ICP Vegetation Informal Document

Minutes of the ozone workshop, January 28th 2014, Paris, France.
Note: For the final decisions and recommendations regarding the ozone workshop in conjunction with the 27th ICP Vegetation Task Force meeting, 28 – 30 January, Paris, France, we refer to the minutes of the Task Force meeting.

Theme 1: Quantifying ozone impacts on trees

Chair: Harry Harmens
Rapporteur: Felicity Hayes

Questions to be discussed:

- *Can we add new flux parameterisations for additional tree species to the Modelling and Mapping Manual (M&M Manual)?*
- *Can we set critical levels for new tree species*
- *Is amendment of current critical levels required?*
- *Is there new field-based evidence of predicted impacts?*

Alessandra De Marco et al. presented visible leaf injury impacts of trees in natural conditions in relation to ozone stomatal flux-based critical levels (FO_3REST project). A large survey of 1040 trees showed that the relationship between canopy moisture content and visible-injury was species-specific. AOT40 overestimated risk (based on observed discolouration and needle loss) in the survey areas (NW Italy and SE France) compared to POD_y, which shows a better correlation with observed effects than AOT40. Species-specific parameterisations for *Pinus cembra* and *Pinus halepensis* (including soil moisture in the model) showed different optimum threshold (y) values for the different species. Critical levels (CLef) were provisionally identified for generic and sensitive forest trees, in order to protect 90% of leaves/needles surface from ozone damage. Further field-based validation of O_3 flux-effect relationships is required via epidemiological studies.

It was noted that many trees show discolouration of leaves during the summer and that for large scale surveys the timing of the survey in relation to ozone episodes would be important. The following questions were discussed:
1). Are there other relationships of POD vs injury? (These would be very useful)
2). Can information for *Pinus halepensis* and *Quercus ilex* be combined? (This was not answered during the meeting)

Silvano Fares et al. presented a comparison between Ball-Berry and Jarvis approaches to model stomatal ozone fluxes in Mediterranean forest by validation using Castelporziano and San Rossore forests as test sites. Fluxes were measured using Eddy covariance and gross primary productivity (GPP) was calculated by modelling night-time respiration. The largest ozone fluxes occurred between 10:00 and 18:00. Incorporation of soil moisture into the parameterisations did not make a significant improvement, due to a high water table in these sites. Within the Ball-Berry model 'm', relating stomatal conductance to photosynthesis, varied with each season (higher in spring and summer than in autumn), hence a variable 'm' produced a better agreement between modelled and measured stomatal concductance. Both the Ball-Berry and Jarvis models worked well when parameterised with field data, although the Ball-Berry model underestimated fluxes in spring. It was noted that a multilayer canopy model would be required to upscale to canopy-level effects, and a variable leaf area index

(LAI) would be needed. Atmospheric CO_2 concentrations also vary and this needs to be included in the model.

Beat Rihm et al. presented the results from a high resolution mapping of ozone flux for epidemiological analysis in Switzerland. Climate and ozone data from 1991 to 2011 and altitude was used in DO_3SE to obtain $F_{phen.}$ Mapping the ozone fluxes on a monthly basis showed clear differences between the mountains and valleys in each month and high ozone concentrations and fluxes were shown for the mountains. The influence of soil water potential (SWP) was shown to be small for most of Switzerland. Simplified flux mapping based on monthly meteorological maps was feasible in Switzerland, as an alternative approach to high temporal but poor spatial resolution. However, the monthly flux data are less suited for epidemiological analysis (maybe due to levelling off peak values). It was noted during the discussion that results from saplings showed a good match to results from large trees.

Patrick Büker et al. presented the effect of ozone on the C sequestration potentials of European forests, based on data of emissions, landcover, C stocks, and hourly meteorology (from EMEP). Analysis was based on net annual increment NAI (rather than total biomass) and included uncertainty analysis based predominantly on variability of the growth function used. This NAI analysis showed that the group 'Norway Spruce + Scots Pine' is more sensitive than currently indicated in the M&M Manual (based on a biomass flux-effect relationship). Higher reductions in relative C loss per country were found using the NAI and ozone flux approach than had previously been found using biomass and AOT40. The effect of soil moisture deficit (SMD) was found to be small (although it was acknowledged that this was for a 'wet' year).

During the discussion it was considered that NAI was a valid parameter in terms of setting critical levels, although it is affected by other factors e.g. temperature. It was noted that as well as the growth rate the felling rate should also be considered. The interaction between ozone and nitrogen may be important. Some participants considered their region to now be at saturating nitrogen conditions.

