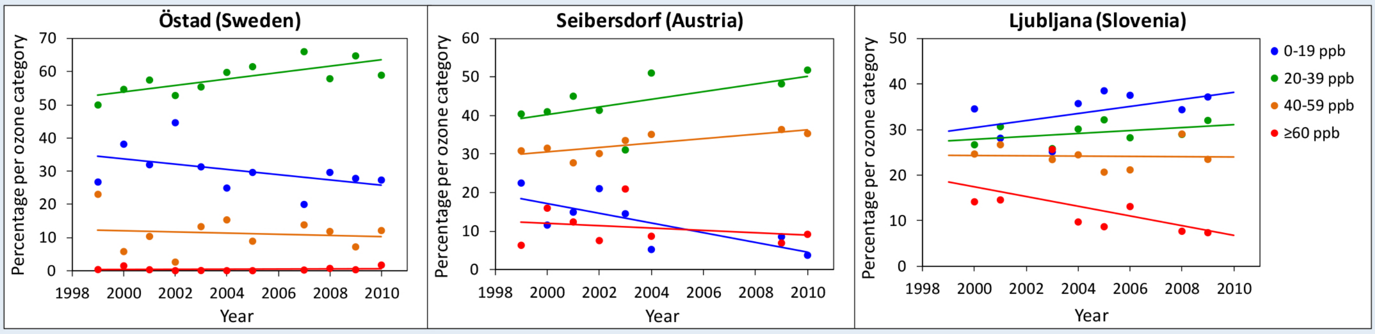
Centre for Ecology & Hydrology

NATURAL ENVIRONMENT RESEARCH COUNCIL

LRTAP

Long-range Transboundary Air Pollution

Changing ozone profiles in Europe: implications for vegetation



Ozone concentration	European trend*
0-19 ppb	Decline
20-39 ppb	Increase
40-59 ppb	None
≥60 ppb	Decline

* ICP Vegetation sites (1999 – 2010)

Whereas peak concentrations of ozone have declined in recent decades in some (but not all) parts of Europe, an increase in background concentrations has contributed to no change in median or average ozone concentrations across Europe. The rise in background concentrations can contribute significantly to impacts of ozone on vegetation.

http://icpvegetation.ceh.ac.uk

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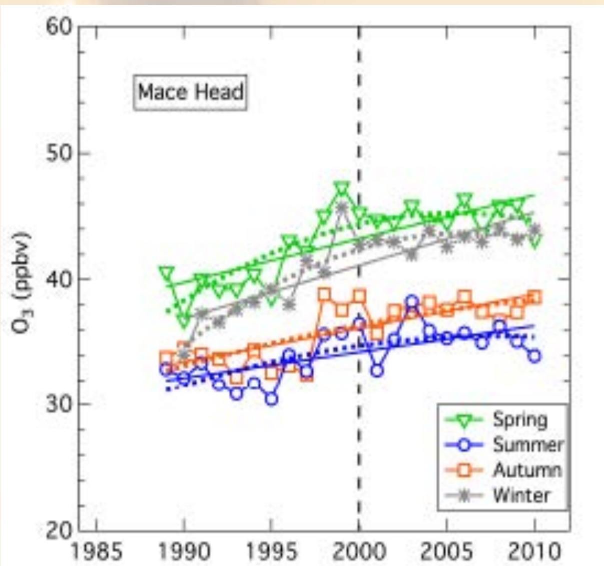
Working Group on Effects of the Convention on Long-range Transboundary Air Pollution

Ozone pollution: a global problem

Ozone is a natural component of the atmosphere. In the upper layer of the Earth's atmosphere, ozone is protecting us from harmful UV light from the sun. However, at ground level, **ozone is a damaging pollutant** that has negative impacts on human health and vegetation. Here, as well as being produced from natural sources, added ozone is formed from chemical reactions involving compounds emitted, for example, from vehicle exhausts and industry in the presence of sunlight. The concentration of ozone is strongly influenced by the weather, being higher on warm, dry sunny days. These conditions can lead to "ozone episodes" where concentrations peak at high levels for several days. Ozone concentrations are generally higher in the summer and spring than in the winter and autumn, and tend to be highest in rural and upland areas, particularly downwind of major cities. However, large regional differences are seen around the world, reflecting varying climate conditions and variations in regional and globally transported sources of ozone-forming chemicals.

