

## CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION

Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) (Twenty-sixth session, Geneva, 2-4 September 2002)

### Item 5 (b) of the provisional agenda

#### Informal Joint ICP Vegetation/EMEP

#### Ad-hoc Expert Panel Meeting on Modelling and Mapping of Ozone Flux and Deposition to Vegetation, Harrogate, UK; 16-19 June 2002

#### Summary Report

1. The meeting was organised to assess the current scientific status of methods to model and map the deposition and flux of ozone to vegetation, in the context of their possible application in revised critical level assessments for ozone under the review of the Gothenburg Protocol, provisionally planned for 2004/5. Specific objectives of the meeting were: (i) to evaluate the models of deposition and flux proposed for application in the EMEP photochemical model; (ii) to assess the ability of these models to predict stomatal and non-stomatal deposition of ozone; (iii) to review progress in modelling flux to vegetation in experimental studies in order to derive flux-based critical levels; (iv) to identify key uncertainties in flux and deposition models; and (v) to assess whether flux-based approaches should be recommended for the development and application of a level II methodology for critical levels of ozone within the Convention.

2. Experts in all relevant fields were invited from Europe and North America. The meeting was attended by 37 experts from the following 12 Parties to the Convention: Belgium, Denmark, Finland, Germany, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom, and the United States of America. The Chairpersons of the Working Group on Effects and ICP Vegetation attended, and EMEP and the Coordination Centre for Effects were also represented. A list of participants is attached as Annexe 2 to this report.

3. The first day of the meeting primarily involved presentations in plenary. For the rest of the meeting, three working groups were formed, to discuss:

- (1) European scale deposition (modelling tools and data requirements);
- (2) stand level deposition assessments (quantifying total and stomatal components); and
- (3) modelling stomatal conductance and flux-effect relationships.

The reports of these three working groups, which were approved by a final plenary session, form Annexe 1 to this summary report.

4. Three key conclusions were reached by the three working groups, and were approved by the final plenary session:

(a) Although the AOT40 index has provided a useful indicator of the potential for ozone damage to vegetation, it is likely that the current definition for the critical level for ozone, based on AOT40 for a fixed time interval (the level I approach), provides an incorrect assessment of the regional distribution of the risk of damage to vegetation by ozone across Europe;

(b) Flux-based risk assessment methods offer the potential for improved quantitative evaluation of the impacts of ozone on vegetation across Europe and should be recommended for future application within the Convention;

(c) The deposition and flux algorithm now implemented within the EMEP photochemical model provides an adequate basis for first estimation and application of flux-based critical levels.

5. It was concluded that it would be possible to use flux-response relationships to derive flux-based critical levels for consideration at the workshop on level II critical levels to be held in Gothenburg in November 2002. It was agreed to focus effort on wheat, potato and clover as crop species and on spruce, pine, beech and oak as major tree species. Agreement was reached on the form of the mathematical algorithms to be used to calculate flux when deriving flux-response relationships and critical levels.

6. The presentation from EMEP demonstrated that first tests of the new deposition algorithm within the EMEP photochemical model produced realistic estimates of ozone concentrations. The EMEP model also provides estimates of deposition velocity which are consistent with measurement data, although it was recognised that more intensive evaluation was needed. Results from the EMEP model show large differences between the spatial distribution of AOT40 and modelled stomatal flux across Europe, demonstrating that the choice of flux rather than AOT40 will significantly influence the results of pan-European risk assessments.

7. Each of the working groups recognised that there are many significant uncertainties in the flux modelling approach which need to be resolved, although these need to be assessed alongside the known uncertainties and systematic errors in the current level I AOT40 approach. Each working group considered these uncertainties in the context of work which might be possible in the next six months, and longer-term objectives.

8. In the next six months, in preparation for the Gothenburg Workshop, the key priorities identified were: (i) improvement and evaluation of the land cover database, including the description of leaf area index; (ii) further quantification of model uncertainty and sensitivity; (iii) further testing of deposition module performance, especially for wheat and grasslands; and (iv) improved parameterisation of the stomatal algorithm for flux-effect modelling of high priority species.

9. An additional set of activities was identified to further evaluate and develop the flux-based approach over the next 2-5 years. The major priorities identified were: (i) development of methods for sub-grid and national flux modelling which can be linked to the EMEP model; (ii) further development of the land-cover database; (iii) development of a flux monitoring strategy within the EMEP network to improve data available for model validation; (iv) intensive evaluation of the EMEP model, and especially the stomatal flux term, using micrometeorological datasets; (v) improved parameterisation of non-stomatal components of the deposition module, including more mechanistic understanding; (vi) extension of flux-effect analysis to more crop and forest species, and possibly to semi-natural vegetation; (vii) comparison of the empirical Jarvis multiplicative algorithm used in modelling stomatal conductance in the current EMEP model with alternative more mechanistic algorithms; (viii) improved modelling of soil moisture and vapour pressure deficit effects on stomatal conductance; and (ix) further evaluation of critical fluxes for effects.

## ANNEXE 1: WORKING GROUP REPORTS

### Report from Working Group I

#### European-scale deposition (modelling tools and data requirements)

##### 1. Introduction

There was general agreement that the flux approach represents an improvement on the AOT40 index for the following reasons: -

- The existing Level I AOT40 approach is not appropriate for estimates of actual damage and as such should not be used to perform estimates of economic losses attributable to ozone.
- In contrast, the flux approach, if used in conjunction with appropriate flux-response relationships, could be used to estimate damage and hence economic estimates of ozone impacts.
- There seems to be strong agreement amongst the scientific community regarding the merits of the flux approach for Level II mapping.

