Final Report

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for

Science Support for the Nimbus G Sensor:
Solar and Backscattered Ultraviolet and
Total Ozone Mapping System (SBUV/TOMS)

and entitled

The chemistry and dynamics of stratospheric ozone:
Satellite observations compared with numerical model results

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An important part of the work under this contract and its preceding contract consisted of the development of a procedure for retrieving ozone profiles from SBUV radiances. This work was previously reported.

Our analysis of the SBUV ozone has, up until this time, focused on a comparison of SBUV and SAGE ozone profiles. A copy of a publication describing this work is attached.

Work is continuing under other contracts: comparing the SBUV and SAGE results over a longer time period and comparing the SBUV (and other ozone observations) against model results.
An Intercomparison of SAGE and SBUV Ozone Observations for March and April 1979

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Thirty-eight latitudinal cross sections of stratospheric ozone observed by the SAGE and SBUV satellite instruments on the same days in March and April 1979 and at approximately the same latitude are compared. Differences in the zonal-mean mixing ratios are found. At pressures less than 5 mbar, SAGE gives approximately 20% larger mixing ratios at tropical latitudes than SBUV. At pressures between 5 and 10 mbar, the mixing ratios are nearly equal. At pressures between 10 and 20 mbar, SAGE underestimates ozone by approximately 15%. Mixing ratio differences are also noted in the tropics at 30 mbar. Longitudinal variations with a vertical scale exceeding 8 km are analyzed. The uncorrelated portions of the SAGE variances are approximately consistent with the SAGE noise model and resulting ozone profile error bars. Between 2 and 10 mbar, the random noise in an individual wave component (having this vertical scale) is expected to be less than 2% everywhere in both experiments except for 1% at tropical latitudes in the SBUV experiment. Based upon the correlated variances, the amplitudes of the inferred longitudinal ozone variations are found to be the same on the average at mid-latitudes between 1 and 10 mbar. However, the relative amplitudes also are found to be dependent on the atmospheric situation. Systematic differences in the amplitudes at 0.4 and 30 mbar are discussed. Wave detectability by both sensors at 58°N in early April is illustrated and compared against TIROS-N temperature observations for that period.

1. INTRODUCTION

Concerns about the atmospheric ozone layer during the past decade [see, e.g., National Academy of Sciences, 1982; World Meteorological Organization, 1982] have led to the development and application of several satellite-borne sensors for observing the global distribution of ozone in the stratosphere. This paper discusses observations from two of these techniques: the solar backscattered ultraviolet experiment (SBUV) on NIMBUS 7, which was launched in October 1978, and the stratospheric aerosol and gas experiment (SAGE), which was on an atmosphere explorer satellite launched in February 1979. The first year data sets from each measurement technique are available from the National Space Science Data Center (NSSDC). Because the rocket optical-sonde observations which were supposed to provide validation (so-called ground truth) for the satellite-derived ozone profiles have proved to be unreliable (because of filter calibration problems), a comparison of the observations from the two techniques is particularly useful. This intercomparison, moreover, provides a means of assessing the capabilities of the two instruments for detecting temporal and spatial variations in stratospheric ozone.

Because the observational geometry of the two techniques is different, these instruments do not observe the same point in space and time. Moreover, the horizontal and vertical resolution of the two instruments is different. This comparison, therefore, emphasizes the larger scale features of the ozone distribution (for example, nonzonal variations in wave number l). By focusing on nonzonal variations, the estimated precision of the SAGE ozone measurements (which possess the higher relative noise level) may be assessed. In this report a statistical comparison of the observed ozone concentrations is made for March and April 1979 when the SAGE instrument was working best and was capable of providing 28–30 observations/day.

During this time period, there is clear evidence of longitudinal ozone variation at mid-latitudes in the stratosphere in both data sets.

2. SAGE OZONE MEASUREMENTS

SAGE consists of a four-channel sun photometer which responds to radiation at wavelengths of 0.385, 0.45, 0.6, and 1.0 \( \mu m \) [McCormick et al., 1979; Chu and McCormick, 1979]. The 0.6 \( \mu m \) channel is located close to the peak of the absorption by the Chappuis band of ozone. Ozone profiles are obtained after small contributions to irradiance reduction from aerosols and Rayleigh scattering have been accounted for. Their contribution to the 0.6 \( \mu m \) irradiance has been estimated from the 1.0 \( \mu m \) irradiance and from the atmospheric temperature data. Irradiances are measured at sunrise and sunset only when the sun is occulted by the atmosphere.

The sensor’s instantaneous field of view (which is circular) is 0.5 min of arc [Chu and McCormick, 1979]; this provides a vertical resolution of 0.5 km. However, instrumental noise and other uncertainties are such that during the data processing the derived ozone profile is smoothed over 1 km below approximately 40 km altitude and over 5 km above 40 km altitude. The horizontal averaging distance, as is typical of any limb-scanning experiment, is 200–300 km in the viewing direction. In the horizontal direction, perpendicular to the field of view, the resolution is determined by the motion of the satellite during a vertical scan and is approximately 100 km.

The irradiances at 0.6 \( \mu m \) are converted in a relatively straightforward manner to ozone extinctions [Chu and McCormick, 1979] and thence to ozone concentrations using an absorption efficiency of 4.7 \( \times \) \( 10^{-21} \) cm\(^2\). Ozone concentrations are converted to mixing ratios using the temperature profile supplied for an individual inversion by the National Oceanic and Atmospheric Administration (NOAA) based upon TIROS-N satellite observations and radiosonde observations at 1200 UT.

The principal sources of uncertainty in an individual SAGE ozone profile are expected to be 0.5% random instrumental noise in each measurement and a 0.5-arc min per second scan
The desired ozone profiles consist of an uncertainty of 1.5% in the estimate of the ozone concentration at each point on the profile, determined as an average of approximately six measurements. The aerosol contribution from the irradiance at 0.6 μm is small, however, there is some uncertainty associated with removing the instrument calibration ozone absorption cross section and an uncertainty of 2% in the ozone concentration at each point on the profile which are large above approximately 40 km. These potential errors translate into a systematic uncertainty in the ozone in the entire profile of approximately 3-6% (see, e.g., Comrath, 1977). Profiles may be retrieved which contain information on a scale shorter than the intrinsic vertical resolution of the experiment (for which, for example, a 1% noise level would give a 1% error in the retrieved ozone) but the error bars increase rapidly with increasing vertical resolution. For the SAGE experiment, the intrinsic vertical resolution is approximately 1 km below approximately 40 km and somewhat less above that altitude. The vertical resolution of the SBUV ozone (as well as of temperature observations) against which the SAGE ozone data is being compared is poorer than this. To ensure closer compatibility of the data sets, the SAGE ozone observations have been vertically smoothed.

