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Responses to ground-level ozone in the 21st century project call for evidence
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AQ/1 **Almut Arneth, Department of Physical Geography and Ecosystems Analysis (INES) Centre for GeoBiosphere Science Lund University**

Results from a model experiment on isoprene emissions from European forest ecosystems, for present climate & at the end of the 21st century.

1 The model simulations might be of interest for topic 1. Ground-level ozone changes over the next century:
a. What will be the important sources and sinks of ozone and ozone precursors and how are these likely to change and why?
b. What are the key models and data resources for the assessment of future ground level ozone concentrations and precursor emissions and impacts at global, European and UK scales?

The attached manuscript is accepted for publication in Plant Biology. In the experiments we calculated isoprene emissions from potential natural woody vegetation in Europe, and for the area that actually is covered by forests. For future scenarios the model accounts for changes in the distribution of dominant European tree species and changes in isoprene emissions in response to climate change and change in atmospheric CO_2 concentration. We also included estimates of the future area covered by forest and changes in woody biofuel plantations (based on two IPCC scenarios).

I hope this study might be useful to the working group's discussions. I do not have an objection to a possible publication of the attached material along the final report, however would like to be given the opportunity of re-submitting the final version of the paper (which hopefully will be in print at the time the report is published). Please do not hesitate to contact me if you require further information from me.

Reference:
A Arneth *et al* (In press) Effects of species composition, land surface cover, CO_2 Concentration and climate on isoprene emissions from European forests, *Plant Biology*

Editor note: Now published

AQ/2 APCEN, the Air Pollution Crop Effect Network

Prepared by: Lisa Emberson
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1 Brief introduction to APCEN

The APCEN Network facilitates information exchange between air pollution effect scientists and air pollution stakeholders with the specific aim of developing methods to reduce impacts on crop productivity and quality in developing country regions. APCEN comprises over 60 members from countries predominantly in Asia, Africa, Europe and North America. The methods employed by the network include observation, experimental and modelling techniques, with a focus on standardisation of assessment and application of these various tools within and between different global regions. The network is working towards developing methods to make socio-economic impact assessments that can be used to identify appropriate policy interventions at a rage of geographical scales.

2 Evidence of Impacts of ozone by region

Over recent years APCEN has been involved in activities to try to collate and synthesise information describing current day impacts of air pollution, with a focus on surface ozone, in developing country regions. These studies have been synthesised in a number of publications (Mauzerall & Wang, 2001; Emberson et al. 2000; Emberson et al. 2003; Emberson et al. (in press)).

Here, members of the APCEN network review some of the key information from these publications as well as presenting more recent information (not included in these earlier publications). Presented are both current day evidence of impacts as well as studies that provide some insight into potential future impacts of this pollutant on crop productivity and crop quality. Where possible this information is provided in national context in terms of food security and pollution control. We also detail what we believe to be some of the urgent research priorities for the future to provide more comprehensive assessments of damage.

3 Current day impacts

Asia

In Asia ground-level O_3 concentrations are alarmingly high in some large metropolitan areas. Severe O_3 episodes are now observed in many countries such as China, Japan, Korea, Taiwan and Thailand. Ground level O_3 concentrations of these countries typically show peak concentrations in the range of 90 – 200 ppb in the afternoon during ozone episodes. In Japan, frequent observations of visible foliar injury in many crop plants during the summer months (June to August) coincides with conditions when O_3 concentrations frequently exceed 100 ppb) with some of the most frequently affected crops being rice, maize, peanut, tomato and aroid (Izuta, Pers. comm.).

In northern Taiwan, observations of O_3 induced visible injury on plant species such as leafy sweet potato and spinach have been made frequently since 1992. To help assess the geographical extent and frequency of such O_3 symptoms researchers in Taiwan have used

an active bio-monitoring approach as a cost effective means of evaluating the pollution situation. This approach has used 2 native (double-fortune tomato and black nightshade) and 2 foreign (Bel-W3 tobacco and morning glory) indicator plants for O_3 and has been successful in identifying annual pollution episodes of four urban areas of Taiwan where the bio-monitoring experiments were established.

Potentially damaging high O_3 concentrations have also been found in other parts of south east Asia with frequent exceedences of national ambient air quality standards (Kim and Ghim, 2002; Zhang and Kim Oanh, 2002; Chen et al., 2003; Lam et al., 2005; Didin and Kim Oanh, 2006). In Southeast Asia the levels in big metropolitan regions such as Bangkok, Jakarta, Manila, Ho Chi Minh City are rising which may already cause substantial impacts on health and crop production but no comprehensive assessment has as yet been performed. 3 month running AOT40 levels in the high ozone season of the year (dry season) are well in exceedance of the WHO guideline of 3 ppm.h (Nghiem and Kim Oanh, 2006 – BAQ06, presentation). Monitoring data are limited, and if available are mainly for the city centres where ozone would not be maximum. There is almost no data on ozone in city plume in the suburb areas where crops grow.

In south Asia, particularly India and Pakistan, evidences of high concentrations of O_3 have been reported. For example, in India hourly maximum O_3 concentrations of between 10 and 273 ppb have been recorded in Delhi (Varshney and Agrawal, 1992). The limited monitoring that does exist in the region suggests that in general, the northern and western parts of the country experience higher levels of air pollutants compared to south and eastern parts, this is corroborated with modelling studies (Fig 1) using the MATCH model to simulate three month AOT40 at 3 m above surface during three different periods for the year 2000.

In Pakistan, levels of O_3 pollution found in the peri-urban areas outside of the city centres exceed 70 ppb characterised as 8 hr daily means. Outside Lahore, controlled experimental investigations using OTCs have investigated the impacts of ambient concentrations of O_3 and NO_X on the growth of local cultivars of wheat, rice, barley, chickpea, mung bean and soybean crops in comparison with those grown in pollution free air. The damage caused by the exposure of plants to ambient air pollution included reduced numbers of tillers, shoots and leaves; accelerated leaf senescence and yield reductions of between 18 and 47% (Wahid, Pers Comm., Wahid, 2006a & Wahid, 2006b). Impacts were also seen on plant physiological parameters including reductions in stomatal conductance, net photosynthetic rate and photosynthetic efficiency. Nutritional quality of seeds was also significantly reduced with respect to starch, though protein and vitamin-E contents were seemingly unaffected. In addition, studies using "EDU" (N-[2-{2-oxo-1-imidazolidinyl}ethyl]-n2phenylurea) as a chemical protectant to O_3 have shown that seasonal mean O_3 concentrations of 75 ppb for 6 hr per day are sufficient to cause yield reductions of up to 64% to soybean in remote rural areas 30 km from Lahore (cf. Emberson et al. 2001).

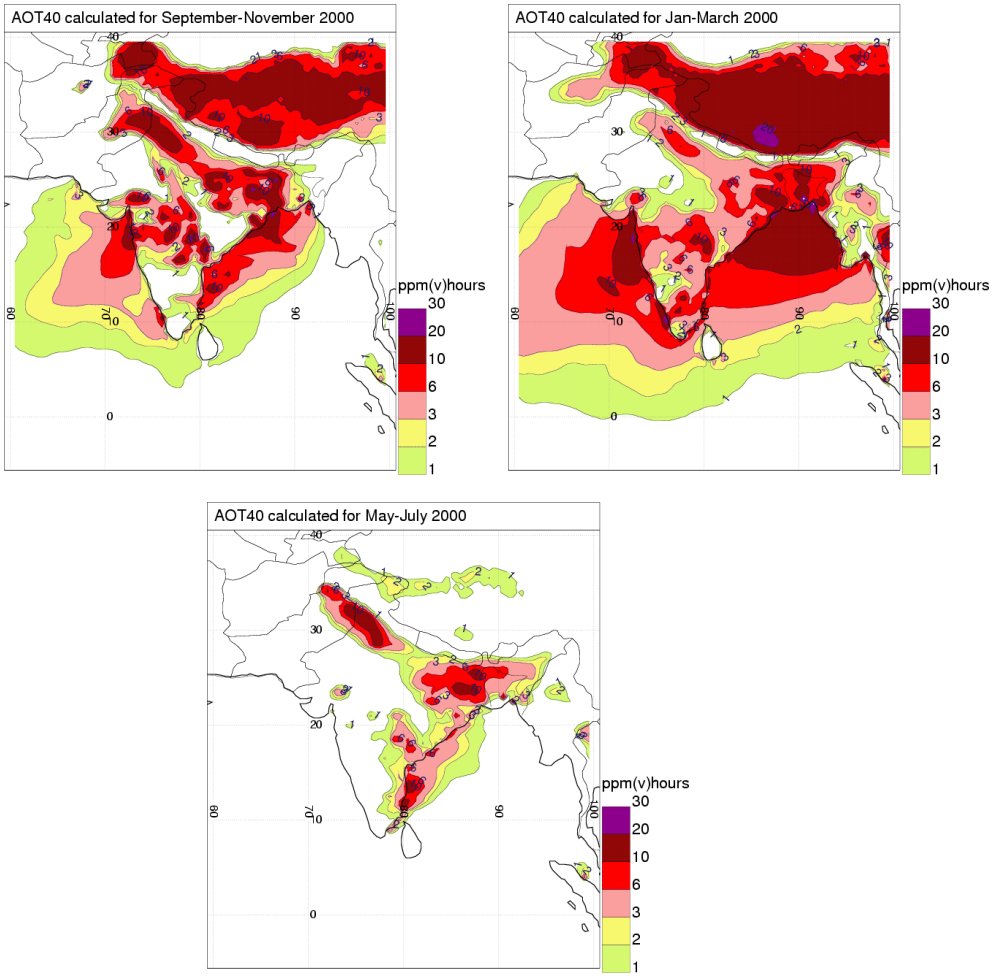
Concern that impacts may be occurring in the Middle East are also emerging. For example, in Iran and in particular Tehran, such concern has resulted in the establishment of more than 15 air quality monitoring stations for a range of pollutants including O_3. The proximity of agricultural areas to Tehran and other large urban centres across the country,

raise concerns over the impact that air pollutants such as O_3 may be having on crop production.

Africa

The increases in air pollution that have occurred around the urban industrial centres of Cairo and Alexandria in Egypt are particularly problematical since these are in the same location as the primary agrarian region, which is limited to the Nile river basin as the primary source of irrigation water. Studies of the effects of air pollution on vegetation have been carried out in the last 20 years in the greater Cairo area and around the main roads within the Nile delta region.

Figure 1 Three month AOT40 simulations calculated using the MATCH model for three different periods for the year 2000 (cf. Emberson et al (in press)).



Hourly mean O_3 concentrations were also recorded of greater than 100 ppb. Visible injuries included necrosis, red spots and chlorosis with 60 % and 54% of clover and Egyptian Mallow leaves injured respectively (cf. Emberson et al 2001).

Hassan *et al*. (1995) assessed the impact of O_3 on the growth and yield of local varieties of radish (*Raphanus sativus* L. cv. Balady) and turnip (*Brassica rapa* L. cv. Sultani) at sub-urban and rural sites in Alexandria using EDU to protect control plants from O_3 effects. At the site mean 6 hr O_3 concentrations over the experimental period were 55 ppb in the

suburban site and 67 ppb at the rural site. O_3 impacts included the formation of chlorotic spots on the upper leaf surface and reductions in plant biomass. These effects were recorded for radish at both sites and for turnip only at the rural site. The study proved that levels of ambient O_3 in Egypt are high enough to have significant impacts on the growth and yield of local varieties of vegetable crops, even at a time of year when O_3 levels are relatively low.

Latin America

We are not aware of any studies investigating the damage of surface ozone to crops in Latin America however; there is evidence of damage to forest trees. In Mexico, the most serious air pollution occurs in the vicinity of Mexico City associated with high O_3. O_3 damage to *Pinus hartwegii*, *P. leiophylla* and *P. montezumae* var. *lindleyi* was observed in a southern forested area of Mexico City (Krupa and Bauer, 1976). Injury included chlorotic mottling and premature senescence. O_3 damage was most prevalent at the end of spring and the beginning of the summer season. *P. hartwegii* has been identified as one of the most sensitive species to O_3 exposures with damage being more severe than that observed to *P. montezumae* at the end of a two year period (Hernández and Bauer, 1984).

The sudden decline in sacred fir trees (*Abies religiosa*) observed in the "Desierto de los Diones" national park located to the south west of the Mexico valley, is considered to be caused by O_3 pollution due to the occurrence of O_3 visible injury symptoms (Bauer et al. 1985). In addition, significant ring width reduction of scared fir trees has been observed since the beginning of the 1970's. Branches protected from O_3 by charcoal filtered air supply chambers or anti-transpirants did not show symptoms of O_3 injury (Alavarado *et al*., 1993).

