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[1] Temporal autocorrelations of monthly mean total ozone anomalies over the 35–60°S and 35–60°N latitude bands reveal that anomalies established in the wintertime midlatitude ozone buildup persist (with photochemical decay) until the end of the following autumn, and then are rapidly erased once the next winter's buildup begins. The photochemical decay rate is found to be identical between the two hemispheres. High predictability of ozone through late summer exists based on the late-spring values. In the northern hemisphere, extending the 1979–2001 springtime ozone trend to other months through regression based on the seasonal persistence of anomalies captures the seasonality of the ozone trends remarkably well. In the southern hemisphere, the springtime trend only accounts for part of the summertime trends. There is a strong correlation between the ozone anomalies in northern hemisphere spring and those in the subsequent southern hemisphere spring, but not the converse. *INDEX TERMS:* 0340 Atmospheric Composition and Structure: Middle atmosphere—composition and chemistry; 0341 Atmospheric Composition and Structure: Middle atmosphere—constituent transport and chemistry (3334). **Citation:** Fioletov, V. E., and T. G. Shepherd, Seasonal persistence of midlatitude total ozone anomalies, *Geophys. Res. Lett.*, *30*(7), 1417, doi:10.1029/2002GL016739, 2003.

1. Introduction

[2] Midlatitude total ozone is controlled by a balance between transport and photochemical loss. Seasonal variations in this balance lead to a marked seasonal cycle in total ozone, with a buildup through the winter when transport is dominant, and a decline through late spring and summer when transport decreases and photochemical loss dominates. The greater abundance of springtime total ozone in the northern hemisphere (NH) relative to the southern hemisphere (SH) reflects the greater wintertime transport in the NH due to larger planetary-wave amplitudes. However, the total ozone abundance in autumn is much more similar between the two hemispheres, suggesting that ozone is close to photochemical control by this point in the year. Indeed, there is a clearly defined anti-correlation between wintertime ozone buildup and summertime ozone loss in the NH [*Fusco and Salby*, 1999; *Randel et al.*, 2002]. The reason is simply that chemistry can only destroy as much ozone as has been transported into midlatitudes in the first place; the more transport there is in a given winter, the more chemical loss is required to return to photochemical control by autumn.

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[3] To the extent that ozone does return to photochemical control by autumn, there is a chemical "resetting" of ozone each year. It has therefore been argued [*Fusco and Salby*, 1999; *Randel et al.*, 2002] that the observed interannual correlation between stratospheric planetary-wave driving and total ozone buildup can be extended to decadal timescales, in order to quantify the dynamical contribution to the ozone decline observed over midlatitudes. There are several issues with this analysis. Since the chemical and dynamical effects are coupled. Nevertheless, it is interesting to assess the extent to which interannual total ozone variations persist throughout the year, and whether they are erased by autumn.

2. Data Sets and Analysis Methods

[4] The merged satellite data set used here is prepared by NASA and combines the TOMS and SBUV-SBUV/2 data; it is available at http://code916.gsfc.nasa.gov/Data_services/. The data set provides a nearly continuous time series of zonal monthly mean total ozone values for the period from 1979 to 2001. However, the data for July–August 1993, and February and August–September 1994, are missing. Estimates of zonal monthly mean total ozone from ground-based measurements were used to fill this gap [*Fioletov et al.*, 2002].

[5] Autocorrelations of area weighted zonal monthly mean total ozone values over the 35°–60°S and 35°–60°N zones as a function of time were calculated for each month of the year and for each hemisphere. A 23-year long set of measurements makes it possible to accurately estimate the correlation coefficient between different months of the year. Our analysis shows that the correlation coefficients between ozone values for the same month in different years are low, therefore each year can be considered as independent. In this case, correlation coefficients greater than 0.4 are statistically significant (the 95% confidence level).

3. Results

[6] Figure 1 shows time series of midlatitude total ozone for each year from 1979–1980 to 1999–2000, for each hemisphere, and illustrates the features of the total ozone distribution noted earlier. The winter buildup and late-spring/summer decline are evident. Examination of individual years reveals that negative or positive anomalies seen in winter-spring appear to persist through the summer/early-autumn period.