Ozone chemistry considerations and ozone observations [e.g., Barnett et al., 1975] indicate that variations in the 1–10 mbar region are related to temperature variations such that changes in the natural logarithm of the ozone mixing ratio (Δln) are proportional to the temperature changes at a particular altitude, latitude and season. For ease of interpretation of the results, the smoothing we employ therefore is

\[
\bar{\chi}(Z_i) = \exp \left( \frac{1}{h} \int_{Z_i-h/2}^{Z_i+h/2} \ln x \, dZ \right)
\]

(1)

Because of the predominantly exponential shape of the ozone profile between 1 and 10 mbar and the relative uniformity of the SBUV contribution functions based on the logarithm of the ozone layer amounts [Mateer, 1977], this smoothing should have some similarities to that employed in the SBUV algorithm. It should be noted, however, that this smoothing only preserves the ozone contents of a prescribed layer if the ozone mixing ratio has a constant scale height. The ozone concentrations used in this study have been taken from the archived SAGE profile tapes, which already contain smoothing over 5 km for heights above approximately 40 km. It should be noted, however, that the error bars which appear on those tapes refer to 1 km smoothing. We have smoothed the SAGE data using expression (1) with \( h = 8 \) km and \( Z_i \) values corresponding to the heights of standard pressure surfaces determined from the analyzed temperature fields for the same day (this information is also given on the SAGE tapes). For \( h = 8 \) km and the calculated average SAGE zonal mean ozone mixing ratios for March and April 1979, expression (1) results in a systematic underestimate of the zonal mean ozone mixing ratio of approximately 10% in the tropics at 30 mbar and of approximately 3% at other latitudes at 30 mbar and at tropical latitudes at 10 mbar.

Errors in the temperature profiles could affect the ozone comparison discussed in this paper and should, therefore, be mentioned. According to Smith et al. [1979] and Phillips et al. [1979], TIROS-N satellite temperature uncertainties are approximately 1% at altitudes below 10 mbar and the errors are correlated over several kilometers. Phillips et al. also note that the satellite temperatures significantly underestimate the variance of atmospheric temperature between 10 and 70 mbar. Above 10 mbar satellite temperature errors are believed to
gradually increase with height to approximately 3% above 1 mbar (J. D. Laver, private communication, 1983). The adjustment of SAGE ozone observations from height surfaces to pressure surfaces is expected to result in similar percentage errors being introduced into the ozone profiles. The temperature errors also affect the ozone profiles through the need to remove the Rayleigh scattered contribution at 6000 Å. This contribution is approximately 10% of the ozone extinction between 2 and 10 mbar increasing to approximately 20% at 30 mbar and 25% at 0.4 mbar. Even a 3% error in temperature would thus result in an error of less than 1% in the ozone extinction. The effect of temperature errors is therefore believed to be significantly less than the potential SAGE ozone errors described earlier and can be neglected.

3. SBUV OZONE MEASUREMENTS

The SBUV instrument is a double monochromator which views the earth's atmosphere in the nadir direction. The instrument measures solar ultraviolet radiation after it has been scattered into the field of view by molecular scatterers and partially absorbed by ozone. The instrument is partially self-calibrating because it also routinely observes the sun after reducing the signal intensity using a diffuser plate. Degradation of the diffuser plate is checked by periodically viewing an on-board mercury lamp. The field of view of the instrument is 11.3° x 11.3°, giving a horizontal resolution of the measurements of approximately 200 km x 200 km.

The monochromator measures radiation in 12 narrow wavelength bands spaced between 0.255 μm and 0.340 μm. By virtue of the wavelength dependence of ozone absorption in this portion of the spectrum and of the increase of molecular scattering with decreasing altitude, the contribution functions for these wavelengths span the height range between the ground and approximately 50 km. Figure 1 shows a typical distribution of these contribution functions. In inverting the data to derive ozone profiles, the measurements at 2556 Å were found to be inconsistent with those at 2736 and 3821 Å (whose contribution functions overlap that for 2556 Å). This may be due to a contribution to the 2556 Å radiance from the NO 2 (0–4) band [Guenther et al., 1979]; the currently available ozone data set was obtained by neglecting the measurements at 2556 Å (a similar problem was encountered in the NIMBUS 4 data) [Fleig et al., 1982].

The retrieved SBUV profile is obtained by updating an a priori (first guess) ozone profile based upon the differences between the measured radiances and radiances estimated from the a priori profile. The updates are based on the sensitivity of calculated radiances (Q) to changes in the ozone content (X) of layers approximately 3 km thick (i.e., partial derivatives ∂Q/∂X). [Schneider et al., 1981; Klenk et al., 1983]. The solution profile can be viewed as an optimal combination of an a priori profile with a "measured profile." The solution profile is iterated a few times because the partial derivatives are profile dependent (i.e., the mapping of ozone profiles into radiances is nonlinear). During the iteration, the algorithm subtracts virtual measurements from the radiances based upon the differences between precisely calculated radiances and those calculated from the quadrature corresponding to 5 km ozone layers and their partial derivatives ∂Q/∂X. These differences, which the algorithm should not be expected to resolve and which should be included in the profile error bars, are also profile dependent.

Before comparing SBUV and SAGE ozone variations, it is useful to discuss the resolution and precision of the SBUV ozone profiles. This depends upon the measurement errors which are assumed to consist of a 0.5% uncertainty in the measured radiances and a 1% uncertainty in the relative ozone absorption coefficients for the measurement channels [Fleig et al., 1982]. In addition, an uncertainty of 2% is included to account for the algorithm's inability to precisely estimate the multiple-scattering contribution to the measured radiances in the longer wavelength channels. These uncertainties are mapped into ozone uncertainties in a rather complicated, profile dependent fashion by the SBUV algorithm.

