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Atmospheric Environment 36 (2002) 3161–3172

ATMOSPHERIC ENVIRONMENT

www.elsevier.com/locate/atmosenv

Visibility trends in the UK 1950–1997

Martin Doyle*, Stephen Dorling

School of Environmental Sciences, University of East Anglia, Norwich, East Anglia, UK

Received 16 November 2001; accepted 6 March 2002

Abstract

Visibility data have been examined for eight UK Meteorological Office surface network sites. Trends from 1950 to 1997 have been constructed using four different statistical methods; ridit analysis, cumulative percentiles, frequency of "very good" visibility and annual and seasonal means. Improvements in visibility have been experienced at the majority of the sites studied. Major improvements can be observed at many of the sites after 1973 and this is attributed to changes in personal behaviour, fuel use and vehicle fleet efficiency during the 1970s and especially after the 1973 oil crisis. Improvements in visibility at the Scottish sites studied are much less than at the other sites due to their locations in less populated and less polluted areas. Aldergrove, near Belfast in Northern Ireland, has also experienced less improvement in the visibility distance than the other sites. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Visibility; Aerosols; Air pollution; Trend analysis; Visual air quality

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1. Introduction

It has long been known that atmospheric pollution can cause a decrease in the atmospheric visibility, defined here as the maximum distance at which the outlines of a target can be recognised against the horizon as background (Horvath, 1981). In a non-polluted atmosphere, visibility would be in the order of 250 km (Leavey and Sweeney, 1990). During the London smog of 1952, visibilities were reduced to near zero (Brimblecombe, 1987) due to a build up of polluted air masses over the city. Even before this in the UK during the 19th Century, Acts were passed in British Parliament to specifically address the problem of smoke nuisance. Over more recent years there has been a growing interest in the use of atmospheric visibility measurements as a surrogate for air pollution concentrations. Studies carried out in the United States (e.g. NAPAP, 1990) have done much to relate finer particulate concentrations (PM2.5, sulphates and nitrates) with visibility degradation across the contiguous United States. Extensive work by Sloane (1982a, b) has examined the methods used to determine trends in visibility due to air pollution and much of this work is drawn upon within this paper. Sloane (1983, 1984) also examined in depth the effect of meteorology on visibility trends and the extraction of valid, air quality related conclusions from these data. Detailed long term studies of haziness within the United States have also been carried out by Husar et al. (1979, 1981) and Schichtel and Husar (2001).

Dedicated visibility and particulate monitoring networks have been in existence in the USA for over 15 years (the Interagency Monitoring of PROtected Visual Environments programme—IMPROVE). Recognising the importance of visual air quality, the US Congress included legislation in the 1977 Clean Air Act to prevent future and remedy existing visibility impairment in national parks and wilderness areas. The Regional Haze Rule was implemented in the USA in 1999 and this calls for states to establish goals for improving visibility in national parks and wilderness areas and to develop long term strategies for reducing emissions of air pollutants that cause visibility impairment (http://www.epa.gov/oar). However, such legislation and co-ordinated monitoring is absent in the United Kingdom. Lee (1983, 1988, 1990, 1994) and Gomez and Smith (1984) have

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*Corresponding author. Tel.: +44-1603-456161; fax: +44-1603-507719.

E-mail address: m.doyle@uea.ac.uk (M. Doyle).

PII: S1352-2310(02)00248-0

examined UK visibility measurements over a period of years and found trends within these data which correlate with changing fuel consumption and changing meteorological conditions (Lee, 1994). The work of Lee did not extend sufficiently far back into the records to capture the effects of the "Great Smog" in London in 1952 and the introduction of the Clean Air Act of 1956 which sought to control emissions of pollutants from domestic heating in addition to industrial sources (Brimblecombe, 1987).

Within this study, we have obtained a long term record of hourly visibility measurements for eight geographically dispersed UK Meteorological Office (UKMO) sites. Although a 50-year record was initially obtained, only data up to 1997 is presented within this paper due to uncertainties in data collection methods after 1997 (see Section 2.1). Several methods of extracting trends from the raw data are detailed and analysed here. Improvements in visibility over this 47-year period can be seen at the majority of the sites examined. Specific events which acted to decrease the ambient concentrations of atmospheric pollutants can be identified, most strikingly the oil crisis of 1973, the effect of which can be identified at all eight of the sites studied.

The United Kingdom has many stunning and scenic views, but pollution haze can diminish the visual amenity by discolouration, loss of texture and by making it harder to distinguish features in the distance. Many attractions within the United Kingdom use this visual amenity as part of their marketing approach. For example, the British Airways London Eye (the world's largest observation wheel) offers visitors "amazing views of Britain's capital city" and has a viewing distance of 40 km on a clear day (http://www.british-airways.com/londoneye/). On days when pollution haze is elevated, however, this distance can be drastically reduced and visitors may return home somewhat disappointed.

Good visibility is an amenity which should not be ignored and one which is valued by the public. A study at the Grand Canyon National Park in the USA questioned a random sample of 1800 visitors and asked whether they were aware of any haze and, if so, how hazy they thought it was. Results showed that visitors' awareness of haze increased as visibility decreased. As awareness of reduced visibility increased, enjoyment of the view, overall park enjoyment and satisfaction with the "clean, clear air" attribute decreased (NAPAP, 1990).

2. Data

UKMO land surface station data was made available by the British Atmospheric Data Centre (http://www.badc.rl.ac.uk). Data were obtained for 14 stations across the UK although only eight sites were taken forward for further analysis based on the continuity and reliability of the available records. These eight sites can be seen in Fig. 1 along with the length of the dataset for each station.

