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Technical Note: A SAGE-corrected SBUV zonal-mean ozone data set

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Abstract. A stratospheric vertically resolved, monthly, zonal-mean ozone data set based on Satellite Aerosol and Gas Experiment (SAGE) and Solar Backscatter UltraViolet (SBUV) data spanning 1979–2005 is presented. Drifts in individual SBUV instruments and inter-SBUV biases are corrected using SAGE I and II by calculating differences between coincident SAGE-SBUV measurements. In this way the daily, near-global coverage of SBUV(/2) is combined with the stability and precision of SAGE to provide a homogeneous ozone record suitable for trend analysis. The resultant SAGE-corrected SBUV data set, shows, for example, a more realistic Quasi-Biennial Oscillation signal compared to the one derived from SBUV data alone. Furthermore, this methodology can be used to extend the present data set beyond the lifetime of SAGE II.

1 Introduction

Monitoring of stratospheric ozone remains an important endeavor for many reasons, chief among them being to clearly identify the recovery of stratospheric ozone following the implementation of Montreal Protocol and subsequent amendments (Austin and Butchart, 2003) and to determine how climate change may be impacting stratospheric ozone, and visa-versa (Waugh et al., 2009). Such tasks require vertically resolved, high quality, global, long-term ozone datasets. While there have been a large number of satellite instruments measuring stratospheric ozone over the past thirty years, each is subject to its own instrument effects (noise, systematic errors) and sampling issues (vertical and horizontal sampling, resolution, repeat time). Knitting together these varied sources into a single, homogeneous data record suitable for trend studies is a difficult challenge.

Several such datasets exist including ones based on SAGE (Satellite Aerosol and Gas Experiment) I and II data (Randel and Wu, 2007), SBUV (Solar Backscatter UltraViolet) and SBUV2 data (Frith et al., 2004), as well as those based on multiple instruments (Hassler et al., 2008; Jones et al., 2009). In this work, a global stratospheric ozone data set it constructed based on two long-term satellite ozone data records: SBUV and SAGE. The aim of this work is to combine the coverage and data density of SBUV with the stability and precision of SAGE to create a homogeneous, vertically-resolved ozone data set. In essence, SBUV will be used to capture short-term variability (days to months) and SAGE will be used for the long-term variability (months to years).

There have been previous attempts at combining data from the various SBUV and SBUV2 instruments, collectively referred to as SBUV(/2). A "merged ozone" data set (Frith et al., 2004) was constructed by adjusting the calibration of individual SBUVs based on comparisons during overlap periods. However, this algorithm does not completely remove biases in some individual SBUV/2 time series because the overlapping periods are not always long enough and biases are not always constant in time. Biases in individual SBUV(/2) instruments have been identified using the SAGE and Umkehr observations (Frith et al., 2004; Petropavlovskikh et al., 2005). There are also limitations related to the SBUV algorithm itself. As discussed by Bhartia et al. (2004), the algorithm is capable of retrieving ozone content for relatively thick (6–8 km) layers at 30–50 km, but very limited information can be retrieved outside these limits. As a result, the amplitude of ozone fluctuations could be dampened if such fluctuations have a fine vertical structure. To illustrate this, the Quasi-Biennial Oscillation (QBO) signal in SAGE II and the SBUV merged-ozone (downloaded from http://hyperion.gsfc.nasa.gov/Data_services/merged/index.html) is examined in Fig. 1.

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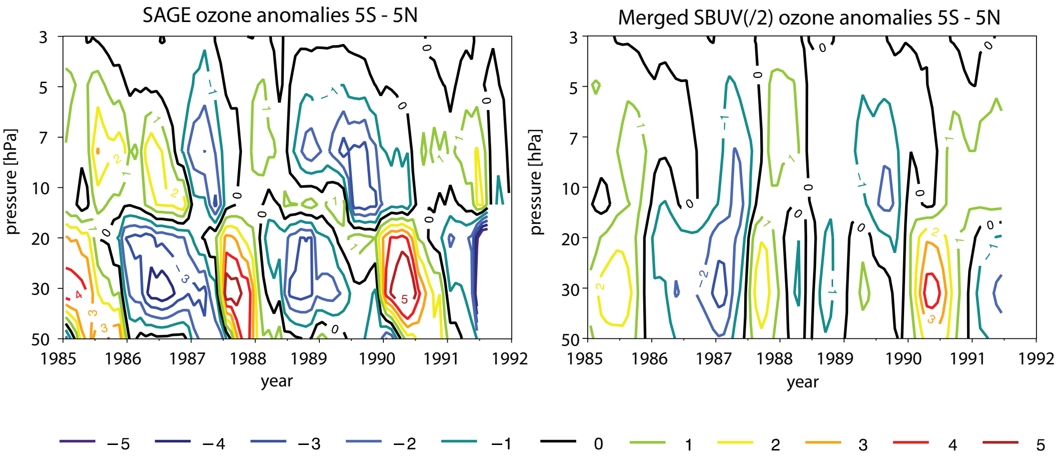

Fig. 1. Quasi-biennial signals in **(a)** SAGE II data and **(b)** merged SBUV data. Plotted are monthly, zonal-mean ozone anomalies in the tropics (5° S–5° N). Anomalies were calculated as percent deviations from the 1979–1990 means.

