The International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops
& ARCHES-Conseils
& International Union of Forest Research Organizations - Research Group 7.01

present the

International Conference on Ozone and Plant Ecosystems

21-25 May, 2018

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Ozone & Plants conference
Florence, 21-25 May 2018

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1. Rationale of the Conference

Ozone pollution continues to be a serious issue for terrestrial ecosystems and plant health. This conference allows all experts in the interactions between ozone and plant ecosystems to meet and discuss the state-of-the-art and the future strategies for decision-makers.

The main subjects of the conference are:

1. Monitoring, modelling and assessing the risk of ozone damage to plant ecosystems

Proofs of the impacts of ambient ozone on plant ecosystems are still elusive. New monitoring approaches and epidemiological studies are developing. Modelling of ozone is becoming more and more sophisticated at high resolution. Risk assessment is evaluating many different metrics for plant protection, with a focus on stomatal ozone flux. All these developments, with focus on the most modern techniques, are discussed in this session.

2. How plant ecosystems affect ozone concentration in the atmosphere

Ozone deposition is strongly affected by the type of vegetation. Exchanges of biogenic volatile organic compounds is known to contribute to ozone chemistry in the atmosphere. This session addresses mechanisms, seasonality, responses to ozone singly and in combination with other environmental factors, as well as selection of appropriate green infrastructure for urban greening.

3. How plant ecosystems respond to ozone exposure

This session includes food security and effects on forests and grasslands. A main aim is to evaluate strategies for maximizing yield, productivity and other environmental services of plant ecosystems under ozone stress.

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2. Opening Addresses

Elena Paoletti, IUFRO RG7.01 Coordinator

As coordinator of the IUFRO (International Union of Forest Research Organizations) Research Group 7.01 'Impacts of Air Pollution and Climate Change on Forest Ecosystems', I am pleased to welcome in Florence around a hundred international experts from 29 countries distributed in four continents. This is an index of the global significance of the ozone and plants subject. IUFRO is the largest network of forest research in the world, and works for strengthening the forest science community worldwide. Within Division 7 'Forest Health', RG 7.01 is a major forum for discussing the topical issues of climate and pollution impacts on forests. This conference, in particular, is supported by the IUFRO Working Parties 7.01.09 'Ground-level ozone', 7.01.02 'Genetic, biochemical and physiological processes' and 7.01.05 'Modelling and risk assessment', because assessing ozone risk to plant ecosystems requires an holistic approach. We are glad to host this second conference on ozone and plant ecosystems in Italy, which traditionally is a hot spot of ozone pollution. Control measures, however, are becoming effective and improvements are coming. We are also very glad to collaborate with ICP Vegetation in expanding our focus from forests to grasslands and crops. We hope that the results of this conference, with 51 talks and 47 poster presentations, will help improving our understanding on the relationships between ozone and plants, and expanding this knowledge worldwide. I would like to express my sincere appreciation to the members of the local organization and wish all participants all the best for a very fruitful conference.

Harry Harmens, Chair of ICP Vegetation

As Chair of the ICP Vegetation I would like to welcome you to the second 'Ozone & Plants' conference. The ICP Vegetation is an International Cooperative Programme (ICP) that reports on the effects of air pollutants on natural vegetation and crops. The ICP Vegetation is a subsidiary body of the Working Group on Effects (WGE) of the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP). In particular, the ICP Vegetation focuses on the following air pollution problems: i) Quantifying the risks to vegetation posed by ozone pollution and collating field-based evidence of ozone impacts; ii) The atmospheric deposition of heavy metals, nitrogen and persistent organic pollutants (POPs) to vegetation. Field-based evidence and assessments of current and future risks of impacts on vegetation are used to guide air pollution abatement policies developed within the LRTAP Convention, for ozone in particular with respect to the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (amended in 2012). The ICP Vegetation also encourages outreach activities to other regions such as Asia, Africa and South America and has recently established an ICP Vegetation-Asia network. Ground-level has been shown to have negative impacts on crop yield (both quality and quantity), tree growth (above- and below-ground) and growth/flower number/seed number of other ozone-sensitive plant species. Hence, ozone adversely affects food production, terrestrial ecosystems and the services they provide. Although peak episodes of ozone pollution have declined in recent decades in many parts of the USA and Europe, peak concentrations have risen in developing regions, in particular in South-East Asia. This has contributed to rising background ozone concentrations elsewhere, hence, air pollution abatement measures are needed globally to combat ozone pollution impacts worldwide. I wish you all a successful meeting and I am looking forward to enhance the evidence and knowledge base of ozone impacts and its mechanisms on vegetation.

3. Schedule and Programme

Programme in short

TIME	Monday, 21	Tuesday, 22	Wednesday, 22	Thursday, 23	Friday, 25
08.00		**Registration**			**Move to Sesto Fiorentino**
08.30			**Session 2** Chair: Z. Feng	**Session 2** Chair: A. Giovannelli	
09.00		**Opening remarks**			
09.30		**Session 1** Chair: Pierre Sicard	**Conference Picture**		**Visiting the Ozone-Face**
10.00		**Coffee break**	**Coffee break and Poster session**	**Coffee break and Poster session**	
10.30		**Session 1** Chair: P. Sicard			
11.00			**Session 2** Chair: E. Paoletti	**Session 2** Chair: E. Agathokleus	
11.30					**Move to Verrazzano**
12.00					
12.30		**Lunch**	**Lunch**		**Visiting the winery**
13.00				**Lunch**	
13.30					**Wine tasting and Lunch**
14.00		**Session 1** Chair: A. De Marco	**Session 2** Chair: L. Zhang	**Session 2** Chair: M. Domingos	
14.30					**Move to Siena**
15.00					
15.30				**Coffee break**	**Free time to visit Siena**
16.00		**Coffee break**		**Session 3** Chair: Y. Hoshika	
16.30		**Session 1** Chair: H. Harmens	**Coffee break**		
17.00			**Session 2** Chair: E. Carrari		
17.30				**Round table** Chair: H. Harmens **Closing remark by** E. Paoletti	
18.00		**Wine tasting and Poster session** (18.10-20.00)			**Back to Florence**
18.30					
19.00	**Welcome cocktail and registration** (19.00-20.30)		**Free time**		
19.30					
20.00			**Conference Dinner** (20.00-23.00)		
20.30					
21.00					
23.00					

Programme

Monday 21st May, 2018

19:00-20:30	**Welcome cocktail, registration of participants, mounting of posters**

Tuesday 22nd May, 2018

8:00	**Registration of participants**	
9:00	**Opening remarks**	
	Elena Paoletti (local organizer) Harry Harmens (ICP Vegetation) Zhaozhong Feng (IUFRO RG7.01.02) Alessandra De Marco (IUFRO RG7.01.05) Pierre Sicard (IUFRO RG7.01.09) Furio Forni (Regione Toscana)	
Session 1	**"Monitoring, modelling and assessing the risk of ozone damage to plant ecosystems"** **Chair: Pierre Sicard**	
9:30	**Keynote speaker- Pierre Dizengremel** (France). Historical approach to research on ozone and plants	**S1.O1**
10:00	**Coffee break**	
10:30	**Harry Harmens** (UK). TOAR-Vegetation: Present day tropospheric ozone distribution and trends relevant to vegetation	**S1.O2**
10:50	**Howard Neufeld** (USA). Ozone trends in Great Smoky Mountains National Park and their implications for plants	**S1.O3**
11:10	**Valda Araminiene** (Lithuania). Meteorological conditions and ambient ozone effects on temperate forest vegetation	**S1.O4**
11:30	**Iva Hůnová** (Czech Republic). Mapping changes in spatial patterns of ambient ozone levels	**S1.O5**
11:50	**Matej Rupel** (Slovenia). Air pollutant ozone comparison between city areas and big forest land in Slovenia	**S1.O6**
12:10	**Algirdas Augustaitis** (Lithuania). Ozone flux and its effect in relation to meteorology on ecophysiological reactions in hemi-boreal forest tree species	**S1.O7**
12:30	**Lunch**	
Session 1	**"Monitoring, modelling and assessing the risk of ozone damage to plant ecosystems"** **Chair: Alessandra De Marco**	
14:00	**Alessandro Anav** (Italy). A multi-model framework for ozone risk assessment	**S1.O8**

14:20	**Barbara B. Moura** (Brazil). Exposure- and flux-based assessment of ozone risk to sugarcane plants	**S1.O9**
14:40	**Yasutomo Hoshika** (Italy). Development of stomatal conductance modeling for forest trees under elevated ozone	**S1.O10**
15:00	**Auke Visser** (Netherlands). Multi-scale monitoring and modeling of ozone deposition to ecosystems	**S1.O11**
15:20	**Ionel Popa** (Romania). Passive vs. active: Applicability of Loibl function in modeling hourly ozone concentrations from passive samplers in Romanian Intensive Monitoring Network	**S1.O12**
15:40	**Ioannis Droutsas** (UK). A new crop modelling technique for dealing with ozone stress	**S1.O13**
16:00	**Coffee break**	
Session 1	**"Monitoring, modelling and assessing the risk of ozone damage to plant ecosystems" Chair: Harry Harmens**	
16:30	**Harry Harmens** (UK). ICP Vegetation-Asia: A new policy-focused evidence collecting and risk assessment network for ozone	**S1.O14**
16:50	**Ya Tang** (China). Research is highly required on the impacts of increasing surface ozone in China	**S1.O15**
17:10	**Xue Qiao** (China). Vegetation exposure to ozone in China: model performance and regions needing further field investigations	**S1.O16**
17:30	**Frode Stordal** (Norway). Ozone and climate stresses on sub-Arctic tundra vegetation: Modelling of stomatal fluxes in midnight sun	**S1.O17**
17:50	**Bheki Maliba** (South Africa). Using OJIP transients to monitor the effect of elevated ozone on canola plants, South Africa	**S1.O18**
18:10	**Wine tasting and poster session**	

Wednesday 23rd May, 2018

Session 2	**"How plant ecosystems respond to ozone exposure" Chair: Zhaozhong Feng**	
08:30	**Keynote speaker - Giacomo Lorenzini** (Italy). A mechanistic understanding of ozone impact on forest ecosystems	**S2.O1**
09:00	**Keynote speaker - Youzhi Feng** (China). Elevated ground-level ozone modifies the microbiome	**S2.O2**
09:30	**Conference picture**	
10:00	**Coffee break & Poster Session**	
Session 2	**"How plant ecosystems respond to ozone exposure" Chair: Elena Paoletti**	
11:00	**Harry Harmens** (UK). Impacts of changing ground-level ozone profiles in Europe on vegetation in the current and future climate	**S2.O3**
11:20	**Zhaozhong Feng** (China). The response of water use efficiency in poplar to elevated ozone	**S2.O4**

11:40	**Ane Vollsnes** (Norway). Ozone stress on sub-Arctic tundra vegetation: ozone exposure experiments with daylength manipulation	**S2.O5**
12:00	**Tsetan Dolker** (India). Grassland community response to elevated ozone exposure by assessment of soil dynamics, plant diversity and total biomass	**S2.O6**
12.20	**Lunch**	
Session 2	**"How plant ecosystems respond to ozone exposure"** **Chairs: Lu Zhang**	
13:40	**Keynote speaker - Hakan Pleijel** (Sweden). Ozone impacts on crop yield and food security	**S2.O7**
14:10	**Katrina Sharps** (UK). Global food security modelling: quantifying the threat to crop production from ozone pollution	**S2.O8**
14.30	**Shashi B. Agrawal** (India). Understanding the ozone response in Indian crop plants	**S2.O9**
14.50	**Elina Oksanen** (Finland). Sensitivity of Indian crop plants to ozone	**S2.O10**
15:10	**Michael Frei** (Germany). Breeding of ozone tolerant cereal crops: progress and prospects	**S2.O11**
15.30	**Felicity Hayes** (UK). Impact of ozone on physiology and yield of African crops	**S2.O12**
15.50	**Juliette Leymarie** (France). Responses of crops to ozone exposure: study of physiological parameters	**S2.O13**
16:10	**Daniel B. Ward** (Portugal). Assessing the risk of tropospheric ozone phytotoxic effect on Southern European Mediterranean environments: a review with emphasis on vineyards	**S2.O14**
16.30	**Coffee break**	
Session 2	**"How plant ecosystems respond to ozone exposure"** **Chair: Elisa Carrari**	
17:00	**Laurence Dalstein-Richier** (France). Monitoring ozone, foliar deficit and ozone-specific foliar damage on national forest plots in France over several years	**S2.O15**
17:20	**Sheng Xu** (China). Physiological responses of turf-type *Festuca arundinacea* to elevated O_3	**S2.O16**
17:40	**Anthony Gandin** (France). Multi-level responses to ozone in Euramerican poplars	**S2.O17**
18:00	**Tetsuto Sugai** (Japan). Non-linear responses of two larch species exposed to four ozone levels	**S2.O18**
18:20	**Maamar Benchohra** (Algeria). Effects of short term ozone fumigation on young trees of poplar *Populus nigra*	**S2.O19**
20:00	**Conference dinner** (Palazzo Budini-Gattai Via De Servi 51, see the map at chapter 6)	

Thursday 24th May, 2018

Session 2	**"How plant ecosystems respond to ozone exposure"** **Chair: Alessio Giovannelli**	
8:30	**Md. Ashrafuzzaman** (Germany). Insights into the mode of action of ethylenediurea (EDU) as an antiozonant in rice (*Oryza sativa* L.)	**S2.O20**
8:50	**Richa Rai** (India). Impact of elevated tropospheric O_3 and ambient temperature on early and late sown cultivars of wheat: an insight to biochemical mechanism and yield	**S2.O21**
9:10	**Makoto Watanabe** (Japan). Leaf internal process of photosynthesis in Siebold's beech seedlings under elevated ozone	**S2.O22**
9:30	**Marisa Domingos** (Brazil). The role of secretory glands in plant sensitivity to ozone: an alternative route for uptake?	**S2.O23**
09.50	**Takayoshi Koike** (Japan). Leaf beetle activities on Japanese white birch grown under elevated O_3	**S2.O24**
10:10	**Coffee break & Poster Session**	
Session 2	**"How plant ecosystems respond to ozone exposure"** **Chair: Evgenios Agathokleous**	
11:00	**Ignacio González-Fernández** (Spain). Tropospheric ozone interactions on nitrogen cycling in Mediterranean annual pastures	**S2.O25**
11:20	**Lucienne De Witte** (Switzerland). Ozone flux is negatively related to foliar N and P in Swiss beech and Norway spruce forest	**S2.O26**
11:40	**Alessandra Podda** (Italy). Nutrient fertilization mitigates the effects of ozone exposure on poplar plants	**S2.O27**
12:00	**Lorenzo Labrador** (Switzerland). The WMO's Global Atmosphere Watch: a general overview and services to ecosystems	**S2.O28**
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Session 3	**"How plant ecosystems affect ozone concentration in the atmosphere" Chair: Yasutomo Hoshika**	
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16:30	**Rüdiger Grote** (Germany). Linking ozone susceptibility to induced emissions of biogenic volatile organic compounds	**S3.O3**
16:50	**Xiangyang Yuan** (China). Spatial variability of isoprene emission in China under ambient conditions	**S3.O4**
17:10	**Saxena Pallavi** (India). Ornamental plants used as tool for remediation of ozone pollution in indoor environment	**S3.O5**
17:30	**Discussion: "The future of research on ozone impacts on plant ecosystems" Chair: Harry Harmens**	
18:30	**Closing remarks with delivery of the best poster award Elena Paoletti**	

Friday 25th May, 2018: Scientific excursion

8:00-8:15	Meeting point Piazza della Libertà, 3 (see map at chapter 6)
8:15-8:45	Transfer by bus from Firenze to Sesto Fiorentino
09:00-11:15	Visit of the O_3 FACE facility
11:15-12:15	Transfer by bus to Castello di Verrazzano
12:15-13:30	Visit of the winery
13:30-14:30	Wine tasting and lunch
14:30-15:30	Transfer by bus to Siena across the Chiantishire
15:30-17:00	Free time to visit Siena (see the map in the information material provided for the excursion)
17:00 - 18:30	Transfer by bus to Firenze

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Session 1

Monitoring, modelling and assessing the risk of ozone damage to plant ecosystems

Historical approach to research on ozone and plants

Pierre Dizengremel

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Seventy years ago, Haagen-Smit was commissioned to determine the nature of the smog in Los Angeles, which caused haze, eye irritation and plant damage. Earlier work related that damages to crops were different from those observed in smog episodes in the eastern USA and Europe. Consequently, Haagen-Smit realized that the odor of smog resembled that of oxidized hydrocarbons. He tested the action of ozone and gasoline on crops and got symptoms of damage similar to those caused by smog. Getting similar results with hydrocarbons and nitrogen dioxide under sunlight, he concluded that the smog resulted from the photochemical reaction of hydrocarbons and nitrogen dioxide from car exhausts and fuel combustion, ozone being a secondary pollutant. Visible symptoms of ozone damage on pines were also identified in the mountains surrounding Los Angeles. This breakthrough in knowledge further led to the development of research programs in the USA. Concurrently, in the eighties in Europe, German scientists claimed that the conifers in Germany and France were declining. A fruitful cooperation started between the two countries, followed by European programs, allowing large improvement in knowledge about the physiology of crops and trees and their behavior when exposed to ozone. At the leaf level, the decreased photosynthesis and the increased respiration were the physiological symptoms of a lower growth of plants. The negative impact of ozone counteracting the possible positive effect of an increasing atmospheric CO_2 cannot be denied. To improve the indices of risk assessment, the SUM0 and AOT40 metrics were abandoned in favor of integrating the real quantity of ozone entering the leaf, leading to POD's. The challenge remains to better include the detoxification capacity of cells even though recent work has discussed this aspect. An important point concerns the differences between C_3 (including trees) and C_4 plants. At similar POD's, C_4 plants show a faster decline in metabolic activities under ozone. However, they resist better to ozone in the fields, thanks to their lower stomatal conductance. The study of the behavior of these two groups of plants exposed to ozone and associated stresses (drought, elevated CO_2), and the upscaling to ecosystems, need to be improved.

Keywords: history, smog, ozone, physiology, C_3 and C_4 plants

S1.O1

TOAR-Vegetation: Present day tropospheric ozone distribution and trends relevant to vegetation

Gina Mills[1,2], Håkan Pleijel[2], Chris Malley[3,4,5], Baerbel Sinha[6], Owen Cooper[7], Martin Schultz[8], **Harry Harmens[1]**, Allen S. Lefohn[9], Howard S. Neufeld[10], David Simpson[11,12], Katrina Sharps[1], Zhaozhong Feng[13], Giacomo Gerosa[14], Kazuhiko Kobayashi[15], Pallavi Saxena[16], Elena Paoletti[17], Vinayak Sinha[6], Sverre Solberg[18], Xiaobin Xu[19]

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This paper summarises results from analysis of ozone vegetation metrics as part of the global Tropospheric Ozone Assessment Report (TOAR), submitted to Elementa as TOAR-Vegetation. It reports on the present day global distribution of ozone at over 3300 vegetated sites across the world and on long-term trends at nearly 1200 sites. TOAR-Vegetation focusses on 5 year means (2010-2014) and long-term trends (1995 to 2014 and 2000 to 2014) for M12, AOT40 and W126. These are presented for climatic-zone relevant three months periods for wheat and rice, and for hemisphere-specific six months periods for perennial vegetation. The highest values for these metrics are currently in mid-latitudes of the northern hemisphere, including S USA, the Mediterranean basin, N India, NW and central China, the Republic of Korea and Japan. Ozone concentrations are lowest in Australia, New Zealand, southern parts of S America and some northern parts of Europe, Canada and the USA. W126 and AOT40 were mainly decreasing in North American and European sites (1995 – 2014) whilst M12 values were increasing at many sites in these regions. AOT40 critical levels and W126 values of concern continue to be exceeded in many of these areas, indicating that vegetation is likely to be at risk of negative effects of ozone exposure. In East Asia, primarily represented by sites in Japan and the Republic of Korea, the mean AOT40 and W126 values were higher than those in North America and Europe for perennial vegetation and wheat time-periods. Trend analysis indicated that the ozone threat to vegetation has increased from 1995 to 2014 in Japan, and 2000 to 2014 in the Republic of Korea.

Keywords: Global, ozone metrics, trends, wheat, rice, perennial vegetation

S1.O2

Ozone trends in Great Smoky Mountains National Park and their implications for plants

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Great Smoky Mountains National Park (GRSM) is the most visited national park in the United States and has some of the highest levels of biodiversity of any park unit. It is topographically complex, with an elevational range of 1757 m, yet relatively small in size (~211,419 ha) with maximum width and length of 29 and 52 km, respectively. The Park has historically been subject to elevated levels of pollutants, including sulfur dioxide (SO_2), ozone (O_3), and nitrogen oxides (NOx), and as a result it is one of the most intensively monitored. This paper reports on [O_3] trends from 1989 to 2016 for six monitoring sites in and adjacent to GRSM, ranging in elevation from 564 m to 2030 m. $W126_{12\text{-}h}$ exposure indices (Apr-Oct) were found to have increased from the 1980s until the late 1990s, before reversing and decreasing to the present. Spatially, [O_3] are higher in the western portion and higher elevations of GRSM. The highest 1-h concentration ever recorded was 135 ppb in 1998, but since 2004, only 2 sites have experienced [O_3] $\geq$ 100 ppb. Decreased exposures result primarily from a reduction in [O_3] $\geq$ 60 ppb. Maximum $W126_{12\text{-}h}$ exposures have shifted almost exclusively to earlier in the season (Apr – Jun). Exposure episodes (3 or more consecutive hours with [O_3] $\geq$ 60 ppb) are greatly reduced in recent years and respite periods (2 or more hours with [O_3} < 60 ppb) are more frequent. Decreases in $W126_{12\text{-}h}$ are highly correlated with reduced NOx emissions from regional power plants and are coincident with those found over most of the eastern United States. The combination of shorter episodes and longer respite times, coupled with reduced peak [O_3], suggests plants are at reduced risk from ozone exposure compared to those experienced 20-25 years ago.

Keywords: Smoky Mountains, ozone trends, W126 exposure, plants

S1.O3

Meteorological conditions and ambient ozone effects on temperate forest vegetation

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Tropospheric ozone can cause damage on sensitive vegetation during the growing season. Higher concentrations of tropospheric ozone more often are fixed in the Northern than in the Southern Hemisphere. Ozone concentrations and emissions of ozone precursors vary in the Northern Hemisphere. As a fact, the emissions of ozone precursors are recently slightly decreasing in Europe and North America and increasing in Asia. Lithuania represents temperate forest zone. Despite relatively low mean ambient ozone concentration in Lithuania, its negative impact on vegetation has been recently registered. The local studies indicated that ozone concentration has induced by 5-10% decrease in crop yield. In Lithuania, visible ozone injuries on forest plant leaves are assessed since 2007. The study aim was to estimate interaction between meteorological conditions, ambient ozone level and the severity of visible ozone injuries on species representing temperate forest zone plants. The study was performed in nine Forest Monitoring Level II plots situated in Lithuania during 2007–2017–year period. Visible foliar injuries were assessed in the Light Exposed Sampling Sites (LESS); main meteorology parameters were provided from six meteorological stations located nearby Forest Monitoring plots. Ozone concentrations were measured in two Monitoring Stations, representing the Western and Eastern Lithuania. During the recent decade, mean tropospheric ozone concentration ranged between 25–34 ppb during April–September period in the Eastern part of Lithuania. Meanwhile, in the Western part of the country, the concentration of ozone ranged within 32–37 ppb or it was significantly higher than in the Eastern part. Mean annual ozone concentration slightly increased during last three years. There was found positive correlation between ozone concentration in August and number of plants with visible ozone injury on leaves. The species *Rubus idaeus*, *Frangula alnus*, *Corylus avellana* and *Fraxinus excelsior* were mostly damaged by ozone.

Keywords: Ozone, forest vegetation, Lithuania, defoliation, visible ozone injury, temperate forest

S1.O4

Mapping changes in spatial patterns of ambient ozone levels

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Ambient ozone (O_3) is a key atmospheric constituent. It belongs to green-house gases and plays a major role in atmospheric chemistry. It contributes substantially to the oxidation capacity of atmosphere supporting its self-cleaning capacity. On the other hand its toxic both for human health and ecosystems. The formation of O_3 is highly dependent on meteorological conditions (such as solar radiation, air temperature, relative humidity, occurence of precipitation events) and thus the year-to-year variability of O_3 concentrations is high. In the Czech Republic (CR), ambient ozone concentrations have been observed within a monitoring network since 1993, currently by *ca* 50 measuring sites representing different environments. Our results reveal that, O_3 levels are high enough to harm both human health and ecosystems (Hůnová, Schreiberová 2012; Hůnová et al. 2013, Hůnová et al. 2016). The aim of our contribution is to map the areas potentially at risk from high ambient ozone exposure. Specifically, we intend to indicate the hotspots, where effects of elevated ozone exposures are to be expected and where forests are endangered due to excessive O_3 loads. We present the-year-to-year spatial variability in O_3 concentrations for forested areas. The final output is a map showing risk areas in the Czech forests averaged over the period of 2000–2015, the risk being defined in relative terms.