Australasia

Most studies of the effects of ozone on Australian native species have been short-term studies using high concentrations to assess acute visible injury (O'Connor *et al.* 1975). In a longer-term study, eight *Eucalyptus* species were exposed to diurnally varied concentration of 26 or 172 nl/l ozone (as a seven hour mean) for 7 hr/day, 5 days in every 14 days for 18 weeks (Monk and Murray, 1995). The results showed considerable differences in the responses of the different species. Some species showed no visible injury or growth changes, but others showed up to 90% leaf injury and 30% growth reductions. The findings were generally consistent with those found for North American woody perennials and northern European herbaceous species (Monk and Murray, 1995). Exposure of pasture grasses in Australia to 90 nl/l ozone for 4 hr /day for 5 days per week for five weeks demonstrated growth reductions of 14-21% (Horsman *et al.* 1980).

The evidence from Australia would suggest that those planning *Eucalyptus* plantations in regions of the world with high or increasing levels of tropospheric ozone, such as rapidly industrialising nations of Asia and South America, need to consider ozone tolerance when selecting plantation trees.

4 Regional risk assessment studies

Based upon dose-response data from US and European studies and a limited amount of Australian data including field pollution gradient studies using ozone-sensitive varieties of plants, current ambient concentrations of ozone in the regions around cities are likely to

reduce growth and yield of sensitive crops, and damage some areas of biodiversity importance.

However, regional studies have been conducted in East Asia and China. These suggest yield losses of staple crops may be currently in the range of 1 to 10% and predict future losses of 4 to 30% in 2020 (Aunan et al. 2000; Wang & Mauzerall, 2004); local yield reductions may be much greater than these regional-scale estimates. In addition, Chameides et al. (1994) estimated that as much as 20 to 75% of the world's cereals may be grown in regions above 50 to 70 ppb resulting in substantial agricultural losses, highlighting the continental scale metro-agro-plexes of East Asia as potential high risk regions. However, all these studies have used dose-response relationships from either Europe or North America since these have been all that are available. Fundamental uncertainties lie in the necessary assumption that the species and cultivars grown in south Asia will respond to O_3 similarly to those grown in Europe and North America. Factors that may alter plant response to O_3 include those associated with climate, agricultural management practices, crop phenology, genetically-based tolerance or resistance and pollutant exposure patterns. Some of these uncertainties could be reduced on application of new risk assessment methods that use flux- rather than concentration based methods to assess risk (Ashmore et al. 2004). However, there is still an urgent need to establish dose-response relationships for locally grown species and cultivars under local environmental conditions and management practice regimes.

The APCEN network identified some of the most important crops for future studies based on existing information describing ozone injury and damage and the importance of the crop as an agricultural commodity (Table 1). Here we focus on Asia since this is the region where impacts to agriculture are perhaps most severe outside of Europe and North America. Also provided is information describing the most important growth period and the common irrigation regime of the crop since these are likely to affect the crop sensitivity to ozone.

Table 1. The most important crops in Asia and their typical growing seasons.

Crop	**Growing season**
Rice	Year round/seasonal
Wheat	Winter
Maize	Summer/rainy
Potato	Winter
Bens	Year round
Cabbage	Winter
Cotton	Winter/summer
Sugar cane	Winter/summer
Pea	Winter
Soybean	Summer/rainy
Peanut	Rainy

Effect variables of significance for the types of crops presented in Table 1 include yield, yield components, harvest index and optionally nutritional quality (including aspects such as protein/nitrogen as well as the content of sugars and certain acids) are important.

Perennial crops species of large importance, where air pollution effects may occur, are also identified as : peach, apple, mango, guava and tea.

5 Future impacts

Studies conducted by e.g. Long et al (2006) using FACE systems to assess ozone damage to elevated ozone concentrations under fully open-air field conditions have been reported in the published literature (e.g. Morgan et al, 2006) and commented on in relation to the global context (Ashmore et al. 2006). Key conclusions from these studies found that increasing ozone concentrations by 23% from average daytime ambient concentrations of 56 ppb to a treatment 69 ppb over two growing seasons decreased soybean seed yield by 20%. Effects were also seen on total above-ground net primary production (decreased by 17%). Fewer live leaves and decreased photosynthesis in late grain filling appear to drive the ozone-induced losses in production and yield. Additionally, these studies found that a 23% elevation of O_3 in the open-air decreased system evapotranspiration by 16%. With much of the region in this type of vegetation this decrease in latent heat transfer could in itself increase regional daytime surface temperature, increase drainage water and with decreased transfer of water to the atmosphere increase drought incidence to the east of the corn-belt.

Importantly, these results validate previous chamber studies suggesting that soybean yields will decrease under increasing ozone exposure. In fact, these results suggested that when treated under open-air conditions yield losses might be even greater than the large losses already reported in the literature for earlier chamber studies.

Unpublished data collected from this FACE study suggests that there was no effect of ozone on grain quality in terms of protein, oil, flavanoid and mineral nutrient contents (Bordingon, Engseth & Long, unpublished). In addition, an assessment of damage to a number of different cultivars exposed during this FACE experiment investigated whether there was any relationship between damage and the date of release of the cultivars (which varied from 1950 to current day). There was no increase in the resistance of later released cultivars suggesting that breeders are not "inadvertently" selecting for ozone tolerance in the US. The findings suggest that adaptation of crop cultivars to rising ozone may be more complex and difficult than thought previously.

Studies at the soybean FACE also found that the levels of enhanced crop production attributable to the direct fertilization effect of elevated CO_2 were approximately 50 % lower than previously estimated from enclosed OTC system studies (Long et al., 2006). These results cast serious doubt on projections that rising [CO_2] will fully offset agricultural productivity losses due to climate change stresses likely from increased temperature and drought stress and increase the importance of reliably predicting future O_3 effects on agricultural productivity as this will act as an additional stress to agricultural systems. It is also worth noting that the O_3 elevated FACE study found that elevated ozone impacts were greater in the second year following a severe hailstorm, suggesting that losses caused by ozone might be exacerbated by extreme climatic events that are likely to become more frequent under climate change conditions.

A new study involving collaboration between Chinese and Japanese scientists (Kobayashi et al. pers comm.) will use a FACE system in China located at Jiangdu, in Jiangsu province to assess the impact of elevated ozone concentrations under fully open-air field conditions

on rice and wheat. This study is the first of its kind in a developing country. The study will investigate 4 key varieties of rice and wheat that are commonly grown across the Chinese region and will aim to develop dose-response relationships for these species that can be used to perform a regional risk assessment of the impacts of ozone across the whole of China. The study will also investigate O_3 impact on plant physiological and biochemical processes in order to develop crop growth models. This study should yield important new evidence within the next two years on how local varieties of Asian wheat and rice are affected by ozone, comparison of these sensitivities with European and North American data will provide insights as to the transferability of existing dose-response data to other regions of the world. The study will also complement other studies being conducted in the region (e.g. studies on rice and peanut in Vietnam in South East Asia (Van, 2005).

6 Conclusions

- There is substantial evidence of the effects of ozone damage on both crop productivity and forest health across many parts of the globe outside of European and North America. In particular, Asia would appear to be at particular risk from loss in agricultural productivity at current ozone levels and studies suggest the situation could significantly worsen in the future.
- There is evidence of variability both within and between species and species cultivars. Further studies are urgently required to further understand which species and strains may be resistant to ozone pollution so that appropriate crop substitution can be employed within high-risk elevated ozone regions. To date, evidence from the US would NOT indicate that farmers are "inadvertently" selecting for resistant strains.
- There is also an urgent need to perform regional risk assessments based on dose-response relationships suitable for local species and varieties. These risk assessments may also benefit from the use of flux-based rather than concentration based methods since these may provide a better opportunity to disentangle the influence of environmental stresses on crop sensitivity to ozone.
- Additional experimental research should be conducted in the future. In particular the use of FACE systems should help to provide reliable crop response data free from many experimental artefacts. These, rather expensive, experimental systems should be supported with a range of experimental techniques including enclosed chamber, filtration, transect and bio-monitoring studies. Where possible these studies should also investigate the influence of climate change stresses on ozone sensitivity.
- There is an urgent need to conduct co-ordinated and standardised ozone monitoring across the globe in peri-urban and rural areas to complement existing monitoring in developing country regions that tends to be performed in urban areas. This will capture the higher ozone concentrations that occur downwind of urban areas and also provide information that can inform crop based risk assessment studies.
- Finally, investigation of the potential indirect effects caused by ozone impacts on vegetation should be investigated as a priority especially where these have direct links with climate change. For example, the effects of ozone reducing transpiration may well alter local and regional climatic systems.

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AQ/3 ARMO project, Phil Gervat, ARMO UK Co-ordinator

Submission of report for consideration:

The Air Rives Manche-Ozone (ARMO) Project Final Report, March 2007. An Anglo/French study to understand ozone pollution in the English Channel region

AQ/4 Nicole Augustin, Department of Mathematical Science, University of Bath

In Baden-Wuerttemberg (Federal state in the Southwest of Germany) extensive monitoring is carried out on Forest health by the Forest Research Institute Baden-Wuerttemberg. Besides other pollutants the levels of ground Ozone have been monitored at three sites since 2002. On page 51 of Meining et al (2006), the observed trend in days, where Ozone levels were above a threshold of 120microg/m^2 was exceeded is shown.

The number of days where the threshold was exceeded is substantial, with a maximum of 27 days in August 2003. Evidence of direct damage of trees in the form of damaged cells of beech tree leaves has been observed at several monitoring sites, see also Meining et al (2006), p. 51.

Meining, S. and von Wilpert, K. 2006. Waldzustandsbericht 2006 der Forstlichen Versuchs- und Forschungsanstalt Baden-Wuerttemberg.
ISSN: 1862-863X
Available for download: http://www.fva-bw.de

AQ/5 **Professor Jonathan Ayres, University of Aberdeen**

It is timely for the Royal Society to address the issue of ground level ozone, particularly given the likelihood of increasing ozone exposure in many parts of the world over the next decade or two.

My comments here are personal as a researcher on the health effects of air pollution of some 20 years standing. It should however also be noted that I have been a member of the Department of Health's Committee on Medical Effects of Air Pollutants (COMEAP) since its inception in 1991 and Chair for the last 4 years. I was also a member of EPAQS (DEFRA's Expert Panel on Air Quality Standards) from 1996 until it was disbanded earlier this year to become a sub-committee of COMEAP. I have also acted as an adviser on the health effects of air pollutants to the WHO over the last decade.

In this context it is important also to recognise that COMEAP is currently producing a large report on the health effects of ozone which is going to be produced in sections. The first section available for comment will appear on the COMEAP website to coincide with our report on quantification of mortality due to air pollution. This section, however, is just one of a number of chapters and at this stage it is not likely that the full ozone report will be available until, at the earliest, the end of 2007 and probably into 2008. I think it is fair to state this will be regarded as a state of the art document on the health effects of ozone. However, this report does not look into the future and there are issues about predicting future exposures and the possible development of tolerance in populations so exposed which I'm sure will be important to discuss.

It is quite clear that background ozone is increasing in the UK although, seemingly paradoxically, episodes or exceedances are reducing. This suggests that the background ozone is not due to UK generated pollutants but to long range, northern hemispheric transport. However this is an issue which I suspect your group will consider in much greater detail.

From a health point of view ozone is a highly oxidant gas which is capable of causing inflammation of mucosal membranes, in particular the respiratory tract, being the main portal of entry. The mechanisms of ozone damage are beginning to be understood and it is quite key that anti-oxidants produced by the body are critical in assessing how an individual will respond to an oxidant load such as ozone. Chief amongst these are urate in the nose and glutathione in the lower respiratory tract as well as vitamin C. Factors governing each of these antioxidants and their production are again becoming better understood although this is not my particular area of expertise. Nevertheless there is no doubt that there are susceptibility factors for adverse affects to ozone, not only in the context of oxidant activity, but also in the context of certain gene polymorphisms which do seem to confer an increased risk of developing problems.

Ozone on a day-to-day basis during episodes is associated with increased health effects but these are perhaps more recognised in non-UK settings where ozone levels are higher. There is some association with ozone exposure being related to cardiac deaths but not with hospital admissions. Professor Anderson will be very well placed to help with this. This suggests to me that there is a potential for ozone to precipitate cardiac arrhythmias, resulting in out of hospital death. Equally there is variable evidence to suggest that it does affect people with asthma on a day to day basis.