To provide some insight into the effects of these errors on the atmospheric variability of ozone which is retained in the retrieved profiles, let us consider the optimal combination of a "measured" coefficient a₀, with an a priori coefficient, a₀. The coefficients are here considered to describe the amount of ozone in layer i or the ith eigenvector of the mapping of the radiance measurements into an ozone profile. The solution profile coefficient, aᵢ, is given by

\[ aᵢ = \frac{σ_m^2}{σ₀^2 + σ_m^2} a₀ + \frac{σ₀^2}{σ₀^2 + σ_m^2} aᵢ² \]

where σ₀ and σ_m represent the uncertainties (expressed as standard deviations) in the a priori and measured profiles. Our discussion will proceed in a qualitative manner only because we do not know the exact eigenvectors for the SBUV algorithm and the ozone layer amounts are interdependent so that...
According to (3), atmospheric variance is expected to will instead result in primarily systematic errors of the ozone uncertainties are 8% at 4 mbar increasing to 12% at 0.4 and 20 mbar [Fleig et al., 1982]. The measurement uncertainty, $\sigma_m$, should be 5–10% between 1 and 10 mbar based on the 1% uncertainty in ozone absorption coefficient and should be larger below approximately 10 mbar because of uncertainties due to multiple scattering. These uncertainties will result in different degrees of damping of the variations in each eigenvector with higher order coefficients receiving more damping and the lowest order coefficients receiving minimal damping. Since SAGE ozone variations have been smoothed over 8 km, the comparison study in this paper is emphasizing those scales of variation which should be more precisely determined from the SBUV data. Note, however, that atmospheric variations on a 5 km vertical scale will have received different damping by the SBUV algorithm and by the SAGE, plus our vertical averaging, algorithm. Because of the effects of off-diagonal matrix elements, it is nontrivial to evaluate the damping of the variations in each ozone layer amount. Some indication can, however, be obtained from some typical results for the SBUV algorithm shown in Table 1. The table lists typical proportions of the a priori in the retrieved profile. These may be considered to be equivalent to

$$\left(1 + \frac{\sigma_0^2}{\sigma_m^2}\right)^{-1} = 1 - \frac{\sigma_m^2}{\sigma_0^2}$$

It is therefore anticipated that approximately 30% of the atmospheric variance may be lost at altitudes above 5 mbar and approximately 50% at 10 mbar. This loss should occur, primarily, on a vertical scale close to 5 km. Moreover, because $\sigma_m < \sigma_0$, the profile to profile variance should be less than the error bars supplied with the profiles which, based on our highly simplified treatment would be

$$\pm \sqrt{\frac{\sigma_0^2 \times \sigma_m^2}{\sigma_0^2 + \sigma_m^2}}$$

Note moreover that, for the estimated $\sigma_0$ and $\sigma_m$, values, the error bars will significantly depend on the a priori uncertainties. Note also that more atmospheric variance could be recovered if the ozone absorption coefficients were known more precisely (or if the portion of this uncertainty which produces systematic ozone profile changes could be removed from $\sigma_m^2$).

In summary, we should expect that SBUV and SAGE ozone variations having a vertical scale greater than approximately 8–10 km should be similar between 1 and 10 mbar. Variations on a smaller vertical scale are expected to be significantly damped by the SBUV algorithm in a way which is profile dependent (i.e., dependent on the eigenvector contents of the atmospheric profile). Furthermore, SBUV error bars provide an estimate of the uncertainty in ozone content of layers approximately 5 km thick. These error bars tend to overestimate for the noise content of profile to profile differences because ozone absorption coefficient errors can lead to systematic errors. These error bars are also expected to substantially overestimate the uncertainties in variations having a vertical scale of 8–10 km or more.

4. Procedure for Processing Ozone Data for Intercomparison

The SAGE ozone profiles are first smoothed vertically over 8 km by the procedure indicated in section 2. Since, however, the observations from the sensors are not simultaneous in either time or space, there is a need to also degrade the horizontal resolution of the observations (or equivalently to perform the comparison as a function of the horizontal resolu-
tion. This is accomplished by performing a longitudinal Fourier analysis on the data. This approach provides the additional advantage that it should produce a signal/noise enhancement of the data because of the tendency for stratospheric oscillations to be predominantly in waves 1 or 2 [see, e.g., Washington, 1972] while the noise in the data should be evenly distributed over all wave numbers.

The analysis procedure is to estimate the amplitude and phase of the planetary wave components using optimal (or equivalently in this case, generalized least squares) estimation. Note that faster Fourier transforms may not be used directly on the ozone data because it is orbital data and there exists a longitudinal shift of approximately 4° between similar orbits on succeeding days. The problem is to estimate the state given by

\[ F(\phi) = a_0 + \sum_{l=1}^{L} [b_l \sin (l\phi) + c_l \cos (l\phi)] \quad (5) \]

where \( \phi \) is the longitude; the problem then is to estimate the column vector \( y = (a_0, b_1, c_1, b_2, c_2, \ldots) \).

The following equation is used to estimate \( y \)

\[ y = y_0 + G(x - x_0) \quad (6) \]

where

\[ G = C_0 P^T [PC_0 P^T + N]^{-1} \quad (7) \]

Here \( x \) is a column vector consisting of the ozone measurements at longitudes \( \phi_k \) (\( k = 1 \) to 14 or 15), and subscript zero represents an a priori estimate. There is no a priori information on wave structure, and hence \( y_0 \) possesses, at most, a single nonzero component (the first), and for \( x_0 \), all elements were set equal to that first-guess zonal-mean estimate of the ozone mixing ratio. The partial derivative matrix \( P \) has elements

\[ \frac{\partial F}{\partial y} = \sin \left( \frac{j}{2} \phi \right) \quad j \text{ even} \]

\[ = \cos \left( \frac{j-1}{2} \phi \right) \quad j \text{ odd} \]

The a priori covariance matrix \( C_0 \) is chosen to be large enough that the solution depends only on the measurement information (it is, in fact, set equal to the identity matrix). Since we know of no reason why noise in the measurements should be correlated between orbits, the off-diagonal elements of the noise matrix \( N \) are set to zero. The diagonal elements of \( N \) are all arbitrarily set equal to \( 10^{-4} \) for SBUV data (corresponding to 1% measurement noise) and are set equal to the square of the ratio of the ozone extinction uncertainty to the ozone extinction for the SAGE data. Thus for the SAGE experiment, "noisy" measurements receive less weight in the determination of longitudinal Fourier components than do "less noisy" measurements. This analysis procedure also inherently allows a missing orbit of data to be given weight zero (in either experiment).

In all the data analyzed, the Fourier series is terminated at wave 4. This has little effect on the derived coefficients if data exist for each orbit because the sines and cosines are almost orthogonal over the sample longitudes. This is, however, less true when even a single orbit of data is missing. To avoid significant contamination of waves 1-4 by wave numbers greater than 4, we have selected for comparison only those days which contain no more than one missing orbit. This is expected to limit contamination of any wave number to approximately one fourteenth of the typical amplitudes of wave numbers greater than 4.

