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Recent results and updating of scientific and technical knowledge

Flux-based assessment of ozone effects for air pollution policy

Report by the Workshop on flux-based assessment of ozone effects for air pollution policy [1]

I. Introduction

1. This report describes the results of the Workshop on flux-based assessment of ozone effects for air pollution policy, held from 9 to 12 November 2009 in Ispra, Italy, in accordance with item 3.5 (d) of the 2010 workplan for the implementation of the Convention (ECE/EB.AIR/99/Add.2) adopted by the Executive Body at its twenty-seventh session in December 2009. The annex reports the follow-on discussions at the relevant Task Force meetings of the International Cooperative Programmes (ICPs) of the Working Group on Effects, in particular of the ICP on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation), as well as decisions adopted on 10 new and/or revised flux-based critical levels of ozone for vegetation.

A. Attendance

2. Forty-two experts from the following Parties to the Convention on Long-range Transboundary Air Pollution attended the workshop: Austria, Belgium, Finland, France, Germany, Greece, Italy, the Netherlands, Spain, Sweden, Switzerland and the United Kingdom of Great Britain and Northern Ireland. Also present were representatives from the following bodies: the Programme Coordination Centre for ICP Vegetation; the Programme Coordination Centre for the ICP on Assessment and Monitoring of Air Pollution Effects on

[1] The report was prepared by the Workshop's organizers, the nationally appointed rapporteurs.

Forests (ICP Forests); the Task Force on Integrated Assessment Modelling; the Centre for Integrated Assessment Modelling (CIAM); the Meteorological Synthesizing Centre-West (MSC-W) of the Steering Body to Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP); and the Joint Research Centre (JRC) of the European Commission. A member of the Convention secretariat also attended.

B. Organization of work

3. The Head of the Programme Coordination Centre of ICP Vegetation chaired the meeting, which was hosted by JRC in Ispra, Italy. The current status and recent developments of flux-based critical levels of ozone for vegetation were discussed in plenary and in three working groups on crops, forest trees and (semi-)natural vegetation.

II. Background

4. The detrimental effects of ground-level ozone on vegetation have been addressed in developing international air pollution policies. The indicators used in the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol) to protect crops, trees and (semi-)natural vegetation were based on AOT40 (accumulated hourly ozone concentration over the threshold of 40 parts per billion (ppb)). Scientific research has developed further and currently the accumulated ozone flux via plant stomata is considered to provide a biologically sound method for describing observed effects. It is calculated from the effects of climate (temperature, humidity, light), ozone, soil (moisture availability) and plant development (growth stage) on the extent of opening of the stomatal pores on leaf surfaces through which ozone enters the plant. Several workshops held under the Working Group on Effects and led by ICP Vegetation have developed ozone flux-modelling methods and indicators for use in integrated assessment modelling. The *Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution Effects, Risks and Trends* (hereinafter *Modelling and Mapping Manual*) has been amended based on solid evidence. Tentative mapping of ozone flux in Europe indicated risks in areas which would not be protected by the indicator for health effects of ozone or by concentration-based critical levels for vegetation. The Executive Body of the Convention recommended that flux-based methods for vegetation be explored in the context of the work on the revision of the Gothenburg Protocol (see ECE/EB.AIR/96). The workshop was held to provide quantified regional indicators for use in the revision of the Gothenburg Protocol.

III. Objectives

5. The purposes of the workshop (and follow-on discussions at the twenty-third ICP Vegetation Task Force meeting) were to:

(a) Review the needs of the Convention in using flux-based methodology;

(b) Review recent progress with developing flux-effect relationships for crops, forest trees and (semi-)natural vegetation, and to agree on those relationships and new critical levels;

(c) Recommend ways to apply these relationships in policymaking;

(d) Recommend changes to the *Modelling and Mapping Manual*.

IV. Recommendations and conclusions

6. Given the importance of defining a robust methodology to provide quantified regional indicators for use in the revision of the Gothenburg Protocol, the workshop concluded that it was beneficial to conduct further modelling analyses before finalizing critical levels, dose-response functions and recommendations for their application. Hence, a common methodology was agreed, with results of the new analyses presented at the twenty-third ICP Vegetation Task Force meeting (see annex).

