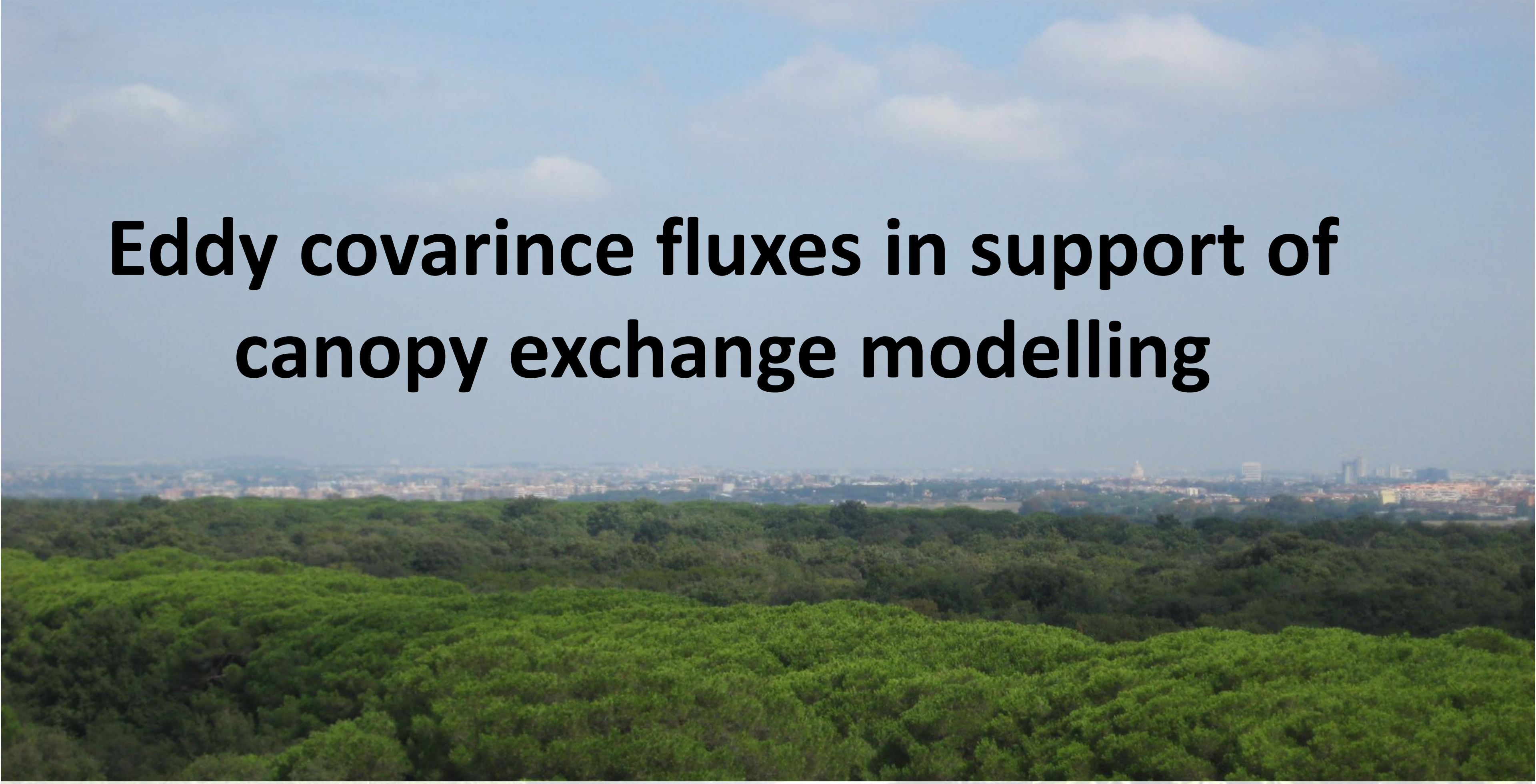


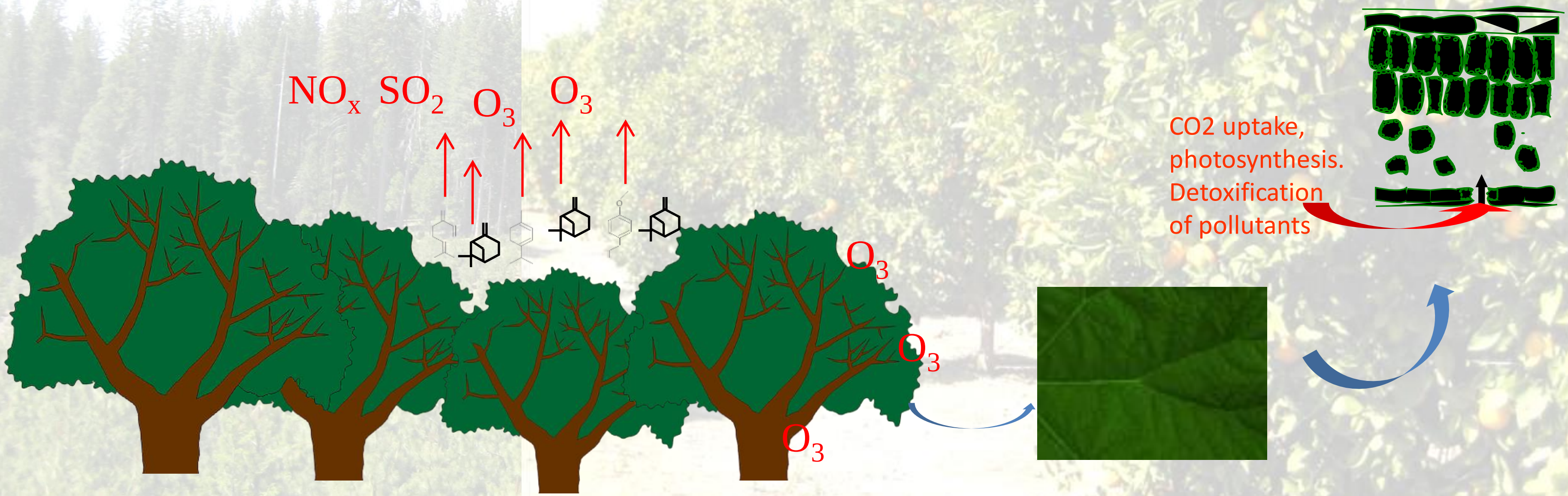
Eddy covarince fluxes in support of canopy exchange modelling

Silvano Fares
National Research Council – Institute of Bioeconomy, Rome, Italy.

FLUXNET seminar, 30/11/2020

Relevance of plants for CO2 and atmospheric pollutant removal

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

"Non-stomatal uptake"

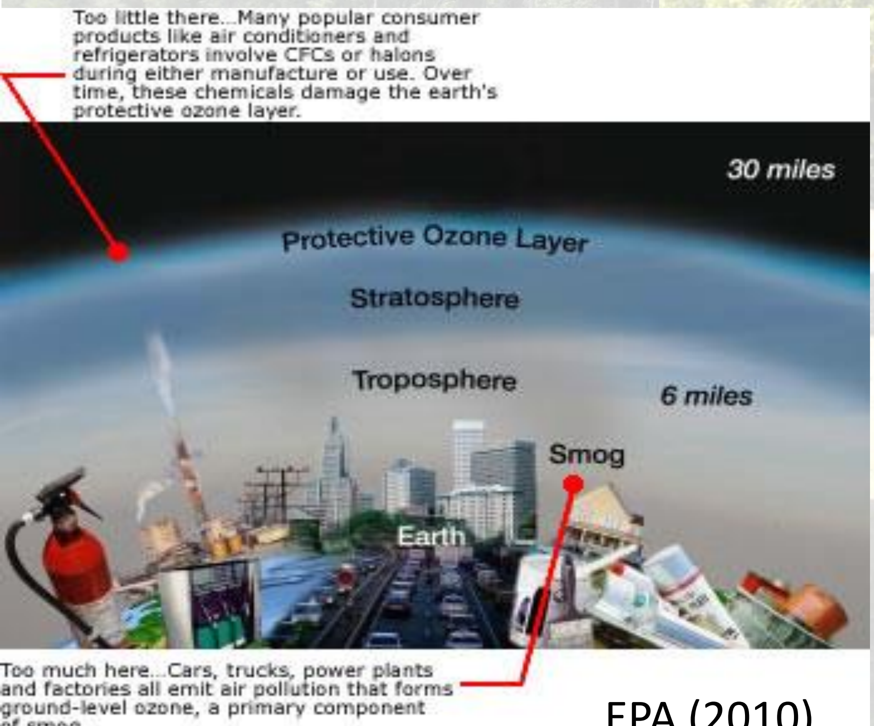
Ozone in low troposphere: an increasing threat for plants

Ozone in the stratosphere is GOOD!

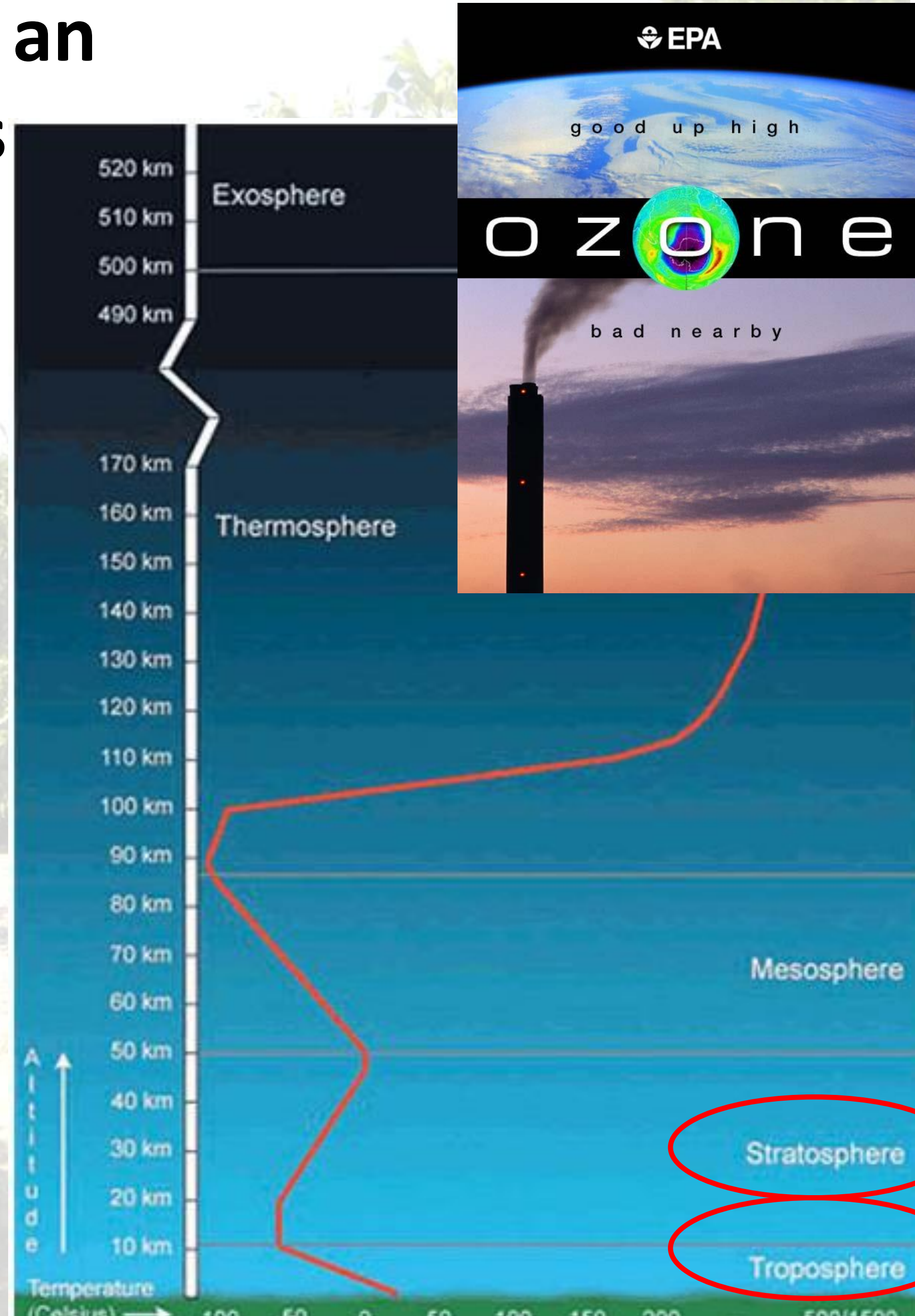
protects life on Earth from the sun's harmful ultraviolet (UV) rays

Ozone in the troposphere is BAD!

Damages humans and plants, greenhouse gas

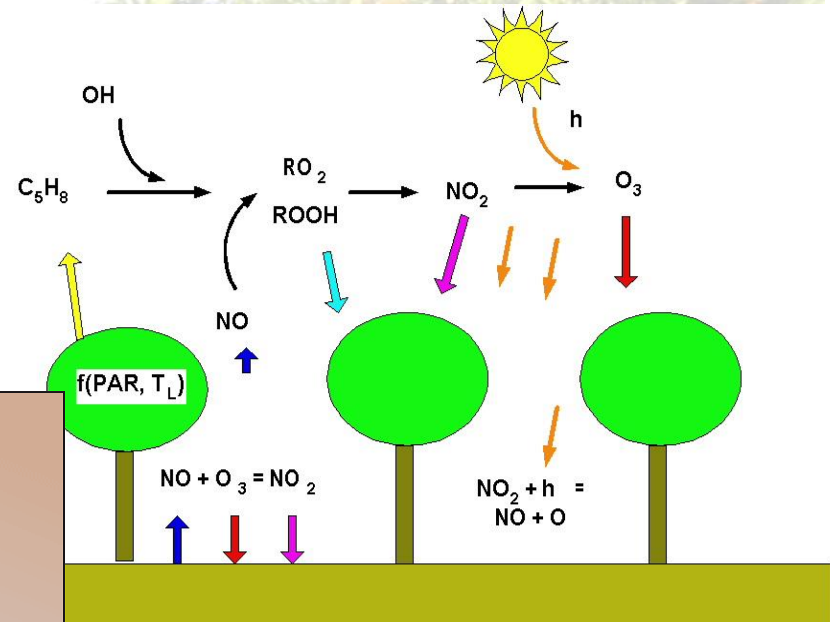


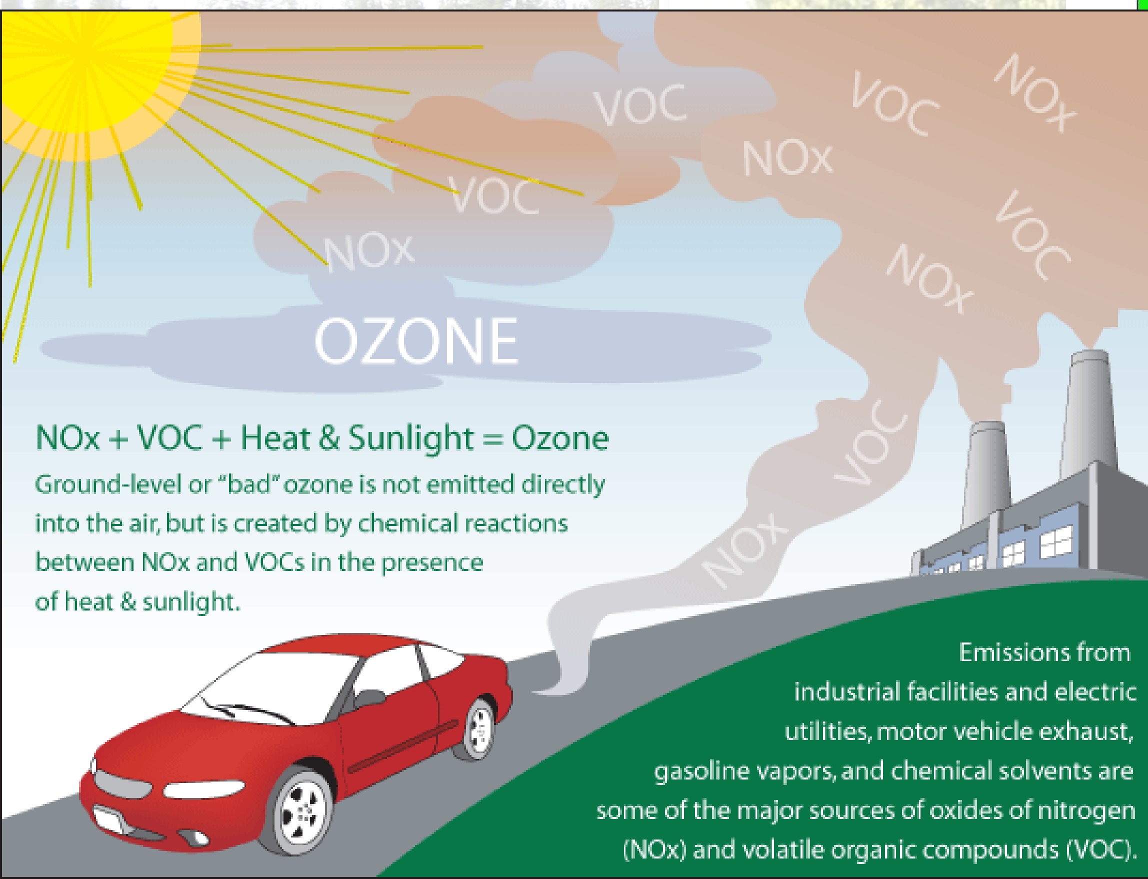
EPA (2010)