The O<sub>3</sub> deposition model that has been developed with the intention of developing a flux-based index has been implemented within the EMEP photochemical model. Results from first calculations show satisfactory agreement with measured O<sub>3</sub> concentrations. The previous work to evaluate the deposition component has shown good agreement with observations, implying that fluxes can now be calculated with greater confidence.

The EMEP model calculations show that the distribution of stomatal uptake is very different from the distribution of AOT40 across Europe. Since the spatial distribution of AOT40 and ozone flux shows a large variability across Europe, the application of a flux-based index would result in the identification of different regions that are potentially sensitive to ozone impacts.

The main advantages to the policy makers of the flux-based index are that it provides a direct link between O<sub>3</sub> exposure and damage. Therefore, this method can be used to assess damage across Europe in a realistic and fair manner. In addition it enables the impacts of ozone to be assessed in terms of socio-economic costs.

Flux estimates provided by the EMEP model for a number of different vegetation classes will be available in time to inform the revision of the Gothenburg protocol.

##### 2. Advantages and disadvantages of the EMEP flux model.

###### 2.1. Advantages

- Provides an integrated and “fair” approach to the estimation of deposition and O<sub>3</sub> uptake for different vegetation cover types across Europe.
- Provides the ability to assess actual vegetation damage and could be used in future assessments of socio-economic costs.

###### 2.2. Disadvantages

- The stomatal and non-stomatal components of the EMEP flux model are difficult to evaluate.
- Relatively low resolution (50 x 50 km<sup>2</sup> spatial and 1 hourly temporal resolution). However, this is offset by the modelling of deposition to sub-grid land-cover classes.

### **3. Priorities before Gothenburg meeting.**

#### 3.1. Improve description of Leaf Area Index (LAI) for forest and grassland cover-types.

For forests it should be possible to use the FIRS European database maps that describe forest tree height. A simple relationship will be identified to relate tree height to LAI hence providing variability in species-specific LAI across Europe. For grasslands it should be possible to identify intensive (managed) and extensive (unmanaged) grassland types. The Swiss (Bassin *et al.*) grassland LAI formulation can be applied to intensive grasslands whilst the current EMEP default grassland parameterisation can be applied to extensive grasslands.

#### 3.2. Aggregation of SEI land-cover classes into appropriate vegetation classes for EMEP flux modelling.

Ensure aggregation of land-cover classes to semi-natural and grassland categories is most appropriate for flux modelling (in terms of model parameterisation) and possible future flux-effect modelling (in terms of sensitive versus insensitive species).

#### 3.3. Additional evaluation of the existing EMEP flux model.

Carry out evaluation of the deposition module with wheat flux data measurements made in Italy.

#### 3.4. Evaluation of the SEI land-cover database.

Carry out evaluation of the reliability of the SEI land-cover map using CORINE as a “ground truth” database. Perform sensitivity analysis to investigate the range of grid averaged deposition estimates according to the % range in land-cover data for selected grid-squares across Europe.

#### 3.5. Preliminary quantification of model uncertainty and sensitivity analysis.

A number of factors were identified within the current model formulation and parameterisation that should be prioritised for investigation. For the stomatal algorithm, these include: -

- i) Are generic relationships an oversimplification of the actual relationships that may exist for different species and land-cover classes and what are the implications for flux estimates?
- ii) Identification of spatially variable values for species  $g_{\max}$  across Europe and an assessment the influence of using such values on deposition and stomatal flux estimates.
- iii) Is there evidence of climatically controlled  $g_{\text{VPD}}$  responses?

### **4. Future work post Gothenburg meeting.**

#### 4.1. Further work to quantify model uncertainty and sensitivity analysis.

A number of factors were identified within the current model formulation and parameterisation that should be investigated over the longer-term. These include: -

- i) What are the ozone interactions with stomatal conductance?

- ii) What is the influence of surface water on deposition to external canopy elements?
- iii) How do we improve modelling of night-time deposition?

#### 4.2. Case study modelling at sub-grid scale.

Sub-grid modelling, defined by the spatial resolution of the land-cover data and other available data (e.g. topography), could provide additional information to inform reliability of EMEP model outputs. This may also lead to the development of new methods to improve flux calculations at the sub-grid scale.

#### 4.3. Collaboration with other groups.

Seek collaboration with other European groups who are collecting spatial data that could be useful to the modelling effort. For example, climate change groups who are collecting remote sensed data (e.g. water flux, soil moisture deficit, LAI). It may be possible to use water flux data to fill evaluation gaps for certain ecosystems where ozone flux measurement data is not available.

## RECOMMENDATIONS

### **Recommendation I**

Adopt the flux model approach and use the EMEP model to quantify ozone impacts to vegetation across Europe.

### **Recommendation II**

Identify existing flux datasets that may be used for evaluation of EMEP flux model.

### **Recommendation III**

Encourage national scale flux modelling. This would ensure that each individual country can be fully involved in flux modelling and also result in more detailed country specific data (in terms of model formulations, model parameterisations, and evaluation of the model) being performed at a national scale and being available for use in improving the EMEP model.

### **Recommendation IV**

#### **Develop a flux monitoring strategy**

A limited number of stations within the EMEP monitoring network should be upgraded to measure dry deposition of gaseous pollutants ( $O_3$ ,  $SO_2$ ,  $NO_x$  and  $NH_4$ ).

It is proposed that a monitoring strategy could be established to optimally utilise available facilities and funds to provide dry deposition information across Europe. This would involve consideration of: -

- i) The methods used to measure dry deposition (e.g. the co-location of sophisticated monitoring equipment and low cost sampling devices to gather information that would provide the necessary information to enable the interpretation of data collected from a more extensive network of low cost samplers located strategically across Europe)
- ii) The identification of ecosystem types and geographical locations (e.g. mountainous areas) for which more information regarding respective deposition velocities is required. Such ecosystems would be prioritised for dry deposition measurements. For example, evaluation of the model has been performed for northern European

conditions, however, no evaluation of the model has yet been conducted for southern European ecosystems and this knowledge gap should be filled in the near future.