Reference:
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Hůnová I., Stoklasová P., Schovánková J., Kulasová A. (2016): Spatial and Temporal Trends of Ozone Distribution in the Jizerské hory Mountains of the Czech Republic. Environmental Science and Pollution Research 23, 377–387.

Keywords: ambient ozone, concentrations, risk areas, spatial variability

S1.O5

Air pollutant ozone comparison between city areas and big forest land in Slovenia

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Ozone is important air pollutant, dangerous for plants, animals and human health.
The Slovenian Forestry Institute (SFI) have 15 years experiences (2003 – 2017), assessing ozone visible injury on forest vegetation in Slovenia, observed as foliage damage on the forest trees and shrubs species. During these years the visible ozone damages were observing at 5 to 11 intensive monitoring plots (ICP Forests Level II) and some last years also in Ljubljana urban and peri-urban forests**.** In the same time span the SFI has been monitoring ozone concentrations in the air with passive samplers. In 2013, we expanded air monitoring to three other pollutant gases: sulphur dioxide, nitrogen dioxide and ammonia. We monitor air pollution with passive samplers also in the capital of Slovenia – Ljubljana. We perform measurements in urban areas and urban and peri-urban forests (city parks, nature park, forest covered hill, riparian forests). Identification of visible ozone or visible ozone like symptoms in small trees and shrubs in Ljubljana urban forests was performed. Visible foliar injury by ozone we surveyed on 3 *off-plots*, on light-exposed sampling sites at urban forest edge according to the ICP Forests manual. Our observations of negative impacts of ozone on forest tress, we compare between city areas in Ljubljana and big forest land Kočevska. Kočevska landscape is one of the most naturally preserved parts of Slovenia and Central Europe. 90% of the province is covered by forests, predominantly Dinaric fir and beech forests. We looked different forest trees and shrubs species. Different species show different sensibility to the same ozone dose. We also try to compare ozone visible damages vegetation and ozone concentrations values in the air with passive samplers.

S1.O6

Ozone flux and its effect in relation to meteorology on ecophysiological reactions in hemi-boreal forest tree species

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In the presented study the causative relationships between environmental factors and tree ring width formation of the prevailing in Lithuania tree species as the main parameters of tree capacity to adapt to and mitigate the recent global changes at hourly and diurnal scales were investigated. The obtained data revealed that Norway spruce trees are better adapted to recent climatic conditions in temperate forest than Scots pine and birch trees. Even during the drought episode spruce stem increment exceeded increment of the rest of the considered tree species. Scots pine seems to be the most sensitive species to seasonal environmental changes. The highest reversible fluctuations in stem circumference on hourly scale resulting from meteorology and surface ozone became the main drivers of their gradually increasing growth intensity. Silver and Downy birch tree reactions indicated the lowest sensitivity of these tree species not only to unfavorable environmental factors but also to favorable factors which should stimulate tree growth intensity. This is why the growth intensity of these tree species recently has been gradually decreasing. The hypothesis that the coniferous species are more adaptive to recent climate changes and their capacity to mitigate the threats of global changes is higher than that of deciduous tree species was confirmed. The study is based on the results obtained conducting national project supported by Lithuanian Council of Research “FOREstRESS” (SIT- 3/2015).

Keywords: ozone flux, meteorology, stem circumference, integrated effect

S1.O7

A multi-model framework for ozone risk assessment

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Plant ecosystems play a key role in regulating the concentration of air pollutants in the planetary boundary layer. Among common air pollutants, O_3 is probably the most damaging to forests and crops, frequently reaching high concentrations over large regions of the world and particularly in Mediterranean area. However, O_3 effects on vegetation depend not only on the atmospheric concentrations but also on O3 uptake through the stomata. Therefore, the quantification of the amount of ozone removed from the atmosphere, and the consequent injuries to vegetation, are particularly relevant for climate, ecological and risk assessment studies. We developed a regional multi-model framework to be used for integrated risk assessment and for studies on potential risks caused by O_3 pollution on European forests. This framework relies on a mesoscale model that generates climate forcing used offline to run a Chemistry Transport Model (CTM). The O_3 concentrations computed through the CTM (CHIMERE) and the climatic variables computed by a regional weather forecast model (WRF) combined with a stomatal conductance model, allowed us to estimate the stomatal O_3 fluxes using different phenological models and assumptions on the water uptake by plants at different soil depths in the rooting zone and to evaluate the differences between an exposure-based index (i.e. AOT40) and an index based on the effective absorbed O_3 dose (i.e. PODY).

Keywords: O_3, AOT40, POD_Y, DO_3SE, Plant Phenology

S1.O8

Exposure- and flux-based assessment of ozone risk to sugarcane plants

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Ozone (O_3) is a toxic oxidative air pollutant, with significant detrimental effects on crops. Sugarcane (*Saccharum* spp.) is an important crop with no O_3 risk assessment performed so far. This study aimed to assess O_3 risk to sugarcane plants by using exposure-based indices (AOT40 and W126) based on O_3 concentrations in the air, and the flux-based index (POD_y, where y is a threshold of uptake) that considers leaf O_3 uptake and the influence of environmental conditions on stomatal conductance (g_{sto}). Two sugarcane genotypes (IACSP94-2094 and IACSP95-5000) were subjected to a 90-day Free-Air Controlled Experiment (FACE) exposure at three levels of O_3 concentrations: ambient (Amb); Amb x1.2; and Amb x1.4. Total above-ground biomass (AGB), stalk biomass (SB) and leaf biomass (LB) were evaluated and the potential biomass production in a clean air was estimated by assuming a theoretical clean atmosphere at 10 ppb as 24 h O_3 average. The Jarvis-type multiplicative algorithm was used to parametrize g_{sto} including environmental factors such as air temperature, light intensity, air vapor pressure deficit, minimum night-time temperature. Ozone exposure caused a negative impact on AGB, SB and LB. The O_3 sensitivity of sugarcane may be related to its high g_{sto} (~535 mmol H_2O m^{-2} s^{-1}). As sugarcane is adapted to hot climate conditions, g_{sto} was restricted when the current minimum air temperature (T_{min}) was below ~14°C and the minimum night-time air temperature of the previous day (T_{nmin}) was below ~7.5°C. The flux-based index (POD_y) performed better than exposure-based indices in estimating O_3 effect on biomass losses. We recommend a y threshold of 2 nmol m^{-2} s^{-1} to incorporate O_3 effects on both AGB and SB and 1 nmol m^{-2} s^{-1} on LB. In order to not exceed 4% reduction in sugarcane growth, and considering the genotypes we recommend the following critical levels: 1.09 and 1.04 mmol m^{-2} POD_2 for AGB, 0.91 and 0.96 mmol m^{-2} POD_2 for SB, and 3.00 and 2.36 mmol m^{-2} POD_1 for LB of IACSP95-5000 and IACSP94-2094 respectively.

Keywords: tropospheric ozone, POD_y, stomatal conductance, ozone FACE, air pollution

S1.O9

Development of stomatal conductance modeling under elevated ozone for forest trees

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Ozone enters leaves via stomata and causes a damage to leaves of trees. Modeling of stomatal conductance (g_s) is considered as an essential factor to assess ozone impacts. In this presentation, recent developments for the modeling of g_s are summarized: 1) we reviewed 235 publications of field-observed g_s for the parameterization of Jarvis-type model in global woody plant functional types (PFTs). The relationships between stomatal parameters and climatic factors (MAT, mean annual air temperature; MAP, mean annual precipitation) were assessed, and 2) to discuss the effect of ozone on g_s, an analytical model was proposed based on the optimization theory for maximizing carbon gain while minimizing concurrent accompanying water loss and ozone influx. Regarding 1), we found that maximum stomatal conductance (g_{max}) in global woody plants correlated with MAP rather than MAT. The optimal temperature of g_s and stomatal response to predawn water potential changed according to the growth conditions. Regarding 2), in the ozone FACE (Free-Air Controlled Exposure) experiments, the optimal stomatal model explained ozone-induced stomatal closure in early summer. This suggests that ozone-induced stomatal closure may reduce ozone influx, and allow maximum photosynthetic capacity to be reached. However, in late summer and autumn, the model did not explain the effects of ozone on stomatal conductance. Also an increase of y-intercept of photosynthesis-stomatal conductance relationship (g_{min}, minimum conductance) was found. This reflects the loss of closing response of stomata by ozone (i.e., stomatal sluggishness). In fact, in late summer, ozone caused : 1) slower dynamic stomatal response to light variation, 2) less sensitivity of stomata to vapour pressure deficit (VPD), 3) reduced sensitivity of stomata to abscisic acid (ABA) and 4) increased night-time stomatal conductance. As a result g_{min} increased with increasing cumulative ozone uptake among species.

Keywords: ozone, stomatal conductance, stomatal conductance model, maximum stomatal conductance, stomatal sluggishness

S1.O10

Multi-scale monitoring and modeling of ozone deposition to ecosystems

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Ozone uptake through stomata damages plant tissue, thereby reducing plant photosynthetic capacity and thus, at a larger scale, inhibiting carbon sequestration by ecosystems. Assessments of such O_3-CO_2 atmosphere-biosphere interactions rely on combined O_3 and CO_2 flux observations. Although essential for process studies focusing e.g. on in-canopy ozone loss mechanisms, O_3 flux data coverage is too sparse in space (only a few European flux measurement sites) and time (often only several years of data) to assess O_3 deposition impacts on ecosystem functioning at a continental scale. Our approach aims to gain a such a larger-scale insight into O_3-CO_2 interactions by combining various modelling approaches with in situ and remote sensing (RS) observations to study ozone deposition impacts on ecosystem functioning in Europe. We use the regional atmospheric chemistry and transport model WRF-Chem to simulate O_3 and its precursor gases nitrogen oxides (NO_x) and volatile organic compounds (VOCs) during a summer season. NO_x emissions in WRF-Chem are constrained using satellite NO_2 column observations from the Ozone Monitoring Instrument. We expect that this will especially improve model-simulated peak O_3 concentrations and deposition fluxes. In addition, a chemical canopy-exchange model is applied for various O_3-CO_2 flux measurement sites to simulate ecosystem NO_x-VOC-O_3 interactions and to assess the partitioning between stomatal and non-stomatal O_3 flux components. The O_3-induced impacts on ecosystem carbon sequestration will eventually be quantified in a multivariate statistical framework combining the highly-resolved O_3 flux simulations and RS-based vegetation productivity products.

Keywords: ozone deposition, air pollution modelling, remote sensing

S1.O11

Passive vs. active: Applicability of Loibl function in modeling hourly ozone concentrations from passive samplers in Romanian Intensive Monitoring Network

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Ozone was monitored using Ogawa passive samplers during 2010 - 2016 growing seasons (biweekly) in four Romanian ICP-Forests Level II Intensive Monitoring plots: Stefanesti-stejar (88 m a.s.l. minimum on a 5 km radius 70 m a.s.l.), Mihaesti-gorun (405 m, 312 m), Fundata-fag (1119 m, 840 m) and Predeal-molid (1107 m, 780 m). Also, hourly ozone concentrations were measured some of the years in all plots. AOT40 was modeled from passive samplers using Loibl function and also calculated from hourly measurements where data were available. The differences between real and estimated AOT40 were significant in all cases, the index calculated based on passive samplers overestimating ones based on hourly ozone concentrations by 67% (2015) - 448% (2016) at Stefanesti-stejar plot, by 75% (2013) – 1485% (2014) at Mihaesti plot, by 173% in 2015 and 1515% in 2016 at Predeal-molid plot and by 102% in 2015 at Fundata-fag plot. In addition, when comparing seasonal mean ozone concentrations derived from active and passive monitoring, the differences are both negative and positive, ranging from -14% in 2015 at Stefanesti-stejar plot to 77% in 2012 at Mihaesti-gorun. These are preliminary results question the applicability of Loibl function for modeling hourly values from passive samplers in Romanian conditions. In the light of the new developed critical levels for ozone based on the pollutant uptake through stomata, the next step is modelling and comparing PODx values from active and passive measurements.

Keywords: passive samplers, Loibl function, AOT40, ICP-Forests level II

S1.O12

A new crop modelling technique for dealing with ozone stress

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Crop protection and preservation is a crucial aspect of food security in a world where food supply is becoming an even bigger challenge for the continuously increasing population. Plants are influenced by a wide range of biotic and abiotic factors which play an important role on their performance and yield. High air pollution levels can damage plant ecosystems while ozone is the most phytotoxic air pollutant at a global scale. Moreover, changes in climatic parameters such as water availability and temperature can be combined with high air pollution levels to impact on crop yield. Crop models are tools for quantifying the growth and development of crops and their responses to stresses. However, only a few crop models include an ozone stress parametrization. Here we introduce a significant modification to an existing crop model (GLAM) in order to apply an ozone dose-response function into the model. The new model version is called GLAM-ROC (GLAM-Relative Ozone Concentrations) and accounts for the ozone impact on wheat. Before the inclusion of the ozone effects, the wheat version of GLAM model was re-parametrized and a new modelling technique has been introduced into the model. This new approach is based on a simultaneous solution of the set of model equations instead of the prevailing step-by-step method used in most crop models. The model was made conceptually simpler by taking in integrated systems approach. The new structure improves the model skill under water stress conditions. GLAM-ROC is therefore suitable also in environments where ozone interacts with other stresses, such as drought.

S1.O13

ICP Vegetation-Asia: A new policy-focused evidence collecting and risk assessment network for ozone

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Reporting to the United Nations Convention on Long-Range Transboundary Air Pollution, the ICP Vegetation involves over 250 scientists representing 50 countries. For ozone, the primary objectives are to (i) collate and review evidence of impacts on vegetation and (ii) to assess spatial patterns and temporal trends in the risks of damage from current and future ozone. As part of the Convention's outreach activities, the ICP Vegetation is developing a new Asian network, ICP Vegetation-Asia. The network is being coordinated by Prof. Kim Oanh of the Asian Institute of Technology, Thailand and will initially focus on food security impacts. Assisted by the ICP Vegetation Coordination Centre in the UK, the first phase of activities is on the theme of "seeing is believing", aiming to show policy makers that effects on crops should also be considered along with effects on health. Activities will include a review of evidence presented in the published and "grey" scientific literature and the establishment of a network of sites where sensitive ozone species (SOS) will be used to draw the attention of policy makers, agronomists and the public to the growing ozone problem in Asia. An initial pilot study will be conducted in 2018 at selected sites in S and SE Asian countries, involving ozone-sensitive and –resistant bean varieties grown together with local varieties. The distinctive visible symptoms on the beans will be used to provide "SOS" warnings of the pollutant's potential to damage food crops. Later activities will include expansion of the SOS network, the development of region-specific critical levels and flux-based risk assessments and organising knowledge exchange workshops. Policy makers are involved from the start to ensure the activities of ICP Vegetation are suitably focussed on policy needs. New groups from Asia are very welcome to join the network.

Keywords: ozone, crops, network, field evidence, visible injury, food security, Asia

S1.O14

Research is highly required on the impacts of increasing surface ozone in China

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Environmental pollution has increased quickly in parallel with fast economic growth in the past three decades in China but has not received adequate attention until about two decades ago. In the past decade, air pollution, particularly PM2.5 pollution has been the focus of the public and many research projects. Public awareness about the effects of PM2.5 on human health has been an important driving force to initiation of many research projects in China. Unlike PM2.5, surface ozone pollution is known only to a very limited number of people despite its recent quick increasing trend in many Chinese cities and its effects on human health and ecosystems. Existing research on ozone in China is largely focused on the effects of ozone on crops and some plants and on characterizing ozone pollution in urban areas. As a result of increasing public awareness about environmental pollution, declining use of coal and fast increasing vehicle population, air pollution in China has been in the transition from that caused largely by coal burning to complex pollution caused by coal burning, use of natural gas and transport. Further increase in surface ozone concentrations is expected in many parts of China. To reduce the effects of elevated ozone in China, research and international collaboration are highly required not only on changes in ozone trend in the urban areas, but on ozone impacts on forests. As the effects of air pollution including ozone on forests are probably seen after decades, building on achievements of existing international knowledge, it would be greatly important to plan and implement integrated research framework on impacts of surface ozone pollution in China. Our surface ozone monitoring and field observations in a few remote forests in southwestern China corroborate the significance of international collaboration and the urgent need for research programs.

S1.O15

Vegetation exposure to ozone in China: model performance and regions needing further field investigations

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As surface ozone concentrations have increased significantly in many regions of China, it is concerned that ozone exposure to forests across the country, particularly those in the national nature reserves and biodiversity hotspots, may have exceeded foliar injury threshold values. To quantitatively assess the impacts of ozone to forests, several most frequently used ozone exposure indices (M7, M24, SUM60, W126, and AOT40f) were calculated using simulated hourly from the Community Multiscale Air Quality (CMAQ) model for the year of 2013. While the annual average ozone concentrations (M7 and M24) were generally higher in the Qinghai-Tibetan Plateau (QTP) in western China due to higher background ozone, the other three ozone exposure indices (SUM60, W126, and AOT40f) were lower in most parts of QTP. In contrast, the North China Plain (NCP) and Yunnan Province had lower annual average concentrations but higher values of SUM60, W126, and AOT40f, as they had larger numbers of high ozone hours (i.e. hourly concentration>100 ppb). The west rims of Sichuan Basin and some regions in the southern and eastern rims of QTP had relatively higher values of all the five exposure indices. Compared with critical loads reported in the literature, about 80% and 75% of forests had SUM60 and W126 higher than the critical load for natural ecosystems (12 ppm-h) for moderately sensitive plant species (23.8 ppm-h), respectively. In addition, about 90% of forests had AOT40f values higher than the critical load of 10 ppm-h. Based on the spatial distributions of ozone exposure, forests, and nature reserves, we suggest that future field observation studies of forest injuries due to air pollution should be prioritized for forested regions in the Yunnan Province, eastern and southern rims of QTP, and western rim of Sichuan Basin.

S1.O16

Ozone and climate stresses on sub-Arctic tundra vegetation: Modelling of stomatal fluxes in midnight sun

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The coupling of biogeochemical and biogeophysical processes are the focus of an interdisciplinary project, OzoNorClim, on the northernmost parts of Fennoscandia, which is exposed to 24 hour daylight during summer, possibly inhibiting night-time repair of ozone-damaged cells and making plants more vulnerable to ozone damage (http://www.mn.uio.no/ibv/english/research/sections/evogene/projects/ozonorclim/).
With less sea ice in the Arctic Ocean, more ships are passing the coast of Northern Fennoscandia, causing increased emissions of ozone precursors. Warming at high latitudes has led to changes in the boreal and Arctic vegetation cover, “Arctic greening”, which is observed across the circumpolar Arctic and boreal region. In particular increase of shrub vegetation cover in the Arctic biomes is a fast response to warming in high latitudes ecosystems. Emission of Biogenic Volatile Organic Compound (BVOC) from expanding shrubs is expected to yield ozone production. Further, oil exploration is being planned in the Barents Sea adjacent to the coastal areas, also yielding ozone precursor emissions. The combination of elevated ozone exposure and potentially higher than expected ozone sensitivity of tundra plants could lead to a much higher ozone effect risk, with negative impacts on the ecosystem (biodiversity) and local economies (livestock farmers). We have modelled stomatal ozone fluxes in a selection of tundra plants. The Deposition of Ozone for Stomatal Exchange (DO3SE) model coupled to the Weather Research and Forecasting model coupled with chemistry (WRF-Chem) has been used for this purpose, applying emissions from increased shipping in the Arctic, potential oil exploration in the Barents Sea, and the expanding shrub cover in the Arctic. Results are presented in terms of the 24 hour accumulative stomatal ozone flux above an hourly threshold Y (in nmol m^{-2}); the Phytotoxic Ozone Dose (POD_Y), e.g. POD_6. Concentration based metrics are also used, such as AOT40 and SUM06 (accumulated exposure when ozone exceeds 40 or 60 ppb).

Keywords: stomatal fluxes, plant stress, repair inhibition, ozone precursor emissions, shipping, oil exploration, shrub expansion

S1.O17

Using OJIP transients to monitor the effect of elevated ozone on canola plants, South Africa

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The effects of high ozone levels (80 and 120 ppb) on photosynthetic efficiency and growth of canola plants were studied in open-top chambers. The chlorophyll *a* polyphasic fluorescence rise kinetics OJIP, stomatal conductance, Chlorophyll Content Index (CCI) and biomass were measured after 15 and 30 days of ozone fumigation, as well as in control plants. Analysis of the OJIP kinetics by the JIP-test led to the calculation of several photosynthetic parameters and the total Performance Index (PI_{total}). The observed decline of PI_{total} under the 80 ppb ozone treatment (about 10%, both after 15 and 30 days of fumigation) was due to a lower density of reaction centers (RC/ABS), while the notable decline under the 120 ppb (about 60% after 15 days and about 85% after 30 days) was found to be due to both a further decline of RC/ABS and the pronounced lowering of the efficiency with which an electron can move from the reduced intersystem electron acceptors to the PSI end acceptors (δ_{Ro}). Stomatal conductance was affected by both treatments, already after 15 days of fumigation, with a decrease of about 45% that reached about 55% after 30 days under 120 ppb ozone. Biomass was found to be affected by ozone fumigation, decreasing by 40% at 80 ppb and by more than 70% under 120 ppb, *i.e.* under a two times and three times, respectively, higher ozone concentration than the limit (40 ppb) known to be tolerated by agricultural crops. Our findings indicate that biomass decline is due to both the lowering of CCI and the photosynthetic efficiency parameters. They thus suggest that two simple, non-invasive and rapid methods, namely the analysis of OJIP fluorescence transients and the measurement of CCI, can be used to screen the effect of elevated ozone on the growth rate of canola plants.

Keywords: canola; chlorophyll *a* fluorescence; JIP-test; open-top chamber; ozone

S1.O18

Session 2

How plant ecosystems affect ozone concentration in the atmosphere

A mechanistic understanding of ozone impact on forest ecosystems

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Changes in air chemistry and subsequent physical changes in the environment have a profound effect on the classic “disease triangle”. Environmental factors alter ecosystem health and host susceptibility to biotic and abiotic factors. Plant response to various disease-causing stressors can be changed through introducing ozone (O_3) into the system. These effects are variable, depending on the timing, intensity and order of the exposure. It is well known that O_3 may produce on a plant functional alterations even without, before the onset of, or in addition, to macroscopic effects. Plants are able to respond to O_3: several potential mechanisms comprehending exclusion, tolerance, compensation and repair may work simultaneously to create a complex signaling network. These include changes in photosynthesis, cellular redox homeostasis, perception by apoplastic proteins, oxidative damage to membranes, hormonal regulation of the lesion formation, modulation of osmoprotectants and activation of enzymatic and non-enzymatic antioxidant systems. Within a single species, differences in structural, functional and transcriptional traits may play important roles in adaptation/acclimation to environments characterized by high oxidative pressure. Functional traits can predict plant behavior in its natural environment and have been correlated to the degree of tolerance to oxidative stress. The science to accurately describe how O_3 (alone and/or in combination with other biotic/abiotic stressors) affects plants and ecosystems in a changing climate is of paramount importance to guide political decision making. Diagnosis based on plant sampling and physiochemical analysis using traditional laboratory methods can be precise, but have a number of limitations as they are commonly time-consuming, destructive, and expensive. An alternative approach to monitoring ecosystem functions includes the development of new technologies, advancing computational capacity and improving methodological approaches to environnemental monitoring.

