Malé Declaration/IG13/4/1

Malé Declaration on Control and Prevention of Air Pollution and its Likely Transboundary Effect for South Asia

Assessment of Impacts of Air Pollution on Crops in South Asia

with a focus on

Tropospheric Ozone

Final Report

Compiled by Patrick Büker, Stockholm Environment Institute, UK

May 2013

This report has been prepared mostly based on the inputs from the following institutes:

Study in Mymensingh, Bangladesh (Prof. M. A. Sattar, Dr. T. Islam)
Bangladesh Agricultural University, Environmental Science Department, Mymensingh-2202, Bangladesh

Study in Kanglung, Bhutan (Dr. K. Tshering, Dr. M. Pelmo)
Sherubtse College, Royal University of Bhutan, Kanglung, Bhutan

Study in Varanasi, India (Prof. M. Agrawal)
Department of Botany, Banaras Hindu University, Varanasi 221005, India

Study in Rampur, Nepal (Prof. N. Chaudhary, Mr. L. Amgain, Ms. M. Bhattarai)
Institute of Agriculture and Animal Science (IAAS), Rampur, Chitwan, Nepal

Study in Lahore, Pakistan (Prof. S.R.A. Shamsi)
The University of the Punjab, Dept. Microbiology and Molecular Genetics, **Quaid-e-Azam Campus,** Lahore, Pakistan.

Study in Peshawar, Pakistan (Dr. M.N. Ahmad)
Agricultural University, Khyber Pakhtun Khwah, Department of Chemistry, Peshawar, Pakistan

Study in Peradeniya, Sri Lanka (Dr. A. Perera)
University of Peradeniya, Department of Chemistry, Peradeniya, Sri Lanka

Secretariat

Regional Resource Centre for Asia and the Pacific (RRC.AP)
Outreach Building, Asian Institute of Technology, P.O. Box 4, Klongluang, Pathumthani 12120, Thailand
http://www.rrcap.ait.asia

Technical Support

Stockholm Environment Institute at York
University of York, Heslington, York, YO10 5DD, UK
http://www.york.ac.uk/sei

Funding

The Swedish International Development Cooperation Agency (Sida) generously funded this component of the Malé Declaration Implementation.

Crop impact assessment

Malé Declaration Achievements

- New large-scale experimental evidence of effects of air pollutant ground-level (or tropospheric) ozone (O_3) on yield of important South Asian crops, such as Mung bean, spinach, wheat and potato; evidence fits well with modelling-based regional prediction of O_3 concentration fields;
- Wide-spread evidence of plant-damaging concentration levels of ground-level O3 during main growing seasons of important South Asian crops;
- Development of standardized risk assessment methodologies that have been evaluated for their application across the region;
- Increased awareness of the yield-damaging effect of ground-level O3 among policy makers, scientific community and general public through seminars, training workshops and information material (e.g. policy briefs);
- Successful capacity building in the region due to training of numerous junior and senior scientists in application of risk assessment methods;
- Enhanced, institutionalized (e.g. via APCEN network and GAP Forum) cooperation between South Asian, European and North American scientists with active mutual exchange of knowledge and skills;
- A Regional Centre of Crop Impact Assessment is currently being established in Pakistan to oversee coordination, harmonization, quality control and reporting of the Malé Declaration crop impact activities.

Setting the scene

Ground level ozone (O_3) is a secondary air pollutant that is formed by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence of sunlight. Major sources of NOx and VOC are related to the combustion of fossil fuels, such as in industrial facilities, motor vehicle engines or domestic heating and cooking facilities.

O_3 is arguably the most important atmospheric pollutant causing damage to agricultural productivity across the globe. Foliar damage and reduced yields after exposure to ambient levels of O_3 have been widely reported from Europe, North America as well as – to a lesser extent - South Asia. However, unlike in Europe and North America, prior to the RAPIDC project a standardised methodological approach for the assessment of O_3 impacts on crops had never been applied across South Asia. The RAPIDC crop impact studies aimed at developing and applying such a standardised regional approach to be able to a) identify agricultural regions in South Asia that are at risk of experiencing O_3 impacts on crops and b) quantify the extent of this risk. A pre-condition for this approach was to train local scientists in applying these standardised regional risk assessment methods.

These findings will eventually contribute to the assessment of socio-economic effects of air pollution impacts on crop yields for (small- to large-scale) farmers and hence offer policy makers a methodology to assess the risk of food insecurity and the population’s susceptibility to poverty.