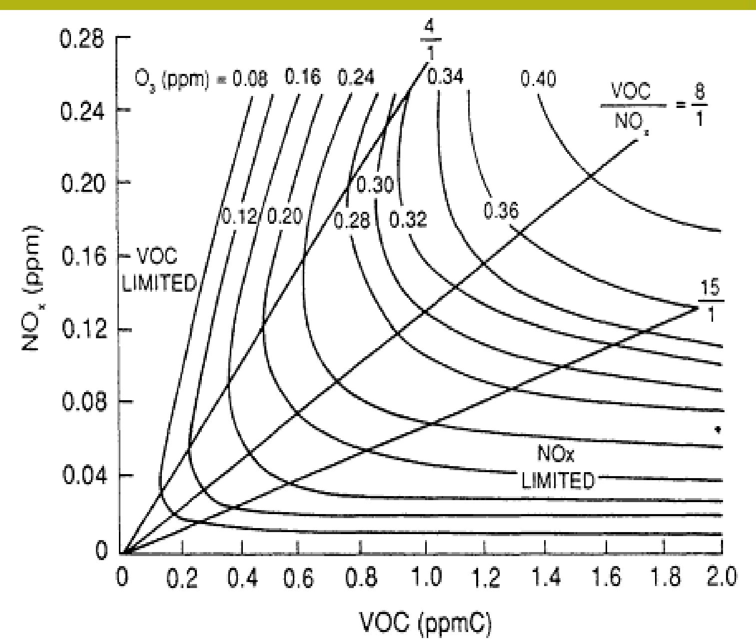


Ozone formation in the troposphere

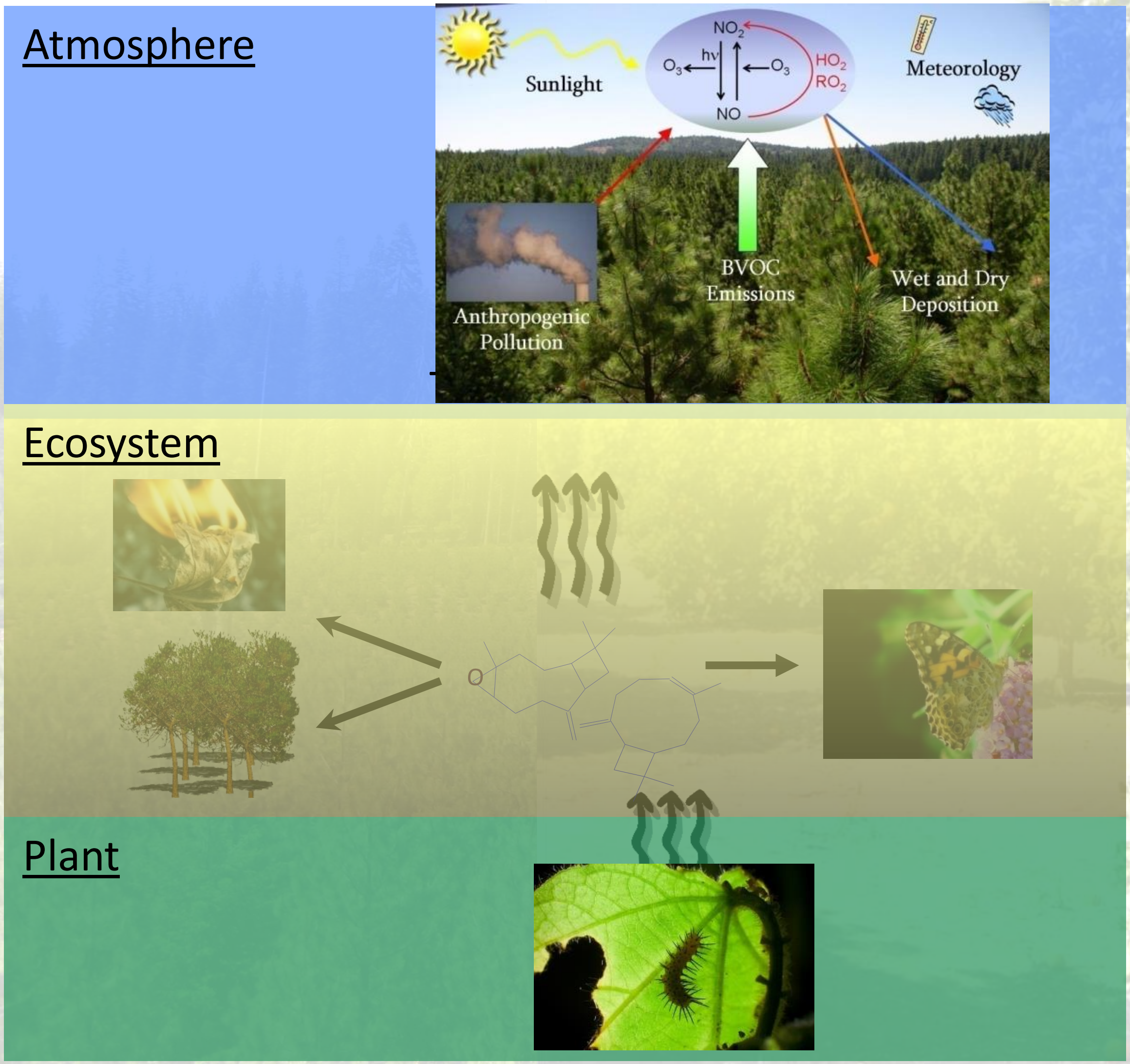
O_3 formation is caused by photolytic reactions in wich NO_2 VOC and OH radicals take part







Plants interact with the ecosystem using BVOC



- Key component in the biosphere-atmosphere interactions.

Sunlight

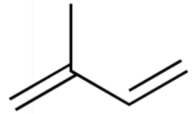
VOC + NOx ⟶ Ozone

- Affect other plants and organism
- Favour the ecosystem perturbation
- Play an additional or alternative role in plant defences

Types of Biogenic VOC

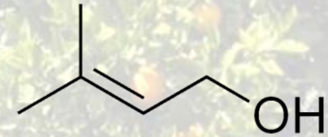
- Hemiterpenoids → C_5, only a few produced naturally
  - Isoprene

    (C_5H_8, alkene)

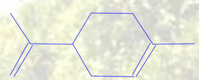
    

  - Methylbutenol

    ($C_5H_{10}O$, alcohol)

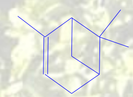
    

- Monoterpenoids → C_{10}, thousands of different structures
  - Limonene

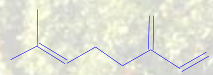
  - α- pinene

    (alkene)

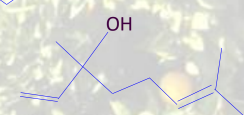
  - myrcene

    (alkene)

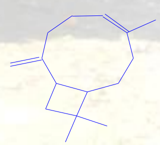
    

  - linalool

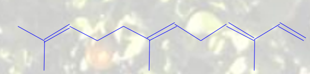
    (alcohols)

- Sesquiterpenoids → C_{15}, most varied class of terpenoids
  - ß-caryophyllene

  - farnesene

- **Isoprene (C_5H_8)**
- **Monoterpenes ($C_{10}H_{16}$)**
- **Oxygenated VOC**
- **Sesquiterpenes ($C_{15}H_{24}$)**

Biogenic emission of VOC is about 10 times higher than anthropogenic emissions globally!

BVOC

Isoprene C_5H_8

Monoterpene $C_{10}H_{16}$

Sesquiterpenes $C_{15}H_{24}$

AVOC

Industrial processes

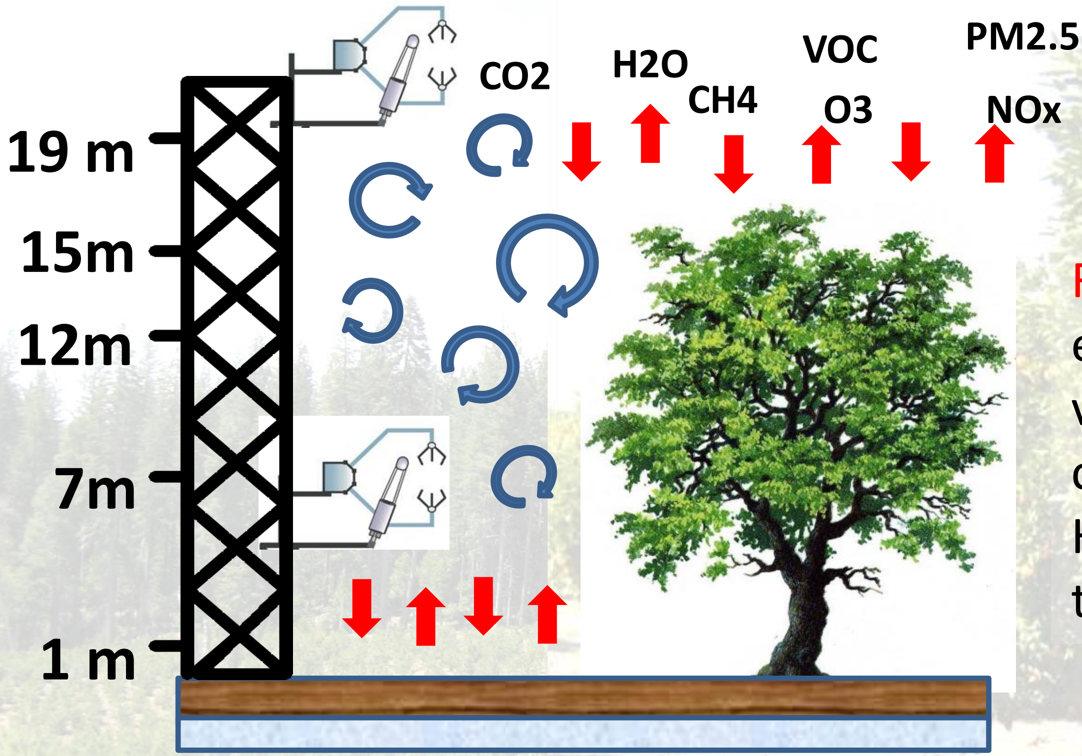
Biomass burning

Animal husbandry

Vehicular traffic

Mining, energy production

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, CO_2, H_2O), with observations 10 times per second

$$\Phi_x = \overline{w' X'}$$

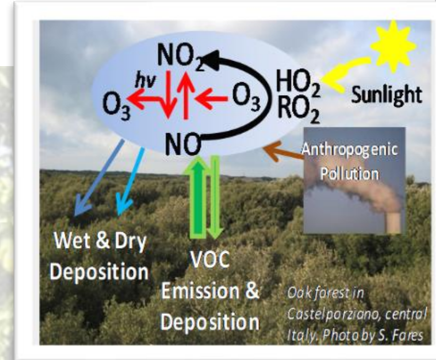
CO2 flux: Subtracting modelled ecosistem respiration to the Net Ecosystem Exchange (NEE) , Gross Primary Productivity (GPP) is calculated

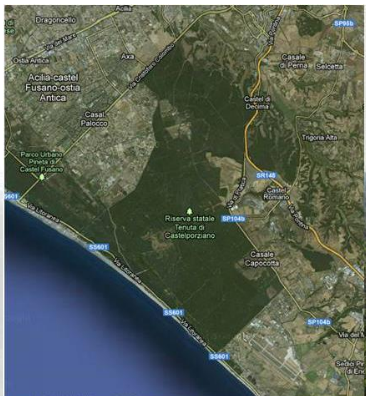
Water flux: Stomatal conductance is calculated from measured transpiration by inversion of Monteith equation, therefore an estimate of stomatal ozone fluxes is possible

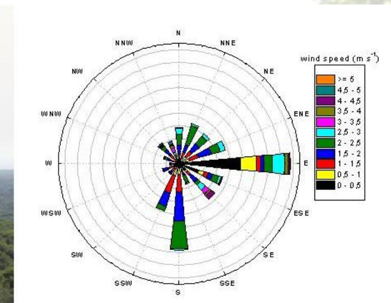
Ozone fluxes: sum of stomatal and non stomatal components

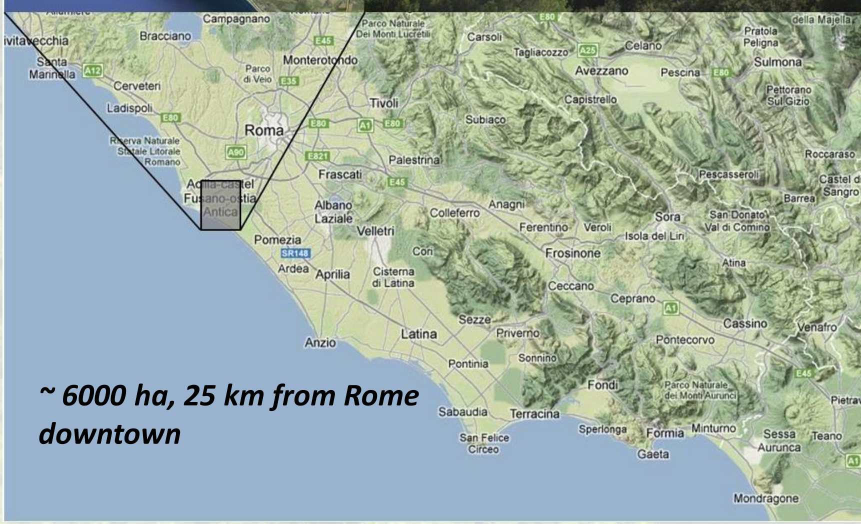
Case studies: the Holm oak urban forest in Castelporziano, Rome

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



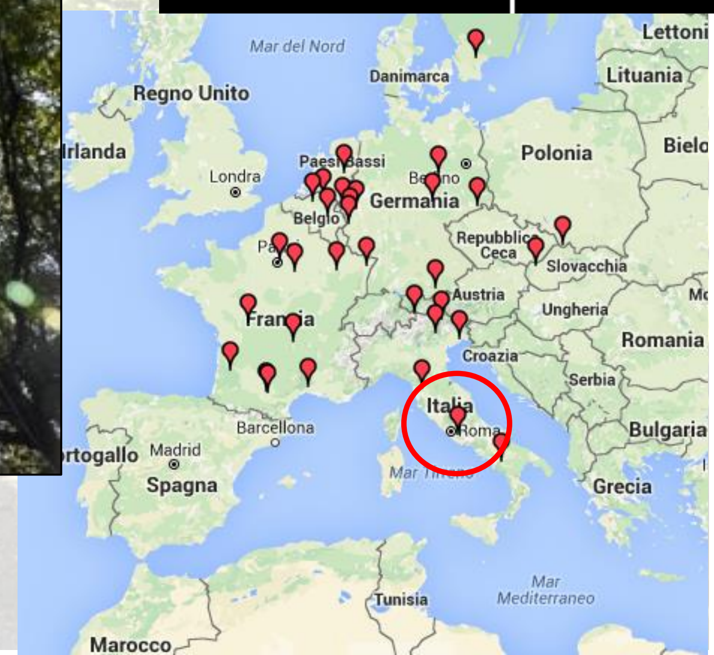






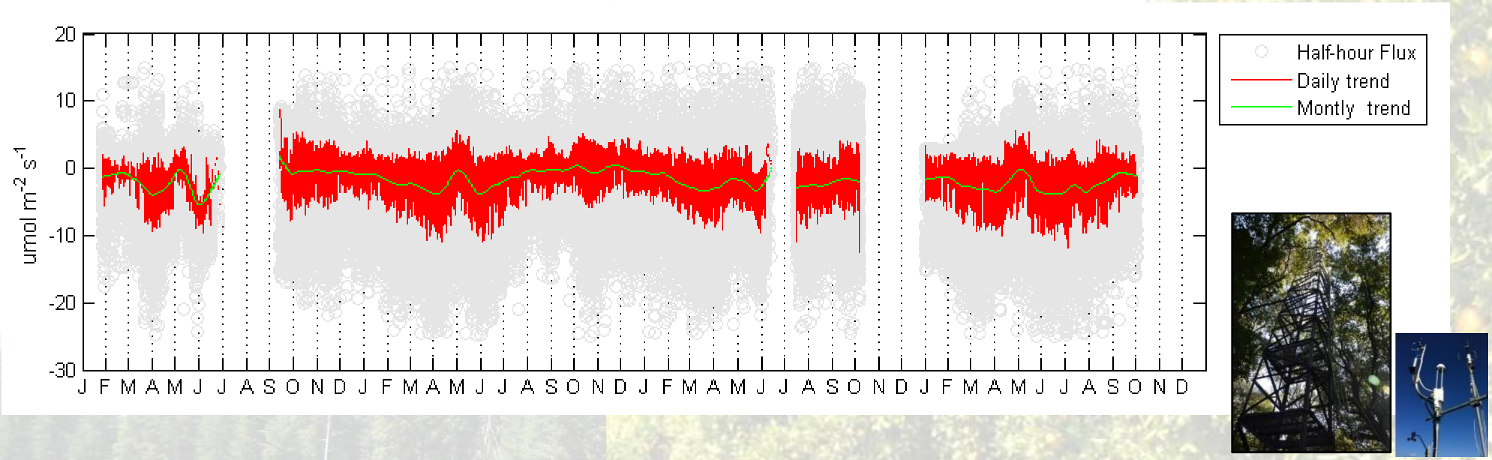
~ 6000 ha, 25 km from Rome downtown

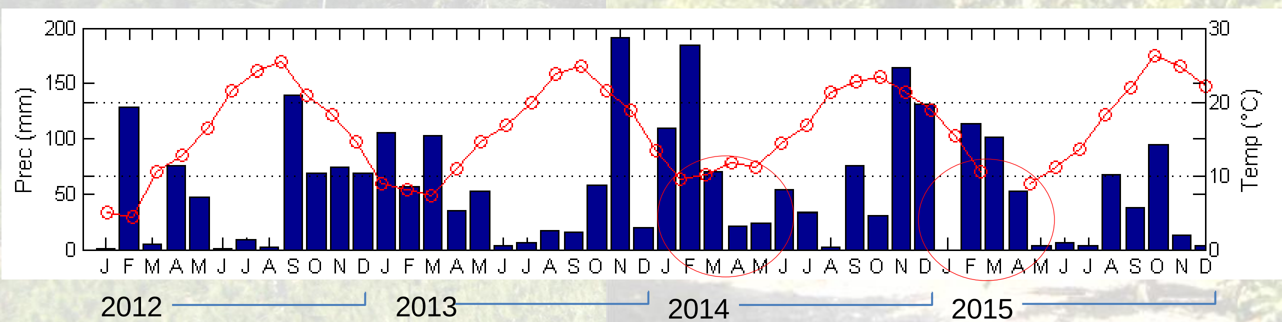
ICOS INTEGRATED CARBON OBSERVATION SYSTEM

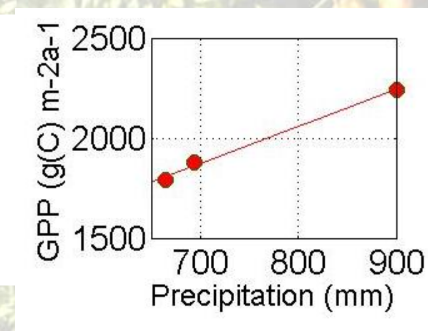


https://www.icos-cp.eu/icoscapes/castelporziano

Wet years in Castelporziano = higher GPP

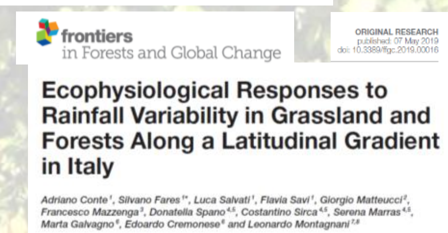






Circa 600 g CO2 m-2 per anno rimossi dal bosco in anni con scarsa precipitazione, quasi il doppio nel 2014!