### **Recommendation V**

Harmonise terminology to ensure consistent and clear communication within and between the scientific community, policy makers and public.

## **Report from Working Group 2**

### **Stand level deposition assessments (quantifying total and stomatal components)**

#### **1. General questions**

*(1.1) Is the modelling approach proposed for pan-European risk assessment appropriate in principle?*

The AOT40 index of exposure of terrestrial surfaces to O<sub>3</sub> has provided a useful indicator of damage to crops, and in the absence of other methods proven to be superior, still has value. However, there are good reasons for believing that the current Level I AOT40 incorrectly quantifies the regional distribution of damage to vegetation in Europe.

The damage to sensitive vegetation is most closely related to the ozone absorbed through stomata, which can now be quantified for a range of characteristic vegetation throughout Europe.

We recommend the application of flux based risk assessment methods to quantify the effects of ozone on European vegetation. Further, we recognise that the methods used to quantify the ozone fluxes to vegetation may also be used to quantify the exposure of vegetation to damaging ozone concentrations.

A flux-based approach would also provide consistency with the risk assessment methods used for compounds leading to acidification and eutrophication.

*(1.2) What are the key recommendations for future research to improve flux and deposition models for ozone? Given adequate funding, over what timescale could these deliver new tools for ozone risk assessment?*

Many more flux measurements of ozone over representative vegetation throughout Europe, in which the total and stomatal fluxes are determined, are required. The priority is for agricultural crops and all vegetation types in Southern Europe.

The timescale for these new tools, which are in an advanced state of development, is 2 years as a minimum. The model is largely developed and now requires further testing against field measurements, and parameterization for a wider range of vegetation.

*(1.3) Is it possible to recommend that a flux-based approach should replace the AOT40 approach as the basis for risk assessment for ozone impacts on vegetation within UN/ECE?*

The group concluded that a flux-based approach should replace the AOT40 index. The preliminary flux mapping studies have indicated significant differences between the spatial distribution of the stomatal uptake and AOT40 across Europe. These results should be incorporated in assessing effects of photochemical pollution on vegetation.

*(1.4) What are the strengths and weaknesses of the EMEP deposition model, the Emberson et al. stomatal flux model, and of other models presented at the meeting?*

In moving from a very simple exposure to a flux approach there is a need for much more data, the quality and quantity of which directly influences the assessment.

Strengths of the EMEP model:

- Represents current understanding
- Is mechanistic, and is as simple as possible yet describes the essential processes
- Is consistent, incorporating numerical weather prediction with the chemistry, transport and deposition processes
- Incorporates explicit land use data

Weaknesses of the EMEP model:

- Quality of the land use data
- The data requirements.
- Resolution (even at 50km x 50km)
- Insufficient validation

*(1.5) Has adequate validation of these models been carried out, and what general conclusions can be drawn about the performance of the models?*

It is obvious that more validation is needed. The validation carried out so far shows that the performance of the models is reasonable. For the deposition velocity, the agreement is good and sufficient for long-range transport modelling. For the estimates of stomatal flux, the uncertainty is much larger. The effect of the meteorological input data should be further tested by running the model by using both local and regional scale data.

*(1.6) Are there further datasets available to test model performance?*

There are many micrometeorological datasets that should be used for further testing the model performance. The highest priority should be placed on data for temperate crops (wheat). Other important land cover types for which there are high-quality data, not utilised so far, include grasslands (several locations in Europe), forests (pine, spruce, beech) and moorland.

*(1.7) Are further changes needed in the formulation and parameterisation of these models?*

Too general a question, see answers to questions specific to Group 2.

*(1.8) Are the data requirements of these models appropriate in terms of the need for pan-European applications?*

A pragmatic approach is adopted, recognising variability in the quality and quantity of data in different parts of Europe.

*(1.9) How can model predictions using local data best be linked to European-scale predictions using broader-scale input data? Should local parameterisation be used e.g. for national scale modelling of ozone flux?*

Comparisons should be carried out between national and regional scale modelling studies. Local parameterisations should be used in a similar manner as in the national modelling work for the acidifying compounds.

*(1.10) Can the uncertainties in current model estimates be defined qualitatively and quantitatively?*

Quantitative estimates of the uncertainties are obtained directly from model validation studies, see Question 1.5. In qualitative terms, uncertainties can be assessed based on the experience of the model performance and sensitivity studies.

*(1.11) Can these uncertainties be incorporated into the results of flux-based ozone risk assessment?*

Yes, in principle it is possible to incorporate these uncertainties in the risk assessment. This would require the use of appropriate statistical methods (e.g., the Monte Carlo analysis). Even though it is not clear what can be achieved from such an exercise, it may be possible to apply uncertainty analysis for determining a 'safety factor' following the precautionary principle.

*(1.12) Have adequate sensitivity analyses been conducted and how can these be used to prioritise future work?*

A limited number of sensitivity analyses have been conducted and reported. These analyses have identified some key topics requiring further attention (e.g., soil moisture modelling, LAI data). Further tests are planned or are in progress. In general, sensitivity analyses were considered a useful approach for communicating between modellers and experimentalists.

## **2. Questions for Working Group 2**

*(2.1) What information does measurement data in published and unpublished studies provide about (a) total ozone deposition to forest stands and crops and (b) partitioning of total and stomatal conductance to ozone, and its dependence on season, time of day and environmental factors?*

(a) Measurements over forest stands provide a considerable data base for limited tree species (Douglas fir, Norway spruce, Scots pine, Maritime pine, Beech, Mountain birch, citrus and apple orchards), including data on fluxes, deposition velocities, surface and stomatal conductances, and meteorology. For short vegetation, there are good data sets for wheat, grassland, soy bean, maize, moorland, arctic fen, pseudosteppe etc.

