WORKSHOP REPORT

Ozone exposure and impacts on vegetation in the Nordic Countries and the Baltic States

Organized by IVL Swedish Environmental Research Institute and the University of Gothenburg

Financed by The Nordic Council of Ministers and
The Swedish Environmental Protection Agency

Tuesday 17th – Wednesday 18th June, 2008

A two-day workshop was held 17th – 18th June 2008, in Gothenburg, Sweden, organized by IVL Swedish Environmental Research Institute and the University of Gothenburg and hosted by IVL Swedish Environmental Research Institute.

The meeting was attended by 16 delegates from 5 countries: Estonia, Finland, Latvia, Russian Federation and Sweden. In addition, a presentation on ozone concentrations and potential ozone effects in northern Norway, prepared by Norwegian scientists, was presented by a Swedish delegate. The workshop was attended by experts and scientists representing environmental monitoring, atmospheric modelling and by scientists working with the effects by ozone pollution on vegetation. In addition to giving an overview of the current situation related to ozone pollution and its effect on vegetation, ongoing and future developments, especially related to climate change and rising background concentrations of ozone, were discussed.

A list of the participants can be found in Appendix 1.

The scope of the workshop

The workshop aimed at reviewing scientific evidence for negative impacts of ozone on vegetation in northern Europe at current, and future, ambient or near-ambient ozone concentrations. In particular the importance of the current and future climate conditions with increasing temperature, prolonged growing season, possibly high humidity in combination with the long summer days at high latitudes was highlighted. Near-ambient ozone concentrations in this context were in this regard defined as below twice current ambient concentrations and below 20 000 ppb hours AOT40 April-September.

The aim was policy-oriented and should eventually provide policymakers with scientific background material in order to promote the introduction of new, ozone-flux based concepts for the air pollution legislation within the LRTAP convention and the EU, in order to protect European vegetation against negative impacts of ozone.

A joint publication of articles within the workshop topic was intended for the scientific journal AMBIO.

Workshop programme

Tuesday 17th June, 2008

11:30 Arrival and registration

12:00 Lunch

Session 1: 13:00 – 14:30 (presentations 25 min, 5 min questions)

- Welcome, background and scope of the workshop. *Håkan Pleijel,*
- Presentation 1. *Magnuz Engardt.* Climate and emission changes contributing to trends and variability in near surface ozone in the Nordic countries over the coming decades - Results from model studies
- Presentation 2. *Lin Tang.* Synoptic circulation and its influence on spring and summer surface ozone concentrations in Southern Sweden

Coffee/tea: 14:30 – 15:00

Session 2: 15:00 – 16:30 (presentations 25 min, 5 min questions)

- Presentation 3. *Elina Oksanen.* Deleterious impact of near-ambient ozone concentrations on Finnish deciduous trees
- Presentation 4. *Sirkku Manninen.* Impact of near ambient O3 concentrations on semi-natural vegetation, Scots pine and mountain birch
- Presentation 5. *Per Erik Karlsson.* Ambient ozone concentrations impacts on vegetation in Sweden

Short break: 16:30-16:45

Session 3: 16:45 – 17:30

- Discussions and summary of first day.

End of first day.

Wednesday 18th June, 2008

Session 4: 8:30 – 10:00 (presentations 25 min, 5 min questions)

- Presentation 6. *Nadezda Prozherina*. Impact of ozone on early development of pine and spruce from Russia.
- Presentation 7. *Rasa Girgždienė*. Ozone concentration and its impacts on forest vegetation in Lithuania
- Presentation 8. *Tarmo Pauklin*. Ozone levels in Estonia

Coffee/tea: 10:00 – 10:30

Session 5: 11:00 – 12:30 (presentations 25 min, 5 min questions)

- Presentation 9. *Jenny Klingberg*. Covariation in the diurnal variation of ground-level ozone and temperature - nocturnal temperature inversions as a source of local variation in ozone exposure
- Workshop conclusions. *Per Erik Karlsson and Håkan Pleijel*

12:30 End and lunch

Abstracts for the presentations can be found in Appendix 2.

