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GLOBAL OZONE MINIMA IN THE HISTORICAL RECORD

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Abstract. The magnitude and structure of the global total ozone minimum between 1958 and 1962 is similar to that observed between 1979 and 1983. Analysis of the single station data that exhibit the most pronounced minima suggest that the spatial structure of the global minimum is different from the currently observed reduction. Very low north polar values were observed, but there is no indication of anomalously low ozone in Antarctica. The temporal relationship to the sun spot cycle is similar in both time periods. Rather than solar terrestrial interaction, however, a more likely explanation of the early 1960's reduction is normal climatology caused by a persistent period of planetary wave activity. Such a natural explanation may also be appropriate for the current depletion.

Introduction

Farman et al. [1985] and Stolarski et al. [1986] have documented the decrease of ozone over Antarctica since 1978. Angell et al. [1985] have documented a global decrease of ozone, with the north temperate zone showing record low values in 1983 and an apparent return to more normal values in late 1983. The purpose of this paper is to re-examine the global ozone minimum in the early 1960's.

The early 1960's minimum is illustrated in Figure 1. This figure is an update of figures that have been presented in Angell et al. [1985, Figure 1] and Angell and Korshover [1983, Figure 2; 1978, Figure 2; 1976, Figure 2; 1973, Figure 1]. Both Figure 1 and the updated data were provided by J.K. Angell [personal communication]. The data are from ground based measurements and are archived in Ozone Data for the World (published by, Atmospheric Environment Service, Department of the Environment, Downsview, Ontario, Canada). The data analysis technique and details on which stations are used in the production of Figure 1 can be found in the above references. Moxim and Mahlman [1980] have documented the ability of the network used by Angell and Korshover [1976] to represent global ozone. Of particular note in Figure 1 are:

A. The global decrease of total ozone between 1979 and 1983, the partial recovery of the ozone in 1984, and then a further decrease.
B. A global decrease in ozone between 1958 and 1962 that is very similar in both magnitude and shape to the 1979-1983 depletion.
C. The pronounced decrease in south polar ozone, particularly between 1984 and 1985.
D. The pronounced decrease in north polar ozone between 1958 and 1962.

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Even though the polar deceases of total ozone in C and D are the largest, because of the area weighting these decreases are not driving the global budget. The polar observations are based on a very limited data set, but the south polar data, which contains only Admundsen Scott (90 S) and Syowa (69 S, 40 E), captures the well documented decrease since 1978.

Figure 1 indicates that changes in global ozone of 1-2% per year are natural and that there are at least two situations were a ≈4% decrease in global total ozone has occurred over the course of ≈4 years. Also, the figure shows that when the TOMS and SBUV instruments were put into operation in 1978 the global total ozone was near a historical maximum. Global total ozone calculated from the SBUV data shows qualitative agreement with the ground based data shown in Figure 1 with SBUV ozone going from approximately 2% above the 1978-1984 time average to 2% below the time average [D. Heath, 1986, personal communication].

The re-examination of the 1958-1962 minimum is important for two reasons. The first is to determine how far the current ozone depletion differs from climatology. The second is that significant large scale depletions in the historical record may help to evaluate (and constrain) the chemical and dynamical mechanisms that have been proposed to explain the Antarctic ozone depletion. For instance, the mechanism described by Callis and Natarajan [1986] contends that the Antarctic depletion is caused by solar cycle modulation of the odd nitrogen budget. If the solar cycle is responsible for such large scale depletions, then there should be evidence of previous solar cycles in the data record.

The early 1960's minimum has received considerable attention because of possible effects by atmospheric nuclear explosions [for a review see CIAP, 1975; Bauer and Gilmore, 1975]. Foley and Ruderman [1973], Angell and Korshover [1973, 1976, 1983], and Bauer and Gilmore [1975] concluded that there was no definitive ozone depletion caused by nuclear testing. Johnston et al. [1973] argued that the observed ozone increase between 1963-1970 was the readjustment to an environment free from nuclear testing. The data presented in Figure 1 indicate low ozone values and a downward trend occurring before the multimegaton tests of 1961 and 1962. There was no testing between 1958 and 1961. Furthermore the individual station data presented in the next section are not consistent with a depletion caused by regional nuclear testing. Therefore it is concluded that the 1958-1962 reduction of ozone is not the result of nuclear testing.