- **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.)**

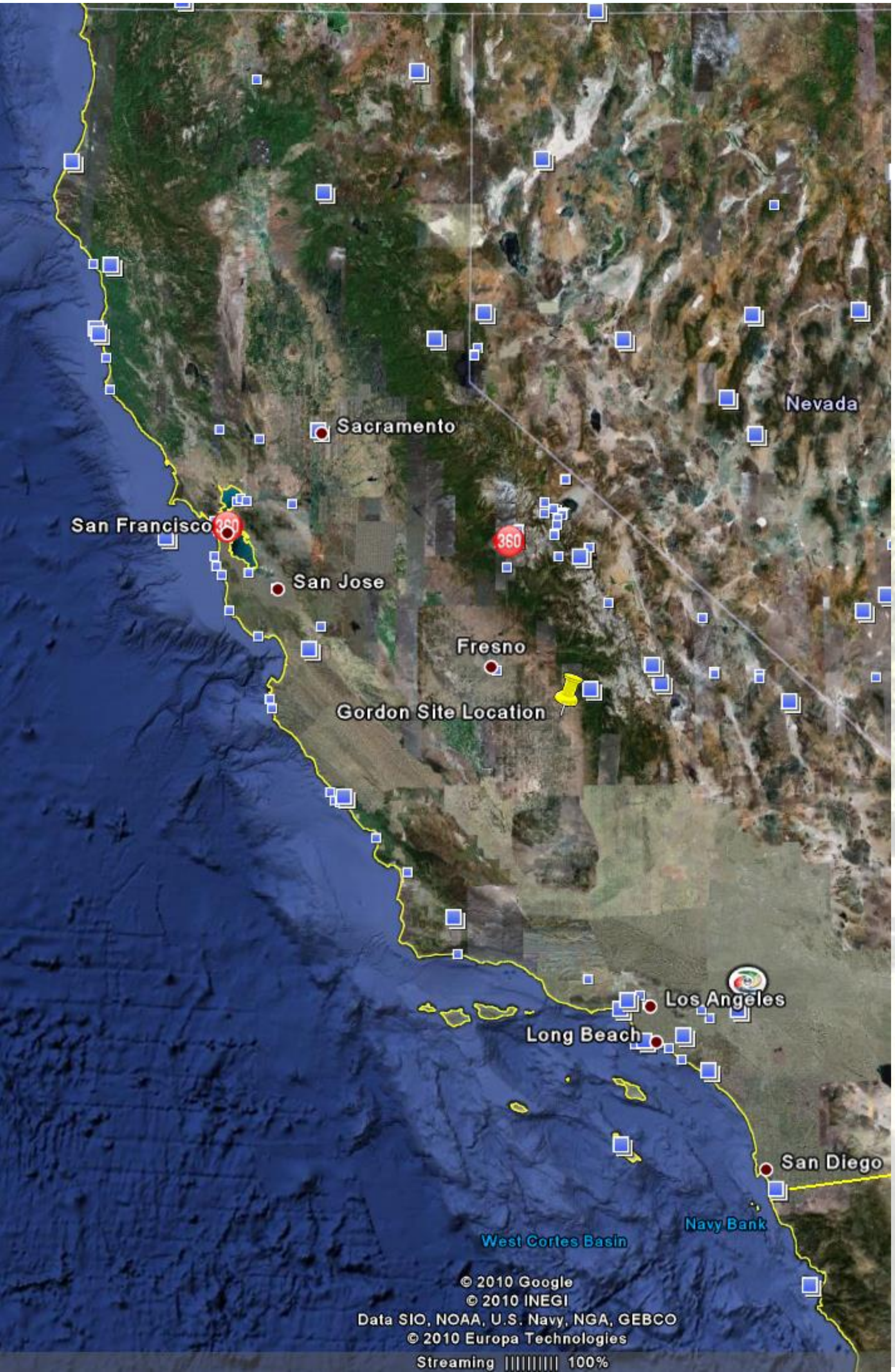


frontiers in Forests and Global Change

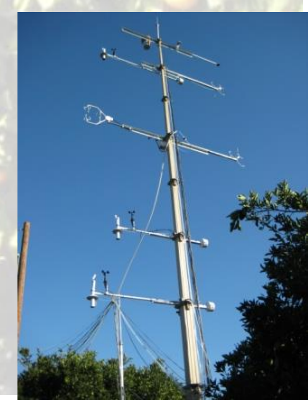
ORIGINAL RESEARCH
published: 07 May 2019
doi: 10.3389/ffgc.2019.00016

Ecophysiological Responses to Rainfall Variability in Grassland and Forests Along a Latitudinal Gradient in Italy

Adriano Conte[1], Silvano Fares[1*], Luca Salvati[1], Flavia Savi[1], Giorgio Matteucci[2], Francesco Mazzenga[3], Donatella Spano[4,5], Costantino Sirca[4,5], Serena Marras[4,5], Marta Galvagno[6], Edoardo Cremonese[6] and Leonardo Montagnani[7,8]



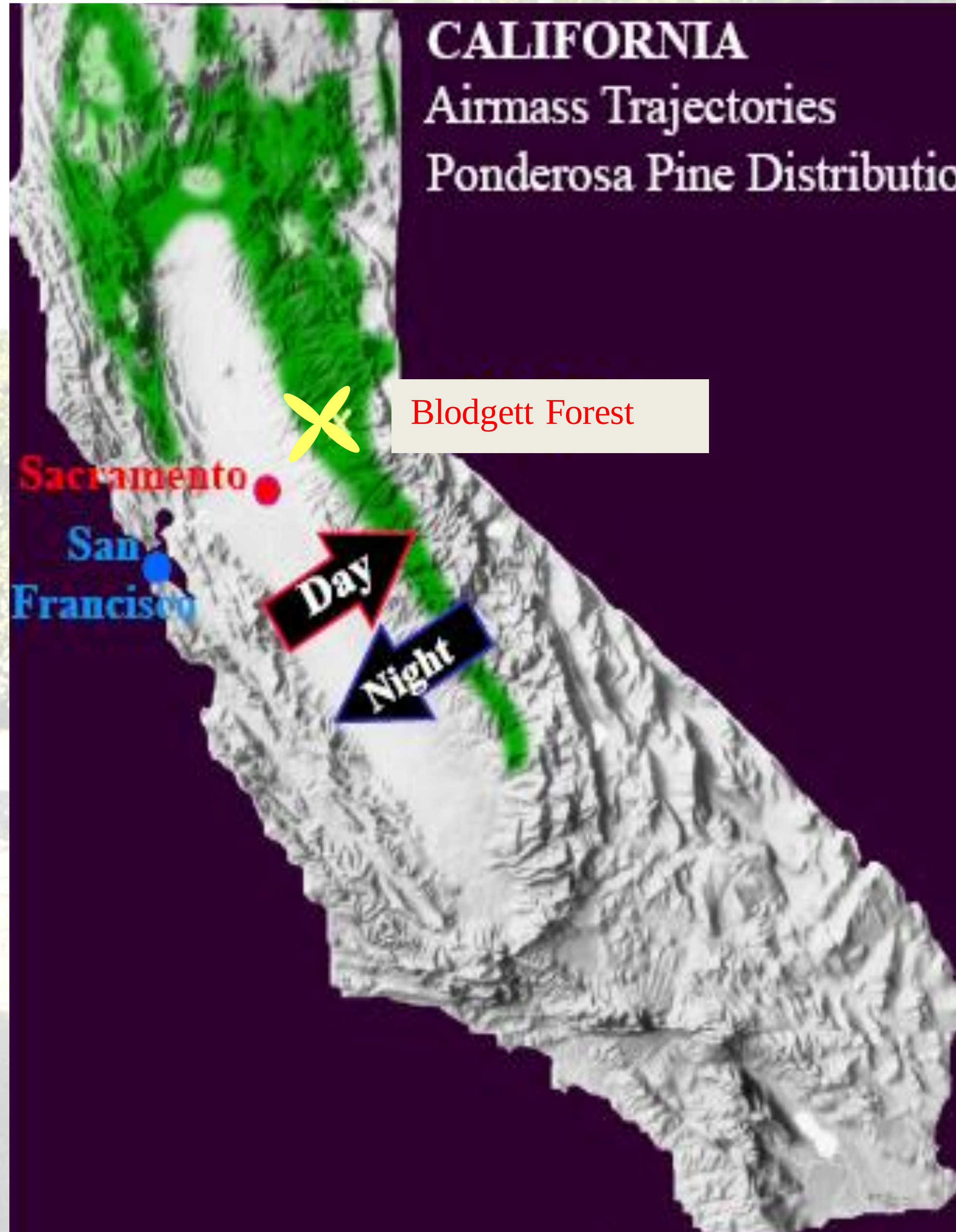
field measurements in Exeter(Central valley, CA)



Long term field measurements in Blodgett Forest

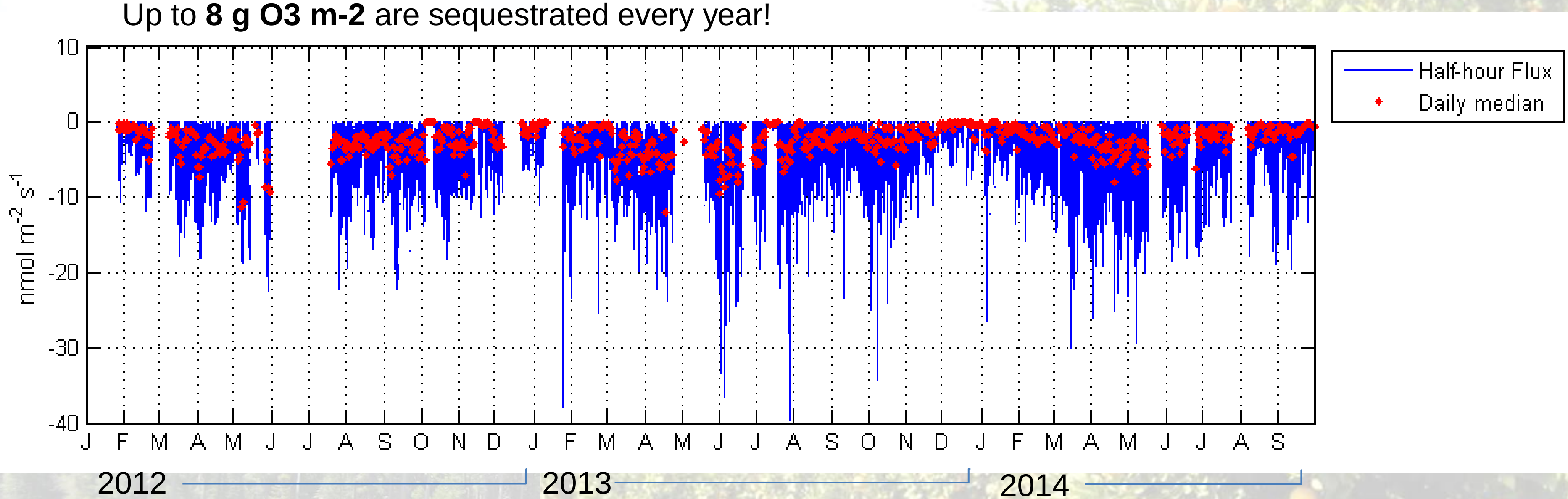
Through a multiyear analysis (2001-2006), we observed different sinks of ozone uptake, elucidating their dependence on plant physiology and environmental conditions


Blodgett Forest, Ameriflux site (38°53’42.9’’N, 120°37’57.9’’W) 1315 m a. s. l., Sierra Nevada Mountains of California

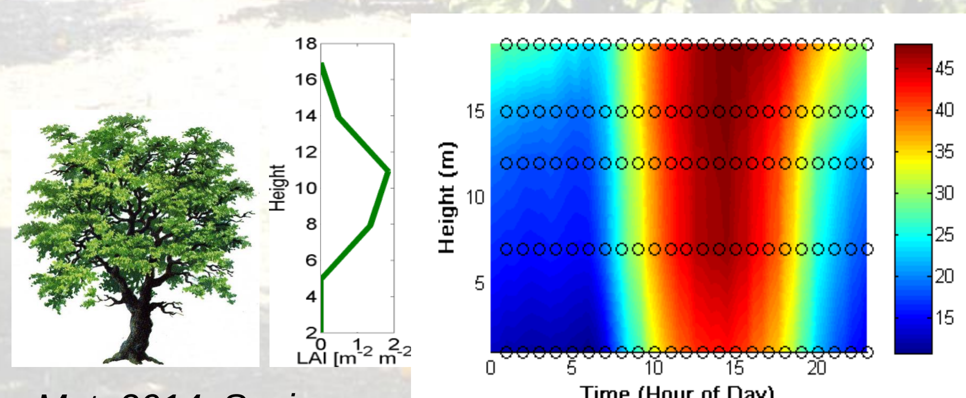


The Hom Oak is a relevant O3 sink

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



Atmospheric O3 concentration gradient from the soil to above the canopy



Fares et al. Atm. Env. 2013; Fares et al. Agr. For. Met. 2014; Savi et al. 2014; Fares et al. Env. Sci. Poll. Res. 2017

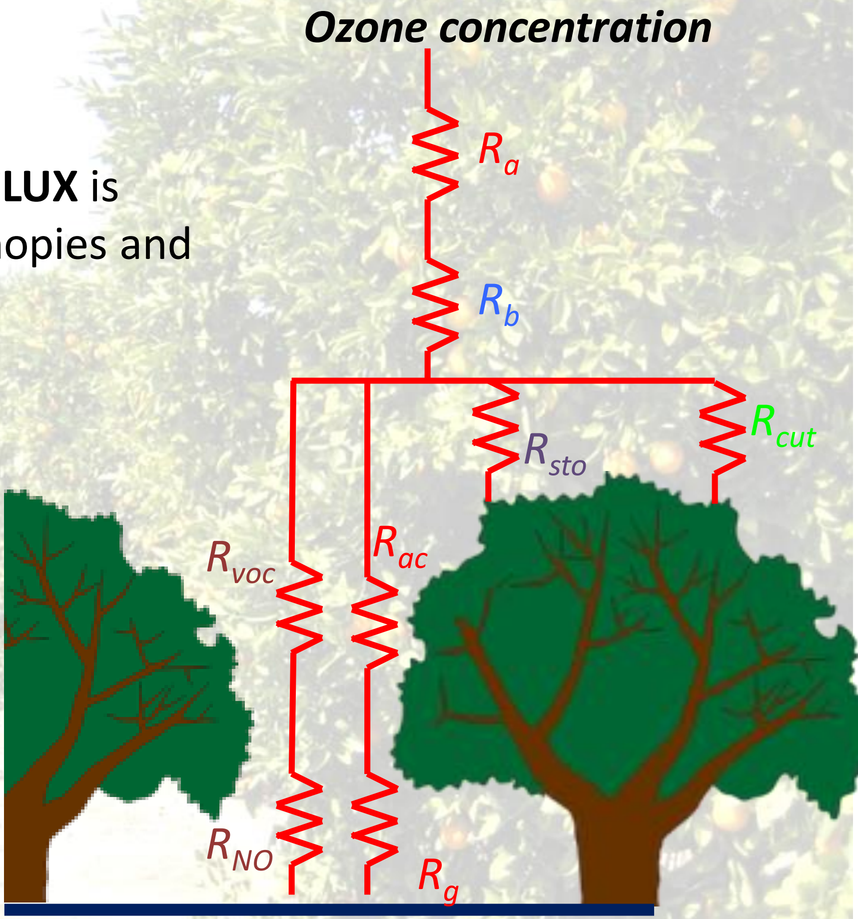
Ozone flux partitioned between stomatal and non-stomatal sinks

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.

$$F_{O3} = F_{O3sto} + F_{O3nsto} = \frac{[O_3]}{R_{sto}} + \frac{[O_3]}{\Sigma R_{nsto}}$$

$$F_{O3sto} = G_{sto} * [O_3]$$

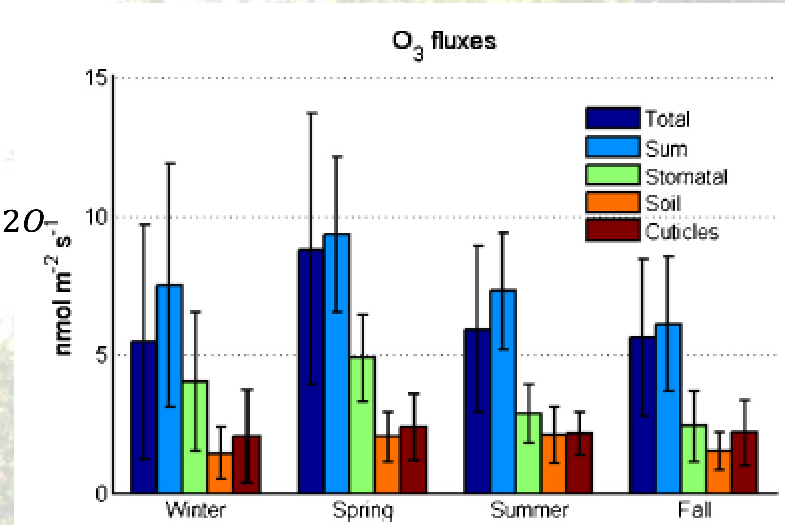


O_3 sink partitoning: stomata are the main sink

- Evaporative/resisitve method for the stomatal component:

$$O_3sto = [O_3]\ canopy \cdot 0.61 \cdot G_{sto,H2O}$$

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



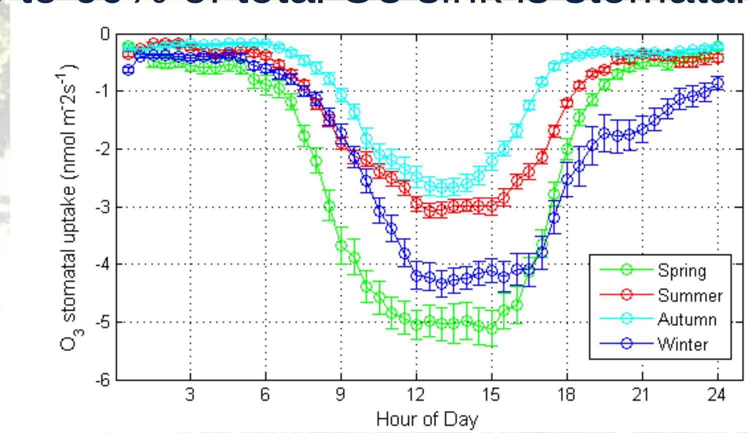
- Soil sink:

(Zhang et al., 2002)

$$R_{ac} = \frac{14 \times \mathrm{LAI} \times z_c}{u*}$$

$$R_g = R_{g1} + R_{g2} \cdot \frac{\mathrm{SWC10}}{\mathrm{SWC_{fc}}}$$

Up to 60% of total O3 sink is stomatal.



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

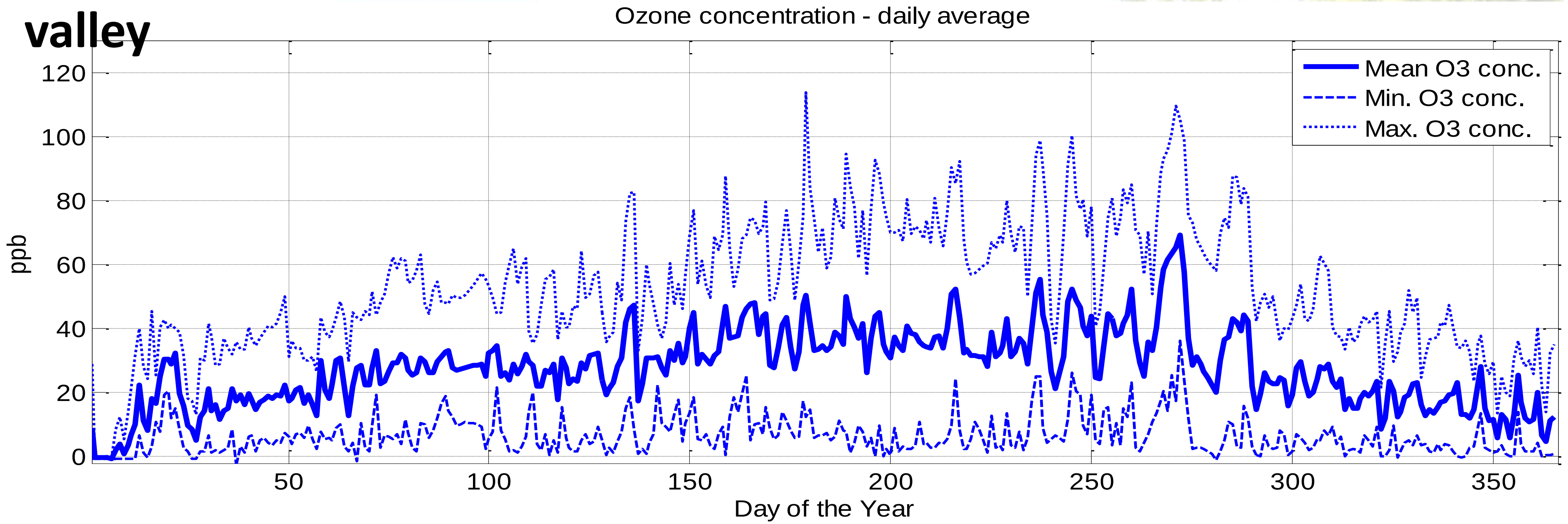
- Cuticoles:

