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WORKSHOP ON CRITICAL LEVELS FOR OZONE - LEVEL II

Summary report prepared by the organizing committee

I. INTRODUCTION

1. The Workshop on critical levels for ozone - level II was organized by the Swiss Agency for the Environment, Forests and Landscape, in cooperation with the Institute of Environmental Protection and Agriculture (IUL) of the Swiss Federal Research Station for Agroecology and Agriculture. The Workshop took place from 11 to 15 April 1999 at Gerzensee (Switzerland).

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2. The Workshop was attended by 77 scientists from the following Parties to the Convention: Austria, Belgium, Canada, Denmark, Finland, Germany, Greece, Italy, Netherlands, Slovenia, Spain, Sweden, Switzerland, United Kingdom, and the United States of America. Two scientists from Japan attended as observers. The Chairman of the Working Group on Effects, as well as representatives of the International Cooperative Programme (ICP) on Crops, the Task Force on Mapping and the Coordination Center for Effects (CCE) were also present. The UN/ECE secretariat was also represented.

3. In a series of previous workshops under the Convention (Egham, Berne, Kuopio), critical levels for ozone were defined on the basis of experimental data from open-top chambers using a level I approach without considering the influence of environmental factors, such as soil moisture or nutrient supply. These critical levels, expressed on the basis of an AOT40 exposure index (accumulated exposure over the threshold concentration of 40 ppb (parts per billion)) and related to the ozone concentrations measured at the top of the canopy, can be applied to evaluate the potential risk of ozone to crops, trees and semi-natural vegetation. This can be done by comparing actual levels of ozone with the critical levels, i.e. by estimating the exceedance of critical levels. The level I approach is attractive because of its simplicity, but it does not consider any biotic or abiotic factors which may influence a plant=s sensitivity to ozone and may thus determine the extent of damage to vegetation. A level II approach is necessary to accurately assess the impacts caused by the exceedance of critical levels for ozone. It is also essential as an input for the economic evaluation of damage due to ozone.

4. The aims of the Workshop were:

(a) To present and discuss new scientific findings concerning the effects of ozone on single plants and plant mixtures as well as interactions between the effects of ozone and other biotic and abiotic factors;

(b) To evaluate modelling tools suitable for estimating long-term impacts of ozone resulting from exceedances of critical levels under variable environmental conditions; and

(c) To consider possible technical guidelines to be included in the mapping manual for mapping critical levels and their exceedance on the basis of a level II approach.

5. A total of 56 extended abstracts of the scientific presentations made during the plenary sessions and/or the poster sessions were published as background documents for participants before the Workshop. In addition to the plenary sessions, four parallel working groups discussed problems related to forest trees, crops, semi-natural vegetation, and mapping/modelling. Each of the groups dealing with vegetation had one joint meeting with the mapping/modelling group in order to identify and discuss their common needs and future collaboration.

II. GENERAL CONCLUSIONS

6. Several options for a level II approach were identified:

(a) The modification of the level I critical levels for ozone;

(b) The modification of the exceedances of the level I critical levels for ozone; and

(c) The development of a flux-based approach which addresses the ozone uptake and the toxicity of the absorbed ozone dose.

7. There was a general agreement in all working groups that the development of a flux-based approach should be the long-term goal of a level II approach, but that many difficulties in applying it on a larger scale to several receptor types might make it necessary to apply interim solutions, such as the modification of the exceedances of the

level I critical levels for ozone. The direct modification of the level I critical levels for ozone was not considered a useful approach, since it would imply a full re-analysis of the exposure-response part of the level I approach.

8. For the development of an approach based on ozone flux-response relationships, the use of a flux model composed of atmospheric, boundary layer, stomatal and non-stomatal resistance components was proposed. Since stomatal uptake of ozone by a plant cannot be measured directly, a receptor-specific micrometeorological parametrization is needed. This involves, for instance, the receptor-specific maximum leaf conductance, which is modified by environmental and phenological parameters. Important environmental and vegetation parameters are soil factors (soil moisture deficit, irrigation), plant development factors (phenological stages) and factors influencing the instantaneous ozone uptake by plants (temperature, vapour pressure deficit, global radiation, wind speed). Finally, specific flux-response relationships must be linked to the ozone flux integrated over time.

III. CONCLUSIONS FOR SPECIFIC RECEPTORS

A. Forest trees

9 Current ozone concentrations in Europe represent a risk for forest trees. Until more information becomes available, particularly for southern European forests, the critical level for ozone at level I should remain at an AOT40 value of 10 ppm-h, calculated for daylight hours and during a six-month period from April to September. Exceedance mapping at level I should continue to be based on this critical level, recognizing the problems of interpretation associated with this index. It should be used only for the spatial identification of potential risks due to ozone and not for quantitative biomass loss estimates or economic evaluation of ozone impacts on forests. However, some new data suggest that a lower index value of 5-7 ppm-h might be needed to protect the most sensitive trees, and a lower (e.g. 30 ppb) or higher cut-off concentration may be required depending on latitude and altitude.