Per Erik Karlsson et al. presented how a simplified Phytotoxic Ozone Dose model (S-POD) could be used to assess the risk for ozone impacts on trees at the regional scale. S-POD uses daylight ozone concentrations and functions for phenology, temperature and VPD. Using biomass data from Norway spruce and silver birch experiments in Sweden and Finland it was shown that S-POD performed almost as well as POD_1. It was suggested that the S-POD concept should be developed and tested on the European scale. It was noted during the following discussion that the sensitivity of Norway spruce and 'Beech-Birch' to ozone was the same with selection of a particular threshold and compensation for g_{max}.

Sabine Braun et al. presented results of validation of stomatal flux in *Quercus* species by comparing the results of oak parameterisations in the M&M Manual to sapflow measurements. Comparisons have been made for oak and beech. It was shown that short-term meteorological conditions (particularly temperature and vapour pressure deficit (VPD)) strongly affected the stomatal response to temperature and VPD, for example, T_{opt} varied between years and data showed a linear relationship with average temperature over the preceding 5 days. During the discussion it was noted that some other research groups are also starting sapflow measurements that can be used to validate model predictions (e.g. Silvano Fares). A question arose as to whether photosynthesis rates acclimatised to meteorological conditions in a similar way.

Patrick Büker et al. presented results of re-analysis of existing tree flux-effect data. An investigation of whether a common value for y in POD_y could be established for tree species was carried out based on criteria of r^2 and intercept of the flux-effect relationship. A y of 2 nmol m^{-2} s^{-1} fitted all the species and functional types tested (although it was noted that this was on the 'border' of the suitable range for some of these). The influence of soil moisture deficit (SMD) was low for all experiments. It was found that the generic dose-response relationship for all tree species grouped together improved if ozone flux was expressed on a unit leaf mass area, rather than unit area.

In this discussion it was commented that the leaf area index (LAI) approach only works well in sparse forests with many sunlit leaves. It was also commented that leaf mass based functions may have benefits in understanding sensitivity to ozone and that it may be useful to show the relationship in the M&M Manual if it is stated what it could be potentially used for.

General Discussion

- When **comparing Ball-Berry to DO_3SE** it was noted that the margins of error can be larger with the Ball-Berry approach. It was noted that although a mechanistic approach was preferred, this requires good parameterisation to reduce uncertainties. Therefore, both approaches might be needed, and the decision of which was most appropriate would depend on the application. It was noted that DO_3SE gives both options. In the USA Ball-Berry is more commonly used, whereas the Jarvis approach is more used in Europe. It was recommended that when included, the M&M Manual should explain how the Ball-Berry model could be used, and to make it very clear how estimates and generalisations could be very influential for the results obtained.
- It is too early to make a decision on changing the current flux-effect relationships for tree species in the M&M Manual based on a generic y value of 2 nmol m^{-2} s^{-1}. The Task Force will need to discuss the new relationships in the coming year and make a decision at the next Task Force Meeting (TFM)/Critical Levels Workshop.
- Generic flux-effect relationships for plant functional types (i.e. broad-leaf species, needle-leaf species and Mediterranean species) were deemed not to be robust enough to be included in the M&M Manual at the moment. However, these relationships should be further developed in the future. Particularly the possibility of a 'Generic Mediterranean' tree should be revisited at the next (TFM)/Critical Levels Workshop.
- At present there are no flux-effect relationships for additional tree species to be included in the M&M Manual, but it was noted that some groups e.g. Giacomo Gerosa have some new data that should be revisited at the next TFM/Critical Levels Workshop.
- Note: In the afternoon session parameterisation of the DO_3SE model for poplar was presented and agreed for inclusion in the annex of the M&M Manual.

Theme 2: Quantifying ozone impacts on crops and (semi-natural) vegetation

Chair: Håkan Pleijel
Rapporteur: Patrick Büker

The following questions needed to be answered:

- Do we have new flux parameterisations for additional crops and (semi-) natural vegetation species?
- Can we set critical levels for new crop species?
- Can we set critical levels for generic crops species for IAM?
- Can we set new critical levels for grassland species?