Several meteorological variables were collected for each station, including wind direction, wind speed, present weather code (PR), visibility distance, air temperature, dew point temperature and wet bulb temperature. Dry bulb temperature and dew point temperature were used in the calculation of relative humidity which was then applied in the analysis as detailed in 2.1.

Station Name	Length of Dataset	Station Description
Aldergrove (Belfast)	1950 – 1997 (47 years)	Urban (Airport)
Heathrow (London)	1950 – 1997 (47 years)	Urban (Airport)
Nottingham	1957 – 1996 (39 years)	Urban
Plymouth	1950 – 1996 (46 years)	Urban
Ringway (Manchester)	1950 – 1997 (47 years)	Urban (Airport)
Tiree	1957 – 1997 (40 years)	Rural
Leuchars	1957 – 1997 (40 years)	Rural (Airport)
Waddington	1950 – 1997 (47 years)	Rural (Airport)

Fig. 1. Locations of UKMO land surface stations used in this study and length of datasets for each Station (N.B. Data obtained to 2000 but not taken forward for further analysis due to problems noted in 2.1).

2.1. Analysis

The main aim of this study is to observe the changes in visibility over time with respect to the loading of aerosols within the atmosphere. However, visibility distances can also be reduced by precipitation effects and on occasions when relative humidities are higher (>90%) (Malm and Day, 2001). Visibility measurements were screened for precipitation events by using the present weather code, part of the World Meteorological Organisation (WMO) synoptic coding system (http://www.zetnet.co.uk/sigs/weather/Met_Codes/wwcode.htm). Present weather codes of 00–05 relate to non-precipitation and haze events. The effect of haze was screened by a previous study (ETSU, 1999) (i.e. codes of 00–04 were used in the analysis as these generally represent an atmospheric situation with less visual impairment), but haze (code 05) has a relationship with atmospheric secondary particle loading, and we have therefore retained it in this analysis. Codes of 06–09 relate to sand or dust storms at or near the observing station. These data were screened from the analysis, as these events are generally natural, localised and very rare in the UK. It is the anthropogenically produced and longer-range transportation of secondary aerosols and their ability to degrade the visual air quality which we are more concerned with here. Table 1 shows those present weather codes used in this analysis and descriptions as defined by the WMO.

At 90% relative humidity the light scattering cross section of an ammonium sulphate particle can be increased by a factor of five or more above that of the dry particle (Malm and Day, 2001). As the particles grow, they increasingly degrade the visual air quality (Tang et al., 1981). Many previous studies on atmospheric visibility have screened any observations of visibility when the relative humidity is >90% (e.g. Craig and Faulkenberry, 1979), and this provides a coarse meteorological screening. It is the visibility impairment due to emissions and ambient concentrations of mainly sulphates and nitrates which we are primarily interested in and not the degradation of visibility which is due to other factors. Within this study, we have examined visibility trends when the relative humidity was <90%.

Relative humidity was calculated from the dry bulb temperature and the dew point temperature.

$$\text{Relative Humidity} \approx 100\left(\frac{112 - 0.1T + T_\mathrm{d}}{112 + 0.9T}\right)^8, \qquad (1.1)$$

where T is the dry bulb temperature (°C) and T_d the dew point temperature (°C) (Linsley et al., 1986; Murphy, 2001).

Visibility observations were available, for most stations, on an hourly basis. Due to the greater difficulty of measuring nighttime visibility (using lights instead of larger visible landmarks) these measurements were screened from further analysis. We chose the 12Z measurement on which to base our trend analyses. Midday values can be considered as more appropriate for studies of this kind as they are more representative of regional visibility levels as early morning radiation fogs and high relative humidity, which may reflect only local conditions, would mostly have dispersed by midday (Lee, 1990). Sensitivity analyses (not shown here due to space limitations) showed that choosing a different observation time such as 10 a.m., 2 p.m. or 4 p.m., had no effect on the conclusions drawn.

After completing initial analyses using data from 1950 to 2000, it was found from the results that unusual effects were observable throughout all sites from 1997 onwards. These effects tended to suggest a significant decrease in the visibility distance since 1997. After investigation it was found that missing present weather codes were a major cause of the problem. From 1950 to 1997, the present weather code (amongst many other variables) was recorded by a human observer on an hourly basis. There are very few cases of missing present weather codes from 1950 to 1997 (see Fig. 2). From 1997 onwards the UKMO started to use SAMOS (Semi Automatic Meteorological Observing System) at the sites used in this analysis. Human intervention is required within this system in order to force a present weather code to be recorded outside of 'significant weather' conditions. We can only presume from that this human intervention was very sporadic from 1997 onwards at many of the sites used in this analysis. It is also unclear at this time how the automated retrieval of visibility distances may also impact on this trend analysis.

In our screening of the present weather code for codes of <06, the visibility data for days on which the codes are missing are also screened out. Therefore, a lack of data on present weather impacts upon our ability to use the visibility data.

