Summary

Elevated tropospheric ozone concentrations (O_3) are not only harmful for human health, but they may also have detrimental effects on agricultural and horticultural crops, trees, grassland and natural ecosystems. In the past, an O_3 exposure index and critical levels for the protection of vegetation have been agreed upon at European level based on atmospheric O_3 concentrations and exposure time. According to the European Air Quality guideline 2008/50/EG, the AOT40 (Accumulated Ozone exposure over a Threshold of 40 ppb) was defined as the sum of hourly O_3 concentrations above a cut-off of 40 ppb, from 8 to 20 h during the growing season. This indicator is presently being used in MINA-plan 4 (2011-2015) to monitor the evolution of the risk for O_3 damage to vegetation in Flanders. The European long term objective is 3000 ppb.h (=6000 (µg/m³).h), the critical level for O_3 damage to sensitive crops and natural vegetation.

Despite the significant improvement in comparison to previous risk assessments, the scientific community has always been well aware of the limitations of this concept by the fact that any factor which may influence a plant's response to O_3 is largely ignored. The O_3 impact is primarily correlated to the amount of O_3 entering the plant which represents only a part of the surrounding atmospheric O_3 concentration. O_3 uptake is controlled by the degree of opening of the leaf stomata (stomatal conductance), that also regulate CO_2 and H_2O exchange. This mechanism allows the plant to adapt the degree of transpiration and photosynthetic activity to changes in environmental conditions. Consequently, also O_3 uptake is dependent upon climatic changes (temperature, air and soil moisture, irradiance …) and plant-specific characteristics (number of stomata, phenology …, Figure 2).

During the last 10 years there has been an intensive development of methods for the estimation of O_3 uptake by plants and to obtain reliable dose-response relationships based on the O_3 flux in order to more accurately assess the effects of O_3. For this purpose, multiplicative models of stomatal conductance, such as the DO_3SE model (Deposition of Ozone and Stomatal Exchange), have been suggested as a basis for calculating the hourly O_3 flux. In deriving dose-response relationships, it has also been observed that the best correlations between effect and accumulated stomatal flux were obtained when using a stomatal flux threshold Y (Figure 4 and 5). This resulted in a new indicator for estimating the O_3 impact on yield and biomass accumulation of crops, forest trees and grassland: the **Phytotoxic Ozone Dose POD_Y** (mmol O_3 m^{-2} plant leaf area), which is the sum of the hourly stomatal O_3 flux over a threshold of Y nmol O_3 m^{-2} s^{-1} accumulated during daylight hours over the appropriate time-window.

The POD_Y value can be applied for the risk assessment of O_3 damage to vegetation in different ways:

- POD_Y is calculated on the basis of a validated species-specific stomatal flux model (available for wheat, potato, tomato, birch/beech, Norway spruce, grassland) and compared to the stomatal flux based critical level above which direct adverse effects may occur according to present knowledge (Table 2). This application is suitable for mapping and quantifying impacts at local and regional scale. In combination with data on land cover this can be used for assessing economic losses.
- POD_Y is calculated on the basis of a simplified flux model that is parameterised for a generic species representative for a certain vegetation type (crops, forests ...) and is specifically designed for application on large-scale modelling, including integrated assessment modelling. No critical levels are defined and the calculated O_3 uptake is viewed as an indicator of the degree of risk of negative impacts.

Next to the long term indicator for risk assessment of chronic O_3 exposure, there have also been some recent improvements with regard to the short term O_3 indicator to estimate the risk for acute, visible O_3 injury. The $AOT30_{VPD}$ (VPD-modified concentration accumulated over a threshold concentration of 30 ppb) takes into account the modifying influence of vapour pressure deficit (VPD) on the stomatal O_3 flux. This is especially useful to estimate the likelihood of visible injury on leafy vegetables where leaf injury reduces the quality and market value (e.g. spinach, lettuce …). The critical level for visible injury (on at least 10% of the leaf area) is exceeded if the $AOT30_{VPD}$, accumulated during daylight hours over 8 days, is higher than 0.16 ppm h.

A Flanders-wide calculation of the POD can be achieved via the Fortran version of the DO_3SE model. This version of DO_3SE was implemented into the European air quality model hosted by EMEP (EMEP model). This implementation can hence serve as a guide for building a Flemish POD model.

The methodology for the calculation of the stomatal conductance in itself is quite complex, but has been included into the DO_3SE model in a simplified way in order to facilitate the calculation of the POD in practice. The problem can be situated, after all, especially in the numerous environmental variables needed to calculate the POD, including, for example photosynthetically active radiation, soil moisture, growing season of crops, etc. During the implementation of DO_3SE into the EMEP model once again a number of simplifications has been carried out because of problems with some input parameters.

We have oriented ourselves to a large extent in this report to the DO_3SE version as it is implemented in the EMEP model. The most obvious way to construct a similar model for Flanders would be a coupling of DO_3SE to the Chimere model. This state-of-the-art air quality model is operational at IRCEL and is used both for assessments and for air quality forecasts. The implementation of DO_3SE in "a" regional air quality model is in any case necessary because of the presence of a large part of the necessary input in these models.

The investigation of the availability of the necessary meteorological input parameters (and the derived parameters) was for this reason carried out starting from the assumption that DO_3SE will be implemented into Chimere. With respect to the meteorological input parameters it became clear that all the necessary basic parameters are present in Chimere. Concerning soil moisture, the parameter present in Chimere can be converted to the necessary input for DO_3SE. For a number of input parameters, there are also alternative sources available, such as for soil moisture and land use information.

As the source of ozone concentrations, we propose to use hourly values from the RIO interpolation method. Those are very close to the measurements, however with the advantage of area covering concentration fields. The calculation of the chemical transformations may be turned off in Chimere and the ozone concentrations originating from RIO are read. Those concentrations have yet to be converted into the relevant ozone concentrations on vegetation height. Depending on the vegetation under consideration (e.g. agricultural crops, forests) another vegetation height must be taken into account. This can be carried out either through the deposition model present in Chimere or through the conversion factors reported in the Mapping Manual.

Summarizing, this study has shown on the one hand that all relevant input parameters for DO_3SE are either available for Flanders, or can be calculated in a parameterized way. On the other hand the study has shown that with the Chimere and RIO models and with the version of DO_3SE implemented in the EMEP model, all important building blocks exist to construct a Flemish POD model. The added value of an estimate of the ozone damage to vegetation based on the POD compared to an estimate based on the AOT40 is so large that the effort necessary for the construction of a POD model for Flanders seems absolutely justified.