493</td>
<td>0.156</td>
<td>299.663</td>
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<tr>
<td>Ta (°C)</td>
<td>-0.350</td>
<td>0.499</td>
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<td>-0.236</td>
<td>0.162</td>
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<td>Soil moisture (%)</td>
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<td>0.502</td>
<td>320.310</td>
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<td>0.163</td>
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**R-square** 0.5, **slope** 0.86, **df** 48399, **F** 211

### Case 2

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<td>PAR (umol m&lt;sup&gt;-2&lt;/sup&gt; s&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>-0.308</td>
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<tr>
<td>Soil moisture (%)</td>
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<td>0.546</td>
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<td>0.234</td>
<td>440.230</td>
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<td>VPD (kpa)</td>
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**R-square** 0.25, **slope** 0.76, **df** 4338, **F** 267

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**R-square** 0.25, **slope** 0.76, **df** 4338, **F** 267

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**R-square** 0.25, **slope** 0.76, **df** 4338, **F** 267

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Stomatal ozone deposition explains better than ozone concentration GPP decrease!
Statistical analysis to estimate ozone effects on GPP

Random Forest Analysis of the effects on GPP at three Mediterranean-type ecosystems: Pinus ponderosa, Citrus sinensis, Quercus ilex

Long-term continuous eddy-covariance measurements (>9 years at 30 min resolution) at three Mediterranean-type sites showed that Up to 12–19% of the carbon assimilation reduction is explained by higher stomatal ozone flux!
Long-term measurements may support the training and application of Neural Network analysis.

A more conservative estimate of ozone-induced GPP reduction was found: 2%.
Refining new metrics for ozone-risk assessment with EC data, is it possible?

Evaluation of reducing factors for Photosynthesis and stomatal conductance $F_{pO3}$ e $F_{cO3}$

Ball, Woodrow & Berry (1987) model nested in the AIRTREE model:

$$g_s = g_0 + m \frac{A_n \times RH}{C_s}$$

$$A_n = A_n \times F_{pO3}$$

$$g_s = g_s \times F_{cO3}$$

$$F_{GSO3} = a_{Gs} \times POD_Y + b_{gs}$$

$$F_{AO3} = a_{A} \times POD_Y + b_{A}$$

$$POD = CEO_3 \times gs \times K_{O3} \times 3600 \times 10^{-6}$$

$$CEO_3 = [O_3] \times H \times D$$

Where $a$ and $b$ are slope and intercept of the regression line between CUO and $g_s$ and $A_n$, respectively. $CEO_3$ is the cumulative ozone concentration (i.e. SUM00, AOT00 etc.).

- POD 3 to 5 works best for Holm oak (ozone resistant).
- POD 0-1 works best for Pinus Ponderosa (ozone sensitive).

5 to 10% reducion of GPP by ozone!

Fares et al. STOTEN 2019
Thanks for your attention!