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Depletions in winter total ozone values over Southern England

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1 Introduction

Total ozone observations have been made in southern England since Professor Dobsons original measurements at Oxford in the 1930's. However it is only since the 1960's that data from the Bracknell station has been regularly published in 'Total ozone data for the world' (the "red book"). The Bracknell station was closed in August 1989 and the Dobson instrument there was transferred to Camborne (a distance of some 340 kilometers) where observations have been continued to the present date.

The Bracknell station was one of those criticised in the report on an intercomparison between TOMS satellite and ground-based total ozone measurements by Bojkov et al in 1989. Errors of up to 7% or more were noted in sections of the data. As a result of this a re-evaluation was made of measurements and intercomparisons since 1979, the earliest time from which raw data was available, and the results republished in the "red book". It is only the measurements from this period of 1979 to the present that have been used in this study. In addition a survey was made of operating practices and improvements were made. It was as a result of this that the move to Camborne was made, as Bracknell was was particularly subject to pollution and did not have as high a number of sunshine hours as Camborne. In addition Camborne was a sonde station from which local upper air data is regularly available and as will be seen below, use has been made of this. The nearest sonde station to Bracknell is Crawley, a distance of about 50km away.

A comparison of total ozone measurements made by the TOMS satellite over the Bracknell and Camborne sites has shown that there is an extremely high correlation between them, as might be expected from their proximity, and for the purposes of this study they have been treated as one station.

Dobson spectrophotometers have been used for all total observations made at both these stations. For the period 1979 to mid-1990, Dobson No 2, Professor Dobsons own instrument, was the main spectrophotometer in use, with No 41 as a backup, while since then the majority of observations have been made by No 41, the U.K. standard instrument. For short periods since 1990, instruments Nos 32 and 35 have replaced No 41.

2 The annual ozone record

An examination of the re-evaluated ozone values over the period shows a seasonal variation typical of mid-latitude stations in which total ozone values rise from a minumum of about 290 dobson units in autumn to a maximum of around 405 dobson units in spring, after which there is a steady decline till autumn. The variability of total ozone amount is high during the winter when ozone amount is increasing, but low during summer when it is decreasing. Dobson (1930) and others have suggested that the annual ozone cycle is due to the transport of air with high ozone mixing ratios from over the equator to high latitudes by the vigorous winter-time stratospheric circulations. Apart from variability due to the global circulation of ozone, total ozone amount has a variation on the order of days that correlates well with locally measured meteorological quantities such as sea level pressure, tropopause height, or stratospheric temperatures. Dobson (1928,1946), Reed (1950), Ohring and Muench (1960), Schubert and Muntenanu (1987), and Vaughan and Price (1991) have shown that much of this correlation is related to ascending and descending motions in the lower stratosphere. Finally, total ozone measurements usually show a diurnal cycle, with higher ozone values during the afternoon caused by daytime increases in boundary layer ozone. There has been a decrease of yearly mean ozone values of -4·6% per decade, which is similar to that found at other stations.

3 Recent measurements

During the last three years, two periods of particularly low ozone monthly means have been measured in southern England. The first of these was during the early months of 1990. The resulting ozone deficit was so great that the annual mean for the year was the lowest recorded during the re-evaluated period 1979 to the present. The value obtained was 325 dobson units compared with a typical value in the past of around 348 dobson units. The satellite data confirms that this record is independent of the fact that the measurement was made at Camborne rather than Bracknell. Although no re-evaluation of the data for the previous decade has been performed, it is of interest to compare the 1990 value with published annual means for this period. There is reason to believe that the No 2 dobson in use suffered less from instrumental problems during this earlier period than during the 1979 to 1990 period when these problems were directly responsible for the poor performance. On average the annual mean values for 1969 to 1978 were higher than those for 1979 to 1991 and none were as low as that in 1990. The second period of reduced ozone values was in December 1991 and January 1992. The January 1992 monthly mean was an exceptional departure from the value over the last decade, having a value of 266 dobson units. This compares with an average value for the January mean over the past decade of 342 dobson units, and is 3·5 standard deviations beneath this value. The only monthly mean in the whole period which is lower than this was November 1988 when the value was 262 dobson units and which was measured at a time of year when low ozone values normally occur. The January 1992 value was so exceptional that a careful check was made of the data. The weather for much of January was overcast, with stratus under an intense anticyclone, so that many of the observations were of the zenith cloudy type. The zenith polynomials were recalculated from data over the past two years but the monthly mean was not significantly altered. In addition checks were made on three periods in January when direct sun measurements were made. These agreed with the zenith observations to within a few dobson units. It should be noted here that as part of the observation program, several observations are made on each day, with as many different observation types as can be fitted in. Another problem is the low sun angle in January, the 'mu' value for midday being between 2·5 and 3·0. Because of this, regular total ozone measurements use the CD wavelengths which are more prone to error than AD observations. This is particularly relevant because during this month observations by lidar at Aberystwyth university show that dust from the Pinatubo eruption covered the region (Vaughan - private communication). However these measurements had detected the dust layer in November and showed that it continued into February and later, which covers periods when AD and CD simultaneous measurements were available. A careful examination of these simultaneous measurements in November, February and March shows that apart from the odd isolated occasion, the AD and CD reading were rarely more than a few Dobson units different. It therefore seems unlikely that the January CD measurements would have been affected by dust relative to the AD standard. It should be noted that any sulphur dioxide accompanying the volcanic dust would have had the effect of increasing rather than decreasing the CD measurement relative to AD. As a final check, TOMS satellite measurements for the Camborne station have recently been sent to us by Dr R. McPeters and these agree within 2% for the January monthly mean.