10 The ultimate goal of a level II approach will be an assessment based on the ozone flux to forests and its link to a response. Since the establishment of such an approach for forest trees still represents a big scientific challenge, further progress in the medium term could be envisaged through a modification of the AOT40 values calculated to express the exceedances of the critical level. The modifying factors to be considered are principally the same as those influencing the ozone flux into trees, such as soil moisture deficit or phenology. Modified AOT40 values would represent a step toward a more realistic assessment of potential risks due to exceedances of critical levels.

11 A full flux approach, including quantitative risk assessments, would require more research in such areas as:

(a) Tree and ecosystem responses associated with modelled fluxes. It is difficult to move from a flux estimate via a biological response to an economic impact. Further work is required to quantify these steps. Economic assessments need to move beyond simplistic assessments of growth losses towards more holistic evaluations of the value of a forest for society;

(b) Influence of environmental modifying factors (e.g. soil moisture) on ozone dose and tree response;

(c) Sensitivity to ozone within and between different tree species;

(d) Tree phenology, in particular the characterization of sensitive periods such as budbreak;

(e) Interactions with other airborne pollutants, particularly with nitrogen.

12 Advanced field studies are needed to validate risk maps and the results of flux-response modelling work. Epidemiological studies are promising options, as they take into account all factors known to influence the response variable being considered. The evaluation of regional data at the national level as well as international studies

covering different pollution climates may have the potential to contribute to this validation exercise. Very large databases, such as the one from ICP Forests, are of potential value to this work.

B. Agricultural crops

13 The critical level at level I defined as an AOT40 value of 3000 ppb-h, calculated for daylight hours and during a 3-month period typically from May to July, will continue to play a significant role due to its use in the preparation of the multi-pollutant/multi-effect protocol expected to be adopted later in 1999. Consequently, it will be used in the follow-up to that protocol, i.e. to map exceedances of the level I critical level over Europe and for studying trends. The existing Mapping Manual stipulates that the relevant ozone concentrations for the calculation of AOT40 values are those at the top of the canopy. This has been largely ignored in many past level I applications, which can lead to significant over-estimates of potential yield effects.

14 For possible future revisions of the multi-pollutant/multi-effect protocol (e.g. around 2003/2004), it was concluded that the level II approach would be the most appropriate, since it made it possible to produce more realistic maps on actual yield loss over Europe. Two main options were identified for a level II approach:

(a) An extended AOT40 approach using modifying factors for variables influencing the ozone uptake by the plants, and considering spatial gradients in the growing season; and
(b) An approach based on flux-response relationships.

Scientific papers addressing both approaches were presented at the workshop. It was concluded that the first approach would lead to faster progress towards level II work, until the second option had been developed sufficiently.

15 It was considered that, for the modified AOT40 approach, the soil moisture could be used as a long term modifying factor of AOT40, while for factors influencing ozone uptake in the short term, such as vapour pressure deficit, temperature and global radiation, the correction had to be made for hourly ozone values before the AOT40 was calculated. The most limiting factor at a certain time should then be chosen to modify the AOT40, since the simultaneous application of all corrective factors would probably lead to an over-correction. However, further work would be necessary in the near future to establish the correct use of such corrective factors. For the assessment of soil moisture deficit, irrigation should be considered according to local agricultural practice. In addition, the variability in sensitivity to ozone during the plant=s development must be considered. One possibility would be to identify a limited number of distinct periods during crop development and to ascribe different ozone sensitivity factors to each period (i.e. phenological weighting).

16 Three options were identified to further develop the flux-response approach:

(a) Analysis of data from all earlier open-top chamber experiments to recalculate flux-response relationships using models for stomatal conductance. Special attention must be given to the chamber effect on ozone uptake by the plants;
(b) Use of multivariate techniques applied to historical series of yield data from field observations, in combination with measurements of ozone and other environmental factors known to influence crop yield;
(c) Analysis of the extensive database of ICP Crops for clover plants grown under different ozone loads across most of Europe.

17 The validation of level II maps was considered to be complicated, but ICP Crops should attempt it through the use of two soil-grown clover clones with different ozone sensitivity, possibly with and without irrigation to influence ozone uptake. Another approach could be to expose ozone-sensitive and resistant cultivars of selected crop species in most of Europe. The choice of cultivar should be adjusted to the area and may therefore vary between sites. They should be field-grown and irrigated according to local agricultural practice.

18 Perennial crops might introduce further complications through the occurrence of memory effects of ozone exposure from one year to another. It is important to address this question since there are strong indications that at least some perennial species are sensitive to ozone.