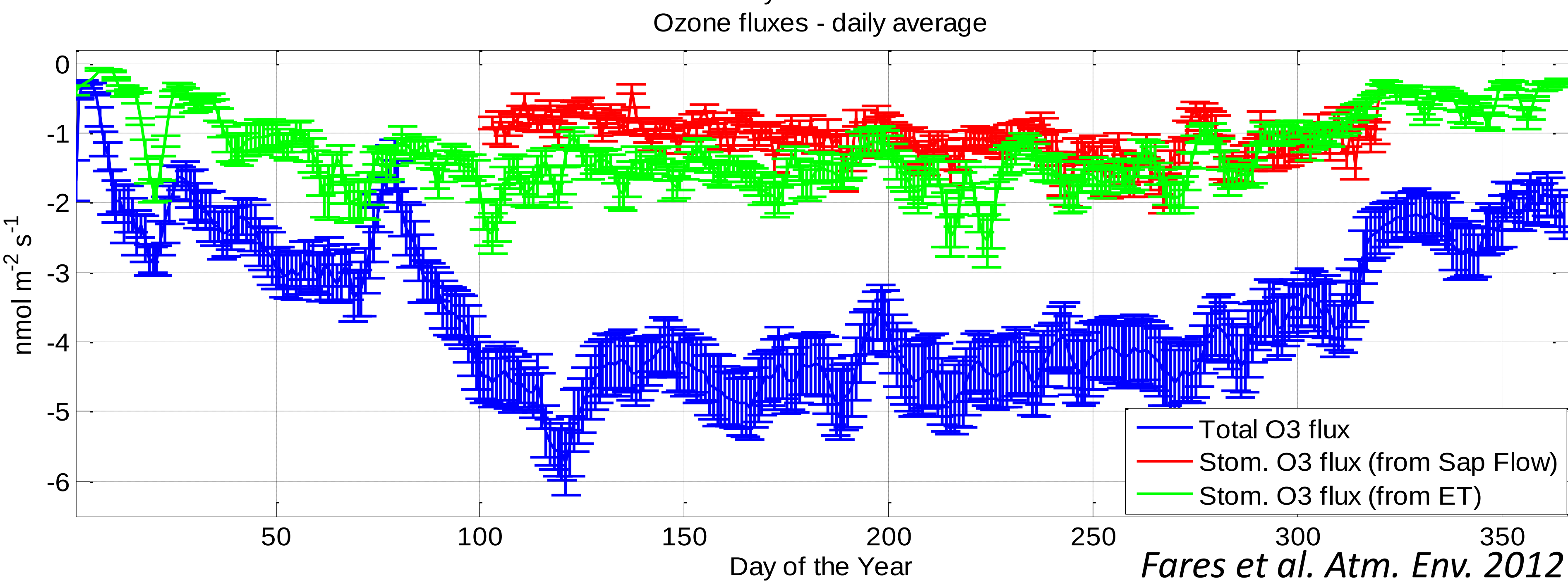
(Zhang et al., 2002)

$$R_{cut(dry)} = \frac{R_{cut(dry)0}}{e^{0.03RH} \times \mathrm{LAI}^{1/4} \times u*}$$

$$R_{cut(wet)} = \frac{R_{cut(wet)0}}{\mathrm{LAI}^{1/2} \times u*}$$

Dramatic levels of tropospheric ozone concentrations in the central valley

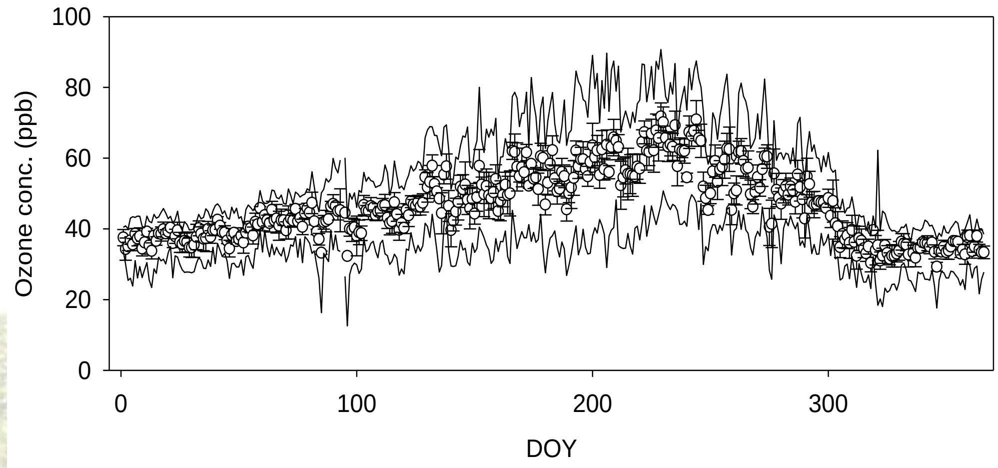




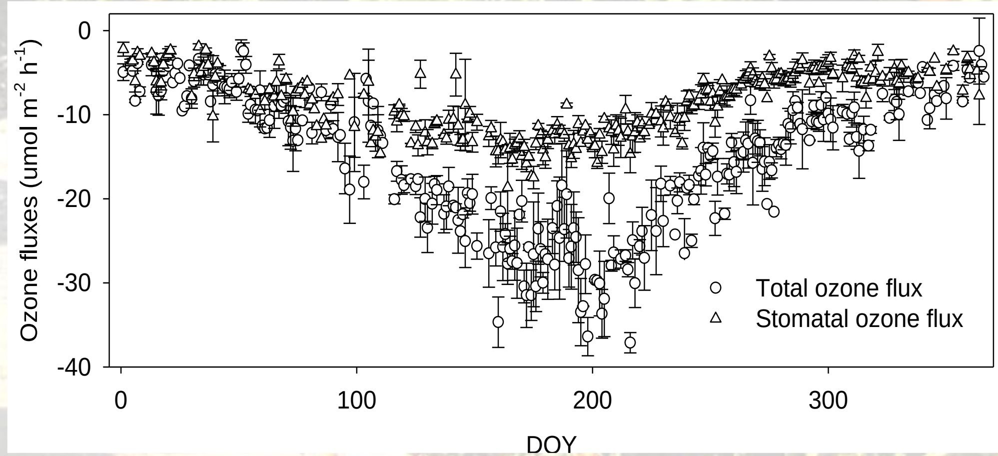
Fares et al. Atm. Env. 2012

Daily ozone concentration & fluxes at Blodgett

The daily ozone concentrations showed maximum diurnal peaks above 90 ppb!

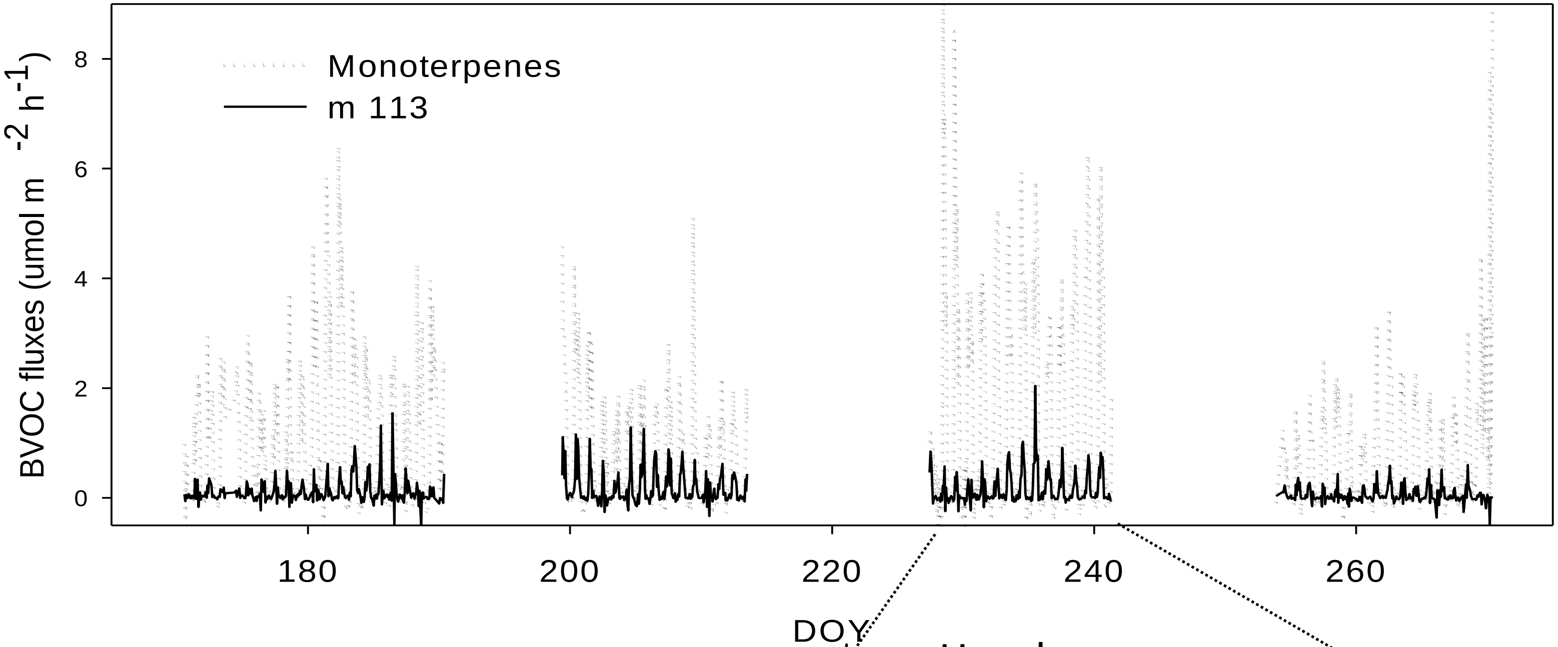


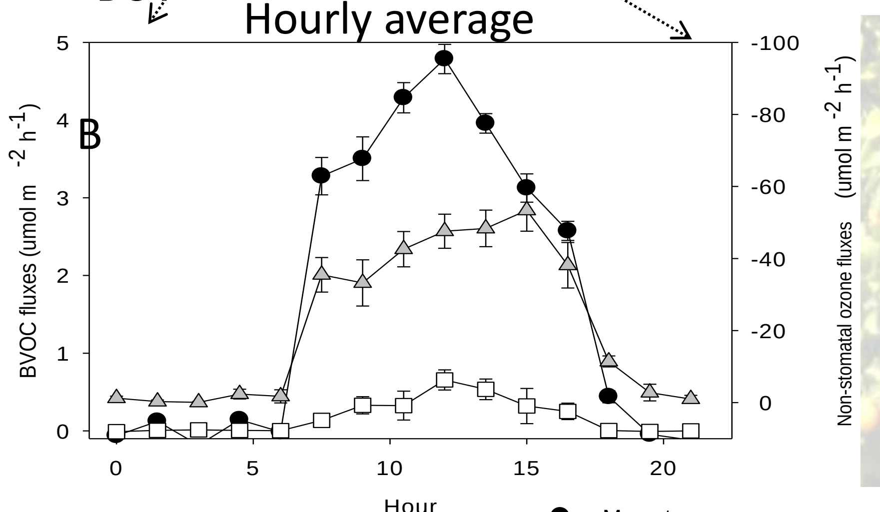
Stomata represented a significant sink of ozone for this ecosystem, but not the major sink, similarly to Citrus site!



Fares et al. Agr. For. Met. 2010

Evidence of non-stomatal ozone removal at Blodgett:





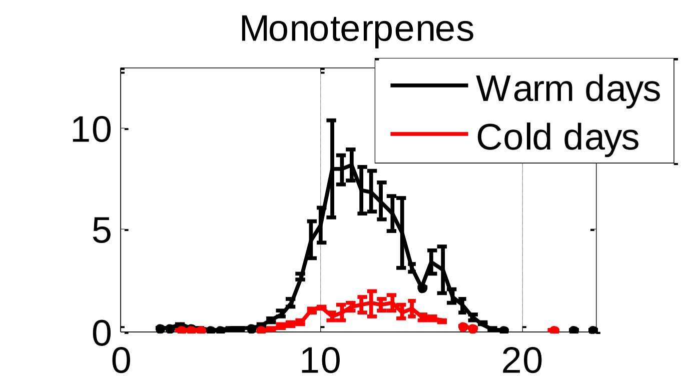
Non-stomatal ozone fluxes peak during the day in coincidence with monoterpene fluxes and the fluxes of the oxidation products of monoterpenes (m113)!

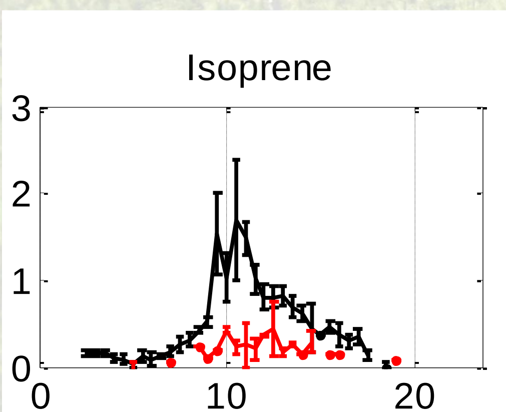
We calculated that up to 40 % of ozone uptake is due to BVOC!

(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

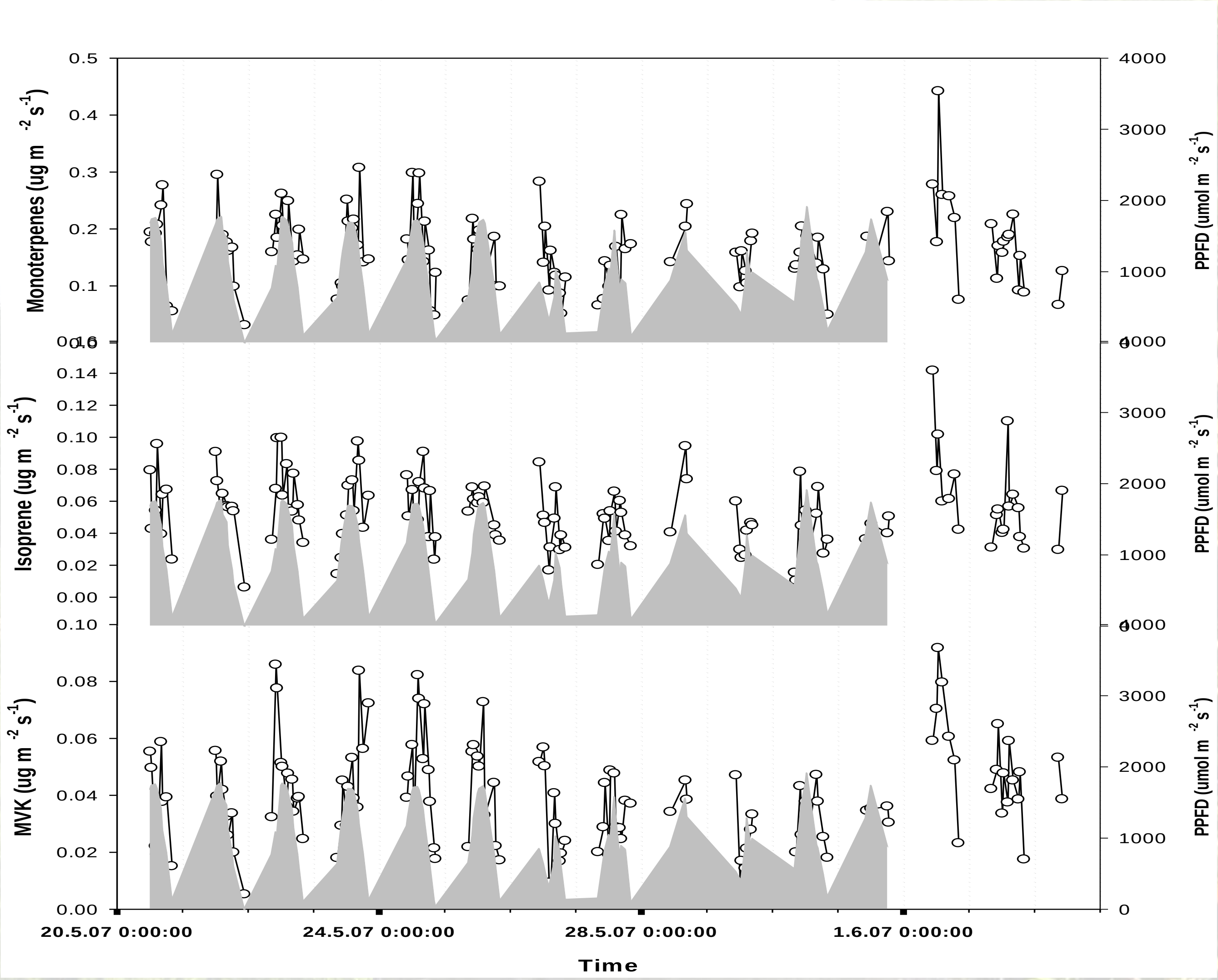
Holm Oak is a predominant Monoterpene emitter





Deployment of PTRMS to the field site

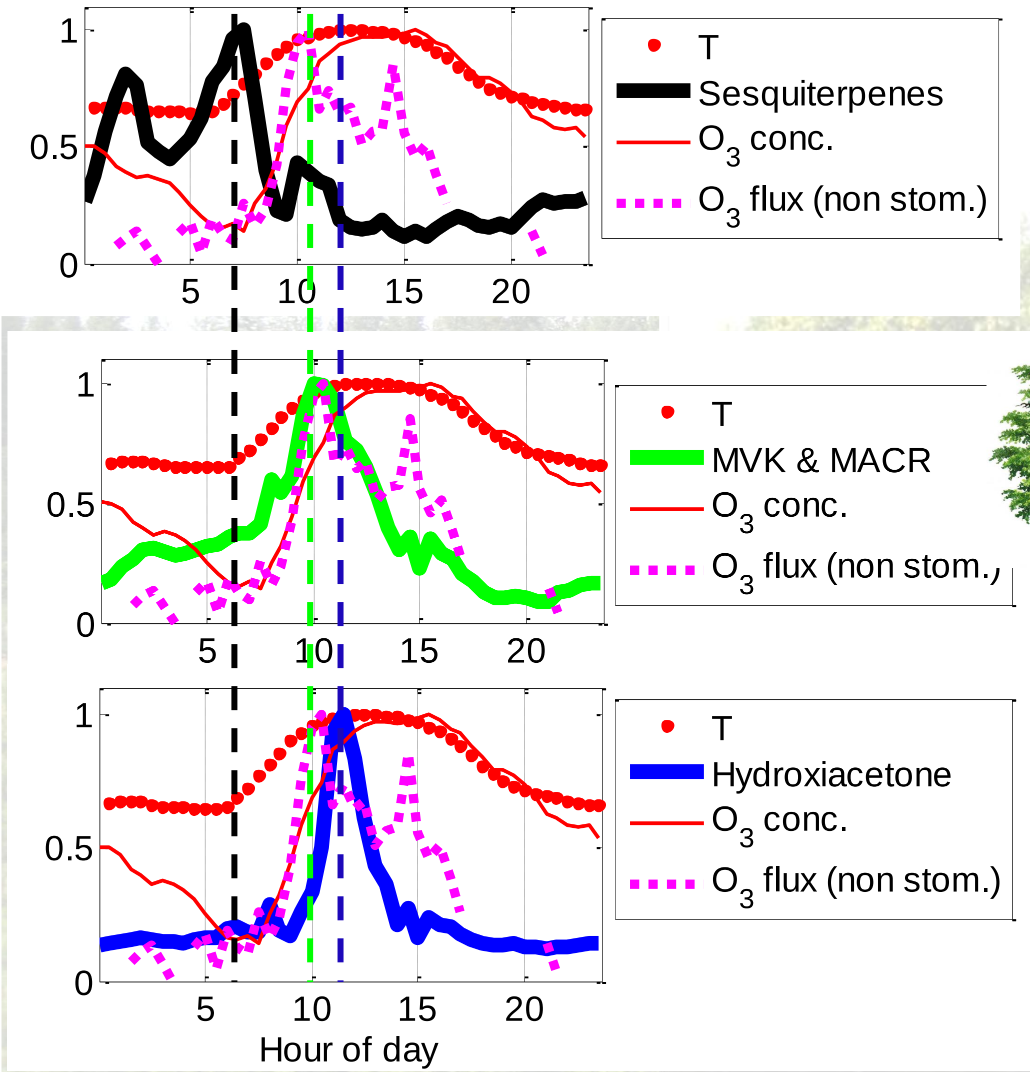
Back in 2007 in a dune ecosystem: Clear diurnal fluxes of isoprene, monoterpenes and of Methyil Vinyl Chetone (MVK), one of the main oxidation products of isoprene