Ozone-induced damage on lettuce (left), French bean (middle) and black cherry (right).

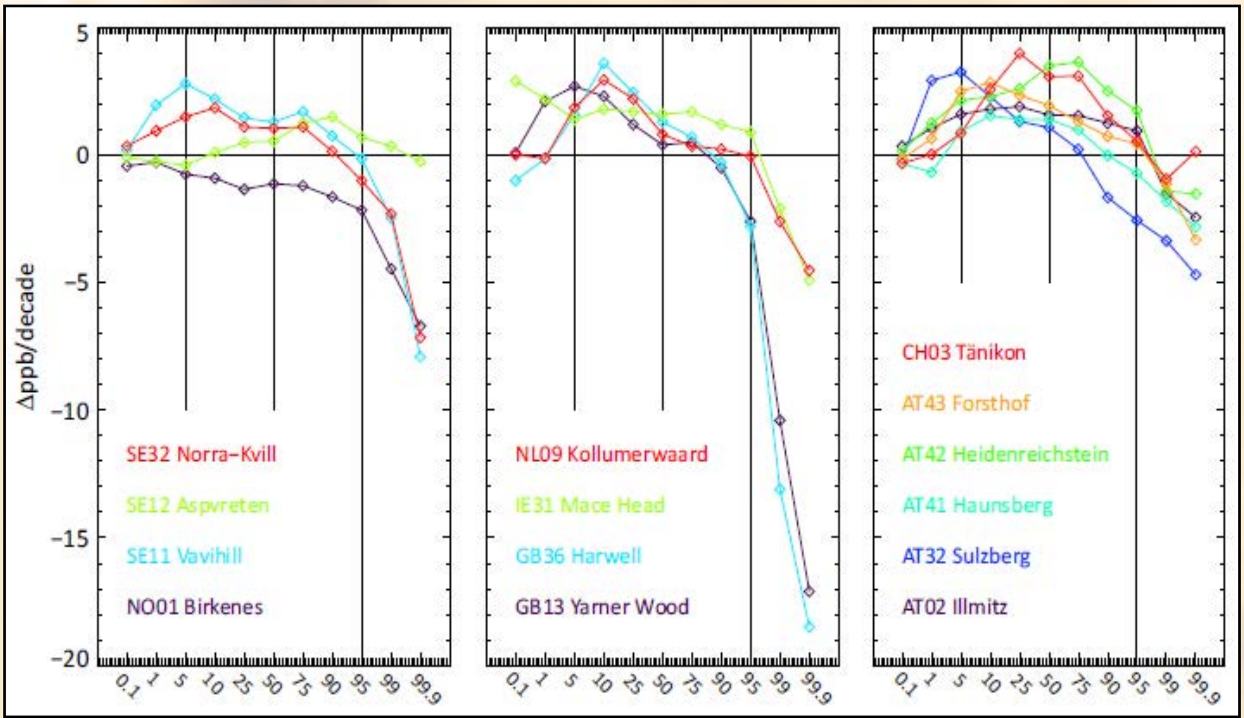


Seasonal ozone average at Mace Head, Northern Ireland (Parish et al., 2012).

With high uncertainty, pre-industrial natural ozone concentrations were estimated to be ca. 10 – 15 parts per billion (ppb). Present day background (seasonal or annual average) ozone concentrations are ca. 30 – 40 ppb. Background concentrations have roughly doubled between 1950 - 2000, followed by a decade with no further rise or even a reduction in ozone at some sites, particularly in the summer (See Figure. *Parish et al., 2012. Atmospheric Chemistry and Physics 12: 11485–11504)*.