Oliver Bethenod et al. presented results of a IFLOZ/VULNOZ field study on ozone impacts on maize in central France (Grignon):

a. FACE-like study with linear ozone release and measurement of ozone concentration at four different distances: control ("behind" release pipe), and 2, 3.5 and 5 meter down-wind from release pipe.
b. Three ozone-indices: AOT40, CUO and POD_x (with POD_0 = CUO).
c. Aim of study:
    i. Develop ozone uptake model for maize.
    ii. Develop dose-response relationship for maize, with focus on yield of grains and shoots.
    iii. Examine response of maize leaf photosynthesis to ozone.
    iv. Discuss detoxification capacities of maize (which threshold for POD_x?).
d. Jarvis-type flux model was parameterised with physiological measurements and model captured measured stomatal conductance (g_{sto}) well.
e. First results indicate that when comparing shoot and grain effects with AOT40, the shoot biomass was more affected by ozone than the grain biomass.
f. VPD and temperature functions were most important with a clear closure of stomata at below-optimum temperatures and above 25°C, when VPD was high.
g. Modelled photosynthesis using the von Caemmerer approach did not show clear effect on ozone exposure (expressed as AOT40), hence the suggestion that photosynthetic system seemed to have been largely protected from ozone effects.
h. Comparison with an earlier (2009) wheat study at the same site showed that despite higher ozone concentrations and AOT40 values during the maize experiment, the POD_0 values were much lower for maize as compared to wheat, again indicating the stomatal closure of maize due to the prevailing meteorological conditions .

Discussion:
During discussion it was suggested that a further maize g_{max} data point could potentially be derived from this experiment for maize parameterisation that will be added to the annex of the M&M Manual.

Patrick Stella et al. presented the two-year total, stomatal, cuticular and soil ozone budgets of a maize and wheat field at Grignon (same experiment as the one above)

a. Aims of study:
    i. Determine the total deposition of ozone to a wheat and maize field.
    ii. Calculate both stomatal and non-stomatal deposition .
    iii. Estimate the trade-off between stomatal/non-stomatal/total deposition.

b. Problem: SVAT models validated only for fully developed canopies at maturity; how to account for effects of phenology (developmental stages) on C partitioning?
c. They used the SURFATM-O_3 model, a coupled energy balance and ozone deposition model with a resistance scheme for water vapour, heat and ozone using the same transfer resistances; it accounts for stomatal sink of senesced leaves (reduced photosynthetic capacity but still transpiring) too.
d. Meteorology, phenology (canopy height, LAI) and fluxes were measured throughout growing season and modelled fluxes matched well measured fluxes.
e. Ozone flux partitioning: Soil removal dominated budget (55%), followed by cuticular uptake (21%), stomatal uptake for green leaves (20%) and stomatal uptake for senesced leaves (4%).
f. Leaf stomatal conductance for wheat two times higher than for maize.
g. Maize was fairly unaffected by ozone, whereas wheat showed a yield reduction of 2 to 4%.

Discussion:
Patrick Stella suggested to maybe determine stomatal conductance from subtracting modelled non-stomatal sinks from total sinks; however, this could increase uncertainty; a two-way approach for determining g_{sto} might be most useful; comparison of results of both approaches might help to identify error sources. The g_{soil} and g_{cut} methodology was further discussed; could also be included in DO_3SE, where currently constants are being used for these conductances/resistances. It was concluded from the experiment that maize was fairly ozone-insensitive at Grignon.

Giacomo Gerosa et al. presented the yield responses of some Italian and Spanish cultivars of durum wheat to elevated ozone as identified by screening experiment

a. Five different cultivars (three Italian, two Spanish) of durum wheat were exposed in open top chambers (OTCs) to two different ozone levels (-50% (Control) and +40% (Ozone+) as compared to ambient levels); plants were irrigated daily, i.e. soil drought effect as non-existent.
b. Measurements of meteorology, growth parameters (phenological stages, number of years, grain yield and above-ground biomass) and physiology (g_{sto}, fluorescence) were recorded; a hysto-cytochemical analysis was performed.
c. Yield of only two cultivars decreased after exposure to ozone; this effect was significant only for cultivar Sculptur, the most productive cultivar.
d. Number of ears of only two cvs. (Sculptur, Vitron) decreased significantly after exposure to ozone; there was a non-significant decrease for two of the three remaining cvs.
e. Above-ground biomass decreased significantly for the three most productive cvs. (Sculptur, Vitron, Colombo) after exposure to ozone, possibly due to reduced g_{sto}.
f. g_{sto} decreased significantly (up to 37%) for all cvs. except Vitron; this effect was especially noticeable during the afternoon.
g. Photosystem's II efficiency as detected by measurements of chlorophyll α fluorescence was not affected by ozone throughout cvs.
h. Stomatal impairment (as detected by hysto-cytochemical analysis on leaves) and increase of intercellular CO_2 might be causes for massive reduction in g_{sto}.
i. In 2014, the effects of ozone on CO_2 assimilation and stomatal functionality will be assessed, as well as the possibility to reduce ozone injury by application of commercial fungicides with antioxidant activity or mild antitranspirants

Discussion:
During follow-up discussion there was agreement that different cvs. have different strategies and defense mechanisms to withstand ozone impacts.