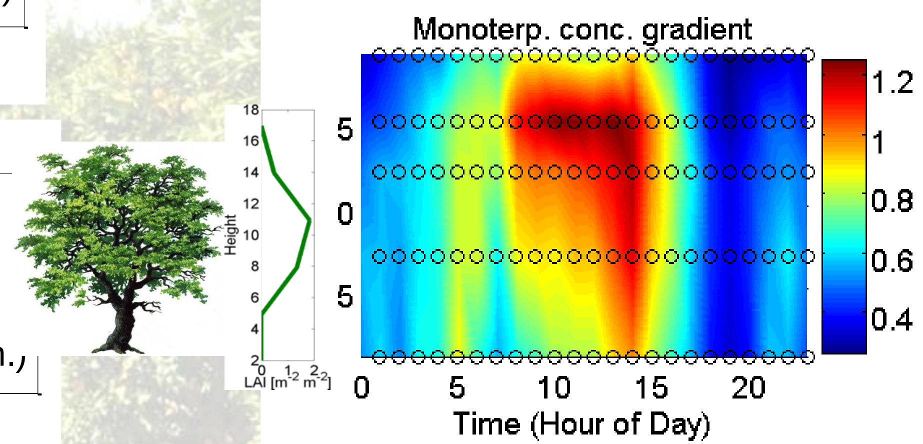


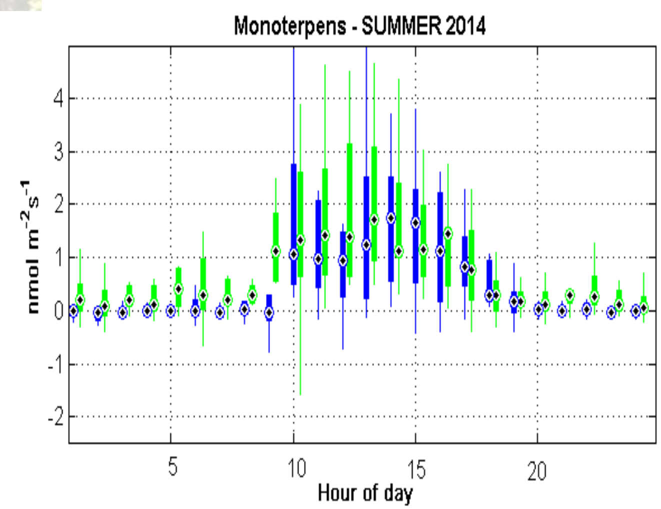
Davison et al. Biogeos. 2009; Fares et al. Biogeos. 2009

Evidences of Ozone – scavenging by VOC

Norm. concentrations and meteor. variables



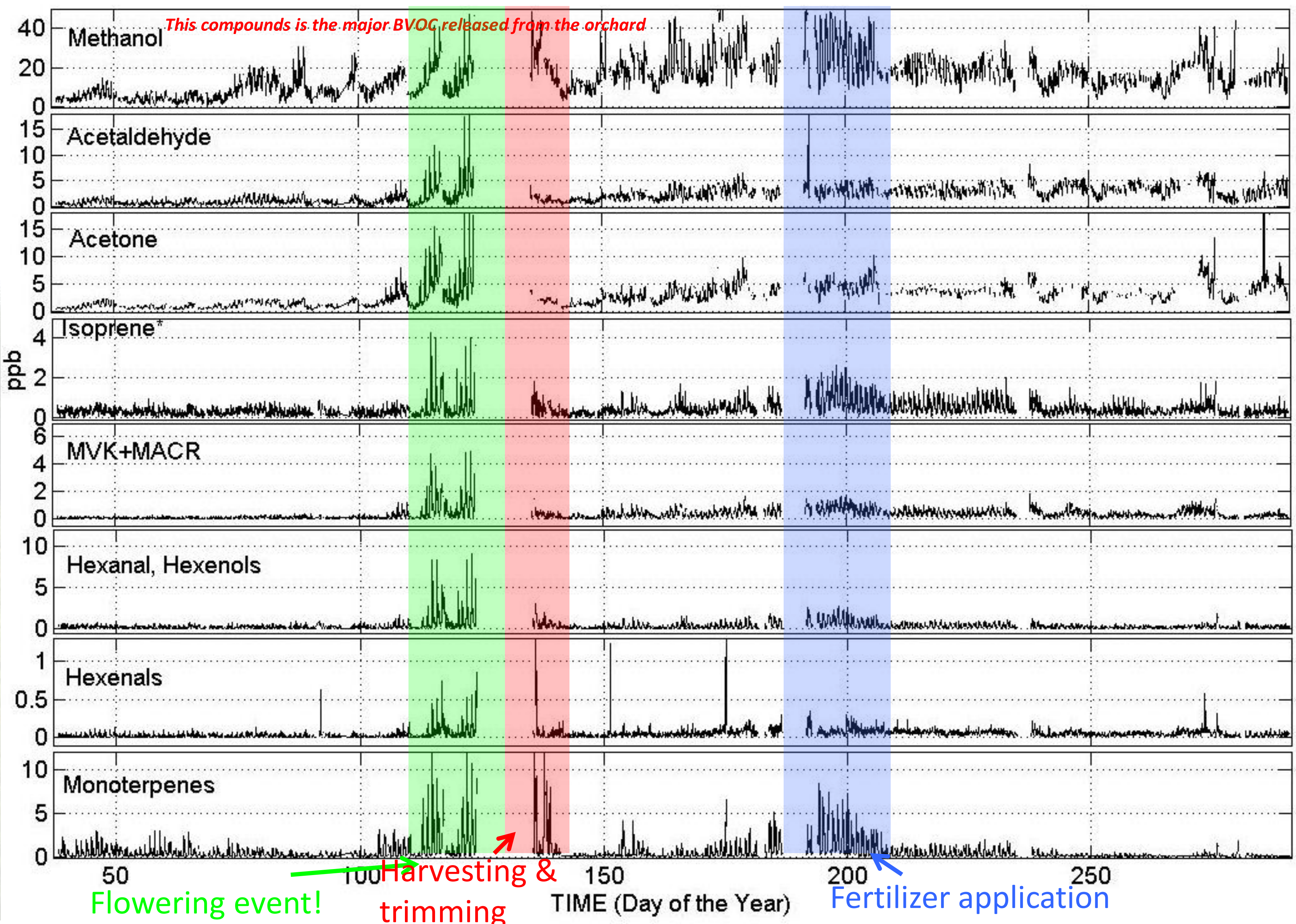




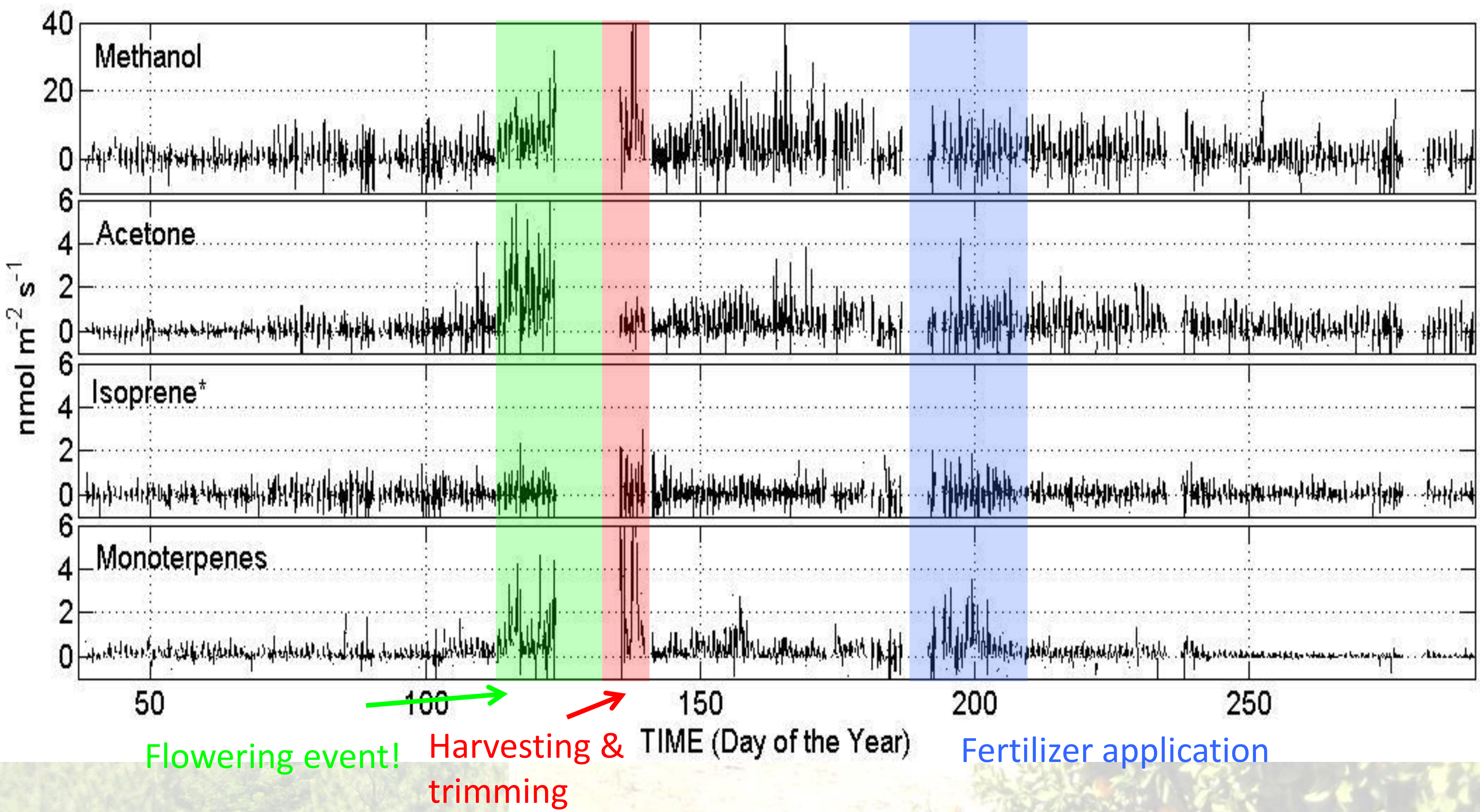
SQT>>Isoprene>>Acetone

BVOC concentration in the Orchard:

Fares et al. ACP 2012



BVOC fluxes

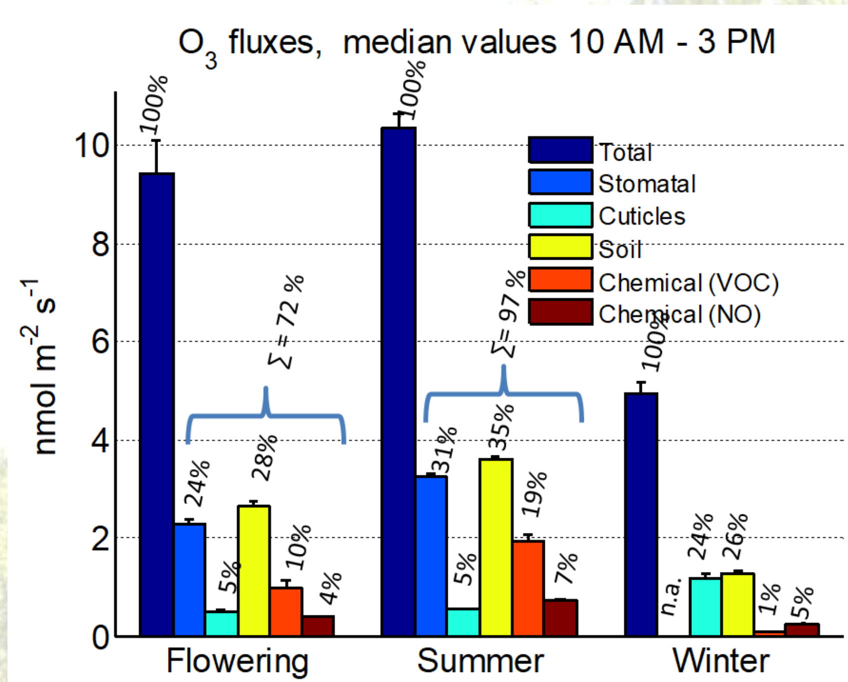


Large fluxes during the flowering period…

Fares et al. ACP 2012

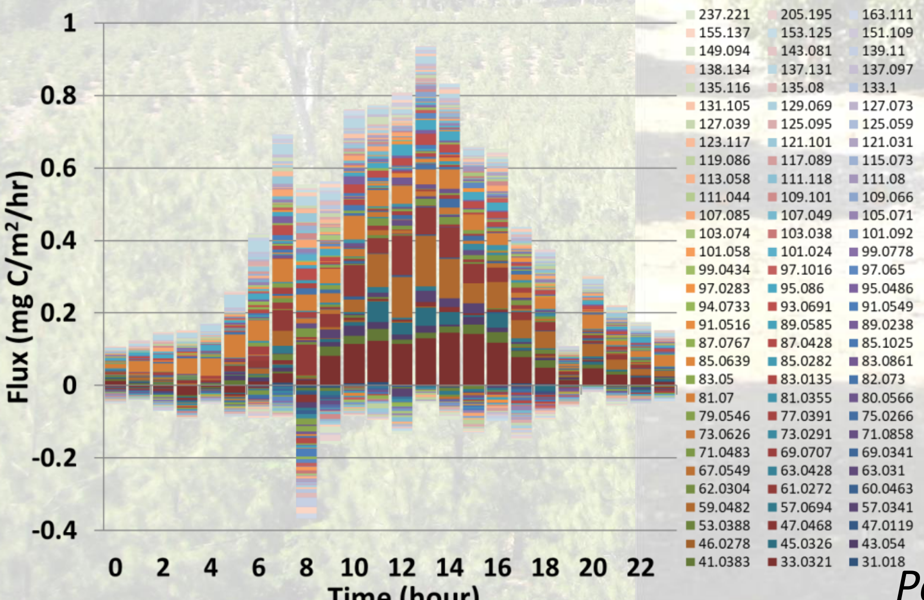
Stomatal and non-stomatal fluxes: final balance

We believe that the model **underestimates Fvoc** during **flowering**, because not fully accounting for the burst of BVOCs coming from flowers.



Fares et al. Env. Poll. 2012

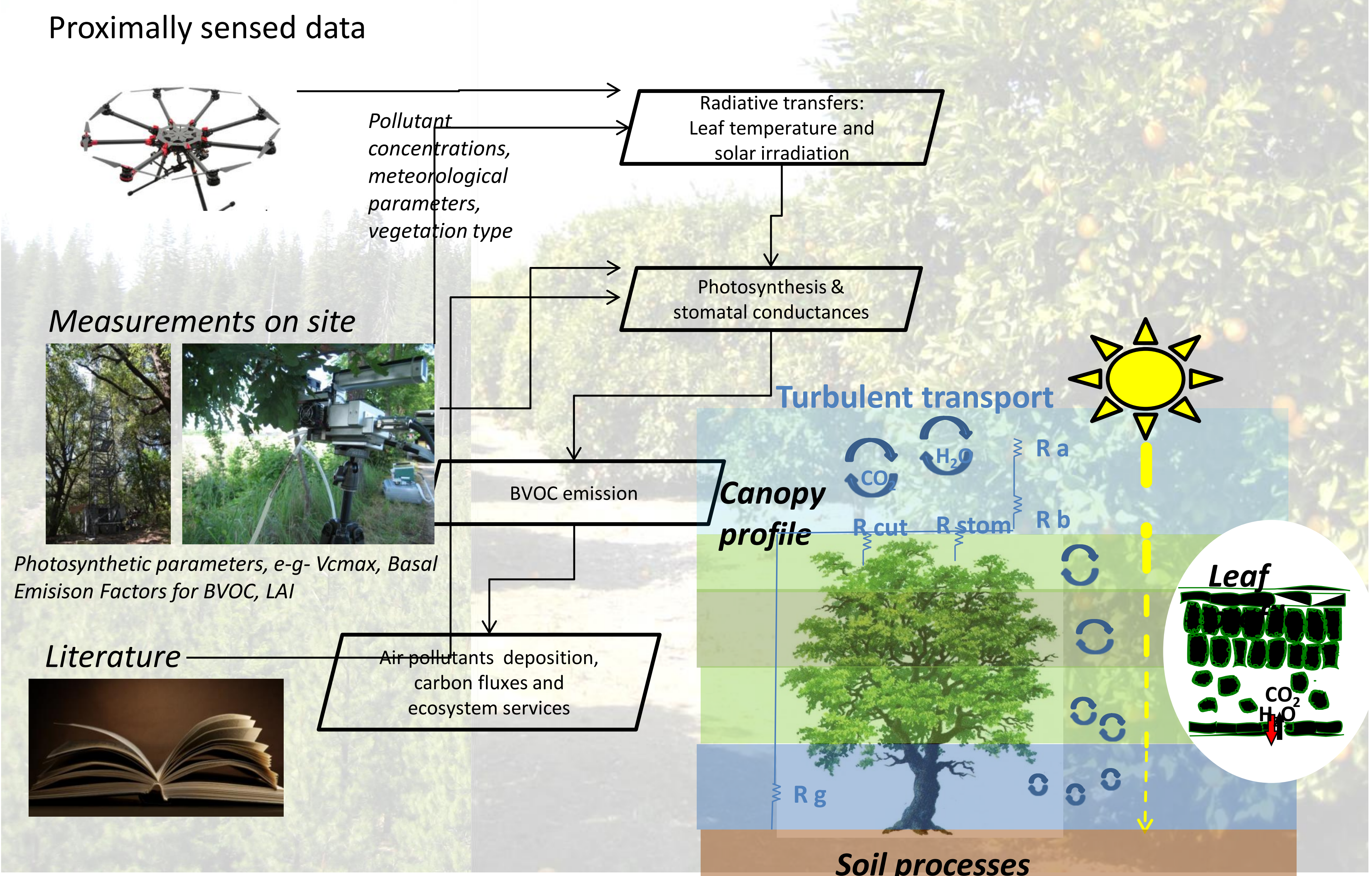
Hundreds of unexplored reactive VOC



Park et al. Science 2013

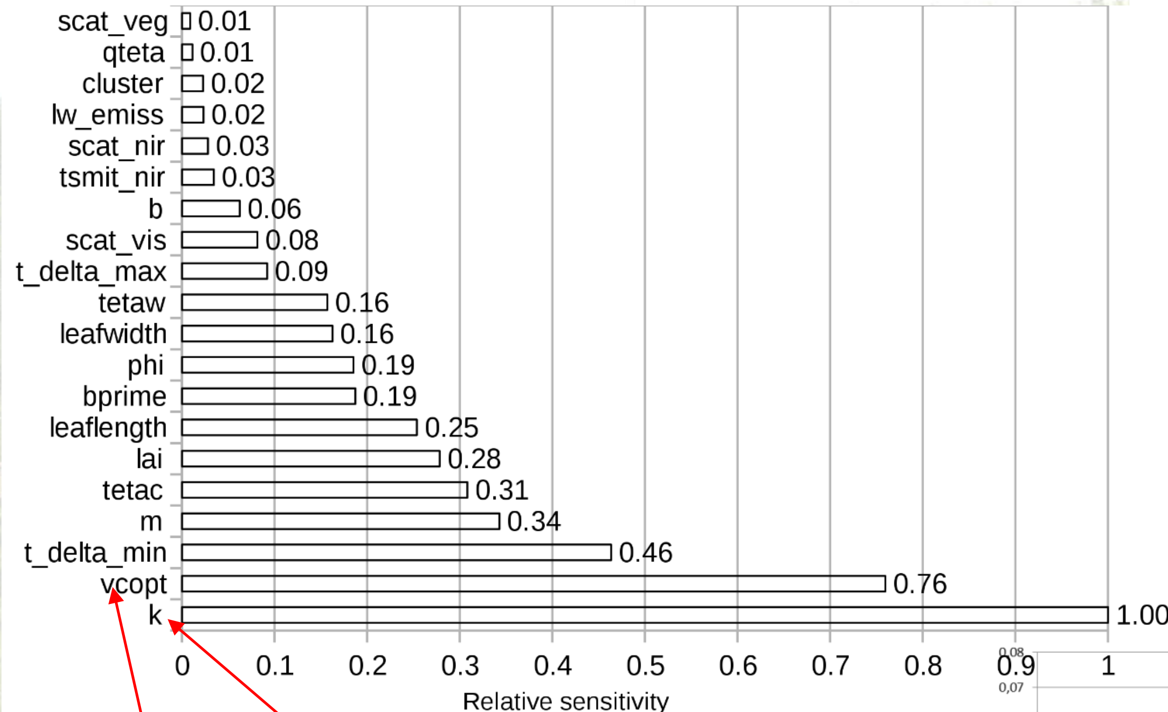
Eddy covariance fluxes to test and validate canopy models