[7] The total ozone autocorrelations are quantified in Figure 2 for each hemisphere. It is seen that in the NH, anomalies decay slowly during winter, spring and summer, but drop sharply through autumn. In the SH, early-winter anomalies do not persist as long as in the NH, but as in the

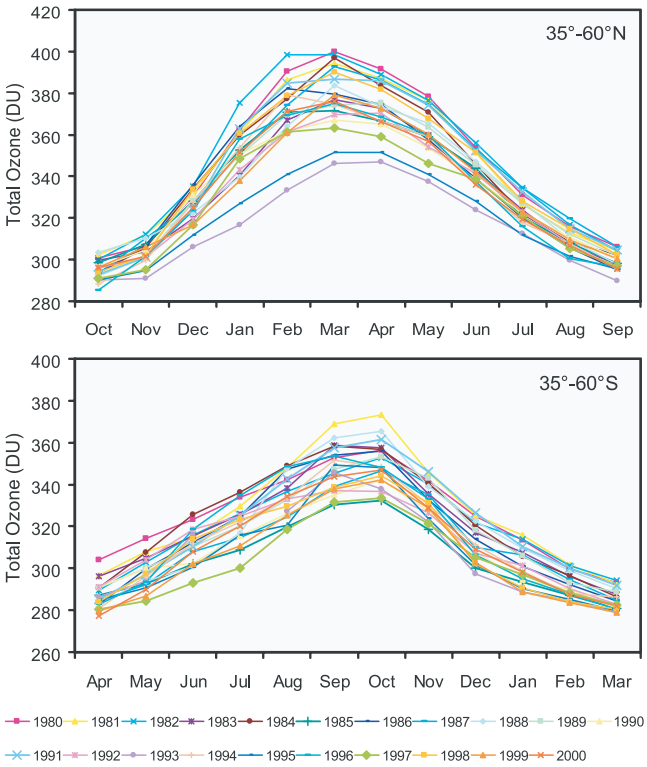

Figure 1. Area weighted total ozone values in Dobson Units (DU) in different years as a function of the month.

NH the anomalies are erased during autumn. This erasure of the anomalies is a dynamical effect, associated with the beginning of the next winter's buildup. High correlations with earlier months of the same winter partly reflect the fact that the ozone anomaly at a given month arises from the anomalous buildup of ozone in all prior months of the same winter. However, the NH correlations between November and subsequent months are too high (0.6–0.7) to be explained by this fact alone, given that November is so early in the buildup cycle (Figure 1). This seems to imply a seasonal persistence in the anomalous planetary-wave driving that is mainly responsible for anomalous ozone buildup.

[8] For this (and the following) figure, a linear trend was estimated for each month of the year and then subtracted from the data. Long-term ozone variations are not linear and therefore the autocorrelation function does not tend to zero even for detrended data. Similarly, the negative correlations in the winter before and after are associated with the QBO. The QBO-related signal is season-dependent with maximum in the spring, and its amplitude is higher in the SH [e.g., *Randel and Cobb*, 1994]. Nevertheless these longer-term correlations do not obscure the basic fact that there is a rapid erasure of ozone anomalies at the end of each fall, in both hemispheres.

[9] A distinct feature seen in Figure 2 is the "clustered" structure of the autocorrelation functions, especially for the NH where the autocorrelations are high (>0.5) within one year from November to November of the next year, and low outside that interval. This suggests that there is considerable seasonal predictability in midlatitude total ozone, depending on the time of year. Figure 3 shows the correlation coefficients between ozone values at a given month of the year with ozone values at subsequent months. In other words, Figure 3 demonstrates the "predictive capability" of ozone values in different months of the year. Predictability is extremely high for the NH where ozone values at the time of the maximum (March–April) have high (>0.75) correlation coefficients with ozone values for any later month up to October. The central diagonal represents the sharp drop-off in the correlation coefficient which occurs between October (on the left) and November (on the right). Correlation coefficients between ozone at the maximum and ozone in subsequent months for the SH are not as high as for the NH, although the late austral summer/early-autumn values are highly correlated with November–December values.

[10] Examples of the remarkable extent of the autocorrelations are shown in Figure 4. It is possible to predict summer and autumn ozone from the measurements in late spring-early summer. However, the predictive capabilities discussed here are applicable for latitudinal belts or vast regions only. The month-to-month autocorrelation of monthly averaged ozone records at individual sites is much smaller, typically ranging from 0.1 to 0.5 [*Weatherhead et al.*, 2000], and it has very limited predictive capabilities.