Whether long term exposure to ozone is also associated with lung damage is also open to some debate, although the evidence is reasonably strong that there is an effect. It appears that ozone does have an effect on small airways and may well potentiate the development of airway narrowing with longer exposure and equally may effect lung growth in children although this effect is at least partly reversible if children move to areas of lower exposure. However, as with all of these pollutant studies it is often very difficult to dissect out which single component of the air pollutant mix is important. During US summer haze events particles and ozone are both elevated although it is much easier to dissect ozone effects from anything that might be related to a molecule such as nitrogen dioxide.

There is however that evidence that repeated exposures to ozone, at least in the laboratory setting, results in amelioration of effects day on day. This suggests tolerance of some degree. Of course, continuing repeated exposure over days, weeks, months or years may then lead on to the chronic inflammatory effects which may lead to changes in lung function which are essentially irreversible and so it may be difficult to determine which of these effects in which individuals will hold sway. Some individuals may develop tolerance and not develop any long term effects while others may do the reverse and at present there is no evidence to help us there.

At present in the UK ozone is much less important than particles as a cause of ill health but the assumption at the moment is that there is no threshold so the health effects continue to be exerted to a greater or lesser extent right down to very low levels. To many, including me, this seems intuitively difficult to deal with as every individual will have their own personal threshold. Rolling out from combinations of personal thresholds to a population effect where no threshold is seen as difficult and it was this particular question that lead COMEAP to start to explore the whole issue of the health effects of ozone, leading on to a report which is much larger than originally envisaged but all the better for it. The issue of threshold is critical. If there is a threshold, then the health impacts are going to be substantially less than if there is no threshold. This was well characterised in the first COMEAP quantification report in 1998 where with an assumed threshold 50 there was a dramatic difference in health impacts in terms of mortality and respiratory hospital admissions. Equally, if ozone levels rise then the threshold effect will become less of an issue, depending on where such a threshold might be at least at a population level.

Consequently, there are many questions which are left unanswered with respect to ozone. The most interesting observation is that background levels are rising and thus the UK population is now being exposed to increasing levels of ozone although, of course, these levels are lower in cities. This suggests that a long term natural experiment is occurring and, in my opinion, it is important to consider looking at this in the context of developing a longitudinal European study prospectively over time which would then enable differences in health effects in relation to exposure to changing levels of ozone to be assessed. Such a study would, of course, need to be considered in the context of other pollutant exposures both outdoor and indoor as a justification on the basis of ozone alone would not result in funding I suspect! Overall it is likely that if the UK is exposed to increasing levels of ozone over the next few decades then this will have an effect on cardio-respiratory health. How big that effect will be is impossible to say at this stage because of the increasing extra levels of uncertainty surrounding predictions of exposure levels to add to the already significant levels of uncertainty that obtain when trying to assess health effects of air pollutants in the present day. Acquisition of more data would unequivocally help in these projections.

AQ/6 Belgian Interregional Environment Agency - Flemish Environment Agency (IRCEL - VMM)
Frans Fierens, Gerwin Dumont

The Belgian Interregional Environment Agency (IRCEL) in which the three Belgian regions (Flanders, Brussels and Wallonia) cooporate, runs an interregional air quality database where data from the regional telemetric networks are gathered, validated an processed into reports and studies. At the IRCEL we are also using the belEUROS air quality model to calculate the impact of local and European measures on ozone
formation.
Possible contributions to the Royal Society project from the IRCEL could be:

1) The evidence that background ozone concentrations in Belgium are increasing based on the analysis of the historic measured groundlevel ozone concentrations (starting from 1979) in the Belgian regional telemetric ozone stations.

2) The evidence that background ozone concentrations in Belgium could further increase in the future (2010-2020) due to local (and European) reduction measures (even without taking into account global warming).
The main reason for the ozone (annual mean) increase in Belgium the next decade is probably the less destruction of ozone due to less titration by nitric oxide (NO).

Some of these findings can be found in the Report to the EU-Commission concerning exceedances of the Ozone Target Values in Belgium for the year 2004 that can be downloaded at:
http://www.irceline.be/~celinair/documents/documents/Report_excTV_2004.pdf

AQ/7 Michelle Bell, Yale University

Submission of 3 articles relating to the health impacts of ground-level ozone for consideration:

M Bell et al 2004 Ozone and short-term mortality in 95 US urban communities, 1987-2000, *JAMA*, November 17, 2004 Vol 292, No 19, p2372

Bell et al 2005 A meta-analysis of time-series studies of ozone and mortality with comparison to the national morbidity, mortality, and air pollution study, *Epidemiology*, Vol 16, No 4, July 2005, p436

Bell et al 2006 The exposure-response curve for ozone and risk of mortality and the adequacy of current ozone regulations, *Environmental Health Perspectives*, Vol 114, No 4 April 2006, p532

AQ/8 Campaign for Clean Air in London

Submission of campaign letters on air pollution

AQ/9 Centre for Ecology and Hydrology, Bangor

Dr Gina Mills, Dr Harry Harmens and Felicity Hayes
Programme Centre, ICP Vegetation of the LRTAP Convention
Centre for Ecology and Hydrology, Bangor

Background:
The ICP Vegetation is an international research programme investigating the impacts of air pollutants on crops and (semi-)natural vegetation. The programme focuses on two air pollution problems: impacts of ozone pollution on vegetation and the atmospheric deposition of heavy metals to vegetation. In addition, the ICP Vegetation is taking into consideration impacts of pollutant mixtures (e.g. ozone and nitrogen), consequences for biodiversity and the modifying influence of climate change on the impacts of air pollutants on vegetation.

The results of studies conducted by the ICP Vegetation are reported to the Working Group on Effects (WGE) of the Convention on Long-Range Transboundary Air Pollution (LRTAP), where they are not only used in assessments of the past and current state (Working Group on Effects, 2004), but also for predictions of the future state of the environment. Thirty four countries of Europe plus the USA participate in the programme. The annual report of the ICP Vegetation (e.g. Harmens et al, 2006) summarises the progress of the programme, including results of biomonitoring studies for ozone, heavy metals and nitrogen, developments in methods for modelling and mapping ozone flux and risk assessment, and ozone interactions with climate change and other pollutants such as nitrogen.

The Convention publishes official documents such as that provided in ANNEX 1 "Impacts of ozone on vegetation in Europe in a changing climate", ECE/EB.AIR/WG.1/2006/8, which are available on the LRTAP Convention web-page (http://www.unece.org/env/wge) in English, Russian and French.

To ensure the Royal Society Commissioned Review becomes widely available within the Convention, we would like to offer to submit the Executive Summary as a formal ICP Vegetation document to the LRTAP Convention in 2008, in the form provided in Annex 1. The source of the document would be clearly indicated throughout.

The ICP Vegetation contributions to the Royal Society Commissioned Review fall into the following categories:

1. Mapping risk of damage to crops and (semi-)natural vegetation in Europe;
2. Consideration of ozone impacts in a changing climate;
3. ICP Vegetation collation of evidence of ozone damage to vegetation in Europe (1990-2006);
4. The impacts of nitrogen on the responses of vegetation to ozone.

At the beginning of each summarised contribution, there is reference to the Royal Society review questions addressed by each of these categories.

1 Mapping risk of damage to crops and (semi-)natural vegetation in Europe

Contribution to:

1b Ground-level ozone changes over the next century - What are the key models and data resources for the assessment of future ground level ozone concentrations and precursor emissions and impacts at global, European and UK scales?

and

4f. Policy drivers and gaps, science gaps and possible solutions. What are the major international, European, and national policy drivers of changes in ground-level ozone?

The ICP Vegetation has been responsible for developing methods of modelling ozone flux to vegetation (See Chapter 3 of the Mapping Manual "Mapping critical levels for vegetation" available at http://www.icpmapping.org/), with flux-based critical levels available for wheat, potato and provisionally for beech and birch. Most recently, generic flux models have been developed for application to assessments of risk within integrated assessment models. These take into account the effects of temperature, light, humidity and phenology on maximum stomatal conductance; due to current technical limitations in mapping procedures, soil moisture deficit is not included (it is assumed to be non-limiting). Maps of ozone flux to generic crop and tree species for 2004 (Figure 1) and 2010 indicate that the highest risk of ozone damage is in central and southern Europe (EMEP Status Report 1/2006, http://www.emep.int/publ/emep2006_publications.html). However, the gradient between northern and southern Europe was much lower for the ozone flux than the concentration-based index (Simpson et al, 2007). Lower fluxes and therefore lower risk is predicted for Mediterranean evergreen tree species.

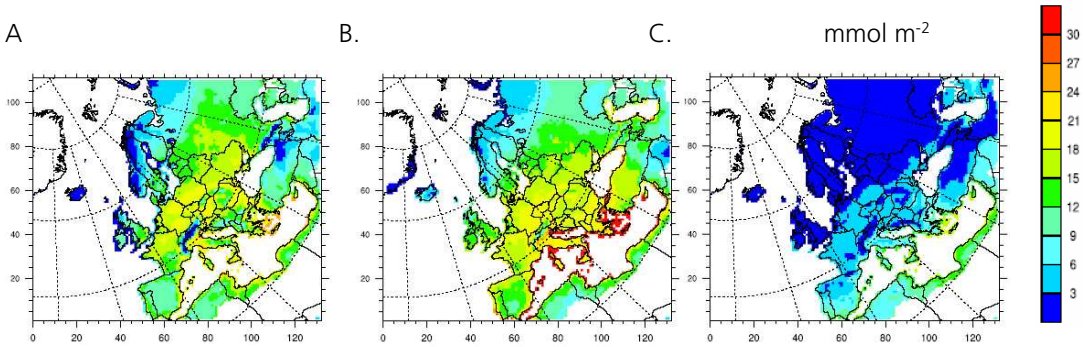

Figure 1: Ozone flux to (a) crops, (b) deciduous trees and (c) Mediterranean evergreen trees in 2004, determined using generic flux models. From EMEP Status Report 1/2006, http://www.emep.int/publ/emep2006_publications.html.

Concentration-based response functions were derived for 23 crops (Mills et al, 2007a) and used to assess the economic impact of ozone on crop yield in 47 countries covering the entire European UNECE domain (Holland et al, 2006). It was predicted that economic losses in the range 4.4 – 9.3 billion Euro could be attributed to ozone for 2000, and that with full implementation of the Gothenburg Protocol and EU National Emissions Ceilings ("baseline scenario") the range could fall to 3.0 – 6.3 billion Euro in 2020. However, this study did not take into account the predicted rise in

background ozone over this period due to hemispherical transport of precursors. Since ozone flux-effect models are only available for wheat and potato, it has not been possible to conduct such a comprehensive Europe-wide assessment based on fluxes.

Predicting the risk of damage to (semi-)natural vegetation is more complex. At the ICP Vegetation Programme Centre, the results from over 60 papers were examined, and dose-response functions were derived for 83 species of (semi-)natural vegetation and included in a database named OZOVEG (ozone impacts on vegetation). As an example, the response functions for species present in semi-managed lowland pasture are presented in Figure 2. Meta-analysis of the ozone sensitivity data showed a wide inter-specific range in response to ozone from strong inhibition to stimulation of growth (Hayes et al, 2007). A regression-based model was developed for predicting changes in biomass of individual species exposed to ozone (RS_p), based on their Ellenberg Indicator values (Jones et al, 2007). The model was applied to plant communities to develop two further predictive tools. The first tool, percentage change in biomass (ORI%) was tested on data from a field-based ozone exposure experiment conducted in Switzerland and predicted a 27% decrease in biomass over 5 years compared with an observed decrease of 23%. The second tool, an index of community sensitivity to ozone (CORI), was applied to 48 grassland communities and suggests that community sensitivity to ozone is primarily species-driven.

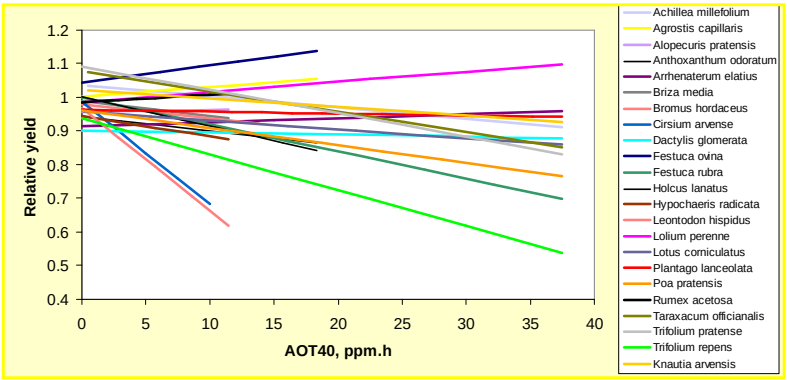

Figure 2: Ozone dose–response functions for species commonly present in semi-managed lowland pasture. Source G Mills, pers comm..