A comparison between screened (12Z, <06 PR code) and unscreened (12Z) visibility data was undertaken in order to identify if there was any significant difference

Table 1
Present weather codes used in the analysis

Code	Present weather
00	Cloud development not observed or observable
01	Clouds dissolving or becoming less developed
02	State of sky on the whole unchanged
03	Clouds generally forming or developing
04	Visibility reduced by smoke haze
05	Haze

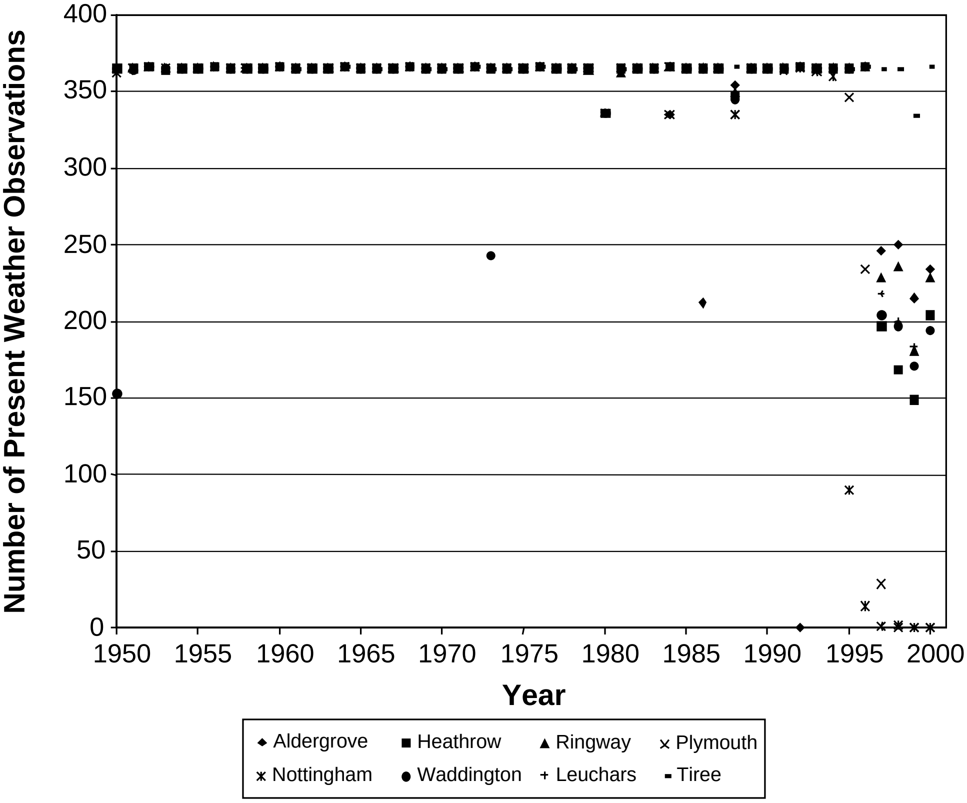

Fig. 2. Number of present weather observations from 1950 to 2000 (12Z).

when "significant weather" was excluded from the analysis. Lee (1990) also examined visibility trends in Southern England from 1966 to 1979 for rain days and non-rain days. The absolute values changed (although not significantly) but the temporal trends did not change. Similar findings were found from an initial analysis carried out by the authors. However, other studies (e.g. Sloane, 1982a) have shown that the combination of a 90% relative humidity filter and removal of certain weather conditions did the best job of removing meteorologically influenced data. Therefore, as it is the anthropogenically influenced visibility changes we are interested in we have used a 90% relative humidity filter, 12Z observations and only data when the PR code is 05 or less. However, if the annual total of visibility measurements made at 12Z was <300, then the year was excluded from further analysis.

Due to the problems of having fewer PR codes after 1997, we decided to leave this data out of the analysis until we have resolved issues regarding automated retrieval of visibility and present weather measurements.

3. Methodology

As part of this study, four methods of studying the historical trends in visibility were examined. These were ridit analysis, the use of cumulative percentiles (median visibility approach), an identification of the frequency of "very good" visibility and the use of annual and seasonal means.

3.1. Ridit analysis

The name ridit has its origins with the probit and logit, the "it" meaning type of transformation. Where probits relate to a theoretical distribution (the normal distribution), ridits relate to an observed, empirical distribution, ***R****elative to an* ***I****dentified* ***D****istribution*, that is, based on the observed distribution of a variable for a set of observations.

Ridit analysis is a statistical technique which can be employed on "borderland" (ordinal) variables. These borderland variables can be subjective scales (severe, moderate, minor) or may take a numerical form where the measurement system relies heavily on the experimental method, experimental protocol or the technical skill of the scientist involved in the measurement of the variable in question. Where manual measurement of visibility distances is concerned, the skill of the observer is crucial in reporting of accurate and reliable data. These borderland variables may not be adequately analysed by tests such as Chi Square and the *t*-test may not be appropriate (Bross, 1958). In these more usual forms of analysis, it is assumed that observations are independent of one another and not autocorrelated—this is generally not the case for visibility measurements separated by short time intervals.

A ridit is the probability that a visibility observation in a given period was better than a visibility observation from a reference distribution. In this study, we sought to compare individual years and seasons with those from the reference distribution, taken as the entire record length of visibility measurements (47 years in most cases). The calculation of ridits in the reference distribution and calculation of the mean ridit is shown below;

Let $f_A(v)$ be the probability density function of visibility observations in a given period A, and let $f_R(v')$ be the reference probability density function. F_A and F_R denote the respective cumulative distribution functions. The probability that an observation from distribution A will exceed an observation from distribution R is given by

$$P(V_A > V_R) = \int_0^{\max} \int_0^{v} f_A(v) f_R(v')\,\mathrm{d}v'\,\mathrm{d}v = \int_0^{\max} f_A(v) f_R(v)\,\mathrm{d}v,$$

where the upper integration limits (max) can be chosen as the distance of the farthest observation target or observation. This probability is estimated by partitioning the interval based on target availability, and representing the distributions by histograms. If f_{A_i} and f_{R_i} are the relative frequencies of the ith subinterval for each distribution, then the probability is estimated by

$$P(v_A > v_R) = \sum_{i=1}^{K} f_{A_i}\left(\sum_{i=1}^{i-1} f_{R_i} + 1/2 f_{R_i}\right) = \text{MEAN RIDIT}$$

with $f_{A_i} = n_i/n, n_i$ being the number of observations in visibility category i and n being the total number of observations, both for distribution $A\, f_{R_i} = N_i/N$, defined analogously to f_{A_i} but for $R\,k$ subdivisions are made (taken from Sloane, 1982a).