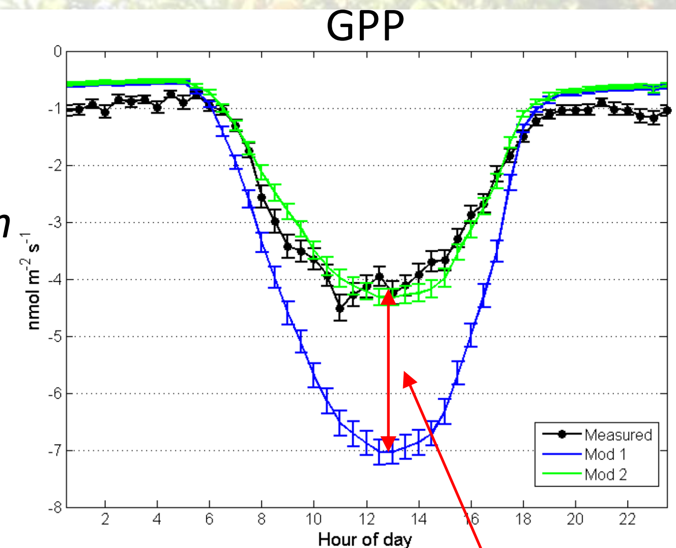
AIRTREE- *Aggregated Interpretation of the Energy balance and water dynamics for Ecosystem services assessment*



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





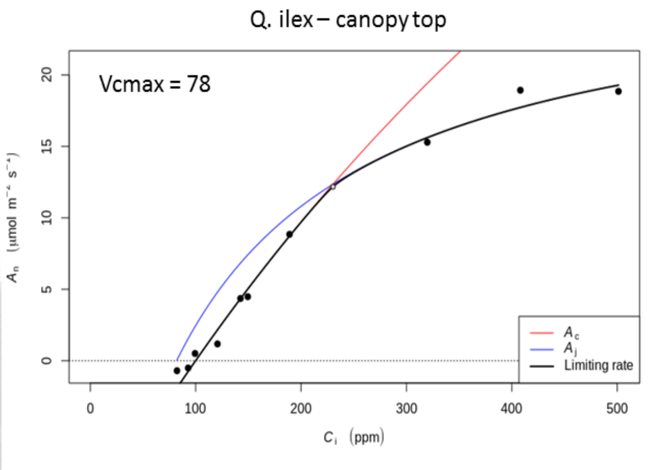
- Unrealistic predictions when soil water content is not included among the parameters driving stomatal regulation

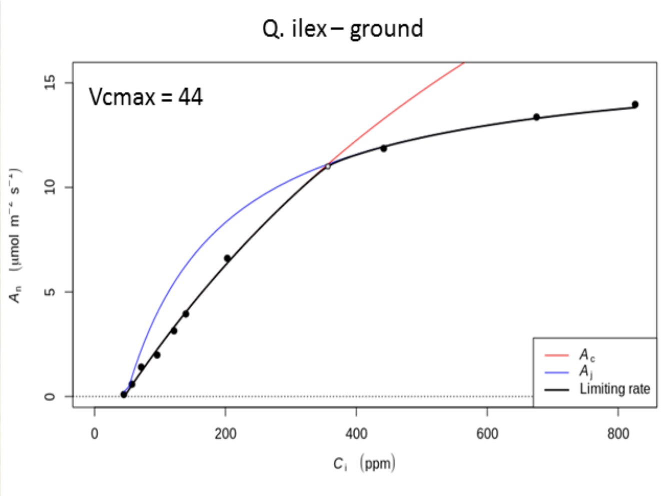
Soil porosity

Velocity of carboxilation changing over the vegetative season

Photosynthetic perfomances change in time and along the vertical canopy profile

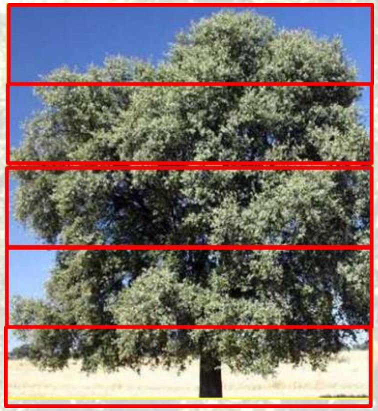
Vc_{max} extinction



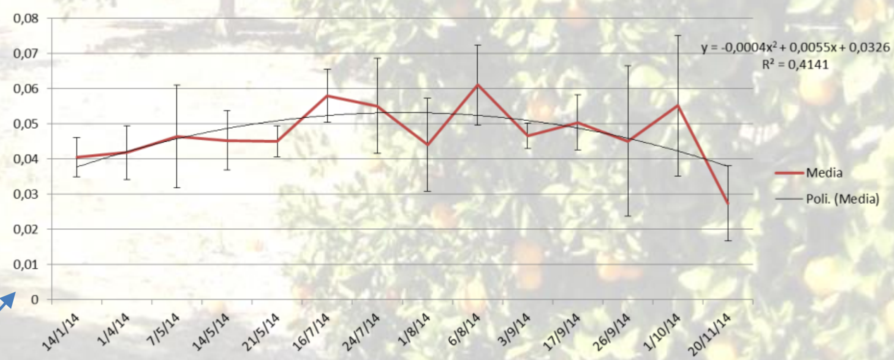


Vc_{max} values scaled at each canopy layer from the top of the canopy (layer 1) to the ground (layers 5)

$$Vc_{max}^{25}(x) = Vc_{max}^{25}(0)e^{-K_n x}$$



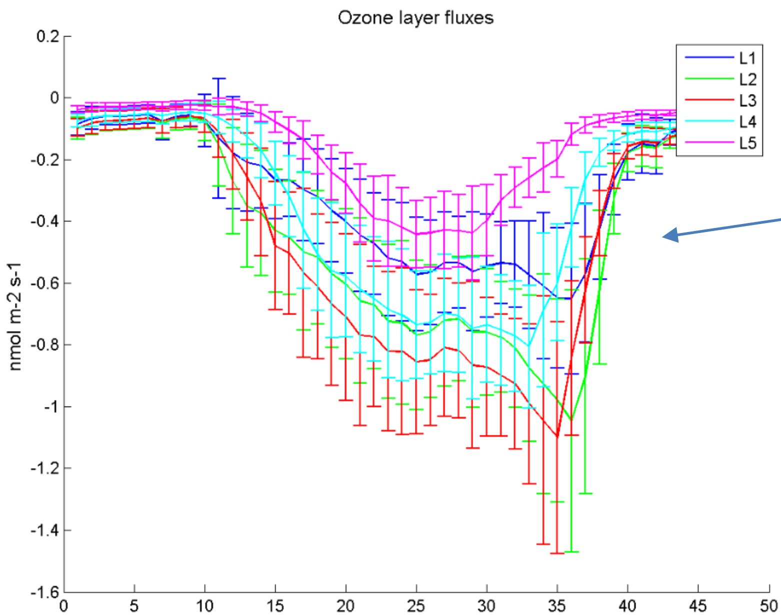
Layer	AIRTREE	
	LAI cumulated	Vc_{max}
1	0.43	73
2	1.32	64
3	2.37	54
4	3.25	48
5	3.69	45



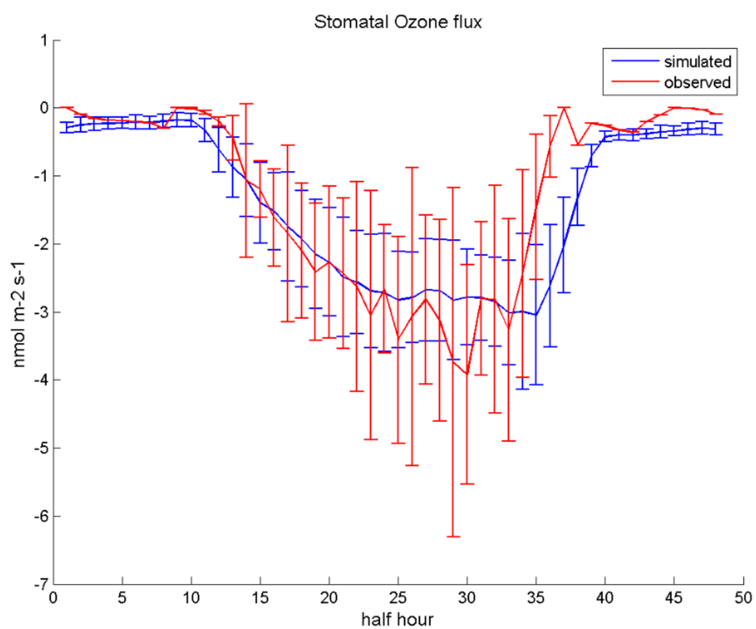
Velocity of carboxilation changing over the vegetative season

Fares et al. Sci. Tot. Env. 2019

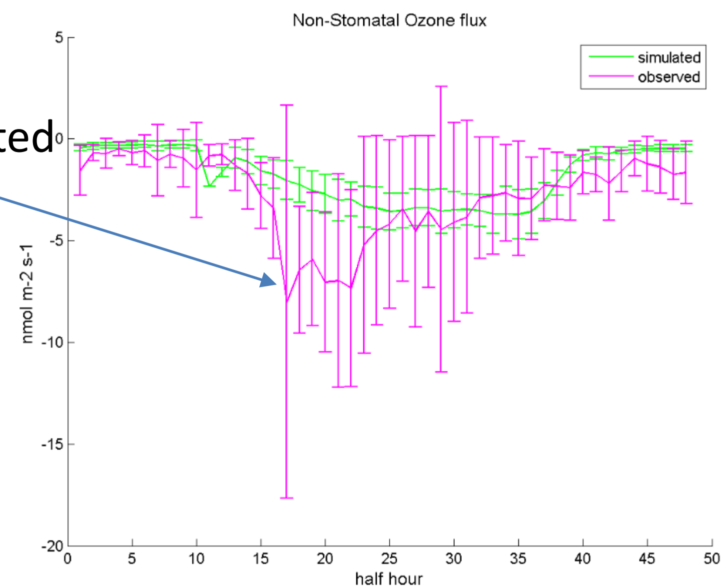
Measured vs simulated ozone fluxes



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

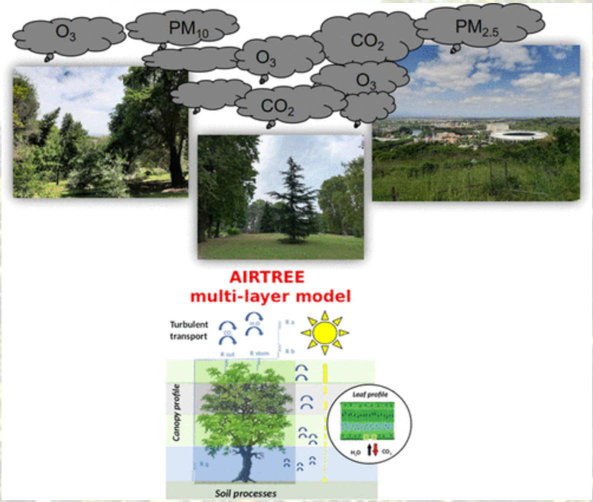


Underesetimated gas phase chamistry



AIRTREE performances: The Castel di Guido periurban forest, Rome

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



Environmental Science & Technology pubs.acs.org/est Article

Table 1. NPP, Tropospheric Ozone (O_3), and Particle (PM_{10} and $PM_{2.5}$) Dry Deposition Simulated by the AIRTREE Model for the Year 2018 at Castel di Guido Natural Reserve[a]

species	dbh (cm)	NPP (g m^{-2})	NPP class	O_3 (g m^{-2})	O_3 class	PM_{10} (g m^{-2})	PM_{10} class	$PM_{2.5}$ (g m^{-2})	$PM_{2.5}$ class
A. campestre	35	354.23 ± 38.76	IV	2.97 ± 0.02	V	1.01 ± 0.0482	II	0.09 ± 0.0041	I
Acer negundo	15	46.6	I	2.75	V	0.77	I	0.06	I
A. cordata	35	438.59 ± 39.9	V	3.27 ± 0.05	VI	1 ± 0.0405	II	0.08 ± 0.0034	I
C. atlantica	35	938.24 ± 128.36	X	5.67 ± 0.33	X	7.39 ± 1.272	VIII	1.01 ± 0.1739	X
C. australis	35	392.79	IV	2.8	V	0.93	I	0.08	I
C. sempervirens	55	1084.6	X	7.4	X	16.23	X	2.27	X
Eucalyptus spp.	55	490.78	V	3.34	VI	1.44	II	0.12	II
Fraxinus angustifolia	15	253.71 ± 79.24	III	2.19 ± 0.09	IV	0.83 ± 0.1507	I	0.07 ± 0.0125	I
F. ornus	35	562.24 ± 95.6	VI	2.88 ± 0.26	V	1.42 ± 0.1802	II	0.12 ± 0.0155	II
Juglans nigra	15	140.48 ± 126.39	II	2.17 ± 0.09	IV	0.82 ± 0.1714	I	0.07 ± 0.0145	I
Juglans regia	35	370.26	IV	2.51	V	1.05	II	0.09	I
Malus sylvestris	35	225.31	III	2.02	IV	0.66	I	0.06	I
Ostrya carpinifolia	35	528.65 ± 91.68	VI	2.85 ± 0.25	V	1.32 ± 0.1603	II	0.11 ± 0.0138	II
Pinus eldarica	35	704.89 ± 97.32	VIII	6.19 ± 0.61	X	9.58 ± 2.4196	X	1.31 ± 0.333	X
Pinus halepensis	55	894.86	IX	6.67	X	13.73	X	1.88	X
Pinus pinaster	55	847.47	IX	6.46	X	12.01	X	1.65	X
Pinus pinea	55	794.22 ± 30.14	VIII	6.39 ± 0.12	X	10.86 ± 0.7685	X	1.49 ± 0.1055	X
Populus nigra	15	83.25	I	2.01	IV	0.69	I	0.06	I
Prunus avium	35	375.44	IV	2.76	V	1.12	II	0.1	I
Pyrus amygdaliformis	15	27.91	I	2.15	IV	0.66	I	0.06	I
Pyrus pyraster	35	319.2	IV	2.57	V	1.08	II	0.09	I
Q. cerris	35	412.27 ± 51.97	V	2.89 ± 0.21	V	1.21 ± 0.1192	II	0.1 ± 0.0103	I
Quercus frainetto	35	332.5 ± 16.7	IV	2.54 ± 0.09	V	1.12 ± 0.0405	II	0.1 ± 0.0035	I
Q. ilex	35	656 ± 162.43	VII	3.43 ± 0.48	VI	2.79 ± 0.7179	III	0.31 ± 0.0803	IV
Q. pubescens	35	486.99 ± 61.35	V	2.98 ± 0.22	V	1.21 ± 0.1192	II	0.1 ± 0.0103	I
Q. robur	15	250.37 ± 77.66	III	2.45 ± 0.12	IV	0.7 ± 0.1171	I	0.06 ± 0.01	I
Quercus suber	35	854.12 ± 87.2	IX	3.52 ± 0.2	VII	2.09 ± 0.1795	III	0.23 ± 0.0201	III
Quercus trojana	15	159.36 ± 80.58	II	2.24 ± 0.08	IV	0.56 ± 0.1356	I	0.05 ± 0.0115	I
R. pseudoacacia	35	474.66	V	2.65	V	1.16	II	0.1	I
Sorbus domestica	15	189.59	II	2.07	IV	1.01	II	0.09	I

[a]Model simulations were carried out for each species at different dbh. We grouped results according the highest dbh group. The groups were: 15 (dbh ranging from 5 to 15 cm), 35 (dbh ranging from 20 to 35 cm), and 55 (dbh ranging from 40 to 55 cm). SD is shown in cases where more dbh classes were present within each group. Evergreen species are marked in bold.