Ozone trends in recent decades in Europe

Despite a more than 30% reduction in European emissions of ozone precursors during the last two decades, a decline in mean ozone concentrations is generally not seen at EMEP* ozone monitoring sites (*Torseth et al., 2012. Atmospheric Chemistry and Physics 12: 5447–5481; Simpson et al., 2014. Current Opinion in Environmental Sustainability 9-10: 9-19*). Rural background data over 1990 – 2010 show a decrease in the highest concentrations and a corresponding increase in low concentrations in the UK, the Netherlands and some other countries, but no clear trends in, for example, Switzerland or Austria (see figure). Reduced precursor emissions might well be being masked by large inter-annual variations in ozone, caused by, for example climate, weather or biomass burning events.



Change in mean annual percentiles of hourly ozone concentrations from the decade 1990–1999 to the decade 2000–2009 at EMEP monitoring sites. Whereas the median (50th percentile) ozone concentration has hardly changed, peak concentrations (above >95th percentile) have declined and background concentrations (lower percentiles) have risen in some places (*Simpson et al., 2014. Current Opinion in Environmental Sustainability 9-10: 9-19*).

Future projections

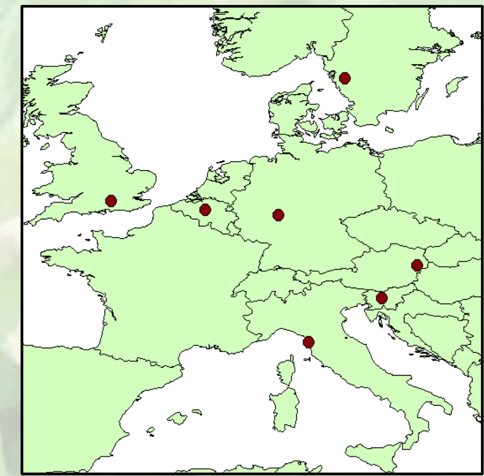
Applying the latest climate change scenarios, surface ozone concentrations are predicted to decline further in the future in Europe and North-America, with the magnitude of decline depending on scenario, whereas an increase is expected in South Asia. Limiting atmospheric methane growth will become more important when emissions of other ozone precursors are controlled (*Wild et al., 2012. Atmospheric Chemistry and Physics 12: 2037–2054*).

* EMEP = European Monitoring and Evaluation Programme (http://www.emep.int).

Ozone trends (1999 – 2010) at ICP Vegetation biomonitoring sites

The ICP Vegetation biomonitoring programme has involved exposure of an ozone-sensitive variety of white clover in early years and an ozone-sensitive variety of French bean in later years to ambient air between 1999 and 2010. A long time-series of ozone concentration data are available from sites spanning a representative north-south and east-west gradient across Europe. Here we report on temporal trends of hourly ozone concentrations and metrics indicating the risk of ozone impacts on vegetation for June, July and August. Earlier analyses has shown that there were no clear temporal trends of ozone impact on white clover leaf injury or biomass (*Hayes et al., 2007. Evidence of widespread ozone damage to vegetation in Europe (1990-2006). Report ICP Vegetation; Mills et al., 2011. Global Change Biology 17: 592–613*).

Ozone-induced leaf injury on white clover.



Sites included in this study.

Biomass reduction in ozone-sensitive (left) compared to resistant variety (right) of white clover.

