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STATUS OF THE SHUTTLE SBUV (SSBUV) CALIBRATION OF THE NOAA SBUV/2 OPERATIONAL OZONE SOUNDERS AND THE DETECTION OF TRENDS

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ABSTRACT

The Shuttle Solar Backscatter Ultraviolet (SSBUV) experiment has flown four times since October 1989. The purpose of SSBUV is to perform calibration checks of the SBUV ozone sounding instruments on the Nimbus and NOAA satellites in order to remove calibration drift so that ozone trends in the middle stratosphere can be accurately derived. Calibration checks are performed by comparing coincident observations between SSBUV and the satellite instruments. Regular flights of about once per year and maintenance of the SSBUV calibration to 1% from flight to flight are the major challenges for SSBUV. To date the required flight frequency has been met and instrument calibration is known to about 1-2% for the first three flights. The first comparisons showed 30% differences between SSBUV and the original archived Nimbus SBUV data, but considerably smaller differences with the new SBUV "Version 6" data. Differences between SSBUV and SBUV/2 instruments on NOAA-11 and NOAA-9 were of the order of 5-10% respectively. These differences have not been accounted for in the present NOAA data set since they contain initial calibration biases as well as long term instrument drift. With subsequent SSBUV comparisons, the satellite calibration can be corrected, which will then allow an accurate estimate of ozone trends in the upper stratosphere. In this initial study, 1989 Nimbus-7 SBUV data have been corrected using SSBUV observations and then compared to SBUV data for 1980. This comparison then leads to an ozone trend of 7% in the upper stratosphere over the tropics for the period 1980 to 1989.

1. INTRODUCTION

SSBUV was conceived about a decade ago because of the concern of satellite instrument calibration drift once placed in orbit. This drift would significantly hinder our ability to accurately detect ozone trends in the stratosphere. A national plan for monitoring the stratosphere (National Plan, 1989) went into effect in 1984 when NOAA-9 carrying the first SBUV/2 instrument was placed into orbit. A second SBUV/2 was launched on NOAA-11 in late 1988. Both instruments continue to operate. In addition to these instruments the Nimbus-7 SBUV/TOMS and the Meteor/TOMS continue to operate. SSBUV is being flown routinely as part of the National Plan in order to provide calibration checks of the NASA and NOAA BUV type instruments. The calibration checks are performed by comparison of coincident observations between SSBUV and the satellite instruments. The overall goal of SSBUV is to remove the uncertainty in the satellite data set to a level less than the expected ozone trend of about 1% per year in the upper stratosphere. This can be accomplished with a flight frequency of once per year and a rigorous calibration program which tracks the SSBUV calibration to a precision of 1% (one sigma) from one flight to next (Hilsenrath et al., 1988). A study employing simulated Shuttle and satellite SBUV/2 data demonstrated that a drift in satellite data could be removed with sufficient precision to detect an ozone trend (Frederick et al., 1992) employing data from regular Shuttle flights. The SSBUV instrument is nearly identical with the ozone instruments being flown on the Nimbus and NOAA operational satellites. This affords a distinct advantage in validating SBUV satellite data over other ground or satellite instruments which employ different measurements techniques. In addition to ozone, SSBUV observes the solar irradiance in the wavelength range 200 to 405 nm, the region of the solar spectrum important to atmospheric chemistry.

SSBUV has now flown 4 times over less than two and one half years. The following are the dates for these flights; October 1989, October 1990, August 1991, and March 1992 which was flown with the ATLAS-1 mission. Four additional flights are manifested on the Shuttle through 1997, beginning in March 1993 with ATLAS-2. This paper is a status report on the first 3 flights. Comparisons of SSBUV-1 with the Nimbus and NOAA satellites are reviewed and the calibration stability of SSBUV-2 and -3 are discussed. Finally the comparison of SSBUV-1 with the Nimbus-7 SBUV is used to estimate the trend of upper stratospheric ozone for the period 1980 to 1989.

2. MATCHUPS OF SSBUV AND SATELLITES

Figure 1 illustrates the location of SSBUV-4 and satellite matchups, which is typical of SSBUV missions. The matchups shown here are the locations for the Nimbus-7 SBUV/TOMS, Meteor/TOMS, NOAA-9, NOAA-11, and UARS limb viewing atmospheric experiments. Typically there are about 20-40 matchups for each satellite (nadir view for TOMS) that meet the matchup criteria of a one hour window (Hilsenrath et al. 1988).