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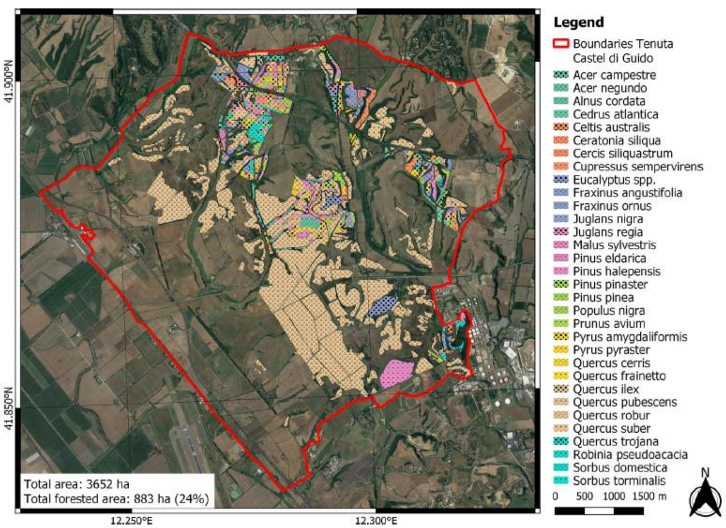
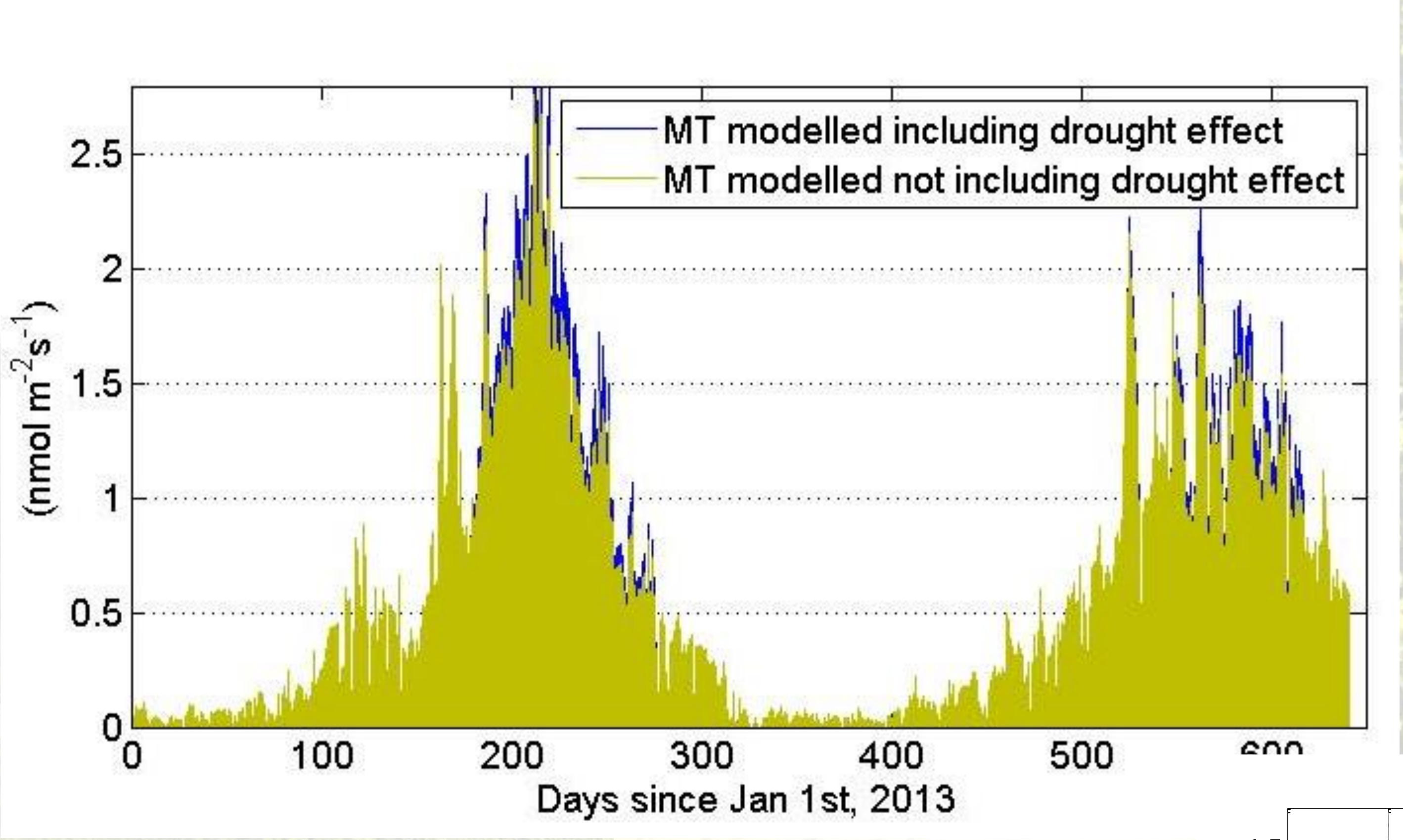


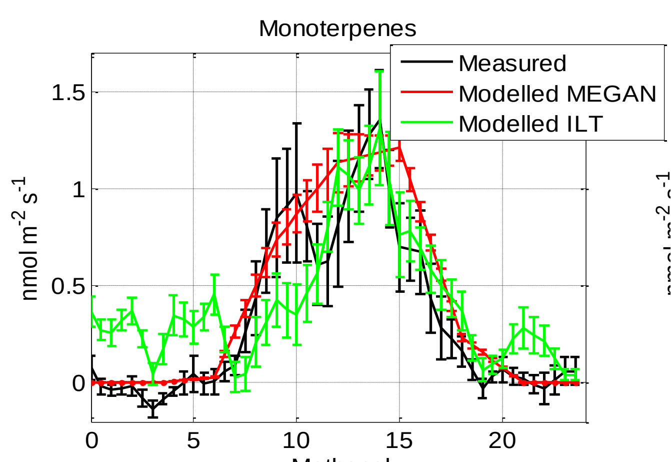
Figure 1. Map of the vegetation surveyed at the park of Castel di Guido, Rome. Map data 2020 Google.

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



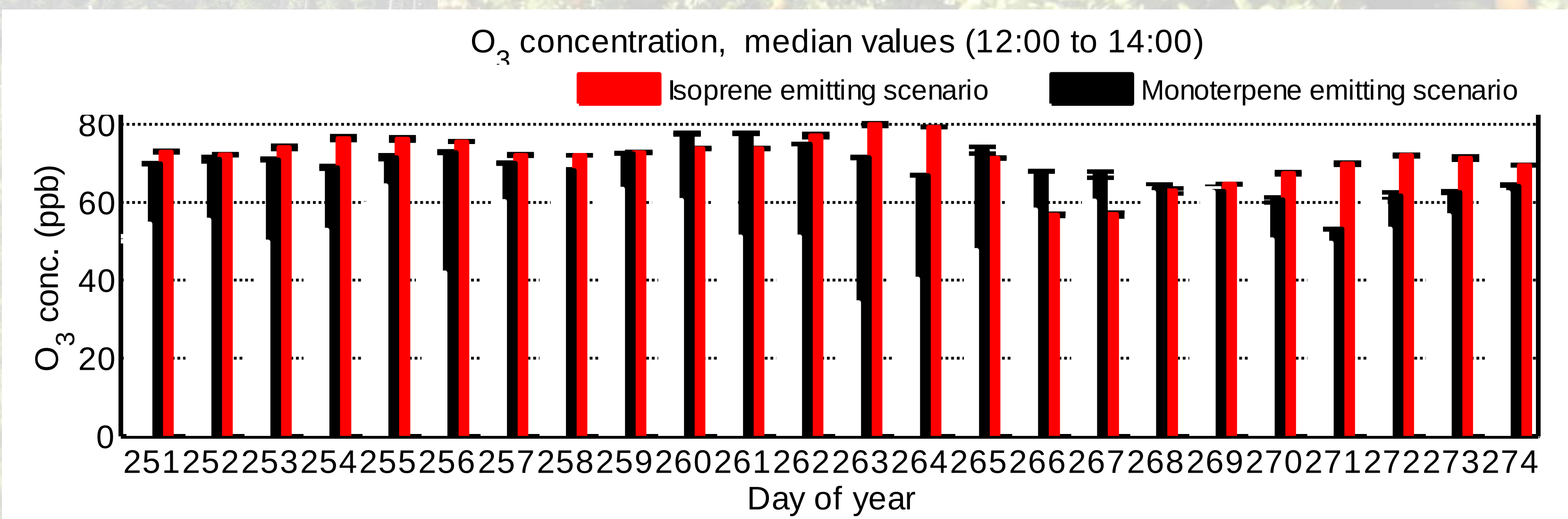
EC VOC fluxes to determine canopy emission factors

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

$$F_{G06} = BEF \cdot b_3 \cdot \exp[b_2 \cdot (P_{24} - P_0)] \cdot (P_{24})^{0,6} \cdot \frac{[b_1 - b_2 \cdot \ln(P_{240})] \cdot PAR}{\sqrt{1 + [b_1 - b_2 \ln(P_{240})]^2 \cdot PAR^2}} \cdot b_5 \cdot \exp[b_6 \cdot (T_{24} - 297)] \quad \cdot b_5 \cdot \exp[b_6 \cdot (T_{24} - 297)] \cdot \exp[b_6 \cdot (T_{240} - 297)] \cdot \frac{C_{T2} \cdot \exp\left[C_{T1} \cdot \left(\frac{1}{T_{opt}}\right) - \left(\frac{1}{T}\right) \cdot \frac{1}{0,00831}\right]}{C_{T2} - C_{T1} \cdot \left[1 - \exp\left(C_{T2} \cdot \left(\frac{1}{T_{opt}}\right) - \left(\frac{1}{T}\right) \cdot \frac{1}{0,00831}\right)\right]}$$

- 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

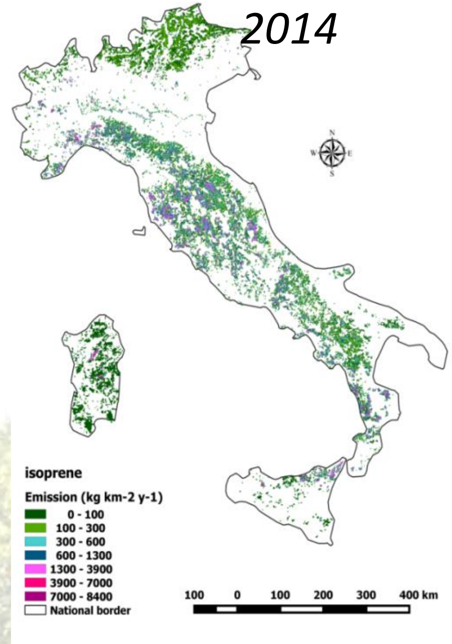
- The global model run with realistic BEF from prevailing MT emitting species predicted lower concentrations of tropospheric ozone compared with an isoprene emitting scenario used in the previous MEGAN version.

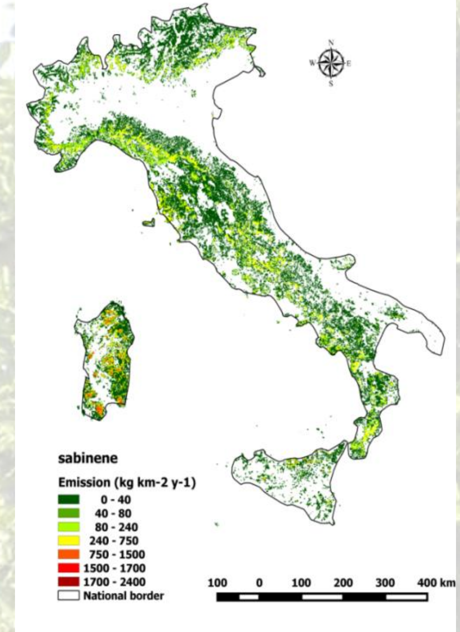


Fares et al. Env. Sc. Tech. 2013

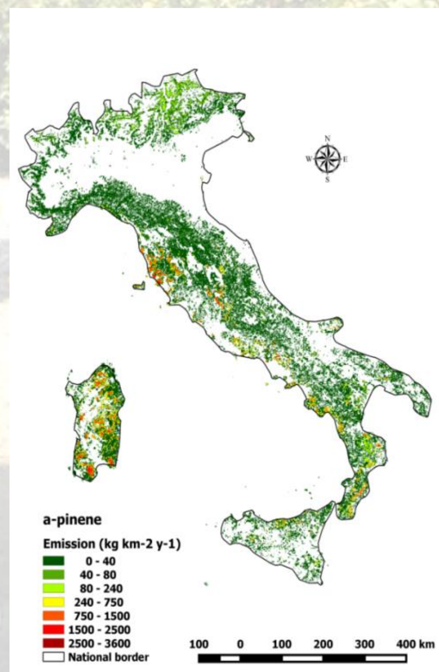
Kemper, Fares and Ciccioli, Atm. Env. 2014

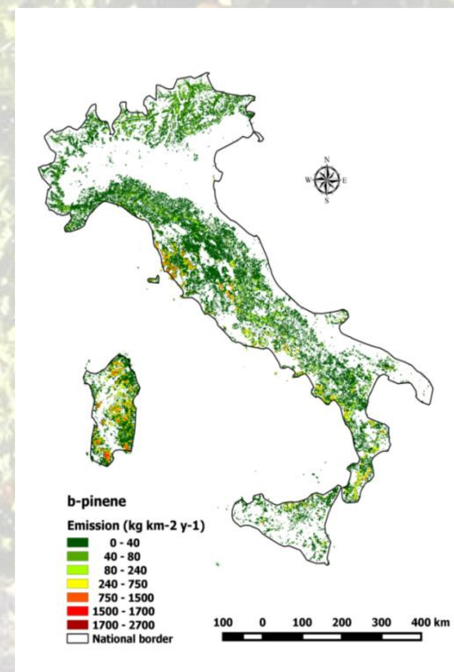
Integration of vegetation maps & national forest inventories: Emission Factor attribution for a realistic estimate



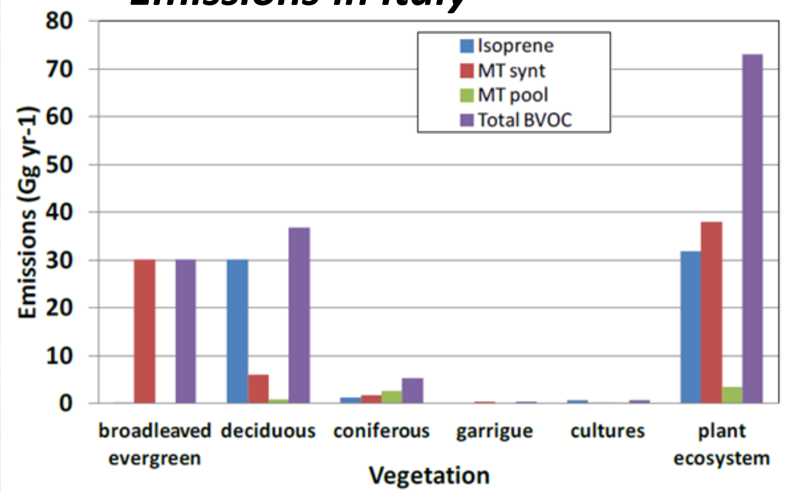


Do we have enough information on BEF? Is it still worth measuring BEF at leaf/ecosystem scale?





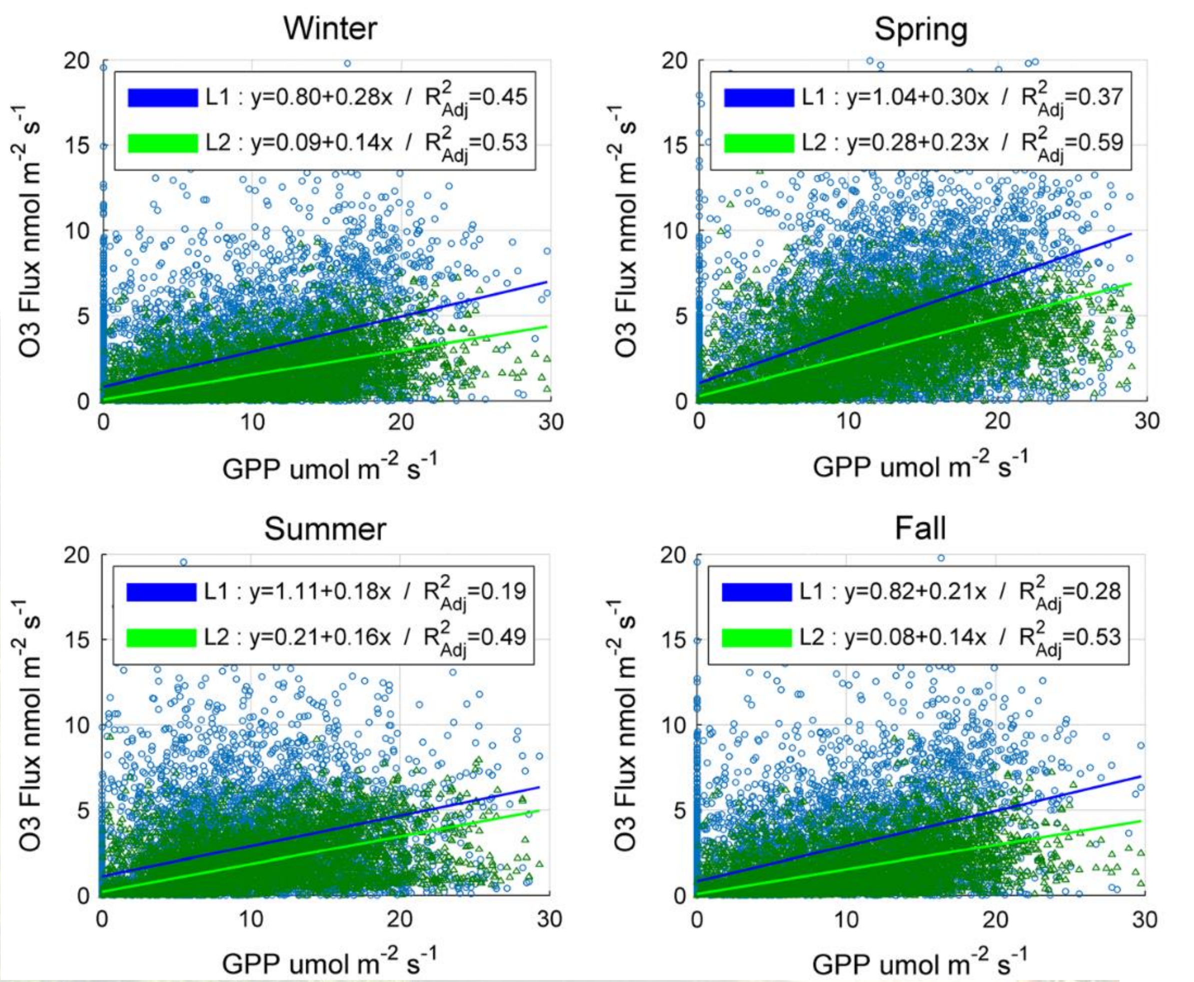
Emissions in Italy

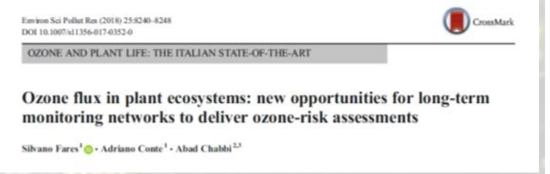


Can we estimate ozone damage to vegetation using continuous EC field measurements?