Ridit analysis has been used within this study to compare summer, winter and yearly visibility measurements. Five visibility categories were chosen to represent those given in the *Monthly Weather Report*, 0–3.9, 4–9, 10–19, 20–39 and >40 km (Lee, 1988). It should be mentioned that in the calculation of annual ridits at each site, the reference distribution was based on a whole years data (i.e. January–December inclusive). In the calculation of winter and summer ridits, the reference distribution used varied accordingly (i.e. September–March inclusive and April–August inclusive, respectively).

3.2. Cumulative percentiles (median visibility)

The *N*th cumulative percentile is the visibility that is equaled or exceeded *N* percent of the time. Visibility data lends itself well to treatment in this manner, as trends are naturally the change in visibility level of a particular percentile (Sloane, 1982a).

Lee (1988) used the categories in the Monthly Weather Report and constructed cumulative percentile plots. As only five visibility categories were used in this analysis, linear interpolation between the categories was required in order to obtain the 50th percentile, or median visibility. If the data were continuously and widely distributed, the 50th percentile would directly correspond to the median value (Sloane, 1982a). When applied to visibility data, where observations are not continuously and widely distributed, some interpolation or extrapolation is required in order to obtain the 50th percentile. As both Lee (1988) and Sloane (1982a) identify, there is no particular reason why the 50th percentile should be used in preference to either the 40th or 60th percentiles, except that it is a readily used and widely understood statistic.

Due to data reporting problems, Sloane (1982a) used the 60th percentile as "representative days" and the 90th percentile as "poor visibility days". In this study, we have used the 50th percentile, 90th percentile and 10th percentile to indicate "median visibility", "poor visibility days" and "good visibility days", respectively.

3.3. Frequency of "very good" visibility

Previously used by Gomez and Smith (1987) and Lee (1983) this is a very simple method and aims to identify the frequency of "very good" visibility, defined by Gomez and Smith as >19 km. Gomez and Smith (1987) argue that this should be a good indicator of the influence of long-range transport of air pollution on summer visibility levels.

This method has been used in this study to assess changing frequencies of "very good" visibilities in summer months in individual years for the entire record lengths by calculating the percentage of observations during the summer months which exceed 19 km.

3.4. Annual and seasonal mean values

This is the simplest approach used within this study. Mean values have been calculated for each year as an annual mean, a summer mean and a winter mean. These can then be examined in order to identify either increasing, decreasing or a combination of trends over time.

4. Results and discussion

Results will be shown here for data filtered for 12Z, relative humidities of <90% and present weather codes of 00–05.

4.1. Ridit analysis

Results from the ridit analysis can be seen in Figs. 3 and 4. It should be remembered at this point that it is not possible to compare the ridit plots with one another due to the methods used to construct them. The ridit is constructed using a reference distribution from the same site, and therefore values of ridits are not directly comparable from site to site. It is also worth noting here that the comparison of a ridit from one year with a ridit from another year at the same site is not a rigorous test for differences. It is possible, however, to use these plots as an indication of improving or worsening trends in visual air quality.

The ridit plot for Aldergrove shows an improvement in visibility from 1950 to 2000 throughout all seasons although does tend to suggest a degradation in the visibility from 1950 until 1973. In 1974, there seems to be a step change where the ridit in 1973 has a value of 0.4 (annual) suggesting that the visibility was worse in 1973 when compared to the entire record length. In 1974, the ridit has a value of 0.51 indicating that the visibility was in fact better when compared to the entire record. From 1950 to 1973 the ridit did not have a value of above 0.5 on more than three occasions in the early 1950s. From 1974 to 2000, the ridit did not fall below 0.5 except on one occasion in 1976. This sudden change from a degrading to an improving visual air quality in 1973–1974 tends to suggest that an event occurred within this year, which caused the air quality to improve and to sustain an improvement over 27 years. However, the annual and seasonal mean values for Aldergrove do not tend to show this step change so well, but do show a definite improvement after 1973 (see Fig. 8). The ridit plot for Aldergrove does not tend to show as great an improvement overall from 1950 to 2000 compared to some of the other sites.

The ridits for Heathrow show something similar, although instead of degradation up to 1973, the annual average visibility remained almost constant (with year-to-year fluctuations). In 1973, a step change was observed with the annual ridit increasing from 0.42 in 1973 to 0.52 in 1974. Before 1973, the ridit did not reach above 0.5 on any occasion and after 1974 it did not go below 0.5 except on three occasions in the late 1970s. This again points to a specific event changing the aerosol content of the atmosphere.

This step change can also be seen at Ringway, Plymouth, Nottingham and Waddington. The change is less dramatic at Waddington perhaps due to the more rural nature indicating a change in atmospheric aerosol content affecting mainly urban areas.