Felicity Hayes et al. gave an update on flux-effect/dose-response relationships for grassland species

a. New published data on effects of ozone i) on single grassland species or ii) at the canopy level is sparse, but some new unpublished data (e.g. from the UK) is available. Felicity will try to access these unpublished datasets.
b. Specifically, g_{sto} and biomass data points are readily available for 15 species (4 grasses, 1 legumes and 10 forbs).
c. Several new flux-effect relationships are available (shown was one for *Leontodon hispidus*) from individual experiments/sites; however, some species could potentially be grouped together (e.g. *Briza media* and *Briza maxima*?).
d. Soil moisture greatly influences the stomatal uptake of ozone by grassland species and is difficult to parameterise (one problem being the use of different soil moisture parameters, some of which are "calculated" rather than directly measured).
e. g_{max} - as needed by the multiplicative flux model – shows a large variation across grassland species; for species with low g_{max}, the flux is usually below the threshold of 1.
f. Some flux-effect relationships are available from ICP Veg. Participants.

Discussion:

- Felicity asked whether it would be useful to have a central grassland data list of respective measurements (on the ICP Vegetation website?) as experiments should ideally be made at several sites/countries per species; this was thought to be a good idea.
- What are the relevant 'endpoints' to measure? (biomass/flower numbers/other?).
- Could/should we combine data from different species? One idea would be the grouping according to plant functional types, but problem there is that some legumes are annuals, whereas others are perennials; so maybe two groups of legumes?
- Grouping of species could also be done according to plant growth strategies of functional traits, e.g. with help of Grimes classification, Ellenberg numbers or general knowledge about species' sensitivity to ozone; existing datasets could be analysed accordingly.
- Jean-Paul Hettelingh from ICP Modelling & Mapping commented on regional point of view: Could there be a list of "central" species (criteria: abundance, richness or distribution)? Which would be suitable endpoints for regional modelling? Biomass?
- Can dose-response relationships be derived at the plant community level? Potential endpoints could be biomass, seed or flower output, distribution, abundance, biodiversity.
- SEI York will finalise multi-layer multi-species version of DO_3SE model in 2014, which will help to model effects of ozone on heterogeneous plant canopies (grasslands, forests).
- Should new measuring campaigns focus on particular grassland species or should the focus rather be on a good representation of some "key" species that are widely distributed across Europe? The latter was believed to be more important.
- Beside semi-natural grasslands, a dose-response relationship might be soon available for productive grasslands consisting of *Trifolium repens* an *Lolium perenne.*

- Due to the general lack of information (e.g. on dose-response relationships) on grassland species/ecosystems responses to ozone, grasslands should be one focus of the Critical Level workshop scheduled for 2016.

Håkan Pleijel presented on behalf of Gina Mills et al. a study on the application of a generic crop flux-effect relationship in integrated assessment modelling in Europe

a. Integrated assessment model used by LRTAP Convention and European Commission: GAINS; runs in scenario analysis and optimisation mode.
b. Ozone flux approach was recently introduced in GAINS, which requires simplified flux model (e.g. without soil moisture effect) because TFIAM links ozone fluxes to economic effects.
c. ICP Vegetation developed for this purpose a response function for a generic crop (wheat) flux model using as ozone index POD_3IAM with a 45 day accumulation period.
d. Predicted mean % yield loss for EU27 countries: 12.4% for GP2005 and 10.3% for GP CLE2020; respective gridded maps were shown.
e. Reduction of mean % yield loss for EU27 countries from GP2005 to GPCE2030: approx. 21%.
f. Since this reduction is not very high, TFIAM tested a higher y threshold of 6 (POD_6IAM), which results in stronger flux-effect relationship and a more pronounced benefit of European control of peak ozone concentrations; BUT: mapping becomes less accurate!
g. It was proposed to include this new generic flux effect relationship for crops based on wheat in the M&M Manual with a critical level for use in IAM (5% yield loss) based on POD_3IAM of 3.9 (rounded of as 4) mmol m^{-2} based on 45 days or 7.8 (rounded of as 8) mmol m^{-2} based on 90 days (preferably the latter); this would not take soil water effects into account. Note: the 90 days period is required for GAINS as it cannot run with the shorter period of 45 days. However, wheat in experiments often not exposed more than 50 days and 90 days goes beyond the sensitive period of wheat to ozone.
h. POD_3IAM will replace POD_3gen.
i. It had to be clearly stated that this approach could only be used for regional-scale scenario and optimisation analysis!