Keywords: global change, abiotic stress, plant response, disease triangle, O_3, oxidative burst, signaling network

S2.O1

Elevated ground-level ozone modifies the microbiome

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Elevated ground-level ozone (eO_3) imposes adverse influences on ecosystems. However, the information regarding responses of belowground, such as soil microorganisms, to eO_3 as well as their feedbacks remains elusive. As the indispensable part of soil ecosystem, the knowledge on soil microorganisms is pivotal to comprehensive understanding of global change influencing ecosystem. To this end, a field experiment in China Ozone Free-Air Concentration Enrichment (FACE-O_3) facility on a rice-wheat rotation system was carried out to investigate paddy microbial responses to eO_3. Using real-time quantitative PCR, DNA-based fingerprinting and high throughput sequencing approaches in combined with culture-reliant method, we evaluated two paddy anoxic microorganisms, anoxygenic phototrophic purple bacteria (AnPPB) and methanogenic archaea, and total bacterial communtiy in response to eO_3 as well as the differences between different O_3-sensitive rice cultivars. It is found that eO_3 reduces AnPPB and methanogenic archaeal abundances in flooded rice soils via decreasing their genotypic diversity and metabolic capability. Concomitantly, their community compositions changes under eO_3. For total bacterial community, the similar phenomena are observed. Furthermore, when comparing two different O_3-sensitive rice cultivars, it is found that crop cultivar is important in determining the responses of soil biota to eO_3. The contrasting responses of soil bacterial and methanogenic archaeal communities in two rice cultivars are observed to eO_3. Although more adverse influences on O_3-sensitive cultivar, several keystone bacterial guilds are consistently negatively affected by O_3 pollution in two rice cultivars. Collectively, the abovementioned findings indicated that continuously eO_3 would negatively influence paddy microorganisms and their critical ecological functions and more attention should be focused on the responses of soil microorganisms in crop cultivars when evaluating the effect of climate change on agroecosystems. These findings will contribute to a comprehensive understanding of the responses and feedbacks of paddy ecosystems to global climate change.

Keywords: Elevated ground-level O_3, Soil microorganisms, Diversity, Paddy soil, Rice cultivars

S2.O2

Impacts of changing ground-level ozone profiles (peak vs background) in Europe on vegetation in the current and future climate

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Recent decades have seen a changing profile of ground-level ozone (O_3) in Europe. While peaks in O_3 concentrations during summer months have been declining in amplitude, background concentrations have gradually increased as a result of the hemispheric transport. Two case studies were conducted to assess the implications for impacts on 1) crop yield and 2) stomatal O_3 fluxes in (semi-)natural vegetation and tree species in future climates: 1) A modern wheat cultivar (Skyfall) was exposed to eight different realistic O_3 profiles repeated weekly: four profiles with increasing background O_3 concentrations (ca. 30 – 60 ppb) and four profiles with increasing O_3 peak concentrations (ca. 35 – 110 ppb). Both wheat yield and 1000-grain weight declined linearly with increasing stomatal O_3 flux. The slope of the flux-effect relationship was not affected significantly by the O_3 profile. Hence, flux-effect relationships developed for wheat based on exposure to enhanced peak O_3 concentrations are also valid for the changing European O_3 profile with higher background and lower peak concentrations. In addition, the modern wheat cultivar Skyfall is more sensitive to O_3 than older wheat varieties. 2) A modelling study using measured site-specific data showed that increases in stomatal O_3 uptake in future climates were larger in northern and mid-Europe than in southern Europe, and showed a strong relationship with latitude. O_3 concentrations as low as 10 ppb can contribute to stomatal O_3 uptake that can be above the Y threshold for accumulation of the Phytotoxic Ozone Dose (POD_Y) of 1 nmol O_3 m^{-2} s^{-1} for trees and (semi-)natural vegetation. Therefore, impacts of O_3 pollution could occur at any time of year when plants are actively growing and not just during periods of peak O_3 concentrations. Contrasting impacts of climate change (+2°C, -20% rainfall) on stomatal O_3 fluxes in northern and southern Europe will be discussed.

Keywords: Background ozone: ozone episodes; climate change; wheat; *Betula pendula; Dactylis glomerata; Leontodon hispidus*

S2.O3

The response of water use efficiency in poplar to elevated ozone

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Ground-level ozone (O_3) negatively influences carbon and water balance by both photosynthesis and stomatal control of plant transpiration and decline in water use efficiency (WUE). We combined stable dual isotopic signatures $\delta^{13}C$ and $\delta^{18}O$ of leaves as well as instantaneous gas exchange performance to determine the effects of both O_3 and leaf aging on light-saturated photosynthetic rate (A_{sat}) and stomatal conductance (g_s) in poplar clones '546', and poplar clones '107' exposed to five O_3 levels in open-top chambers for one growing season. Intrinsic WUE decreased with increasing O_3 concentration for all species, and it was more affected in mature than young leaves. The tight coupling of A_{sat} and g_s occurred at ambient O_3 condition, but uncoupled under higher O_3 treatment, as A_{sat} decreased while g_s did not response or increase. Ozone exposure increased stomatal sluggishness, and caused progressive loss in stomatal control over transpiration during the growing season. Furthermore, Ozone-induced reductions of g_m and V_{cmax} may play key roles in limiting A_{sat} and thus decreasing WUE. Mild-drought increased WUE, while O_3 decreased it. But no significant interactions were detected. Our results suggest that O_3-induced loss of stomatal control could have an aggravating effect on carbon assimilation and water use efficiency of forest trees under future O_3-enriched air.

Keywords: $\delta^{13}C$, $\delta^{18}O$, ozone, photosynthesis, stomatal conductance, mesophyll conductance, water use efficiency

S2.O4

Ozone stress on sub-Arctic tundra vegetation: ozone exposure experiments with daylength manipulation

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The coupling of biogeochemical and biogeophysical processes are the focus of an interdisciplinary study on the northernmost parts of Fennoscandia, which is exposed to 24 hour daylight during summer, possibly inhibiting night-time repair of ozone-damaged cells and making plants more vulnerable to ozone damage (http://www.mn.uio.no/ibv/english/research/sections/evogene/projects/ozonorclim/).
The sub-Arctic tundra has its western limit in Northern Norway. Many of the dominant plant species found there are also important in other circumpolar tundra areas. Therefore, increased knowledge of these species' reaction to increased tropospheric ozone concentration is of great importance to climate modelling. Further, farmers in these areas grow grass and clovers to feed livestock, using cultivars adapted to short summer season and frost. Hence, there is also an economic interest in understanding the impact of ozone and climate change on plants of the northern latitudes. Several *Trifolium* species have shown increased ozone sensitivity in response to long as compared to short daylength. The effect was not due to differences in ozone doses or physiological status of the plants. We hypothesize that the lack of night-time repair in darkness may, at least partly, contribute to the reported increased ozone sensitivity. Although one may assume that the local vegetation is adapted to long days in northern latitudes, the ability to repair damages due to oxidative stress may be lower than in areas with dark periods during night, as seen in a *Trifolium pratense* cultivar developed in Sweden (65°N). Thus, plants growing in northern areas may be more sensitive to ozone than expected. We have grown plants from two sources: species native to the tundra, including expanding bushes, and frequently used grass and clover species in meadows North of 67°N for ozone exposure experiments. The daylength dependency of the ozone sensitivity and impacts on visible injuries, stomatal conductance, photosynthesis rates and night-time respiration were studied.

Keywords: tundra vegetation, ozone sensitivity, stomatal conductance, visible injuries, night-time repair

S2.O5

Grassland community response to elevated ozone exposure by assessment of soil dynamics, plant diversity and total biomass

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Tropospheric ozone (O_3) is a serious threat to global food security as well as to natural vegetation. The phytotoxic effects of O_3 on agricultural plants are well known, but its effects on natural grassland community and their belowground soil health are yet to be ascertained in developing countries. Considering these facts, plant composition and soil physiochemical properties of grassland (semi-natural community) were assessed in response to ambient (48ppb) and elevated (Ambient+20ppb) O_3 treatments in open top chambers installed directly on semi-natural grassland community. Elevated ozone induced alterations in soil properties with significant reductions in soil microbial biomass, total nitrogen, organic carbon, available phosphorus, β-glucosidase activities and polyphenol oxidase enzyme activities, while phosphatase enzyme activity was significantly increased under elevated O_3 concentration. O_3 treatment also showed significant decline in most of the soil nutrient contents (Na, Mg, K, Zn, Fe and Cu) compared to ambient, suggesting influence of O_3 in altering soil nutrient availability. Morphological characterization of dominant grass species such as of *Digitaria sanguinalis* and *Brachiaria* sp. showed significant reductions in shoot and root height, number of leaves, dry weights of shoot and leaves, whereas in case of *Cynodon. dactylon*, a positive effect of elevated O_3 on plant biomass was recorded. The root dry weight of *Brachiaria* sp increased but of *Digitaria sanguinalis* decreased under elevated O_3 concentration. The total above ground biomass measurement of community showed increase in grass contribution whereas forbs biomass declined significantly under elevated O_3 compared to ambient. The variabilities in most of the soil parameters and differential sensitivity of two functional groups clearly suggest that elevated ozone may cause shift in community pattern due to changes in soil properties.

Keywords: Ozone; grass; soil properties; semi-natural grassland community; soil microbial biomass; soil enzymes

S2.O6

Ozone impacts on crop yield and food security

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Tropospheric ozone is generally considered to be the globally most important air pollutant with respect to effects on crops. Today, elevated levels of ozone are known to occur over large areas of the world´s important agricultural production areas in Asia, Europe and North America. In other geographical regions the degree of ozone pollution and its effects on agriculture are less well known, but are likely to be significant. When assessing and communicating the importance of ozone for crop production and food security the evidence of effects from current ozone exposure is of particular importance. Although plant response to experimentally elevated of ozone is important for risk assessment and the derivation of response functions, effects of present ozone are highly relevant from a policy perspective, to evaluate the gains from reducing current air pollution, rather than to estimate the damage by potential future elevated ozone levels. The evidence of effects from present ozone comes mainly from bioindication, protection of plants by use of the ozone protectant chemical EDU and (meta-)analysis of the effects of reducing ozone by air filtration in chamber experiments. Examples of these three types of evidence will be given as well as of response functions based on stomatal ozone uptake including elevated ozone treatments. There is strong evidence that the variation in ozone sensitivity varies among crops species. A corresponding variation has also been established for different cultivars or varieties of certain crop species. The magnitude, statistical evidence and potential exploration, e.g. in decisions on the choice of crop and in plant breeding, of this variation will be described and exemplified. Also the causes for variation in sensitivity, depending on stomatal ozone uptake, antioxidant defense and crop life history, will be discussed. An important matter is the reasons why the threats of ozone to food security is often neglected in policy and agronomic contexts. Potential explanations for this will be outlined along with suggestions of ways to remedy this problem. Highlighting experimental evidence of ozone effects on crops from interaction experiments where ozone exposure was administered in combination with other environmental factors, like temperature, irrigation/water availability, fertilization and elevated CO_2, which are familiar to agronomists and/or plant physiologists, is one example. The direct comparison of ozone effects with those from other factors could facilitate the communication of the importance of ozone effects. Another benefit from this approach is that it will promote an integrated analysis of different environmental drivers on food security, including ozone, which will be necessary in any case to understand the net effect of the multitude of aspects of global change. Finally, scenarios for the future development of ozone effects on food security will be given. Obviously, the long-term development will depend on a range of decisions related to emissions of ozone precursors including methane, climate change and adaptation of crops and agriculture. Current trends for ozone exposure of crops in different parts of the world will be described as well as projections of surface ozone development over the present century. To conclude, a reflection will be made over how international policy making can best handle the threats from ozone to food security.

S2.O7

Global food security modelling: quantifying the threat to crop production from ozone pollution

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At the global scale, ozone pollution has been predicted to pose as big a threat to food security as climate change by 2030. Several of the world's most important crops such as wheat, soybean, maize and rice respond to ozone pollution by decreasing vegetative growth, seed production and root growth, leading to reductions in both quantity and quality of yield. We have developed response functions relating crop yield and associated key crop processes to the cumulative stomatal uptake ("flux") of ozone modelled from plant, soil and climate factors and applied these models on a global scale to predict impacts of ozone on food security. Evidence from European chamber and field studies shows that the uptake of ozone by stomata (flux) is a superior predictor of ozone damage, compared to more conventional exceedance of ozone threshold concentrations. This analysis presents a major step forwards from previous predictions of risk based on ozone concentration as it includes the modifying effects of climate and soil moisture (including irrigation) on instantaneous ozone uptake and subsequent effect. We show that ozone is currently reducing wheat yield by 9% globally and causes a total of 49 million tonnes (Tg) of lost grain in the five biggest producing countries (China, India, USA, Russia and France). Within these countries, effects are highest where irrigation is already in use or in areas where rainfall is sufficient to ensure soil moisture is non-limiting to stomatal uptake. We also show the regions of the world where soybean, maize and rice are being impacted by ozone, and discuss other possible factors contributing to yield loss. This work highlights the spatial variability of global impacts of ozone pollution on crop production and demonstrates the need to consider ozone pollution as a modifying factor in global crop production and food security modelling.

Keywords: food security; global mapping; stomatal flux; yield loss; wheat

S2.O8

Understanding the ozone response in Indian crop plants

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Tropospheric ozone (O_3), a secondary air pollutant and a major greenhouse gas, has already been recognized as a prime component of predicted global climate change. Numerous studies have confirmed the negative impact of O_3 on agricultural productivity throughout the world. Ozone, a strong oxidant, enters plants through the stomata where it can be dissolved in the apoplastic fluid. Ozone can directly react with the plasma membrane through "*ozonolysis*" or it can be converted into reactive oxygen species (ROS), which can alter the major cellular functions causing cell death, premature senescence, and also the up- or down-regulation of specific genes. Like other tropical countries, India is also under the severe threat of O_3 pollution. Our studies with major crops, *i.e.* rice, wheat, soybean, linseed etc., clearly established the damaging effect of O_3 on Indian scenario. Yield of all the crops were significantly decreased under ambient levels of O_3; however, the reduction was increased by many fold with elevation of O_3 levels. Distinct foliar injuries were also observed in O_3-exposed plants. Different growth parameters, like – shoot height, root height, total number of leaves, leaf area, NAR, RGR, etc. were also affected. Plants, generally posses a vast array of anti-oxidants to cope up with prevailing ROS; however, under O_3 stress, the amount and activity of those anti-oxidant molecules were induced by many times, irrespective of nature of plants. Even the reproductive structures like viable floral composition, viability and germination of pollen grains were also affected under O_3 stress. RAPD analysis demonstrated that O_3 severely affected the 'genome template stability' (GTS) in all the studied plants, and acted as a potent mutagen. In-depth proteomics analysis; through 1-DGE, 2-DGE coupled with protein sequencing, and immuno-blotting; again revealed that major photosynthetic proteins, like – RuBisCO, RuBisCO activase, O_2 evolving protein; primary metabolism related proteins were highly affected under O_3 stress; whereas, defense /stress related proteins were induced. Physiological traits; especially stomatal conductance in plants, act as a very important parameter under O_3 exposure and controls the overall gaseous exchange; hence decide the sensitivity of crop cultivar. Results obtained would definitely help in selecting suitable resistant cultivars of crop plants to get optimum growth, and yield and also in strengthen the knowledge of molecular mechanism of action of ozone.

Keywords: Tropospheric ozone, Reactive oxygen species (ROS), proteomics, Indian crops, growth, yield, quality parameters

S2.O9

Sensitivity of Indian crop plants to ozone

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Increasing anthropogenic and biogenic emissions of precursor compounds have led to high tropospheric ozone concentrations in India particularly in Indo-Gangetic Plains (IGP), which is the most fertile and cultivated area of this rapidly developing country. Current ozone risk models, based on European and North American data, provide inaccurate estimations for crop losses in India. Therefore, we have conducted several experiments with the main Indian crop species to estimate the magnitude of ozone risk on agriculture, and to screen the variation in ozone sensitivity/tolerance among the local cultivars. Field experiments in India, Lucknow area, were conducted with rice, wheat and mustard using EDU (ethylenediurea) as a chemical protectant against the adverse effects of ozone. The field experiments were complemented with chamber studies in Finland, simulating the prevailing ozone and climatic conditions in India. The plants were assessed for growth, gas-exchange (photosynthesis, stomatal conductance), antioxidants (SOD, CAT, GSH, GSSG), malondialdehyde (MDA) and biomass at the vegetative and the flowering phases. Yield parameters were measured at the final harvest phase. All study species showed sensitivity to prevailing ozone concentrations as indicated by yield losses and activation of defence systems. Seven out of the 18 rice cultivars and only three cultivars of the 11 wheat cultivars tested showed the good adaptability to high-ozone environment in terms of grain yield. Therefore, most of the Indian rice and wheat cultivars selected for the study showed high sensitivity to ozone. Both mustard cultivars under study were sensitive to ozone, but showed different strategies against ozone stress. Our results highlight the need for extensive screening of ozone sensitivity/tolerance of the cultivars of the main crops in order to maintain and improve the production rates and food security in this highly populated and polluted area of India.

Keywords: India, ozone, wheat, rice, mustard, EDU

S2.O10

Breeding of ozone tolerant cereal crops: progress and prospects

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Tropospheric ozone poses a major threat to global cereal production, especially in Asia, where air pollution has been rising steeply in recent years. As farmers have almost no management options to control the atmosphere which their crops are exposed to, the breeding of novel, ozone tolerant cereal varieties constitutes a promising approach to enhancing global food security. Therefore, we have screened for natural genetic diversity in adaptation to high ozone concentrations in rice, the main staple crop in Asia. We have identified substantial variability in ozone adaptation in terms of biomass and yield losses as well as ozone symptom formation. This phenotypic diversity was genetically dissected by mapping of quantitative trait loci (QTL) using bi-parental mapping populations or genome wide association study (GWAS) using a diversity panel. The QTL *OzT8* (affecting photosynthetic performance) and *OzT9* (affecting symptom formation) were demonstrated to alleviate adverse ozone effects on crop yield, grain and straw quality in rice plants grown in high ozone conditions. A candidate gene, *OsORAP1* (*OZONE RESPONSIVE APOPLASTIC PROTEIN1*) underlying the locus *OzT9* was characterized by reverse genetics, heterologous expression, and subcellular localization analysis. These analyses revealed that OsORAP1 is an apoplastic protein, which is highly expressed in ozone stress and belongs to a subclade of ascorbate oxidases, which does not oxidize ascorbate *in planta* but is involved in programmed cell death. Naturally occurring polymorphisms in the promoter and 5'-UTR regions of *OsORAP1* in rice were highly correlated with mRNA expression and symptom formation, further highlighting the importance of this gene in ozone response of rice. In ongoing experiments, we are investigating the transcriptional responses to ozone and sequence polymorphisms of *OsORAP1* orthologues in other cereal crops including wheat, barley and maize. These investigations will contribute to the breeding of ozone tolerant cereal crops in the future.

Keywords: air pollution, barley, cereals, maize, molecular breeding, rice, wheat

S2.O11

Impact of ozone on physiology and yield of African crops

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Ozone pollution is a growing problem in Africa. There is much evidence of adverse effects of ozone on crop yield and crop quality for European crops, but not for crops grown in Africa, or for African varieties of crops also grown elsewhere. We performed two experiments to investigate a) the impact of ozone on African crops and varieties, and b) whether irrigation strategies could be used to reduce the impact of ozone on wheat. African varieties of wheat (5 varieties), pearl millet (4 varieties) and finger millet (6 varieties), together with 6 varieties of dry (shelling) beans were exposed to ozone in ambient temperature (wheat) or heated (finger and pearl millet, beans) solardomes, with peak ozone concentrations of approximately 30 to 110 ppb. Ozone-induced visible leaf injury was observed on all crops and varieties tested, with a range of ozone-sensitivity between the different varieties. Large reductions in total yield and 1000 seed weight were found for wheat and bean in the highest ozone treatment. The ozone sensitivity of African wheat compared to European varieties based on Phytotoxic ozone dose will be shown, together with flux-based dose response relationships for the other crops. In a follow-up experiment, one of the ozone-sensitive varieties of wheat ('Kenya Korongo') was exposed to control (30 ppb) or elevated ozone (peaks of 80 ppb) for 3 weeks following anthesis, together with one of three irrigation regimes – well watered, frequent deficit or infrequent deficit irrigation. Reduced visible leaf injury with the deficit irrigation regimes and effects on yield will also be presented.

Keywords: crop yield, wheat, millet, beans, deficit irrigation, Phytotoxic ozone dose

S2.O12

Responses of crops to ozone exposure: study of physiological parameters

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In the context of increasing population and decreasing acreages, the reduction in crop yields induced by tropospheric ozone should be better evaluated. Therefore, ozone-resistant and -sensitive tobacco (cv. Bel-B and Bel-W3), barley and rapeseed plants were submitted to ozone-enriched air, during pre-flowering period. Six ozone concentrations (ranging from 30 to 130 ppb for six hours during the photoperiod) and two treatment durations (1 or 2 weeks) were applied. These treatments correspond to low, moderate and high exposure levels that occurs in France. Several leaf parameters were measured: necrosis development, chlorophyll content, chlorophyll fluorescence (Fv/Fm, ΦPSII), gas exchange (carbon assimilation and leaf conductance), seed yield, and fatty acid composition in cell membranes. The fatty acid composition was used to calculate the "Omega-3 index", a biomarker based on stress-induced changes in leaf 18:3 content, developed to assess soil quality. To estimate the oxidative load in leaf tissues, quantification of targets of oxidative stress (such as intracellular proteins carbonylation) was rather used instead poorly reproductible ROS quantification. Results show that ozone treatments decrease chlorophyll content and omega-3 index. The extent of the declines and the threshold levels of ozone exposure triggering the declines observed in the different plant species studied will be discussed. Direct continuation of this study, will involve a water stress applied to the plants subsequent to the ozone treatments. The same physiological approach will then be used to characterize the plant responses to the combined stress treatments, to assess their resilience to drought after an ozone pollution episode.

Keywords: elevated CO_2, tropospheric ozone, barley, tobacco, rapeseed, oxidative stress, omega-3 index

S2.O13

Assessing the risk of tropospheric ozone phytotoxic effect on Southern European Mediterranean environments: a review with emphasis on vineyards

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Tropospheric ozone in Southern Europe has an increasing tendency in association with a greater incidence of warm summers and heatwaves. As there is already much evidence of the negative effects that current ambient ozone has on vegetation, there is a need for consistent risk assessment methods. Ozone plant exposure-based parameters have been used extensively to support decision-making. However, these parameters have been also criticised, as they do not relate with the actual dose of ozone entering the plant. Moreover, in Mediterranean environments, they often overestimate the risk as thresholds are exceeded without corresponding evidence of damaging effects. To overcome these limitations, dose-based approaches were developed. These approaches have a stronger biological basis as they are based on estimates of the amount of ozone molecules that diffuse into the leaf cells through the stomata. However, they have also limitations, as detoxification processes or non-stomatal uptake are not often taken into consideration. This work presents a review regarding ambient ozone effects on vegetation and the indices used to assess phytotoxic risk in southern European Mediterranean plant communities and crops. Emphasis is given to the grapevine as three southern European countries (Spain, Italy and Portugal) are major wine producers concentrating more than 20% of the area under grapevines globally. These countries hold a long winemaking tradition associated to renowned denominations of origin (DOs). Therefore, there is concern regarding climate change as a potential threat to wine typicity in these areas, most of the work focusing on atmospheric variables, bioclimatic and climate change indices only. Results from the DOUROZONE project are presented with the aim to analyse the implications climate change can have in a significant Portuguese wine region such as the Douro Demarcated Region (DDR) including ozone-related indices as a novelty among other more frequently used bioclimatic and climate change indices.

Keywords: tropospheric ozone, climate change, grapevine, phytotoxic risk assessment, Portuguese Douro Demarcated Region

S2.O14

Monitoring ozone, foliar deficit and ozone-specific foliar damage on national forest plots in France over several years

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Since 2000, the GIEFS (Groupe International d'Etudes des Forêts Sud-européennes) and the National Forestry Office (ONF) have joined forces to monitor ozone concentrations and their effects on forest plots belonging to the National Long-Term Monitoring Network of Forest ecosystems (RENECOFOR). The RENECOFOR plots are distributed throughout the French national territory. The measurements of ozone concentration, foliar deficit and ozone injury were carried out on a selection of fifteen conifer and deciduous plots. The studied conifer species were the fir (*Abies alba)*, the Scots pine (*Pinus sylvestris*) and the Norway spruce (*Picea abies*). The harwoods studied were the beech (*Fagus sylvatica*), the sessile oak (*Quercus petraea*) and pedunculate oak (*Quercus robur*). Leaf deficit data from 2000 to 2015 and a follow-up of ozone foliar symptoms during the period 2013 to 2015 were analyzed in this study. The Mann Kendall test has been used to identify possible leaf deficit trends for each specie over the past 15 years. The Spearman statistical test was applied to establish correlations between leaf deficit, atmospheric ozone concentration and weather parameters (humidity, precipitation, temperature) observed *in situ*. The percentage of ozone injury has been related to meteorological parameters and ozone concentration each year. Observations were also made on clearings (LESS) located near the plots in order to detect the damage specifically induced by ozone on the vegetation outside the forest. Species sensitivity to ozone and the importance of topographical situation are also presented in this study.