(b) Total and stomatal conductance, and their dependence on PAR, temperature and air humidity, are available for most of the above. Soil moisture data are not available for many of these.

*(2.2) Are the total and stomatal deposition rates predicted by the EMEP model for different land covers consistent with the values suggested by these measurement data?*

In general the EMEP model deposition velocities are consistent with the measurement data; however there are few site-specific comparisons. Stomatal conductance is more difficult to validate and the measurement-model comparisons show greater variability.

*(2.3) To what extent can field studies assist in testing the parameterisation of the different non-stomatal resistances?*

Existing data take us only part of the way towards validation as, in the case of forest, only limited comparisons have been made and it is not known how far the analysis can reach due to the complexity of the in-canopy processes. For shorter vegetation, more progress can be made using the existing data sets.

*(2.4) How far would improved partitioning of ozone deposition between different surface and in-canopy resistances help in modelling ozone deposition and in risk assessment for ozone?*

It is expected that very important progress can be made here as it is essential that we are able to quantify the fate of O<sub>3</sub> within the canopy. For risk assessment it is even more important.

*(2.5) What implications does the reliability of measurement data have for evaluation of the performance of the EMEP model, and other deposition models?*

Basic tests of the credibility of the data form an important part of the comparison between model and measurement data. A documented assessment of the reliability is required. A large part of the existing data is poorly documented.

*(2.6) What site-specific comparisons have been conducted across Europe of model predictions with deposition estimates from micrometeorological studies, and what are the key conclusions from these studies?*

Site-specific comparisons have been completed for Scots pine and Mountain birch in Finland, Norway spruce in Denmark, and for moorland and grassland in Scotland. The remaining surfaces identified in Question 2.1 above, have not been completed. Literature comparisons which are necessarily more limited have also been completed. For conclusions, see Question 2.2.

*(2.7) For which types of land-cover and conditions are more stand-level tests of the EMEP model performance needed?*

Temperate crops, grasslands, especially in Southern Europe, where data for forests are also needed.

*(2.8) Is the formulation used to estimate Rinc adequate? Should the model attempt to include the effect of in-canopy chemical reactions with O<sub>3</sub> on deposition processes?*

Rinc is based on a very small fraction of the published data; however, there is no obvious way of deriving a better parameterization from the literature values. In-canopy chemistry is not included and may represent a significant fraction of the deposited O<sub>3</sub>, at sites with large nitrogen deposition and hence large NO emission from soil. This was not identified as a high priority area for model development on account of the magnitude of the effect relative to the likely improvement in the model.

*(2.9) Is the parameterisation of soil and external plant surface resistances adequate? Should more attention be made to variation in these values (e.g. wet vs. dry surfaces?)*

For many land cover types the model is insensitive to  $R_{soil}$ . However, for land cover with small LAI, this sink may represent a significant deposition pathway. It is not simply the bare soil surface as this term represents many other surfaces including litter or lower canopy (which may have an appreciable LAI, and stomatal uptake, this makes it very difficult to parameterize). However, the deposition of  $O_3$  on cuticular and other external surfaces has recently been shown to be much more important than earlier studies imply. It is important to be able to quantify the fate of  $O_3$  in plant canopies and the effect of surface conditions including wet and dry surfaces.

*(2.10) Is the 'big leaf' approach appropriate for modelling canopy conductance, and is the radiation scheme for leaf-to-canopy up-scaling in the EMEP model adequate?*

Multi-layer models have been shown to provide improved simulation of the deposition velocity at the local scale and where considerable data on the site and plant canopy are available. Such an approach is not practical given the constraints of data for regional scale models in Europe.

*(2.11) Is it possible to conduct more detailed site-specific comparisons over the next few months? Which data-sets should be prioritised?*

See Question 2.7. However, it is possible to include a comparison with the Italian wheat and Scottish grassland data in time for the Göteborg meeting.

*(2.12) Can comparisons of measurement data and models identify key uncertainties in model parameterisation which need to be resolved?*

See above.

## **Report from Working Group 3**

### **Modelling stomatal conductance and flux-effect relationships**

#### **1. General conclusions for all vegetation types**

##### 1.1 Flux Modelling

The group decided that there is a good degree of confidence in the flux modelling approach, and that for selected species (wheat, potato and clover), it is anticipated that flux-based critical levels would be agreed upon at the Gothenburg Workshop. It is therefore possible to recommend that flux rather than AOT40 be used in future risk assessment for ozone.

##### 1.2 Modified AOTx

It would be possible to use the functions from the flux models to improve the application of the AOT40 concept, by calculating a modified AOT40 or AOTx, using a variable growing season and by applying the calculation to the top of the canopy. However, group and plenary discussions considered this to be unnecessary given the confidence now placed in flux-effect modelling, and because the derivation of canopy-level ozone concentrations for use in calculating AOTx values already depends on flux calculations. Since the use of a modified

AOTx approach involves the same uncertainties as in direct modelling of flux, there is no added benefit from using the modified AOTx approach instead of the flux-modelling approach.

### 1.3 Alternative flux-modelling approaches

The multiplicative flux algorithm developed by Emberson *et al* (2000) from that described by Jarvis (1976), was selected as the most appropriate for use at this stage. It seems to be working quite well, given the limitations. However, there may be a need to introduce additional functions, for example for time of day or for the cumulative effect of ozone exposure. The realistic alternatives are:

- a. The Ball *et al* (1987)  $g_s$  algorithm, which is photosynthesis-based and offers a flexible way of dealing with interactions, but would need complete re-parameterisation.
- b. Artificial neural networks (ANNs) which need a large well-defined database of the type which is currently only available for clover.