Discussion:

- Strong concerns were raised that the same parameterisation would be used for wheat grown all over Europe, i.e. no distinction for wheat grown in southern European countries where wheat is known to react differently to VPD as compared to central and northern European wheat [This issue was discussed further during the Task Force meeting].
- To find a compromise, the use of different VPD functions for southern as compared to central and northern European wheat was preferred to entirely excluding southern countries in respective flux and yield loss maps.
- Jean-Paul Hettelingh informed audience that climate change effects (change in temperature and CO_2 concentrations) will soon be included in 2020 and 2030 scenarios (currently not included).
- Ideally, soil water effects should be accounted for in future versions of IAM flux effect relationship.

Patrick Büker et al. presented overview of the DO_3SE parameterisation for new crop and tree species

a. Aim of study:
   i. Develop robust parameterisations for new crop and forest tree species to be applied for ozone flux modelling (using DO_3SE model).
   ii. Follow-up of earlier study that was presented at Obergurgl workshop in 2005.
b. Criteria for selection of species:
   i. Sufficient peer-reviewed information on species' g_{max} and influence of meteorology (f_{Temp}, f_{VPD}, f_{light}) and phenology (f_{phen}) on g_{sto}.
   ii. Not previously included in M&M Manual., i.e. new species.
   iii. Known to be of high or medium sensitivity to ozone, widely cultivated across Europe, and of economic importance in Europe.
c. Based on these criteria, the following six species were selected:
   Grapevine (*Vitis vinifera*), Maize (*Zea mays*), Oilseed rape (*Brassica napus*), Poplar (*Populus ssp.*), Soybean (*Glycine max*), Sunflower (*Helianthus annuus*).
d. Information for respective DO_3SE model parameterisation was derived from comprehensive literature review according to the following criteria:
   iii. Field-based experiments.
   iv. European experiments; if none, then also consider North American studies.
   v. Reporting of g_{sto} and information about measuring device used, leaf area reference (total vs. projected) and conditions under which g_{sto} was measured.
   vi. Study published after 2005, if species was already searched for in 2005 study.
e. Data referring to total leaf area were recalculated to represent projected leaf area.
f. H_2O g_{max} was converted to O_3 g_{max} using molecular diffusivity conversion factor of 0.663 (Grünhage et al., 2012).
g. No. of data points for derivation of g_{max} was 23, 6, 5, 10, 8 and 15 for grapevine, maize, oilseed rape, poplar, soybean and sunflower, respectively.
h. g_{max} was defined as 229, 326, 495, 392, 706 and 386 mmol O_3 m^{-2} PLA s^{-1} for grapevine, maize, oilseed rape, poplar, soybean and sunflower, respectively.
i. Environmental functions were based on varying number of peer-reviewed papers, with the strongest and hence most robust database for grapevine and weakest and hence least robust database for oilseed rape.

Discussion:

The experts discussed whether these parameterisations are robust enough to be included as annex in revision of M&M Manual in late March 2014, together with associated explanatory text. It was suggested that this was the case for grapevine, maize, soybean, poplar and sunflower. Next step will be to derive dose-response relationships for these species.

General final discussion

It was discussed whether new critical levels for crops and/or grassland species could be derived and added to the M&M Manual in time for the March 2014 revision; this was deemed to be too early, given that first an agreement on respective dose-response relationships has to be found. Such a change could, for example, be added to the M&M Manual at some time after the next ICP Vegetation Task Force meeting in 2015 or after the ozone critical level workshop in 2016.

Harry Harmens summarised the conclusions and recommendation from the ozone workshop. These conclusions and recommendations were presented to the ICP Vegetation Task Force during their meeting following the ozone workshop and further discussed where needed, in

particular regarding the adoption of the dose-response relationship for a generic crop species (based on wheat parameterisations) for integrated assessment modelling and associated critical level. Recommendations for future work were included. For further details of the conclusions and recommendations we refer to the minutes of the 27th ICP Vegetation Task Force meeting (Annex I).