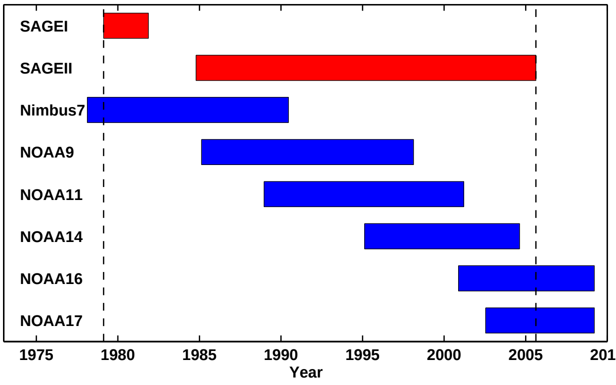

Fig. 2. Satellite instruments used in this study, and their temporal coverage. The period used to denote Dashed vertical lines indicate period of overlap used to create SAGE-corrected SBUV dataset (red – SAGE instruments, blue – SBUV(/2) instruments).

The QBO is a periodic oscillation of the zonal-mean wind in the tropical, lower-mid stratosphere with a period of about 28 months (Baldwin et al., 2001). It also manifests itself in other geophysical quantities, including ozone. Figure 1 shows the zonal, monthly-mean tropical (5° S to 5° N) ozone anomalies (monthly-mean with annual cycle removed). SAGE II data have been mapped onto SBUV layers (see below) so that equivalent quantities are being compared. The left panel, displaying SAGE II anomalies, shows the characteristic QBO downward propagation of the maxima and minima in the ozone anomaly with time (Randel and Wu, 1996). By contrast, while there is some oscillatory behavior in the merged-SBUV data, the amplitude is much smaller and the downward propagation is not properly captured as seen in the right panel.

2 Data sets

2.1 SBUV(/2)

The SBUV-family of instruments date back to 1978 when the original, SBUV, was launched on Nimbus 7. Operational versions, SBUV2, were launched in 1984 on NOAA 9 and later on NOAA 11, 14, 16, 17, 18, and 19. Collectively they cover the period from 1978 to present with minimal gaps. Figure 2 shows the temporal coverage of those used in this study.

SBUV(/2) measures sunlight scattered from the atmosphere and surface into the nadir via a scanning double monochrometer. Twelve discrete wavelengths from 252.0 to 339.8 nm are measured at a resolution of 1.1 nm. The ground swath is about 160 km × 160 km and provides daily, near-global coverage. Profiles are retrieved on a standard 21 layer grid such that there are 5 layers every decade of pressure. Hence each layer is roughly 3–3.5 km thick. Ozone data are reported for each layer as a partial column (in DU). The layers used in this study are given in Table 1 and span roughly 18–51 km. The SBUV(/2) vertical resolution is 6 km at an altitude of 40 km and increases above and below, with only one piece of vertical information below the number density peak (Bhartia et al., 2004). SBUV measures roughly 35 000 profiles per month. See Fig. 3 for coverage.

SBUV data version 8.0 (Bhartia et al., 2004), obtained from http://www.orbit.nesdis.noaa.gov, is used. Only profiles that are measured at a solar zenith angle of 80° or smaller and assigned an error code of “0” are retained. Furthermore, data in the aftermath of two major volcanic eruptions, El Chichon (1982) and Pinatubo (1991), are excluded as follows: for El Chichon all levels from 10° S to 30° N between March 1982 and February 1983, and for Pinatubo all levels from 20° S to 30° N between June 1991 and May 1992.

Table 1. SBUV (v8) layer definitions. Layer 1, not used in this study, is 1013–63.9 hPa.

SBUV layer number	Pressure limits (hPa)	Approximate altitude (km)
2	63.9–40.3	21
3	40.3–25.5	24
4	25.5–16.1	27
5	16.1–10.1	30
6	10.1–6.39	33
7	6.39–4.03	37
8	4.03–2.55	40
9	2.55–1.61	43
10	1.61–1.01	46
11	1.01–0.64	49

2.2 SAGE I and II

The SAGE series of instruments utilize the technique of solar occultation in which the sun is tracked during a satellite sunrise or sunset event. The first, SAGE I, was a four channel (380, 450, 600, and 1000 nm) spectrometer collecting data from 1979 to 1981. SAGE II was a seven channel spectrometer (385, 448, 453, 525, 600, 940, and 1020 nm) that operated between 1984 and 2005. See Fig. 2 for temporal overlap with the SBUV(/2) instrument series. Inversion of SAGE radiometric data first requires the normalization of spectra to a high-tangent altitude reference spectrum (Chu et al., 1989). From this all interfering species are removed, including Rayleigh, aerosols, and NO_2, whose concentrations are inferred simultaneously. The final step is the conversion of slant path ozone extinctions to vertical profiles of concentrations.

The solar occultation technique offers the benefit of being insensitive to the absolute response of the instrument which makes it ideal for long-term monitoring. Its primary shortcoming is that only two profiles are obtained per orbit and latitudinal sampling is uneven. On average, SAGE II measured about 800 profiles per month, with some tropical and/or midlatitudes not sampled in the summer and winter months. See Fig. 3 for coverage.

This study uses SAGE I version 7.0 and SAGE II version 6.2 (Wang et al., 2006). Each profile is reported in number density on a 0.5 km standard grid, 0.5–70 km, and is accompanied by NMC/NCEP (National Meteorological Center / National Center for Environmental Prediction) temperature and pressure profiles. SAGE pointing is stable with an uncertainty of about 0.2 km (Chu et al., 1989). Validation studies indicate the SAGE I precision is roughly 10% and SAGE II is 5% (Cunnold et al., 1989). This is in agreement with a more recent study that found SAGE II precision to be 4–8% (Fioletov et al., 2006).