For wider application to mapping risk within Europe, a simpler method based on the proportion of ozone-sensitive species was developed (Mills et al, 2007b). Using data within OZOVEG, 54 EUNIS (European Nature Information System) level 4 communities with six or more ozone-sensitive species (%OS) and c. 20% or more species tested for ozone sensitivity, were identified as potentially ozone-sensitive. The largest number of these communities (23) was associated with Grasslands, with Heathland, scrub and tundra, and Mires, bogs and fens having the next highest representation at 11 and 8 level 4 communities each respectively. Within the grasslands classification, E4 (Alpine and sub-alpine grasslands), E5 (Woodland fringes and clearings) and E1 (Dry grasslands) were the most sensitive with 68, 52 and 49%OS respectively. Methods for mapping the location of these communities in Europe have been developed by harmonising the Stockholm Environment Institute landcover map with the European Environment Agency Corine landcover map.

As a first step towards flux-effect relationships for (semi-)natural vegetation, a climate-dependent simulation of canopy growth and transpiration was integrated with the DO_3SE (Deposition of Ozone and Stomatal Exchange) model of ozone flux (Mills et al, 2006). The focus of the analysis was the interaction of three factors: nutrient status, soil moisture and management regime. A key conclusion was that these factors need to be considered in combination rather than in isolation. Actively managed mesic and wet grasslands are likely to have a high ozone flux and experience a greater impact of ozone. Nutrient-poor dry grasslands may have lower flux and be less sensitive *in situ* than the examination of the responses of individual species suggests.

2 Consideration of ozone impacts in a changing climate

Contribution to:

3c *Impacts of ozone: How are the (human and environmental) impacts of ground-level ozone likely to be affected by future changes in climate and increasing carbon dioxide levels?*

Harmens et al (2005) reviewed the literature on the effects of climate change on ozone impacts on vegetation, and summarised the findings in a WGE document (LRTAP Convention, 2006, reproduced here as Annex 1).

It was concluded that the overall impact of warming on the canopy flux of O_3 is difficult to predict and will depend on the location of the vegetation, severity and timing (e.g. summer or winter) of warming, its impacts on soil water potential and phenology of the vegetation. Each plant species has its own optimum temperature for stomatal conductance (g_s) and the impact of warming on g_s will depend on which part of the temperature response function corresponds with the current ambient temperature. Indirect effects of warming via changes in vapour pressure deficit and soil water potential and enhanced plant development will also alter stomatal flux of O_3 into leaves. In general, elevated CO_2 ameliorates O_3-induced stress and the combined effects of O_3 and CO_2-enrichment on plant growth and physiology has often been near neutral as elevated CO_2 and O_3 affect vegetation in opposite ways. Effects of changes in precipitation patterns are likely to be mediated directly through (a) effects of VPD on g_s with increasing VPD causing a decrease in flux and (b) changes in SMD, with increasing SMD resulting in decreased stomatal flux and vice versa. The little data that is available on interactive impacts of combined global climate change factors has indicated that the interactions are complex and that generalisations might be difficult.

A case study for five EMEP 50 x 50 grid squares representing five geographical regions of Europe investigated the potential impact of global change on ozone flux and AOT40 by the end of the 21st century (Harmens et al, 2007). The study used the following climate change criteria, in various combinations: current ambient ozone + 5ppb, + 3°C rise in temperature, 10% increase in precipitation in central and northern Europe, and a 35% reduction in maximum stomatal conductance due to the effect of rising CO_2. Application of the various climate change scenarios resulted in the ozone flux to winter wheat decreasing, even with an increase in tropospheric background O_3 concentration (Figure 3. AOT40 increased in all regions reflecting the increase in many areas of background concentrations above 40 ppb.

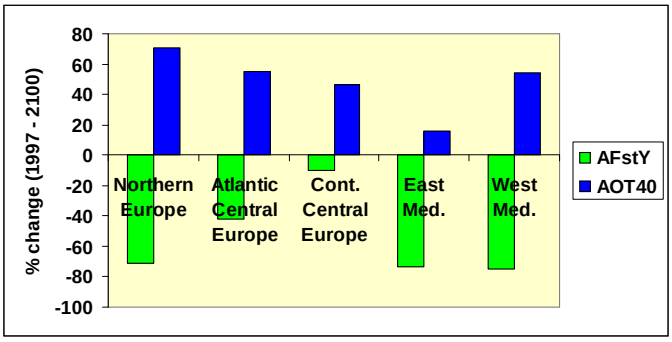

Figure 3: Impact of a climate change scenario for the end of this century on ozone flux (AFstY) to wheat and the three-month AOT40 for EMEP grid squares representing five geographical regions of Europe (re-drawn from Harmens et al., 2007).

3 ICP Vegetation collation of evidence of ozone damage to vegetation in Europe (1990-2006)

Contribution to:

3a Impacts of ozone- what are the impacts of ground-level ozone on vegetation (natural, semi natural, and agricultural)?

The Programme Centre of the ICP Vegetation is currently collating and analysing available information in Europe on incidences of damage to vegetation caused by ambient ozone pollution during the period 1990 - 2006. We are currently approaching the end phase of a year-long data collection, and will conduct the data analysis, mapping, and writing phases in the next few months. The results will be presented in a glossy ca. 50 page full colour "Evidence Report" which will be printed in late 2007 and presented at the LRTAP Convention Executive Body meeting in December 2007 where the review of the Gothenburg Protocol will be considered. We could contribute individual figures as requested to the Royal Society Review. and a pre-print document will be available from October, 2007. Types of evidence being collated include:

- Results of ICP Vegetation biomonitoring experiments with clover species and *Centaurea jacea*. Experiments conducted to a standard protocol using cloned plant material supplied by the Programme Centre, 15-30 sites per year. Injury and biomass differences recorded for ozone-sensitive and ozone-resistant biotypes.
- Published and nationally-funded surveys and biomonitoring activities. The database currently contains over 500 records of ozone injury in ambient air on a wide range of crop, forb and shrub species from 17 countries. Each record includes the country, grid reference, year of observation, species and species type. Examples of the type of results are provided in Figure 4.
- Published experimental comparisons of growth and yield responses in ambient ozone and filtered air. The database currently comprises over 100 data points from eight countries to date, from a wide range of crop, grass and forb species, although data collation is still ongoing.

So far, trends in impact reflect the spatial and temporal variation in ozone concentration, with no marked decline or increase evident. For example, ozone injury was greatest in 2003 when ozone concentrations were relatively high across most of Europe and lowest in the cooler, wetter year of 2002 when ozone concentrations were relatively low. Ozone impacts will be mapped against ozone fluxes and concentrations for selected years to determine the strength of the evidence for ozone impacts in areas with high ozone concentrations or predicted fluxes.

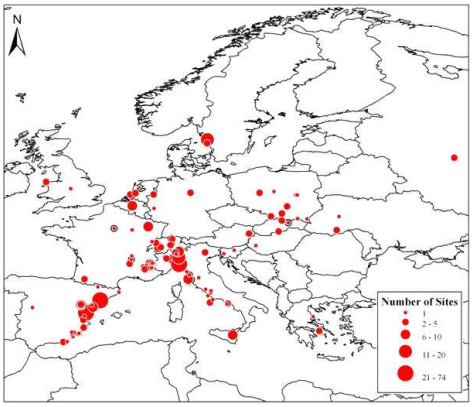

Figure 4: Locations where visible ozone injury has been reported in commercial agricultural and horticultural fields and natural or semi-natural grasslands (1990 – 2006). (Note data collation is ongoing).

4 The impacts of nitrogen on the responses of vegetation to ozone

Contribution to:

3c Impacts of ozone: How are the (human and environmental) impacts of ground-level ozone likely to be affected by future changes in climate and increasing carbon dioxide levels?

The Royal Society review could also consider how ozone effects will be influenced by other pollutants in a changing climate. This is especially relevant for upland areas in many European countries where ozone-sensitive vegetation is and will continue to be exposed to both ozone and nitrogen deposition. The literature on the impacts of nitrogen pollution on the responses of vegetation to ozone has been reviewed at the ICP vegetation Programme Centre (Mills et al, 2006). Nitrogen can affect the *sensitivity* of species to ozone by altering uptake *via* physiological and morphological parameters and by altering the capacity for detoxification and repair. There are numerous ways in which N may alter *exposure* to ozone. These include geographical exposure, life strategy, growth form, and the timing of key events through the year such as seedling emergence, the main period of vegetative growth, flowering and seed set. Changes in resource partitioning and in tissue chemistry due to both N and ozone may have indirect effects on wider components of the ecosystem such as mycorrhizal and symbiotic relationships, soil microbial activity and rates of litter decomposition and N mineralisation. Other effects may be mediated by external factors such as herbivory, disease, management and limitation of other resources such as soil phosphorus, while competitive interactions may affect individual plant exposure and community sensitivity as a whole.

The evidence above suggests that ozone and nitrogen can have both synergistic and antagonistic effects on species and ecosystem processes, and that they may interact in unpredictable ways to affect plant communities. Three EUNIS communities have been

identified which are potentially at risk of exposure to both elevated nitrogen and ozone. These are: E1 - Dry grasslands; E4 - Alpine and sub-alpine grasslands; and F4 - Temperate shrub heathland. Initial studies have indicated that geographical co-occurrence of both pollutants is greatest in southern Germany and parts of northern Italy. Co-exposure is most likely to affect E1 and E4 grasslands.

Results from ICP Vegetation biomonitoring experiments with *Centaurea jacea* suggest that nitrogen-limited plants are unable to allocate sufficient resources to ozone detoxification and cell repair. Elevated levels of N were generally found to reduce ozone injury but could also increase injury in very young fresh shoot material.

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Impacts of increasing background ozone pollution on (semi-)natural vegetation

Dr Gina Mills, Felicity Hayes and Jennifer Williamson (Centre for Ecology and Hydrology, Bangor) and Professor C Freeman and Dr T Jones (University of Wales, Bangor)

Introduction

We provide here a brief synthesis of recent results from ozone exposure experiments conducted using the CEH Bangor solardome facility (Figure 1) in which dome-shaped greenhouses are ventilated with finely controlled concentrations of ozone. The experiments were designed to investigate the impacts of increasing background ozone concentration on (semi-)natural vegetation. In 2004 and 2005, the study investigated the effect of increasing the background ozone concentration from 25 ppb to 50 ppb plus/minus added 50 ppb peaks, whilst in 2006, we investigated the effect of background ozone concentrations of 10, 35, 60 and 85 ppb with added 20 ppb peaks. These studies provide an insight into how grassland communities might respond to ozone profiles predicted for later this century (between 2030 and 2100). This is a new approach to ozone exposure experiments. In the past, researchers conducted experiments designed to investigate responses to increased peak ozone at constant background. Such experiments are less suited to interpreting the effects of the changing ozone profiles predicted for this century.

Figure 1: CEH Bangor computer-controlled ozone exposure facility.

Responses of grassland species to ozone

Over the last four years, we have exposed 47 species of grasslands to elevated ozone for 10-12 weeks at concentrations between 50 and 100 ppb. Nearly 50 % of these species have shown a response to ozone at concentrations that could be expected this century. The nature of the responses were varied (Figure 2), with 21% indicating reduced growth, 10% of the 33 tested

showing reduced re-growth the following spring, 21 % showing visible ozone injury (fine yellow or bronze spots) and 44.7% showing earlier and more pronounced senescence. Overall the number of responding species was evenly split between forbs, and grasses and sedges. The *Carex* species (sedges) were found to be particularly sensitive with five of the six species tested responding to ozone. The results from exposure of 33 of these species are included in Hayes et al, 2006.

Responses of simulated plant communities to rising background ozone

In the 2004/05 experiment, mesocosms were established that contained seven grass, forb and sedge species typically found in upland grasslands and representing the NVC U4 community, *Festuca ovina-Agrostis capillaris-Galium saxatile* grassland (Mills et al, 2006, Hayes (PhD thesis, submitted). Increasing the background from 25 ppb to 50 ppb (with/without peaks) resulted in a significant increase ($p<0.05$) in the amount of senescence on *Carex echinata, Festuca ovina and Potentilla erecta* at the end of the 2004 exposure and *Festuca ovina* at the end of the 2005 exposure. The same species showed increased senescence in response to 50 ppb peaks (at 25 ppb and 50 ppb background). Species such as *Agrostis capillaris* and *Anthoxanthum odoratum* also showed enhanced senescence although these effects were only significant at the $p<0.1$ level. At the end of the 2004 exposure, both increasing background *($p<0.05$)* and added peak ozone treatment ($p<0.05$) reduced the biomass of the low-growing forb, *Potentilla erecta,* with effects being carried over to the end of the following winter. By the end of the second exposure in 2005, there were there was a 15% reduction in the biomass of the dominant grass species, *Anthoxanthum odoratum* ($p<0.05$), with a corresponding increase in the presence of a competitor grass, *Agrostis capillaris*. There was no overall change in the total biomass of the communities in any treatment. In summary, this experiment has shown that increasing the background ozone concentration from 25 ppb to 50 ppb, caused enhanced senescence in most of the component species and caused a shift in the balance of grass species.