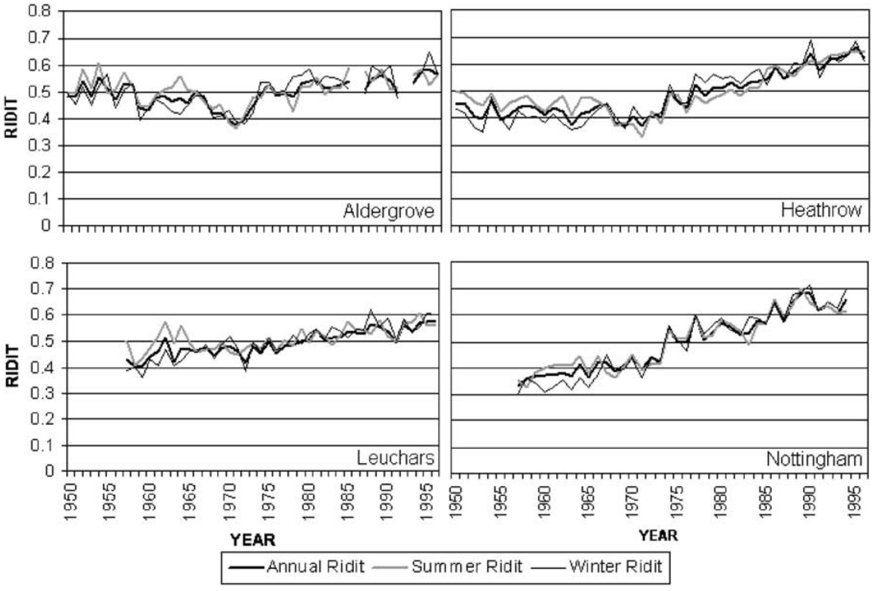

Fig. 3. Ridit plots for Aldergrove, Heathrow, Leuchars and Nottingham.

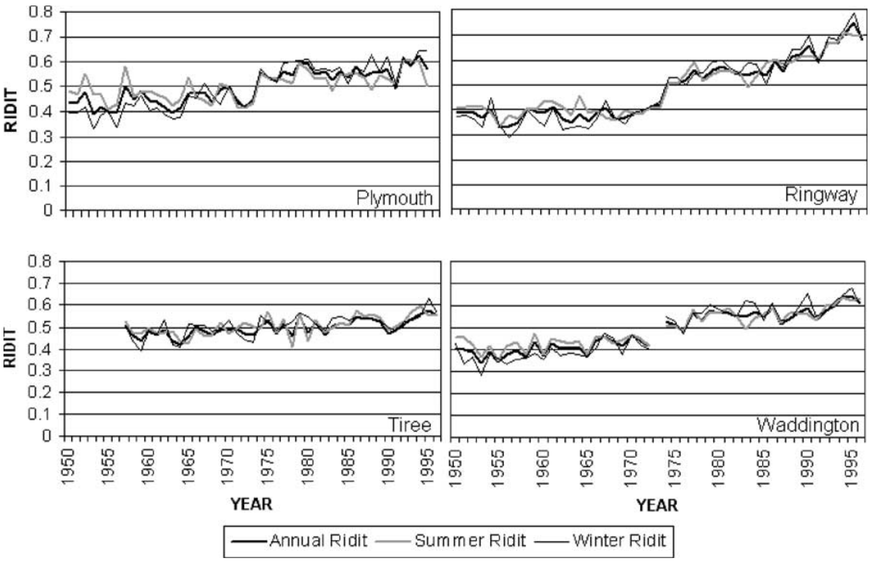

Fig. 4. Ridit plots for Plymouth, Ringway, Tiree and Waddington.

The two sites in Scotland, Tiree and Leuchars, show different trends to those experienced elsewhere in the UK. At Tiree, no dramatic year-to-year improvements can be seen when compared with the other sites. However after 1983, the ridit does go above 0.5, indicating an improving visibility. This falls below 0.5 in 1990 and 1991, but remains above 0.5 until 1997. At Leuchars, a gradually improving visibility can be determined from the plot in Fig. 3. In 1958 the ridit has a value of 0.4 which increases over the record period to a value of around 0.6 in 1997.

At all sites except Nottingham, Tiree and Leuchars, a decreasing or more constant visual air quality up until 1973 is replaced by an improving trend after 1974. At Nottingham, the step change in 1973 can be seen but the trend from 1950 to 1973 is an improving one and this trend is continued after 1974. The step change is also seen at Plymouth, but here a more constant visual air quality is seen both before 1973 and up to 1997 although visibility is improved after 1974, when compared to the reference distribution.

Decreases in the ridit value below 0.5 during 1976 can be observed at four of the eight sites. This indicates that the visibility in 1976 was worse than that of the reference distribution (the entire record length) at all sites except Ringway, Nottingham, Tiree and Leuchars. This may be due to the dry summer experienced in the UK in 1976 and associated resuspension of particulate matter, but without further evidence and investigation, this cannot be proven here.

Step changes such as the ones noted here are most likely due to anthropogenic factors. However, changes in the visibility reporting methodology may also have some bearing on the results. For example, on a very good visibility day, the visibility distance might be recorded as the distance of the furthest visibility marker, rather than the "actual" visibility, truncating the distribution at a certain distance. As visibility markers might also change over time, so might this maximum distance which is reported. At the time of going to press investigations into this possible effect were underway.

4.2. *Cumulative percentiles*

Cumulative percentiles were generated for "median visibility days", "worst visibility days" and "best visibility days" defined as the 50th percentile, 10th percentile and 90th percentile of values, respectively. Results are presented here as 5-year averages in order to illustrate the trend over time. 1997 was not included in this analysis as it did not fall within a 5-year period. Note the changes in the *y*-axis in the three plots in Fig. 5.