Sufficient information might be available to apply the Ball *et al* approach for wheat, potato (from the CHIP project), possibly for clover (although further data processing would be necessary), and for some tree species. Given the limited time available before the Gothenburg Workshop, effort will be focussed on the multiplicative approach. The feasibility of using either of the alternative methods will be considered after the Gothenburg Workshop.

### 1.4 Ozone concentration and VPD at canopy height

The flux-effect models for individual species will be based on canopy-height ozone concentrations and VPDs. It is assumed that the EMEP deposition module will be able to calculate these.

### 1.5 Flux threshold for calculating cumulative flux

It was agreed that there is a sound physiological basis for using a flux threshold, at least for crops, in the calculation of accumulated flux over time. For the Gothenburg Workshop, flux thresholds derived from theory using the contrasting methods of Massman (based on photosynthesis and leaf area index, see background paper) and Barnes (SODA ozone detoxification model), together with statistical evidence from flux-effect relationships derived using a range of thresholds, would be available to support the decision on appropriate flux threshold values.

### 1.6 Time resolution for the EMEP model

The models will assume the inputs are hourly mean values.

### 1.7 Boundary line approach

It was agreed that we would continue to use the boundary line approach, but that we need to ensure that all groups are using the same systematic approach (absolute boundary or 95<sup>th</sup> or 90<sup>th</sup> percentiles). Further advice will be sought from a statistician, and the suggestions will be circulated amongst the group in the near future, so that a decision can be made quickly.

### 1.8 Uncertainty and sensitivity analysis

Prior to the Gothenburg Workshop, we recommend that a sensitivity analysis is performed for each flux algorithm/species to see which parameters are most important at selected locations

in Europe. An uncertainty analysis will also be performed in order to quantify the confidence we have in each input parameter.

## 2 Crops

### 2.1 Choice of response

Yield quantity will be used. A critical flux for injury may also be derived from the ICP Vegetation clover data.

### 2.2 Choice of crops

Prior to Gothenburg, effort will be focused on wheat and potato as the most information is available for the parameterisation of models for these crops. Furthermore, there is an economic justification for choosing these two crops since the ICP Vegetation analysis of economic losses in Europe (based on AOT40-response relationships) identified that the losses are highest for these crops. After the Gothenburg Workshop, it will be possible to derive flux-effect relationships for examples of southern crops such as water melon, tomato and bean (*Phaseolus vulgaris*), and other more ubiquitous crops in Europe. The group recognised the importance of perennial crops such as grapevine. We felt that further collaboration with scientists from the USA might assist in the derivation of flux-effect relationships for crops other than those already listed, especially for perennial crops.

### 2.3 Influence of cultivars.

It was recognised that the flux models may be being developed for cultivars that are no longer grown commercially in Europe. There is little new data to work with, but it was felt that for wheat, at least, the inclusion of data from several cultivars in the models strengthens our confidence in the applicability of the model to currently used cultivars.

### 2.4 Parameterisation of the model

It was agreed that the flux algorithm used to derive flux-response relationships would be that giving the best fit to the experimental data; for wheat and potato this involves using the more complex Ostad algorithm with additional terms in place of the original Emberson *et al.* algorithm. We recognised the importance of using consistent parameterisation between the various algorithms available (e.g. Ostad, Emberson), and between deriving flux-effect relationships and modelling flux in the EMEP model. Table 1 shows the agreements that were made, including further work needed before the Gothenburg Workshop.

Table 1 Parameterisation of the wheat and potato stomatal conductance algorithms

Parameter	Wheat	Potato
Time period	Anthesis to end of grain fill ( $T_{sum}$ -derived)	Whole season ( $T_{sum}$ -derived)
SMD	Use the new parameterisation produced by Andrew Terry. Additional data from Spain on well-watered and water-stressed wheat will also become available before the Gothenburg Workshop.	There exists a relationship, but we are less confident about it than we are for wheat. However, this crop is usually irrigated when water is limiting. Thus, for initial flux modelling, SMD can probably be ignored for potato.
PAR	Good function available.	Good function available.
$T_{air}$	Good function available (will merge Emberson and Ostad models, as they are very similar)	Good function available
<b>VPD</b> Note: VPD is considered to be a very important driver of $g_s$ , but source of several uncertainties, both in the modelled VPD at the canopy height, and in the VPD vs $g_s$ functions.	Further work required to standardise the function, as the Ostad, Gruters <i>et al.</i> , 1995, and Emberson models differ widely. Need to check sources of data to ensure that no other factors were influencing the response to VPD (such as SMD) at the time of measurement.	Will use the function from the CHIP programme.
$g_{max}$ Note: rarely actually achieved in nature, there is uncertainty in using the available values	Reconsider the data available, and use the median of suitable values.	Reconsider the data available, and use the median of suitable values.
Time of day function Note: may be a surrogate for leaf water potential	Use Ostad function	Seems to be especially important, use CHIP function.
$g_{age}$	Over the time period, only a small change occurs	Important, use CHIP function
$g_{ozone}$ Note: This is important at high ozone exposures, both in instantaneous effects, and long-term accumulative effects	Long-term effects are covered by the Ostad model.	Long-term effects are covered by the CHIP model.

Note: CHIP refers to the EC-funded project – Changing Climate and Potential Impacts on Potato yield and quality.