Methodological approach

Field experiments to quantitatively assess the effect of ambient O_3 on the nutritionally and economically important crops mung bean, spinach, potato and wheat were carried out in Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka between 2006 and 2012. All these field campaigns were carried out according to crop-specific **standardised protocols** that were specifically developed for the application in South Asia. As such, the results between countries are directly comparable and therefore offer interpretations of the **regional extent** of the threat O_3 poses to crop yields. O_3 concentrations were monitored at all field sites using passive samplers, as were the prevailing meteorological conditions using local weather stations or provided data loggers.

The effect of O_3 on the yield of locally grown crops was quantified using the chemical protectant ethylenediurea ((N-[2-(2-oxo-1- imidazolidinyl)ethyl]-N-phenylurea), abbreviated EDU). EDU is an anti-ozonant that has been used successfully throughout the globe; it suppresses typical O_3-induced biomass reductions. Half of the plants exposed to ambient O_3 were treated with EDU. The biomass difference between EDU-treated and non-treated plants at the final harvest can then be directly attributed to O_3. In addition, foliar injury was recorded weekly during the experiment; this parameter is especially important for leafy crops such as spinach, because leaves with clear damage symptoms are less likely to be sold on markets with direct economic effects for farmers.

Evidence of wide-spread impacts of ozone on crops in South Asia

Regional ozone pollution and prevailing meteorological conditions

Ambient four-weekly mean O_3 concentrations at various experimental sites across South Asia as monitored with passive samplers are presented in Fig 1. Since passive samplers capture both night-time (low O_3 concentrations) and day-time (high O_3 concentrations) periods, peak day-time O_3 concentrations during each four-week passive sampler exposure period will have been much higher than the average recorded here. Generally, O_3 concentrations above 40 ppb are considered as being toxic to plants; as such, Fig. 1 indicates that peak O_3 concentrations during the major South Asian crop growing seasons (Nov. – Jan. and March – June) will have almost certainly been at levels that were toxic to plants (i.e. above 40 ppb).