Comparisons of the data sets have been made at latitudes determined to be the mid-point of each day's SAGE data. No attempt has made to allow for the typical spreads of \( \pm 3^\circ \) latitude in a single day of SAGE observations; although a latitudinal variation of ozone would tend to introduce a spurious wave 1 into the analysis, its amplitude would be no larger at any location than the expected noise level. For SBUV observations, data at each pressure level has been first interpolated along orbits to a set of 28 latitudes (approximately \( 6^\circ \) apart) using cubic splines. Fourier coefficients were then determined at each of these latitudes. Finally, the Fourier coefficients were linearly interpolated to the latitude corresponding to the SAGE observations.
To aid the interpretation of the ozone observations, Figure 3 shows some predicted variances of longitudinal ozone variations normalized by the zonal-mean mixing ratios. This figure is derived from the three-dimensional stratospheric model of Cunnold et al. [1975, 1980] which included two-dimensional distributions of NO, ClO, and OH and chemical rate constants estimated in the mid-1970's. The rate constants differ significantly from current estimates [Baulch et al., 1982] only through the temperature dependence of the reactions NO + O, H + O2 (which were from Hampson et al., [1973]), HO2 + O (exp (-250/T)), and NO + ClO for which the room temperature rate constant was used. The modeled ozone mixing ratios have been smoothed over three model levels (approximately 8 km) based on expression (1) prior to the calculation of the variances. It should be noted that Figure 3 contains six planetary wave numbers, whereas the observational analysis is based on only four. Removal of components 5 and 6 from the modeled results has no effect above 5 mbar but produces reductions of approximately 25 and 33% in the mid-latitude variances at 10 and 30 mbar, respectively.

5. COMPARISONS OF SAGE AND SBUV OZONE DATA

Based upon the criterion of not more than one missing orbit of data for either data base, 11 longitudinal cross sections in March 1979 and 27 in April 1979 were selected for comparison (see Table 2 for more detailed information on the selected cross sections). Comparative statistics have been generated for 10° latitude boxes.

Zonal Means

Figure 4 shows a comparison of the measured zonal-mean mass mixing ratios of ozone for the days selected at the standard meteorological pressure levels. It is evident that although the agreement is reasonably good at lower altitudes, there are substantial differences at high altitudes. To interpret the differences, the expected diurnal variations of ozone must first be removed.

SAGE observations are made at a local solar zenith angle of approximately 90°. The time constant for the destruction of atomic oxygen is approximately 10 s at 1 mbar, where the atomic oxygen contribution to odd oxygen is significant. As the sun sets, photodissociation of ozone decreases rapidly at this level and the atomic oxygen is all converted to ozone. At sunrise, significant dissociation of oxygen does not occur at 1 mbar until a solar zenith angle > 84° (sec θ = 10) is attained. Thus, the SAGE ozone measurements should be considered nighttime measurements (and may be considered nighttime or daytime measurements at lower altitudes where the atomic oxygen content is insignificant). NIMBUS 7, on the other hand, possesses an orbit close to local noon and SBUV observations are considered to be midday observations.

The amplitude of the diurnal cycle of ozone may be calculated quite accurately from the absorption cross section in the Hartley continuum, which is known to an accuracy of 10% [Klenk, 1980] and from the three-body production rate for ozone (which is also accurately known). The diurnal cycle used here is taken from Prather [1981] for the tropics and is slightly reduced (based upon our own calculations) for a lati-
tude of 60°. Although inclusion of the diurnal cycle reduces the difference between the measurements at 0.4 and 1 mbar, substantial differences (≈ 20%) still exist between the measurements above 5 mbar at latitudes less than 40°.

The systematic error in the SAGE experiment is estimated to be approximately 3% [see McCormick et al., this issue] and even at 1 mbar the standard error of the mean from just a single day's data is roughly 25%/15 longitudes x 8 km vertical averaging) ≈ 2%. For SBUV, the principle source of systematic error is an uncertainty of approximately 3% in the ozone absorption cross section for wavelengths less than 2900 Å increasing to approximately 10% at longer wavelengths [Klenk, 1980]. Not only are these possible sources of systematic error unable to account for the measured difference, but also the ozone absorption cross section used in the SBUV algorithm is close to the lower limit of the various measurements of that cross section.

Because of the broad yet restricted area over which the differences occur, it is tempting to infer the presence of an additional high altitude constituent which absorbs energy at 6000 Å. Such an absorber would have to provide a maximum extinction in the SAGE passband (approximately 150 Å) of approximately $5 \times 10^{-5}$/km between 2 and 5 mbar in the tropics decreasing to approximately $3 \times 10^{-6}$/km at 0.4 mbar and to less than $10^{-6}$/km at 50° latitude at all levels. If the extinction of $5 \times 10^{-7}$/km at 6000 Å is associated with photodissociation of a molecule, the lifetime (in seconds) of that molecule must be less than $2.5 \times 10^{-6}$ times its concentration (based on an incident flux of $8 \times 10^{12}$ photons/cm²/s). For a concentration of $10^8$ molecules/cm³, this yields a lifetime of less than 4 min. However, the sunrise and sunset observations at approximately the same latitude (26°) on April 16 and 17 indicate that the observed differences do not change significantly between sunrise and sunset and we have not been able to identify any absorber which satisfies the requirements of this paragraph.

The second systematic difference between the ozone observations occurs at latitudes greater than 30° at 10 mbar. For example, at 55° latitude, the SBUV mixing ratios are 1.5 ppm (or approximately 15%) lower than those measured by SAGE. Since the difference has the opposite sign at 5 and 30 mbar, it might be asked whether SBUV is resolving structure in this case on the 5 km scale. However, when SAGE data which has been averaged over 5 km is compared against that averaged over 10 km at these locations, we find no significant change in the zonal-mean concentrations. We infer that the SBUV algorithm is introducing small-scale structure systematically into the ozone profiles at these locations. This might be produced by a small error (≈ few percent) in the absorption coefficient of an SBUV channel at approximately 3000 Å whose contribution function peaks at approximately 10 mbar for these solar zenith angles [Schneider et al., 1981]. It is interesting that a difference of the same form as that described here is found when the NIMBUS 7 data is reprocessed with the algorithm which was used for processing NIMBUS 4 data (Systems and Applied Sciences report to SBUV/TOMS NIMBUS Experiment Team, 1982). The ozone absorption coefficients for the SBUV profile wavelengths have recently been
TABLE 2: Days Used in the Comparison of SAGE and SBUV Ozone Data