Summary of the presentations

The sessions were each day ended with a summary of the presentations, made by Håkan Pleijel. These summaries can be found below:

There is substantial evidence, especially from Sweden and Finland based on large-scale experimental work, that ozone, at levels realistic to northern Europe can have significant effects on vegetation. Forest trees, crops and semi-natural vegetation may all be affected. Further support for ozone as an important factor, has been derived from dendrochronological studies and observations within the network of ICP-Forest. Different genotypes of the same species may also be differently sensitive to ozone as indicated in an experiment with different provenances of spruce from The Russian Federation exposed in an experimental system in Finland. Interactions with nitrogen (and sulphur) deposition should be paid more attention, since the nutritional status of plants may influence the sensitivity to ozone. Also phenological aspects need further attention, since there are indications that the ozone sensitivity varies considerably during the vegetation period.

Several presentations clearly indicated the significance of the interaction between ozone effects and climate change. Firstly, climate change can promote the formation of ozone itself, at a certain rate of emissions. Although this effect may be of some importance in the Nordic region, it is likely to be more important further south in Europe. In addition, climate change may promote higher stomatal conductance of plants, thus enhancing ozone uptake and thereby the risk for effects on vegetation. In wintertime, a lower degree of snow cover is likely to enhance ozone deposition significantly. This can result in lower surface ozone concentrations during the winter period. Since periods with high or low ozone concentrations are closely associated with the synoptic weather situations, any changes in the climatic pattern influencing the occurrence and duration of cyclonic, anticyclonic situations as well as the dominating wind direction, this may strongly influence future ozone patterns in the North European region.

A significant problem is the rising background ozone concentration on a hemispheric level, which has been shown to lead to rising average ozone concentration in northern Fennoscandia as well as in coastal Lithuania. This development is likely to continue in the future.

In general ozone concentrations are higher in the southern part of the region considered. There is also a significant variation on a smaller geographical scale, which may be related to the local climate. Coastal areas and elevated positions in the landscape tend to experience higher ozone concentrations than inland valley sites. In addition, emissions of precursors may be of local-regional importance. Variation in ozone between the six monitoring sites in Estonia indicated a potential effect of emission of ozone precursors at a site nearby a major industrial area.

The north European summer climate is characterised by short summer nights. Since ozone uptake takes place during sunlight hours mainly, the short nights dispose the plants for high ozone uptake, in particular in the far north.

An important issue in relation to climate change is the possible impact of ozone on carbon sinks. The boreal forest is today mainly a carbon sink, which will tend to remove carbon dioxide from the atmosphere. If ozone negatively affects the net carbon removal from the atmosphere through photosynthesis, this will lead to a contribution to greenhouse warming.

It is important to continue to have sufficient network of ozone monitoring stations in the region to cover important sources of variation. An essential part of this work is to follow trends in background and peak ozone levels. Furthermore, biomonitoring within the ICP-forest as well as research into the effects of ozone on plants in a climate change and nitrogen availability perspective is necessary to consider the special features of the north European countries. The influence of climate change as well as of the special features of the north European climate suggest the use and further development of ozone uptake models for the risk analysis of ozone effects on vegetation.

Workshop statements

- The elevated ozone concentrations in the Nordic countries and the Baltic states have the potential to influence important vegetation types
- Ozone concentrations, especially the general background, are likely to rise in the future
- Climate change may alter the the rate of leaf ozone uptake, as well as the plant response to the amount of ozone taken up, and thus altogether the vegetation response to ozone exposure
- The northern European climate has short summer nights permitting ozone uptake during many hours of the day, especially in the far north
- Continued monitoring and research into ozone effects are essential as part of the environmental work in the Nordic countries and the Baltic states
- It is important that risk assessments for negative impacts of vegetation on the European scale are based on leaf ozone uptake instead of the ozone concentrations in the air

Appendix 1.

Workshop 17-18 juni 2008. List of participants.

Camilla Andersson
ITM
Stockholm University
Sweden

Helena Danielsson
IVL
Swedish Env. Res. Inst.

Magnuz Engardt
SMHI
Swedish Met. & Hydr. Inst.

Rasa Girgzdien
Inst of Physics
Lithuanea

Per Erik Karlsson
IVL
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Gunilla Pihl Karlsson
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Jenny Klingberg
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Kai Luht
Estonian Environment
Information Centre

Sirkku Manninen
Dept. of Biol. and Env. Sci.
Helsinki University
Finland

Elina Oksanen
Univ. of Joensuu
Finland

Tarmo Pauklin
Estonian Environment
Research Centre

Kristin Piikki
Dept of Plant. & Env. Sci.
Gothenburg University
Sweden

Håkan Pleijel
Dept of Plant. & Env. Sci.
Gothenburg University
Sweden

Nadezda Prozherin
Inst. of Ecol. Probl. in the North
UB RAS
Russia

Brigita Serafinaviciute
Lithuanian Forest
Research Institute

Lin Tang
Dept. of Earth Sciences,
Gothenburg University
Sweden

Appendix 2.