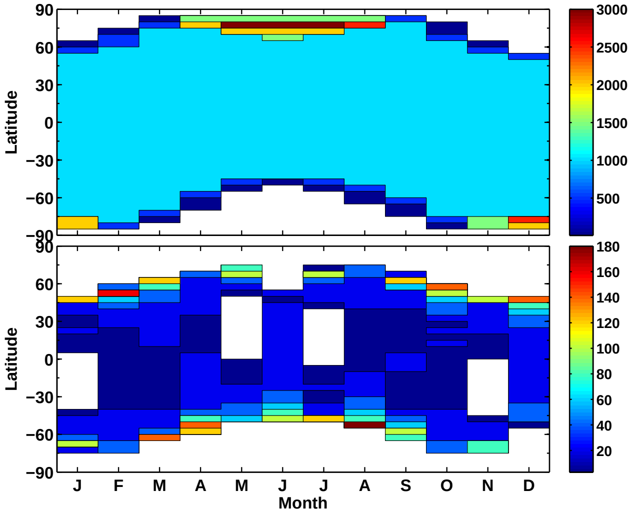

Fig. 3. Comparison of NOAA14/SBUV2 (top) and SAGE II (bottom) data density. Shown are the number of profiles in each month and latitude bin for 1997. White indicates months/latitudes with no data.

The SAGE data screening methodology employed by Hassler et al. (2008), based on suggestions by Wang et al. (1996) and Rind et al. (2005), was adopted here. Rejection criteria are as follows: (i) all profiles are excluded for times when the absolute value of the beta angle exceeds 60° until it returns to less than 40°; (ii) altitudes between 30 and 50 km from 23 June 1993 to 11 April 1994 whenever the error exceeds 10%; (iii) between 10.5 and 24.5 km if the mixing ratio exceeds 10 ppmv; (iv) altitudes above 25 km if the mixing ratio exceeds 100 ppmv; and (v) altitudes above 3 hPa if the mixing ratio exceeds 50 ppmv. In addition, an altitude shift as a function of latitude has been applied to SAGE I data according to the results of Wang et al. (1996), Fig. 3. This amounted to an upward shift of the profiles by 0.3±0.3 km. The only departure from the Hassler et al. (2008) screening is following the El Chichon and Pinatubo eruptions where the criteria described for the SBUV are employed.

2.3 SAGE II sunrise-sunset bias

The coverage of SAGE II is such that frequently at tropical latitudes both sunrises and sunsets occur in the same month. On these occasions, when averaged separately, sunrise/sunset (SR/SS) differences can be observed, beginning in layer 7 (∼37 km) with differences about 2% and increasing with altitude up to a maximum of ∼10% in layer 10, with the largest differences occurring in the tropics. Wang et al. (1996) observed the same SR/SS bias, the cause of which is not completely understood, but appears to be due to multiple factors, both geophysical and satellite-related. When the absolute value of the beta angle drops below ∼60° this bias appears. This motivated the beta angle screening criteria mentioned

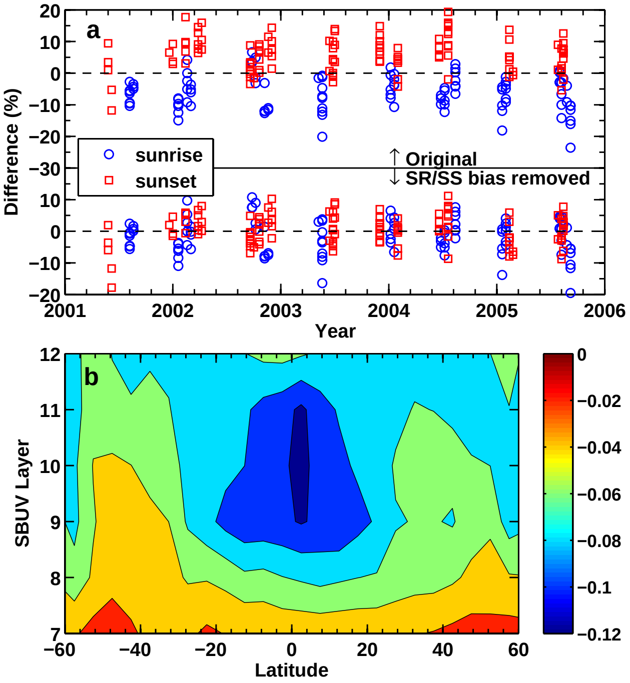

Fig. 4. **(a)** Relative difference between SAGEII and NOAA16/SBUV2 ozone partial columns in layer 10 at 0-5 ° N before and after the sunrise/sunset (SR/SS) bias was removed. **(b)** SR/SS bias, $(b/a)_{\mathrm{avg}}$, coefficient as determined using Eq. (1).

above, but it may not completely eliminate this source of bias. Additionally, there is evidence that there may be errors in the satellite ephemeris in January. The diurnal tide may also explain 1–2% of the bias. While not considered important in Wang et al. (1996), it is suggested here that the diurnal cycle of ozone may also be contributing to the bias. Above 45 km the odd-oxygen ($O+O_3$) lifetime is less than 1 day (Brasseur and Solomon, 1984) and as a consequence ozone at sunrise and sunset will differ, with the largest gradients in ozone occurring through sunrise and sunset when the sunlight available for photolysis rapidly varies. As occultation samples all altitudes down to the tangent height, and the solar zenith angle varies along this path, it seems likely that some component of the bias is related to the diurnal cycle.