<table>
<thead>
<tr>
<th>Day, 1979</th>
<th>Latitude of Events Used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sunrise</td>
</tr>
<tr>
<td>March 7</td>
<td>54.2°</td>
</tr>
<tr>
<td>March 8</td>
<td>44.6°</td>
</tr>
<tr>
<td>March 11</td>
<td>32.8°</td>
</tr>
<tr>
<td>March 13</td>
<td>57.2°</td>
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<tr>
<td>March 19</td>
<td>−50.2°</td>
</tr>
<tr>
<td>March 27</td>
<td>−57.2°</td>
</tr>
<tr>
<td>March 28</td>
<td>−58.4°</td>
</tr>
<tr>
<td>April 2</td>
<td>−58.6°</td>
</tr>
<tr>
<td>April 3</td>
<td>−58.6°</td>
</tr>
<tr>
<td>April 6</td>
<td>−58.8°</td>
</tr>
<tr>
<td>April 7</td>
<td>−58.8°</td>
</tr>
<tr>
<td>April 8</td>
<td>−57.4°</td>
</tr>
<tr>
<td>April 9</td>
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</tr>
<tr>
<td>April 11</td>
<td>6.0°</td>
</tr>
<tr>
<td>April 12</td>
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</tr>
<tr>
<td>April 15</td>
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<td>−57.2°</td>
</tr>
<tr>
<td>April 20</td>
<td>−37.8°</td>
</tr>
<tr>
<td>April 29</td>
<td>41.4°</td>
</tr>
</tbody>
</table>

remasured by Bass and Paur [1982]; preliminary retrievals using these coefficients lead to changes of ozone mixing ratio in the ±10% range and include a significant increase at 10 mbar at high latitudes [Bhartia et al., this issue]. The final systematic difference occurs at 30 mbar where, particularly in the tropics, SBUV ozone concentrations are approximately 1 μm/gm larger (±15%) than those measured by SAGE. Much of this difference (approximately 10%) is produced by our procedure (expression (1)) for smoothing the SAGE data. In addition, the aerosol contribution to SAGE extinction at 6000 Å at 30 mbar in the tropics is approximately 10% and the aerosol model used in the SAGE ozone retrieval may produce a systematic error of 4% there [McCormick et al., this issue]. It should be noted that in this region of the atmosphere the “measured” SBUV ozone profile possesses considerable uncertainty and the retrieved profile is therefore being strongly constrained by a priori information based on ozonesondes.

Deviations From the Zonal Mean

Figure 5 summarizes the statistics of the comparison of the deviations of ozone from the zonal mean values in the SBUV and SAGE observations for the days given in Table 2. Because the SBUV ozone mixing ratios have a tendency to be proportional to the ozone absorption coefficients and errors in these coefficients are expected to be the principal source of error in the experiment, the comparison of SBUV and SAGE variances is based on normalizing the deviations by the zonal mean mixing ratio. It is immediately evident that the SAGE data is more variable; this occurs despite the fact that the quoted measurement errors at 5 mbar in the two experiments are quite similar (±5%). In the tropics, between 1 and 10 mbar, the SBUV data exhibit a relative variance of approximately 0.0002 (these results indicate that the SBUV absorption coefficient errors which should affect tropical profiles less than high-latitude profiles according to Bhartia et al. [this issue]) are not resulting in significant profile to profile varia-

bility in the tropics at these levels). The observed variances suggest that the profile to profile precision of the SBUV measurements restricted to wave numbers 1–4 is approximately 1.4% and that the contribution of radiance measurement noise to the SBUV longitudinal variance in an individual wave component between 1 and 10 mbar is less than 10–4. Since the effect of radiance measurement errors should be independent of latitude, these observations should provide an upper limit on the ozone profile variance at all latitudes due to radiance measurement noise. Note that the noise contribution thus inferred is significantly smaller than 0.5% in radiance. Because of the smaller SBUV variances, the error analysis will concentrate on the SAGE variances.

The following model for the relationship between SBUV and SAGE deviations of ozone from the zonal mean (X) is assumed

\[
\frac{\sigma(X)}{\sigma(X)}_{\text{SAGE}} = a\left(\frac{\sigma(X)}{\sigma(X)}_{\text{SBUV}}\right) + \text{noise}
\]

where \(\sigma(X)\) is the temporally averaged zonal-mean mixing ratio of ozone in a 10° latitude swath. Here we are allowing the relative amplitudes of the variations to be determined by the data. The noise is expected to be dominated by SAGE measurement errors except perhaps at the 30 mbar level where SAGE measurement errors are small and the SBUV profiles are somewhat lacking in information content (see Table 1).

A correlation analysis provides an estimate of the parameter "a" and of the noise term. Examining the noise first, Figure 6 shows the uncorrelated portion of the SAGE variance. This variance may be interpreted in terms both of the expected measurement errors and of the individual profile uncertainties given on the SAGE tapes. First, however, the error estimates must be adjusted for a vertical resolution of 8 km.

From McCormick et al. [this issue], the noise model describing the ozone profile uncertainties consists primarily of an uncertainty of 0.05 km in determining the reference altitude and an uncertainty related to the precision of the measurements of radiance. A reference altitude error will produce a systematic error in the ozone profile and should be degraded differently for smoothing over 8 km than should random measurement errors. To convert to an 8 km resolution, the reference altitude uncertainty is first subtracted from the profile measurement errors given on the archived SAGE tapes. For typical SAGE profiles, this uncertainty is calculated to give an uncertainty of approximately 3% at 10 mbar and 5% at 2 mbar in the tropics. This portion of the uncertainty is converted to an error variance for the SBUV-SAGE comparison by multiplication by 8/15 corresponding to the four waves (8 degrees of freedom) retained in this analysis. The remaining portion of the quoted profile errors is converted to an 8 km error variance by multiplication by the factor 1/8 x 8/15 which is based on assuming that the errors in each 1 km layer of the profile are uncorrelated.