ABSTRACTS

PRESENTATION 1

Climate and emission changes contributing to trends and variability in near surface ozone in the Nordic countries over the coming decades - Results from model studies

Magnuz Engardt[1], Robert Bergström [1,2] and Camilla Andersson[3]

1 Swedish Meteorological and Hydrological Institute, Norrköping.
2 Department of Chemistry, University of Gothenburg
3 Department of Applied Environmental Research, Stockholm university

We have used a state-of-the-art off-line chemical transport model (MATCH) to investigate current and future levels of ozone in Europe, including the Nordic countries.

The model domain covers the whole of Europe. The present situation was modelled by using our best estimate of current anthropogenic emissions and background tracer concentrations together with observed meteorology for a number of recent years. To assess changes in ozone concentrations due to climate change, the model was run using meteorology from a regional climate model. To assess changes in ozone concentrations due to emission changes, the model was run using different precursor emissions from a number of IIASA scenarios.

The results indicate that climate change will have a small direct impact on O3 concentrations in the Nordic countries. Changes in (hemispheric) background O3 concentrations and changes in precursor emissions in Europe will have a larger effect on O3 in Northern Europe.. The situation is quite different in southern Europe where climate change alone will result in a very large increase in near-surface O3 concentrations.

PRESENTATION 2

Synoptic circulation and its influence on spring and summer surface ozone concentrations in Southern Sweden

Lin Tang[1], Deliang Chen[1], Per Erik Karlsson[2], Yongfeng Gu[1], Tinghai Ou[1]

[1]Department of Earth Sciences, University of Gothenburg, Sweden
[2]IVL Swedish Environmental Research Institute

The influence of synoptic circulation patterns on the surface ozone concentrations at three monitoring sites in Southern Sweden during spring (April—May) and summer (June—

August) was investigated over the period 1990—2005. Six Lamb Weather Types (LWTs) and their impacts on surface mean ozone concentrations (daily mean, daytime mean and nighttime mean) and ozone episodes were examined. The analysis showed that anticyclone (A), directional flows from east and south-east (E and SE) and from south and south-west (S and SW) were most closely associated with high ozone levels. At Rörvik/Råö, Norra Kvill and Vavihill, 85.5%, 73.3% and 83.5% of the ozone episode days were observed under these three patterns respectively. Cyclone (C), westerly wind flow (W) and northerly wind flow (N+) were generally associated with low ozone levels. A trend analysis for the period 1998—2005 revealed a significant increase for the domain-averaged spring ozone concentrations. Nighttime spring ozone concentrations changed considerably over this time period, both on a temporal and spatial scale. A model based on the frequencies and strengths of LWTs explained 85% and 71% of the total variances in the observed high ozone episodes in spring and summer respectively, during the examined time period. Our results demonstrated the strong synoptic control on surface ozone in Southern Sweden.

PRESENTATION 3

Deleterious impact of near-ambient ozone concentrations on Finnish deciduous trees

Oksanen Elina, Häikiö Elina, Kontunen-Soppela Sari

Silver birch (Betula pendula) and aspen species (Populus tremula and Populus tremula x P. tremuloides) have been intensively investigated for their capacity for climate change adaptation, because they are fast-growing trees with high carbon sink strength and good potential for greenhouse gas mitigation in northern conditions. We have studied impacts of near-ambient ozone concentrations on Finnish birch and aspens using realistic open-field exposure system located in Kuopio, central Finland (described in Karnosky et al., 2007). These experiments provide plenty of evidence that elevating ozone is one of the most important risk factor for northern deciduous tree species causing chronic oxidative stress and a multiple stress situation together with other climate change factors.
Birch experiments were conduced from May 1996 until October 2002 with AOT40-exposures ranging from 5.9 to 22.0 ppm-h per growing season. After seven growing seasons, ozone-caused growth losses in total dry mass were 39% in the more tolerant genotype and 54% in the sensitive genotype as compared to ambient-air grown control trees. Negative impacts on growth was accompanied by a significant shift in leaf chemistry revealing carbon allocation towards defensive phenolic compounds and protective leaf cuticular wax layer (Kontunen-Soppela et al. 2007).