To remove any SR/SS bias, a simple model is employed. For a SBUV-SAGE II instrument pair, all coincident measurements (see below) for a particular layer within a latitude band are fit to the following model:

$$X_{\mathrm{SBUV}}=X_{\mathrm{SAGE}}(a+b\,i), \qquad (1)$$

where X is the partial column in a layer, a and b are constants, and i is an indicator function assigned a value of $-\frac{1}{2}$ for a sunrise and $+\frac{1}{2}$ for a sunset. SBUV data is reported in partial columns in SBUV layers (see Table 1) while SAGE data has been integrated over SBUV layers (see below). A linear regression is performed to determine the values of a and b. The coefficient a can be interpreted as the constant SBUV-SAGE ratio, independent of SR/SS, and is close to unity while b/a represents the SR/SS bias. Evaluating b/a for each SBUV-SAGE II pair gave very consistent results for all individual SBUV instruments with typical standard deviations over the various SBUV-SAGE pairs of about 0.01. Thus it suffices to use a value of b/a averaged over all pairs, $(b/a)_{\mathrm{avg}}$. The SR/SS corrected SAGE ozone is thus,

$$X_{\mathrm{SAGE,c}}=X_{\mathrm{SAGE}}/[1+(b/a)_{\mathrm{avg}}i]. \qquad (2)$$

The SBUV-SAGE II relative differences, together with their differences calculated after the correction was applied to the SAGE II profile, are shown in Fig. 4a for NOAA16, 2001–2006, layer 10, 0–5° N. The corrected time series shows less month-to-month variability. Following a failure of the azimuth gimbal system in July 2000, the number of SAGE II measurements was reduced by a factor of two with alternating periods of sunrise-only and sunset-only occultations. Thus, every month consisted of one or the other, as opposed to some months prior to 2001 that consisted of both, thereby increasing the overall impact of the bias.

The magnitude of the bias coefficient, $(b/a)_{\mathrm{avg}}$, is shown in Fig. 4b as a function of latitude and layer. Below layer 7 the magnitude of b did not differ significantly from zero and so no correction was applied. The magnitude is seen to increase with altitude reaching a maximum of about −0.1 in the tropics for layer 10. Above and poleward of this the magnitude decreases.

This correction was applied only to SAGE II data. Due to power issues, SAGE I measured sunrises and sunsets only during the first six months of operation; the remaining 2+ years were strictly sunsets. Analysis of the six months of sunrise + sunset data reveals no significant SR/SS bias, consistent with the results of Wang et al. (1996), who also found no significant bias between SAGE SR and SS measurements and SBUV data. The reason for this is not known. Outside of the first six months, any correction applied would amount to a constant scaling of the original data. As there is no apparent bias between the end of the SAGE I data record and the beginning of the SAGE II record, it seems reasonable to leave the SAGE I data as is.

2.4 SAGE temperature

An analysis of the NMC/NCEP temperature profiles in the SAGE I and II data files indicated that they possess an anomalous trend. Above 30–35 km, the 1979–2005 linear trend becomes positive, peaking at +2–3 K/decade in the tropics. This is in contrast to measured values of about −1 K/decade (Randel et al., 2009). The lid of NMC/NCEP reanalysis model is at 10 hPa, about 32 km, and it is not clear where the portion of the temperature profile above this originated. This anomalous temperature trend makes the associated NMC/NCEP pressure profiles unusable for trend studies. As an alternative, a zonal, monthly-mean temperature climatology is employed (Nagatani and Rosenfield, 1993). Imposed on the climatology is a linear temperature trend as a function of altitude taken from Fig. 19 in Randel et al. (2009). The trended climatology is sampled for each SAGE profile to obtain a temperature profile as a function of altitude. Pressure is then calculated using the hydrostatic equation. It is this pressure profile that is used to map the SAGE ozone profiles onto SBUV-layers (see below).

3 SAGE-corrected SBUV ozone data set

As stated above, the SBUV(/2) data set offers global coverage spanning thirty years (1978–present). Yet differences between the individual instruments reveal unexplained biases making it unsuitable for trend analysis without some kind of bias correction. Figure 5 shows an example of these differences for layer 8 at mid-latitudes. Plotted are monthly, zonal mean ozone anomalies, expressed as a fraction of the removed annual cycle, for each SBUV(/2) instrument. Jumps of 5–10% are evident and other latitude/layers reveal even larger discrepancies.

The biases between the individual SBUV data sets can be removed with the help of SAGE data. The SAGE I and II data sets span the first 25 years of the SBUV data record, with a 3 years long gap between them. Using the difference between SAGE monthly, zonal means and the individual SBUV monthly, zonal means directly might remove the inter-SBUV biases but would introduce sampling biases due to the greatly reduced data density of SAGE. SBUV data will populate a particular month and latitude-band equally, but SAGE may not, as is clear from Fig. 3. In more extreme cases SAGE might move through a latitude band in a single day or just sample the edge of a latitude band.

In order to avoid the introduction of a sampling bias, an intermediate step is required: the comparison of SAGE and SBUV zonal means where only coincident data are used. It is therefore necessary to map SAGE data, reported on a standard 0.5 km vertical grid (0.5–70 km), onto SBUV layers. Each SBUV layer is approximately 3 km thick and so will contain multiple SAGE levels. Pressure at each SAGE level, obtained as discussed in section 2.4, is interpolated to the mid-points between the standard SAGE grid (0.75–69.75 km). The number density is taken as a constant between the mid-point levels and used to calculate the partial ozone column between these two levels. Based on this method the partial column for each 0.5 km SAGE layer is computed. The partial column over each SBUV layer is then determined by summing over all SAGE layers it contains. For SAGE layers that span two SBUV layers, it is split between them according to the fractional overlap, in pressure.