Keywords: Forest, ozone, monitoring network, trend, defoliation, visible injury

S2.O15

Physiological responses of turf-type *Festuca arundinacea* to elevated O_3

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Taking ambient environmental O_3 (40 ppb) as control, this experiment was conduncted to assess the impacts of elevated O_3 (80 and 160 ppb) on growth, subcellular structure and reactive oxygen metabolism of turf-type *Festuca arundinace* by using open top chambers (OTCs). The results showed that after 14-day fumigation, the height and leaf width of *F. arundinace* decreased significantly, and total biomass decreased by 43.7%, and some fully expanded leaves yellowed under 80 ppb O_3. Some visible injury symptoms, brown spots and necrosis appeared in leaves, the total biomass decreased by 46.2%, and plasma membrane became loose from the cell wall and convoluted, chloroplast and mitochondria were damaged under 160 ppb O_3 exposure. Compared with control, the rate of superoxide anion (O_2^-)production, hydrogen peroxide (H_2O_2) content, malonaldehyde (MDA) content and the activity of antioxidant enzyme were higher under the increasing O_3 concentrations (80 and 160 ppb). Total phenolics content and the antioxidant capacity increased at first and then decreased with the rise of O_3 concentration. It indicated that elevated O_3 (80 ppb) inhibited growth of *F. arundinace* and antioxidative metabolism before visible injury symptom appared in leaves. *F. arundinace* had an adaptive response to elevated O_3 in early stage of development, but it could not protect itself from excessive O_3 or long-term O_3 exposure.

Keywords: antioxidant capacity, biomass, *Festuca arundinacea*, turfgrass, ultrastructure

S2.O16

Multi-level responses to ozone in Euramerican poplars

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Tropospheric ozone (O_3) is the main secondary pollutant and considered to be the most damaging for plant growth and productivity. In addition to be the third strongest greenhouse gas O_3 has the capacity to significantly alter forest carbon sink strength. O_3 is well known to induce oxidative stress and ROS accumulation in leaf tissues. Therefore, several works have focused on tree abilities to cope with ozone exposure, either by closing stomata to limit ozone fluxes into the leaf, by modifying anatomy to limit O3 diffusion through leaf tissues or by activating antioxidant defenses to limit ROS accumulation. However, the relative contribution of these defense mechanisms to O3 tolerance is still unclear in trees. Here, we investigated the responses of these barriers in nine Euramerican poplar clones (*Populus deltoides* × *P. nigra*) exposed to 120 ppb of O_3 for 3 weeks. Main drivers of tolerance and sensibility to O_3 were isolated to explain the lesser and greater losses of biomass, respectively. It appeared that ascorbate peroxidase and ascorbate regeneration process are the main determinants of ozone tolerance in poplar, in protecting photosynthesis capacity from ozone damage and therefore, maintaining growth and productivity. Furthermore, closing stomata appeared very harmful for sensitive clones, suggesting that avoidance strategy may be even worth than coping with excessive accumulation of ROS. Finally, changes in gas diffusion properties of leaf tissues are currently studied in order to improve flux-based functions and highlight adaptative mechanisms restricting O_3 influxes through leaf tissues.
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Keywords: antioxidant defense, ascorbate, ozone flux, poplar

S2.O17

Non-linear responses of two larches species exposed to four ozone levels

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The ground-level ozone (O_3) concentration has been increasing especially in Northeast Asian region. In several tree species, elevated O_3 inhibits growth and alters several physiological processes including stomatal reactions, photosynthesis, and nutrient translocation or storage. Larches (*Larix*) are representative trees in boreal forest and widely and continuously distribute at Eurasian continent. Japanese larch (*L. kaempferi*) has been major species in artificial forests in Asian countries due to high growth rate. However, it has been suffering from some biotic stresses, especially grazing by voles. To overcome difficulties, hybrid larch F_1 (*L. gmelinii* var. *japonica* x *L. kaempferi*) has been developed. Nowadays, relatively high O_3 is detected in Japan. Therefore to conserve these larch forests, we should reveal the effects of O_3 on the physiological responses and growth. In this study, Japanese larch and its hybrid were exposed to four O_3 levels [ranging from 10 to 60 nmol O_3 mol^{-1}] in open-top chambers (OTCs) for two consecutive growing seasons. We found a significant hormetic response in net photosynthetic rate at 1700 µmol (CO_2) mol^{-1} (A_{max}), maximum rates of carboxylation (Vc_{max}) and electron transport (J_{max}) in both larches. Hormesis indicates that low levels of exposure to an agent stimulate the performance of an organism but high levels of exposure inhibit its performance. Despite the stimulation by low O_3 levels in physiological endpoints, hybrid larch had suppressed production of dry matter. These findings suggest that stimulation of physiological functions by low O_3 exposures may have negative consequences for larch afforestation.

Keywords: Hormesis, Species difference, Larch, Ground level O_3

S2.O18

Effects of short term ozone fumigation on young trees of poplar *Populus nigra*

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During a period of 30 days, young trees of *Populus nigra* were fumigated with a single dose of ozone, 30 ppb for 4 hours, under open top chamber. Typical adaxial leaf brozing appeared since the 5th day and lesions gradually enlarged until the end of experiment. The relationship between necrosis and days was shown to be linear ($p<0.0000$). Some physiological parameters were investigated; ozone exposure caused a decrease of the amount of total chlorophylls, chlorophylls a and b, whereas membrane integrity, soluble sugars and stomatal conductance increased significantly after fumigation.

Keywords: Ozone, *Populus nigra*, Open Top Chamber, Physiological parameters, Tiaret

S2.O19

Insights into the mode of action of ethylenediurea (EDU) as an antiozonant in rice (*Oryza sativa* L.)

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Ethylenediurea (EDU) has been widely used to suppress detrimental effects of ozone on crops. However, the protection mechanisms against ozone injury still remain elusive and constitutive effects of EDU on crops have barely been studied. Therefore, we performed a series of agronomic and physiological experiments exposing rice to four different treatments, (i) control, (ii) control+EDU, (iii) ozone (average 77 to 108 ppb for daily 7 h), and ozone+EDU. Our first experiment in a controlled soil-based open top chamber system confirmed the lack of constitutive effects of EDU on ozone-free control plants, while it significantly offset the negative ozone effects in sensitive genotypes on foliar symptoms, lipid peroxidation, stomatal conductance, SPAD value, spectral reflectance vegetation indices (NDVI, SR and PRI and ARI), panicle number, spikelet sterility and grain yields. Subsequently, we conducted in depth physiological analyses including transcriptomics using the ozone sensitive and EDU responsive genotype BR28. Transcriptome analysis using Illumina HiSeq 4000 revealed no differentially regulated genes (0.1 FDR) between control and control+EDU, further confirming the absence of constitutive effects of EDU. However, 3182 and 3367 (0.1 FDR) differentially expressed genes were found between control vs ozone and control+EDU vs ozone out of a total 23208 expressed rice genes, indicating significant effects of ozone on rice gene expression pattern. In contrast, only 7 differential genes (0.1 FDR) were found for the ozone and EDU interaction. Despite the obvious lack of the direct effects of EDU on rice metabolism, its application significantly ameliorated the foliar symptoms, tiller number, shoot length, carbon assimilation rate, Vcmax, Jmax and lipid peroxidation. These results indicated that EDU does not have any direct effect on plants under ozone stress, and rather provides an indirect damage prevention mechanism due to abiotic interaction with ozone on the leaf surface that restricted the entry of ozone into the leaf.

Keywords: Air pollution, Molecular breeding, Global change, Food security, Gene expression, Phenotyping

S2.O20

Impact of elevated tropospheric O_3 and ambient temperature on early and late sown cultivars of wheat: an insight to biochemical mechanism and yield

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Tropospheric ozone (O3) is a highly phytotoxic air pollutant and its higher concentrations during crop growing season may lead to substantial reductions in crop production. The present study was undertaken with the hypothesis that early sown cultivars will perform better than late sown cultivars in response to elevated O3 and temperature variations in between early and late sown wheat cultivars with respect to their defence capacity and yield losses under elevated O3 and ambient climatic variables. Experiments were conducted in open top chambers receiving ambient and elevated O3 concentrations (ambient+20 ppb). Two wheat cultivars of early sown (HD 3086 and HUW 468) and late sown (HUW 234 and HD 3118) cultivars were chosen for the experiments. Eight hourly O3 concentrations and meteorological parameters were measured throughout the experiment. Superoxide and H2O2 content and its localization, lipid peroxidation, superoxide dismutase (SOD), ascorbate peroxidase (APX), glutathione reductase (GR) activities, ascorbic acid content and yield (wt. of grains plant-1) were measured. Mean (8h) ambient and elevated O3 concentrations were 52.7 to 76.5 ppb for early sown cultivars (November, 2016 – March, 2017) and 52.6 to 75.2 ppb for late sown cultivars (December- March, 2017) in ambient and elevated O3 chambers. Mean maximum temperatures were 26.7 and 27.8°C and minimum temperatures were 13.3 and 14.3°C during growth period of early and late sown cultivars, while SOD activity was higher in early sown cultivars. Ascorbic acid content was significantly higher in early sown than late sown cultivars. Yield measured as weight of grains plant-1 showed higher reductions in early sown compared to late sown cultivars. The present study concludes that higher minimum temperature along with high O3 concentration might have affected reproductive processes of early sown more than late sown cultivars, which led to higher yield reduction in early sown cultivars.

Keywords: wheat cultivars, tropospheric O_3, temperature, ROS, antioxidative enzymes, yield

S2.O21

Leaf internal photosynthetic activity of Siebold's beech seedlings under elevated ozone

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Ozone is a phytotoxic gaseous air pollutant. It is well known leaf photosynthetic activity decreased by ozone. Main factor of ozone-induced reduction in photosynthetic activity is considered as biochemical limitation at chloroplast (e.g. maximum carboxylation rate, V_{cmax}). However, previous studies did not consider a conductivity of CO_2 transfer from intercellular air space to chloroplast (i.e. mesophyll conductance, G_m). In the present study, we analyzed leaf internal processes of photosynthesis including G_m in leaves of Siebold's beech (*Fagus crenata*) seedlings under elevated ozone. Seedlings of Siebold's beech were grown in the three gas treatments (charcoal-filtered air or ozone at 1.0- or 1.5-times ambient concentration) for two growing season in 2016-2017. Leaf gas exchange and chlorophyll fluorescence were simultaneously measured in July and September of the second growing season. We determined light saturated net photosynthetic rate (A), stomatal conductance to water vapor (G_s) and G_m, and analyzed the responses of A to intercellular CO_2 concentration (C_i) (A-C_i curve) and to chloroplast CO_2 concentration (C_c) (A-C_c curve) for calculating V_{cmax} (V_{cmaxCi} and V_{cmaxCc}, respectively). We also determined the contents of Rubisco and chlorophyll. There was no significant effect of ozone on any photosynthetic parameter in July. In September, ozone significantly decreased V_{cmaxCi}. At the same time, a reduction of G_m was found, whereas there was no significant reduction in V_{cmaxCc} and contents of Rubisco and chlorophyll in leaves. These results indicate that apparent reduction in V_{cmax} (i.e. V_{cmaxCi}) does not mean a reduction of carboxylation capacity. Although G_m was decreased by ozone, C_c did not decreased. This is because of significant increase of C_i due to the insufficient stomatal closure. As a result of no change in C_c and V_{cmaxCc}, the A was not affected by ozone. We conclude that G_m is important factor explaining ozone effects on photosynthesis of Siebold's beech.

Keywords: A-C_c curve, chloroplast CO_2 concentration, maximum carboxylation rate, mesophyll conductance, Siebold's beech

S2.O22

The role of secretory glands in plant sensitivity to ozone: an alternative route for uptake?

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Ozone (O_3) dissociation leading to ROS formation occurs precisely in the aqueous medium, generally in the leaf apoplast. However, secretory glands located at the external surface of the leaf may also produce and reabsorb aqueous exudates (nectar and guttation droplets) that may be suitable places to ROS dissociation and direct uptake. Although the relevance of morphological structures in conferring tolerance to O_3 effects is often mentioned, the effective role of O_3 on secretory glands functioning and consequences to the plant is still unknown. Here we tested the hypothesis that aqueous secretory glands are direct routes of O_3-dissociated ROS entrance into leaf tissues, resulting in higher vulnerability of the plant to O_3 effects. To test it, we worked on extrafloral nectaries of tropical species [*Astronium graveolens* (Anacardiaceae), *Piptadenia gonoacantha* (Fabaceae), *Passiflora edulis* (Passifloraceae)], and hydathode pores of sugarcane (Poaceae). Young plants were submitted to an acute O_3 fumigation inside chambers, and routes of nectar and guttation droplets reabsorption were identified by the application of Lucifer Yellow (LYCH) tracer over the exuded droplets. This methodology was also performed in a FACE experiment to verify if the results obtained in chambers are reflected in the real environment. In both chamber and FACE situations, LYCH tracer experiments showed that nectar or guttation droplets reabsorption (i.e. direct ROS entrance considering the O_3 dissociation in the exuded nectar/guttation droplets) occurred through extrafloral nectaries and hydathode pores previous to the rising of specific O_3-symptoms. The reabsorption of ROS-dissociated nectar or guttation droplets is a route of direct ROS entrance into inner leaf tissues, thus increasing the bearing plant sensitivity to O_3. This study highlights the relevance of plant surface structures as mechanisms of O_3 resistance or susceptibility. An alternative model for ozone uptake and plant sensitivity based on glands is proposed.

Keywords: *Astronium graveolens*, extrafloral nectaries, FACE system, fumigation chambers, hydathodes, *Passiflora edulis*, *Piptadenia gonoacantha*, sugarcane

S2.O23

Leaf beetle activities on Japanese white birch grown under elevated O_3

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Ground level ozone concentration (O_3) has been increasing. Elevated O_3 reduces photosynthetic activities and usually leaf area. Grazing damages on Japanese white birch saplings by leaf beetle were frequently found in the center part of Sapporo city, nothern Japan (Lat 43.01, Lon 141.35) whereas the damages were rare in suburb. Based on our free-air O_3 fumigation system, grazing damages caused by leaf beetles were smaller at ambient O_3 condition (about 40 ppb) than those at elevated O_3 (about 70 ppb). Although concentration of leaf defense chemicals (total phenolics and condensed tannin) was lower in elevated O_3, adult leaf beetles avoided leaf grazing at alevated O_3. To reveal the reason why grazing damages were smaller at O_3 site, we determined BVOC (Biologocal volatile organic compound) with a gas chromatography. There were no statistical differences between ambient and elevated O_3 sites in the compsotion of BVOC (i.e. monoterpine and sesquiterpene) emitted from birch leaves. However, some kinds of aldehyde were slightly larger at elevated O_3. We further studied the preference traits of adult leaf beetles prior to oviposition in June and August. We could not distinguish female and male of leaf beetle by the size so we collected adults of leaf beetles of around 80-90 individuals as one cohort. And we used them randomly for the following preference experiments. By using the Y-shape tube test, we found that no preference of adults was found at O_3 concetnration at less than 40 ppb, however, adults did not prefer BVOC with elevated O_3 (80 and 120 ppb). We may conclude behovior of grazing and making oviposition of leaf beeltes is attributed to BVOC emission under elevated O_3.

Keywords: Leaf phenology, Japanese white birch, leaf beetle, Y-shape tube, BVOC

S2.O24

Tropospheric ozone interactions on nitrogen cycling in Mediterranean annual pastures

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Annual herbaceous species are widely present in Mediterranean landscapes either forming pastures, dehesas or the understory of Mediterranean forests, and usually represent an important fraction of the biodiversity of Mediterranean ecosystems. Among them, dehesas, sparsely wooded grasslands commonly found in the Iberian peninsula, have been protected under the Habitats Directive (92/43/EEC) of the EU. Annual Mediterranean pastures are chronically exposed to tropospheric ozone levels above current European air quality regulations for the protection of vegetation and in some areas they are also subject to atmospheric nitrogen deposition levels that exceed empirical critical loads established for the protection of European grassland habitats. Recent studies on the ozone sensitivity of annual Mediterranean pasture species have shown that besides direct effects on plant growth, forage quality and reproductive ability, indirect effects on the nitrogen cycling may also be operating, changing the ecosystem functioning. Ozone has been described to reduce the fertilization effect of nitrogen and to increase soil nitrous oxide emissions of an annual Mediterranean pasture under experimental conditions (Calvete-Sogo et al., 2014, AtmosEnv. 95; Sánchez-Martín et al., 2017, AtmosEnv. 165). An open-top chamber experiment on the interaction of ozone and nitrogen in a simplified Mediterranean annual pasture community has been used to gain insights on the effects of ozone on nitrogen cycling and how these two pollutants interact at the plant and soil compartments. Ozone effects on the nitrogen use efficiency of component species and on the nitrogen balance of the pasture will be presented. Potential interactions between tropospheric ozone and nitrogen in will be put into context with the most important, present and foreseen, environmental driver of annual Mediterranean pastures: drought. Understanding interactions among air pollutants and how these interactions are modified by climate is one of the main current challenges for Mediterranean ecosystems.

Keywords: Mediterranean annual pasture; phytotoxic ozone dose; nitrogen use efficiency; nitrogen balance; soil nitrous oxide emissions; drought

S2.O25

Ozone flux is negatively related to foliar N and P in Swiss beech and Norway spruce forest

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Observations in a network of Swiss forest monitoring plots show a decrease in foliar concentrations of nitrogen (N) and phosphorus (P) in European beech (*Fagus sylvatica*), Norway spruce (*Picea abies*) and oaks (*Quercus* sp.) during the last decades. In beech, also foliar potassium (K) and magnesium (Mg) concentrations decreased. The potential drivers for these changes were evaluated with the help of multivariable regression models. Among other drivers such as nitrogen deposition and soil acidification, ozone flux (POD1) was negatively related to foliar N and P in beech and Norway spruce. Meanwhile, ozone was found to be a significant predictor for the community composition of ectomycorrhiza in 15 beech plots of the same forest monitoring network. These results suggest a possible pathway for the reduced foliar nutrient concentrations. Decreased carbon allocation to roots is a known impact of ozone and mycorrhizal symbiosis plays a key role in nutrient uptake of trees.

Keywords: ozone, foliar nutrients, phosphorus, European beech, Norway spruce, ectomycorrhiza

S2.O26

Nutrient fertilization mitigates the effects of ozone exposure on poplar plants

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During the last century, concentrations of tropospheric ozone (O_3) have risen substantially on a global scale as a result of increasing anthropogenic emissions. Nutrient availability in the soil, especially nitrogen (N) and phosphorus (P), is considered as a pivotal modifier of plant response to O_3. In this work, the interactions of three levels of O_3 (1.0, 1.5 and 2.0 times the ambient O_3 concentration; AA, 1.5 × AA and 2.0 × AA) and six combinations of nutrient treatment [two levels of N (0 and 80 kg N ha^{-1}; N0 and N80) and three P concentrations (0, 40 and 80 kg P ha^{-1}; P0, P40 and P80)] on biochemical traits were investigated in an O_3 sensitive poplar clone (rooted cuttings of *Populus maximoviczii* Henry x *P. berolinensis* Dippel) in an O_3 free air controlled exposure facility (FACE). Plants exposed to increasing O_3 concentrations (alone and in combination with N/P fertilization) developed visible stipples of browning tissue localized in the interveinal adaxial leaf area. This macroscopic effect was twinned with the alteration of membrane integrity and the impairment of PSII photochemistry: plants exposed to 2.0 × AA displayed 2-fold higher values of malondialdehyde and total carotenoids/chlorophylls ratio than plants exposed to AA. N fertilization had some “mitigating effects” against O_3-induced oxidative burst by activating different detoxification mechanisms, i.e. accumulation of proline (+12, +67 and +18% in comparison to AA, 1.5 × AA and 2.0 × AA) and reduced ascorbate (+10, +5 and +8%, respectively). P fertilization partially balanced the reactive oxygen species production as confirmed by the significant decrease of the hydrogen peroxide content, but did not prevent foliar damage. Nutrient fertilization induced qualitative change of the carbohydrate pool suggesting a possible effect on the photosynthetic process and allocation of resources.

Keywords: climate change, oxidative stress, nutrients availability, membrane integrity, reactive oxygen species, proline, carbohydrates, non-enzymatic antioxidants

S2.O27

The WMO's Global Atmosphere Watch: a general overview and services to ecosystems

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The Global Atmosphere Watch (GAW) is the World Meteorological Organization's research programme tasked with monitoring and keeping track of tendencies in the composition of the Earth's atmosphere. The GAW programme achieves this via an international network of high-quality atmospheric observations stations across local to global scales as well as teams of scientists providing expert advice on a range of atmospheric composition-related areas such as aerosols, reactive and greenhouse gases, urban air quality, total atmosphere deposition, etc. The programme's aim is to drive high quality and impact science while co-producing a new generation of research-enabled products and services. GAW's Scientific Advisory Group for Total Atmospheric Deposition (SAG-TAD) has a mandate to produce global maps of wet, dry and total atmospheric deposition for important atmospheric chemicals to enable research into biogeochemical cycles and assessment of ecosystem and human health effects. The most suitable scientific approach for this activity is the emerging technique of measurement-model fusion for total atmospheric deposition. This technique requires global-scale measurements of atmospheric trace gases, particles, precipitation composition and precipitation depth, as well as predictions of the same from global/regional chemical transport models.

S2.O28

Poplar submitted to a succession of ozone and drought stresses: dynamic of stomatal responses

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Nowadays, plants are facing stronger environmental stresses due to anthropogenic activities (atmospheric pollution, climate changes). To protect forest health, we need to improve risk assessment, taking into account interacting stresses. For example, the impact of ozone (O_3) events pollution on drought response needs a special attention. Indeed, it is very likely to have an O_3 spring episode before summer drought. O_3 could affect the stomatal dynamic under drought through stomatal sluggishness. We intend to decipher the response of stomatal closure/aperture mechanisms relative to light or vapor pressure deficit variation in condition of O_3 stresses and for drought stress (with or without previous O_3 stress). Two genotypes of *Populus nigra x deltoides* were exposed to various treatments during 21 days. Trees were exposed to 80 ppb/day O_3 for 13th day then to a moderate drought. The objectives of this work: - Are there differences of stomatal movement dynamics linked to environmental variables (light, VPD) among poplar genotypes and between hydric regimes or O_3? - Does O_3 treatment modify the drought-induced stomatal closure? - How do those differences, studied at the leaf scale, contribute to WUE at the whole plant scale?

Keywords: poplar, ozone, drought, light, VPD, stomatal closure

S2.O29

Influence of drought stress on the ozone-induced signalling mechanisms of two Mediterranean tree species

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The aim of the study was to investigate the influence of drought stress on the responses of two Mediterranean tree species, characterized by different drought-sensitivity, to a single pulse of ozone (O_3). The behaviour of *Quercus cerris* (drought-sensitive) and *Q. pubescens* (mild-drought-sensitive) was evaluated in terms of ecophysiology and cross-talk responses among signalling molecules. Control plants maintained in well-watered and under filtered air conditions were compared with individuals subjected to drought (20% of the effective daily evapotranspiration, for 15 days) and later exposed to a single episode of O_3 (200 ppb, 5 h day^{-1}). Both stressors, applied alone or combined, affected ecophysiological responses. However, differential behaviour was observed between the species: under drought, photosynthetic capacity significantly decreased (-69% in comparison to controls), due to both stomatal and mesophyllic limitations only in *Q. pubescens*; the concomitant presence of drought and O_3 induced an ameliorative effect on photosystem II (PSII) performance during the fumigation in *Q. cerris*, whereas photochemical efficiency of PSII in light conditions of *Q. pubescens* was highly impacted by O_3 treatment (-75%). These differences were confirmed by the different oxidative load showed by the species. Different trends and consequently different role of phytohormones was observed in relation to drought and O_3. Under O_3 alone, similar spatial and functional correlations among these molecules were shown by the two species: ethylene emission values peaked at the end of the treatment (4- and 8-fold higher than controls, in *Q. cerris* and *Q. pubescens*). In drought stressed-plants, phytohormones were differently involved in O_3-induced signalling mechanisms: abscisic acid concentrations progressively increased starting to 2 and 5 h from the beginning of the exposure in *Q. cerris* and *Q. pubescens*. Our results highlight a differential response of plants suffering from water withholding to a single O_3 episode compared to well-watered plants.