7. The accumulated ozone flux via plant stomata was redefined as the phytotoxic ozone dose above a threshold of Y, POD_Y (previously denoted as accumulated stomatal flux over a threshold, $AF_{st}Y$). All fluxes were calculated at leaf level.

8. The workshop agreed that, presently, it was unnecessary to include a function for the carbon dioxide (CO_2) response of stomatal conductance, since the time horizon considered in the revision of the Gothenburg Protocol was too short to lead to changes in CO_2 concentrations that would significantly impact on stomatal conductance.

9. The workshop proposed that flux-based indicators (see annex) should be included in the EMEP and the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model. Further collaboration with the EMEP centres was encouraged to explore the possibility of including the indicators in the GAINS model optimization and to carry out ex post analysis for the revision of the Gothenburg Protocol. The workshop also drew attention to the significant co-benefits for food security, biofuel production, carbon capture and global warming.

10. The workshop agreed that the detailed aspects of the new indicators would be discussed and adopted in the meetings of relevant Task Forces in spring 2010 in time to propose them for adoption at the twenty-ninth session of the Working Group on Effects in September 2010.

Annex

Follow-on discussions at relevant meetings of the International Cooperative Programmes and decisions on new and/or revised flux-based critical levels of ozone for vegetation

I. New and/or revised flux-based critical levels

1. The results presented in this annex are mainly based on the discussion of the twenty-third Task Force meeting of ICP Vegetation in February 2010. The proposed decisions were also discussed and agreed in the Task Force meetings of the ICP on Modelling and Mapping of Critical Loads and Levels and Air Pollution Effects, Risks and Trends (ICP Modelling and Mapping) and ICP Forests, in spring 2010.

2. The Task Forces agreed that concentration-based critical levels should be retained in the *Modelling and Mapping Manual*. Ten new and/or revised flux-based critical levels were derived using a common methodology (table 1).

Table 1
Revised and/or new flux-based critical levels for effects of ozone on vegetation
(Please note that there are different flux model parameterizations for each species)

Receptor	*Effect (per cent reduction)*	*Parameter**	*Critical level (mmol m^{-2})*
Wheat	Grain yield (5)	POD_6	1
Wheat	1,000 grain weight (5)	POD_6	2
Wheat	Protein yield (5)	POD_6	2
Potato	Tuber yield (5)	POD_6	4
Tomato	Fruit yield (5)	POD_6	2
Norway spruce	Biomass (2)	POD_1	8
Birch and beech	Biomass (4)	POD_1	4
Productive grasslands (clover)	Biomass (10)	POD_1	2
Conservation grasslands (clover)	Biomass (10)	POD_1	2
Conservation grasslands (Viola spp), provisional	Biomass (15)	POD_1	6

***** POD_Y = phytotoxic ozone dose above a threshold Y.

A. Crops

3. Response functions for effects of ozone on wheat (grain yield, protein content, 1,000 grain weight), potato (tuber yield), tomato (fruit yield), oilseed rape (oil content, seed yield), broccoli (floret yield) and bean (seed yield) were reviewed. The Task Forces approved the use of POD_6-based functions for wheat, potato and tomato for derivation of critical levels, based on the range of cultivars and countries represented for each and the statistical strength of the regression function. Critical levels were derived for a 5 per cent reduction in the yield quantity/quality parameter.

4. Further modifications to the methodology within the *Modelling and Mapping Manual* were agreed: a small change in molecular diffusivity ratio; a change in the phenology function for wheat based on additional information from Germany, Sweden and France; a small change in the description of height for ozone concentration relevant to risk assessment; a revised vapour pressure deficit function for wheat to be applied in Mediterranean areas; and the use of plant available water content instead of soil-water potential.

B. Forest trees

5. Across Europe, the effects of ozone on trees were best correlated with the modelled stomatal flux. Flux-effect relationships were strongest when using either no threshold or a small threshold above which flux was accumulated (i.e. POD_0 or POD_1). There was strong biological support for the use of a threshold to represent the detoxification capacity of the tree. For that reason, expert judgement had been used to set Y (in POD_Y) to 1 for forest trees.