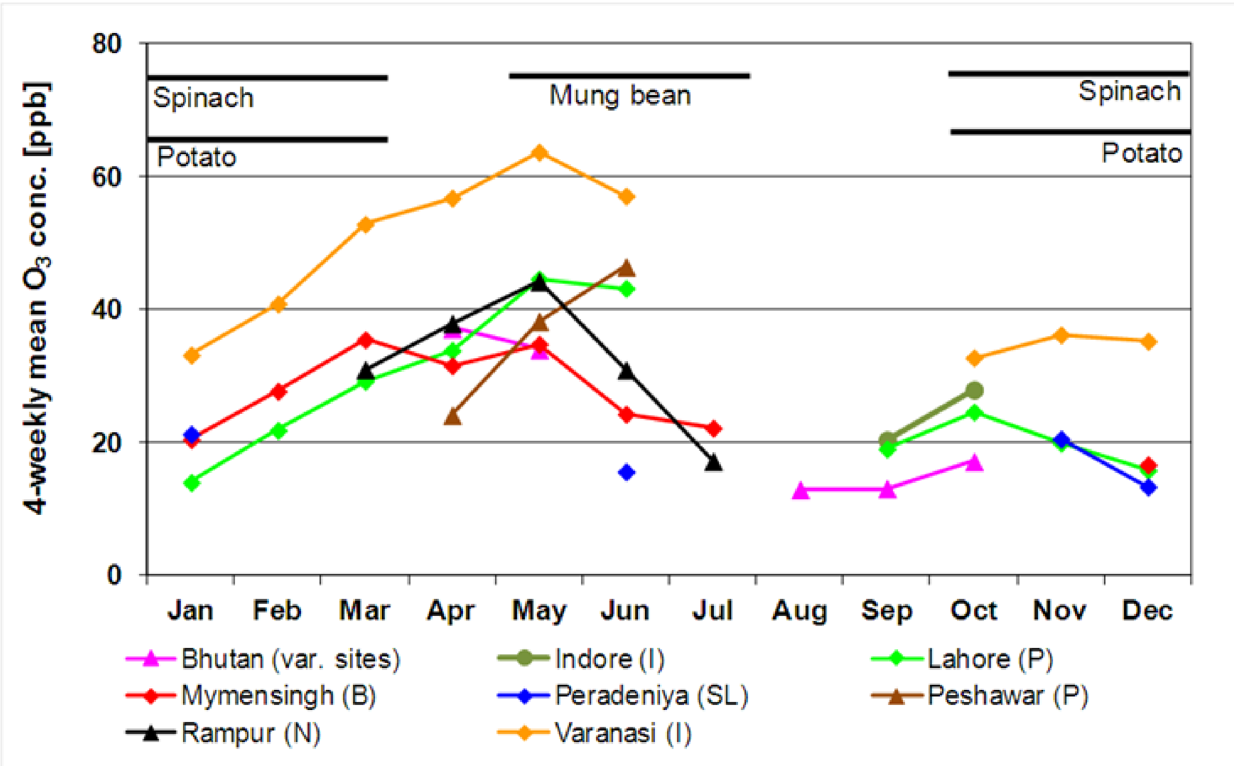

Fig. 1. Four-weekly mean ambient ozone concentration monitored using passive samplers at various sites across the South Asian region.

High air temperatures due to high levels of solar radiation and high levels of air humidity were detected during field campaigns. These meteorological conditions not only favour O_3 formation, but also the plants' uptake of O_3 due to an increased gas exchange at the leaf level in hot and humid conditions. In fact, the experimental sites with the highest temperatures and relative humidity levels experienced the highest levels of O_3 and yield losses (see next section).

Yield losses

Substantial yield losses to mung bean, spinach, potato and wheat were found after exposure of these crops to ambient air at various field sites in six Malé Declaration countries. The extent of these yield losses are presented in Fig. 2 and range from 17 to more than 50% with an average yield loss for mung bean and spinach of 24% and 31% respectively. Please note that with some very few exceptions there is a good match of O_3 concentrations with yield loss levels.

These yield losses are in the range of losses that were reported from other field studies in South Asian countries and that were published in the scientific literature during the last two decades. Yield loss figures of 20 to 30% clearly demonstrate that current ambient levels of O_3 pose already now a threat to crop yields in large parts of South Asia. With O_3 concentrations expected to rise in the region during the next decades, these yield losses might even be higher and more wide-spread in the foreseeable future. Concern also arises from the fact that scientists have found that Asian cultivars of wheat, soybean and rice are in general more sensitive to O_3 as compared to their European and North American counterparts (Emberson et al., 2009),