### 2.5 Use of the ICP Vegetation clover data:

This experiment has confirmed that the most sensitive biotype has higher stomatal conductance ( $g_s$ ) than the resistant biotype in ambient ozone. This provides a clear statement to the policy maker that higher flux is associated with ozone injury to plants in ambient air in Europe, and supports other experimental evidence that higher flux is associated with greater ozone impacts. Flux-effect modelling will continue for both biomass and injury responses as this is the only dataset available for effects of ambient ozone in ambient air. Further quality checks will also be made on the data including separating it into (a) cuvette measured climatic conditions (leaf conditions), (b) climatic data from separate monitors (climate).

### 3 Trees

#### 3.1 Flux modelling

Although considerable progress has been made since the current critical levels were derived at the Kuopio Workshop in 1996, there remains some concern over the derivation of flux-effect relationships for trees. Flux-effect relationships would be derived using local parameterisation where available, with the Emberson *et al.* parameterisation being used as a default; inter-calibration of local and Emberson *et al.* parameterisations would be needed. It was agreed that the Emberson *et al.* algorithm would be used on a Europe-wide basis, recognising that there would be large local-scale spatial variation in parameterisation. Estimates of growth loss at the ecosystem level would not be realistic, but the development of flux-effect relationships for saplings (e.g. 4-year old trees) should be possible in time for the Gothenburg Workshop. It will also be possible to apply the critical level (flux) for crops to selected tree species, to test if trees will be protected by the critical levels for crops.

#### 3.2 Species

It should be possible to derive flux-effect relationships for some, or all, of the following species before the Gothenburg Workshop, but with less certainty than associated with the wheat and potato models:

- Oak (mature tree flux, sapling effect model)
- Norway Spruce (sapling flux, sapling effect model)
- Birch (sapling flux, sapling effect model)
- Beech (sapling flux, sapling effect model)
- Scots Pine (sapling flux, sapling effect model)
- Aleppo pine (sapling flux, sapling effect model)

It may be possible to use additional data from the EC-funded Euroflux project (30 sites across Europe) in the parameterisation of  $g_s$  within the models for these species. The availability of these data will be investigated. After the Gothenburg Workshop, it should be possible to derive flux-effect relationships for other species, in some cases in collaboration with scientists from the USA.

#### 3.3 Responses of mature trees

The preferred response is the growth of woody biomass of mature trees. However, such growth responses are difficult to quantify. A flux-based threshold for visible injury exists for mature beech and could be used in addition to the flux-effect models for saplings, described in 3.2. It is possible that the flux models could be used in conjunction with the ICP Forests 2001 injury survey data, although hourly ozone data may not be available for all of the sites. Furthermore, since multivariate analysis suggested that ozone was one of the influencing factors in the ICP Forests crown defoliation data (1986-1995), it may be possible, after the Gothenburg Workshop, to use this large database in the derivation of flux-effect relationships for crown defoliation in mature trees. In the longer term, the aim will also be to identify other effect parameters suitable for mature trees such as leaf area index.

#### 3.4 Which leaves/needles?

There is a tendency for measurements of  $g_s$  to have only been made for the upper sunlit canopy leaves. Concern was raised over the large variation found within nearby needles, as well as the variability with height within the canopy.

#### 3.5 The basis for ozone uptake estimates

This should be on a per total leaf area or projected leaf area basis.

### 3.6 Up-scaling from the leaf to the canopy

In up-scaling, the “big leaf” approach does not allow for differences in  $g_s$  parameterisation, nor the ozone profile, within the canopy. Although we appreciate the uncertainties in using the “big leaf” approach, we are unable, as yet, to use any alternative. Ongoing experiments by R. Matyssek’s group may provide very valuable information for up-scaling.

### 3.7 Uncertainties within the flux model.

Several areas of concern were raised. For example, there are major uncertainties in the derivation of  $g_{max}$  for tree species, and it is recognised that systematic spatial variation in  $g_{max}$  may exist, while inclusion of “afternoon opening” in the Emberson *et al.* model could overestimate flux by a factor of two for some species. The background document for the Gothenburg Workshop will provide an overview of these uncertainties.

## **4. Semi-natural vegetation**

### 4.1 Flux modelling

Considerably more information is now available on the responses of semi-natural vegetation to ozone than was available at the time of the Gerzensee Workshop (1999). However, the group thought that it was unlikely that it would be possible to move to a flux-effect relationship for such complex plant communities by the time of the Gothenburg Workshop.

### 4.2 Choice of parameter

Some species are very sensitive to visible injury, with the forbs being more sensitive to ozone than the grasses. However, effects on relative growth rates or seed production are more relevant to plant communities than the presence of ozone injury as these factors might influence competitive ability and could potentially cause a shift in community dynamics.

### 4.3 Ranking of sensitivity

This could be achieved because several large databases exist, such as that at the ICP Vegetation Coordination Centre, CEAM (shrubs, ICP Forests), one in Sweden and another in Spain, that provide information on the injury and/or biomass responses of numerous species (>200) of semi-natural vegetation, when exposed to ozone in experimental systems. Functional types, morphology and physiological parameters are included in the ICP Vegetation database and could be used to see if there are any characteristics typically associated with ozone sensitivity. Thus, for individual species exposed to ozone in experimental systems, we could provide information factors associated with the most sensitive species. However, it is worth noting that the experiments conducted so far with semi-natural vegetation have tended to consider common species, and not those of high conservation value.

### 4.4 Responses within communities

The EU-funded BIOSTRESS (Biodiversity in herbaceous semi-natural vegetation ecosystems under stress by global change components) experiments are designed to investigate the influence of competition for resources, and should provide information on the modifying influence of this level II factor. In addition, R Matyssek is currently studying the influence of ozone on the competition between tree species seedlings in mixtures of Norway spruce and beech. However, concern was raised that experiments involving the exposure of semi-natural vegetation in the field (by field release), or swards of grassland in open-top chambers, have shown that the responses of whole communities, or single species growing in complex communities, may not reflect the responses of the individual species when grown in isolation.

