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An assessment of the surface ozone trend in Ireland relevant to air pollution and environmental protection

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ABSTRACT

Hourly data (1994–2009) of surface ozone concentrations at eight monitoring sites have been investigated to assess target level and long–term objective exceedances and their trends. The European Union (EU) ozone target value for human health (60 ppb–maximum daily 8–hour running mean) has been exceeded for a number of years for almost all sites but never exceeded the set limit of 25 exceedances in one year. Second highest annual hourly and 4th highest annual 8–hourly mean ozone concentrations have shown a statistically significant negative trend for in–land sites of Cork–Glashaboy, Monaghan and Lough Navar and no significant trend for the Mace Head site. Peak afternoon ozone concentrations averaged over a three year period from 2007 to 2009 have been found to be lower than corresponding values over a three–year period from 1996 to 1998 for two sites: Cork–Glashaboy and Lough Navar sites. The EU long–term objective value of AOT40 (Accumulated Ozone Exposure over a threshold of 40 ppb) for protection of vegetation (3 ppm–hour, calculated from May to July) has been exceeded, on an individual year basis, for two sites: Mace Head and Valentia. The critical level for the protection of forest (10 ppm–hour from April to September) has not been exceeded for any site except at Valentia in the year 2003. AOT40–Vegetation shows a significant negative trend for a 3–year running average at Cork–Glashaboy (–0.13±0.02 ppm–hour per year), at Lough Navar (–0.05±0.02 ppm–hour per year) and at Monaghan (–0.03±0.03 ppm–hour per year–not statistically significant) sites. No statistically significant trend was observed for the coastal site of Mace head. Overall, with the exception of the Mace Head and Monaghan sites, ozone measurement records at Irish sites show a downward negative trend in peak values that affect human health and vegetation.

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1. Introduction

Tropospheric ozone is known to be an important pollutant and it has been established that ozone has significant impact on human health globally, and in the European Union 21 400 premature deaths each year are associated with ozone (EEA, 2007a). An informative review chapter on the effects of ozone on human health is given in the Royal Society Report (Royal Society, 2008), some of whose conclusions are: (i) health effects of ozone increase with increasing concentrations, (ii) health impacts have been observed at around ambient concentrations (~35 ppb), (iii) the existence of a threshold concentration, below that ozone has no effect on humans is not yet determined. Despite the lack of clear evidence of a threshold, nevertheless, the World Health Organization (WHO), based on epidemiological time–series studies and on chamber and field studies, have set a new air quality guideline and interim target of 50 ppb (daily maximum 8–hourly mean), WHO (2006). The ambient air quality and Cleaner Air For Europe (CAFE) Directive [2008/50/EC], (CEC, 2008) has been adopted, and sets an ozone target concentration value of 60 ppb not to be exceeded for the protection of human health.

Tropospheric ozone is also known to affect forest, vegetation, and many species of crops (Fuhrer, 1994; Sanders et al., 1994; US EPA, 1996; Schaub et al., 2005; Bassin et al., 2007; Hayes et al., 2007; Mills et al., 2007). Experimental studies have shown that besides a visible impact on growth, ozone exposure also affects the reproductive capacity, biomass allocation, and biological aging (senescence, i.e. a change in the biology of an organism as it ages after its maturity) (Davison and Barnes, 1998; Fuhrer and Booker, 2003; Bassin et al., 2007). The severity of ozone on vegetation and forest depends on the concentration, duration of exposure, and activity level (stomatal conductance) during the time of exposure. The stomatal conductance depends upon various climatic parameters, e.g. temperature, humidity, vapor pressure deficit, and availability of light as well as soil water potential and phenology (Emberson et al., 2000; LRTAP, 2004; Pleijel et al., 2007). Assessment and quantification of the impacts of ground–level ozone on terrestrial vegetation relies primarily on empirical exposure–response relationships between ozone concentration and changes in crop yield, derived mainly from chamber studies (Royal Society, 2008). Hourly averaged data are analyzed in different ways for the assessment of the impact of ozone exposure on vegetation. In the US, as per 2008, standard concentration based parameters such as a 3–year average of the fourth–highest daily maximum 8–hour average ozone concentrations (should not exceed 75 ppb) are used for this purpose (US EPA, 2009) whereas in Europe a target level approach is used. The UN Economic

Commission for Europe (UNECE) Convention on Long–Range Transboundary Air Pollution (CLRTAP) has set out an exposure level for long–term injury and damage to vegetation (and human health) (Fuhrer et al, 1997). The target level is referred to as AOT40 (Accumulated exposure Over a Threshold of 40 ppb–more detail is given in Section 3), whose target value for the protection of vegetation is AOT40 9 ppm–hour (CEC, 2008).