The 2006 experiment involved exposure of three-species mesocosms to simulated upland ozone climates representing pristine conditions (10 ppb background/four day peak of 30 ppb), current polluted (35 ppb/55ppb), current +25 ppb (60 ppb/80 ppb) and current +50 ppb (85 ppb/105 ppb). Although the ten week exposure period was insufficiently long to induce biomass changes, the proportion of senesced leaves increased from 18% in the current background treatment to 28% and 35% in the +25 and +50 ppb treatments respectively for the grass species, *Anthoxanthum odoratum* (Figure 3). Effects on the low-growing forb, *Viola riviniana* were less pronounced, but were significant in the +50 ppb treatment.

Exposure of cores from wetlands to increasing background ozone concentration

The effects of ozone on peatland ecosystems have received relatively little attention, despite their importance within the global carbon cycle. The few previous investigations used relatively high ozone concentrations (100 – 200 ppb) and showed that ozone can induce methane release from wetlands (Rinnan et al, 2003, Niemi et al, 2002). In 2004, cores from Welsh fen and bog peatlands were exposed in the solardomes to four ambient/elevated ozone concentration regimes representing current and predicted 2050 profiles. A dramatic reduction in the concentration of dissolved organic carbon (DOC) was recorded after exposure of the fen cores to elevated ozone (- 40 to -55%), with the low molecular weight fraction most affected (Jones et al, submitted). Additionally, a significant stimulation of methane emissions was recorded under the highest ozone concentration (+375%,

Figure 4). The bog cores were less susceptible, although exposure to the highest concentration of ozone resulted in a significant stimulation of porewater DOC concentrations and a reduction in molecular weight after 6 days, suggesting a short-term increase in decomposition processes within the soil. The data suggest higher ozone sensitivity of the below-ground responses of plants growing in the fen type peatland and that detrimental impacts on vegetation can have important consequences for carbon cycling within the soil. Studies are ongoing in our laboratory to understand the mechanisms behind these changes and to identify the threshold ozone concentrations for triggering these effects.

Implications for ecosystems and global climate change

The most common response to increasing background ozone concentration has been an earlier and greater senescence in a variety of species typical of central and northern European uplands. This effect has potentially serious implications for the long-term viability of ecosystems. By shortening the growing period, exposure to increasing background ozone will reduce the time period for carbon assimilation and will reduce carbon storage in the over-wintering organs. This effect will reduce the capacity of species both to re-grow the following year (as shown for some species) and to withstand other stresses such as drought and frost.

Our results also show that there are also implications for the global carbon cycle. Reduced carbon storage by vegetation in an increasingly ozone polluted climate will result in more CO_2 in the atmosphere with consequent feedback effects on the global climate. Similarly, a further increase in methane release from wetlands, the largest global source of methane, under an increasingly ozone polluted environment would have significant implications for future global warming.

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(Figures 3 pages)

AQ/9 part2 Additional Submission from the Centre for Ecology and Hydrology

Submission of report for consideration:

M Holland et al 2006: Development of a framework for probabilistic assessment of the economic losses caused by ozone damage to crops in Europe, CEH (NERC) CEH Project No. C02309NEW

AQ/10 CREAF (Centre de Recerca Ecologica I Aplicacions Forestals)

References submitted by Professor J Penuelas and Dr A Ribas for consideration:

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J Penuelas et all (1999) Dependende of ozone biomonitoring on meteorological conditions of different sites in Catalonia (NE Spain) *Environmental Monitoring and Assessment* 56: 221-224, 1999

A Ribas and J Penuelas (2000) Effects of ethylene diurea as a protective antiozonant beans (Phaseolus vulgaris cv lit) exposed to different tropospheric ozone doses in catalonia (NE Spain) *Water, Air and Soil Pollution* 117: 263-271, 2000

A Ribas and J Penuelas (2003) Biomonitoring of tropospheric ozone phytotoxicity in rural Catalonia, *Atmospheric Environment* 37 (2003) 63-71

A Ribas and J Penuelas (2004) Temporal patterns of surface ozone levels in different habitats of the North Western Mediterranean basin *Atmospheric Environment* 38 (2004) 985-992

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A Ribas et al (2005) Ozone exposure induces the activation of leaf senescence-related processes and morphological and growth changes in seedlings of Mediterranean tree species *Environmental Pollution* 134 (2005) 291-300

A Ribas and J Penuelas (2006) Surface ozone mixing ration increase with altitude in a transect in the Catalan Pyrenees *Atmospheric Environment* 40 (2006) 7308-7315

A Klumpp et al (2006) Ozone pollution and ozone biomonitoring in European cities. Part 1 Ozone concentrations and cumulative exposure indices at urban and suburban sites *Atmospheric Environment* 40 (2006) 7963-7974

A Klumpp et al (2006) Ozone pollution and ozone biomonitoring in European cities Part II. Ozone-induced plant injury and its relationship with descriptors of ozone pollution Atmospheric *Environment* 40 (2006) 7437-7448

AQ/11 Dr P Cristofanelli and P Bonasoni, Institute for Atmospheric Sciences and Climate – National Research Council (ISAC-CNR)

P. Bonasoni, P. Cristofanelli
"Ottavio Vittori" CNR Mt. Cimone Research station
Institute for Atmospheric Sciences and Climate – National Research Council (ISAC-CNR) (Italy)

2: ''Climate and ground-level ozone: How do weather regimes and regional climate variability influence ground-level ozone?''

Background
Mt. Cimone (44°12'N, 10°42'E, 2165 m a.s.l.) is the highest peak of northern Apennines in Italy. As large industrialized and urban areas are far away from the measurement site, the monitoring of atmospheric compounds and meteorological parameters conducted at the ISAC-CNR "O. Vittori" research station (www.isac.cnr.it/cimone), is considered representative for the background conditions of the South European free troposphere (Bonasoni et al., 2000; Fischer et al., 2003). Only during the warmer months can an influence of boundary layer air masses be detected due to convective processes, mountain breeze regime as well as mixing height oscillation (Fischer et al., 2003; Van Dingenen, 2005). Being located to the South of the Alps, (overlooking the highly polluted Po Valley), Mt. Cimone represents a suitable site to investigate atmospheric processes related with regional and long-range transport of polluted air masses, mineral dust transport from Sahara desert and North Africa as well as stratospheric intrusion events. Moreover, as other similar high mountain areas, Mt. Cimone is an ideal site where atmospheric background conditions and environmental changes can be studied by continuous monitoring activities. For these reasons, several scientific programs were established at Mt. Cimone to study climatology and the chemical-physical characteristics of trace gases and aerosol properties.

Ozone measurements at Mt. Cimone.
Since 1996 , the "Ottavio Vittori" research station (hosted by Italian Air Force Meteorological Service) is part of the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO) for tropospheric O_3 measurements which have been carried out continuously by using a UV-photometric analyser (Dasibi 1108). The accuracy and the quality of measurements (time sampling: 1-min, accuracy and precision: ± 2 ppb) are guaranteed within the GAW requirements. During the period 1996 – 2004 a yearly mean value of 54 ±11 ppbv (1 σ) has been recorded. These measurements showed a seasonal ozone cycle with high values during spring - summer (mean values 59 ppbv and 63 ppbv, respectively) and lower values during winter (mean value: 45 ppbv). This continuous monitoring activity, permitted to evaluate the impact of stratospheric intrusion events as well as mineral dust transports on the background ozone levels here recorded. In addition, regional and long-range transports of polluted air masses (also due to forest/bush fires) can strongly influence the ozone concentrations, as occurred in August 2003 when a very intense heatwave affected the central Europe and the North of Italy.

Influence of heat-wave phenomena on surface ozone at Mt. Cimone: Summer 2003 (Ref. Cristofanelli et al., 2007)

With the purpose to evaluate the possible effects of heatwave phenomena on Mt. Cimone background ozone concentrations, the average summer ozone concentrations have been analysed. In particular, unusually high O_3 concentrations were recorded during August 2003, when an intense heatwave affected North, Central and South Europe. During this heatwave, the highest O_3 concentrations were recorded in connection with air masses coming from continental Europe and the Po basin boundary layer as shown by three-dimensional air mass back-trajectory and mixing height analyses. However, high O_3 concentrations were also recorded in air masses coming from the middle troposphere (above 3000 m a.s.l.), thus suggesting the presence of ozone-rich atmospheric layers over Europe. This could be due to the large extension of the mixing layer which favoured the transport of high concentrations of O_3 and its precursors to altitudes that would usually be in the free troposphere. Other than from traffic and industrial activities, a contribution to the high O_3 concentrations recorded at Mt. Cimone during the August heatwave could derive from fires in the North of Italy, as suggested by a well-documented episode and supported by in-situ CO_2 measurements used as non-conventional tracer for fire emissions.

Influence of stratospheric intrusion events on surface ozone at Mt. Cimone (Ref. Bonasoni et al., 2001; Cristofanelli et al., 2006).

A six years study on stratospheric intrusion (SI) events has been conducted at Mt. Cimone, considering the period 1998-2003 in the framework of VOTALP I and II and STACCATO EU projects. Surface ozone and beryllium-7 concentration measurements, as well as relative humidity values recorded at this measurement site were analysed. Moreover, three-dimensional backward trajectories calculated by the FLEXTRA model and potential vorticity values along these trajectories were used. In order to identify SI and evaluate their contribution to the tropospheric ozone at Mt. Cimone, a statistical methodology was developed. This methodology consists of different selection criteria, based on observed and modeled stratospheric tracers (beryllium-7, relative humidity, potential vorticity) as well as on tropopause height values recorded by radio soundings. On average, SI effects affected Mt. Cimone for about 36 days/year. The obtained 6-year SI climatology showed a clear seasonal cycle with a winter maximum and a spring-summer minimum. The seasonal cycle was also characterised by an interannual variation. In particular, during winter (autumn), SI frequency could be related to the intensity of the positive (negative) NAO phase. In order to separate direct SI from indirect SI, a restrictive selection criterion was set. Direct SI affected Mt. Cimone for about 6 days/year, with frequency peaks in winter and early summer. At Mt. Cimone SI contribution to background ozone concentrations was largest in winter. On average, an ozone increase of 8% (3%) with respect to the monthly running mean was found during direct (indirect) SI. Finally, the typical variations of stratospheric tracers during SI events were analysed. The analysis of in-situ atmospheric pressure values suggested that direct SI were connected with intense fronts affecting the region, while indirect SI were possibly connected with subsiding structures related with anticyclonic areas.

Influence of Saharan dust transport on surface ozone at Mt. Cimone (Ref. Bonasoni et al., 2004).

The continuous monitoring of aerosol size distribution, allowing the identification of the impact of mineral dust transports on free tropospheric ozone concentrations at Mt. Cimone. In particular, in the framework of EU-MINATROC project, 12 dust events were registered during the period June - December 2000. Three-dimensional backward trajectories were used to determine the air mass

origin, while TOMS Aerosol Index data for the Mt. Cimone area were used to confirm the presence of absorbing aerosol over the measurement site.

A trajectory statistical analysis allowed identifying the main source areas of ozone and aerosols. The analysis of these back trajectories showed that the North African desert regions were the most important source areas for coarse aerosol and low ozone concentrations at Mt. Cimone. During dust events, the Mt. Cimone mean volume concentration for coarse particles was 6.18 m^3/cm^3 compared to 0.63 m^3/cm^3 in dust-free conditions, while the mean ozone concentrations were 4% to 21% lower than the monthly mean background values. Our observations show that surface ozone concentrations were lower than the background values in air masses coming from North Africa, and when these air masses were also rich in coarse particles, the lowest ozone values were registered. Although there is a large variability in the ozone data during "dust events", this analysis confirms that ozone concentrations during dust events are systematically reduced. In fact, air masses coming from the North Africa region during dust events are characterised by high values of aerosol mean volumes (greater than about 6.15 m^3/cm^3) and low de-trended ozone concentrations (50 ± 8 ppbv; mean ± 1 σ) compared to mean values of 0.92 m^3/cm^3 and 54 ± 6 ppbv for African air masses outside "Saharan dust events" and 0.63 m^3/cm^3 and 55 ± 6 ppbv for all other data. This analysis provided independent confirmation of the hypothesis put forward in other studies that significant heterogeneous ozone destruction can occur on the surfaces of the dust aerosols and that desert aerosols can cause a decrease in photolysis rate throughout the troposphere, having a negative impact on ozone concentration in the lower troposphere.