## 5. Background papers for the Gothenburg Workshop

The background papers for presentation in plenary, which will form the basis for discussion of Level II and flux-based critical levels at the Gothenburg Workshop, will be on the following themes:

### Trees

Flux-response relationships for young trees  
Scaling issues for trees  
ICP Forests visible injury data

### Semi-natural vegetation

Database on effects on individual species and results from BIOSTRESS experiments

### Crops

Flux-response relationships for wheat and potato  
Flux-response relationships for clover injury and biomass  
Economic evaluation of yield losses in Europe

### EMEP modelling

Paper summarising results of this workshop

### Background documents (Deadline 31 September, 2002)

For plenary papers – 10 pages  
For individual papers – 5 pages

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**ANNEXE 2: LIST OF PARTICIPANTS****Ms Nuria ALTIMIR**

Department of Forest Ecology  
University of Helsinki  
PL 27 (Latokartanon Kaari 7)  
Helsinki 00014, FINLAND  
nuria.altimir@helsinki.fi  
Tel: 358 9 191 58128  
Fax: 358 9 191 58100

**Mr Jeremy BARNES**

Air Pollution Laboratory  
Dept of Agriculture & Environ. Sci  
Ridley Building, The University  
Newcastle Upon Tyne NE1 7RU, UK  
j.d.barnes@ncl.ac.uk  
Tel: 44 191 222 7374  
Fax: 44 191 222 5229

**Mr Mark BROADMEADOW**

Forest Research Station  
Alice Holt Lodge  
Wrecclesham  
Farnham GU10 4LH, UK  
mark.broadmeadow@forestry.gsi.gov.uk  
Tel: 44 1420 526 204  
Fax: 44 1420 520 180

**Mr Stanislaw CIESLIK**

Joint Research Centre  
Ispra I-21020, ITALY  
stanislaw.cieslik@jrc.it  
Tel: 39 332 789 567  
Fax: 39 332 785 022

**Ms Mhairi COYLE**

Centre for Ecology and Hydrology Edinburgh  
Bush Estate  
Penicuik EH26 0QB, UK  
mcoy@ceh.ac.uk  
Tel: 44 131 445 8528  
Fax: 44 131 445 3943

**Ms Jenny DUCKMANTON**

Stockholm Environment Institute-York  
Department of Biology  
University of York, PO Box 373  
York YO10 5YW, UK  
jmd4@york.ac.uk  
Tel: 44 1904 432 897  
Fax: 44 1904 432 898

**Mr Mike ASHMORE**

Dept of Environmental Science  
University of Bradford  
Bradford BD7 1DP, UK  
m.r.ashmore@bradford.ac.uk  
Tel: 44 1274 235 695  
Fax: 44 1274-235 699

**Ms Seraina BASSIN**

Swiss Federal Research Station for Agroecology &  
Agriculture (FAL)  
Reckenholzstrasse 191  
Zurich CH-8046, SWITZERLAND  
Seraina.Bassin@fal.admin.ch  
Tel: 41 1 377 75 08  
Fax: 41 1 377 72 01

**Mr Patrick BÜKER**

Trier University  
Faculty of Geography, Department of Geobotany  
Universitätsring 15  
Trier D-54286, GERMANY  
bueker@uni-trier.de  
Tel: 49 651 201 2249  
Fax: 49 651 201 3808

**Mr Steve CINDERBY**

Stockholm Environment Institute-York  
Department of Biology  
University of York, PO Box 373  
York YO10 5YW, UK  
sc9@york.ac.uk  
Tel: 44 1904 432 994  
Fax: 44 1904 432 898

**Mr James DORSEY**

Physics Department  
UMIST  
PO Box 88, Sackville Street  
Manchester M60 1QD, UK  
j.dorsey@umist.ac.uk  
Tel: 44 161 200 3311 extn 2490  
Fax: 44 161 200 3951

**Ms Lisa EMBERSON**

Stockholm Environment Institute-York  
Department of Biology  
University of York, PO Box 373  
York YO10 5YW, UK  
l.emberson@york.ac.uk  
Tel: 44 1904 432 925/434789  
Fax: 44 1904 432 898

**Mr Jan-Willem ERISMAN**

Dept of Air Quality  
Netherlands Energy Research Foundation  
PO Box 1  
Petten 1755 ZG, THE NETHERLANDS  
erisman@ecn.nl  
Tel: 31 224 564 155  
Fax: 31 224 568 488

**Mr David FOWLER,**

Centre for Ecology and Hydrology Edinburgh  
Bush Estate  
Penicuik EH26 0QB, UK  
dfo@ceh.ac.uk  
Tel: 44 131 445 4343  
Fax: 44 131 445 3943

**Mr Giacomo GEROSA**

Università degli Studi di Milano  
via Pertini, 11  
Curno (BG) 24035, ITALY  
giacomo.gerosa@unimi.it  
Tel: 39 035 462 339  
Fax: 39 035 462 339

**Mr Max HANSSON**

Division for Environmental Sciences, Biology  
Karlstad University  
Universitetsgatan 1  
Karlstad S-651 88, SWEDEN  
Max.Hansson@kau.se  
Tel: 46 54 70 02 403  
Fax: 46 54 70 01 462

**Mr Per Erik KARLSSON**

IVL - Swedish Environmental Research Institute  
PO Box 47086  
Göteborg S-402 58, SWEDEN  
pererik.karlsson@ivl.se  
Tel: 46 31 725 6207  
Fax: 46 31 725 6290

**Mr Bill MASSMAN**

USDA Forest Service  
Rocky Mountain Research Station  
240 West Prospect Road, Fort Collins  
Colorado 80526, USA  
wmassman@fs.fed.us  
Tel: 1 970 498 1296  
Fax: 1 970 498 1314