Keywords: climate change, oak species, phytohormones, oxidative stress, photo-assimilation, ethylene, abscisic acid

S2.O30

Antioxidative responses of three oak species under ozone and water stress conditions

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The Mediterranean basin is considered a global biodiversity hotspot but Mediterranean plants are threatened by natural and anthropogenic factors (e.g., tropospheric ozone, O_3) which are expected to be harsher in the near future. The objective of this work was to give a thorough description of the detoxification mechanisms at the basis of the high plasticity of Mediterranean oak species. Two-year-old seedlings of *Quercus ilex*, *Q. pubescens* and *Q. robur* were grown under the combination of three levels of O_3 (1.0, 1.2 and 1.4 times the ambient O_3 concentration; AA, 1.2×AA and 1.4×AA) and water irrigation [1.2, 0.6 and 0.12 l day^{-1}; well-watered (WW), moderate drought (MD) and severe drought (SD)] from June to October 2015. In *Q. ilex*, no symptoms due to O_3 and/or drought were observed. This was confirmed by the minor propagation of reactive oxygen species (ROS) and the subsequent reduced cellular oxidative burst. *Q. pubescens* exposed to 1.4×AA and subjected to SD developed O_3 injuries, consisting in minute roundish browning necrosis scattered among the leaf veins of both surfaces of mature leaves. An induction of the phenylpropanoid biosynthetic pathway by both stressors leaded to an increase of phenolic acids (+61% in comparison to AA). This enhanced antiradical ability of cell wall components partially balanced the ROS production but did not prevent foliar damage. In *Q. robur*, O_3 symptoms were induced by both 1.2×AA and 1.4×AA concentrations under WW or MD conditions. Increasing O_3 levels induced a significant rise of total flavonoids (+43 and +16% in 1.2×AA and1.4×AA). This species also displayed higher constitutive level of ascorbate. These mechanisms did not preserve the PSII photochemistry from impairment, as confirmed by the decrease of total chlorophylls under O_3. A different species-specific degree of tolerance to single and combined stress was observed.

Keywords: global climate change, mediterranean plant species, drought, atmospheric pollution, reactive oxygen species, carotenoids, phenols, flavonoids, ascorbate

S2.O31

Effects of elevated O_3 on biomass allocation, nonstructural carbohydrates and rhizosphere soil function in poplar by joint water and nitrogen limitation

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Ground-level ozone (O_3) pollution has affected carbon metabolism and allocation in tree spceies, which is limited joint by water and nutrient availability. How variation in soil nutrients and water may act together to influence O_3 effect on plant and soil is unresolved. Here we report plant biomass allocation, major nonstructural carbohydrates in leaves and roots and rhizosphere edaphic functions from 1-year-old seedlings of poplar clones 546 (*Populus deltoides* cv. '55/56' × *P. deltoides* cv. 'Imperial') under two contrasting levels of O_3 concentration (CF, charcoal-filtered air, and E-O_3, non-filtered air + 40 ppb), soil nitrogen treatments (N0, 0 kg N ha^{-1} $year^{-1}$, and N50, 50 kg N ha^{-1} $year^{-1}$) and watering regimes (well-watered, and reduced watering, 40-50% irrigation) for one growing season. We find that the O_3 deleterious effects depends on the amount of available nitrogen and water. Specifically, elevated O_3 levels led to decreases in root biomass and root-to-shoot ratio when well-watered, no nitrogen supply, or both; but these negative effects have alleviated when reduced watering and nitrogen supply. O_3 induced much greater changes in the amounts of carbohydrates in roots than in leaves when both water and nitrogen were at theri lower level. We conclude that given widespread, simultaneous limitation by water and nutrients, large stimulation of biomass by increasing O_3 pollution may not be ubiquitous.

Keywords: Ozone; allocation; nonstructural carbohydrate (NSC) concentrations; nutrient availability; water limitation; poplar; rhizosphere soil

S2.O32

Session 3

How plant ecosystems respond to ozone exposure

Ozone and BVOC exchanges between biosphere and atmosphere

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Ozone is the main oxidant stressor in regions with warm climates, where high temperatures and large emission of precursors (Nitrogen oxides and hydrocarbons) from anthropic sources lead to the formation of this secondary pollutant. Plants can remove ozone from the atmosphere through stomatal absorption (i.e. ozone penetrates stomata and reacts with leaf tissues) and various non-stomatal deposition processes. Many vascular plants can produce and emit into the atmosphere large amount of Biogenic Volatile Organic Compounds (BVOC), largely represented by isoprenoids. BVOC emission is particularly stimulated by high temperatures, similar conditions promoting high levels of tropospheric ozone. One of the reason why plants invest energy to produce BVOC is that these molecules can play as antioxidant, thus defending leaf tissues from the adverse effects of oxidant molecules. Chemical lifetime of isoprenoids such as sesquiterpenes is very short due to fast reactions with ozone and other reactive molecules. In order to fully explore plant-atmosphere interactions under environmental stress, bi-directional exchanges of BVOC, CO_2, water, and ozone should be investigated simultaneously. Gas exchange studies through laboratory experiments using branch enclosures and through field measurements at canopy level with the Eddy Covariance technique help to understand possible links between BVOC emission and ozone removal inside leaves and in the gas phase in the sub-canopy region. In my talk, I will introduce examples of such studies, mostly performed in agricultural and forest ecosystems located in ozone stressed Mediterranean areas. Mediterranean forest ecosystems are indeed exposed to high loads of anthropogenic pollutants and are among the most threatened ecosystems on Earth by climate changes. Advantages and disadvantages from using state of the art instrumentation for fast detection of ozone and BVOC will be analysed, as well as the most advanced modelling approaches currently adopted to predict BVOC emission, and ozone sequestration in the soil-plant-atmosphere continuum. Future research needs will emerge after deep evaluation of what has been discovered so far and what is highly needed to better understand the link between BVOC emission and ozone removal by plants.

S3.O1

Ozone fluxes from an urban park: the unique station of Bosco di Capodimonte in Naples

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The air quality of urban areas, and consequently the health of the citizens, is related mainly to the concentration of primary and secondary pollutants such as particulate matter (PM), nitrogen Oxides (NO_X), ozone (O_3). Particularly in Mediterranean environments, there is a growing interest to understand O_3 flux in cities and its removal by urban trees. Beyond the chemical reactions, air O_3 removal mainly occur by tree leaves through both stomatal and nonstomatal mechanisms. Moreover, oxidation of biogenic volatile organic compounds (VOC) by OH, in the presence of nitric oxide (NO), produces molecules of O_3. Thus, in urban environment, plants can contribute to both O_3 removal and formation. For the elevated number of interacting factors, several models have been developed to estimate O_3 fluxes by urban forest (UF), rarely compared with field measurements, thus producing uncertain estimates. The eddy covariance (EC) technique is a reliable method to directly measure exchange of gases between biosphere and atmosphere. Here, we present the results of an innovative EC station in an UF, where fluxes of CO_2 and H_2O along with several other trace gases including O_3 are simultaneously measured. The station was established in the “Real Bosco di Capodimonte”, a large urban park, dominated by *Quercus ilex*, within the large city of Naples in Italy. The high radiative force and temperature, coupled with the elevated urbanization level in Naples, offer a unique opportunity to study the interaction between vegetation and trace gases, and consequently the contribution of vegetation on O_3 concentration, through the balance between formation and uptake. Results demonstrate that O_3 fluxes are influenced by park spatial variability, especially because of the gradient between meadow and forest, and by the seasonality highlighting the role of physiological status of the vegetation and of the ambient O_3 concentrations.

Keywords: Urban forest, Eddy covariance, Ozone, Quercus ilex, Traces gas fluxes

S3.O2

Linking ozone susceptibility to induced emissions of biogenic volatile organic compounds

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Ozone damage is usually linked to ozone concentration and/ or uptake but the large variety of sensitivities is either neglected or linked to a single species-specific property. However, sensitivity to ozone stress differs not only by species but also by season, pre-disposition to other stresses (e.g. drought) and environmental conditions such as temperature. Therefore, estimates of damages due to ozone under future climates are highly uncertain. Sensitivity depends on at least four processes that are either related to stomatal control or to biochemical defense reactions. The latter are generally assumed to be constitutive but also have an inducible component. It has been noted that this inducible component is linked to the capacity of plants to form biogenic volatile organic compounds (BVOCs) such as isoprene. The current work describes the link as it has been put into a physiological model. Since the BVOC emission depends on photosynthesis activity, photosynthesis can be damaged by ozone uptake, but the damage depends on BVOC emission, and a full feedback cycle has been implemented. The model offers the possibility to hypothesize about future plant responses to air pollutants as well as about the effect of emission changes that in turn might affect ozone formation.

Keywords: ozone damage, BVOC emission, induced defense, modelling

S3.O3

Spatial variability of isoprene emission in China under the ambient O_3 concentration using MEGAN and PS_BVOCs model

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Due to a significant interaction between biogenic volatile organic compounds (BVOCs) and global climate change, improving understanding of regional isoprene emissions under the present and future elevated O_3 conditions is imperative. Past estimations of BVOC emissions in China were based on conventional algorithms and models, few take into account the impacts of O_3. With an increasing ambient O_3 concentration in most parts of China, previous models will lead to large inaccuracies in the estimated results. To refine isoprene emission estimation for China and to further explore the role of O_3 impact on isoprene emission, the latest algorithms of MEGAN (Model of Emissions of Gases and Aerosols from Nature) and PS_BVOCs model with the parameterization of O_3 were used to estimate the biogenic emissions of isoprene (C_5H_8) in China. The combined local-survey and experiment-based data were used to characterize plant functional types, and base emission factors of isoprene. Real-time MODIS (Moderate Resolution Imaging Spectroradiometer) data were introduced to update the land-use parameters and high-resolution meteorological outputs from the MM5 model to determine the influence of leaf area index (LAI) and leaf age deviation from standard conditions. Because of the considerable regional disparity in plant distributions and meteorological conditions across China, isoprene emission presented significant spatial and temporal variations in both two models. Compared with isoprene emission data from MEGAN model, the effects of O_3 was obvious especial in eastern region of China. The results also indicate high uncertainties in isoprene emission estimated. We present an improved estimation of isoprene emissions, which provides important information for further exploration of the role of global climate change on BVOCs emission.

Key words: Isoprene emission, Tropospheric O_3, MEGAN model, PS_BVOCs model

S3.O4

Ornamental plants used as tool for remediation of ozone pollution in indoor environment

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Indoor air pollution is more severe than outdoor air pollution especially in context with human health. A number of studies have been reported on outdoor environments which indicate that vegetation act as sink for outdoor ozone but very less data available for indoor environment taken ozone as a pollutant with the help of indoor ornamental plants. This study evaluate ozone deposition velocities (v_d) for three common indoor ornamental plants (Dracaena deremensis, Tagetes erecta and Lilium candidum). Vd was calculated by using measured leaf areas of each plant and give exposures for two diurnal cycles where ozone concentrations in chamber tests were elevated for 8 h followed by 16 h in the absence of ozone. Estimates of vd after the exposures ranged from 5.6 m/h for Dracaena deremensis to 0.9 m/h for Lilium candidum. Values of vd were approximately 50% and 66% lower at the end of a second exposure and third exposure, respectively. For deposition velocities measured in this study, the ozone removal effectiveness ranges from 0.9% to 9% for leaf surface area to room volume ratio of 0.06/m when accounting for values for air exchange and background loss typical of a residential environment.

S3.O5

5.
Abstracts of poster presentations

Posters are sorted in alphabetical order. The poster session is in the open cloister of the Auditorium. Poster slots are marked by Px in alphabetical order (see below). There are three poster sessions: on 22nd (18.00-19.00), 23rd (10.00-11.00) and 24th (10.00-11.00) regardless session number. Corresponding authors are required to attend the poster session in order to reply to questions.

All posters have the opportunity to receive the **Best Poster Award for Ozone and Plants 2018**. To apply for the Award, authors need to include the specific mark in the upper right corner of their poster.

During the poster sessions, participants will evaluate posters based on the level of research, quality of the poster and clarity of the presentation. The award consists in a certificate and will be assigned during the closing ceremony.

Elevated O_3 affects the decomposition process in different types of soil

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Ozone (O_3) pollution remains a global challenge for the scientific community and stakeholders. Ample scientific evidence shows that elevated O_3 levels negatively affect trees with further potential ecological consequences in the long term. It remains however poorly understood whether and how elevated O_3 alters the core process of litter decomposition in forest ecosystems and how the type of soil modifies the impact of O_3. We will present our novel project for studying the decomposition process in communities of native to Northeast Asia deciduous trees. Trees of these communities are growing in three different types of soil. These trees have been previously (during the years 2014-2016) exposed to ambient or elevated O_3 levels, in a novel and globally unique experimental station located at the Northern island of Japan, Hokkaido. Based on plant-level data, according to which O_3 affected nutrient re-translocation during the seasons 2014-2016, we hypothesized indirect effects of O_3 on the decomposition process in soils, independently from O_3 injury on plants and the leaf litter *per se*. To investigate the impacts on decomposition process, we employed the standardized Tea Bag Index (TBI) method. Accordingly, we implanted tea bags of two types of tea in the soil of each experimental condition in Autumn 2016, which we retrieve periodically. In addition, we installed field chambers from which we periodically receive samples to analyze the major greenhouse gases emitted from soil. This project will provide critical information which can be served as the basis for modeling too.

Keywords: nutrient cycling, decomposition, greenhouse gases, ozone, tea bag index

P1

Japanese larch seedlings grown in containers, inoculated with ectomycorrhizal fungi, and exposed to ozone

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Ozone (O_3) levels in wide areas of Asia already exceed O_3 air quality standards for protecting plants. Trees are exposed to chronic elevated O_3 levels throughout their life and may have degraded production in forestry practice. Hence, future timber production may be threatened. Many trees depend on root symbionts for their survival. Successful symbiosis of trees with ectomycorrhizae fungi may promote seedling tolerance to O_3. However, successful symbiosis may also promote seedling tolerance to drought through an increase in water uptake. Such an improvement of water status may cause higher O_3 uptake via stomatal openness, leading to higher sensitivity to O_3. In the framework of low-cost silviculture practice, container grown seedlings are widely used. Container-grown seedlings with high or low fertilization were irrigated with inoculated or non-inoculated water and exposed to ambient or elevated O_3 conditions to examine whether ectomycorrhizae may influence plant tolerance to O_3. We will discuss our recent findings which will contribute in understanding tree responses to changing environment and promoting tree tolerance to O_3 in Asia.

Keywords: drought, ectomycorrhizae, fertilization, forestry practice, ozone, stress, tolerance

P2

Ozone deposition in forest canopies

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Dry deposition is the dominant sink for tropospheric ozone and removal rates by vegetated surfaces are several times higher than bare ground. However, ozone is a powerful phytotoxin and uptake through the stomata leads to oxidative stress and damage to plant cells. This impairs many physiological processes, reducing photosynthesis and carbon assimilation, inducing early senescence and disrupting stomatal functioning. However, the net effect of these various impacts on plant health and growth, and on ozone deposition rates and atmospheric concentrations is not well understood. Here we apply the FORCAsT (FORest Canopy-Atmosphere Transfer) one-dimensional canopy model to investigate the underlying processes driving ozone deposition and uptake. We incorporate three photosynthesis and stomatal conductance models and evaluate the ability of the model to capture observed ozone concentrations and fluxes in a Holm oak forest at Castelporziano Estate, Rome. We perform sensitivity tests with each physiological mechanism to investigate stomatal and non-stomatal ozone deposition fluxes under a range of background ozone concentrations and environmental conditions. We determine the impact of ozone damage to physiological processes on atmospheric fluxes and concentrations and ozone reactivity within the canopy space. We identify the key processes governing the rate of ozone uptake in each case.

Keywords: ozone deposition, stomatal conductance, forest canopy, biosphere-atmosphere exchange, ozone reactivity

P3

Resiliency of Scots pine (*Pinus sylvestris* L.) tree to acidifying compounds and surface ozone under the pressures of climate changes

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The aim of the study was to quantify the integrated effect of meteorology and air pollutants on stem basal area increment and crown defoliation of Scots pine trees located in the north-eastern part of Lithuania. Air concentrations of sulphur species and ammonium as well as their deposition were the main drivers resulting in changes in mean defoliation of Scots pine trees in Lithuania. Meteorological factors stimulated the recovery of pine tree crown condition, while ozone concentrations were close to the level of insignificance. Contrary to this, meteorology was a key factor resulting in variation in stem basal area. During vegetation nitrate deposition as fertilizing compound stimulated the pine tree stem BAI formation while ammonium compounds reduced it on both diurnal and annual scale. Negative ozone effect on pine growth intensity was significant only on mineral soil FS. Higher moisture regime significantly increased the tolerance of pine trees to the negative effect of air concentration of acidifying compounds, their wet deposition and surface ozone. The study is based on the results obtained conducting national project supported by Lithuanian Council of Research “FOREstRESS” (SIT-3/2015).

Keywords: Scots pine, meteorology, acidifying compounds, ozone, defoliation, increment

P4

Ozone risk for trees – dose response functions embedded in future climatic scenarios

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Validation of ozone doses and adaption of model parametrization are crucial to ensure a state-of-the-art basis for future ozone risk assessments for forest trees. The main objective of our new research project starting in 2019 is to advance ozone risk assessment and modelling for forest trees including future climate scenarios based on the recently established representative concentration pathways (RCP, IPCC 2013) considering tropospheric O_3 and CO_2-concentrations. Fundamental for evaluation of ozone doses is the determination of stomatal ozone fluxes and several gas exchange parameters. Besides biomass and tree allometric data, N- and C-allocation, fine root development and changes in ecto-mycorrhizal diversity will be assessed. The experiment will be conducted in newly established phytotrones with 5-8 year-old beech and spruce from natural regeneration, growing in their natural soil monolith. Two experimental approaches will be applied (1) simulation of an O_3-gradient under standard climate/CO_2 -conditions and (2) a sophisticated simulation of a future climate and O_3/CO_2-gradient: (I) In order to develop ozone dose-response-functions adjusted to present conditions and to derive realistic target values for spruce and beech, four different O_3-concentrations (pre-industrial, ambient, moderately elevated and high) will be applied for two vegetation periods. (II) In order to evaluate effects of a changing climate and emission scenarios in the future, daily cycles will be simulated for preindustrial conditions, the present, and future scenarios RCP2.6 as well as RCP8.5 (2100). The simulation of the corresponding O_3-concentrations and the combination of ozone and CO_2 emission will on the one hand explain the CO_2-influence and on the other hand indicate combined effects, which have to be implemented in future growth modelling. A low mountain range region is serving as a model forest region for Germany. All simulation data will be acquired at a hourly resolution as it is crucial to generate scenarios as "realistic" as possible, especially concerning the concordance of meteorological values with O_3-concentration values within a hourly resolution. This represents the first simulation database in experimental climate impact research. Our experimental concept is open to further collaboration from interested international groups.

Keywords: stomatal ozone uptake, ozone dose-response functions, RCP future scenarios, ozone and CO_2 interactions, beech, spruce

P5

Phytotoxic ozone effects on montane pines in the High Tatra Mts., Slovakia

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Ozone (O_3) concentrations in European mountains are high enough to cause injury to sensitive trees such as Swiss stone pine *(Pinus cembra*) and dwarf mountain pine (*Pinus mugo)*. The aim of this work was to assess Phytotoxic Ozone Dose metric without threshold limitation (POD_0) obtained for the temperate mountain forests in the High Tatra Mts in Slovakia. Field measurement of O_3 concentration and meteorological data were incorporated into the DO_3SE deposition model. The model parameterization included the recommendations from available literature and the preset for coniferous forests (CF) parameter values built into model. Maximum level of stomatal conductance (Gmax) as a key parameter for calculation of stomatal O_3 flux has not been specified neither for dwarf mountain pine nor for Swiss stone pine. We carried out field measurements of stomatal conductance using LI-6400 photosynthesis system (Li-Cor, Inc., Lincoln, NE) on both pine species. Based on these measurements, maximum level of stomatal conductance for O_3 was determined as Gmax = 110 mmol O_3 m^{-2} PLA s^{-1} for both studied montane pines. Model results of POD_0 ranged from 12.5 to 22.4 mmol m^{-2} PLA for Swiss stone pine and 11.4 to 19.3 mmol m^{-2} PLA for dwarf mountain pine during the 2016 growing season. POD_0 exceeded critical level for highly O_3 sensitive conifers (CLef = 19 mmol m^{-2} PLA) such as Swiss stone pine only at sites with favourable sunshine exposure. The concentration of O_3 and sufficient amount of soil water in the submontane and alpine zones contributed to higher level of POD_0 (16.9–22.4 mmol m^{-2} PLA) for Swiss stone pine compared with dwarf mountain pine (12.2–19.3 mmol m^{-2} PLA). These differences between the two species may be associated with their different canopy height and root depth. Swiss stone pine and dwarf mountain pine branches showed an obvious visible O_3 injury at higher altitudes. More pronounced visual symptoms were observed for dwarf mountain pine than for Swiss stone pine plots. The oldest needles of both species were more frequently damaged by O_3 injury at all plots.

Keywords: O_3 concentration, montane forest, stomatal O_3 flux, soil water, visible O_3 injury

P6

Ozone fluxes and GHG balance in a Spanish rice paddy field

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Project GEISPAIN (CGL2014-52838-C2-2-R, MINECO, Spain) has been launched with the general objective of quantifying the GHG balance of different relevant Spanish ecosystems. Measurements of O_3 fluxes with a fast O_3 analyzer (FOS, Sextant) in combination with eddy covariance technique were carried out in a rice paddy in Sueca (eastern Spain) during all the vegetative period of the crop. During rice cropping period, ozone fluxes were highly correlated with CO_2 fluxes and largely driven by stomatal conductance, while during non-cropping period, the fluxes were lower and driven by non-stomatal surface resistance. Complementarily, gas exchange leaf measurements under ambient conditions were carried out with a LICOR-6400 in order to parameterize the DO_3SE model and to model stomatal O_3 fluxes in rice. The proposed parameterization for “Japonica” varieties exhibited about double maximum stomatal conductance values (g_{max}) than the Asian “Indica” varieties. We additionally measured carbon dioxide (CO_2) and methane (CH_4) fluxes with eddy covariance in order to obtain a full carbon balance. Methane (CH_4) were also determined at different stages of rice cultivation using the static chambers technique to estimate greenhouse gas (GHG) budget. The ecosystem was a net carbon source during non-cropping period, reaching high respiratory rates (> 5 µmol m^{-2} s^{-1}) during pre-seedling and post-harvest periods and nearly null CO_2 fluxes during autumn-winter flooding period. During rice cropping period (June-July), the ecosystem was a strong carbon sink with maximum CO_2 sequestration rates up to ca. 50 µmol m^{-2} s^{-1}. Overall, the studied paddy rice field presented a net ecosystem productivity (NEP) of ca. 650 g C m^{-2} y^{-1} and a Net Ecosystem Carbon Balance (NECB = NEP – C harvested) of ca. 250 g C m^{-2} y^{-1}. The rice paddy field behaved as a CH_4 source most of the year, with higher emissions rates during the rice cropping period.

Keywords: GHG, ozone fluxes, eddy covariance

P7

MOTTLES: an innovative long term strategy for the definition of new critical levels to protect forest from ozone

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Current European directives for forest protection from ozone are based on the atmospheric concentrations (AOT40). Even if ozone levels regularly exceed the EU standards calculated for forests, very often no significant correlations are found in the epidemiological analyses combining concentration and ozone indicators for vegetation (e.g. visible leaf injury, crown defoliation and radial growth). It is widely demonstrated that ozone effects on forests depend not only on air concentration but also on O_3 uptake through stomata. Hence, the idea that EU Directives should adopt indexes based on stomatal fluxes, such as the PODY (Phytotoxic Ozone Dose above a threshold Y of uptake) is largely accepted. In this context, MOTTLES (LIFE15 ENV / IT / 183) establish a permanent new-generation monitoring system in areas at highest and medium risk of ozone injuriy (France, Italy and Romania) to define new standards based on PODY. Thanks to continuous measurements of ozone concentrations and meteorological parameters with hourly temporal resolution and annual in-field surveys, fluxes are modelled and combined with the results of epidemiological analyses. The derived flux based critical levels (CLef) set new levels of damaging ozone for forests and will be proposed as legislative standards to European political institutions in order to define new European standards biologically relevant. MOTTLES provide also a support for forest managers and planners, indicating the best strategies for ozone-oriented forestry and climate change.

P8

Effect of ozone on physiological response of Israeli wheat cultivars

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Tropospheric ozone (O_3) is globally recognized as a phytotoxic atmospheric pollutant become a potential threat to agriculture. Numerous studies on effect of O_3 on crop plants revealed wheat as one of the sensitive crop additionally the effect varies with species, cultivars and environmental factors. Wheat is a major crop in Israel and the present study is the first attempt to investigate the effect of O_3 on commercial Israeli wheat (*Triticum aestivum* L.) cultivars selected according to phenological variability. Yuval, Zahir and Amit are very early; Galil, Negev and Ruta are late, while Gedera, Binyamin and Bar-Nir are intermediate maturing phenotypes. Study was undertaken to determine the effect of chronic O_3 expsoure on plants using open top chambers and exposed with ~10 %, above ambient O_3 from flag leaf emergence till the maturity of the plants. Gas exchange measurements accomplished on randomly selected fully expanded flag leaf from emergence, heading and flowering stages of plants with maintained microclimatic condition inside the leaf chamber of photosynthetic system. Statistically significant reduction in photosynthtic rate (*Ps*) was observed between O_3 and control treatments; however, across cultivar variations were insignificant. Amongst test cultivars BarNir showed maximum reduction in O_3 exposed plants as comparison to control. Stomatal conductance (gs) reduced in Amit and BarNir (significant) and Gedera, however, increased in others. Intercellular CO_2 also followed the similar trend of variation. An acute O_3 exposure experiment was also carried out in the greenhouse; cultivars were exposed continuously above 100 ppb O_3 for four days at the flowering stage resulted significant variation across treatment in *Ps* and within cultivars in gs, besides O_3 induced foliar injury symptoms were also observed under elevated O_3 treatment. Study suggests that O_3 is the threat for wheat cultivation and pave the way for further investigation for differential cultivar respons with altering environmental factors and comparison with the present study results.