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AQ/12 EANET (Acid Deposition Monitoring Centre in East Asia), RATSUKA Motoshi, Mitsubisi UFJ Research & Consulting (MURC).

Annual trend of ozone concentrations at remote sites in EANET Network Center for EANET

EANET was established as regional cooperative initiative to promote efforts for environmental sustainability and protection of human health. The preparatory phase of monitoring activities was from April 1998 to December 2000 while the regular phase was implemented since January 2001. Ten countries, namely, China, Indonesia, Japan, Malaysia, Mongolia, Philippines, Republic of Korea, Russia, Thailand and Viet Nam participated in EANET during the preparatory phase. Subsequently, Cambodia, Lao P.D.R. and Myanmar joined EANET in 2001, 2002 and 2005, respectively. Currently EANET consists of 13 participating countries and there are 47 wet deposition monitoring sites and 35 dry deposition (air concentration) monitoring sites located in 12 countries, with each country managing its own sites. Each monitoring site is classified as either Urban, Rural or Remote according to the regulations described in the Monitoring Guidelines of EANET. All sites are operated using common quality assurance/quality control (QA/QC) standards promoted by the Acid Deposition and Oxidant Research Center (ADORC) which is designated as the Network Center for EANET.

Besides monitoring of acid deposition and its impacts on the ecosystem, EANET is also focusing on the monitoring of ozone due to its importance as a harmful air pollutant. The monitoring for ozone is currently conducted at 17 sites located in 4 countries by using Ultraviolet Photometric method (UVP). Figure 1 shows the annual trend of ozone concentrations recorded at 11 remote sites over a period of 5 years, from 2001-2005. The locations of the sites are shown in Figure 2 below. The numbers in the legend represent the altitude of each site.

Most of the remote sites show an upward trend in ozone concentrations suggesting that ground level ozone is a growing air pollution problem in this region. There is concern, particularly in Japan, that the concentration will continue to increase into the future. A comparison of average concentrations between 1985 to 1990 and 1994 to 2002 at monitoring sites in Japan indicate that there has been an increase of about 3.5 ppb over the whole of Japan. The increases in average concentrations for the 10 years from 1992 to 2002 in Happo and Ryouri were 9.0 ppb and 7.3 ppb, representing annual increases of 2.0 and 2.1 percent respectively[1]. Quantitative assessments of the data are urgently needed to determine the contributing factors, including the role of long-range transport of air pollutants, and to develop effective countermeasures.

Ozone measurements are also made at sites located in Southeast Asia belonging to the EANET network. The regional data are still being collected and will be assessed under a related activity of EANET. Thus they are not yet available in the EANET database.

1 Acid deposition and oxidant Research Center, 2006. Tropospheric Ozone: A Growing Threat

[1] Acid Deposition and Oxidant Research Center, 2006. Tropospheric Ozone: A Growing Threat.

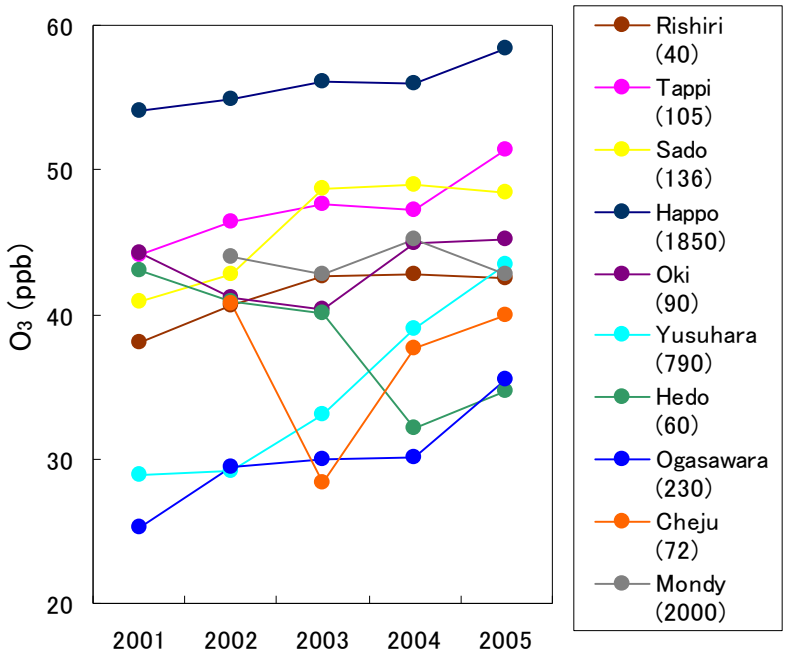

Figure 1 Annual trend of O_3 concentrations observed over 5 years (2001-2005) in 10 EANET remote sites. The numbers in the legend represent the altitude (m) of each site.

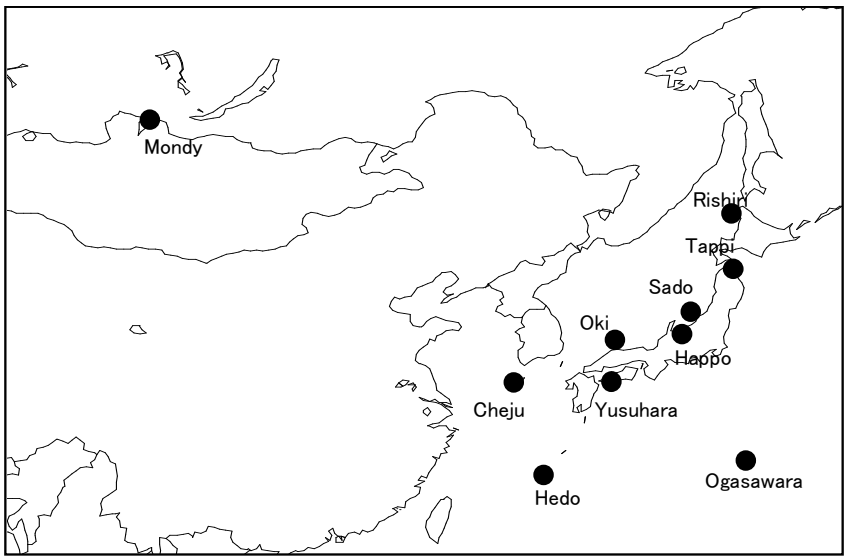

Figure 2 Location of the 10 remote sites in EANET where ground level ozone are monitored.

AQ/13 European Commission, DG Environment

Letter submission

AQ/14 Dr F Fehsenfeld, National Oceanic and Atmospheric Administration (NOAA), USA

Systematic Springtime Trend in O_3 in Remote Regions of the Northern Hemisphere

The following information is submitted in response to your request for "evidence". This information pertains to the following questions from a global, regional (Europe) and national (UK) perspective:

1 Ground-level ozone changes over the next century:

a. What are the key models and data resources for the assessment of future ground level ozone concentrations and precursor emissions and impacts at global, European and UK scales?

b. Where are the current gaps and uncertainties in assessing ground-levels ozone changes over this period?

Our group has been able to discern from available date that there has been a systematic increase in the background ozone that is being imported to the West Coast of the United States. The electronic versions of two manuscripts that detail our observation are enclosed. The excerpts from the abstracts of the two papers (enclosed) that describe these results are attached below.

Using a 15-year record of O_3 from Lassen Volcanic National Park, a rural elevated site in northern California, data from two aircraft campaigns conducted in 1984 and 2002 over the eastern North Pacific, and observations spanning 18 years from five U.S. west coast, marine boundary layer sites, we show that O_3 in air arriving from the Eastern Pacific in spring has increased by approximately 10 ppbv, i.e. 30% from the mid 1980s to the present.
Citation: *Jaffe, D., H. Price, D. Parrish, A. Goldstein, and J. Harris, Increasing background ozone during spring on the west coast of North America, Geophys. Res. Lett., 30(12), 1613, doi:10.1029/2003GL017024, 2003.*

Measurements during the Intercontinental Transport and Chemical Transformation 2002 (ITCT 2K2) field study characterized the springtime, eastern Pacific ozone distribution at two ground sites, from the National Oceanic and Atmospheric Administration WP-3D aircraft, and from a light aircraft operated by the University of Washington. D. Jaffe and colleagues compared the 2002 ozone distribution with measurements made in the region over the two previous decades and show that average ozone levels over the eastern mid-latitude Pacific have systematically increased by 10 ppbv in the last two decades. Here we provide substantial evidence that a marked change in the photochemical environment in the springtime troposphere of the North Pacific is responsible for this increased O_3. This change is evidenced in the eastern North Pacific ITCT 2K2 study region by (1) larger increases in the minimum observed ozone levels compared to more modest increases in the maximum levels, (2) increased peroxyacetyl nitrate (PAN) levels that parallel trends in NO_X emissions, and (3) decreased efficiency of photochemical O_3 destruction, i.e., less negative O_3 photochemical tendency (or net rate of O_3 photochemical production; $P(O_3)$). This changed photochemical environment is hypothesized to be due to anthropogenic emissions from Asia, which are believed to have substantially increased over the two decades preceding the study. We propose that their influence has changed the springtime Pacific

tropospheric photochemistry from predominately ozone destroying to more nearly ozone producing. However, chemical transport model calculations indicate the possible influence of a confounding factor; unusual transport of tropical air to the western North Pacific during one early field study may have played a role in this apparent change in the photochemistry.

Reference: Parrish, D. D., et al. (2004), Changes in the photochemical environment of the temperate North Pacific troposphere in response to increased Asian emissions, J. Geophys. Res., 109, D23S18, doi:10.1029/2004JD004978.

We believe that this may indicate a systematic upward tend in background ozone concentrations during the springtime in the more remote regions of the Northern Hemisphere. We feel that a full understanding of the trends at all seasons and the projections into the future is critically important.

Reliable Emission Inventories for Ozone Precursors Are Needed:
The following information is submitted in response to your request for "evidence". This information pertains to the following questions from a global, regional (Europe) and national (UK) perspective:

1 Ground-level ozone changes over the next century:
1.1 What will be the important sources and sinks of ozone and ozone precursors and how are these likely to change and why?
1.2 What are the key models and data resources for the assessment of future ground level ozone concentrations and precursor emissions and impacts at global, European and UK scales?
1.3 Where are the current gaps and uncertainties in assessing ground-level ozone changes over this period?

Our group has found that there has are large uncertainties in emission inventories for the emission of ozone precursors for sources in the United States. The electronic versions of two manuscripts that detail some our findings are enclosed. The excerpts from the abstract that describe some of these results are attached below.

US Environmental Protection Agency estimates of on-road vehicle emissions are compared with ambient measurements and a fuel-based emission inventory. Several significant weaknesses and strengths are identified. (1) The emission estimates have varied considerably over the past 15 years and are not clearly converging to progressively more accurate and certain results. (2) The most recent emissions estimate accurately captures the rapid decrease in carbon monoxide (CO) and volatile organic compounds (VOC) emissions, but overestimates the magnitude of CO emissions by about a factor of two. (3) The oxides of nitrogen (NO_X) emission estimates for the mid to late 1990s are reasonably accurate, but NO_X emissions have increased through that decade rather than decreased as indicated in emission estimates. (4) The most recent emissions estimate more accurately apportions NO_X emissions between diesel and gasoline fuelled vehicles than did earlier reports. (5) The ratio of two specific VOC species that has been characterized by ambient measurements suggests that the inventory speciation of the VOCs is inaccurate by factors of 3–4. These tests lead to the derivation of ''inferred emissions'' for CO and NO_X from the US on-road vehicle fleet that are consistent with all information used in these tests. Finally, it is shown that the international picture of US emissions has significant inaccuracies and

inconsistencies.

Reference: David D. Parrish, Critical evaluation of US on-road vehicle emission inventories, Atmospheric Environment 40 (2006) 2288–2300.

We find that in the United States emission inventories for ozone precursors, VOCs and NO_X, from many important sources are not adequate and in certain cases (included some cases alluded to in the enclosed manuscript) fail to capture the proper trends. We have published many similar examples of inventory shortcomings for other ozone precursors. Similar inventories for ozone precursors for other regions of the world are probably no better and in some case substantially worse. These results suggest that in order to understand processes and produce meaningful model simulations in the future more reliable emission inventories must be developed and maintained.