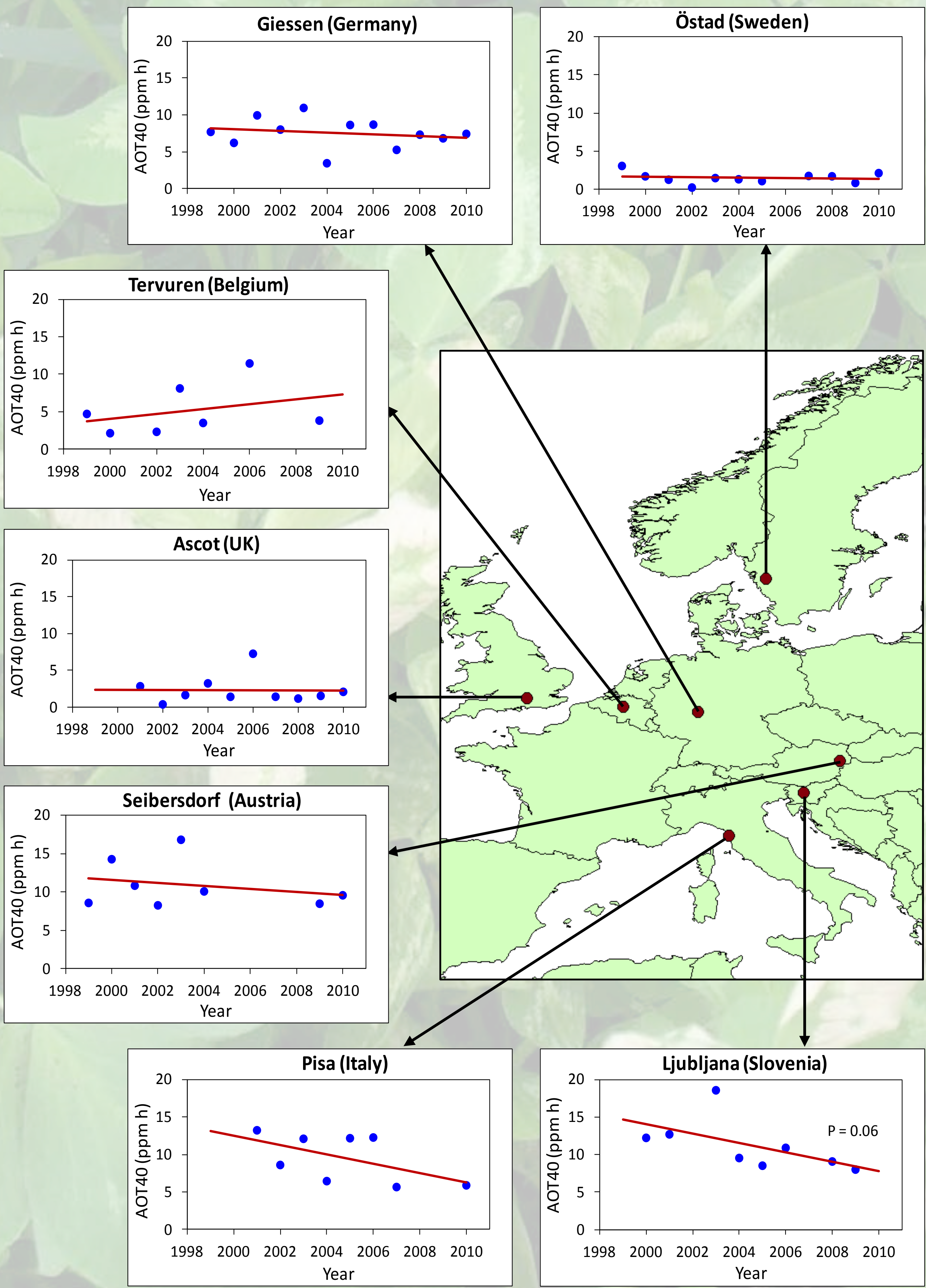
Trends in ozone concentration distribution

Analysis of the European data showed that in recent years the proportion of hourly ozone concentration in the lowest and highest ozone categories has declined ($P < 0.10$), whereas the proportion in the category 20 - 39 ppb has increased ($P < 0.001$); the proportion in the category 40 - 59 ppb has not changed (see table). These results confirm the general trend observed across Europe, i.e. background ozone concentrations are rising whereas peak concentrations are declining.

Trends (1999 – 2010) in ozone concentrations at ICP Vegetation sites.