Aspen experiments were conducted from June 2002 until September 2003 with AOT40-exposures of 16.6 and 17.7 ppm-h per growing season. After two growing seasons, major differences were found in growth responses among native aspen and hybrid aspen genotypes. The genotypes were clustered into sensitivity groups, where growth responses ranged from slightly increased stem growth to 9-24% losses in stem, leaf and root dry masses (Häikiö et al., 2007). In addition, ca. 40 % reduction in net photosynthesis was demonstrated in the early season, while function of light reactions

(photosystem II) was impaired at the end of the growing season in ozone-exposed plants, as indicated by chlorophyll fluorescence measurements.

References: Karnosky, DF, Werner H, Holopainen T, Percy K, Oksanen T, Oksanen E , Heerdt C, Fabian P, Nagy J, Heilman W, Cox R, Nelson N, Matyssek R. 2007. Plant Biology 9: 181-190; Kontunen-Soppela S, Ossipov V, Ossipova S, Oksanen E. 2007. Global Change Biology 13: 1053-1067; Häikiö E, Freiwald V, Silfver T, Beuker E, Holopainen T, Oksanen E. 2007. Canadian Journal of Forest Research 37: 2326-2336.

PRESENTATION 4

Impact of near ambient O3 concentrations on semi-natural vegetation, Scots pine and mountain birch

Sirkku Manninen[1] and Satu Huttunen[2]

[1]Department of Biological and Environmental Sciences, P.O. Box 56, FIN-00014 University of Helsinki, Finland
[2]Botany Division, Department of Biology, P.O. Box 3000, FIN-90014 University of Oulu, Finland

Our results from 3-year open-top chamber experiments, in which also temperature is elevated, show that average daytime O3 concentrations of 33-54 ppb decrease markedly above- and belowground biomass production of semi-natural vegetation as well as of both coniferous and deciduous trees. Such O3 concentrations also have negative impact on reproduction of semi-natural vegetation and can disturb soil microbiological processes contributing hence to e.g. N cycling and emissions of greenhouse gases as shown by our results on a grassland ecosystem. As high episodic O3 concentrations may occur especially in spring at the same time when background O3 concentration and temperature are increasing, the risk of harmful O3 effects on northern ecosystems in considered to increase. The responses may be enhanced by other stress factors such as increasing N availability and frost events. However, long-term field studies e.g. within the scope of AMAP should be conducted to verify the effects of O3 in combination with other climate change factors (i.e. changes in CO2, temperature, precipitation) on structure and function of northernmost ecosystems.

PRESENTATION 5.

Evidences for impacts of near ambient ozone concentrations on vegetation in Sweden

Karlsson, P.E.*, Pleijel, H.#, Danielsson, H.*, Pihl Karlsson, G.* Piikki, K.#

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#Göteborg University, Dept of Plant and Environmental Science

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We provide evidence for substatial impacts of near-ambient ozone concentrations on crops, vegetables, trees and semi-natural vegetation in Sweden, at ambient ozone levels corresponding to an annual AOT40, apr-Sep, around 10 ppm h..

The magnitude of impacts per 10 ppm h annual AOT40 range:

- 2 – 10 % for trees (leaf chl – growth)
- 5 – 30 % for crops (yield, wheat – potato)
- variable impacts on vegetables
- visible injury on bioindicator plants

PRESENTATION 6

Impact of ozone on early development of pine and spruce from Russia

Nadezda Prozherina,

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We studied the impact of the elevated ozone concentrations on early development stages of forest trees seedlings by exposing imbibed seeds of pine and spruce (collected from different provenances in Russia) to ozone in the open-field ozone experiment at the University of Kuopio. The seedlings were grown in ambient and elevated ozone levels in ozone field fumigation system for two years. Ozone exposure (AOT40) was 14.2 ppm, being 1.5 times higher as compared to the ambient air concentration. Growth parameters such as length of hypocotyls, epicotyl, needles and shoots, dry mass of needles shoots and roots were measured. The results show significant differences between pine and spruce origins in growth and biomass parameters. The most fast-growing origins were from southern latitudes. Negative impact of ozone on growth was cumulative and was revealed not before the second year of treatment. Ozone treatment had no significant effect on growth during the first growing season. However during the second year elevated ozone significantly decreased the growth and biomass parameters of shoots, roots and needles for all pine origins and two north origins of spruce. Our results showed that there is a large variation between Russian pine and spruce origins in their responses to the ozone. These differences can be explained by genetic properties of provenances which were formed after the last glaciation. Screening the germination and early growth

of plant material from gradually changing latitude gives valuable information about shifts in population's resistance against environmental change.