Keywords: Wheat; Ozone, Physiology, Open top chamber; Ozone injury

P9

Vine and ozone

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Grape vine (*Vitis vinifera,* L.) has since long been recognized as an ozone-sensitive crop. When the concentration of ozone in the atmosphere is high due to air pollution, important quantities of this substance penetrate the vine leaf tissues, causing cell damage and interfering with photosynthetic mechanisms, with subsequent slowing down of plant growth and premature leaf senescence. Secondary effects are changes in biochemical processes which affect the chemical composition of the must and are likely to cause alteration of the quality of the wine. An experiment was conducted during two growing seasons of grapevine in 2010 and 2011 to gain knowledge on the effect of high ozone levels on the yield and several biochemical characteristics of the plant, that could influence the quality of the final product, which is of economic importance for the agricultural production in Italy. The method used was a fumigation facility consisting of Open Top Chambers operated at a vineyard in Angera (northern Italy). Fumigation permitted to study the effect of different ozone levels. After the end of the experiment, the grapes were weighted and chemical analyses were carried out in order to gain understanding on the effect of ozone on the level of several chemical substances in thye grapes, which influence the quality of the wine: degree Brix, pH, tartaric and malic acids; assimilable nitrogen, reservatrol, polyphenols. The parameters characterizing the different ozone levels were expressed in terms of exposure (AOT40) and dose (POD). High ozone levels affect grape weight and thus the grapevine yield. In addition, the quality of wine is affected by a reduction of malic acid and polyphenols, which cause a more aggressive taste of the wine.

P10

Anatomical responses of a tropical liana species (*Passiflora edulis*) to ozone stress

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Passiflora edulis (Passifloreaceae) is a wide-world distributed Brazilian native liana species. It has a high economic value due to its fruits and pharmacological properties. Most *Passiflora* species are identified and collected in the border of fragmented vegetation. Indeed, lianas compete with trees, interfering in their growth and mortality rate. Due to these effects over trees, lianas are considered as plagues, compromising the ecosystem homeostasis. The effects of ozone over liana species are, however, almost completely unknown. Thus, we aimed to identify microscopic changes in *P. edulis* leaves maintained in a FACE (Free-Air Controlled Exposure) ozone system installed at the Institute of Sustainable Plant Protection/National Council of Research (IPSP/CNR). Plants were submitted to a high ozone exposure (ambient O_3 x 2.0) and compared to ambient air concentrations. Samples from asymptomatic and symptomatic leaves (predominantly chloroses) were collected at the beginning and after 94 days of exposure and detailed microscopic analyses were performed. Preliminary results indicated following changes in leaf structure of plants from high free air ozone exposure: epidermal cells with sinuous walls, and alterations in the palisade parenchyma tissue, such as a fraction of chloroplasts with plastoglobuli accumulation and fewer starch grains, nuclei deformation and plasmolysis of some cell groups. All of them are indicative of plant sensitivity to ozone. In addition, macroscopic symptoms and changes in leaf architecture were observed. We are now evaluating physiological and volatile data also collected during the fumigation exposure period to compare with anatomical data obtained so far.

Keywords: FACE system, leaf anatomy, microscopic markers, oxidative stress, passion fruit.

P11

Regulation of the ascorbate-glutathione cycle in leaves of poplar exposed to combined stresses (ozone and/or drought)

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Nowadays, due to anthropogenic atmospheric pollution, trees are facing stronger environmental stresses leading to an increase of oxidative stress. To protect forest health, improvements in risk assessment are needed, taking into account detoxification mechanisms and interacting stresses. For example, the impact of drought events on the effect of ozone (O_3) pollution needs a special attention. In this work, we intended to decipher the response of detoxification mechanisms relative to Halliwell-Asada-Foyer cycle (HAF) in condition of combined stresses (drought + O_3). Genotypes of *Populus nigra* x *P. deltoides* were exposed during 17 days to various treatments: i) a mild drought, ii) an exposure to 120 ppb O_3 and iii) a combination of both treatments. Ascorbate and glutathione pools (reduced and oxidized), enzyme activity and expression of the different gene isoforms coding for HAF proteins were studied. Depending the isoforms, and probably linked with the putative localization of ROS production in response to drought and ozone, respectively, different expression profiles were observed. Finally, some enzymes of ascorbate-glutathione cycle displayed an intermediate regulation (gene expression, activity level) for combined treatment compared to drought and ozone separately applied.

Keywords: poplar, ozone, drought, detoxification, ascorbate, glutathione

P12

Assessment of tolerance level of *Eugenia uniflora* L. to ozone under FACE fumigation

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Eugenia uniflora L. (Myrtaceae) is a native Brazilian tree species with wide distribution in different Biomes, like those regionally known as Caatinga, Cerrado and Floresta Atlântica. Although this species is commonly found in the city of São Paulo, growing and fruiting in urban locations highly contaminated by ozone, its tolerance level to this pollutant is still unknown. Thus, the objective of the present work was to establish the tolerance level of this tropical tree species, by measuring physiological leaf traits – enzymatic and non-enzymatic antioxidants, reactive oxygen species and relative growth rates (TGR) – in seedlings exposed to ozone for 70 days in a Free-Air Controlled Exposure (FACE) installed at the Institute of Sustainable Plant Protection/National Council of Research (IPSP/CNR). Two treatments were adopted: ambient O_3 concentrations (AA) and doubled ambient O_3 concentrations (O_3x2.0). The first results indicated a significant increase in the leaf concentrations of hydroxyl radical and superoxide ion, as well as of compounds indicators of lipid peroxidation - hydroperoxidene and malondialdehyde acid - and decreased levels of ascorbate peroxidase, superoxide dismutase and glutathione in plants exposed to O_3x2.0. Although the TGR estimated for height, stem diameter and leaf number was similar in both O_3 treatments, the root biomass decreased and the leaf biomass and shoot/root ratio increased significanly in the plants exposed to O_3x2.0. The changes in these physiological leaf traits seem to indicate that *Eugenia uniflora* is sensitive to high O_3 levels. This assumption will be checked more appropriately in a longer experiment.

Keywords: antioxidant defense, Brazilian native tree species, lipid peroxidation, reactive oxygen species, relative growth rates

P13

Ozone and biogenic volatile organic compound (BVOC) interactions on leaf surfaces of stressed urban trees: A project plan

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Stomatal absorption has long been thought to dominate O_3 absorption. However, lately the role of BVOCs in O_3 absorption at a stand level has been highlighted. Close to the leaves and in the intercellular space, BVOCs can be present in relative high concentrations and thus should have the capacity to absorb O_3. In addition surface assisted ozone reactions are thought to play a role for ozone dry deposition. The absorption of O_3 by BVOCs may be important when the trees' stomata are closed, such as under salt or drought stress. Some BVOCs have been found to increase under stressed conditions, especially when high temperatures and radiation prevail which normally also occur during conditions which induce drought. In this study we want to measure the effect of BVOC emission on the O_3 absorption in the vicinity of the leaf surface under drought and salt stress, both of which lead to a decrease in stomata conductivity. We will compare high BVOC emitting tree species with low emitting tree species and compare the physiological stress level indicated by, for example, peroxidase and polyphenol oxidase activities under different O_3 concentrations. The O_3 absorption and BVOC emissions of 5 common urban tree species in Vienna will be studied under different stress levels using Teflon coated chambers enclosing branches with a constant airflow. Leaf stress will be linked to O_3 absorption and the amount and type of emitted BVOCs. In the second phase of the project, we will attempt to model future ozone concentration in the Viennese air, taking into account the responses of stress on O_3 absorption and BVOC emission combining micro climate- soil vegetation atmosphere transfer-, air chemistry- and tree stress models

Keywords: Urban trees, BVOC, chamber measurements, drought stress, salt stress

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P14

PEPc contribution to CO_2 assimilation in ozone-treated poplars

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Ground-level ozone (O_3) is a major secondary pollutant that negatively affects plant growth and productivity. O_3 is well known to induce oxidative stress and ROS accumulation that are deleterious for most cell components and their functioning. In C_3 plants, O_3 decrease carbon fixation in lowering Rubisco content and activity. However, a higher PEPc content was also widely reported in O_3-treated plants. PEPc could contribute to leaf CO_2 fixation and partly compensate for the loss of Rubisco capacity in supplying carbon ressources to cell metabolism. Due to technical difficulties to separate CO_2 influx through PEPc or Rubisco, PEPc contribution to CO_2 uptake was never confirmed *in vivo* and quantified under O_3. Here, we quantified changes in *in vivo* PEPc activity in O_3-treated poplars using method based on photosynthetic discrimination against ^{13}C ($\Delta^{13}CO_2$) measurements and modeling. A lower $\Delta^{13}CO_2$ was observed in O_3-treated poplars compared to control. This decrease was accompanied by a lower mesophyll conductance. However, taking into account changes in mesophyll conductance in the model did not explain the changes in $\Delta^{13}CO_2$ under elevated O_3. Only an enhanced *in vivo* PEPc activity was able to match modeled and measured $\Delta^{13}CO_2$ values. Presently, focus is set on the fate of carbon fixed by PEPc across primary metabolism to reveal PEPc-specific metabolic pathways that may contribute to the overall plant-detoxifying arsenal.

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Keywords: oxidative stress; carbon uptake; photosynthetic discrimination; PEPc; poplar

P15

Effects of long-term ambient ozone exposure on xylem morphology of O_3 sensitive poplar treated with ethylenediurea (EDU)

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Wood quality is influenced by many environmental and biotic stressors. Although O_3 is considered one of the most important environmental stressor affecting plant growth, the knowledge on the effects of long-term ambient ozone exposure on wood quality is limited. The chemical ethylenediurea, N-[2-(2-oxo-1 imidazolidinyl)ethyl]-N0- phenylurea (abbreviated as EDU) is used to prevent foliar O_3 injury and to study O_3 effects on woody plants. While the protective effect of EDU against O_3 injury was widely demonstrated in short-term experiments (usually < 2 years), the aim of this study is to study the effects of long-term (6 years) ambient O_3 exposure and EDU treatment on xylem morphology, the main trait for wood quality. Transverse sections of 8–12 µm thickness were dissected out from the last two formed woody rings of the O_3 sensitive poplar clone 'Oxford' (*Populus maximoviczii* Henry x *berolinensis* Dippel) growing at the experimental site of Antella (Central Italy) and subjected for six years (2007-2014) to different treatments: a) WAT (not-protected trees) as ambient O_3 exposure; b) EDU (protected trees) as O_3 protection by weekly soil drenches of EDU solution at concentration of 450 ppm. Xylem morphology traits were analysed by a Nikon Eclipse 800E light microscope connected to a Nikon DS-Fi2 microscope camera. Vessels and fibres density, length and lumen cross-section were measured and frequency distribution analysed. Theoretical Hydraulic Conductivity (K_{st}) and hydraulic diameter (d_H) were calculated as proxy of hydraulic efficiency of the xylem in WAT and EDU plants. The results highlight the importance to investigate the effects of O_3 on xylem morphology and forecast wood properties of trees and hydraulic vulnerability of the xylem under future climate and O_3 pollution.

Keywords: vessel density, fibre lenght, xylem hydraulic efficiency, *Populus maximoviczii*, woody ring

P16

Evidence of impacts of ozone on ecosystem services of grasslands

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Ozone pollution can directly or indirectly cause impacts on many ecological processes that underpin ecosystem services. Over recent years we have performed many experimental studies on the impacts of ozone on grassland vegetation in solardomes. Here we collate datasets from these to provide evidence for ozone impacts on ecosystem services provided by grasslands. The ecosystem services included in this overview are 'supporting', 'provisioning', 'regulating' and 'cultural'. Presented evidence includes: *Impacts of ozone on flower numbers and timing (cultural and regulating services)*. Our results show that several iconic species show a strong decline in flower number with increasing ozone concentration and flux, including harebell (*Campanula rotundifolia*). These results have recently been used to establish critical levels for ozone in Europe. Timing of maximum flowering was significantly advanced by ozone in *Lotus corniculatus. Above- and below-ground biomass (supporting and regulating services)*. We have shown that ozone can reduce whole plant photosynthesis, and in addition, following early leaf senescence carbon allocation can be altered to maintain above-ground biomass at the expense of roots. *Litter quantity and quality (supporting services).* Ozone has been shown to alter the chemical composition of plant material, including the timing, quantity and quality of litter. This can subsequently affect nutrient cycling and other soil processes. *Water cycling (supporting services).* In addition to alterations in stomatal responses to environmental stimuli following ozone exposure we have shown changes in the water-holding capacity of soils, linked to changes in root biomass. In addition, impacts on provisioning services are considered using effects of ozone on pasture quality and quantity. A case study of how this could affect lamb production in the UK is presented. This showed that modest increases in ozone concentration could have large impacts on lamb production in regions where lamb numbers are high, due to the negative impact on pasture quality.

Keywords: grasslands, flowering, ecosystem services, root biomass, nutrient cycling

P17

Soil water availability affects ozone risk assessment in three European oaks

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In semi-dry ecosystems such as in Mediterranean climate, two main co-occurring climate change factors emerge, i.e. drought and ozone (O_3) pollution. Limited water availability usually occurs concurrently with climatic conditions that favor O_3 photochemical production, i.e. high sunlight and high temperature. To derive ozone (O_3) dose-response relationships for three European oak species (*Quercus ilex*, *Q. pubescens* and *Q. robur*) under a range of soil water availability, an experiment was carried out in an ozone FACE (Free-Air Controlled Exposure) facility. The ozone FACE facility is located at Sesto Fiorentino, near Florence, central Italy (43° 48' 59" N, 11° 12' 01" E, 55 m a.s.l.). Two-year-old seedlings of potted *Q. ilex*, *Q. pubescens* and *Q. robur* were grown under the combination of three levels of O_3 (1.0, 1.2 and 1.4 times the ambient concentration) and three levels of water irrigation (1.2, 0.6, 0.12 L day^{-1}) from June to October 2015. Total biomass losses were estimated relative to a hypothetical clean air at the pre-industrial age, i.e. at 10 ppb as daily average (M24). A stomatal conductance model was parameterized with inputs from the three species for calculating the stomatal O_3 flux. Exposure-based (M24, W126 and AOT40) and flux-based (POD_{0-3}) dose-response relationships were estimated and critical levels (CL) were calculated for a 5% decline of total biomass. Results show that water availability can significantly affect O_3 risk assessment. In fact, flux-based approach explained better the dose-response relationships than exposure-indices when combining results in different water regimes. In a simplified approach where species were aggregated on the basis of their O_3 sensitivity, the best metric was $POD_{0.5}$, with a CL of 6.8 mmol m^{-2} for the less O_3 sensitive species *Q. ilex* and *Q. pubescens*, and of 3.5 mmol m^{-2} for the more O_3 sensitive species *Q. robur*.

Keywords: ozone, drought, water stress, risk assessment, oak, biomass

P18

Plant-insect interaction of elm seedlings treated with $(NH_4)_2SO_4$ spray grown under free-air O_3 fumigation

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Dutch elm disease was found in mature elm trees in Sapporo, northern Japan at around 2005. Not largetrees but Intermediate size trees had been dead in Hokkaido University campus. Dead trees were slighly suppressed and gown near walkway. We consided the reason why decling sympom occured. Ground level ozone concentration (O_3) has been increasing in northeasten part of Asia. Elevated O_3 reduces photosynthetic activities and cosequently plant defense capacities would be surpressed. Moreover nitrogen deposition (N ; now anmonium sulfate is dominant in PM2.5) is increasing and chages growth of many kinds of trees. We fumigated O_3 (70 noml/mol)) and sparied N as a form of fogy (50kgN/ha・yr). We monitored seasonal trend of the grazing damages caused by insect herbivore in the site. We found major insects on elm leaves were follows: leaf beetle of elm (*Pyrrhalta maculicollis*) and alder (*Agelastica coerulea*), and Japanese Argidae (*Arge captiva*). Elm leaf beetle started to graze June to the end of September. Alder leaf beetle was found latter part of July to mid September. Argidae grazed from mid July to the endo of September. This insect made opiposition for two times: mid-July and late September. We compared visiting frequency of these insects (elm leaf beetle and Argidae) to host individuals. At the peak season of insect grazing, grazing of elma and alder leaf beetle was tended to be increased by N but was significantly reduced by O_3. This tendency is the same for alder leaf beetle on Jpananese white birch. According to analysis of the plant defense chemicals, concentration of total penolics of leaves was higher at elevated O_3. N concentration was higher in leaves with N spraied. These leaves are suitable food for insects. However, Argidae grazed significantly leaves at elaveted O_3 but not N spraied. Spraied anmonium surfate was accumulated at leaf edge and induced to be dead. This dead part of a leaf may inhibite grazing leaves due to the behavior of grazing by Argidae: This insect grazes from leaf edge. Effeciency of photosynthetic oxygen evolution (PS II) was reduced by incraesed N. Moreover, Chl (a +b) increased by N spraied. Based on our findings, we may counclude vigor and heath of elm trees would be reduced by elevated O_3 and increased N.

Keywords: Leaf phenology, elm, elevated O_3, increased nitrogen deposition, leaf beetles, Japanese Argidae

P19

Reversible photoinhibition in purple- and green-leafed sweet basil (*Ocimum basilicum*) exposed to ozone

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A research was conducted to investigate the physiological response of two cultivars of sweet basil (*Ocimum basilicum*) characterized by the different colour of leaves (Purple Ruffle, PR, red, and Green Ruffle, GR, green) to realistic ozone (O_3) dosages (60, 80 and 100 nL L^{-1} for 3 or 5 h). The aim was to evaluate the influence of anthocyanins on the oxidative stress induced by the pollutant in relation to their photoprotective and antioxidant capacity. At the end of the exposure and during the recovery in filtered air, chlorophyll *a* fluorescence and gas exchange were analysed on mature leaves. Overall, PR showed a lower sensitivity to O_3 as compared to GR as testimony by the appearance of minute roundish browning necrosis only on both the surfaces of the fully-expanded leaves of GR. Chlorophyll *a* fluorescence analysis revealed differences in the responses of genotypes to O_3. The potential PSII photochemical efficiency (F_v/F_m ratio) significantly changed in PR only at the highest O_3 dose (0.77 and 0.76 in comparison to ~0.80 in controls, respectively at 3 and 5 h). However, this ratio recovered 2 h after the end of the fumigation reaching the values of controls. Differently, GR showed a decrease in F_v/F_m at all the dosages (excluded the lowest 60 nL L^{-1} for 3 h) and the values did not recover until 3 h after the end of the fumigation (100 nL L^{-1}, independently of the duration). Analysis of gas exchanges revealed differences in the response of the two cultivars to O_3 (80 nL L^{-1} for 5 h), which negatively affected CO_2 photoassimilation more in GR (-54%) than in PR (-28%), but no differences in stomatal conductance were observed (-46 and -52%, in PR and GR, respectively). A detailed analysis of the mechanisms involved in the reversible photoinhibition is discussed.

Keywords: O_3, photosynthesis, PSII, chlorophyll *a* fluorescence, gas exchange, visible injury, photochemical efficiency

P20

Radial growth response to ozone exposure and uptake of sessile oak (*Quercus petraea*) in Mihaesti Level II Forest Monitoring plot, Romania

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In order to determine specific effects of ozone on sessile oak mature trees, especially in the presence of co-varying influence of other environmental factors, continuous measurements of ozone concentrations, meteorological parameters and tree growth were performed during the 2012-2016 growing seasons in Mihaesti level II plot (405 m a.s.l.). The main species are sessile oak (Quercus petraea) – 80% and beech (Fagus sylvatica) – 20%, the mean temperature having values of approximately 10°C in all years and the precipitation quantity ranging between 562 mm (2013) and 628 mm (2016). Fluxes of ozone were calculated as described in UNECE Manual (2010), using CCE parameters for the “generic” deciduous tree species, except fphen for which real observations were used. Hourly growth data from four trees were processed as described in Deslauriers et al. (2011). Daily and cycardian cycle basal area increments for each tree were calculated. Growth data was partially correlated (Kendall test) with AOT40 at daily/cycle level, with meteorological parameters as controlling variables. AOT40 calculated for the growing season had decreasing values, from 12.7 ppm in 2012, 9.9 ppm in 2014 to 5.1 ppm in 2016. Although not statistically significant, negative correlations between daily/cycle growth and AOT40 appeared in 2012, 2013 and in 2014. Multiple regression analysis showed a reduction in 2012 daily growth up to 2% due to ozone for 3 of the trees. Further analysis will be performed and presented.

Keywords: radial growth, ozone concentrations, AOT40, level II forest monitoring, growing season

P21

Physiological and ecological consequences of changes in volatile plant emissions induced by elevated atmospheric ozone and CO_2 concentrations

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Volatile organic compounds (VOC) emitted from terrestrial vegetation constitute complex olfactory environments (odorscapes) and play major roles in the interactions between organisms. Insects for instance, extract essential cues for their reproduction from their olfactory environment. Plant VOC production and emission are affected by environmental parameters, such heat and drought. As part of ODORSCAPE, a research program funded by French ANR, the effects of combined elevated atmospheric ozone and CO_2 concentrations on plant VOC production are studied, by assessing the stress-induced variations in the VOC emissions and in the corresponding biosynthesis pathways. Two crops representative of temperate agro-ecosystems, maize and poplar, are considered in this study. For CO_2, 400 ppm or 800 ppm are applied to plants, starting at the germination step for maize and at the acclimatization step for poplar, while 30 ppb or 110 ppb of ozone are applied on fully developed plants, during 6h of the photoperiod, for 2 weeks. At the end of the four treatment combinations, photosynthetic and gas exchange parameters, and VOC emissions are measured and will be related to changes in the potential activity of key enzymes in the major VOC biosynthetic pathways (such as the lipoxygenase, mevalonate and methylerythritol phosphate pathways) and carbon fixing metabolisms (RubisCO and PEP carboxylase). This will allow us to evaluate the extent of photosynthetic carbon allocation toward VOC biosynthesis pathways in response to both elevated ozone and CO_2. In addition, the stress-induced odorscapes will be tested for their effects on olfaction of herbivorous insects at gene, neural coding and behavior levels. Together, the results of this multidisciplinary project should reveal new aspects of the ecological consequences of climate change.

Keywords: elevated CO_2, tropospheric ozone, maize, poplar, plant volatile organic compounds (VOC), VOC biosynthesis pathways, insect behaviour

P22

Estimating the contribution of urban woody plants to the removal of atmospheric pollution: a species-specific case study in Italy

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A consolidated consensus is now available about the important role of plants in removing air pollutants in the cities. Selecting the right species for urban green infrastructure, however, is still a critical step for a proper planning, due to fragmented knowledge about the species-specific ability of ameliorating air quality. In this work, we collected all knowledge available in the literature and filled the modelling gaps in order to develop an approach suitable to be applied to any city in the world. As a case study, we selected the main cities of the Tuscany Region in Italy. Average data on local pollution and meteorology were used as input into the models. We hypothesized that the plants were isolated, not pruned and healthy. For each woody plant species (trees and shrubs) used in these cities, we estimated the size at maturity (50 years), the balance of ozone (by summing up potential ozone formation based on the emission of volatile organic compounds, and the surface and stomatal deposition of ozone), the total deposition of nitrogen dioxide (stomatal and non-stomatal), the deposition of particles (PM10 and PM2.5) and the uptake and storage of carbon dioxide. All these variables were finally merged into a species air-quality index (SAQI), to summarise the overall ability of the individual woody species in ameliorating urban air pollution. Out of the 278 available species, data in the literature were missing for around 100 species, suggesting further experimental studies are needed. Results suggested that the best species are those with large crowns at maturity and high stomatal conductance e.g. *Fagus sylvatica* and *Acer pseudoplatanus*, while the worst species show little crowns and high emission of volatile organic compounds, e.g. *Prunus* and *Cornus* sp. For instance, an adult plant of *Quercus petraea* shows one of the highest ozone uptake (33.81 g/tree/day) but an even higher potential ozone formation (38.55 g/tree/day). This kind of knowledge will help urban planners and managers of cities with priority issues of air quality in selecting the best species and avoiding the species that are not well suited to these issues.