Ozone concentration	European trend	Sites showing European trend
0-19 ppb	**Decline**	Tervuren (BE), Seibersdorf (AT)
20-39 ppb	**Increase**	Östad (SE), Ascot (GB), Tervuren (BE), Giessen (DE)
40-59 ppb	None	All, except increase in Seibersdorf (AT)
≥60 ppb	**Decline**	Ljubljana (SI)

Trends* (1999 – 2010) in AOT40



* A significant decline (at $P < 0.10$) was only observed in Ljubljana (Slovenia).

Further trends in ozone concentrations and fluxes: risk of impacts

No temporal trends were found for the 24 hr mean and daylight mean ozone concentrations (see table). This is in agreement with trends reported for mean and median ozone concentrations at EMEP monitoring sites. However, night time mean and daily minimum ozone concentration have increased (0.27 ppb per year) across Europe, although only significantly ($P < 0.10$) in Tervuren, Belgium. Despite a decline in the ozone concentrations of 60 ppb or higher, the average European daily maximum ozone concentration has not changed, although a decline was reported for Ljubljana, Slovenia.

Trends (1999 – 2010) in ozone concentrations and leaf fluxes at sites** across Europe.*

Country	Site	24 hr mean	Daylight mean	Night mean	Daily max	Daily min	AOT40[a]	POD_3 IAM[b]
Belgium	Tervuren	None	None	Increase	None	Increase	None	None
Slovenia	Ljubljana	None	None	None	Decline	None	Decline	None
European mean		**None**	**None**	**Increase**	**None**	**Increase**	**None**	**None**

* The non-parametric Mann-Kendall trend test was applied.

** Data are shown for sites showing at least one significant trend ($P < 0.10$). No significant trends for any of the variables were observed for Östad (Sweden), Ascot (UK), Giessen (Germany), Seibersdorf (Austria) and Pisa (Italy).

AOT40[a] and ozone fluxes into the leaf pores (POD_3IAM[b]) provide an indication of ozone risk to vegetation. It should be noted that ozone flux provides a biologically more meaningful assessment of ozone risk (*Mills et al., 2011. Atmospheric Environment 45: 5064-5068*). Despite a European decline in ozone concentrations of more than 60 ppb, AOT40 did not show any trend, apart from a decline in Slovenia ($P = 0.06$), reflecting the trend observed for the daily maximum ozone concentration. Concentrations much lower than 40 ppb contribute to the ozone flux. The ozone flux into leaves showed no trend between 1999 and 2010, indicating that the risk of ozone-induced effects on wheat has not changed with time. Considering the annual variation in ozone concentrations due to climate variation, much longer time series are probably required to detect temporal trends in ozone concentrations and effects on vegetation across Europe.

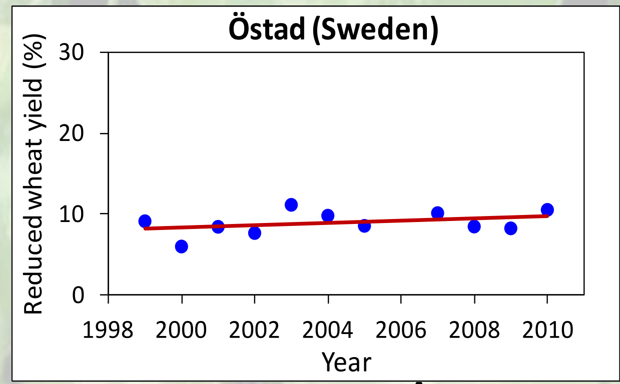
[a] AOT40 = Sum of differences between hourly mean ozone concentration (in ppb) and 40 ppb for each hour when the concentration exceeds 40 ppb, accumulated during daylight.

