CHANGES IN AIR QUALITY OF EUROPE BETWEEN 1990 AND 2020: A MODELING STUDY

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Abstract: In this project, we studied the changes in air quality due to emission reductions in Europe with a focus on Switzerland using an air quality model (CAMx). We performed the model simulations for 1990, 2005, 2006 and 2020 using the same meteorology. There were 3 selected emission scenarios for 2020 within the framework of Gothenburg Protocol. The focus was on PM2.5 and ozone damage indicators AOT40 (for vegetation) and SOMO35 (for health impacts). We could reproduce the relative change of about 40% in PM2.5 concentrations very well between 1990 and 2005. The absolute values of modelled AOT40 and SOMO35 for 2005 were in the same range as the estimates based on measurements. The model results suggest a significant decrease in AOT40 and SOMO35 for the period between 1990 and 2005 whereas observations do not show any significant trend. Even though the background ozone concentrations used in the model for 1990 and 2005 are based on recent observations, they might need further revision. Among the three Gothenburg scenarios BL (baseline), Mid and MTFR, the BL scenario is the closest to the recently revised Gothenburg Protocol. Results suggest that emission reductions according to the BL scenario would lead to a 30% decrease in PM2.5 concentrations. On the other hand, assuming constant background ozone levels in Europe after 2005, AOT40 values were predicted to decrease in 2020 by a large amount (50%). The health-relevant indicator SOMO35 for 2020 was also predicted to be lower by about 30-40% with respect to the reference year 2005. In addition to the pollutant concentrations, we analysed the nitrogen deposition in Switzerland as well. We modelled both dry and wet deposition of all oxidized and reduced nitrogen species. The largest nitrogen depositions were predicted to be over the Swiss Plateau and in southern Switzerland (20-25 kg N $ha^{-1}.y^{-1}$). The fraction of modelled reduced nitrogen species ammonia and particulate ammonium in Switzerland was larger than the oxidized species. The results of the retrospective study indicated a decrease of 10 – 30% in nitrogen deposition since 1990, mainly due to the reduction of NO_x emissions. Applying the baseline scenario, we found that the nitrogen deposition would decrease by about 25% mostly in southern Switzerland in 2020.

Key words: *CAMx, Gothenburg Protocol, PM2.5, background ozone, AOT40, SOMO35*

INTRODUCTION

Air quality is important for the human health, crop growth and ecological system (Pope and Dockery, 2006; Ashmore et al., 1992). One of Europe's main environmental concerns is the air pollution and current policy focuses mainly on ozone (O_3) and particulate matter (PM10). In spite of the current legislation devoted to air pollution control, ozone and PM10 levels often exceed the ambient air quality standards in Europe (for ozone 120 μgm^{-3} maximum daily 8-hour mean, for PM10 50 μgm^{-3} daily mean).

In an earlier study we calculated the effects of numerous regulations enforced in Europe since 1985 and predicted the effects of Gothenburg targets for 2010 on ozone (Andreani-Aksoyoglu et al., 2008). Our results suggested that the decrease in local ozone production due to emission reductions might have been partly or completely compensated by the simultaneous increase in the background ozone, indicating that the further development of the background ozone concentrations in Europe would be very important. The ozone precursor emissions in Europe and in North America have decreased significantly since 1980s. As a result of large reductions, sensitivity of ozone to its precursor emissions in Europe decreased as well (Aksoyoglu et al., 2012). On the other hand, NO_x emissions increased dramatically in Asia in the last decade (Zhang et al., 2010). Ozone concentrations in Europe can therefore be affected by emissions from other continents. In 2007, the Convention on Long-Range Transboundary Air Pollution initiated the revision of its Gothenburg multi-pollutant/multi-effect protocol (UNECE, 1999). In the revised protocol, fine particulate matter (PM2.5) was included. EMEP Centre for Integrated Assessment Modelling (CIAM) and IIASA prepared various emission control scenarios for cost-effective improvements of air quality in Europe in 2020 using the GAINS (Greenhouse gas – Air pollution Interactions and Synergies) model. In this study, we investigated the effects of selected emission scenarios for 2020 on ozone and particulate matter in Europe with a focus on Switzerland. We also performed model simulations for 1990 and evaluated the changes in air quality since then. In this report, we discussed the changes in annual average concentrations of PM2.5, nitrogen deposition and damage indicators AOT40 and SOMO35 between 1990 and 2020.