Keywords: Urban forests, urban trees, urban pollution

P23

Variable ozone episodes influence on yield and physiology in old and new wheat accessions under a climate change regime with elevated temperature and CO_2

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Air pollution effects on vegetation have always been modified by the environment, but in the future crops will be exposed to a, so far, unseen increase in atmospheric carbon dioxide concentration. In addition, other environmental parameters will change e.g. air temperature. These variables will unlikely influence the plant responses to ozone episodes, but the outcome is hard to predict from single factor experiments, since the interaction between parameters is, among other things, depending of timing of ozone episodes and plant development stage. This study, part of the EU Climate Café project, will present the results from a phytotron experiment with three varieties of spring wheat (Triticum aestivum L.) varieties of European origins (Lennox, currently used in southern France, KWS Bittern, currently in use in Germany and Denmark and Lantvete, a Swedish landrace) separated into 8 treatments that were grown in 6 different atmospheres. The following environmental conditions were set: Temperature levels (12 /19 °C and 17/ 24 °C night and day resp.), Light level was app. 400 μmol m^{-2} s^{-1}, day length 16 h, two concentrations of CO2 (400 and 700 ppm) and three ozone settings: no ozone, episodic ozone and full time ozone. The ozone concentration target in the chambers was 80-100 ppb. We fitted eight climate treatments in the six chambers. We are looking at the impact of ozone and global change under current conditions and that of 2050, as well as the factors of this warming tested separately. Our results show a negative impact of ozone on growth and yields, and the current climate (control) is showing the highest yield. The wheat varieties showed a general response pattern, but with different impact on yield. Warmer temperatures decreases crop yield, and increased CO2 concentration only partly counterbalance the influence of ozone. Under our experimental conditions, a reduction of about 30% in yields is envisaged between today (2017) and the year 2050.

Keywords: Climate change, climate interaction, CO2 concentration, Ozone, warming, wheat varieties, yield

P24

Effects of water deficiency and elevated ozone on root traits of three oak species

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In many areas of the world, plants are increasingly subjected to water deficiency in combination with elevated levels of tropospheric ozone. Tree roots are largely neglected in studies of combined effects of both stressors, although their role in water and nutrient absorption is crucial for tree growth and survival. Seedlings of three oak species with different strategies for water use (*Quercus ilex*, *Q. pubescens* and *Q. robur*) were exposed to a combination of water deficiency and ozone stress at a free air ozone exposure facility in Italy. After one growth season, they were destructively sampled. Ectomycorrhizal communities were analysed by morpho-anatomical and molecular tools. Fine roots (< 2 mm) were scanned and analysed with WinRhizo to obtain root morphological parameters. Cross-sections were prepared from 2 mm roots, observed under the light microscope and anatomical features analysed. Fine and coarse roots were dried and weighted to obtain dry weight. Observed effects were root trait specific. Ectomycorrhizal species richness and community composition were significantly affected by combination of ozone and water deficiency in all three species. Due to water deficiency, smaller mean fine root diameter and increased proportion of the thinnest roots (0.0-0.1 mm) were detected in *Q. robur,* while elevated ozone reduced the proportion of the thinnest roots in *Q. pubescens.* Elevated ozone levels resulted in reduced vessel tangential diameter and vessel area in *Q. ilex* and in increased vessel density in all three oak species. Combined effects of ozone and water were detected in bark to secondary xylem ratio. Coarse root biomass was smaller in water deficient seedlings of *Q. pubescens* and *Q. robur*. Observed effects have a potential to affect water, nutrient and carbon cycling in oak forests subjected to combined stressors.

Keywords: trees, stress combinations, drought, fine roots, ectomycorrhiza

P25

Complex responses of volatile organic compound emission to realistic levels of ozone and drought stress in three oak species

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Plants emit biogenic volatile organic compounds (BVOCs) that are important precursors of secondary pollutants such as ozone (O3) and organic aerosol. The role of stressors in affecting BVOC emission from plant leaves is still unclear, as both stimulation and inhibition have been recorded. In addition, most of experiments have investigated individual stressors under artificial conditions. Here, we assessed the interactive seasonal effects of O_3 and drought exposure on the BVOC emissions from three oak species showing different O_3 sensitivity, water requirements and BVOC emission patterns. Stomatal regulation types during drought go from isohydric plants – that avoid low leaf water potential by closing stomata - to anisohydric plants – that keep their stomata open and endure lower water potentials. The isohydric isoprene-emitting *Quercus robur* L. is a main component of deciduous broadleaved forests of Europe, and is more O_3-tolerant than the anisohydric monoterpene-emitting *Q. ilex* L., an evergreen Mediterranean oak. The intermediate isoprene-emitting *Q. pubescens* Willd. is a deciduous oak distributed in Southern Europe. We worked in an ozone FACE (free air controlled exposure) facility under ambient conditions where only O_3 and water availability were manipulated. We successfully tested the following hypotheses: (1) the combined effects of O_3 and drought on BVOCs emission from oaks is additive and not synergistic; (2) these effects are more severe in the most O_3- and drought-sensitive species; and (3) direction and magnitude of the effects are affected by the time of the growing season.

Keywords: BVOC sampling, drought, elevated O_3 monoterpenes emission, O_3 FACE facility, free air controlled exposure, oak species

P26

Isoprene response to increasing ozone concentrations in Oxford 'O3-sensitive' poplar clone grown in enhanced nitrogen and phosphorus soil content

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Tropospheric ozone (O_3) has been recognized as a significant toxic air pollutant that causes deleterious effects on plants. Such effects may be mitigated by the soil nutritional status. In recent years, nitrogen (N) deposition to forest ecosystems has been rapidly increased. Together with excess of N, phosphorus (P) is considered to be a key limiting factor for tree growth. Isoprene is a major volatile organic compound emitted at high rates by adult and fully expanded poplar leaves and may play an antioxidant role in protecting plants against O_3 stress. However, the interactive effects of O_3, and enhanced N and P soil content on isoprene emission are still not investigated. Here, for the first time, we have examined both the response of plant performances and isoprene emission in O_3-sensitive poplar clone (Oxford, *Populus maximoviczii* Henry × *berolinensis* Dippel) grown under various concentration of O_3, and different amounts of N and P in soil. The experiments were carried out in a last-generation O_3 FACE (Free-Air Controlled Exposure) facility located in Sesto Fiorentino (Florence, Italy). Isoprene emission varied across the growing season. In early summer (July), isoprene emission increased either under exposure to elevated O_3 concentrations (+14% in 1.5 x ambient concentration (1.5AA), +32% in 2.0AA) or by N fertilization (+12%). However, later in the growing season (September-October) the stimulation of isoprene emission due to enhanced N in soil was impaired by the level of O_3 concentration. In fall, isoprene emission declined under increasing O_3 (-60% in 1.5AA, -69% in 2.0AA). Although significant effects of P on the emission rate was not found, P fertilization tended to sustain isoprene emission under 2.0AA. Isoprene emissions and photosynthetic CO_2 assimilation rates declined in parallel in fall. At the same time, O_3 declined the percentage of photosynthetically assimilated carbon that was re-emitted as isoprene. Overall, enhanced N and P amount in soil did not mitigate the inhibition on isoprene emission due to increasing O_3 concentration while increased isoprene emission in early summer and decreased isoprene emission in fall in response to O_3 suggests that the latter induces early senescence.

Keywords: poplars, isoprene, ozone, nitrogen, phosphorus

P27

Siberian pine and fir decline in the southern Siberian mountains: hypotheses and investigations

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The mountains of South Siberia are located in the center of the Asian continent and stretches sublatitudinally for three thousand kilometers. Their elevations reach more than 3000 meters. The mountains are the barriers for intercepting moisture-bearing air masses that create favorable conditions for growing of water-loving tree species Siberan pine (*Pinus sibirica* Du Tour) and Siberian fir (*Abies sibirica* Ledeb.). These tree species are shade tolerant and named by darkleaf conifers in Russian geobotanic classifications. From the 1970s scientists observed damage and decline of these darkleaf coniferous forests at middle-to-high elevations. The damage was expressed by necroses of branches with generative organs, by the linear and radial increment decrease, by chloroses, necroses and premature needle falls, the occurrence of stem rot. There exist several hypotheses to explain this phenomenon: - decline of water-loving darkleaf conifers is associated with climate change (aridization). We found from the temperature and rainfall trends for the last 50 years did not change enough across the highlands to cause die-back of Siberian pine and fir; - anthropogenic environmental pollution (various gas emissions, acid rainfall). Specific investigations did not detect increased concentrations of technogenic elements in needles, soils and snow over the mountains;- trees are affected by phytopathogens (*Armillaria mellea*, *Heterobasidion annosum*, etc.); - trees are affected by invasive insect pests. Foresters and ecologists are skeptical about diseases and insect attacks to be the primary causes and consider them as consequences of already weakened trees; - recently, the hypothesis emerged that dark coniferous forest die-backs over the southern Siberian mountains may be associated with the ozone layer depletion caused by tropical volcano eruptions. The increased shortwave ultraviolet radiation (UV-B) that follows the depleted concentration of stratospheric ozone in turn may damage the plant photosynthetic and reproductive apparatus. We hypothesise that the increased ozone concentration in the near-surface air layer may additionally amplify the damage and die-back of the middle-to-high mountain forests.

Keywords: forest forming conifer tree species, climate change, ozone concentration, UV-B

P28

Potential roles of WRKY transcription factors in regulating oxidative protection and signalling in *Salvia officinalis* plants exposed to ozone

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Tropospheric ozone (O_3) is a global air pollutant that causes negative effects on plant metabolism, physiology and growth. Because of its strong oxidative potential, O_3 has a large spectrum of biocidal activities by inducing plant signal molecules that can mediate the stimulation of secondary answers at genetic and metabolic level. The objective of this work is to elucidate the potential roles of WRKY transcription factors in regulating oxidative protection and signalling in *Salvia officinalis* (sage, one of the most well-known aromatic herbs) exposed to a single pulse of O_3 (200 ppb, 5 h day^{-1}) in controlled environmental conditions. At the end of the treatment, leaves appeared symptomless. Minute chlorotic spots were recognizable 48 h from the beginning of the exposure and especially on the adaxial leaf surface. To identify WRKY transcriptional factors genes involved in the oxidative burst, BLASTX analysis against the current assembly of the *S. miltiorrhiza* sequence genome was performed using *Arabidopsis* WRKY protein sequences as queries. A total of 14 gene sequences were predicted for sage WRKYs. The relative expression assessment of WRKY genes were analysed by quantitative real-time reverse transcription-PCR and carried out in asymptomatic leaves. Four WRKY were highly induced by O_3 at different time-points. WRKY11 and WRKY46 were significantly up-regulated after 2 h from the beginning of exposure. WRKY4 and WRKY5 have altered expression levels at the end of treatment (about 2-fold higher that controls). Only WRKY23 was significantly down-regulated by O_3. No significant expression level changes were observed during the recovery period. This result suggests that WRKYs can be important components in the complex signalling processes during O_3 responses. In particular, they could act as redox-responsive sequences and, consequently, as promoter elements specific for O_3 perception/signal transduction. Furthermore, transcriptional and metabolic relationships will be elucidated.

Keywords: Oxidative stress, sage, signalling molecules, lipoxygenase activity, reactive oxygen species, phytohormones, antioxidant response

P29

Photosynthetic performance, oxidative injury and growth of pomegranate plants under salt and ozone stress

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Plants are exposed to a broad range of environmental stresses under natural conditions including ozone (O_3) and salinity. The combinations of more stressors are common and may have strong impact. The progressive salinization of irrigated lands can limit crop production in the Mediterranean basin. One-year-old plants of *Punica granatum* L. cv. Dente di cavallo were exposed to two levels of O_3 (1.0 and 2.0 times the ambient O_3 concentration: AA and 2.0 × AA) and two levels of salinity (0 and 50 mM NaCl) for three consecutive months in an O_3 free air controlled exposure facility. The aim of the work was to evaluate the cross-talking mechanisms between the two stressors. At the end of the experiment, plants showed leaf yellowing (i.e. typical salt-induced symptoms) and developed visible stipples of browning tissue localized in the interveinal adaxial leaf area (i.e. typical O_3-induced symptoms). Leaf and root dry weight decreased in plants exposed to 2.0 × AA (-15 and -23% in comparison to AA, respectively) and subjected to salt stress (-2 and -10%, respectively). The effects induced by O_3 were twinned with the alteration of the potential PSII photochemical efficiency (-12%), the production of reactive oxygen species (ROS) [hydrogen peroxide concentrations (H_2O_2) were 2-fold higher than AA] and the accumulation of proline (Pro, +46%). Similarly, salinity induced a reduction of the photochemical efficiency of PSII in light conditions (-10%), an oxidative burst (as confirmed by the increase of H_2O_2, +5%) and a rise of Pro (+41%). However, the combination of both stressors determined an opposite effect including minor propagation of ROS, lesser modulation of Pro and slight impairment of PSII (-12, -7 and -3%, respectively). The possible “antagonistic” interactions between O_3 and salt will be elucidated.

Keywords: O_3, salinity, *Punica granatum*, reactive oxygen species, photosynthesis, proline, symptoms

P30

What we can't see in the urban forest ecosystem: greenhouse gases or its precursors

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Increasing urban trees and green areas is becoming a greater priority for all boroughs within cities and towns throughout Chile. Our team is working with a group of native and exotic trees to provide scientific insight to support management decisions, particularly into greenhouse gases (CO_2, H_2O, CH_4, O_3, N_2O), gas exchange in plants (CO_2 and H_2O), volatile organic compounds (VOCs) as precursors of O_3, and particulate matter retention by plants. First results show that the use of perennial native trees as opposed to deciduous exotic fast growing trees in cities of Central Chile may be highly beneficial. First of all, as water use efficiency, or the moles of H2O released to the atmosphere compared to the moles of CO_2 uptake by the photosynthesis, is relatively stable for C_3 plants at about 300-500 mol H2O per mol-1 CO_2, fast growing exotic plants would consume large amounts of water compared to the more conservative native trees, in an environment of climate change. Second, deciduous exotic trees would lose all their foliage through autumn and winter when particulate matter (PM), is at its peak, so that they will be incapable of intercepting any of the PM while native evergreen trees will do the opposite. Third, we have shown that various exotic deciduous trees would emit larger quantities of VOCs producing greater amounts of tropospheric O_3 with known effects on human and plant health. Native and exotic studied trees generally emit small amounts of CH_4 in spring and summer, the day around double the night, while urban soils would sequester CH_4, although the CH_4 balance in these ecosystems is still under study. A better knowing of the pros and cons of each tree species within the city, provided by scientific research, will better contribute decision makers to carry out better and sounder urban planning.

Keywords: Greenhouse gases, gas exchange in plants, particulate matter, volatile organic compounds (VOCs), urban trees and green areas, Chile

P31

Biomonitoring of anthropogenic volatile organic compounds in a urban arboreal species. Santiago de Chile

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Volatile organic compounds (VOCs) are chemical species that actively participate in the formation of photochemical oxidants like as tropospheric ozone and secondary aerosols (SOA). In the Metropolitan Region, Chile, anthropogenic VOCs, represent the third largest contribution in gaseous emissions; it is reported that their toxic or mutagenic characteristics cause a serious damage to human health and decrease the growth and development of plant species. Urban green areas play an important role in the quality of life of the population and within the urban ecology they deliver varied benefits On the other hand, there is little international information related to the possibility of capturing atmospheric pollutants through the leaves of trees exposed to defined sources of pollution, specifically for anthropogenic VOCs; in Chile, there is no information. The purpose of this work is to study the impact of anthropogenic VOCs emitted by the distribution of fuels. A petrol distribution service station located in the commune of Vitacura was selected, the area where the official monitoring stations of the Region report the highest concentrations of ambient tropospheric ozone; samples of *Platanus orientalis* were collected at different distances from the gas distribution center during austral spring (November) and summer (March). Samples were pulverized with a cryogenic mill; certain amount was weighed for the analysis (triplicate) to take it to a vial of headspace; the remaining material was stored as a counter sample. Determination and quantification of each chemical species were done through the use of analytical equipment GC / MSD. Preliminarily, it was possible to identify chemical species belonging to Organic Range of Gasoline (GRO: range 6-10C), specifically benzene, toluene, xylenes, ethylbenzene and other chemical species that need to be confirmed, in leaves of individua.

P32

Ozone and climate change impacts on Southern European forests: MITIMPACT project concept

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Climate change and air pollution are two significant stressors affecting forest health and vitality of European forests. Mediterranean area has been identified as one of the most prominent "Hot-Spots" in future climate change projections and is seriously affected by air pollution, in particular ozone (O_3). The MITIMPACT ALCOTRA project aims to quantify ozone impacts on 42 forest test sites distributed in South East France and Northwest Italy, by evaluating ecosystem health (e.g. crown defoliation and visible foliar injury) and ecosystem services, as well as their vulnerability at medium (year 2035) and long term (year 2055, 2085). The project area can be considered as a case study for the assessment of global change impacts in Mediterranean forests. Based on dose-response functions, new appropriate thresholds to protect Mediterranean forest against the negative effect of O_3 will be recommended. In particular, the influence of soil water availability on the effective dose of O_3 entering into the stomata, the so called Phytotoxic Ozone Dose with a threshold Y (PODy) will be estimated. Moreover, O_3-related forest damages will be economically assessed and mitigation strategies will be identified on the basis of cost-benefit analysis. This innovative aspect of the project can be particularly useful to provide cost-effective measures for forest management in preparation to future climate conditions.

Keywords: Ozone, Mediterranean forest ecosystem, soil water limitation, ecosystem health indicators, mitigation strategies, PODy, climate scenarios

P33

The importance of soil water availability on stomatal conductance regulation: implications for tropospheric ozone

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Soil moisture and water stress play a pivotal role in regulating stomatal behaviour of plants; however, in the last decade, the role of water availability was often neglected in atmospheric chemistry modelling studies as well as in integrated risk assessments, despite through stomata plants remove a large amount of atmospheric compounds from the lower troposphere. The study aims to evaluate the effects of soil water limitation on stomatal conductance and to assess the resulting changes in atmospheric chemistry testing various hypotheses of water uptake by plants in the rooting zone. We use a multi-model system to reproduce the meteorological conditions and the concentration of gases in the troposphere, specifically the WRF (Weather Research and Forecast Model) regional meteorological model and the CHIMERE chemistry-transport model. The inclusion of soil water stress leads to a reduction of stomatal conductance and thus, the amount of ozone removed by dry deposition is lower. As an example, the amount of ozone removed by dry deposition in one year without considering any soil water limitation to stomatal conductance is about 8.5 TgO_3, while considering a dynamic layer that ensures plants to maximize the water uptake from soil, we found a reduction of about 10% (7.7 TgO_3), affecting, the concentration of gases remaining into the lower atmosphere. Our results highlight the importance of improving the parameterizations of processes occurring at plant level (i.e. from the soil to the canopy) as they have significant implications on concentration of gases in the lower troposphere and consequently on risk assessment studies.

Keywords: Ozone, soil water limitation, dry deposition, CTM

P34

Isoprene contribution to ozone production in a context of climate change in a *Quercus pubescens* forest

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Tropospheric ozone is a strong pollutant, which can affect human health, agricultural yields as well as ecosystems functioning. This compound can come from the reaction between isoprene, the most emitted Biogenic Volatile Organic Compound (BVOC), and nitrogen oxides (NOx) coming from anthropogenic emissions. For instance, it has been estimated that between 16 and 20% of ozone comes from isoprene emissions in Mediterranean region. This proportion could change in the future with climate change since it has been demonstrated that isoprene emissions can increase, decrease or remains unchanged according to drought. Moreover, there is still a lack of knowledge about the effect of a recurrent drought (applied during several years) on isoprene emissions. In this study, we wanted to evaluate the impact of climate change, expected in Mediterranean region, on isoprene emissions as well as on ozone concentration. Isoprene emissions factors of *Quercus pubescens* were measured, at the branch level, during the first and the third year of a simulated amplified drought expected with climate change (exclusion of 30% of natural rain). An increase of isoprene emissions was observed after the first year whereas a decrease was highlighted after 3 years of drought. Then, CHIMERE model was used to forecast ozone concentration according to three scenarios: a REF scenario (based on summer 2003 known to be extreme in terms of temperature), a Short Drought scenario (after 1 year of drought, +83% isoprene emissions) and a Recurrent Drought scenario (after 3 years of drought, -26% isoprene emissions). Our results showed that short term involved an increase of ozone concentration up to 28.8µg.m-3 compared to REF scenario whereas, with recurrent drought scenario, a decrease up to 10.1 µg.m-3 was observed. Our results indicate that more than drought itself, the duration is an important factor to take into account for ozone modelling.

Keywords: recurrent drought, climate change, isoprene emissions, ozone

P35

Ozone exposure- and flux-based response relationships with photosynthesis, leaf morphology and biomass in two poplar clones

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Poplar clones 546 (*P. deltoides* cv. '55/56' × *P. deltoides* cv. 'Imperial') and 107 (*P. euramericana* cv. '74/76') were exposed to five ozone concentrations in 15 open-top chambers (OTCs). Both ozone exposure (AOT40, accumulation over a threshold hourly ozone concentration of 40 ppb) and flux-based (POD7, Phytotoxic Ozone Dose above an hourly flux threshold of 7 nmol O_3 m^{-2} PLA s^{-1}) response relationships were established with photosynthesis, leaf morphology and biomass variables. Increases in both metrics showed significant negative relationships with light-saturated photosynthesis rate, chlorophyll content, leaf mass per area, actual photochemical efficiency of PSII in the light and root biomass but not with stomatal conductance (g_s), leaf and stem biomass. Ozone had a greater impact on belowground than on aboveground biomass. The ranking of these indicators from higher to lower sensitivity to ozone was: photosynthetic parameters, morphological index, and biomass. Clone 546 had a higher sensitivity to ozone than clone 107. The coefficients of determination (R^2) were similar between exposure- and flux-based dose-response relationships for each variable. The critical levels (CLs) for a 5% reduction in total biomass for the two poplar clones were 14.8 ppm h for AOT40 and 9.8 mmol O_3 m^{-2} PLA (projected leaf area) for POD7. In comparison, equivalent reduction occurred at much values in photosynthetic parameters (4 ppm h for AOT40 and 3 mmol O_3 m^{-2} PLA for POD7) and LMA (5.8 ppm h for AOT40 and 4 mmol O_3 m^{-2} PLA for POD7). While in recent decades different CLs have been proposed for several plant receptors especially in Europe, studies focusing on both flux-based dose-response relationships and CLs are still scarce in Asia. This study is therefore valuable for regional O_3 risk assessment in Asia.

Keywords: Ozone, Dose-response relationships, Sensitivity, Critical level, Poplar

P36

ICP Vegetation smart-phone App for recording incidences of ozone injury on vegetation

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Exposure of vegetation to ozone pollution can cause visible injury on the leaf surface of ozone-sensitive species. In 2007, the ICP Vegetation published a report documenting over 500 incidences of visible ozone injury on crops, grassland species and shrubs growing in the field under ambient air conditions in 17 countries of Europe (Hayes *et al*., 2007). Field-based evidence is needed to verify predictions from experiments and to validate risk maps. It also demonstrates the negative impact of ambient ozone to policy makers. To build upon the evidence gathered in the 2007 report, we have developed an ozone smart-phone App, with the aim of creating a global database of injury records. The App, suitable for use on iPhones, Android or Windows phones, allows participants to upload photographs of ozone injury and the coordinates of the location where the injury was detected. There is also an online recording form, for those without a smart-phone. Users are asked a series of questions designed to assist with quality assurance, including details on their previous experience of identifying ozone damage and recent weather conditions. For guidance, the App also contains an 'Ozone Information' section, which provides details of the key visible injury symptoms and example photographs for a variety of different species. Since its development in 2014, we have received injury records from Europe, the USA and Asia for 20 different species. We are keen for many more people to take part to increase the number of records we receive from around the world. One way to collect evidence and report it via the App is to expose sensitive ozone species (SOS) to ambient air, and upload the injury photos. Information on how to download the App and a method for exposing sensitive ozone species are available on the ICP Vegetation website: http://icpvegetation.ceh.ac.uk/record/index.

Keywords: Smart-phone App; visible ozone injury; ICP Vegetation; field evidence; sensitive ozone species (SOS)

Reference

Hayes, F., Mills, G., Harmens, H., Norris, D. (2007) Evidence of widespread ozone damage to vegetation in Europe (1990 – 2006). Programme Coordination Centre of the ICP Vegetation, Centre for Ecology and Hydrology, Bangor, UK. ISBN 978-0-9557672-1-0.