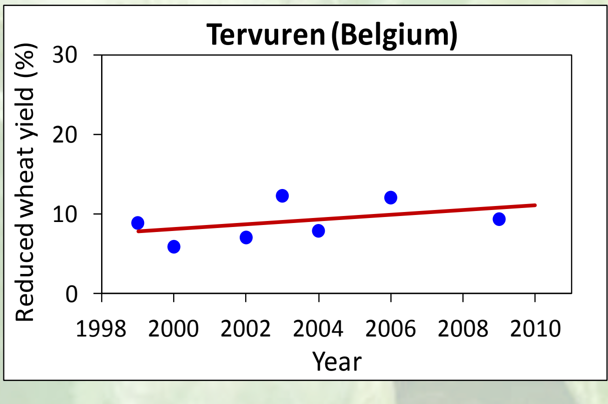
[b] POD_3IAM = Phytotoxic Ozone Dose above a flux threshold of 3 nmol m^{-2} s^{-1}, accumulated during daylight hours. Parameterisation is based on wheat for application in integrated assessment modelling (IAM); adequate soil water supply was assumed.

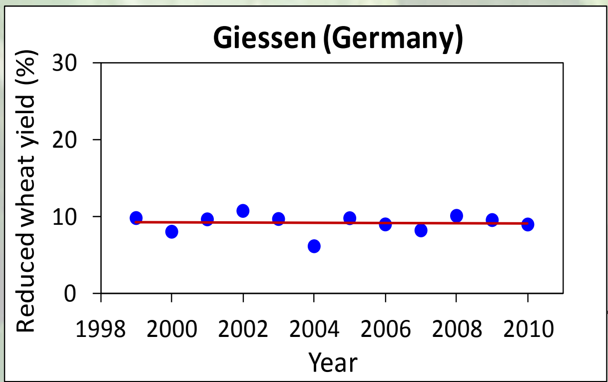
Trends* in ozone effects on wheat yield based on calculated ozone flux (POD_3IAM)

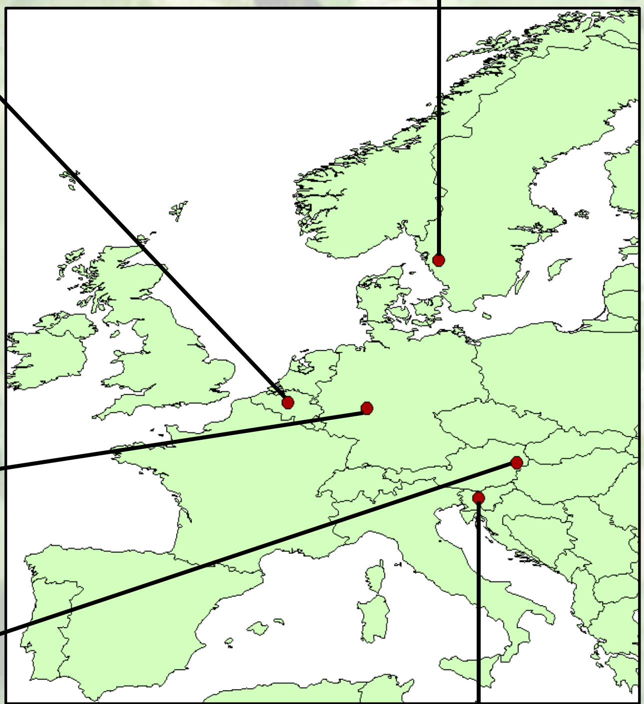
The lack of trends in ozone flux into the leaf pores means that there is also a lack of trends in the effects of ozone on wheat yield. On average over the period, wheat yield was the least reduced by ozone in the area of Seibersdorf (7%), followed by Östad, Tervuren and Giessen (9%) and was most reduced in the area of Llubljana (18%), assuming no soil water limitation. This reduction in yield is calculated relative to that at $POD_3IAM = 0$, which is approximately equivalent to the flux at pre-industrial ozone concentrations of ca. 10 – 15 ppb. A rise in the background concentration of 5 ppb in a relatively low ozone year, for example 2009, would result in additional wheat yield reduction of 1.8% (Seibersdorf) – 2.6% (Ljubljana).