[11] The high predictability of midlatitude total ozone from the spring maximum to the late autumn reflects the fact that dynamical variability is virtually absent in the summer stratosphere, so ozone simply relaxes photochemically in a predictable fashion from whatever maximum is established by the wintertime buildup. The interannual variability of ozone consists then of variability in the wintertime buildup, followed by a "slaved" variability in

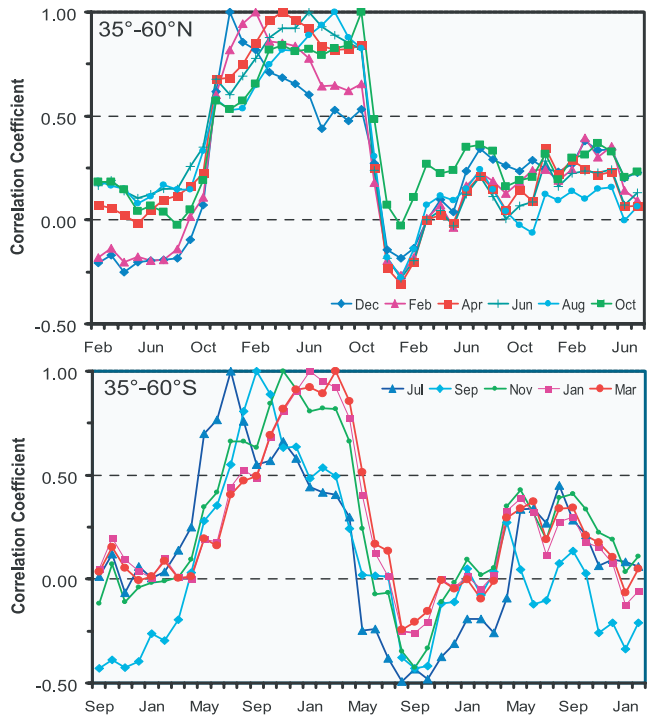

Figure 2. Total ozone autocorrelation function for different months of the year estimated using detrended data from 1979–2001. Each curve represents the autocorrelation with respect to a particular month. Its value is unity for the month itself. Points to the left side of that month represent data prior to that month and to the right side data after that month.

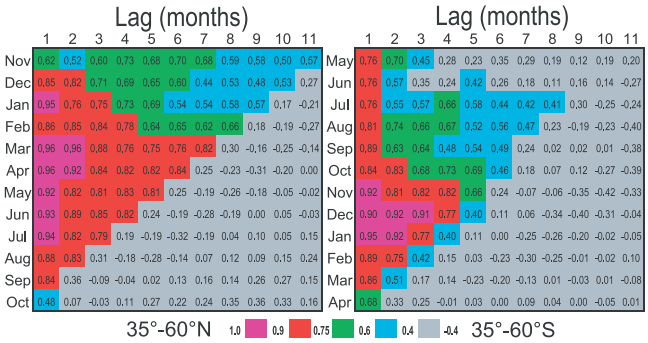

Figure 3. Correlation coefficient between ozone values at a given month of the year with ozone values in the subsequent months. For example, the correlation coefficient between total ozone in March and in the subsequent April is shown in the first column for March.

the summertime chemical loss. The ozone buildup typically ends in April (for 35°–60°N) and in November (for 35°–60°S). If we assume a linear relationship between ozone anomalies at the end of the buildup period and in subsequent months, it is possible to quantify the photochemical relaxation rate. Figure 5a shows the relationship between NH ozone anomalies in April (November for the SH) and anomalies in other months estimated using a linear regression. It is seen that the decay rate is identical in the two hemispheres, with an e-folding time of several months.