PRESENTATION 7

Ozone concentration and its impacts on forest vegetation in Lithuania

Rasa Girgždienė[1], Svetlana Byčenkienė[1], Algirdas Augustaitis[2], Brigita Serafinavičiūtė[3], Vidas Stakėnas[3]

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[2]Lithuanian University of Agriculture, Kaunas dstr., Lithuania
[3]Lithuanian Forest Research Institute, Kaunas, Lithuania

Continuous ozone concentration measurements at longest are performed at the rural site Preila in Lithuania since 1982. Measurement network was expanded after a joining in ICP IM Program. Three new stations with the ozone measurements were established during 1993-1996 period. All these four stations are located in the National Parks territories.

Obtained ozone data show that periods of increase or decrease in monthly average and peak concentrations could be identified. The analysis of ozone effect on tree growth showed that it could be related to changes in ambient ozone concentration which is below critical level.

Some studies demonstrate that peak ozone concentration has more significant effect on tree defoliation and increment than other indices, such as AOT40 for vegetation and forest as well as mean ozone concentration for a vegetation period.

Several studies were performed in order to evaluate the troposphere ozone effect on the morphology of the main Lithuanian forest plants. A strong correlation was found between AOT 40 index and the defoliation of Fraxinus excelsior trees in Lithuanian forest (r= 0.67) during 1991-2001. In 2002, visible ozone induced injuries were found on the foliage of Rubus idaeus, Alnus incana, Salix caprea, and Frangula alnus plants. More injured plants were found in the Eastern part of Lithuania. The results suggest that even a relatively low level of ozone in Lithuania is enough to negatively affect vegetation.

PRESENTATION 8

Ozone levels in Estonia

Tarmo Paukli, Kai Luht

PRESENTATION 9

Covariation in the diurnal variation of ground-level ozone and temperature - nocturnal temperature inversions as a source of local variation in ozone exposure

Piikki K.[1,2], Klingberg J.[1], Karlsson P. E.[2], Pihl Karlsson G.[2] and Pleijel H.[1] (presentation made by Jenny Klingberg)

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[2] School of Life Sciences, University of Skövde, Sweden
[3] Swedish Environmental Research Institute, Göteborg, Sweden

Even though ground-level ozone is usually seen as a regional air quality problem, the ozone concentration can vary considerably over rather short distances. It has earlier been indicated that coastal sites as well as hilltop sites tend to have considerably higher ozone concentrations than sites positioned at low elevation relative to the surrounding landscape, in particular during the night but partly also during the day. It has also been indicated that the diurnal variation in ground-level ozone concentration tends to covariate with that of temperature, reflecting the temporal and spatial variation in the development of the planetary boundary layer (PBL). Strong surface cooling during the night is associated with a stabilisation of the PBL and thus with reduced vertical air mixing. This leads to a situation with restricted vertical transport of ozone. In combination with deposition to vegetation and other surfaces this leads to low or very low ozone concentrations near the ground. The hypothesis investigated in this study was that the local variation in ozone can be explained to a large extent by its covariation with the local daily variation in temperature.
To test this hypothesis, data from south-west Sweden was used. Measurements were made using a mobile ozone monitoring station equipped also with instruments to measure meteorology in coastal sites (4), low elevation sites (4) and high elevation sites (2). In addition, comparison was made with permanent monitoring stations. The results showed that the diurnal temperature range and the diurnal ozone concentration range had a strong correlation which could be explained to a large extent by the location in the landscape. Using passive diffusion samplers, which provide only an average of the ozone concentration over ~one week to one month, in combination with observations of hourly temperature, was shown to permit the estimation of ozone exposure indices based on hourly ozone concentrations, such as AOT40 (vegetation) and SOMO35 (health), with relatively high accuracy by generating an estimate of the ozone dynamics from temperature dynamics. The local climate was shown to have a profound effect on the ozone dynamics which has strong implications for the interpretation of ozone data from a certain monitoring location. It is also of large importance to consider this source of variation in ozone concentration when validating large scale photo-oxidant models, since local scale climate can vary considerably within the grids used in such models.