As a result of legislation to reduce emissions of ozone precursors, downward trends of high ozone concentrations have been reported in various areas of Europe (Monks et al., 2003; Solberg et al., 2005; Vautard et al., 2006) and most recently in Ireland (Tripathi et al., 2010) during the last two decades. The negative trend in Europe is observed mainly in higher percentiles and in some cases the observed trend is steeper than expected from changes in emission levels (Vautard et al., 2006). In another model experiment to simulate the European heat wave of 2003, Vautard et al. (2005) predicted that extreme ozone events corresponding to health related ozone indices will be drastically reduced as a result of strict compliance of emission legislation in Europe. Surface ozone levels in Europe and in Ireland are controlled mainly by two sources: photochemical production and loss processes due to local variations in precursor emissions and ozone transported to Europe from outside that is strongly influenced by broader global emissions, often referred to as background ozone. Peak ozone concentrations are mainly affected by local production and loss processes and are controlled mainly by local changes in precursor emissions whereas mid–level ozone is determined by the ozone entering from outside the region and strongly controlled by broader global emissions.

Exposure analysis for Ireland was first performed by Kluizenaar et al. (2001) based on three years of ozone data (1995 to 1997) just after systematic monitoring of ozone in Ireland started in 1994. Since then, no integrated approach for ozone exposure analysis of ozone data in Ireland has been made. In this paper, we determine for the first time, based on some 16 years of hourly ozone monitoring data (1994–2009) if the new target ozone values and long–term objectives for human health and protection of vegetation are being met in Ireland. Furthermore, we analyze ground level hourly ozone data at eight sites in Ireland to study trends in ozone exposure levels in relation to humans and to vegetation. In addition, we examine changes in diurnal variation of ozone concentration, over an 11 year time span.

2. Data

An ozone monitoring network in Ireland has been operational since 1994 (McGettigan, 1996) and is managed and quality controlled by the Irish Environmental Protection Agency (EPA). Table 1 shows the stations covered in this network. Lough Navar is part of the UK automatic urban rural network (AURN) monitoring sites and is included in the analysis. Mace Head ozone measurements also operate as part of the UK AURN. In addition to being a background site for the AURN network, it is a Global Atmosphere Watch (GAW) global station since 1994. It also has been a part of the EUROTRAC Tropospheric Ozone Research (TOR) network (1988 to 1995) and was integrated into the Irish EPA network in 1994. Valentia Meteorological and Geophysical Observatory is operated by Met Eireann, the Irish Meteorological Service. Ozone concentrations at all stations are measured continuously by UV photometry and averaged to produce a dataset of hourly values. These data have been utilized by several other studies; in particular the Mace Head data are extensively analyzed for background level ozone (Scheel et al., 1997; Simmonds et al., 2004; Carslaw, 2005; Oltmans et al., 2006; Derwent et al., 2007; Tripathi et al., 2010).

3. Background and Methods

The methods used for analysis is in compliance with the ambient air quality and CAFE Directive (2008/50/EC) for ozone levels in ambient air (CEC, 2008) that has been adopted into Irish law in 2011 by the Air Quality Standards Regulations 2011 (S.I. Number 180 of 2011, http://www.epa.ie). The CEC (Commission of the European Communities) as well as WHO (World Health Organization) directives defines the criteria, target values and long–term objectives for the protection of human health and vegetation and use μg/m^3 as the unit of ozone concentration in the ambient air. However, much of the research community and scientists working in the vegetation and human health areas, report AOT in ppm–hour and hourly and 8–hourly mean concentration in ppb. For ozone, two μg/m^3 is equivalent to one ppb (based on the environmental conditions where the temperature is 20 degrees Celsius and atmospheric pressure is 1 013 mb), using standard textbook gaseous parameter definitions and the ideal gas law equation. In this work, ppb is used as the unit for concentration and the unit of ppm–hour is used for AOT. All time stamps used in this study are Central European Time (CET) unless stated otherwise. For protection of human health, the target limit is based on a maximum daily 8–hour running mean. The running mean is calculated from hourly data and the 8–hour running mean at time t is the mean of the hourly values at time t, t–1, t–2,…., t–7 hours. So for example, the 8–hour running mean at 01:00 is the average of hourly values from 17:00 hrs on the previous day to 01:00 hour on that day. Exposure indices focused on human health are also provided by the US EPA (United States Environmental Protection Agency) and are based on higher hourly ozone concentration. They are annual second highest hourly–averaged concentration and 4th highest daily maximum 8–hourly average concentration (US EPA, 2006). These metrics indicating the effect of ozone on human health are also calculated in this work and long–term trend estimates are analyzed.

Table 1. *Network of ozone monitoring sites, abbreviations, their co–ordinates, altitude and a brief description of site type*

Stations	Abbreviation	Station Category	Altitude, above sea-level (m)	Latitude (°)	Longitude (°)
Dublin (Rathmines)	DR	Urban	25	53.32	-6.26
Dublin (Pottery Road)	DP	Suburb of Dublin city – light industrial suburb	30	53.27	-6.15
Cork-Glashaboy	CG	Near city rural (4 km north-east of Cork city)	75	53.05	-8.69
Wexford	WX	Near town rural	40	52.25	-7.14
Monaghan	MN	Remote rural hilly moorland	170	54.19	-6.87
Lough Navar	LN	Remote rural clearing near edge of semi-natural forest	130	54.44	-7.87
Mace Head	MH	Remote rural exposed flat land on the eastern North Atlantic coast	5	53.33	-9.90
Valentia	VA	Regional rural coastal	14	51.94	-10.25