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)





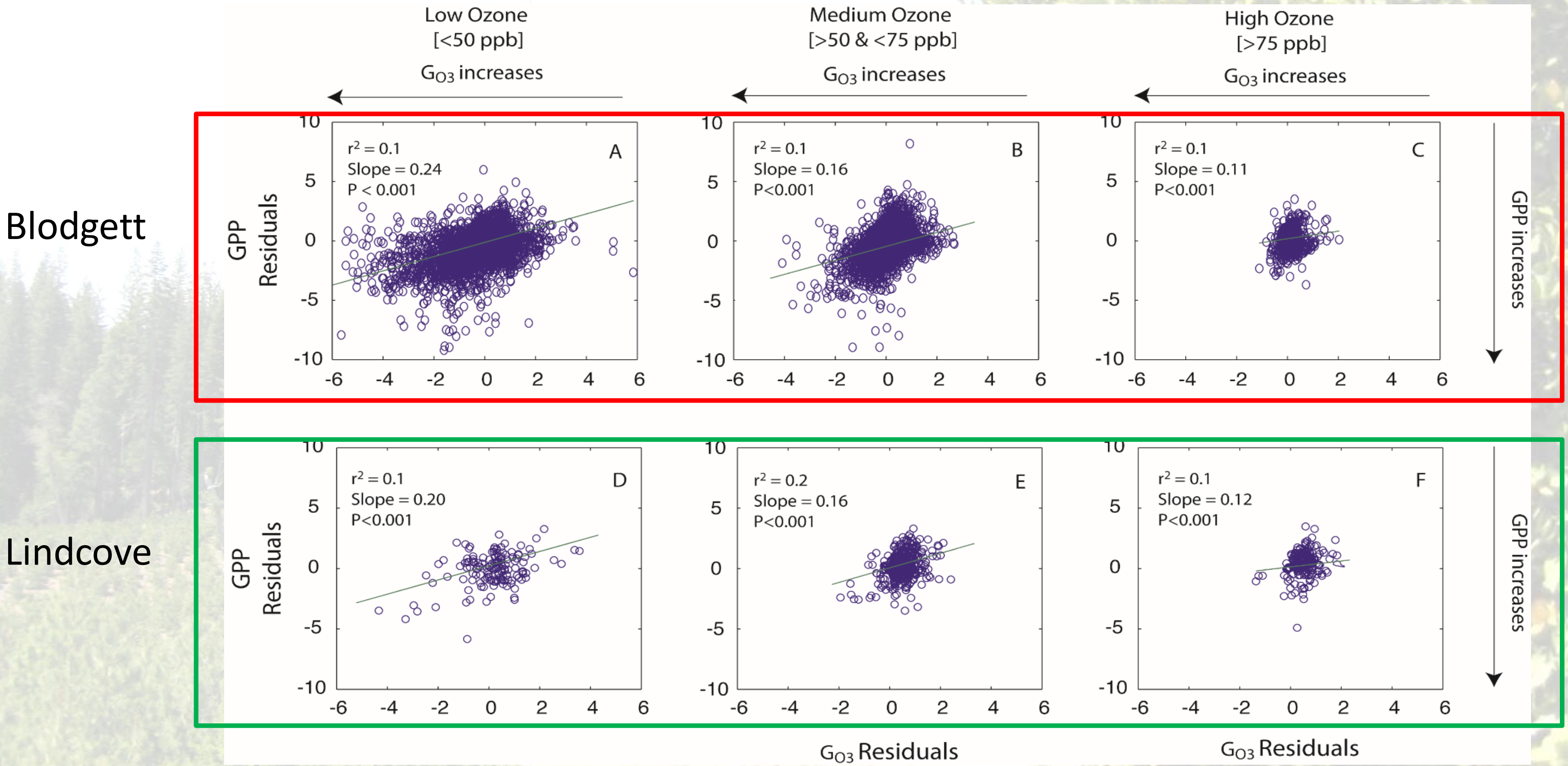
Environ Sci Pollut Res (2018) 25:8240–8248
DOI 10.1007/s11356-017-0352-0

OZONE AND PLANT LIFE: THE ITALIAN STATE-OF-THE-ART

Ozone flux in plant ecosystems: new opportunities for long-term monitoring networks to deliver ozone-risk assessments

Silvano Fares[1] · Adriano Conte[1] · Abad Chabbi[2,3]

At increasing ground levels of ozone, the slope between GPP and stomatal ozone deposition decreases



Photosynthesis uncoupling from stomatal conductance ay high levels of O3 concentrations

Fares et al. 2013 Glob. Chan. Biol.

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

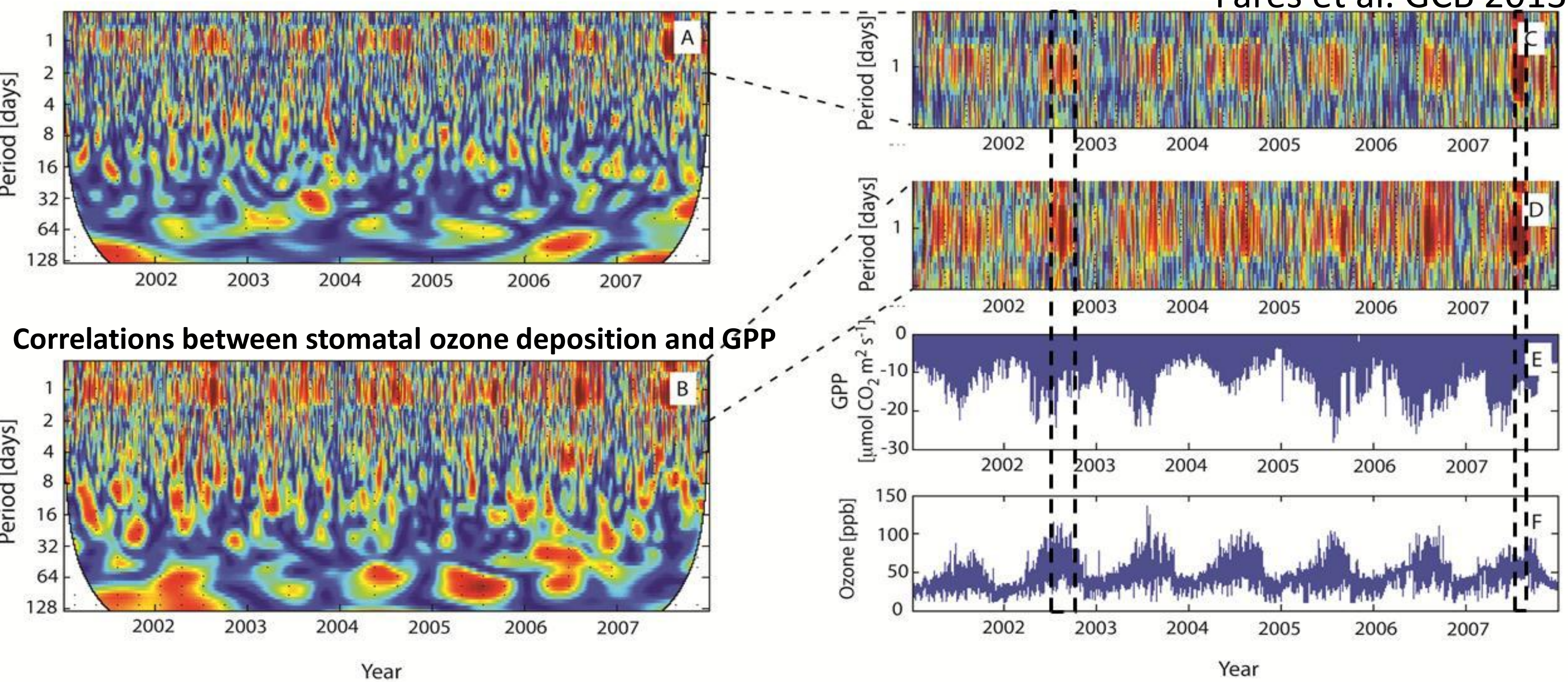
Temporal correlation between GPP (residuals), ozone concentration and stomatal ozone flux exists

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

Fares et al. GCB 2013



Can we predict GPP using multiple regression linear and non-linear models?

Multiple regression linear model: (GPP = b1P + b2Q + b3R…+bnN)

4 case studies

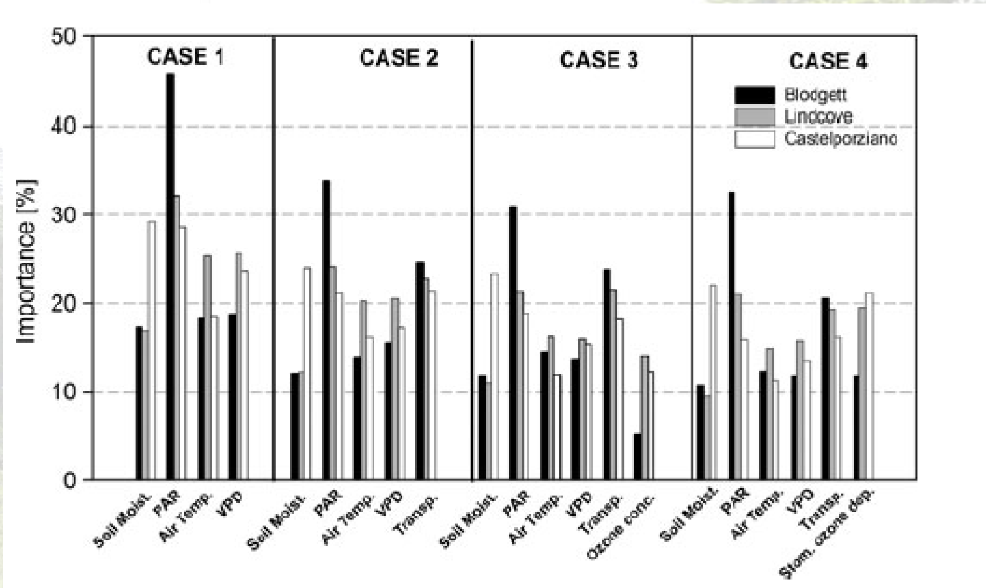
Negative sign of predictor: negative effect on GPP

Stomatal ozone deposition explains better than ozone concentration GPP decrease!

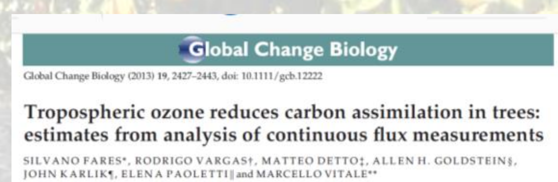
	Blodgett					Lindcove					Castelporziano			
Case 1														
Predictors	beta	multiple R^2	F	total		beta	multiple R^2	F	total		beta	multiple R^2	F	total
PAR (umolm^{-2}s^{-1})	-0.722	0.489	46407.180		PAR (umolm^{-2}s^{-1})	-0.431	0.098	470.028		Soil moisture (%)	-0.414	0.115	176.796	
VPD (kpa)	0.457	0.492	210.360		VPD (kpa)	0.493	0.156	299.663		PAR (umolm^{-2}s^{-1})	-0.438	0.209	159.452	
Ta (°C)	-0.350	0.499	680.680		Ta (°C)	-0.236	0.162	29.010		VPD (kpa)	0.089	0.215	10.667	
Soil moisture (%)	0.087	0.502	320.310		Soil moisture (%)	-0.035	0.163	6.161		Ta (°C)	0.081	0.217	3.257	
R-square				0.5					0.17					0.22
slope				0.86					0.74					0.77
df				48399					4338					1351
F				12198					211					94
Case 2														
ET (mmolm^{-2}s^{-1})	-0.469	0.483	27355.570		PAR (umolm^{-2}s^{-1})	-0.253	0.098	470.028		Soil moisture (%)	-0.331	0.115	176.796	
PAR (umolm^{-2}s^{-1})	-0.308	0.542	3771.650		VPD (kpa)	0.352	0.156	299.663		ET (mmolm^{-2}s^{-1})	-0.239	0.214	169.705	
Soil moisture (%)	0.072	0.546	213.980		ET (mmolm^{-2}s^{-1})	-0.438	0.234	440.230		PAR (umolm^{-2}s^{-1})	-0.323	0.233	32.896	
VPD (kpa)	0.375	0.547	71.590		Ta (°C)	0.115	0.235	5.738		VPD (kpa)	0.126	0.245	21.623	
Ta (°C)	-0.352	0.551	312.320		Soil moisture (%)	0.032	0.236	5.394		Ta (°C)	0.121	0.249	7.515	
R-square				0.55					0.24					0.25
slope				0.88					0.76					0.78
df				29254					4338					1356
F				7192					267					89.52
Case 3														
ET (mmolm^{-2}s^{-1})	-0.469	0.483	27355.570		PAR (umolm^{-2}s^{-1})	-0.254	0.098	471.990		Soil moisture (%)	-0.331	0.115	176.796	
PAR (umolm^{-2}s^{-1})	-0.308	0.542	3771.650		VPD (kpa)	0.277	0.156	298.684		ET (mmolm^{-2}s^{-1})	-0.239	0.214	169.705	
Soil moisture (%)	0.072	0.546	213.980		ET (mmolm^{-2}s^{-1})	-0.453	0.234	441.996		PAR (umolm^{-2}s^{-1})	-0.323	0.233	32.896	
VPD (kpa)	0.375	0.547	71.590		[O_3] (ppb)	0.106	0.237	14.196		VPD(kpa)	0.126	0.245	21.623	
Ta (°C)	-0.352	0.551	312.320		Ta (°C)	0.103	0.238	4.598		Ta (°C)	0.121	0.249	7.515	
[O_3] (ppb)	n.s.	n.s.	n.s.		Soil moisture (%)	0.026002	0.238265	3.5346		[O_3] (ppb)	n.s.	n.s.	n.s.	
R-square				0.55					0.24					0.25
slope				0.88					0.76					0.78
df				29254					4332					1350
F				7192					225.84					90
Case 4														
ET (mmolm^{-2}s^{-1})	-0.730	0.473	21686.430		G_{O3} (m s^{-1})	0.053	0.085	272.181		G_{O3} (m s^{-1})	-0.347	0.240	422.360	
G_{O3} (m s^{-1})	0.271	0.525	2639.770		PAR (umolm^{-2}s^{-1})	-0.203	0.152	235.276		Soil moisture (%)	-0.258	0.293	100.616	
PAR (umolm^{-2}s^{-1})	-0.242	0.540	813.270		VPD (kpa)	0.385	0.180	99.428		PAR (umolm^{-2}s^{-1})	-0.199	0.308	28.848	
VPD (kpa)	0.252	0.548	446.420		ET (mmolm^{-2}s^{-1})	-0.461	0.225	168.336		Ta (°C)	0.134	0.314	10.790	
Soil moisture (%)	0.062	0.551	131.650		Ta (°C)	0.048	0.226	6.805		ET (mmolm^{-2}s^{-1})	-0.056	0.315	2.796	
Ta (°C)	-0.082	0.551065	12.11		Soil moisture (%)	0.143966	0.227684	4.8459		VPD (kpa)	n.s.	n.s	n.s	
R-square				0.55					0.23					0.315
slope				0.89					0.79					0.79
df				24184					2937					1332
F				4947					144					153

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!

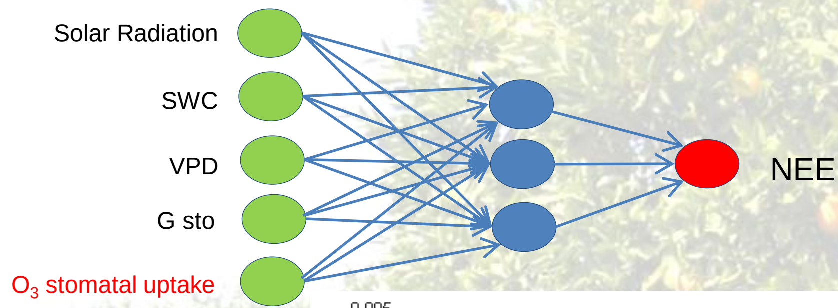

Global Change Biology

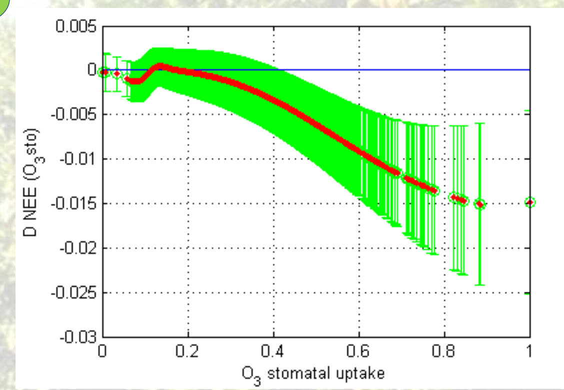
Global Change Biology (2013) 19, 2427–2443, doi: 10.1111/gcb.12222

Tropospheric ozone reduces carbon assimilation in trees: estimates from analysis of continuous flux measurements

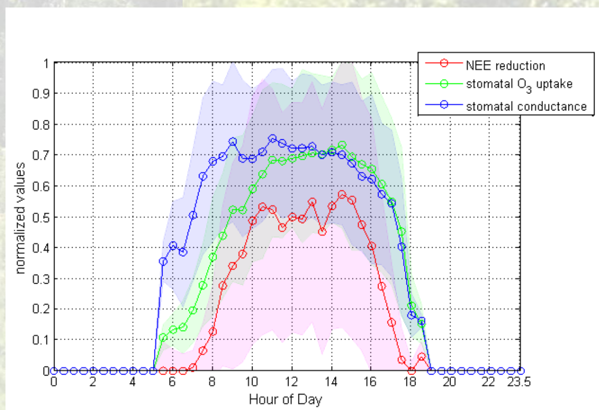
SILVANO FARES*, RODRIGO VARGAS†, MATTEO DETTO‡, ALLEN H. GOLDSTEIN§, JOHN KARLIK¶, ELENA PAOLETTI‖ and MARCELLO VITALE**

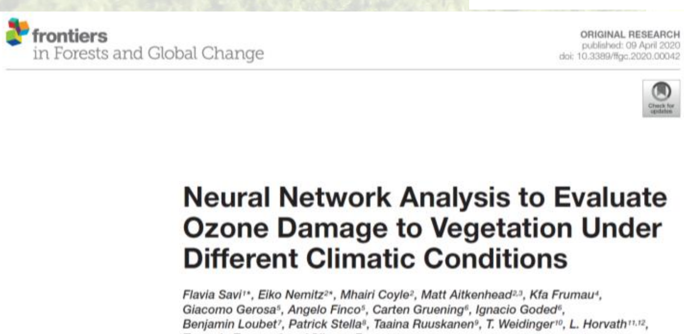
Long-term measurements may support the training and application of Neural Network analysis





A more conservative estimate of ozone-induced GPP reduction was found: **2%**





frontiers in Forests and Global Change
ORIGINAL RESEARCH
published: 09 April 2020
doi: 10.3389/ffgc.2020.00042

Neural Network Analysis to Evaluate Ozone Damage to Vegetation Under Different Climatic Conditions

Flavia Savi[1*], Eiko Nemitz[2*], Mhairi Coyle[2], Matt Aitkenhead[2,3], Kfa Frumau[4], Giacomo Gerosa[5], Angelo Finco[5], Carten Gruening[6], Ignacio Goded[6], Benjamin Loubet[7], Patrick Stella[8], Taaina Ruuskanen[9], T. Weidinger[10], L. Horvath[11,12], Terenzio Zenone[13] and Silvano Fares[1,14*]

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:

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

$$A_n = A_n * F_{pO_3}$$

$$g_s = g_s * F_{cO_3}$$

$$F_{GsO_3} = a_{Gs} * POD_Y + b_{gs}$$

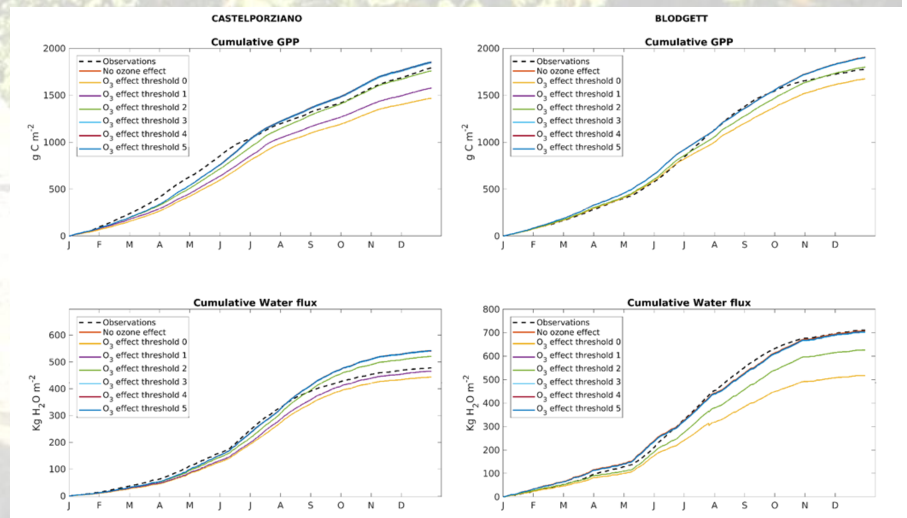
$$F_{AO_3} = a_A * POD_Y + b_A$$

$$POD = CEO_3 * gs * K_{O3} * 3600 * 10\text{-}6$$

$$CEO_3 = [O_3] * H * D$$

Species	Photosynthesis		Conductance	
	Slope (a_p)	Intercept (b_p)	Slope (a_c)	Intercept (b_c)
Q.ilex	-0.0003	0.7930	-0.0009	0.8572
P.ponderosa	-0.0005	0.9152	-0.0007	1.0671

Where *a* and *b* are slope and intercept of the regression line between CUO and gs and An, 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

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Thanks for your attention!