[12] The seasonal persistence of ozone anomalies implies that some of the long-term trend in summer-autumn ozone simply reflects a photochemically damped signal from the springtime ozone trends. Figure 5b shows the results for 35°–60°N if a monthly trend is calculated by multiplying the trend value for April by the regression coefficient between April and that month plotted in Figure 5a. The slopes of the linear trend function estimated for each month of the year are also shown. Calculations of results based instead on the March or May trends give virtually the same result. Similarly, Figure 5c shows the results for 35°–60°S based on trends in October, November, or December. The long-term trends over the NH are seen to agree extremely well with the estimates predicted from the relationship

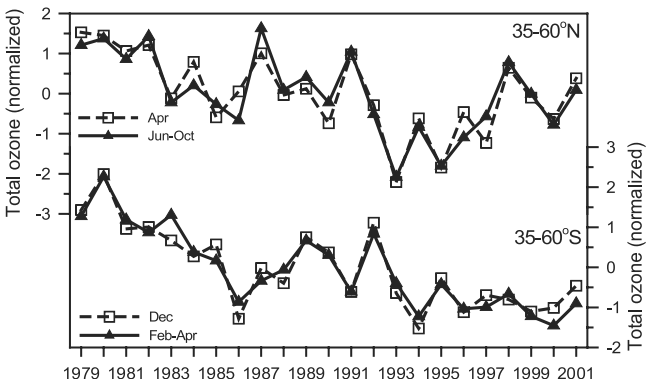

Figure 4. Normalized (i.e. with the mean = 0 and standard deviation = 1) area weighted total ozone. Values are plotted for April and for the average for June–October for 35°–60°N, and for December and for the average for February–April for 35°–60°S. The correlation coefficient between data sets is 0.93 for 35°–60°N, and 0.96 for 35°–60°S.

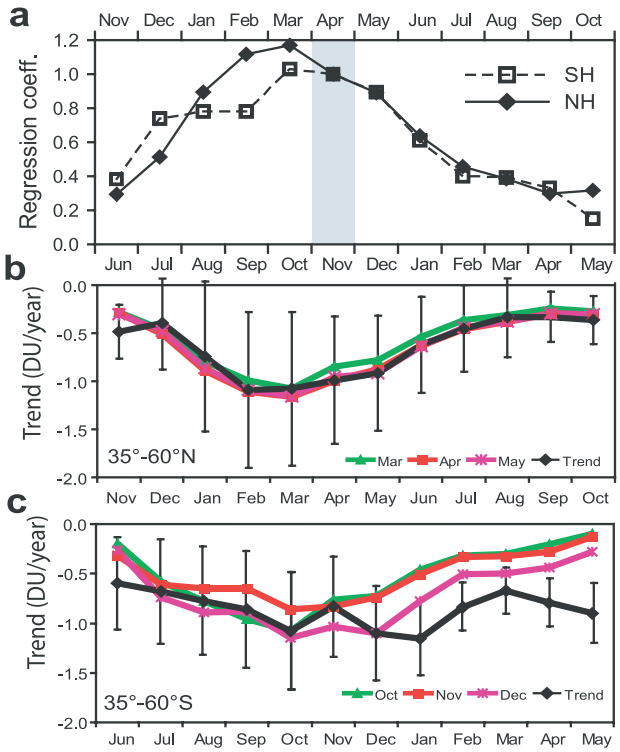

Figure 5. (a) Linear regression coefficients (solid line) between ozone anomalies in April and in other months of the year (labeled at the top) for the 35°–60°N. Similarly, the dashed line shows the regression coefficients between November anomalies and those in other months for 35°–60°S. Detrended data were used. (b) Total ozone trends at 35°–60°N in different months of the year for the 1979–2001 period with 95% confidence limits (solid black line). Total ozone trends estimated from the linear trend in March, April, and May using the linear regression coefficient between the March (April, May) detrended values and the values in other months. (c) As in (b) but for 35°–60°S.

between ozone anomalies in April and in other months. This suggests that the seasonality of the long-term trend in the NH results from the seasonality of ozone autocorrelations, and that the trends in all seasons are determined by the (negative) trends in the winter/spring buildup. The implication is that halogen-induced perturbations to summertime chemistry are not required to account for summertime ozone depletion, which is consistent with our understanding of ozone photochemistry [*Fahey et al.*, 2000; *Brühl and Crutzen*, 2000]. In contrast, the negative linear trend in January–April over the SH is significantly stronger than what is predicted from the autocorrelation of detrended ozone values, based on trends in spring.