SAGE-SBUV coincidences are determined for each combination of SAGE and SBUV instrument that overlap in time. The coincidence criteria adopted are same-day and within 1000 km. This ensures that the large majority of SAGE observations have a coincidence with SBUV. If more than one SBUV observation met these criteria then the one closest in distance was used. Only SBUV and SAGE data that passed their respective screening criteria are retained. In addition, for a given SBUV-SAGE instrument pair, the distribution of monthly-mean differences for a particular latitude and layer were examined. Months in which this difference was outside of the mean ±5-sigma were excluded. Such differences are typically caused by errors in SAGE profiles. For example, in at least one case the cause of the anomalously large difference appeared to be an altitude shift of the SAGE II profiles by about 500 m that lasted ∼3 days. Overall, very few monthly-means were removed based on this 5-sigma criteria, much less than 0.1%.

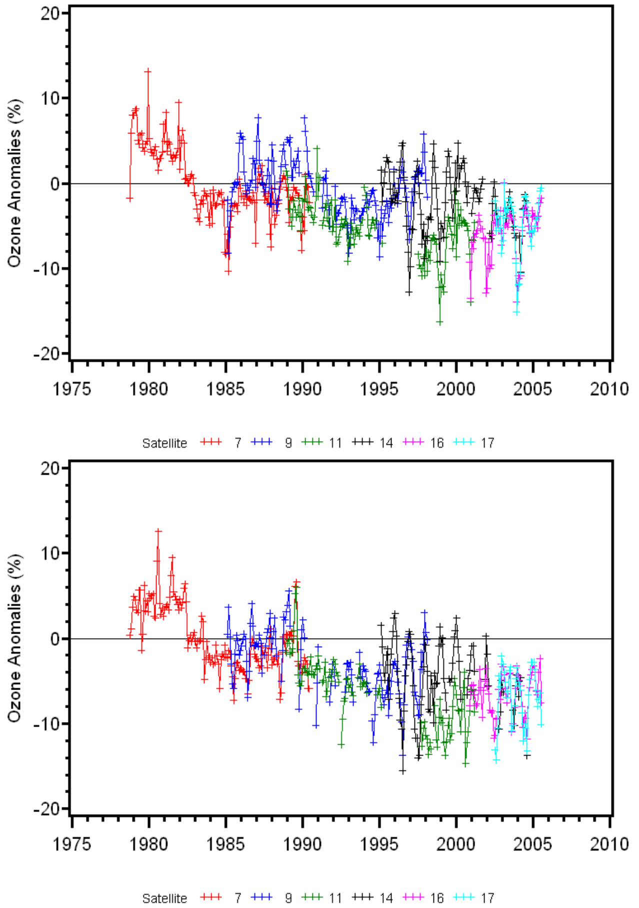

Fig. 5. Time series of SBUV(/2) zonal mean ozone anomalies in layer 8 (∼40 km) at 40–45° N (top) and 40–45° S (bottom) for Nimbus 7, and NOAA 9, 11, 14, 16, and 17 instruments.

Zonal, monthly-means were calculated over 5°-wide latitude bands, centred at −87.5°, −82.5°, . . . , 87.5°, for:

(i) SBUV, all data

(ii) SBUV, considering only SAGE-SBUV coincidences

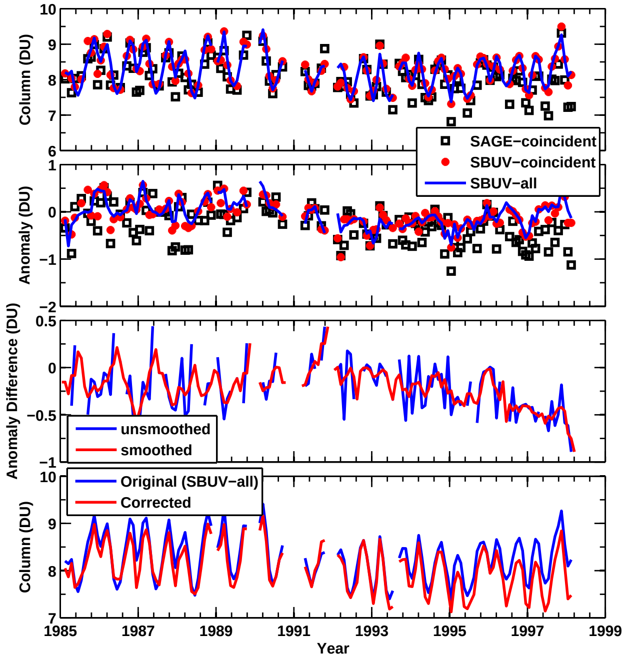

Fig. 6. Steps in the removal of the SBUV bias illustrated for NOAA 9, 40–45° N, layer 8: **(a)** Monthly, zonal-mean ozone for SAGE data (coincident with SBUV), SBUV (coincident with SAGE II), and SBUV; **(b)** as **(a)** after the removal of the annual cycle, **(c)** difference between SAGE II and SBUV coincident means, before and after application of a 3-month running mean; **(d)** original, from panel (a), and corrected SBUV time series after the annual cycle has been added.