**Mr Marco FERRETTI**

Linnaea Ambiente  
Via G. Sirtori 37  
Firenze t-50137, ITALY  
m.ferretti@linnaea.org  
Tel: 39 55 608 073  
Fax: 39 55 608 311

**Mr Jürg FUHRER**

Swiss Federal Research Station for Agroecology &  
Agriculture (FAL)  
PO Box, Reckenholzstrasse 191  
CH-8046, Zurich, SWITZERLAND  
juerg.fuhrer@fal.admin.ch  
Tel: 41 1 3777 505  
Fax: 41 1 3777 201

**Mr Heinz-Detlef GREGOR**

Federal Environmental Agency  
Bismarckplatz 1  
Berlin D-14191, GERMANY  
heinz-detlef.gregor@uba.de  
Tel: 49 30 8903 2846  
Fax: 49 30 8903 2907

**Mr Lars HOLE**

Norwegian Institute for Air Research - NILU  
PO Box 100  
Kjeller N-2027, NORWAY  
lrh@nilu.no  
Tel: 47 638 981 87  
Fax: 47 638 980 50

**Mr Ullrich LORENZ**

Federal Environmental Agency  
Bismarckplatz 1  
Berlin D-14193, GERMANY  
ullrich.lorenz@uba.de  
Tel: 49 30 8903 2149  
Fax: 49 30 8903 2907

**Ms Gina MILLS**

CEH-Bangor  
Delniol Road  
Bangor LL57 2UP, UK  
gmi@ceh.ac.uk  
Tel: 44 1248 370 045  
Fax: 44 1248 355 365

**Mr Bob MUSSELMAN**

USDA Forest Service  
Rocky Mountain Research Station  
240 West Prospect Road, Fort Collins  
Colorado 80526, USA  
bobm@lamar.colostate.edu  
Tel: 1 970 498 1239  
Fax: 1 970 498 1010

**Mr Kim PILEGAARD**

RISØ National Laboratory  
Plant Research Dept  
Building 309, PO Box 49  
Roskilde DK 4000, DENMARK  
kim.pilegaard@risoe.dk  
Tel: 45 4677 4175  
Fax: 45 4677 4160

**Mr Max POSCH**

RIVM/MNV (pb.47)  
PO Box 1  
Bilthoven NL-3720 BA, THE NETHERLANDS  
max.posch@rivm.nl  
Tel: 31 30 274 2573  
Fax: 31 30 274 2573

**Ms Lisa SAMUELSON**

School of Forestry and Wildlife Sciences  
224 M. White Smith Hall  
Auburn University  
Auburn Alabama 36849, USA  
samuelj@auburn.edu  
Tel: 1 334 844 1040  
Fax: 1 334 844 1084

**Mr Dave SIMPSON**

Physical Geography  
Gothenburg University  
Earth Sciences Centre  
Box 460  
Gothenburg SE-40530, SWEDEN  
david.simpson@ivl.se  
Tel: 46 70 330 5691

**Mr Juha-Pekka TUOVINEN**

Finnish Meteorological Institute  
Sahaajankatu 20 E  
Helsinki 00810, FINLAND  
juha-pekka.tuovinen@fmi.fi  
Tel: 358 9 1929 5515  
Fax: 358 9 1929 5403

**Ms Jeanne PANEK**

Environmental Science, Policy & Management  
151 Hilgard Hall  
University of California  
Berkeley CA 94720, USA  
jpanek@nature.berkeley.edu  
Tel: 1 510 642 9732  
Fax: 1 510 643 5098

**Mr Håkan PLEIJEL**

Applied Environmental Science  
Göteborg University  
PO Box 464  
Göteborg 405 30, SWEDEN  
hakan.pleijel@miljo.gu.se  
Tel: 46 31 773 2532  
Fax: 46 31 773 2984

**Mr Helge RO-POULSEN**

Botanical Institute  
University of Copenhagen  
Oester Farimagsgade 2D  
Copenhagen DK-1353, DENMARK  
helgerp@bot.ku.dk  
Tel: 45 35 32 22 58  
Fax: 45 53 32 23 21

**Mr Ben SANCHEZ GIMENO**

CIEMAT (ed.70)  
Avda. Complutense 22  
Madrid 28040, SPAIN  
benjamin.gimeno@ciemat.es  
Tel: 34 91 346 6556  
Fax: 34 91 346 6121

**Mr Andrew TERRY**

Dept of Environmental Science  
University of Bradford  
Bradford BD7 1DP, UK  
A.C.Terry@bradford.ac.uk  
Tel: 44 1274 235 393  
Fax: 44 1274 235 699

**Ms Karine VANDERMEIREN  
VAR**

Leuvensesteenweg 17  
B-3018 Tervuren 11, BELGIUM  
Karine.Vandermeiren@terv.var.fgov.be  
Tel: 32 2 769 22 33  
Fax: 32 2 769 23 05

**Ms Alison VIPOND**

DEFRA  
Zone 4/D11/Ashdown House  
123 Victoria Street  
London SW1E 6DE, UK  
alison.vipond@defra.gsi.gov.uk  
Tel: 44 20 7944 6293  
Fax: 44 20 7944 6290

Late registrant

**Mr Jan DUYZER**

TNO-MEP  
PO Box 342, Laan van Westenenk 501  
7300 AH Apeldoorn, THE NETHERLANDS  
Tel: 31 55 5493 944  
Fax: 31 55 5493 252  
E-mail:duyzer@mep.tno.nl

**Mr Yihua WU**

Atmospheric Science Modelling Division  
USEPA  
Mail Drop E243-01  
Research Triangle Park, NC 27711, USA  
Tel: 919 541 4612  
Fax: 919 541 1379