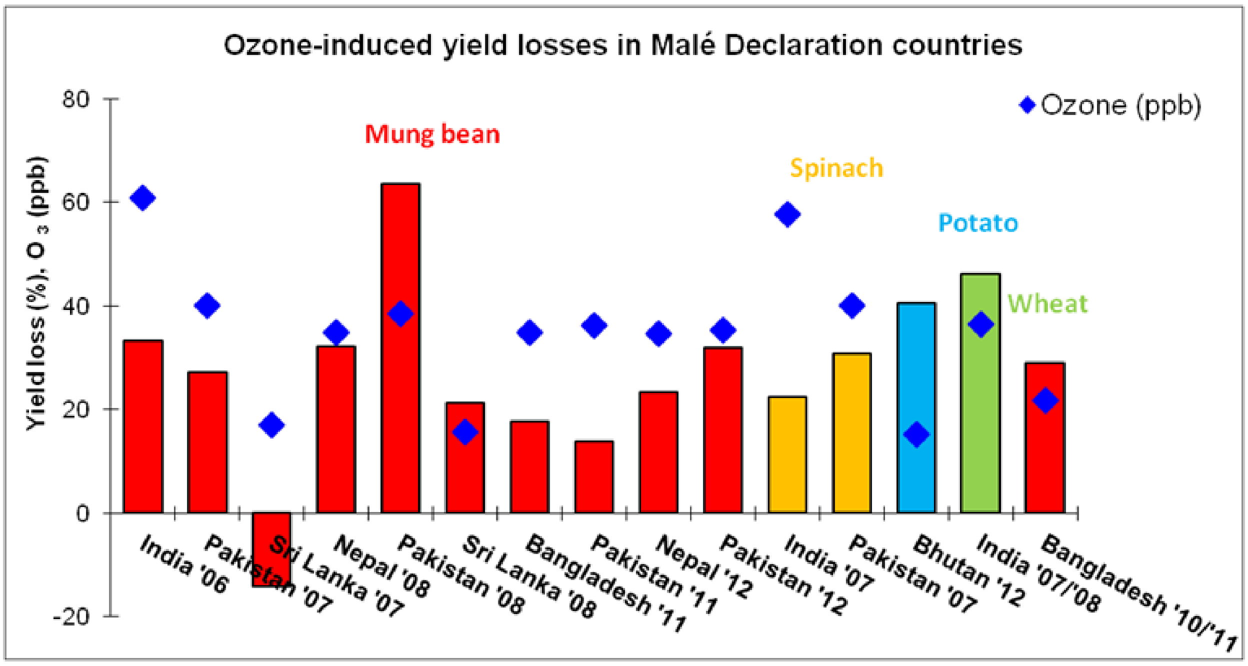

Fig. 2. Ozone-induced yield losses for Mung bean, spinach, potato and wheat in various South Asian countries as recorded during field experiments conducted between 2006 and 2012.

The spatial distribution of yield losses across Malé Declaration countries confirms the results of a modelling-based provisional risk assessment that was performed at an early stage of the RAPIDC programme. Fig. 3 shows the yield losses in relation to O_3 concentrations predicted by the MATCH model and presented as AOT40 (hourly O_3 concentrations Accumulated Over a Threshold of 40 ppb) for the period May, June and July which coincides with the important "pod filling" mung bean growth period. Those areas identified by the modelling study as being at greater risk from prevailing O_3 concentrations correlate well with those sites where statistically significant damage was recorded during the experiments. The sites with the greatest O_3 damage are those in the Indo-Gangetic plain where between 2006 and 2012 robust statistically significant yield losses for mung bean ranged from 23 to 64 %. In contrast, statistically significant yield losses were not recorded in Sri Lanka.