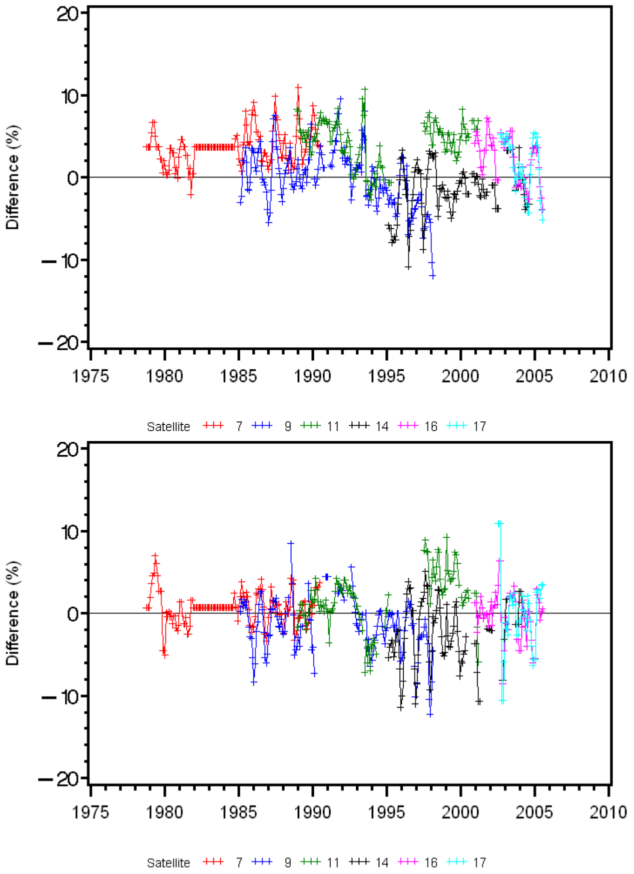

Fig. 7. Differences between SAGE and SBUV(/2) monthly, zonal-means (considering only coincident data) in layer 8 (∼40 km) at 40–45° N and 40–45° S for Nimbus 7, and NOAA 9, 11, 14, 16, and 17 instruments.

(iii) SAGE (SR/SS bias removed), considering only SAGE-SBUV coincidences.

The means were computed for each SBUV(/2) and for each SAGE-SBUV pair that overlapped in time.

The Nimbus 7 data set (1978–1990) was used to calculate an annual cycle which was then subtracted from each time series (i, ii, and iii, above), yielding ozone anomalies. The bias for a given SBUV is taken as the difference between the coincident SAGE and SBUV anomaly time series (SAGE minus SBUV). A three-month running mean of this correction is calculated. Of the three months being averaged over, if one or two months are missing, the mean is calculated over the month(s) for which data is present. This smoothed-correction is then applied to each time series of SBUV monthly-mean anomalies.

The steps outlined above are shown in Fig. 6 using SBUV2 from NOAA 9 (40–45° N, layer 8) as an example. Panel (a) shows the three initial time series and panel (b) with their annual cycles removed. The correction, smoothed and unsmoothed, is shown in panel (c). The original, from panel (a), and corrected data are shown in panel (d), after the addition of the annual cycle. Note the correction is not constant in time and so simply shifting the data to match another SBUV(/2) would introduce spurious trends.

Figure 7 shows the corrections at 40–45° S and 40–45° N, layer 8, that need to be applied to each SBUV(/2). These are generally consistent with other estimates of SBUV(/2) biases, given the different time and spatial averages in the different studies (Frith et al., 2004; http://acdb-ext.gsfc.nasa.gov/Data_services/merged/prof_external_cal.html). The gap between SAGE I and II is taken as constant in time as there is no relative bias between the two due to the correction applied to SAGE I data (Wang et al., 1996). The same constant was also used to fill the gaps in the SBUV-SAGE I differences record since there are periods where the number of SAGE I profiles is not enough to estimate the SBUV-SAGE I bias within a 3-month window.

Corrected SBUV ozone anomalies are shown in Fig. 8, and can be compared with the original data in Fig. 5. For periods of overlap there are virtually no inter-SBUV differences. The final data set is obtained by taking the average over all instruments for these overlap periods. This is referred to as the SAGE-corrected SBUV ozone data. Latitude-time slices

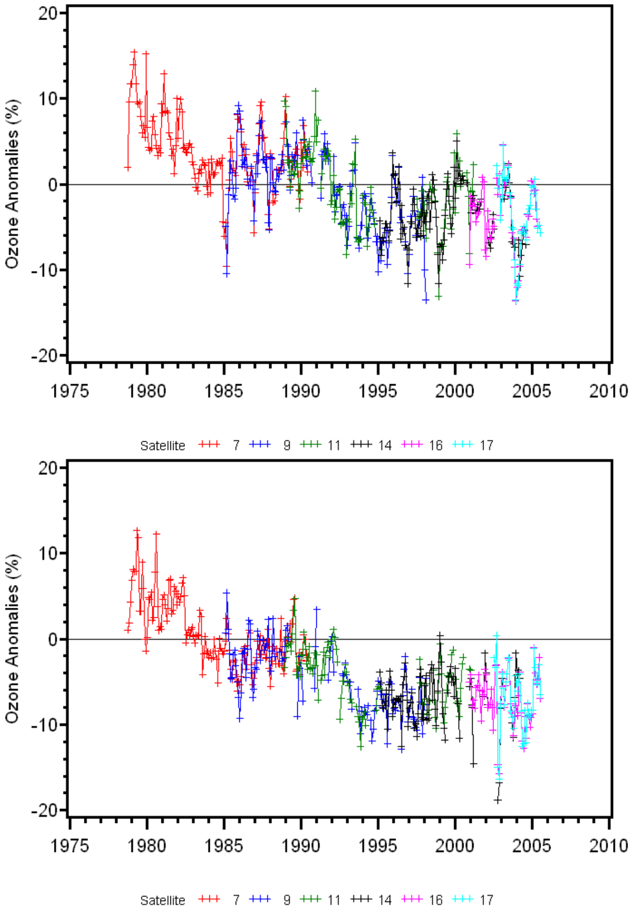

Fig. 8. Time series of SAGE-corrected SBUV(/2) zonal mean ozone anomalies (considering only coincident data) in layer 8 (∼40 km) at 40–45° N and 40–45° S for Nimbus 7, and NOAA 9, 11, 14, 16, and 17 instruments.

of the SAGE-corrected SBUV data set for layers 4 and 8 are shown in Fig. 9 where anomalies in percent from the annual cycle (estimated for the period 1978–2005) are plotted. Figure 9 shows no major gaps in data (except for the periods following the El Chichon and Pinatubo eruptions). The two panels show an overall ozone decline from the early 1980s to the late 1990s over middle and high latitudes. The QBO signal is also evident from the plot. Calculating the zonal-monthly mean anomalies in the tropics now reveals a high level of consistency in the SAGE-corrected SBUV ozone QBO signal with the SAGE II QBO signal from Fig. 1. This is shown in Fig. 10.