It therefore appears that the January monthly mean was real rather than related to instrumental problems, and it is useful to consider possible causes of the anomaly.

4 Meteorological anomalies

There seem to be at least three possible causes for the anomalous total ozone values in January, and the first two of these are related to the presence in January of a prolonged anticyclone that covered North-west Europe for much of December and January. Unusually high sea-level pressures of around 1050 hPa were measured in some parts, although not at Camborne itself. Such a blocking feature may have three effects. It will reduce total ozone due to the related ascent of stratospheric air. This is a relatively local effect. As noted above, several meteorological variables are well correlated with total ozone values but this correlation falls off significantly with distance. The best correlated meteorological quantity is the 100 hPa temperature, being at a height of around 17km which is just below the maximum in stratospheric ozone and is the region where vertical air motions are expected to have their greatest effect. The correlation between total ozone value and local 100 hPa temperature is about 60% at Camborne, which is typical of a mid-latitude station, but this correlation falls to 35% if ozone values at Bracknell, 340km distant, are correlated with Camborne 100hP temperatures. Although vertical motions contribute a large part to this type of correlation, it is probable that other advective effects play a minor part.

The second effect of such a prolonged blocking pattern is the possible cutting off of the circulation supplying ozone from the production regions over the equator to middle latitudes that starts in late autumn. Such advective components are unlikely to be detected in the local meteorological correlations.

The third possible cause of ozone depletion is a chemical mechanism related to the reactions involved in the formation of the Antarctic ozone hole. Possible factors involved are the low Stratospheric temperatures necessary for the chemical reactions to take place and which may be found in a winter anticyclone and the volcanic dust veil mentioned above which may provide a surface area for heterogenous chemistry to take place on (Hofmann and Solomon 1989).

It is not possible to differentiate between the last two depletion mechanisms from single station measurements, but it it possible to quantify the probable effect of vertical stratospheric air motions by making use of the time series of measured total ozone values together with simultaneous meteorological observations. A relation between the ozone values and meteorological variables can be derived from a correlation of past observations and this can be used to quantify the effects of weather systems on total ozone.

5 Meteorological correlations

The meteorological quantities used in the correlation studies described below were surface pressure, tropopause height, 100hPa temperature and 50hPa temperature. For the Camborne station these variables are all measured locally, but for the Bracknell station, upper air quantities were obtained from soundings at Crawley which reduced the correlations because of the separation of these two stations. For each meteorological quantity a linear regression was performed on two variables. The first variable was the deviation of daily total ozone values from either a filtered time series or a slightly filtered 12 year daily mean value. The second variable was the deviation of the meteorological quantity from either a filtered time series or a 12 year daily mean value. The filters used had a half width of 60 days but the result was not found to be sensitive to the period chosen, and neither was it sensitive to whether the filtered series or 12 year mean was used. The linear regression coefficients were then applied to the difference between the daily values of the meteorological quantity and its 12 year daily mean to give an ozone adjustment which could then be applied to the measured total ozone value. The resulting adjusted ozone value can be considered as the total ozone value that would have been expected in the absence of an anomaly in the meteorological quantity. The linear regression coefficients for the whole time series, together with the correlation coefficients for the Camborne station are given in the table below. Also shown are the adjusted total ozone mean values for January 1992.

Met. Var.	Regress. Coeff.	Corr. Coeff.	Adj.ozone Camb. Jan.'92
Sea lev. Pres.	1·5 DU/hPa	-0·4	283 DU
Trop. Height	0·0145 DU/Dm	-0·55	282 DU
100 hPa Temp.	6·0 DU/deg C	0·6	285 DU
50 hPa Temp.	6·0 DU/deg C	0·55	292 DU

As has been found by previous workers, the 100hPa temperatures are the Meteorological variables best correlated with total ozone measurements, followed by tropopause height and 50 millibar temperatures, with sea level pressures the least well correlated. It is noticeable that the adjusted January 1992 monthly mean total ozone values all lie fairly close together between 282 and 293 dobson units, with the value for the best correlated meteorological quantity, the 100hPa temperature being 285 Dobson units. This value is still considerably below the annual mean value for January of·348 Dobson units and is 2·5 standard deviations different. It therefore seems apparent that one or both of the other two mechanisms described above are necessary to explain the anomalous January value. However it should be noted that this analysis assumes that the correlation between meteorological variables and ozone amount is not itself significantly affected by the anomalous synoptic pattern.