It can be seen from Fig. 5 that all stations have experienced improved visibility distances since 1950 during the median visibility days. During these periods, visibilities were generally higher at Tiree and Leuchars. Of the other sites, visibilities were generally much higher at Aldergrove until the 1970s before improvements on the scale of the mainland UK sites were evident. Median visibilities for the English sites in the 1950s were around 9–15 km, whereas in the 1990s had improved to between 24 and 29 km. For sites in Scotland, median visibilities were around 33 km in the early 1960s. At Leuchars, this distance increased during the 1980s and 1990s to nearly

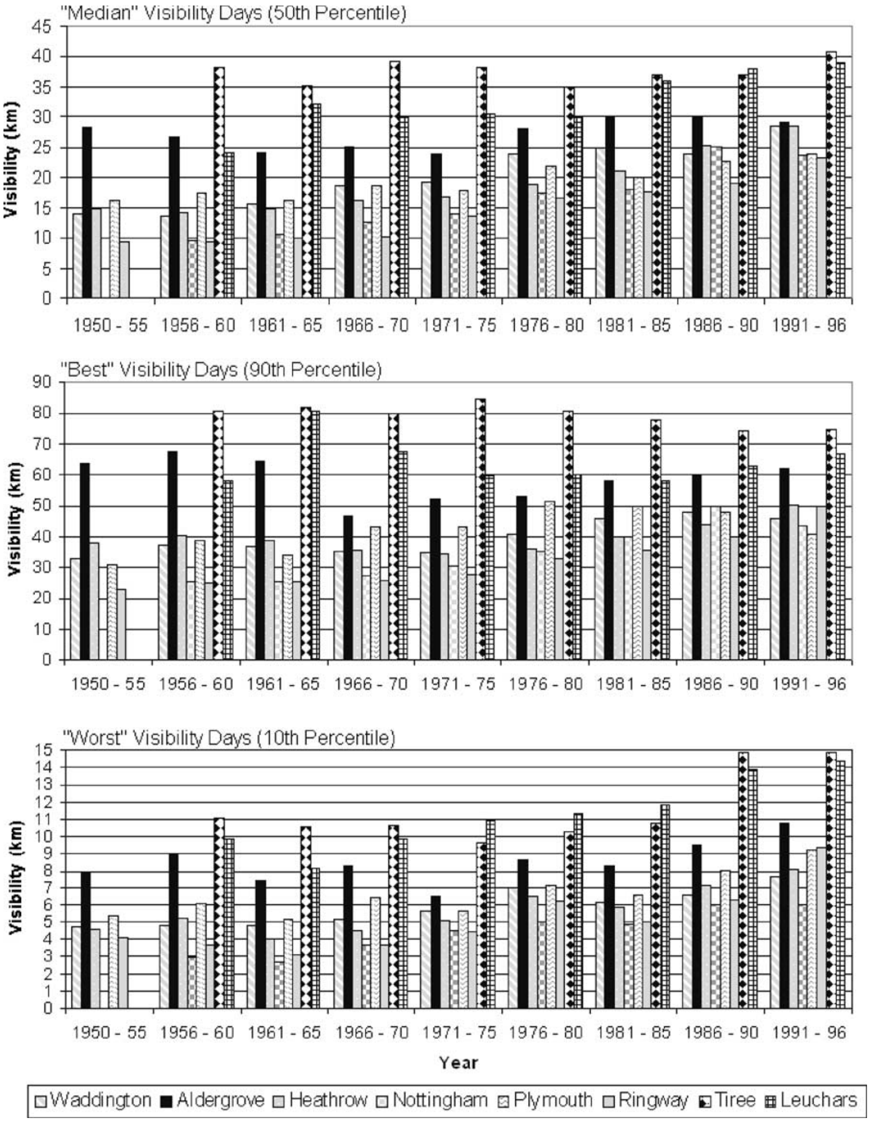

Fig. 5. Visibilities during "Median", "Best" and "Worst" days at all sites.

40 km in 1991–1996. At Tiree little improvement in the median visibility distance (typically 35–40 km) can be seen over the period of study. The second panel in Fig. 5 shows visibilities during the "best" days. During the 1950s, Aldergrove had higher visibilities during these "best days" than it did during the 1990s. The downward trend evident from 1950 to 1970 was halted however, and visibilities during these 10th percentile days began to increase again to the levels observed in more recent times. This downward trend is not so evident at the other seven sites. However, improvements in visibility distances during these "best" days are not so apparent from 1950 to 1970 as they are from 1970 to 1996. Visibilities during the best visibility days were around 30–40 km in the 1950s and 1960s (60 km + at Aldergrove, 80 km + at Tiree and 50 km + at Leuchars) but in more present times can reach up to 50 km at all English and Northern Ireland sites.

The third panel in Fig. 5 shows visibility distances during the "worst" or 90th percentile days. Once more at Aldergrove these distances were generally much higher during the 1950s and 1960s than at the English sites examined. Visibilities tended not to show much improvement here until the mid 1970s when visibility distances started to fall in line with those experienced at the other sites. Visibilities during the worst visibility days at the English sites are generally between 4 and 5 km. In the 1990s this rose to between 6 and 9 km.

At the two Scottish sites (Tiree and Leuchars), visibilities during the "worst" days were 10.5 km at Tiree and 8 km at Leuchars during the 1960s. During the late 1980s these both increased to 14.5 km at Leuchars and just under 15 km at Tiree.

4.3. Frequency of "very good" visibility

Frequencies of very good visibility (defined by Gomez and Smith (1987) as >19 km) were calculated for each of the eight sites for each year of data available. Those years with <300 hours of visibility data available at 12Z were excluded from this analysis. The plots can be seen in Fig. 6.

All of the sites except Aldergrove, Plymouth, Tiree and Leuchars exhibit a large increase in the frequency of very good visibility. Aldergrove experienced very good visibility during the summer months $\approx 70\%$ of the time in 1950 and 80% in 1996. At the Scottish sites, very good visibility was experienced around 80% of the time in 1957 and 85–90% during 1996. Frequencies at Ringway were $\approx 30\%$ in 1950 rising to above 70% during the 1990s. Improvements can also be seen at Heathrow, with frequencies $\approx 60\%$ during the 1950s rising to around 80% during the 1990s. Increases in frequency from one year to the next at Waddington are fairly well reflected in the data for Nottingham although frequencies of very good visibility are higher at Waddington possibly due to the more rural nature of the site.