[13] The winter-spring ozone buildup is driven by planetary-wave induced transport, which is modulated by the tropical zonal winds [*Holton and Tan*, 1980; *Tung and Yang*, 1994]. Tropical zonal winds have considerable inertia, as a result of the flywheel effect [*Scott and Haynes*, 1998], and as manifested in the QBO. Some similarity in interannual ozone variability over northern and southern midlatitudes is therefore expected. It is found that the largest interhemispheric correlation coefficient (0.71 for detrended data) is between total ozone over 35°–60°N in April and over

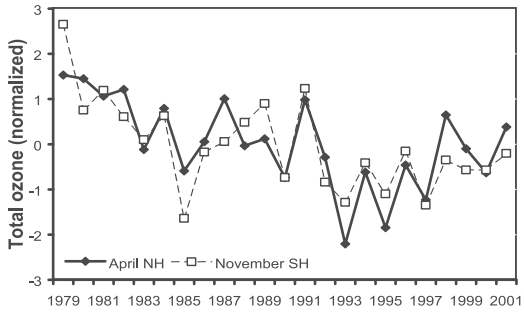

Figure 6. Normalized total ozone variations over 35°–60°N in April and 35°–60°S in November.

35°–60°S in November of the same year. These months represent the end of the buildup period in the two hemispheres, when the cumulative effect of transport anomalies is the greatest. The magnitude of the long-term percentage trends at these two months is almost identical (−0.26% per year for April and −0.25% per year for November), and the correlation coefficient for the original (not detrended) data is even higher (0.81). The normalized data records for 35°–60°N in April and for 35°–60°S in November are plotted in Figure 6. It is clear that NH anomalies in April are reflected in SH anomalies in the following November, but not vice-versa; the correlation coefficient between SH November and the following NH April, using detrended data, is only −0.14. The causality suggested by this is that the stronger NH planetary-wave variability (which is reflected in the NH ozone variability) drives tropical wind anomalies which (through the flywheel effect) last long enough to modulate the SH planetary-wave driving, and hence the total ozone, in the subsequent SH winter through the Holton-Tan mechanism. However, the SH planetary-wave driving is evidently not strong enough to have a reciprocal effect on the NH. This suggests that SH stratospheric dynamical variability is, to some extent, slaved to the NH stratospheric variability, with a half-year offset (since variability is a wintertime phenomenon). While there is clearly a QBO component to the variability in both hemispheres [e.g., *Randel and Cobb*, 1994], the QBO signal cannot explain why NH anomalies lead SH anomalies but not the converse.

4. Summary and Discussion

[14] Analysis of detrended area weighted zonal monthly mean total ozone over northern and southern midlatitudes demonstrates that ozone values are correlated through the annual cycle from the buildup in winter-spring to the ozone minimum in autumn. NH ozone anomalies as early as November are significantly correlated (above 0.6) with the anomalies at the end of the buildup period. Particularly high correlation coefficients (>0.75) are found between ozone values at the time of the maximum (or immediately after) and in subsequent months, until the beginning of the next buildup cycle. The correlation becomes insignificant in November in the NH and in May in the SH. The high correlation between ozone maximum values and summer/early-autumn values can be regarded as a confirmation of the causal link between the winter-spring ozone buildup due to transport and the subsequent chemical loss.

[15] The ''clustered'' structure of the autocorrelation functions found here has implications for statistical models of ozone trend estimation. Although a better understanding of the autocorrelation does not affect the trend values, it could improve estimates of the trend errors and may help to determine the most informative seasons from the point of view of trend detectability.

[16] Long-term trends over northern midlatitudes are in line with interannual variability: trend magnitudes from late spring to early autumn are related to the trend in April in the same way as the corresponding monthly ozone anomalies are related to the April anomaly in the detrended data. This suggests that changes in transport and/or chemical loss in the winter/early-spring ozone buildup may be enough to explain the seasonality of the ozone decline over northern midlatitudes. In contrast, the summer ozone long-term decline over southern midlatitudes is stronger than one would expect purely from the spring trend together with the link between the interannual spring and summer ozone values. Transport of ozone-depleted Antarctic air may contribute to the midlatitude decline in summer-autumn. However, it was shown that midlatitude ozone anomalies in NH spring and in the following SH spring are strongly related, presumably through NH-planetary-wave induced tropical wind anomalies. If so, any dynamical contribution to NH ozone trends would be expected to contribute to SH trends as well.

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