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D Parrish et al (2004) Changes in the photochemical environment of the temperate North Pacific troposphere in response to increased Asian emissions *Journal of Geophysical Research*, Vol 109 D23S18

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D Parrish (2006) Critical evaluation of US on-road vehicle emission inventories *Atmospheric Environment* 40 (2006) 2288-2300

AQ/15 **Dr. Marco Ferretti, PhD, TerraData environmetrics, Dipartimento di Scienze, Ambientali 'G. Sarfatti' Università degli Studi di Siena**

Submission of the following references for consideration:

Ferretti et al 2007 Ozone and forests in South-Western Europe – what have we learned? *Environmental Pollution* 145 (2007) 652-655

Ferretti 2007 Ozone and forests in South-Western Europe. *Environmental Pollution* 145 (2007) 617-619

Ferretti et al 2007 Ozone exposure, defoliation of beech (Fagus sylvatica L.) and visible foliar symptoms on native plants in selected plots of South-Western Europe *Environmental Pollution* 145 (2007) 644-651

Gerosa et al (2007) Estimates of ozone AOT40 from passive sampling in forest sites in South-Western Europe *Environmental Pollution* 145 (2007) 629-635

Ferretti et al 2007 Measuring, modelling and testing ozone exposure, flux and effects on vegetation in southern European conditions – What does not work? A review from Italy *Environmental Pollution* 146 (2007) 648-658

AQ/16 Professor Jürg Fuhrer, Air Pollution/Climate Group, Agroscope Reckenholz-Taenikon ART, Switzerland

Submission of the following references for consideration:

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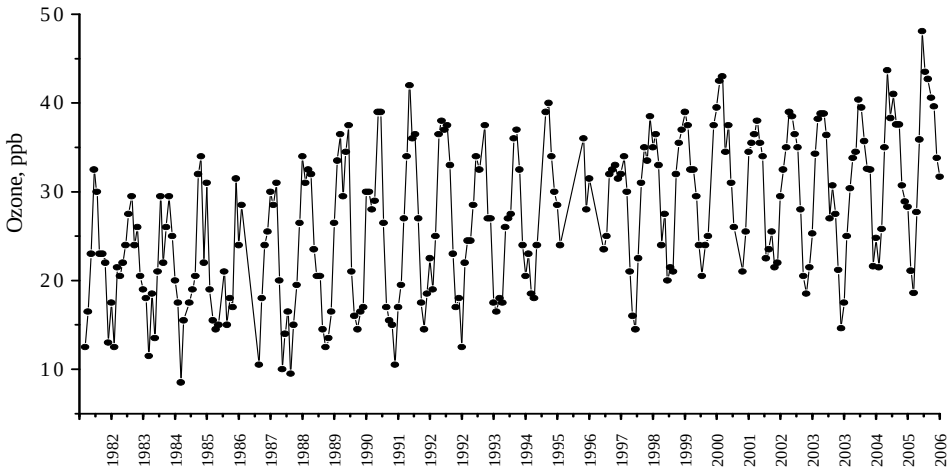
AQ/17 Dr Rasa Girgzdiene, Institute of Physics, Lithuania

Information about ground-level ozone changes in the Lithuanian background station.

Surface ozone observations at preila station, lithuania
The coastal station Preila (55^{0}20′ N and 21^{0}00′ E, 5 m a.s.l.) is located in the western part of Lithuania on the peninsula of the Curonian Spit. The climate is typically marine. There are no great sources of anthropogenic pollution of the atmosphere, soil or water close to the observation site. One of the nearest industrial cities, Klaipeda, is at a distance of about 40 km to the north and the other, Kaliningrad, is 90 km to the south from the site. The regular ozone concentration measurements were started in the summer 1980 with an electrochemical analyser (Girgzdiene, 1991), which in 1992 was replaced with the commercial monitor 10003 RS based on UV-absorption. The instruments were calibrated against the reference standard UV photometer SRP11 at the Air Pollution Laboratory at the Institute of Applied Environmental Research, Stockholm University, Sweden, since 2002 year against SRP17 at Czech Hydrometeorological Institute. The obvious



increasing trend of ozone at Preila was stablished (Fig. 1).
Fig. 1. Variation of the monthly ozone at Preila station during 1982-2006 years.

Substantial reduction of SO_2 and NO_2 emissions was achieved during the last decade in Central Europe. This reduction was also observed in Lithuania as well in other Eastern European countries after the economic depression in 1989-1991 (Girgzdiene *et.al*., 2002). It is understandable that the reduction of emissions should have influence on the concentration level of pollutants in the atmosphere, especially on the pick concentrations. In Lithuania high ozone concentration are observed generally not often. The highest ozone hourly of 114 ppb was observed in July of 1990. However, it is observed tendencies of moving high concentration from summer to spring months (Fig. 2).

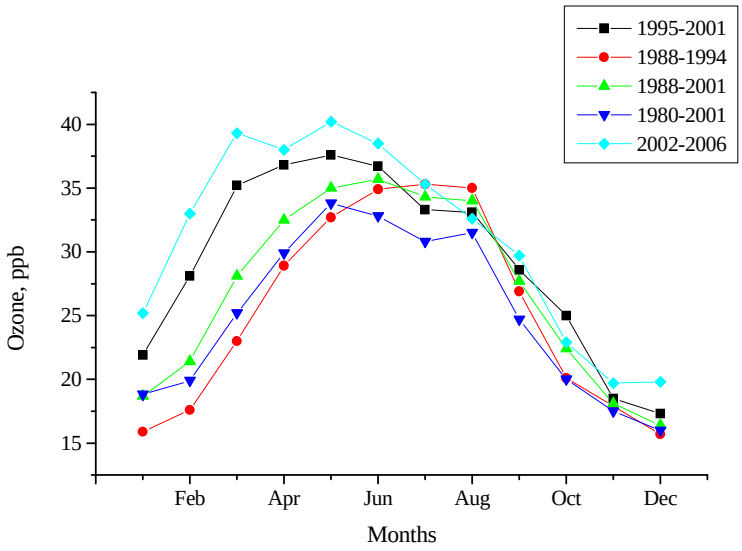


Fig. 2. The seasonal ozone courses in the Preila station during different periods.

The data analysis (Girgzdiene and Girgzdys, 2003) showed that average ozone seasonal courses over the 1980-2001 period were distinguished by a broad spring peak and by a second peak in August (Fig. 2). However, the seasonal course over a shorter 1988-2001 period had a broader common spring-summer peak with a slight increase in August. The amplitude of the average ozone seasonal cycle in Preila over this period was 19.3 ppb, or about 73% of the mean concentration. The seasonal ozone cycle showed interannual variability both in the magnitude of the amplitude and in the timing of the annual maximum and minimum. By estimating the average ozone seasonal course for a longer period, it is possible to notice the tendencies of its variations more evidently. From the data presented in Figure 2, could be discerned the differences in the shape of seasonal courses during 1988-1994,1995-2001and 2002-2006 periods. The first two periods were selected due to the well-defined increase of ozone annual level since 1995 (Fig. 3). The obvious increase of the ozone level during January – May and a decrease of the late summer peak are observed.

The previous investigations of the influence of the air masses origin on the ozone concentration level showed a relationship between these subjects. On this basis, the analysis of the recurrences of the air masses back-trajectories from different sectors during 1988-2001 was extended. The air masses were grouped according to their origin only into two large clusters, i.e., ''polluted' and ''unpolluted'' sectors (Fig. 3). The analysis highlighted that if the air masses from the broad ''unpolluted'' (295° – 360° –110°) sector were prevailing on average during the 1988-1994 period, so from the ''polluted'' one (110° – 180° –295°) dominated during 1995-2001. This could cause the increase of the average ozone level in the Preila station and the decrease of the summer maximum. The regions, identified in this work as ''polluted'', are located in the West and South Europe. It can be observed that the decrease of the peak ozone values in a most of these regions during the summer time and the increase of the concentrations during a cold period were established.

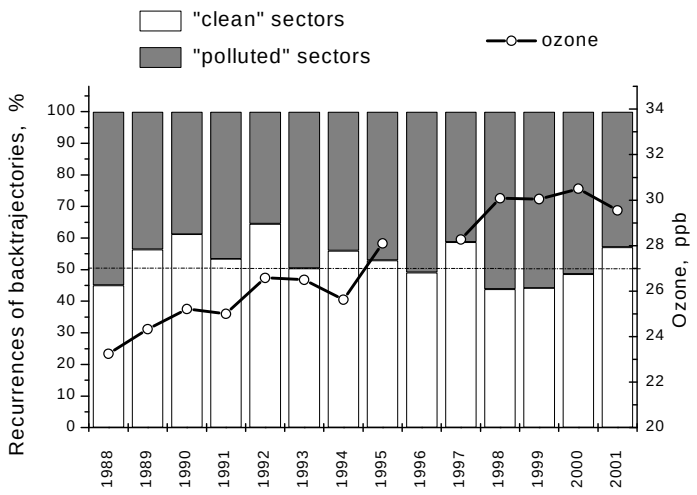


Fig. 3. The relation between the recurrences of the air masses back-trajectories from the "unpolluted" and "polluted" sectors and the ozone level.

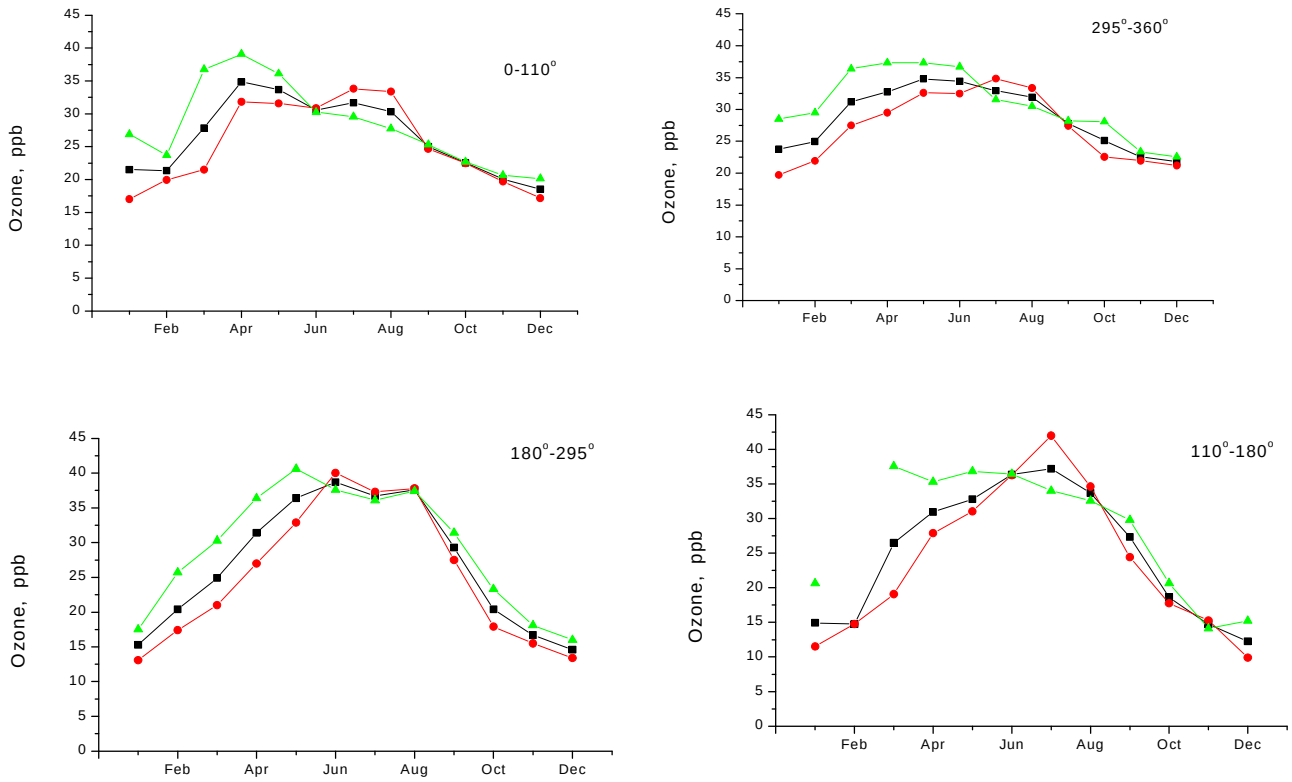


Fig. 4. Ozone seasonal cycles in four different sectors during the separate periods: 1988-2001 (squares), 1988-1994 (circles) and 1995-2001 (triangles).