4 Regression analysis

A statistical regression analysis of the SAGE-corrected SBUV ozone data set was performed to estimate long-term ozone changes and compare them with the available long-term trend estimates for SBUV and SAGE data (WMO, 2007). The ozone time series for each latitude band and layer were fitted with a regression model including seasonal cycle, equivalent effective stratospheric chlorine (EESC), solar cycle, and QBO, as explanatory variables (WMO, 2007 and references therein). The EESC term is a measure of the stratospheric halogen burden and is used in the regression analysis to isolate long-term ozone changes associated with the amount of ozone depleting chlorine and bromine in the stratosphere. The EESC function used here increases nearly linearly from 1979 to its maximum in 1997 and thus the EESC fit to ozone can be expressed as decadal ozone change in percent during that time (Stolarski et al., 2006; WMO, 2007). The QBO time series are based on observed equatorial winds at 30 hPa and 50 hPa and the solar cycle term is the standard F10.7 radio flux. Two QBO time series are included as the phase of the QBO is altitude-dependent. The regression model includes a constant and annual and semi-annual harmonic terms for the regression coefficients of the EESC and QBO functions.

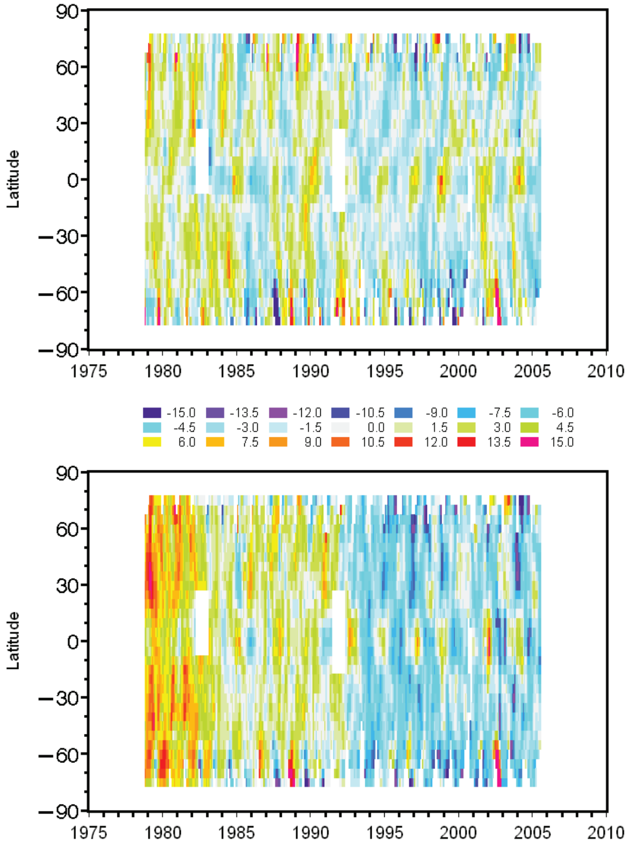

Fig. 9. Latitude-time slices of SAGE-corrected SBUV ozone. Ozone anomalies in percent deviation from the annual cycle (estimated for the period 1978–2005) are plotted. Layer 4 (top) and layer 8 (bottom) are shown.

Figure 11a shows the meridional cross section of zonal mean ozone trends derived from the ozone projection onto

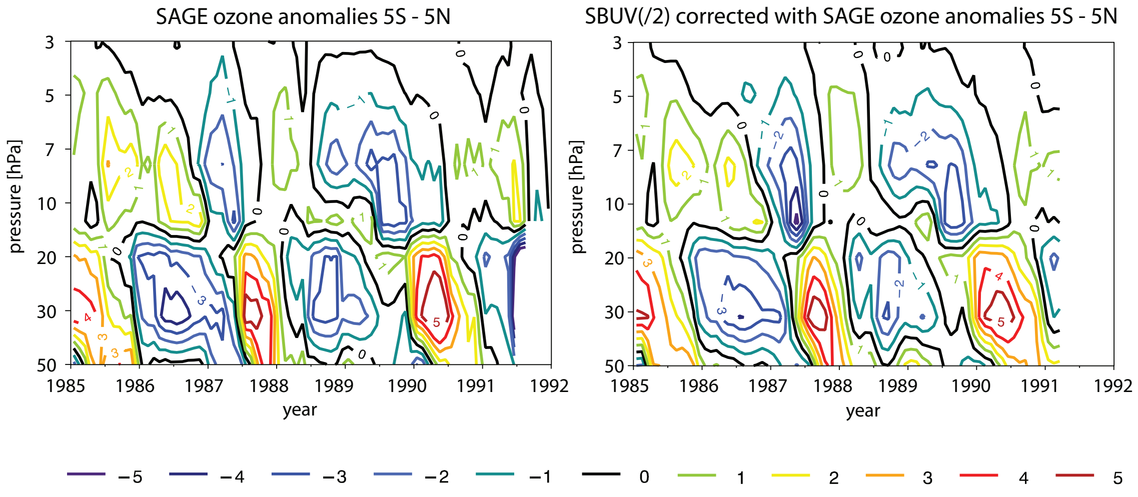

Fig. 10. Quasi-biennial signals in **(a)** 0SAGE II data and **(b)** SAGE-corrected SBUV data. Plotted are monthly, zonal-mean ozone anomalies in the tropics (5° S–5° N).