4.4. Annual and seasonal mean values

Annual, winter and summer mean values have been calculated for each site and are shown in Figs. 7 and 8.

Average visibilities for Aldergrove tend to see a decline from 1950 until 1973, after which they increase to the distances, which observe in more recent times. At their minimum in 1973, annual average visibilities at Aldergrove were around 25 km, this still being larger than the other sites at that time (except at the Scottish stations). At Heathrow airport, increases in both annual and seasonal average visibility were not observable until 1973, after which annual average visibility increased from 20 to 30 km in 1997.

Increases in average visibility were observed at Nottingham from 1957, although this increase was steepened after 1973. A significant drop in annual and seasonal average visibility was noted in 1990, persisting until 1994, which is not observed in the record of Waddington, the site in closest proximity to Nottingham.

At Plymouth increases in annual and seasonal average visibilities are observed from 1950 to 1997. As in the ridit plots for Plymouth, a change is observable in 1973, where prior to this date annual average visibilities were around the 20 km region, and after this date were of the order of 23 km.

A gradual increase in the seasonal and annual average visibility can be observed at Ringway. Small

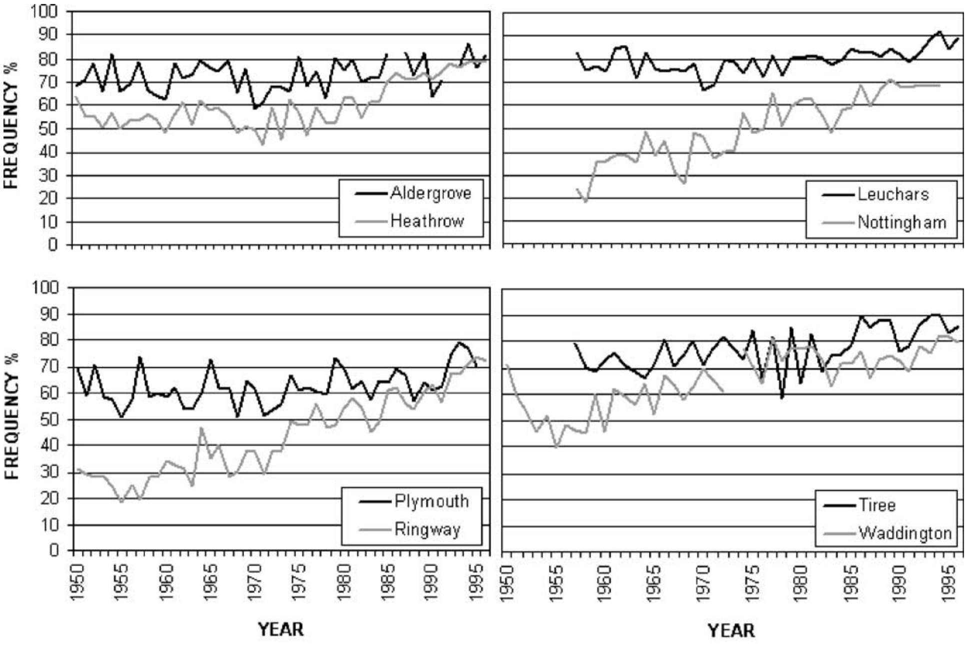

Fig. 6. Frequencies of "very good" (>19 km) visibility.

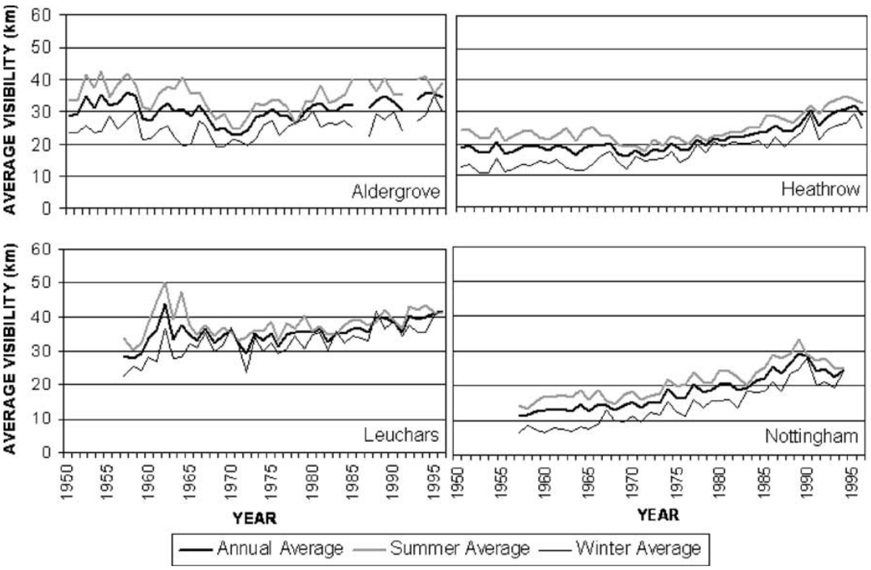

Fig. 7. Annual and seasonal average visibilities for Aldergrove, Heathrow, Leuchars and Nottingham.