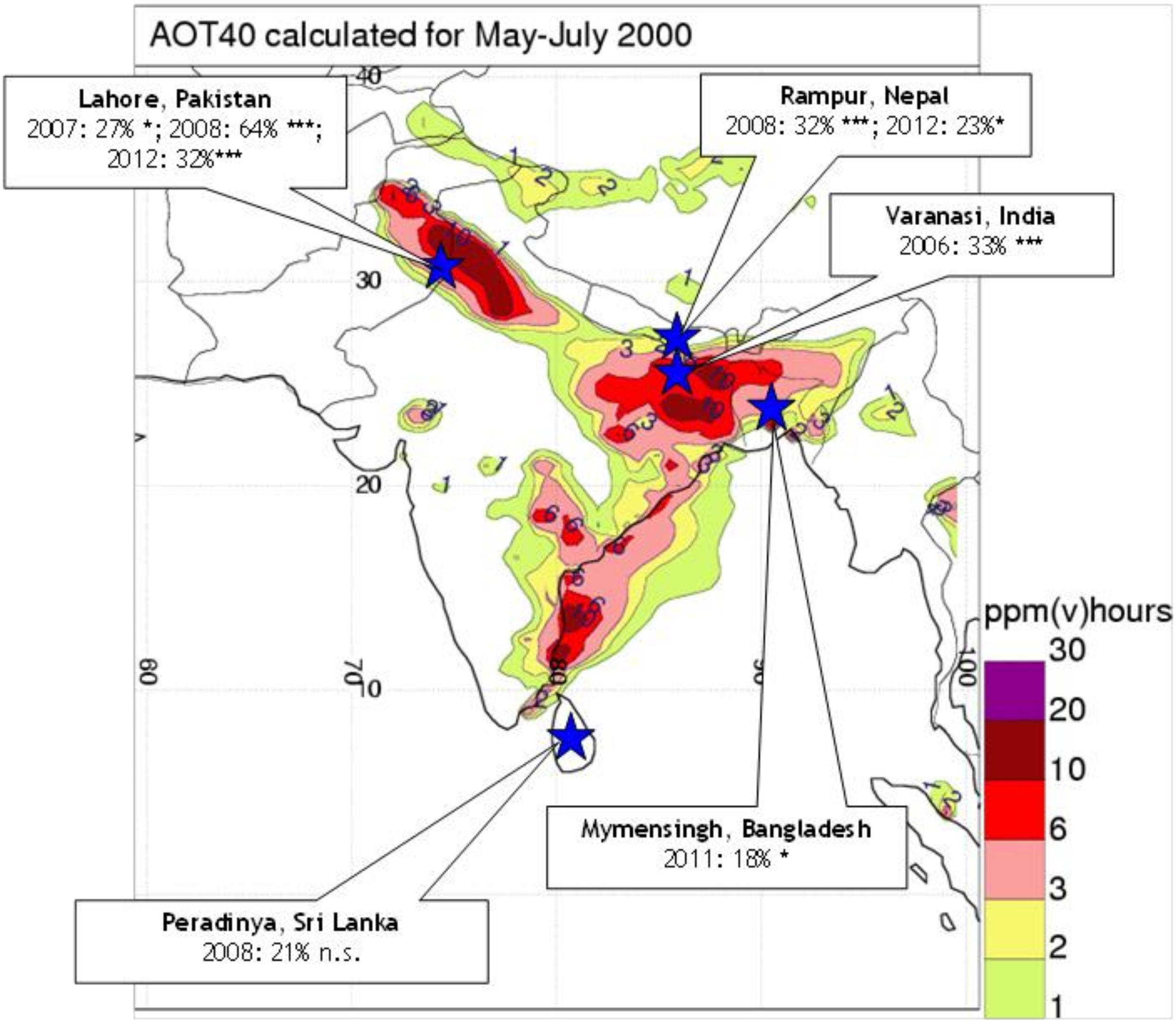

Fig. 3. MATCH modelled O_3 concentrations for the year 2000 presented as 3-month AOT40 values for May to July. Also shown are the results of the EDU chemical protectant study for mung bean (% yield loss) conducted at the South Asian experimental sites (indicated by blue stars) during equivalent months. The significance of the experimental results is presented (n.s. = not significant; * moderately significant and *** highly significant).

Significance of results for Malé Declaration countries

The future sustainability of cereal production in South Asia is rather uncertain. South Asia's Indo-Gangetic Plains benefited from the 1960s Green Revolution. Using improved wheat and rice varieties, irrigation and higher doses of fertilizer, South Asian farmers were able to double rice production and boost wheat output by almost five times in just three decades. However, the area under rice and wheat cultivation has stabilized, and further expansion seems unlikely. In addition, evidence suggests that growth in cereal yields have begun to slow down in many high-potential agricultural areas, with large variability in trends occurring between countries of South Asia. Factors such as soil nutrient mining, declining levels of organic matter, increasing salinity, falling water tables and the build-up of weed, pathogen and pest populations will all have contributed to this decline. Given the magnitude and extent of yield losses found for key crops across the South Asian region in this and other studies, it would seem that O_3 pollution might well be an additional and significant stress on agro-ecosystems. A comprehensive understanding of the relative importance of all stresses facing current and future agricultural production in the South Asian regions is vitally important given the challenge of the region to provide sustainable increases in productivity to balance reduced per capita area harvested.

Global modelling of ground level O3 concentrations (Dentener et al., 2006; Prather et al., 2008) suggests that O_3 concentrations, which are already at concentrations capable of causing yield and productivity losses across many parts of South Asia, will continue to rise over the next decades. This prediction highlights the importance to consider O_3 in future research to assess the effect of multiple-stresses on sustainable crop production across South Asia.

This crop impact assessment programme also provided the Malé Declaration with the opportunity to more closely co-operate with other regional air pollution networks of policy bodies, such as the Global Atmospheric Pollution (GAP) Forum and the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation) of the United Nations Economic Commission for Europe's (UNECE) Convention on Long-Range Transboundary Air Pollution (LRTAP). In fact, an official exchange of letters between the LRTAP Convention and the Malé Declaration on the development of joint programmes and sharing of expertise was initialised in 2007 and further developed ever since. This co-operation for example included the attendance of ICP Vegetation meetings by junior and senior Asian scientists and vice versa to discuss potential future research collaborations.

A substantial number of scientists in the Malé Declaration countries were trained in the application of crop impact assessment at various workshops across the region. Emerging young scientists in all involved countries used the EDU field studies as subject for their MSc and PhD theses and quite a few of them have since pursued a promising career in science. As such, the RAPIDC crop programme has been extremely successful in building capacity in the South Asian region and is expected to benefit from this new capacity in the foreseeable future.

Last but not least, during the RAPIDC programme, the awareness of the threat O_3 poses on crop yields in the South Asian region was raised significantly among policy makers, the scientific community and the general public through public seminars, training workshops and the production of information material (e.g. policy briefs).

Future challenges – knowledge gaps

Although this work has established methods that enable increased understanding of current day air pollution impacts in the Malé Declaration countries, there still remain a large number of future challenges to fill the remaining knowledge gaps, such as a better estimation of the extent of yield losses of staple crops across the entire South Asian region, the differing O_3 sensitivity of common crop cultivars cultivated in the region, the effect of a changing climate on crop growth and eventually a robust estimation of the extent of the socio-economic effects of O_3 and climate change on crop yields for small- to large-scale farmers in the region.