6 Adjusted winter ozone values

The use of adjusted total ozone values has several advantages in the study of time series from a station. In general the standard deviation of adjusted daily ozone values is reduced by about 30% from that of non-adjusted values, and a graph of daily ozone values over a year shows a significantly reduced scatter. One particular application is in the comparison of total ozone time series with 100hPa temperatures. A technique often used (Bojkov - private communication) is to form an average annual time series of monthly means, the average being taken over a period of a decade or more. A time series of differences is produced by subtracting these averaged monthly mean values from the individual monthly means and normalising the differences by dividing by the standard deviation of the observations for a month. A similar series is then constructed for the 100hPa temperature observations and the two series are compared. However if ozone values adjusted for 100 hPa measurements as described above are used, there is no need to compare with the 100hPa series as the correlation is automatically included. The normalised difference series is found to have considerable less scatter and is much easier to use. This plot has applications in the detection of anomalies in total ozone values and can also be used in re-evaluation of instrument calibrations.

Another method of applying adjusted ozone values is by plotting a time series of a particular month in a year. This plot has been used for the Bracknell - Camborne time series and for all the plots, the adjusted ozone values show less scatter than the unadjusted values. As noted previously, the scatter is greater in the winter than in the summer months, and the plots show that, as is well known, part of this increased scatter is due to meteorological variations.

The plots for January show a continuous decline in total ozone amount over the last decade. This decline is pronounced only in the spring months and is a major component of the decrease in annual ozone mean values. Use of data published in the decade 1969 to 1979 shows that this decline spans both decades. There is a very pronounced drop in the monthly mean ozone value in January 1992, which is particularly clear in the adjusted ozone plot. A drop in monthly mean ozone value is also evident in the plot for the previous month of December 1991. Looking back over the previous decade there are noticeable dips in adjusted ozone value in December 1982 and January 1983 although the reduction in ozone was not nearly so extreme in those cases as for 1991/1992. Several workers (e.g. Angell et al.,1985) have already noted a minimum in total ozone at several northern hemisphere stations in the winter of 1982/1983

These two winters have the following circumstance in common, that they were both preceded by a major northern hemisphere volcanic eruption in the previous late spring/early summer and in both cases the dust from the eruptions reached the United Kingdom during the autumn. The two eruptions were those of El Chichon and Pinatubo. No other major eruptions with dust significantly affecting the U.K. occurred during the decade. It is possible that the reductions in total ozone value noted during the winter months over southern England for these two years are in some way related to the two eruptions. As mentioned above, such an anomaly may have occurred either due to changes in the stratospheric circulation or by chemical processes or by a combination of these two effects. However it is also possible that the ozone reductions are unrelated and have different causes. In particular, there was a pronounced ENSO event in 1982 and several studies of the 1983 ozone minimum (e.g. Chandra and Stolarski 1991) indicate that much of that anomaly was related to the Quasi-Biennial Oscillation, although some may have been an effect of the volcano.

7 Conclusions

A study has been made of the recently re-evaluated time series of daily total ozone values for the period 1979 to 1992 for southern England. The series consists of measurements made at two stations, Bracknell and Camborne. The series shows a steady decline in ozone values in the spring months over the period, and this is consistent with data from an earlier decade that has been published but not re-evaluated. Of exceptional note is the monthly mean for January 1992 which was very significantly reduced from the normal value, and was the lowest so far measured for this. month. This winter was also noteworthy for a prolonged period during which a blocking anticyclone dominated the region, and the possibility existed that this was related to the ozone anomaly.

It was possible to determine whether the origin of the low ozone value lay in ascending stratospheric motions. A linear regression analysis of ozone value deviation against 100hPa temperature deviations was used to reduce ozone values to those expected in the absence of high pressure. The assumption was made that the normal regression relation was not affected by atmospheric anomalies during the winter. This showed that vertical motions in the stratosphere only accounted for part of the ozone anomaly and that the main cause of the ozone deficit lay either in a reduced stratospheric circulation to which the anticyclone may be related or in chemical effects in the reduced stratospheric temperatures above the high pressure area. A study of the ozone time series adjusted to remove variations correlated with meteorological quantities, showed that during the period since 1979, one other winter, that of 1982/3, showed a similar although less well defined deficit in total ozone values. It is possible that these two periods of low ozone amounts are related to the fact that large quantities of volcanic dust covered the region on these two occasions. However work that included a far greater area than a single station is necessary to show that such a correlation indeed exists. Previous work on the 1983 anomaly has indicated that much of the ozone reduction then may be attributable to non-volcanic causes.

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