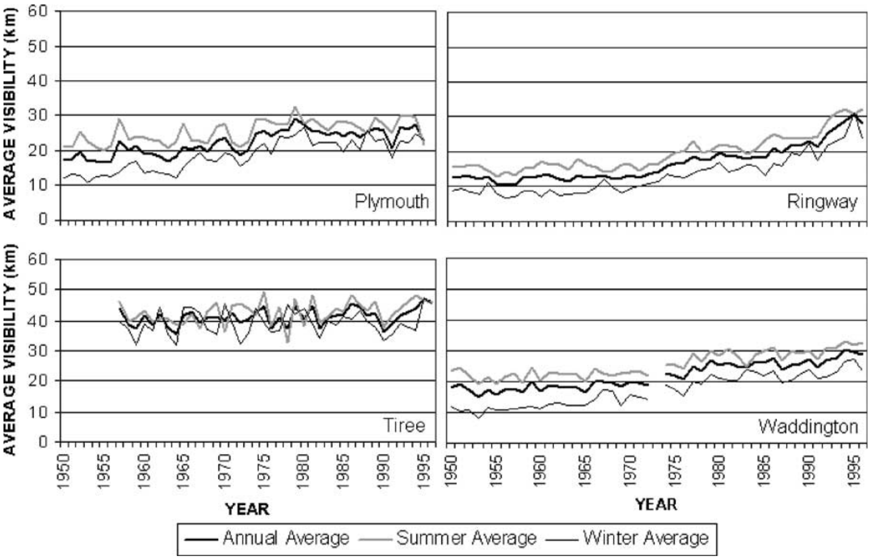

Fig. 8. Annual and seasonal average visibilities for Plymouth, Ringway, Tiree and Waddington.

improvements are made between 1950 and 1973, with greater year-to-year improvements being made after this date. Annual average visibilities in 1997 were in the region of 30 km, being a little over 10 km in 1950.

Averages for Waddington again follow the pattern for many of the other sites with the pivotal date being seen around 1973 although this is much less evident than in the data for sites such as Heathrow, Plymouth and Aldergrove.

At Tiree average visibilities in 1957 were in the order of 40 km (annual). In 1997, this was similar. Over the whole period average visibilities tended to be much greater than the English and Northern Ireland sites. Leuchars does show an improving trend from 1957 to 1997. In the early 1960s, annual average visibilities were around 35 km and in 1997 were almost 40 km, once again much higher than the English sites.

5. Conclusions

Improvements in the visibility resource over the 47-year period of study have been noted at the majority of the sites examined. Striking improvements in the visibility resource have not been made at Aldergrove and Tiree as they have at the other six sites. During the 1950s, 1960s and 1970s, Aldergrove had one of the largest visibility distances from any of the eight sites studied. However, lack of improvement in this visibility distance as observed at many of the other sites examined brought these other sites more into line, with all eight sites now observing annual average visibilities of more than 20 km (more than 40 km at Tiree and Leuchars).

Belfast is well known for its pollution problems. These mainly arise due to high incidences of fossil fuel burning for domestic heating purposes and also because of the proximity of two large power stations to Belfast. At the present time ≈74% of homes in the Belfast urban area use either solid fuel or fuel oil in order to heat their homes (Lo et al., 2001). These, therefore, have the potential to collectively release large quantities of particulates and sulphur dioxide into the atmosphere, which may either directly or indirectly degrade the visual air quality.

Annual average visibilities at Nottingham and Waddington show good agreement in trend, but not in absolute values. With these two sites being separated by ≈50 km, this shows the regionality of atmospheric aerosol effects and an "urban increment". In the ridit plots for Nottingham, the step change can be seen in 1973, indicating an atmospheric aerosol-reducing event. This step change is not so evident at the Waddington site, indicating that perhaps this aerosol-reducing event was more confined to the urban atmosphere and was perhaps due to changes in emissions of vehicular pollutants than perhaps changes in the longer-range transport of pollutants.

Frequencies of very good visibility have largely increased at all sites except Aldergrove, Tiree and Leuchars. However, frequencies of very good visibility have always been much higher at the two Scottish sites examined within this study. This suggests that these sites are less in the plume for longer-range transport of pollution from mainland Europe, or may simply be in cleaner, less populated areas. The lack of improvement in visibility distances can be seen at both Scottish stations, but especially so at Tiree. In the Hebridean Islands, Tiree generally experiences much cleaner maritime air than does Leuchars, itself, despite being rural still closer to many population centres and receiving polluted transported air from Eastern Europe (Beverland et al., 2000). We would, therefore, expect visibility distances to be relatively high at both sites, but with improvements to be more notable at Leuchars rather than at Tiree.

Although the use of ridits are not a wholly rigorous test for year-to-year differences, certain assumptions can be made as to the origin of the step changes seen in 1973 in the ridit plots and the improvements seen in the annual and seasonal average plots for the English and Northern Ireland stations. The 1973 oil crisis springs immediately to mind, and this is the most likely explanation for the immediate changes seen around this time. However, although the oil crisis temporarily changed personal use of fuels over a relatively short period, this would not account for the way in which these suddenly improving trends persisted right up until the present day in many cases. This period within the UK was also a time when catalytic converters were being incorporated more into the vehicle fleet and vehicle fleet fuel efficiency was also on the increase and this may go some way to explain the sustained improvements seen within this study. Governmental policy changes may well have inadvertently maintained this improvement in visual air quality, but such policy changes are not known to occur so soon after a pivotal event such as the oil crisis. Interim measures can sometimes be introduced, but it can often take years for changes in policy to be implemented. Such programmes as Auto Oil II (Directives 98/69/EC and 98/70/EC) and the Low Sulphur Fuels Directive (98/70/EC) may also help these improvements to persist, but this can only be determined through monitoring of ambient concentrations of pollutants or by using surrogate techniques such as those examined within this paper.

Acknowledgements

Thanks to Anabelle Ménochet at the British Atmospheric Data Centre for supplying the data for this study. Thanks also to Philip Wills at the UK Meteorological Office for advice on changing observation practices and to both reviewers for their extremely helpful comments.

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