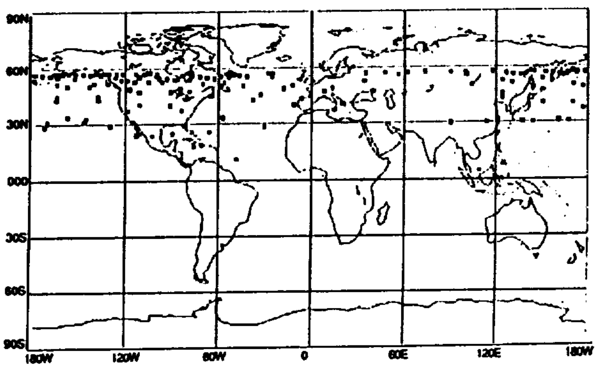

Figure 1. Matchup locations for SSBUV and the BUV type instruments on Nimbus-7, NOAA-9, NOAA-11, Meteor-35, and the ozone sounders on UARS. A matchup is defined as the location where the SSBUV and the satellite viewed the same scene within a one hour window.

3. SSBUV-1 COMPARISONS

The SSBUV performs calibration checks by comparison of observables which are the ultraviolet backscattered radiances and solar irradiance, where their ratio is related to the Earth albedo. In practice comparisons are made with the "Q" values derived by each satellite instrument with respect to those derived from SSBUV. The Q values are proportional to the ultraviolet albedo of the Earth (the measured ratio of the backscattered radiance to solar irradiance) at the SBUV observed wavelengths and the cosine of solar zenith angle at the time of the observation (Fleig et al, 1990). Figure 2 is a comparison of SSBUV-1 with the Nimbus 7 SBUV, as originally archived (Version 5) and with the NOAA-9 and NOAA-11 SBUV/2 instruments. Also shown is the comparability with the recently recalibrated Version 6 of Nimbus-7 SBUV ozone profile data (Taylor et al., 1992), now archived from November 1978 to February 1987 in the National Space Science Data Center in Greenbelt MD. Figure 2 compares observed Q values measured by the satellite instrument with respect to SSBUV. In order to compare Q values, the differences in time (over the one hour window) must be accounted for, since the backscattered radiances are solar zenith angle dependent. Therefore, Q values for the satellites are normalized to Q values of SSBUV through the ratio of the respective cosines of the solar zenith angles.

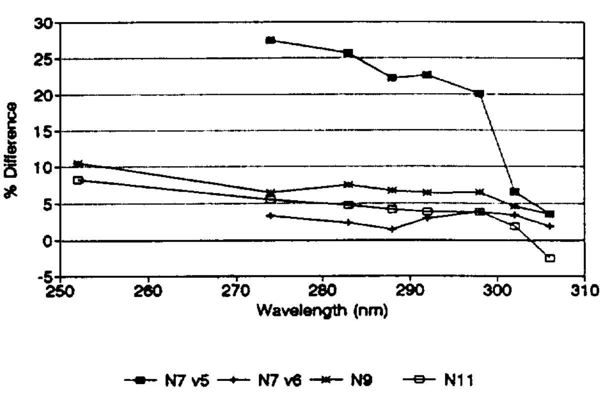

Figure 2. Calibration or sensitivity differences between SSBUV and the satellites are shown as percent differences, (Satellite-SSBUV)/SSBUV*100, of Q values (see text). N7 v5 and v6 is Nimbus-7 version 5 and 6 respectively, and N9 and N11 are NOAA-9 and NOAA-11 respectively.

It should be noted that differences in albedos shown here result from two effects; 1) initial calibration biases and 2) uncorrected change in the satellite sensitivity since the instrument was placed in orbit. The wavelength range 252 to 306 nm covers ozone sensed between about 0.7 to 22 mb. At wavelengths longer than 297 nm (corresponding to ozone in the lower stratosphere) the albedos are influenced by multiple scattering in the lower stratosphere and troposphere, therefore the differences shown there are highly influenced by cloud surface reflectance variability with time scales shorter than the 1 hour matchup coincidence criteria. Further research is necessary to understand the albedo or Q value differences between SSBUV and the satellite instruments at wavelengths longer than 290 nm. Therefor this paper focuses on the upper stratosphere. The largest difference with respect to SSBUV is the Nimbus-7 SBUV version 5. The SBUV version 6 data shows considerably better agreement. SSBUV comparisons with the NOAA-9 and NOAA-11 SBUV/2 indicate a systematic calibration difference.