Individual Stations

The analysis here will concentrate on single station data in order to characterize the

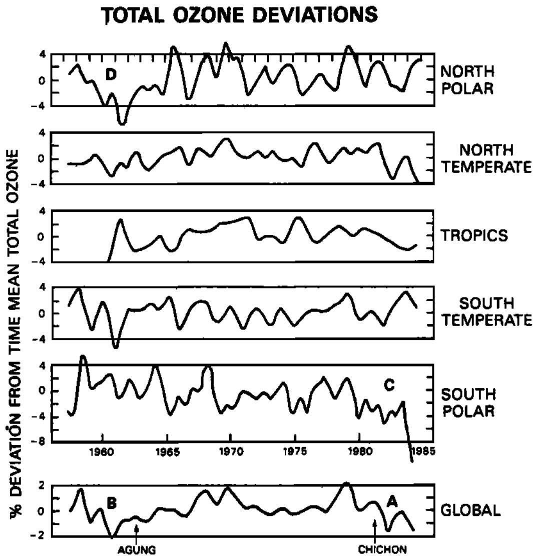

Fig. 1. Per cent deviation of seasonal ground based total ozone from time average (courtesy of J.K. Angell).

temporal and spatial structure of the 1960's minimum. The data come from Ozone Data for the World. The global ozone values between 1961 and 1962 result from a reduction that is visible at many stations. The northern hemisphere stations have received much attention in the nuclear weapon-ozone studies cited above. The emphasis here will be placed on the south temperate zone stations which show distinct minima in 1961 and 1962.

Some of the reported stations show very low values. An attempt has been made to verify the data with neighboring stations. However, neighboring stations are frequently far away and in very different meteorological situations. In light of the current very low values, it is felt that it is not prudent to reject these historical data simply because the values are low.

Figure 2a-c shows the monthly averaged total ozone for Brisbane (27 S, 153 E) and Aspendale (38 S, 145 E), Australia, and Kagoshima (32 N, 131 E), Japan. All of these stations are in the "Western Pacific." Figure 2d shows the 12 month running mean of the Brisbane and Aspendale data.

The filtered Brisbane data (Figure 2d) shows a distinct ozone minimum between May and November of 1961. The Aspendale data shows a similar, less distinct, minimum. The Aspendale data give the impression that there is a change in the quasi-biennial oscillation between the early and middle 1960's. Angell and Korshover [1973, 1976, 1978] have noted the change in the ozone quasibiennial oscillation, and they have attributed the global minimum in the early 1960's to an exceptionally strong quasibiennial oscillation. An interesting feature in the unfiltered Brisbane data (Figure 2a) is seen by looking at the yearly minima which show a smooth rise between 1962 and 1968 and a decrease between 1968 and 1974.

The unfiltered Kagoshima data shows a very distinct absolute minimum in December 1960 and January 1961, the year prior to the Brisbane and Aspendale reduction. There are consistently low daily measurements throughout this time period with 9 readings below 200 D.U. There were known calibration errors with the Kagoshima instrument and the instrument was replaced in 1963 (Bojkov, 1986, personal communication). Therefore, the credibility of the Kagoshima data is a question. Nevertheless the return of the measurements in 1962 to more nearly climatological values and the spatial coherence with other stations in the Western Pacific make the data worth noting.

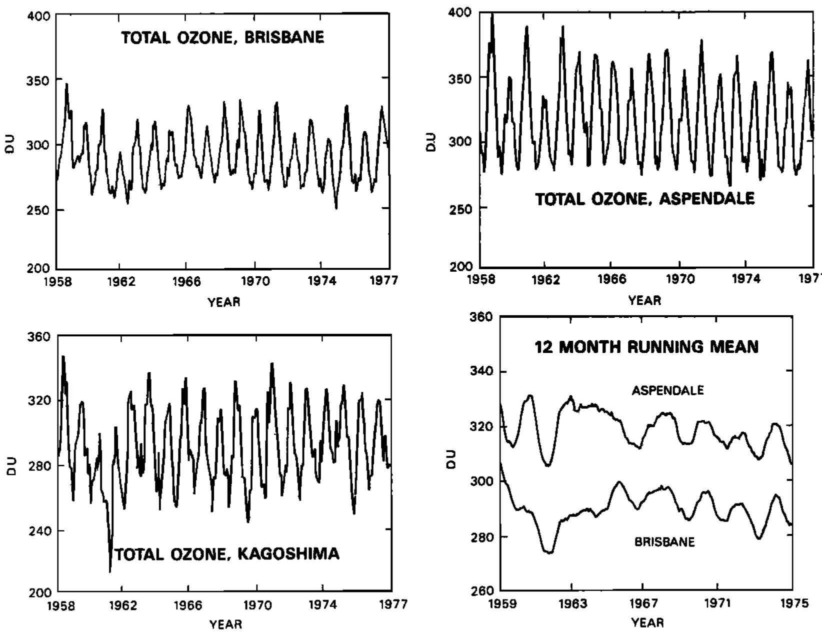

Fig. 2. a) (upper left) Monthly average total ozone for Brisbane, Australia from 1958-1976. b) (upper right) The same as 2a but for Aspendale Australia. c) (lower left) The same as 2a but for Kagoshima, Japan. d) (lower right) Twelve month running mean of 2a and 2b to remove the annual cycle.