Future assessments related to crop impacts from O_3 would therefore ideally incorporate the effects of climate change, and seek to involve specialists on adaptation options. Ideally, key decision-makers from governments would come together to discuss likely combined impacts, measures to reduce vulnerability of end users, national risk assessments and policy options to reduce the threat from this environmental problem. The opportunity for co-benefits for air pollution and climate change in emission reduction policy is of particular importance in South Asia as well as in other developing regions around the globe.

Future Steps

- Modelling studies to be able to derive dose-response relationships for crops in South Asia.
- Pan-Asian Open Top Chamber (OTC) studies.
- Crop impact studies that account for changing climate (temperature rise and shift of growing seasons).

The Air Pollution Crop Effect Network (APCEN)

During Phase II of the Sida funded Regional Air Pollution in Developing Countries (RAPIDC) Programme the Air Pollution Crop Effect Network (APCEN) network was established to facilitate communication between air quality stakeholders concerned with assessing the risks posed by air pollution to agriculture. The geographical focus of network activities has been developing countries (in particular South Asia and southern Africa), although the 70+ network members (mainly air pollution effects scientists, modellers and policy makers) are located across the globe. The main aims of APCEN are:-

- Capacity building and outreach: Development of experimental protocols for crop impact assessment studies; organisation and facilitation of training workshops; publication of results of impact assessments in reports and peer-reviewed journals.
- Data compilation: Management of data recorded during experimental field campaigns to set RAPIDC work in context of other existing studies.
- Application of modelling methods: Development and test of methodological frameworks for model-based impact assessments.

Three APCEN workshops were held in 2003 (Thailand), 2006 (South Africa) and 2008 (Thailand) to facilitate exchange of information between air pollution effect practitioners and other air pollution stakeholders. In 2010 APCEN co-organised with UNEP and the Global Atmospheric Pollution Forum (GAP Forum) the “Multi-stakeholder policy dialogue: Ground level ozone as a threat to food security in Asia” in Delhi, India. This high-level meeting was attended by ministerial departments (representing the Malé Declaration), science institutes and universities, research funding agencies and UNEP/FAO, and was aimed at assessing the current knowledge on the effect of air pollution on food security in Asia. Detailed seminar conclusions can be found under:
www.sei-international.org/gapforum/reports/Ozone_as_a_threat_to_food_security_seminar_Conclusions.pdf

References

Dentener, F., Stevenson, D., Ellingsen, K., Van Noije, T., Schultz, M., Amann, M., Atherton, C., Bell, N., Bergmann, D., Bey, I., Bouwman, L., Butler, T., Cofala, J., Collins, B., Drevet, J., Doherty, R., Eickhout, B., Eskes, H., Fiore, A., Gauss, M., Hauglustaine, D., Horowitz, L., Isaksen, I.S.A., Josse, B., Lawrence, M., Krol, M., Lamarque, J.F., Montanaro, V., Mu¨ ller, J.F., Peuch, V.H., Pitari, G., Pyle, J., Rast, S., Rodriguez, J., Sanderson, M., Savage, N.H., Shindell, D., Strahan, S., Szopa, S., Sudo, K., Van Dingenen, R., Wild, O., Zeng, G. (2006). The global atmospheric environment for the next generation. Environmental Science & Technology 40, 3586–3594.

Emberson, L.D., Büker, P., Ashmore, M.R., Mills, G., Jackson, L., Agrawal, M., Atikuzzaman, M.D., Cinderby, S., Engardt, M., Jamir, C., Kobayashi, K., Oanh, K., Quadir, Q.F., Wahid, A. (2009). Dose-response relationships derived in North America underestimate the effects of ozone (O_3) on crop yields in Asia. Atmospheric Environment 43, 1945-1953.

Prather, M., Gauss, M., Berntsen, T., Isaksen, I., Sundet, J., Bey, I., Brasseur, G., Dentener, F., Derwent, R., Stevenson, D., Grenfell, L., Hauglustaine, D., Horowitz, L., Jacob, D., Mickley, L., Lawrence, M., von Kuhlmann, R., Muller, J.F., Pitari, G., Rogers, H., Johnson, M., Pyle, J., Law, K., van Weele, M., Wild, O. (2003). Fresh air in the 21st century? Geophysical Research Letters, 30 (2), 72-1 – 72-4.