6. The functions for Norway spruce and combined beech and birch were sufficiently robust for the derivation of critical levels due to their statistical strength and good representation of the data sets for Europe. However, it was suggested that those critical levels might not be fully applicable in the Mediterranean area, as they had not been derived from experiments conducted in a Mediterranean climate. There were insufficient data available as yet to derive robust critical levels for trees specific to the Mediterranean area (i.e., Holm oak and Aleppo pine).

7. Critical levels had been derived for the cumulative ozone flux (over the growing season) responsible for either a 2 or a 4 per cent reduction (dependent on species and the statistical strength of the relationship) in annual growth (whole tree biomass) of young trees of up to 10 years of age. The age criterion was set to reflect the age of the trees used in the ozone exposure experiments contributing data to the response function. There was strong support for those critical levels from epidemiological studies of mature trees in Switzerland, and some scientific papers indicated that mature trees were at least as sensitive to ozone as young trees.

C. (Semi-)natural vegetation

8. As semi-(natural) vegetation was the most diverse of the receptor types considered, discussions focussed on establishing critical levels for indicator species of three permanent grassland types: (a) productive grasslands that were intensively managed and grazed; (b) grasslands of high conservation value with low management and little/low fertilizer input; and (c) natural unmanaged ecosystems (excluding forests).

9. As for forest trees, flux-based response relationships for indicator species were strongest when using either no threshold or a small threshold above which flux was accumulated (i.e., POD_0 or POD_1). Hence, expert judgement was used to set Y to 1 for (semi-)natural vegetation.

10. For only one species, *Trifolium repens* (white clover), flux-effect data was available from more than one country. Since that species was widespread in Europe and had an important role in ecosystems as a nitrogen-fixer, that response function was considered suitable for setting a flux-based critical level for perennial grassland. Data for two *Viola* species, although only from experiments from the United Kingdom, were considered suitable for a provisional critical level for early-season exposure of grasslands of high conservation value.

II. Policy-relevant indicators for integrated assessment modelling

11. The Task Force meeting of ICP Vegetation proposed the following policy-relevant indicators:

(a) *Agricultural crops*. POD_6 of 2 mmol m^2 to protect security of food supplies by protecting against loss of protein yield, an important crop quality parameter (NB: a POD_6 of 1 mmol m^2 was also defined to protect against loss of yield quantity);

(b) *Forest trees*. POD_1 of 4 mmol m^2 to protect against loss of carbon storage in living trees and loss of ecosystem services such as soil erosion, avalanche protection and flood prevention;

(c) *Grasslands and pastures*. POD_1 of 2 mmol m^2 to protect against loss of vitality and fodder quality in productive grasslands;

(d) *Grassland areas of high conservation value*. POD_1 of 2 mmol m^2 to protect against loss of vitality of natural species.

12. The Task Force also noted that in some Mediterranean areas the flux-based methodology might underestimate effects.

III. Robustness of the flux-based critical levels

13. The Task Force meeting of ICP Vegetation agreed that the new critical levels had been derived from sufficiently robust relationships, all statistically significant (at the level of $p<0.05$). The main uncertainties arose from the effects of soil moisture on ozone flux, in particular in Mediterranean areas, and the extrapolation from different exposure systems to field conditions. For crops and (semi-)natural vegetation, the robustness in the understanding of ozone damage in Europe had been substantiated by the compilation of the observed effects in ambient air (see ECE/EB.AIR/WG.1/2008/9). For trees, the main source of uncertainty lay in the application of critical levels derived from effects on trees of up to 10 years of age growing in an exposure facility, to mature trees growing within a forest stand. It was encouraging, however, that epidemiological studies had shown that the critical level for birch and beech would protect mature beech trees in Switzerland. Data in the literature suggested that young trees might be as sensitive to ozone as mature trees and results of chamber studies might be underestimates of what would occur in the open air and over longer growth periods. The critical levels for (semi-)natural vegetation could be considered the most uncertain due to the complexity of those ecosystems and the small number of species for which flux-effect models existed.