It is of interest to note how calibration differences translate into ozone differences. Figure 3 illustrates ozone comparability between SSBUV and the satellites. In this comparison, ratios of the daily zonal averages measured by the satellites with respect to the daily zonal averages from SSBUV are shown as a function of pressure. The ratios of the satellite to SSBUV for the two cases, equator and 30 N, illustrate a small latitude effect of calibration errors on the ozone retrievals. This would be expected since the ozone retrieval is dependent on optical path length which in turn is related to the solar angle and therefore dependent on latitude.

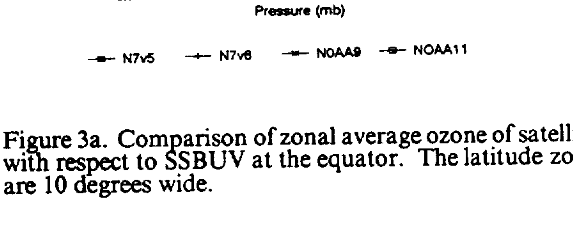

Figure 3a. Comparison of zonal average ozone of satellites with respect to SSBUV at the equator. The latitude zones are 10 degrees wide.

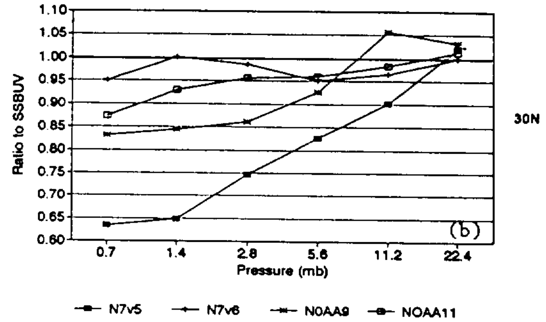

Figure 3b. Comparison of zonal average ozone of satellites with respect to SSBUV at 30 North. The latitude zones are 10 degrees wide.

4. SSBUV CALIBRATION REPEATABILITY

As discussed above the differences between SSBUV and the satellite instruments reflect laboratory calibration biases and drift in the satellite instrument after launch. Therefore, the important observation is how the differences between SSBUV and the satellites evolve over time. Tracking the satellites with SSBUV can only be meaningful if the SSBUV calibration is known to within about 1 percent from one flight to the next. The success of this requirement can be depicted in the next figure. Figure 4a illustrates the repeatability of the Solar irradiance measurements in the ozone measuring channels for two successive SSBUV missions relative to the first. Here we have assumed that the sun is a constant source and used as a reference to ascertain calibration stability. At wavelengths longer than 250 nm this assumption is quite valid. In this comparison, SSBUV-2 and SSBUV-3 differ from SSBUV-1 by 1-2% while they agree with each other to within a few tenths of a percent. These results are encouraging, but further study is necessary to understand the larger difference between flight 1 and flights 2 and 3. A more detailed discussion of the SSBUV Solar irradiance measurements is given in a companion paper in these proceedings by Cebula and Hilsenrath (1992).

Unlike the solar irradiance measurement, there is no unvarying source in space to evaluate the precision of the radiance measurement from one flight to the next. Radiance stability can be ascertained by comparing the radiance calibration (laboratory radiance standards change over time but are traceable to the National Institutes for Standards and Technology) over the same three flights. This comparison is shown in Figure 4b. The figure illustrates calibration changes of about 1-1.5 percent over three flights. The is an excellent result since the instrument appears to be stable to within this amount. The radiance sensitivity or calibration is actually known to better than this amount because the SSBUV calibration can be measured with a precision of a few tenths of a percent (Cebula and Hilsenrath, 1991).