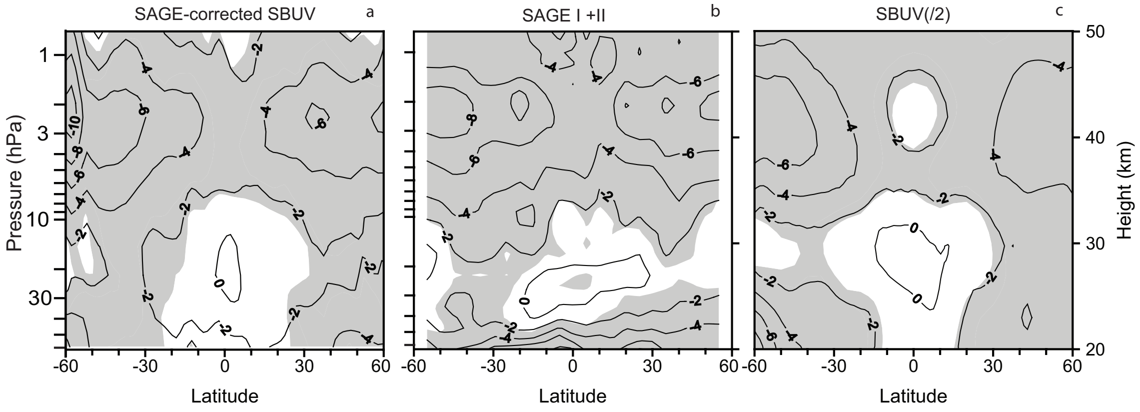

Fig. 11. Annual ozone trends in percent per decade as a function of latitude and altitude/pressure for the period 1979-2005 derived from regression analysis for **(a)** the SAGE-corrected SBUV (this work), **(b)** SAGE I+II, and **(c)** merged SBUV(/2). Shadings indicate that the changes are statistically significant at the 2σ level. Panels (a) and (c) have pressure as the vertical co-ordinate, and altitude should be considered as approximate. Panel (b) has altitude as the vertical co-ordinate, and pressure should be considered as approximate.

the EESC term for the SAGE-corrected SBUV data set. These are as a function of pressure. The long term changes of ozone profiles show a maximum in the regions above 40 km reaching −10%/decade around 60° S. In the northern hemisphere upper stratosphere a negative trend of up to −6% can be found. The negative trend decreases towards the equator where it shows values between −4 and −2%/decade. Between 35 and 25 km the trend is small with values around −2 to 0%/decade for all latitude bands. For comparison, Figs. 11b and 11c show zonal mean ozone trends for SAGE I+II as a function of altitude and SBUV(/2) as a function of pressure, respectively. The estimates for SAGEI+II and SBUV(/2) ozone trends are derived from regression onto EESC and taken from the Figs. 3–7 of the 2006 WMO ozone assessment (WMO, 2007). The magnitude and morphology of the trends for the SAGE-corrected SBUV data set are found to be very similar to both SAGE I+II and SBUV(/2) trends. In the upper stratosphere the SAGE-corrected SBUV trends appear more consistent with the SBUV(/2) values. This is because the SAGE-corrected SBUV trends, like the SBUV(/2) and in contrast to the SAGE I+II trends, were derived on pressure levels.

As discussed in the WMO assessment, care needs to be taken when comparing trends derived from data in different vertical coordinate systems (WMO, 2007). Rosenfield et al. (2005) found that trends at 3 hPa may differ by up to 1–2% depending on how they are reported, with the more negative trends arising from the use of an altitude coordinate system. This is at least qualitatively consistent with the results from Fig. 11. This difference is driven by stratospheric temperature trends which, in turn, will introduce a trend in the altitude of a given pressure level and is the reason why the NMC/NCEP pressures (in the SAGE data files) could not be used. A much more thorough study is required to better understand the interaction of trends in temperature and ozone.

5 Summary

A vertically resolved stratospheric monthly, zonal-mean ozone data set based on Satellite Aerosol and Gas Experiment (SAGE) and Solar Backscatter UltraViolet (SBUV) data spanning 1979–2005 was presented. Drifts in individual SBUV instruments and inter-SBUV biases are corrected using SAGE I and II by calculating differences considering SAGE-SBUV coincidences. In this way the daily, near-global coverage of SBUV(/2) is combined with the stability of SAGE to provide a homogeneous ozone record. The resultant SAGE-corrected SBUV data set shows a realistic Quasi-Biennial Oscillation signal in contrast to other SBUV data sets.

The pressure profiles that are given in the SAGE data were found to contain an anomalous temperature trend and thus unsuitable. Instead, a temperature climatology is employed with a measured temperature trend imposed on top. A regression analysis performed on the SAGE-corrected SBUV time-series produced trend estimates consistent with other current estimates.

The SAGE-corrected SBUV data set presented is limited by the end of the SAGE II operations. However, with multiple SBUVs still in operation this method can be used to extend the time series using limb instruments such as MAESTRO (Measurement of Aerosol in the Stratosphere and Troposphere Retrieved by Occultation) or OSIRIS (Optical Spectrograph and InfraRed Imager System) to provide the bias correction.

The SAGE-corrected SBUV data set is available for download at ftp://es-ee.tor.ec.gc.ca/pub/SAGE_corrected_SBUV.

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