C. Semi-natural vegetation

19 For the annuals of semi-natural vegetation, the provisional critical level at level I, expressed as AOT40, calculated for daylight hours over three months, should remain at 3000 ppb-h. The response parameter with the highest ecological significance to plant species with a short life cycle is seed output. The critical level for annuals is thus the same as for crops. To account for different growth periods of annuals with different life cycles, or growing in different parts of Europe, three-month AOT40s will have to be calculated for the time when vegetation is actively growing.

20 For the protection of ozone-sensitive perennials, a provisional critical level at level I of 7000 ppb-h was proposed, expressed as AOT40 and calculated for daylight hours over six months. The response parameters with the greatest ecological significance to long-lived species are shoot and root biomass. As with annuals, the time period of six months for the calculation of AOT40 should be flexible, relating to the growth period when the vegetation is the most active.

21 The application of a level II approach to semi-natural vegetation was considered even more difficult than for crops and trees, due to the lack of receptor-specific micrometeorological parametrization and the presence of many species within a plant community with different canopy heights. Fluxes within the canopy cannot be accurately addressed by the methodologies presented at the Workshop. The alternative of applying simple corrective factors to the AOT40 exposure index to account for the effect of level II factors was not considered to be feasible because of the complex patterns of interaction between ozone and environmental factors (e.g. soil moisture stress) in a range of species with different ecological strategies. Further research is needed to prepare the basis for the application of a level II approach to complex plant communities. Response variables so far considered for single species, such as shoot and root biomass or seed output, need to be complemented with variables covering community responses, such as competition and biodiversity.

IV. CONCLUSIONS FOR MODELLING AND MAPPING

22 Due to the threshold concentration of 40 ppb involved, calculated and modelled AOT40 values are very sensitive to uncertainties in the ozone concentrations used. These uncertainties may arise from real problems with calibration, or from the use of ozone data from locations which are not truly representative of the ozone experienced by the receptor considered. A flux approach without a threshold concentration would partly overcome these difficulties. The correct derivation of AOT40 values at the top of the canopy requires the same information as a direct flux estimate.

23 The modification of AOT40 values requires methods and data similar to those used in flux calculations. Modifying factors such as soil moisture deficit, vapour pressure deficit and surface wind speed (all influencing the uptake of ozone) can be derived from flux modelling studies or from measurements. Moreover, AOT40 values so far

calculated for fixed three- or six-month periods could be modified by considering phenology through a regionally adapted growing season. The first modified AOT40 maps for Europe were presented at the Workshop.

24 The level II approach should result in impact or damage assessment. In the case of flux modelling this requires the incorporation of flux-response relationships at a finer spatial resolution than currently carried out with the EMEP model. Local modelling is needed in addition to the regional modelling of EMEP in order to prepare the tools for an adequate up- and downscaling. Biology has to be the driving force in a flux-based level II approach. The task of the modellers is to translate the level II knowledge into tools which satisfy the needs of the work under the Convention. The ultimate purpose is to use the models in negotiations of effects-based air pollution abatement strategies.

25 The main problems for the regional modelling and mapping of ozone fluxes are:

(a) The difficulty of model validation. Only about ten research sites in Europe carry out the micrometeorological measurements that can be used for a detailed evaluation of flux models; however, these sites do not cover the biological response part of the relationship;

(b) Parameters for surface resistance modelling, especially for semi-natural vegetation, need to be collected and evaluated;

(c) There is a strong need for improved land cover maps (land use, priority ecosystems, species occurrence and distribution) covering the whole of Europe;

(d) There are many difficult modelling tasks, e.g. modelling fluxes over complex terrain (e.g. the Alps) or modelling fluxes at different canopy heights in a plant community.

26 Different methods exist for modelling ozone fluxes. Some of these were presented during the Workshop, but no single method was preferred. The various options should be tested and further developed in different areas of Europe with different environmental conditions. On the basis of species-specific vegetation parameters derived from the literature, flux modelling could be carried out today on the European scale for about 50 species, but it has been done so far for only two species (wheat and beech). This is an over-simplification given Europe=s variety of cultivars and ecotypes. There is a need to consider whether improvements could be realized through spatial variation of the model parametrization for species-specific vegetation parameters and micro-climatic conditions. For the purpose of transparency, it is essential that the selected process should be well documented.

27 The need for more detailed information in the Mapping Manual was recognized. This information could cover the definition of technical terms such as soil moisture deficit, vapour pressure deficit, leaf area index, flux etc., methods for their calculation and the physical units used. Moreover, simple guidance for instance for spreadsheet calculations or other computer-based calculation methods could be made available to scientists wishing to move from concentration-based or AOT40-based to flux-based data analysis. Such guidance could be included as options in future versions of the Mapping Manual or on the Internet.