Figure 6 shows that this noise model provides a reasonable simulation of that portion of the SAGE longitudinal ozone variance which is uncorrelated with the SBUV observations. At 2 mbar in particular, not only is the fit good but the statistical measure of goodness of fit (the variation of the variance: the Snedecor F test) indicates agreement with a normal distribution. For example, for three cross sections (24 degrees of freedom) based on 95% confidence levels, the variance should be no more than 1.6 times a point in the dashed line and no more than a factor of 1.8 less than a point in the line.
ceeding approximately 6% at 0.4 mbar and exceeding 3% at 1 mbar. Assuming that the noise is equally distributed among the individual longitudinal wave modes, the uncorrelated SAGE variance typically implies detectability for wave amplitudes exceeding approximately 6% at 0.4 mbar and exceeding 3% at 1 mbar for an 8 km vertical resolution.

Below altitudes corresponding to 2 mbar, the altitude reference level uncertainty dominates the SAGE ozone uncertainties. At 5 mbar, the noise model variances appear to be roughly 30% high which suggests that this uncertainty is closer to 0.2 km than to 0.25 km. At 10 mbar at extratropical latitudes and at 30 mbar at all latitudes, the noise model clearly underpredicts the uncorrelated ozone variance. In the tropics at 30 mbar, further examination of the SAGE data reveals that the large variances north of the equator are produced by a few profiles which possess very high or very low ozone concentrations at approximately 20 km altitude (e.g., $6 \times 10^{11}$ and $7 \times 10^{12}$ cm$^{-3}$ on March 8) which are mapped up to 30 mbar by the smoothing algorithm (1). A perusal of the SAGE profiles indicates that this effect only reaches as high as 30 mbar in the tropics. When these particular profiles are excluded, the SAGE ozone tropical variances are similar to those shown south of the equator and are significantly less than the SBUV ozone variances there. We therefore believe that the unexplained variance at 30 mbar is primarily a reflection of uncertainties in the SBUV ozone data there. This could result from uncertainties in the multiple scattering contribution and from the tendency for all sources of SBUV measurement error to produce larger effects on the ozone profile below 10 mbar. Based on the above hypothesis, the SBUV noise (upper limit) is approximately 0.001 at 30 mbar from Figure 6. Assuming equipartition by wave number, an SBUV relative variance of 0.001 corresponds to a contribution of 0.00025 per wave and to a precision of estimating an individual longitudinal wave of 1.6%.

Analyzing the unexplained variance in the SBUV observations, which may be obtained by multiplying the variances of Figure 6 by the ratio of the relative variances given in Figure 5, and summarizing the results in terms of the detectability of an individual longitudinal wave component (based on the white noise assumption), we obtain the upper limits on the noise contributions given in Table 3. The derived increase of variance with latitude may result from absorption coefficient errors producing larger effects at high latitudes and from more atmospheric variance at high latitudes, some of which may not be retrieved by the SBUV algorithm. This table also summa-
rizes the expected noise contributions per wave component based on the SAGE noise model (reduced at 0.4 mbar to be consistent with the unexplained variance) and equi-partition by wavenumber. Note that although Table 3 shows equal uncertainties in the SAGE and SBUV data at mid-latitudes at 2 and 5 mbar, the SAGE noise model suggests that most of this uncertainty is associated with the SAGE data.

The factors $\alpha$ in equation (8) describing the relative amplitudes of longitudinal waves in the SAGE and SBUV data may be derived from the variances ($\sigma_{\text{SAGE}}^2$ and $\sigma_{\text{SBUV}}^2$) and correlation coefficients ($r$) already calculated:

$$\alpha = \frac{r_{\text{SAGE}}}{\sigma_{\text{SBUV}}}$$

Values of $\alpha$ have been calculated for each latitude and each level; they are useful estimates only when the SBUV variances are much larger than the SBUV noise levels. Figures 5 and 6 suggest that the estimates should be made poleward of 40° latitude. Table 4 shows the average values of $\alpha$ (and the standard error of the mean) obtained by optimally combining those estimates poleward of 40° latitude for which the SBUV relative variance exceeds $8 \times 10^{-4}$ (no significant differences are obtained if the criterion is $16 \times 10^{-4}$). The standard errors of the mean values of $\alpha$ are based upon the uncertainty in the correlation coefficients equal to $N^{-1/2}$ where $N$ is the number of degrees of freedom. Values of $N$ equal to eight Fourier components times the number of independent days of observation have been used. A particular day of observations is considered to be independent only if it is three or more days and/or 5° latitude away from another day of observations. Confidence that the standard errors are approximately correct is provided by the consistency of the individual latitude-belt estimate of $\alpha$ and their error bars. We believe, however, that there exist real variations in $\alpha$ from one atmospheric event to another since the variations in the correlated variances are much larger than the average SAGE errors previously described. Since the number of independent days used is 17, Table 4 indicates that $\alpha$ typically lies between 0.6 and 1.4.

Table 4 indicates that between 1 and 10 mbar, after subtraction of the noise, the SBUV and SAGE experiments, on the average, are detecting similar longitudinal ozone variances with a vertical scale greater than or equal to 8 km. Since the SBUV retrieval treats different vertical length scales differently, this statement does not imply that similar SBUV and SAGE wave amplitudes will be observed during all atmospheric events.

At 30 and 0.4 mbar, the correlated SAGE variations have a smaller amplitude than the SBUV variations. At 0.4 mbar we hypothesize that SBUV is overpredicting the variations of ozone. This hypothesis is supported by calculated correlations and covariances between SBUV ozone retrievals and temperature. Results from a photochemical-dynamical model of the atmosphere (Figure 3) indicate that ozone variances (expressed relative to the zonal mean concentrations) are expected to decrease substantially (by a factor of approximately 4) between 1 and 0.4 mbar at mid-latitudes because of a marked reduction in the sensitivity of ozone to temperature change, a result which is readily predictable from the chemistry of ozone. The portions of the SAGE ozone variances which are correlated with temperature and with SBUV ozone show a strong decrease but the SBUV ozone variations themselves decrease by a factor of less than 2. This indicates that the SBUV algorithm may be mapping much of the atmospheric variability at the 1 mbar level to the 0.4 mbar level as well, a result which is not surprising in view of the poor vertical resolution of the SBUV experiment at 0.4 mbar [Conrath, 1977]. This tendency could be controlled by reducing the amplitude of the a priori covariance matrix at the 0.4 mbar to reflect the "expected" (modeled) variability at this level.