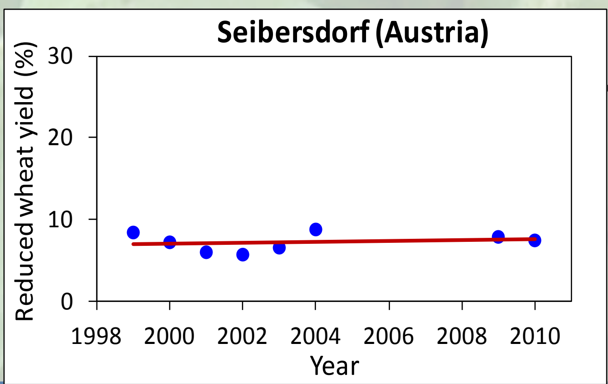
* No significant trends were observed.

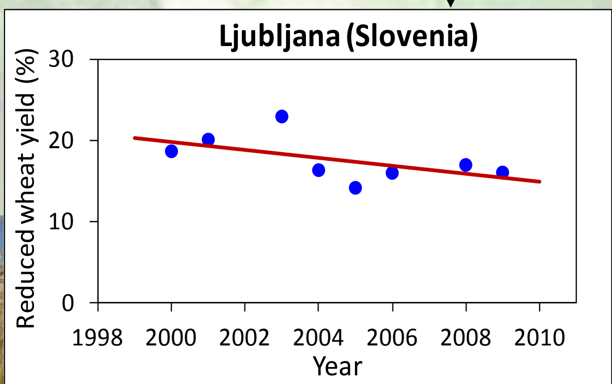












Key messages

- Few trends have been observed at ICP Vegetation monitoring sites between 1999 and 2010 regarding ozone concentrations and risk of ozone impacts on vegetation.
- Time series much longer than 12 years are required to distinguish significant long-term trends from inter-annual variability in ozone concentrations due to climate variation.
- Whereas peak concentrations of ozone have declined in recent decades in some (but not all) parts of Europe, an increase in background concentrations at the same time has contributed to no change in median or average ozone concentrations across Europe. The rise in background concentrations can contribute significantly to impacts of ozone on vegetation.
- Ozone pollution in Europe in the future is critically dependent on changes in regional emissions and global transport of ozone precursors.

This brochure was produced by the ICP Vegetation, an International Cooperative Programme reporting on effects of air pollution on vegetation to the Working Group on Effects of the UNECE Convention on Long-range Transboundary Air Pollution.

Acknowledgements

We would like to thank the UK Department for Environment, Food and Rural Affairs (Defra, contract AQ0833), the UNECE (Trust Fund) and the Natural Environment Research Council (NERC) for financial support of the ICP Vegetation.

We would like to thank the following ICP Vegetation participants for providing data:
- Per Erik Karlsson, IVL Swedish Environmental Research Institute, Gothenburg, Sweden.
- Ludwig De Temmerman, Karine Vandermeiren, CODA-CERVA, Tervuren, Belgium.
- Gerhard Soja, AIT Austrian Institute of Technology GmbH, Tulin, Austria.
- Frank Batic, Boris Turk, University of Ljubljana, Ljubljana, Slovenia.
- Cristina Nali, University of Pisa, Pisa, Italy.
- Sally Power, Imperial College, Ascot, UK.
- Ludger Grünhage, Justus-Leibig-University, Giessen, Germany.

Photos were provided by: Shutterstock (UK), G. Mills (UK), F. Hayes (UK), D. Velissariou (Greece), C. Saitanis (Greece), M. Schaub (Switzerland).

For further information, please contact:

Harry Harmens, Gina Mills
ICP Vegetation Coordination Centre
Centre for Ecology & Hydrology
Deiniol Road, Bangor, Gwynedd, LL57 2UW, UK
Tel: +44 (0) 1248 374500
Email: hh@ceh.ac.uk, gmi@ceh.ac.uk
This brochure and other publications are also available at http://icpvegetation.ceh.ac.uk

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