METHOD

In this project we used the 3-dimensional air quality model CAMx (Comprehensive Air quality Model with extensions, http://www.camx.com) and meteorological model WRF (Weather Research and Forecasting Model, http://wrf-model.org/index.php). We performed simulations for the following years: 1990 (retrospective), 2005 (reference case), 2006 (model validation), 2020 (with 3 emission scenarios, baseline (BL), Mid, MTFR). The meteorological fields calculated for 2006 were used for all the CAMx simulations with different emission scenarios. Details on model parameterization can be found in Aksoyoglu et al. (2011). The coarse model domain covered whole Europe with a horizontal resolution of 0.250º x 0.125º. A nested domain with three times higher resolution covered Switzerland. There were 31 layers in WRF of which 14 were used in CAMx and the lowest layer was 20 m above ground. Initial and boundary concentrations for the reference year (2005) were extracted from the output of the global model MOZART (Horowitz et al., 2003). In this work, we modified background ozone values for 1990 and 2005 according to the data available for Europe in literature (Wilson et al., 2012; Logan et al., 2012). Biogenic emissions (isoprene, monoterpenes and sesquiterpenes) were calculated using the meteorological data (Andreani-Aksoyoglu and Keller, 1995). European emissions for anthropogenic sources for 2006 were from TNO (http://www.gmes-atmosphere.eu/). Anthropogenic emissions in Switzerland originated from INFRAS and Meteotest (Keller and de Haan, 2004; Heldstab and Wuethrich, 2006). The gridded emissions for 2020 were prepared using the selected GAINS scenarios calculated by IIASA (http://gains.iiasa.ac.at/index.php/policyapplications/gothenburg-protocol-revision). The model results for 1990 and for 2020 were compared with those for the reference year, 2005. We calculated the ozone damage indicators for vegetation and health impacts for all scenarios. AOT40 (Accumulated dose of ozone Over the Threshold of 40 ppb) was calculated from April to September, for the daytime hours for all scenarios (Ashmore and Wilson, 1992). SOMO35 (Sum of Ozone Means Over 35 ppb) is the yearly sum of the daily maximum of 8-hour running average over 35 ppb (Amann et al., 2008).

RESULTS AND DISCUSSION

In general, the model could reproduce the overall PM2.5 concentrations and temporal variation quite well except at some urban sites in winter mostly due to cold inversion periods and extended fog layers. The modelled relative changes of 35-45% in annual average concentrations of PM2.5 between 1990 and 2005 agree very well with those from measurements at various stations in Switzerland. The absolute values of modelled AOT40 and SOMO35 for 2005 in Europe are shown in Figures 1 and 2, respectively.

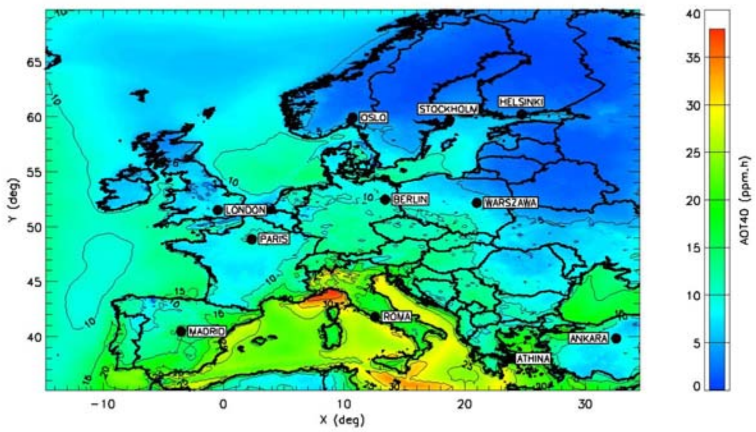

Figure 1: AOT40 (ppm.h) for the reference case (RC 2005)

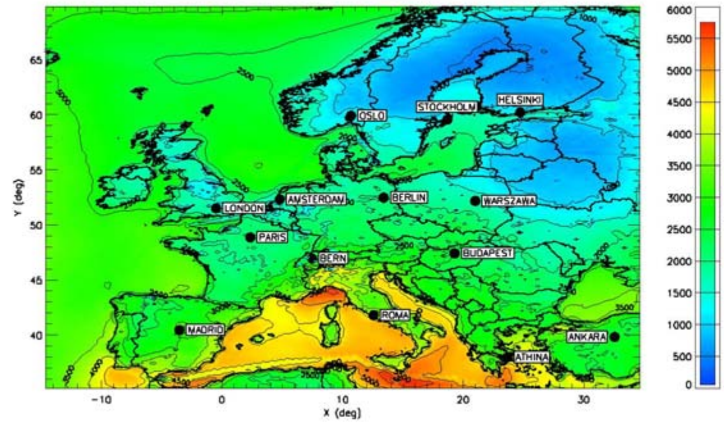

Figure 2: SOMO35 (ppb.d) for the reference case (RC 2005).

The modelled indicator values are in the same range as the data estimated from measurements at some Swiss stations. The model results suggest a significant decrease in AOT40 since 1990 whereas observations at some Swiss stations show no significant trend during that period. A similar discrepancy was found for SOMO35. These comparisons indicate the importance of the background ozone concentrations. Even though the background ozone concentrations used in the model for 1990 and 2005 were based on recent observations, they might need further revision.