At 30 mbar the variance ratio shown in Table 3 is misleading because the SBUV experiment seems to have a larger noise content than SAGE at that level. Based on the SAGE noise model used in this paper, the SAGE variance is expected to be 90% real at mid-latitudes at 30 mbar. It is then more useful to calculate $\alpha = r_{\text{SBUV}}/\sigma_{\text{SAGE}}$. We obtain $\alpha = 0.7 \pm 0.1$. It then appears that the SBUV algorithm is significantly damping the variations on a vertical scale exceeding 8 km at 30 mbar. This result is consistent with the expected reduction in SBUV information content at that level [e.g., Conrath, 1977; Yarger and Mateer, 1976].

### 6. An Example of Planetary Scale Ozone Variations Observed by the SBUV and SAGE Instruments

During the period from April 1 to 9, 1979, the SAGE sunrise observations were all located between 50° and 60°S. The persistence of wave structure during this period provides an additional check on the reality of observed variations and on the nature of the differences between the observed ozone variations. The wave 1 and 3 amplitudes and phases at 10 mbar for this period determined from the SBUV and SAGE data are shown in Figure 7. These are the largest wave amplitudes observed in this comparison study. If the ozone measurement uncertainty is $\sigma_o$ and the wave amplitude is $W (> \sigma_o)$, the most likely estimate of the wave amplitude is approximately

### Table 4. The Ratio [(|ξ|^2/|ξ|^2_SAGE)]/[(|ξ|^2/|ξ|^2_SBUV)]\(^{1/2}\) Determined From 38 Cross Sections of Ozone Observations in March and April 1979

<table>
<thead>
<tr>
<th>Pressure, mbar</th>
<th>SAGE/SBUV Wave Amplitude Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.8 ± 0.1</td>
</tr>
<tr>
<td>10</td>
<td>1.0 ± 0.1</td>
</tr>
<tr>
<td>5</td>
<td>1.0 ± 0.1</td>
</tr>
<tr>
<td>2</td>
<td>1.0 ± 0.1</td>
</tr>
<tr>
<td>1</td>
<td>1.0 ± 0.1</td>
</tr>
<tr>
<td>0.4</td>
<td>0.6 ± 0.2</td>
</tr>
</tbody>
</table>

See text for discussion of 30 mbar result.
Fig. 7. The amplitudes and phases of (a) wave 1 and (b) wave 3 in ozone mixing ratio from SAGE (circles) and SBUV (crosses) observations and in temperature (triangles) for early April 1979 at 10 mbar at approximately 58°S.

(W^2 + σ_n^2)^{1/2} and the phase error will be approximately ± tan^{-1} (σ_n/W). At 10 mbar and 58°S, the mean ozone mixing ratio determined by the SAGE measurements is approximately 10 μgm/gm. Hence, from Table 3, the measurement uncertainty should be approximately 0.2 μgm/gm which for a wave amplitude of 1 μgm/gm implies an overestimate of wave amplitude of approximately 2% and a phase error of 10°. Note, however, from Figures 5 and 6 that at this latitude at 10 mbar there exists a particularly large difference between the measured variances and apparently a particularly large noise content.

Approximately one quarter of the differences in wave amplitudes shown in Figure 7 may be removed by normalizing the amplitudes by the zonal mean mixing ratio which is approximately 15% larger for SAGE than for SBUV at this location. Although on the average at 10 mbar, SAGE and SBUV measure the same relative wave amplitudes after the removal of SAGE measurement noise (see Table 4), this is not the case for the conditions of Figure 7 (for which the calculated "α" factor is approximately 1.4). This is an example of the statement that the amplitude ratio seems to be event dependent. Bearing in mind that vertical averaging over 8 km is not identical to the filtering that is applied during the SBUV retrieval, it is not surprising that the amplitude ratio seems to be dependent on the vertical structure of ozone during an event. In this particular event, the SAGE data indicates that the ozone perturbation is highly peaked at 10 mbar. Based on Figure 2 and Table 1, it is quite possible that the SBUV retrieval is damping the perturbation at 10 mbar. The temporal variation of the wave amplitudes is quite similar in the two experiments with a maximum amplitude for wave 3 occurring early in the observational period and for wave 1 late in the period. The agreement between the measured phases of wave 3 is remarkably good. For wave 1, phase differences are typically 20° (which is reasonably consistent with the expected noise levels) except on April 2 when the data would be expected to possess a substantial noise contribution because of the small wave 1 amplitude.

Figure 8 shows the vertical structure of the waves averaged for April 7-8. The waves possess maximum amplitudes at 10-30 mbar and minima at 2 mbar. From Table 3 it should be noted that we should expect a substantial noise component for wave 3 above 5 mbar for both experiments. The differences in amplitudes of wave number 1 at and above 5 mbar are expected to be due to noise in the SAGE experiment. Within the
noise levels, the phase variations with height are consistent for the two experiments although at 30 mbar the SBUV algorithm may be basing its phase estimate on what is happening in the data region above that altitude.

The variations in atmospheric temperature are also shown in Figures 7 and 8. These have been derived from global temperature data supplied from the TIROS-N satellite by the National Oceanographic and Atmospheric Administration (NOAA). Wave structure has been derived from the temperature distributions by a procedure similar to that used to determine ozone variations from the SBUV ozone measurements. We note that during the period, bearing in mind that the precision of the temperature measurements is no better than approximately 2°K, there is good correlation between the temporal changes of ozone and temperature at 10 mbar. For wave 1 during the period April 6–8 when the ozone and temperature oscillations are largest, the wave is almost stationary at 10 mbar. In the southern hemisphere at that time, the mean zonal wind field is calculated to exhibit a maximum westerly speed at approximately 60° latitude and to increase slowly from 16 m/s at 60 mbar to 20 m/s at 10 mbar and to 40 m/s at 1 mbar. These conditions are appropriate for the upward propagation of energy by stationary wave 1 to 1 mbar, provided its latitudinal scale is greater than approximately 10⁴ km [see, e.g., Holton, 1975]. During this period, wave 3 in ozone and temperature is fairly steady and travels toward the east at a speed of approximately 30° ± 10°/day (19 ± 6 m/s). The vertical structure of the waves on April 7 and 8 (Figure 8) indicates that the waves tilt westward with height indicating an upward propagation of energy up to 2 mbar.

Figure 8 also clearly exhibits a phase shift in the ozone temperature relationship occurring between 2 and 5 mbar. Above an altitude corresponding to 5 mbar, the ozone wave is approximately 180° out of phase with the temperature wave. This is consistent with our expectation that ozone variations are controlled by chemistry (and hence temperature) in the upper stratosphere. In our stratospheric model [Cunnold et al., 1980], this transition occurs at approximately 5 mbar at this latitude at this time of year. This may indicate a slightly larger transport contribution to ozone irregularity generation during these 2 days than is typically present in the model. Because of this phase change with height, the model exhibits a ozone relative variance minimum between 2 and 5 mbar (see Figure 3), a result not inconsistent with Figure 8. Based on a total of 17 SAGE cross sections at this latitude in March and April 1979, the ozone relative variance minimum is observed to occur at 2 mbar.