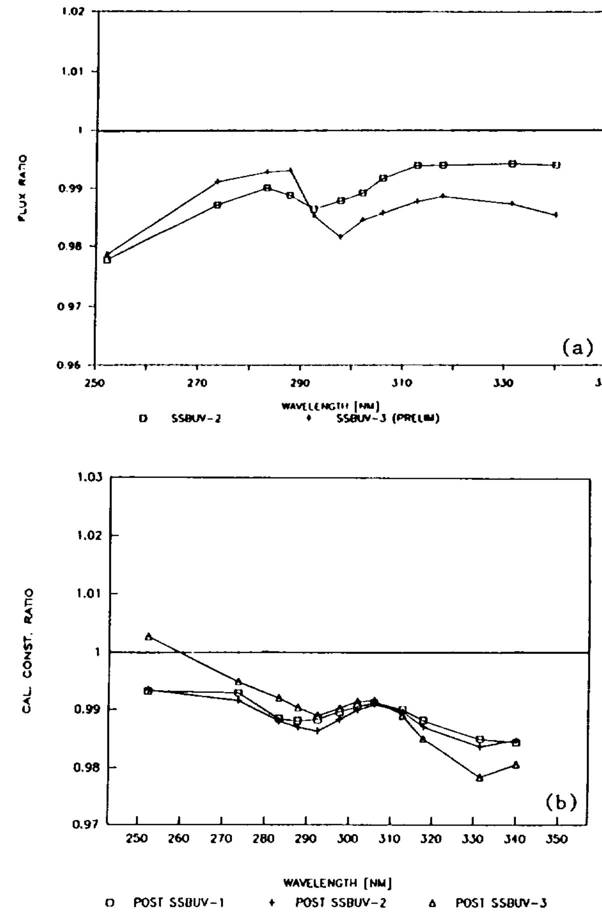

Figure 4. This figure illustrates the stability of SSBUV. 4a compares the solar irradiance measured by SSBUV-2, and -3 relative to SSBUV-1. 4b compares the radiance sensitivity of SSBUV-2 and -3 relative to SSBUV-1.

5. OZONE TRENDS

Although SSBUV was not expected to have an impact on our ability to detect trends until about half way through the ten year program, we have employed data from SSBUV-1 (October 1989) to derive an ozone trend in the upper stratosphere over the period 1980 to 1989. This was accomplished by deriving a correction factor for the Nimbus-7 SBUV using the data similar to that shown in Figure 3. The correction factor includes matchup comparisons and comparisons of zonal averages. The derivation of this correction factor are described by Hilsenrath et al. (1992) where they show its validity over the latitude range 30 S to 30 N for the month of October. An ozone trend is derived by subtracting the Nimbus SBUV data in 1980 from the SSBUV corrected Nimbus 1989 data. The 1980 data are used because that year matches the phase of the quasibiennial oscillation in 1989. In addition, the Nimbus-7 SBUV degradation was properly accounted for in 1980 (Trends Panel Report, 1990). Note also that these times are also periods of solar maximum. Therefore the ozone changes illustrated here are most likely due to anthropogenic effects alone.

The derived trend appears in Figure 5 along with a model calculation (Jackman et al.; 1989, Hilsenrath et al., 1992) and the trend derived by the SAGE satellite for the period 1979 to 1990 (McCormick et al., 1992). All three trends show basically the same features with a maximum depletion near 45 km and an ozone increase below 34 km. The absolute error bar indicates possible initial calibration biases between Nimbus SBUV and SSBUV while the precision error bar represents the uncertainty resulting from zonal and latitudinal averaging. The SAGE errors are similar to ours and therefore overlap our errors. However, the SAGE data seem to be systematically lower than the SBUV observations and the model calculations.

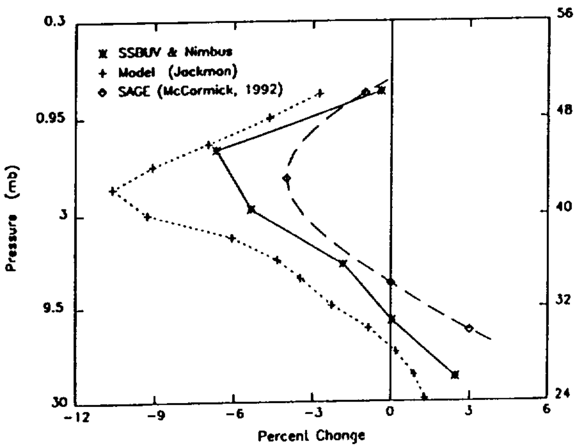

Figure 5. Ozone trend for October for the period 1980 to 1989 derived from SSBUV corrected Nimbus-7 SBUV data, a two-dimensional model calculation, and the SAGE data.

6. SUMMARY

This paper reports on the status of SSBUV which is being flown to provide a calibration check of the SBUV/2 ozone sounders on the NOAA operational satellites. SSBUV has flown four times since 1989 and four additional flights are scheduled through 1997. It is likely that these flights will continue on a once per year basis for as long as the SBUV/2 instruments are employed for ozone monitoring. This is planned well beyond the year 2000. To date instrument calibration has been tracked with a precision of 1-2%. The SSBUV calibration program continues to strive for the highest calibration accuracy and precision.

The first SSBUV flight was used to estimate an ozone trend in the upper stratosphere for the period 1980 to 1989. This was accomplished by correcting the Nimbus-7 SBUV data in 1989 using SSBUV and comparing it to SBUV data in 1980. The estimated trend showed a maximum depletion at about 46 km of about 7%. This depletion agrees with a 2-D model calculation and is consistent to, within the errors, trends derived from SAGE satellite data.

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