The ozone mean, 25th and 95th percentiles in both "polluted" and "unpolluted" sectors for each months over 1988-2002 were investigated (Figs. 4 and 5) to establish the seasonal ozone changes (Girgzdiene *et.al*, 2007).

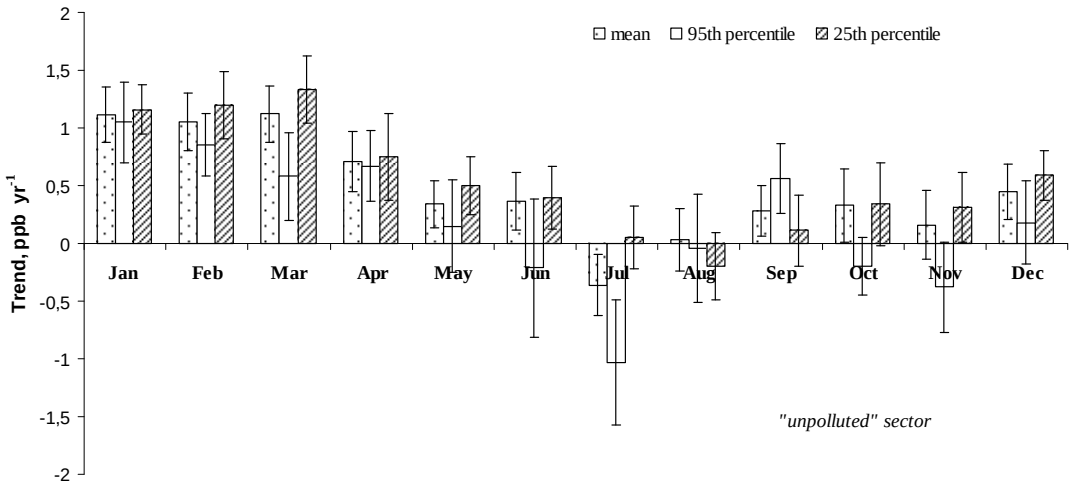


Fig. 4. Trends in monthly mean, 95th and 25th percentiles in "unpolluted" sector in Preila during 1988-2002.

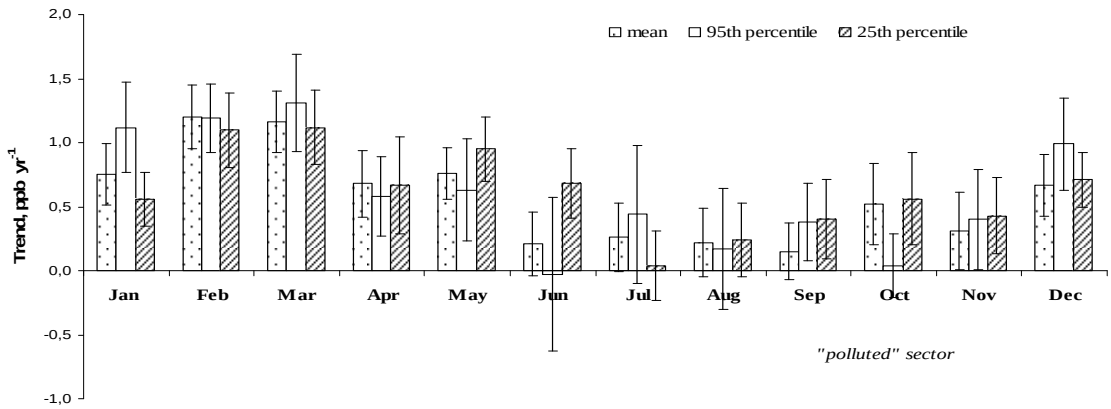


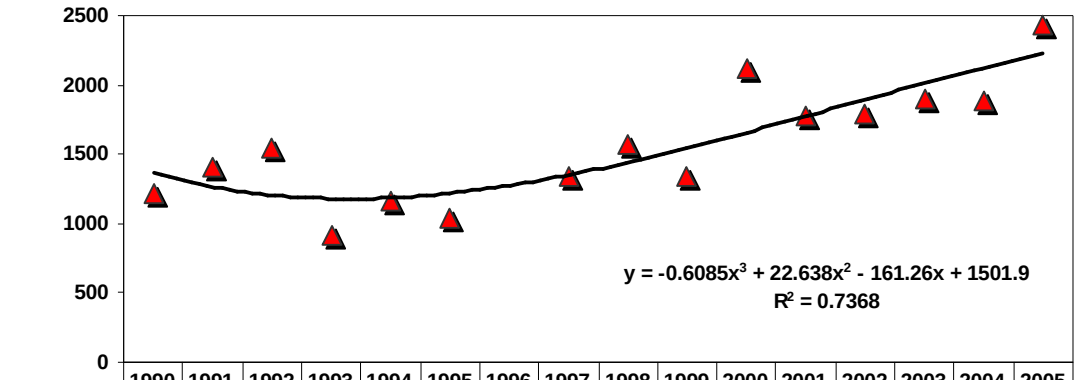
Fig. 5. Trends in monthly mean, 95th and 25th percentiles in "polluted" sector in Preila during 1988-2002

The ozone and its precursor levels in separate regions surrounding Lithuania are various. Likewise, the recurrence of the air masses, which reach the Preila station territory from these regions, is very unequal. It is natural, that the pollution level of these air masses should be different too. For this reason, their influence on the formation of the ozone level in the station environment, in respective of meteorological conditions, is unequal. The accomplished comprehensive analysis of the changes in seasonal ozone courses in the air masses from four different sectors showed that the average summer maximum levels had not increased in all sectors during the 1995-2001 period as compared with the 1988-1994 one (Fig. 4).

The particular analysis (Girgzdiene, 2007) of ozone changes in the "unpolluted" sector during separate months revealed that significant upward trends in the ozone mean were in January – April, in 95th percentile - during February and in 25th percentile - during January–March. It was established that change tendencies of highest and lowest percentiles were opposite during June, July, October, November, i.e., the difference between ozone highest and lowest concentration decreased.
The investigations of the ozone variations in the "polluted" sector during separate months showed that only upward tendencies were observed. A statistically significant trend was found during the first half of the year in the "unpolluted" sector. The significant trends of ozone 25th, 95th percentile and mean concentration were established in December-May, in December-March and in January-May, respectively. Insignificant trends were observed during other months. Contrary to concentration change tendencies in the "unpolluted" sector, no obvious downward tendencies in the "polluted" sector were established during summer months. This partly supports the proposition that positive influence of the decrease of ozone precursors emission in Europe is minified by emission increase in Lithuania.

The trend analysis showed that the most important changes in the ozone concentration occurred mainly during January-April. Over this period, the lowest monthly ozone level, which is characterized as 25th percentile, increased by about 11% in the "unpolluted" sector and by about 9.5% in the "polluted" sector.

The analysis of the environment condition changes and the possible influence on the human health by means of ozone related indicators in Lithuania was performed (Girgzdiene and Girgzdys, 2006). The comparison of the results obtained with different indicators - daily 8-hour mean and SOMO35 – shows that in spite of low frequency of the highest ozone concentrations the common ozone level is increasing. Consequently, the harmful effects of ozone on human health can be more significant than it was considered earlier.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
▲ SOMO35	1210	1410	1547	911	1155	1043		1337	1567	1342	2120	1778	1794	1897	1890	2436

Fig. 6. The variations of SOMO35 at the Preila station

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AQ/18 Health Protection Agency

Dr RL Maynard, Head, Air Pollution & Noise Group

Submission of two documents:

1 An extract from a WHO report: Health Aspects of Air Pollution – answers to follow up questions from CAFÉ (Clean Air For Europe). This provides a useful summary of current knowledge of the effects on health of exposure to ozone.

2 An extract from the as yet unpublished report on climate change: Effects on Health in the UK. This will be published shortly by the Department of Health and the Health Protection Agency (Editor note: this report has now been published).

AQ/19 Alun Hodgson, Consultant

In response to question 3f
"Are there any other significant impacts of ground-level ozone that should be considered within the scope of the project?"

I suggest that you consider the effect on our heritage. Ozone has a deleterious effect on many of the colorants used in printing. Over the last few years we have seen more imagery printed through digital techniques such as inkjet printing. Many of these are rather more sensitive to ozone than previous recording media such as traditional silver halide photography. This trend, together with the increases in ground level ozone put collections more at risk as we look to the future.
Although I am an independent consultant I write this from several perspectives:

1. I am chair of BSI committee CPW/42. This is the group that looks after standards for photography from the UK perspective. I am currently taking part in an ISO standards group to derive a standard for ozone susceptibility of colour hard copy.
2. As a committee member of the Print, Paper and Packaging group at the Institute of Physics I am involved in a conference on print permanence. Ozone sensitivity is a "hot topic" in this community. I wrote a paper on this topic for the 2003 conference which I could supply on request.
3. As a committee member of the Imaging Science Group of the Royal Photographic society I see the issue coming up in our conferences too.

I have been session chair and co-chair for Image Permanence sessions at 2 conferences in the US in 2006 where this has been a big issue. Once again I can send reference to the papers.

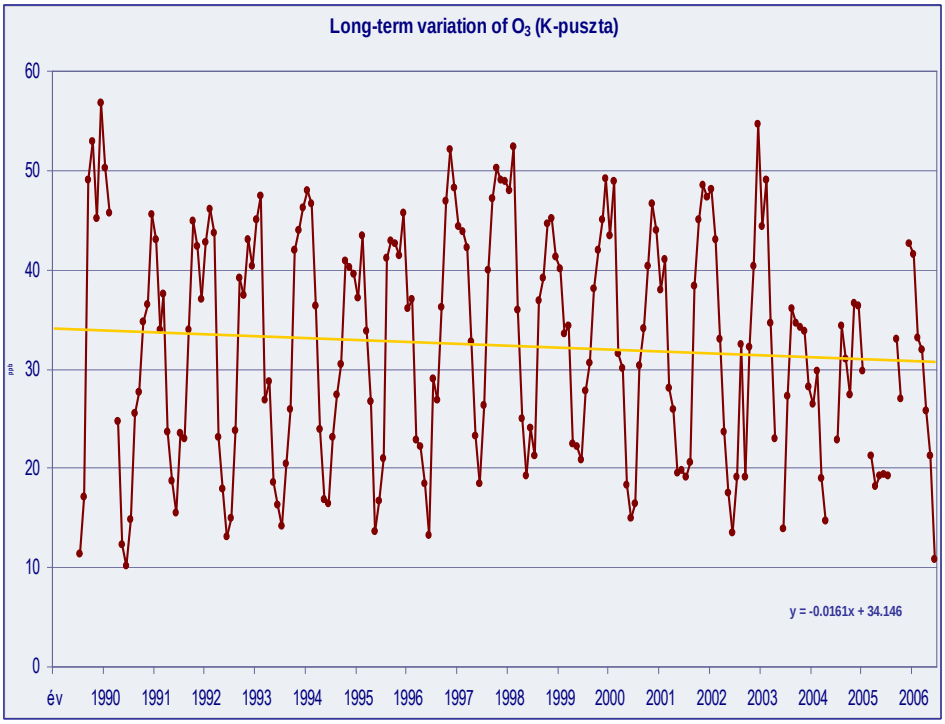
AQ/20 Hungarian Meteorological Service, Zita Ferenczi

Our department is responsible for the measuring of tropospheric ozone concentration under background condition. Below you can find a sort description about K-puszta, where our background monitoring station is located, and some information about the tropospheric ozone measurements at this station.

Tropospheric ozone measurements at K-puszta station

K-puszta is the regional background air pollution monitoring station of the Hungarian Meteorological Service, located in the central part of Hungary, on the Hungarian Great Plain (46°58'N, 19°33'E, 125 m asl). The station is located in a big forest clearing. In the wider region agricultural fields, forest patches, pastures and open bushy regions can be found. The prevailing wind blows from the west-to-north sector. The nearest town (Kecskemét, approx. 110 thousands of inhabitants) is about 15 km to the southwest.

The monitoring site at K-puszta participates in the international monitoring programs of UN ECE EMEP and WMO GAW. Data measured at K-puszta are submitted to the EMEP and WMO centers.

The ozone trend lightly increased until 2003, after 2004 the direction of this trend has changed. In the last 3 years the trend was decreasing. This change might be caused by the changeable weather situations. In the last 3 years the weather conditions at K-puszta were more cloudy than in the previous years.

The figure presents the long-term variation of tropospheric ozone at K-puszta.