An observation which should provide an important test of
ozone model chemistry is the relative amplitude of ozone and temperature fluctuations. For wave 1 on April 7 and 8, this ratio is approximately 7 for SAGE and 4 for SBUV at 10 mbar. It should be noted, however, that the temperature wave amplitudes are not large and may be influenced by noise. We have, therefore, calculated the amplitude ratio at 10 mbar for SAGE data averaged over the 50°–70° latitude belts from the expression $r_{T/SAGE}$ where $r$ is the correlation between SAGE ozone and temperature (variance $\sigma_r^2$) observations. The ratio is found to be approximately 0.12 versus 0.23 calculated in the photochemical-dynamical model. An over-prediction of smaller amplitude is also found at 1 mbar in comparing the SBUV ozone and temperature data. We recall, however, the results of Phillips et al. [1979] which indicate that satellite temperature variances have been found to be substantially lower than variances determined by radiosonde observations above 70 mbar. Therefore, this ratio needs to be interpreted cautiously and further examination of TIROS-N temperature retrievals in the stratosphere are desirable.

In conclusion then, the observed ozone variations have been found to be fairly consistent with the observed temperature structure. Moreover, inasmuch as the ozone variations are large relative to the temperature variations at 1 mbar at mid-latitudes and the phase difference between the two parameters may be assumed to be 180°, it should be possible to improve temperature retrievals using SBUV or SAGE ozone observations.

7. SUMMARY AND CONCLUSIONS

Thirty-eight longitudinal ozone cross sections inferred from SBUV and SAGE observations have been compared at latitudes between 65°N and 60°S. Differences in zonal mean concentrations which exceed the projected uncertainties of the measurement techniques have been found. At atmospheric pressures smaller than 5 mbar, the SAGE ozone concentrations are approximately 20% larger than SBUV at tropical latitudes (after removal of the effect of time differences in the observations). At 50°–60° latitude, such a difference is only found at pressures smaller than 1 mbar. An unknown constituent would have to provide an extinction of $5 \times 10^{-5}$/km at 6000 Å to account for this difference. Significant differences in the zonal mean ozone concentrations poleward of 30° latitude at 10 mbar and in the tropics at 30 mbar have also been found. At 10 mbar, the differences increase with increasing latitude and the SAGE ozone concentrations are approximately 15% larger than SBUV concentrations at 50°–60° latitude. Differences at pressures higher than 2 mbar may be produced by SBUV absorption coefficient errors [Bhuria et al., this issue].

The data comparison allows an a posteriori assessment of the measurement errors of the two techniques based upon an analysis of the uncorrelated portions of the ozone variances. The noise model for the SAGE data consists primarily of a profile reference altitude uncertainty of ±0.25 km together with irradiance measurement errors which are assessed during the retrieval from several scans across an individual altitude. Based on this model, the archived SAGE tapes provide uncertainty limits appropriate to a vertical resolution of 1 km. In this data analysis, the SAGE data was vertically smoothed over 8 km. At this resolution, the irradiance measurement errors, which have been assumed to be uncorrelated in altitude, dominate at altitudes above 1 mbar while the reference altitude uncertainty dominates at lower altitudes. The results suggest that the noise model overestimates the SAGE noise variance at 0.4 mbar by a factor of approximately 2. Therefore, profile error bars for vertical resolutions poorer than 5 km may conservatively be estimated by dividing the prescribed error bars by $\sqrt{n}$, where $n$ is the desired resolution in kilometers. Furthermore, the uncorrelated SAGE variances at 5 mbar suggest that the reference altitude error may be ±0.2 km. This noise model indicates that the SAGE should be able to detect longitudinal variations of ozone which have a vertical scale greater than 8 km and whose amplitudes exceed approximately 2% between 1 and 10 mbar, 1% at 30 mbar, and 5% at 0.4 mbar.

The uncorrelated portion of the SBUV variances are smaller than the SAGE noise variances at altitudes above 10 mbar which indicates that the SBUV experiment should provide excellent detectability of longitudinal ozone variations. Assuming equipartition of noise by wave number component, the experiment should be able to detect longitudinal waves having a vertical scale exceeding 8 km and whose amplitudes exceed approximately 1% in the tropics and 2% at mid-latitudes between 0.4 and 10 mbar. These uncertainty limits are smaller than the error bars given on the archived SBUV tapes presumably primarily because the latter must include variations on scales between 5 and 8 km. At 30 mbar the SBUV uncorrelated variances provide a (mean) upper limit on the detectability of longitudinal ozone variations of 2% at all latitudes. Moreover, assuming the correctness of the SAGE noise model, the SBUV ozone noise exceeds that for SAGE ozone at this level.

The longitudinal variations of ozone inferred from this data set exhibit good agreement over the primary data region for the SBUV experiment (1–10 mbar) when the known sources of noise are considered. In particular, over this pressure range at mid-latitudes, it was shown that, on the average, the SBUV variance and the correlated SAGE variance (after vertical smoothing over 8 km) are the same. It was also noted, however, that this relationship varied from one atmospheric situation to another. At 0.4 mbar the SBUV variance was calculated to be larger than the correlated SAGE variance by a factor of approximately 3. It was suggested that the SBUV algorithm is importing oscillations from 1 mbar. At 30 mbar, using the SAGE noise model, and the fact that the SAGE ozone variances exceeded the correlated SBUV variances there, it was concluded the SBUV ozone retrieval is damping the atmospheric ozone variations there.

The ability of these sensors to detect longitudinal variations has been illustrated for the first 8 days of April 1979 at 58°S. Excellent agreement between the detected phases of waves 1 and 3 was noted both on a daily basis and in the changes from day to day. These phases were also consistent with the phases determined from atmospheric temperature observations based on a numerical model of the ozone-temperature relationship.

The relative amplitude of the ozone variations is several times that of the temperature variation suggesting that it should be possible to enhance measurements of variations in stratospheric temperature using ozone observations from either the SBUV or SAGE sensor. However, at 10 mbar, the relative amplitudes of ozone and temperature variations were not the same during this observational period as in a photochemical-dynamical model suggesting a need for further examination of the temperature observations and the model results.

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