Among the three Gothenburg scenarios for 2020, BL (baseline), Mid and MTFR (Maximum Technically Feasible Reduction), the BL scenario is the closest to the recently revised Gothenburg Protocol. In this paper, therefore, we focus on the results of the baseline scenario for 2020. The model results suggest that emission reductions according to the baseline scenario would lead to about a 30% decrease in PM2.5 concentrations in Europe (Figure 3). The vegetation-relevant AOT40 and health-relevant SOMO35 were predicted to decrease in 2020 significantly (30-50%) relative to the reference year 2005.

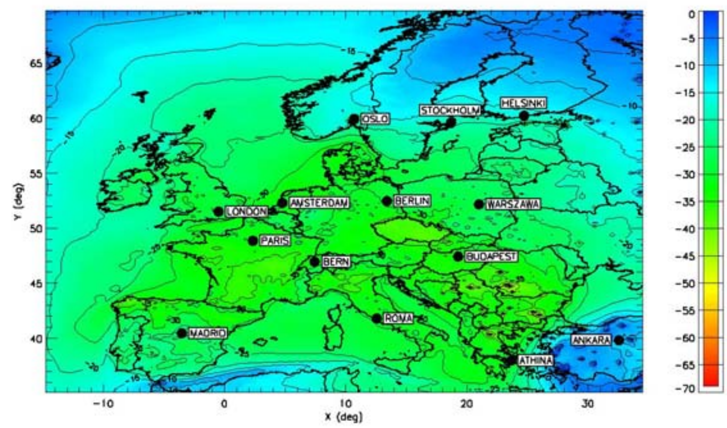

Figure 3: Difference in annual average of PM2.5 (%), BL 2020 – RC 2005.

In addition to the pollutant concentrations, we analysed the dry and wet nitrogen deposition as well. The modelled nitrogen depositions were predicted to vary between 5-40 kg N $ha^{-1}.y^{-1}$ and largest deposition was over the Swiss Plateau and in the south (see Figure 4). These results are in the same range as reported from measurements (Schmitt et al., 2005). The fraction of the reduced nitrogen species was found to be higher than the oxidized species in Switzerland. The results of the retrospective study indicated a decrease of 10 – 30% in total nitrogen deposition since 1990. Applying the baseline scenario for 2020, we found that the nitrogen deposition would decrease further by about 25% mainly in the south.

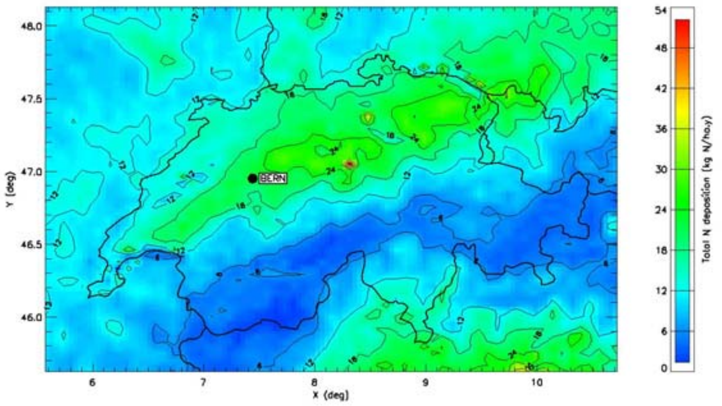

Figure 4: Deposition of nitrogen species (kg N ha^{-1} y^{-1}) for the reference case (2005).

CONCLUSIONS

The modelled relative changes of 35-45% in annual average concentrations of PM2.5 between 1990 and 2005 agree very well with those from measurements. Our results show that the application of emission reductions according to the BL scenario for 2020 would lead to a significant decrease of particulate matter (30%) in Europe.

The modelled ozone damage indicators AOT40 (for vegetation) and SOMO35 (for health impacts) for 2005 are in the same range as the data obtained from measurements. The model results suggest a decrease in AOT40 since 1990 whereas observations at some Swiss stations show no significant trend during that period. A similar discrepancy was found for SOMO35. We conclude that even though the background ozone concentrations used in the model for 1990 and 2005 were based on recent observations, they might need further revision. Assuming constant background ozone concentrations after 2005, AOT40 and SOMO35 values were predicted to decrease in 2020 by 50% and 30%, respectively.

We also analysed the nitrogen deposition. We modelled both dry and wet deposition of all oxidized and reduced nitrogen species. The highest modelled nitrogen depositions are over the Swiss Plateau and in the south (20 - 25 kg N $ha^{-1}.y^{-1}$). These results are in the same range as some measurements available in Switzerland. The depositions of the reduced nitrogen species ammonia and particulate ammonium in Switzerland were found to be larger than the deposition of the oxidized species. The results of the retrospective study indicated a decrease of 10 – 30% in nitrogen deposition since 1990. On the other hand, nitrogen deposition is predicted to decrease further until 2020 by about 10-20% assuming the baseline scenario, mainly over the Alpine regions and in the south.

The results obtained in this modelling study show the need for a detailed analysis of background ozone concentrations for use in calculating AOT40 and SOMO35 trends. Such vegetation and health impact indicators are very sensitive to that parameter.

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