P37

Modelling BVOC potential emission from energy crops – a case study in Brandenburg, Germany

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Biogenic volatile organic compounds (BVOCs) emitted from vegetation have significant effects on the atmosphere, playing a primary role in formation of tropospheric ozone. As BVOC emissions vary with species, the relative abundance of different crops in the landscape is a major factor determining the contribution of agriculture to ozone pollution. The global mandate of developing renewable energy is promoting widespread adoption of bioenergy crops. For some of them, recent experimental work made available data for calibration of BVOC emission models at the field scale. On these bases, we upscale here –by means of process-based simulation– potential BVOC emissions from maize and rapeseed in the German state of Brandenburg, where such emissions are dominated by agriculture. The crop model MONICA was extended to simulate monoterpene and isoprene emissions from the canopy, according to alternate approaches differing in structure and mechanisms. The model was calibrated using data from field experiments carried out in Dedelow, NE Germany, where BVOC fluxes from maize and rapeseed were monitored during the growing seasons 2015-2016. The model is then applied over the entire state of Brandenburg in the period 1995-2012. Each crop is simulated as monoculture over a 1 km^2 resolution grid covering the study area. The ultimate mechanistic description of the processes underlying the emission of BVOCs from vegetation is yet to come, as their physiological controls remain partially unresolved. However, this does not prevent emission models to achieve acceptable performance. The coupling with a full-blown crop model allows for the dynamic quantification of factors that influence patterns in BVOC emissions, such as the amount of photosynthetically active radiation reaching the leaf surface, phenological development and possible stressors the crop is exposed to. At the scale of the study area, this approach lays the foundations for BVOC emissions budgets from established energy crops.

Keywords: BVOC, energy crops, simulation models, MONICA

P38

Effects of ozone on two larch species treated with ammonium sulfate or salt loading

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The ground-level ozone (O_3) concentration has been increasing especially in Northeast Asian region. Elevated O_3 reduces growth and suppresses many physiological processes. In addition, the amount of nitrogen (N) deposition has been increased in Asian region. Effects of N deposition, especially N loading on soil, can promote tree growth and physiological activities in short-term but the excess deposition could also cause nutrient imbalances and acidification in soil i.e. N saturation. Much worse, soil salinization area has been increased due to global warming, especially low precipitation region in the northeastern China. At the wide area of soil salinization in Northeast China, they may empoly larch species for making forest plantation. Therefore, we studied on effects of elevated O_3 on lach species grwon under high N loading and salinity soil.. Here, we investigated on two larch species (Japanese : larch *L. kaempferi*, hybrid larch F_1 : *L. gmelinii* var. *japonica* x *L. kaempferi*).. Japanese larch (*L. kaempferi*) has been major afforestational species in Northereast Asian because its high growth rate and adaptability to harsh conditions. However, it has been suffering from biotic stresses, e.g. grazing by voles. To overcome difficulties, we developed hybrid larch F_1 (*L. gmelinii* var. *japonica* x *L. kaempferi*). These seedlings, which were exposed to elevated O_3 [60 nmol O_3 mol^{-1}] in open-top chambers (OTCs), were treated with ammonium sulfate [50 kgN ha^{-1} yr^{-1}] or salt [$NaHCO_3$ and NaCl] loading. We mainly discuss on the responses the growth of them for the future afforestation.

Keywords: Combination effect, Ground level O_3, Nitrogen deposition, Salinity, Species difference, Larch

P39

Effects of elevated ozone concentration on CH_4 and N_2O emission from paddy soil with two Chinese rice cultivars under fully open-air field conditions

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We investigated the effects of elevated ozone concentration (E-O3) on CH4 and N2O emission from paddies with two rice cultivars (inbred Yangdao 6 (YD6) and hybrid II-you 084 (IIY084)) under fully open-air field conditions in China. A mean 26.7% enhancement above the ambient ozone concentration (A-O3, 33.7 ppb) significantly reduced the whole-plant biomass by 13.2%, root biomass by 34.7%, dissolved organic carbon in soil solution by 12.3% and CH4 emission by 29.6%, on average of the two cultivars. Significant varietal difference in CH4 emission response to E-O3 was detected in tiller stage because E-O3 significantly reduced the maximum tiller number of IIY084 (-16.5%, P = 0.0311) but that effect was not significant with YD6 (-4.1%, P = 0.2231). Additionally, we found E-O3 reduced seasonal mean NOx flux by 5.7% and 11.8% with IIY084 and YD6, respectively, but the effects were not significant in statistical. Our field study has thus supported the findings in controlled-environment chambers that increasing ozone concentration might mitigate the global warming potential of CH_4, and indicated that the response of tiller number to E-O3 should be considered in selecting rice cultivars for mitigating CH_4 emissions from paddy soils.

Keywords: CH_4 emission, N_2O emission, elevated ozone, rice cultivar, biomass, paddy soil, FACE

P40

Diurnal and phenological variations of O_3 and CO_2 fluxes of winter wheat canopy under short-term O_3 exposure

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A dynamic chamber system was designed to measure simultaneously the diurnal and phenological canopy ozone (O_3) and carbon dioxide (CO_2) fluxes in the winter wheat field under different O_3 concentrations (0, 40, 80 and 120 nmol mol^{-1}). On the diurnal timescale, canopy fluxes usually peaked around noon in early growing stages, while a generally decreasing trend from morning to afternoon was observed in the later stages. O_3 and CO_2 fluxes were positively and negatively correlated with O_3 concentration, respectively. Significant differences were observed in O_3 fluxes but CO_2 fluxes among O_3 treatments. On the phenological timescale, both O_3 and CO_2 fluxes followed the variation of leaf area index (LAI) with the maximum occurring simultaneously at the booting stage. The daytime mean fluxes varied from 10.6 to 17.2 nmol m^{-2} s^{-1} for O_3 and from 5.9 to 19.6 μmol m^{-2} s^{-1} for CO_2. Quantitatively important O_3 deposition (3.1~11.6 nmol m^{-2} s^{-1}) was also observed at night with the ratios being about 40~70 % relative to the daytime O_3 fluxes for most measuring days, which indicates a significant contribution from non-stomatal components to canopy O_3 removal.

Keywords: chamber system; ozone; carbon dioxide; flux; phenology; *Triticum aestivum*

P41

Effect of ozone and/or EDU on Pinto bean plants' metabolism

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Ambient ozone (O_3) is considered one of the most widespread phytotoxic air pollutants across the globe. Its levels in the atmosphere are continuously increasing, threatening natural and agricultural ecosystems. It is well documented that ozone enters through stomata, affects plants' metabolism, causes oxidative stress and foliar injury and finally yield reduction. Ethylenediurea (EDU) prevents acute and chronic injury due to ozone stress in various plant species; however, its exact mechanism of action has not been elucidated yet. Metabolomics is a new approach on systems biology, which studies the changes of the intermediates and the final products of metabolism. Here, effects of O_3, EDU and O_3 x EDU interaction on plants' metabolism were investigated. To this purpose, three week-old plants, of the sensitive to ozone bean (*Phaseolus vulgaris* L.) cultivar Pinto were treated with EDU or water and, after 24 hours, were exposed either to ozone (70 ppb) or to charcoal filtered air for 4 hours. Samples of leaf tissues were taken from the first trifoliate (fully expanded) leaf of the plants on the end of the exposure. The experiment was conducted in controlled environment chambers under laboratory conditions. Gas chromatography-mass spectrometry (GC/EI/MS) metabolomic analysis was performed. The data were compared to databases (KEGG, NIST) for compounds identification. The findings were further submitted to multifactorial analysis (OPLS-DA). Metabolomic analysis detected 179 metabolic characters, of which 149 were identified compounds (this, in terms of concentrations, corresponds to 95% of the total metabolic amount). Major plant biosynthetic pathways were either up or down-regulated in response to O_3, EDU and O_3 x EDU. The concentration of many important bioactive metabolites, such as compounds with antioxidant role (GABA, 4-coumarate, etc.) or signal transduction molecules (ethylene, etc.) were affected. The major important results will be extensively presented.

Keywords: Phaseolus, GABA, 4-Coumarate, ethylene

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Penconazole: A potential ozone protectant of plants? A metabolomics approach

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Several agrochemicals have been tested as antiozonants and some of them have been found to offer, as a side effect, a kind of protection to plants against ozone phytotoxicity. The near ground level ozone, is gradually increasing over the decades, and is known to cause adverse effects in plants as a result of metabolic disturbances. Metabolomics is among the innovate methods used, nowadays, in studies dealing with the influence of xenobiotics in plants. In this study, we conducted a metabolomics analysis, in order to investigate the potential protective effects of Penconazole against O_3 in plants. To this purpose, seeds, of the sensitive to ozone *Phaseolus vulgaris* L. cv Pinto, were planted in pots and placed in two walk-in chambers, fed with charcoal filtered air, under controlled environment conditions (T: 27 ^oC, RH: 65-70%, Photoperiod: 14L/10D). When they were three weeks' old, the plants of each chamber, were spayed either with Penconazole or with water. After 24h, the plants of the one chamber were fumigated by ozone (35 $\mu g/m^3$ x 4 hours), while the plants of the other chamber served as control. At the mid (2h) and at the end (4h) of the exposure, samples of leaf tissues were taken from the first trifoliate (fully expanded) leaf of the plants, from both chambers. Samples were submitted to gas chromatography-mass spectrometry (GC/EI/MS) for metabolomic analysis. Bioniformatic tools were used to identify the given chromatographs. Multivariate analysis of metabolic profiles resulted completely distinct groups, differentiating the O_3 and Penconazole treated plants from their control counterparts. The analysis revealed significant main and interaction effects of both (ozone and Penconazole) factors. Some biosynthetic pathways were either up or down-regulated while other remained undisturbed. Complex and contrasting effects were also observed in the concentrations of bioactive metabolites (like linoleate, GABA, L-ornithine, trehalose, ethylene, etc.).

Keywords: Phaseolus, GABA, trehalose, ethylene, linoleate

P43

Effects of elevated tropospheric ozone and N fertilisation on greenhouse gas emission and net ecosystem carbon exchange in British grasslands

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Rising ozone (O_3) concentration and nitrogen (N) fertilisation can affect plant growth differently, whereas their effects on soil greenhouse gas emission and ecosystem carbon dynamics remain uncertain. Here, we investigated effects of elevated tropospheric O_3 ($e[O_3]$) and N fertilisation on CH_4 and N_2O emission from the lowland and upland grasslands under fully open-air field conditions in North Wales, UK. For each grassland site, intact soil cores were collected and placed inside the rings of O_3 exposure. A two-level factorial experiment with three replicate was established. From May 2017 to this April, we measured the fluxes of soil CH_4 and N_2O emission. Using the static-chamber method, we measured net ecosystem carbon exchange (NEE) and ecosystem respiration (R_{eco}) across the growing season. Soil moisture, soil temperature, and solar radiation were monitored simultaneously. Our preliminary results showed that CH_4 uptake rates were significantly higher in the upland grassland (−10.11 to −3.21 μg C m^{-2} h^{-1}) than in the lowland grassland (−20.82 to −16.78 μg C m^{-2} h^{-1}; $P < 0.001$), whereas it was not affected by either $e[O_3]$ or N addition. Similar to N addition ($P = 0.024$), $e[O_3]$ significantly stimulated soil N_2O emission ($P = 0.0013$), especially for the lowland grassland with higher flux rates (1.23 to 8.89 μg N m^{-2} h^{-1}) than that from the upland grassland (0.81 to 5.48 μg N m^{-2} h^{-1}). R_{eco} was significantly increased by an average of 19% under N addition, and there was a marginal interaction between $e[O_3]$ and N addition ($P = 0.089$), especially for the lowland grassland. Across all treatments, N addition significantly increased the aboveground biomass of both grasslands by *c*. 40%, despite the absence of effects of $e[O_3]$ and grassland type. Taken together, our current results that rising tropospheric $[O_3]$ may have negative impacts on soil N_2O emission and ecosystem carbon balance.

Keywords: semi-natural grassland; elevated ground-level ozone; greenhouse gases; fertiliser management; soil respiration; GEP

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Relationships of CO_2 assimilation rates with exposure- and flux-based O_3 metrics in three urban tree species

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The relationships of CO_2 assimilation under saturated-light conditions (A_{sat}) with exposure- (AOTX, Accumulated Ozone exposure over a hourly Threshold of X ppb) and flux-based (POD_Y, Phytotoxic Ozone Dose over a hourly threshold Y nmol. m^{-2}. s^{-1}) O_3 metrics was studied on three common urban trees, *Fraxinus chinensis* (FC), *Platanus orientalis* (PO) and *Robinia pseudoacacia* (RP). Parameterizations for a stomatal multiplicative model were proposed for the three species. RP was the species showing lower species-specific maximum stomatal conductance (g_{max}) and experiencing lower cumulative O_3 uptake along the experiment, but in contrast it was the most sensitive to O_3. POD_Y was slightly better than AOTX metric at estimating R-A_{sat} changes for PO and RB but not for FC. The best fittings obtained for the regressions between relative A_{sat} (R-A_{sat}) and AOTX for FC, PO and RP were 0.904, 0.868, and 0.876, when the thresholds of X were 60 ppb, 55 ppb and 30 ppb, respectively. However, AOT40 performed also well for all of them, with R^2 always >0.83. For POD_Y, the highest R^2 values for FC, PO and RB were 0.863, 0.897 and 0.911 at thresholds Y=7, 5 and 1, respectively. Given the potentially higher O_3 removal capacity of FC and PO by stomatal uptake and their lower sensitivity to this pollutant with regard to RP, the former two species would be appropriate for urban gardens and areas where O_3 levels are high. Parameterization and modeling of stomatal conductance for the main urban tree species may provide reliable estimations of the stomatal uptake of O_3 and other gaseous pollutants by vegetation, which may suport decision making on the most suitable species for green urban planning in polluted areas.

Keywords: Ozone, Photosynthesis, Flux-response relationships, China, urban trees

P45

Ozone pollution impacts on crops and forests in China

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Global mean tropospheric ozone concentration has been predicted to double over the rest of this century, predominantly due to emissions associated with fossil fuel and biomass burning. Tropospheric ozone is known to have detrimental effects on carbon uptake by land ecosystems through damaging photosynthesis, thereby reducing plant growth and biomass accumulation, limiting crop yields, and affecting stomatal control over plant transportation of water vapour between the leaf surface and atmosphere. The current and future food production in China is highly vulnerable to high levels of ozone concentration; however, it remains unclear how the different plant functional types (PFTs) and crops respond to increased concentrations of ozone for different regions only based on a single ozone flux (e.g. stomatal conductance). The UK Met Office land surface JULES-crop model represents a set of 9 PFTs characterised by leaf traits, including Leaf Mass Area (LMA), and a marginal cost of water-use parameter. Linking ozone sensitivity to LMA provides a powerful unifying explanation for variation in plant ozone sensitivity, and make the modelling of ozone plant damage at the large-scale become possible.In this work, results will be presented based on JULES-crop for China using a resolution up to 0.5 degrees and calibrated and validated with multiple measurement datasets (FACE etc.). Results will be presented illustrating the effect of predicted increased ozone levels (e.g. LMA-ozone) on net primary productivity (NPP) and main crop (Rice, Maize, Wheat, and Soybean) yield for China. An estimation of ozone effect on PFTs and crop yield under future scenarios and present day will also be shown.

Keywords: JULES-crop, PFTs, NPP, crop yield, China

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Effects of nutrient availability on O_3-caused damage of poplar Oxford clone

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Ozone pollution is often associated with nitrogen (N) deposition because nitrogen oxides (NOx) are the main O_3 precursor. In addition, N deposition may limit the availability of phosphorus (P) through soil acidification. However, to our knowledge, there are only few reports about the impacts of N and P availability individually or in combination on the O_3-caused damage of forest species. In the present study, the potential impacts of N and/or P enrichment on poplar Oxford clone under different O_3 concentrations in a free air controlled exposure (FACE) system were investigated. Compared to AA (ambient O_3 concentration), O_3 decreased total annual biomass by 18% in 1.5xAA and 23% in 2.0×AA. Nitrogen enrichment changed the response of total annual biomass to O_3, but P addition did not. The O_3×N×P interaction on biomass was significant indicated that the combination of N and P enrichment affected the O_3-caused biomass loss. Ozone decreased the leaf amount and increased the number of leaf trace. When P levels were low and medium, N addition mitigated the O_3-caused leaf loss, but it was aggravated by N enrichment under high P. In August, plant injury index (PII) was much higher in 1.5×AA and 2.0×AA than in AA. Under 2.0×AA, the addition of N decreased PII. During the same period, net photosynthetic rate was decreased by elevated O_3 and the relative loss in 1.5 xAA could be alleviated by N addition. At the end of the growth season, Fv/Fm and performance index (PI) were reduced by 2.0×AA, while the addition of N or P singly mitigated the relative loss. In summary, nutrient availability and O_3 are interrelated to change the visible injury, phenology, photosynthesis and biomass. The imbalance of N and P should be emphasized for forest protection under O_3 pollution.

Keywords: biomass, nitrogen, ozone, phenology, phosphorus, photosynthesis, visible injury

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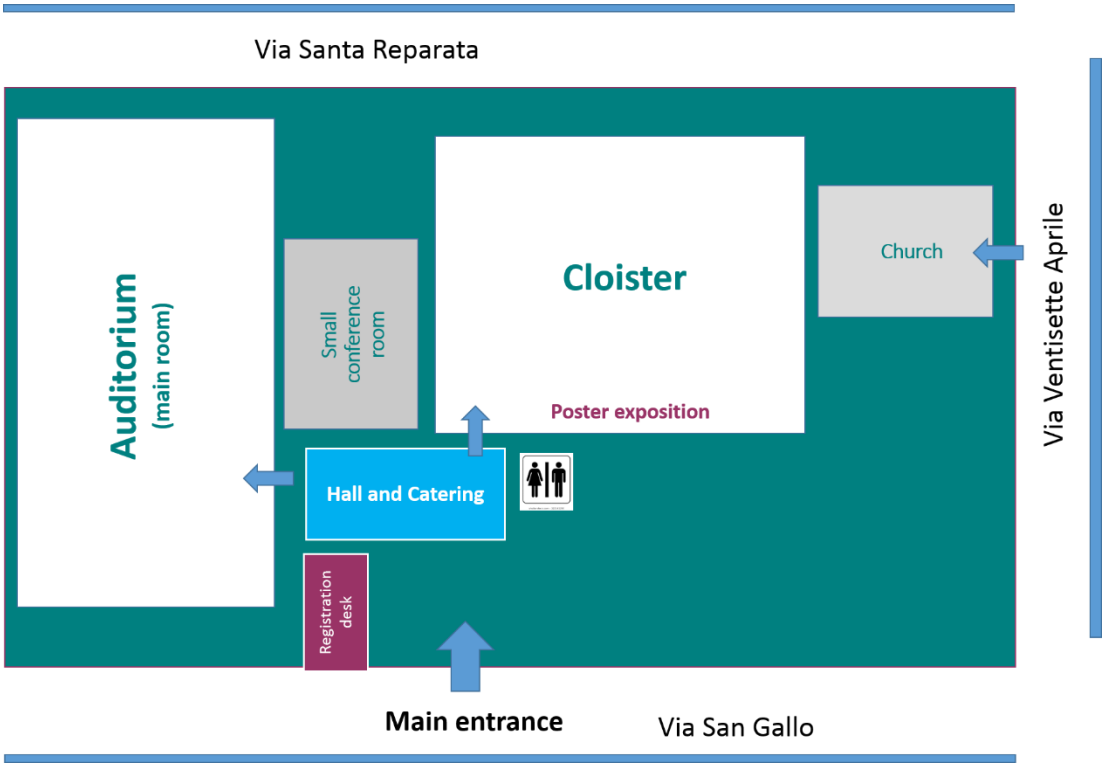
6. Maps and useful tips

Auditorium of Sant'Apollonia – The Conference Venue

The Auditorium of Sant'Apollonia is located in Via San Gallo 25, Firenze. It is about 15 minutes walking distance from the main train station of Firenze S.M.N. (Santa Maria Novella).
The Auditorium is a portion of the monastic complex of the Church of Sant'Apollonia. Sant'Apollonia was a former Benedictine convent, founded in 1339. The structures of the convent, suppressed since the 19th century, are now put to different uses, e.g. event venue with two rooms with 200 (Auditorium) and 40 (small conference room) seats.



The small church building is still present on the corner of Via Ventisette Aprile and San Gallo. The best known component is the former refectory or dining hall of the convent, the Cenacolo of Sant'Apollonia now part of the Museums of the Comune of Florence, with entrance through a nondescript door near the corner of Via Ventisette Aprile and Reparata. The refectory (1445) harbors the well-conserved fresco, The Last Supper by the Italian Renaissance artist Andrea del Castagno. Castagno created the rich marble panels that checkerboard the trompe-l'oeil walls and broke up the long white tablecloth with the dark figure of Judas the Betrayer, whose face is painted to resemble a satyr, an ancient symbol of evil.

The Last Supper by Andrea del Castagno

Palazzo Budini-Gattai – Venue of the Social Dinner

Budini Gattai Palace, formerly Grifoni Palace, was built by Baccio d'Agnolo and Bartolomeo Ammannati, in 1563, 16th century.

Ugolino di Iacopo Grifoni, secretary to Duke Cosimo de' Medici, purchased a number of houses in the area close to Piazza Santissima Annunziata and via de' Servi. His intention was to demolish them and construct a *palazzo* (palace) that would bring honor to his family. Baccio d'Agnolo, a student of Michelangelo, started the project, but it was completed by Bartolomeo Ammannati, who was likely the architect of the garden as well. The Italian garden was created around 1573, as a monumental fountain with statues of Giasone, Venus and sea monsters attributed to sculptor Giovanni Bandini. The garden was enlarged in the 18th century and the fountain moved and substituted with a walled fountain where the statue of Venus was housed. The Grifoni family died out in the 18th century and the property passed into the Riccardi family before going to the Budini Gattai family, to whom it still belongs today. The current garden, further modified in the late 1800s boasts curved flowerbeds and beautiful collections of camellias and azaleas. Other decorative elements of the garden include a glass and iron greenhouse dating back to 1892; a banana grove; and the "Monument to the lost tree" completed in 1908 in memory of an ancient *Cinnamomum camphora*

A story of lovers and ghosts

The far right window on the second floor of the Palazzo has been open for centuries. One of the legends says that at the end of 1500, a son of the Grifoni family was called off to war and had to leave his young bride. The wife had been waiting for the return of his beloved, seating at open window for decades, but her loved one never came back. Only when she died the window was shut. Two versions are told of this story: according to the first, the neighborhood was so touched that the window was opened again in memory of this story of love and devotion. The second argues that when the family attempted to close the window, the furniture started shaking, books flew off the shelves, paintings fell of the walls. The palace was back in order only when finally the shutters were reopened: the window has always been left ajar ever since. Another legend tells that the room with the open window belonged to a woman who was the secret lover of Ferdinando I de' Medici, Grand Duke of Tuscany: the statue depicting him, placed exactly in front of the Grifoni Palace, in fact keeps his eyes focused on that window…

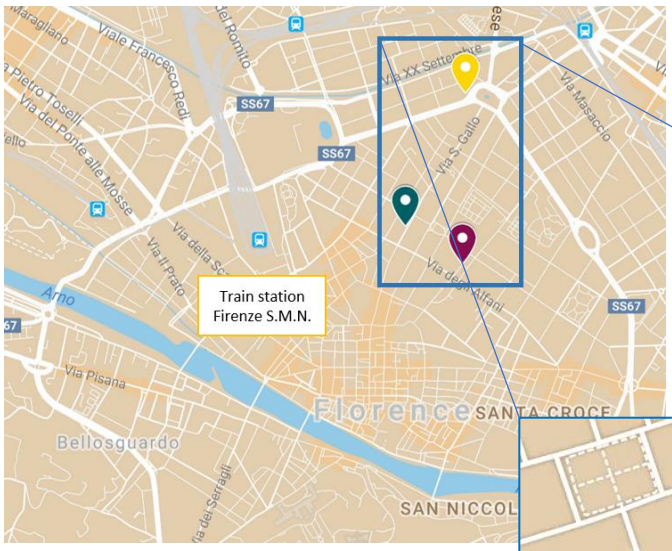
The facade of Palazzo Budini Gattai with the always-open window

Maps of Conference places

Walking distance:

A → **B** 6 minutes

A → **C** 11 minutes



A **Auditorium di Sant'Apollonia- Conference Venue,**
Via San Gallo 25

B **Palazzo Budini-Gattai, Venue of the Social Dinner,**
Via De Servi 51

C **Meeting point for Excursion,**
Piazza della Libertà 3

In case you need, please contact **Elisa +39 338 1580798**; **Elena +39 329 8061717**

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