The data from Sapporo (43 N, 141 E; ≈10° north of Kagoshima) does not show a pronounced minimum in late 1960, early 1961. There is, however, a slight downward tendency of the yearly minima between 1958 and 1961. Sapporo is a distinctly midlatitude location, and Kagoshima is in a more tropical regime. Therefore, the dynamical processes at the two stations are different, and the fact that Sapporo does not mimic Kagoshima is not surprising.

The Resolute (74 N, 95 W) data, which is an important part of the north polar data record reported in Figure 1, does show a 1961-1962 minimum. As is seen in Farman et al. [1985] the Halley Bay (76 S, 27 W) record does not show an early 1960's minimum of even approximately the magnitude of the currently observed depletion. The relatively low values of September-October 1960-1961 are well within the climatology of the pre 1978 record. The relatively low values at Argentine Island (65 S, 64 W) during 1962 and 1963 are suspect because the instrument was changed in 1962 and 1964 [Repapis et al., 1980].

Measurements taken with the experimental Vassey instrument at Dumont d'Urville (67 S, 140 E; hereafter, DdU) are worth noting because of the presence of some very low values. The DdU data are not included in Figure 1. The data from DdU for 1958 show very low quality with total ozone readings regularly varying from below 200 D.U. to above 400 D.U. on the time scale of days. These data are frequently inconsistent with surrounding stations and are suspect [R. Bojkov, 1986, personal communication].

By 1962 there is an obvious increase in the quality of the DdU data (measured by standard deviation and comparison to Halley Bay during late summer). During April of 1962 (in autumn, during low light conditions) there is a systematic downward tendency of the DdU values to less than 200 D.U. These very low values are worthy of further investigation.

Summary and Discussion

Examination of individual station data helps to characterize the nature of the global ozone depletion observed between 1958-1962. It would appear that there is a distinct minimum in late 1961-early 1962 that occurs before the eruption of Agung and is not directly related to nuclear testing.

The early 1960's event does not exhibit the same spatial structure as the current reduction. Very low values were not reported from Halley Bay and Argentine Island in the 1960's. The persistent obvious decline of ozone over a large specific area was not observed in the early 1960's, but the lack of global coverage by satellites would make such a feature difficult to observe. As is shown in Figure 1, without satellite data, the current global minimum would be dominated by the north temperate zone, and the south polar data would appear conspicuously anomalous.

Callis and Natarajan [1986] have suggested that the current ozone reduction over Antarctica is related to odd nitrogen production associated with the solar cycle. They also predict significant ozone reductions at midlatitudes. Therefore it is of interest to determine the relation between the solar cycle and the 1958-1962 depletion. After the 1957-1958 solar maximum and after the 1979 maximum there is a drop in global total ozone. The current depletion is much more long lived than the 1958-1962 depletion. If there is a depletion associated with the 1969-1970 solar maximum, then it is not as large as that associated with the other solar cycles. Pittock [1978] has reviewed attempts to isolate solar cycles in geophysical data including ozone.

The presence of the 1960's minimum suggests that enhanced chlorine levels are not required to produce changes in global total ozone similar in magnitude to the current reduction. Total ozone variations on an annual time scale are largely determined by transport [for instance, see Rood, 1983]. A quasi-biennial oscillation is obvious in Figure 1. The distinct presence of the minima at stations in the Western Pacific is suggestive of El Nino effects. Assuming that there is no new exotic chemistry, then it is logical to investigate the role of dynamics in the current depletion.

Planetary waves are a dominant transport mechanism in determining the total ozone distribution. Any systematic trend in planetary wave activity could affect how much ozone is transported into the polar regions. Namias [1970, 1972] has stated that decadel episodes in sea surface temperature (SST) are in fact normal climatology. In particular the SST data reported by Namias [1972, Figure 16] show unusual behavior in 1957-58 followed by a period of very persistent SST anomaly from 1958-61. Since the SST is important in determining planetary wave forcing (and therefore polar latitude ozone and temperature budgets) decadel episodes in polar ozone and temperature may in fact be normal climatology. Ten to twenty year variations ("trends") in the ozone record between 1923 and 1955 have been noted by Angione and Roosen [1983]. They found no apparent relationship to the solar cycle or nuclear testing.

Comparison of the 1958-1962 global ozone minimum to the current reduction is confounded by many aspects: the quality and quantity of the data, atmospheric dynamic states, increasing halocarbons and other photochemically and radiatively active compounds, volcanic eruptions, and nuclear testing. Both minima may be natural events with different signatures.

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