N95-11123

PROCEDURES TO VALIDATE/CORRECT CALIBRATION ERROR IN SOLAR BACKSCATTERED ULTRAVIOLET INSTRUMENTS

Steven L. Taylor
Hughes/STX
Lanham, Maryland

R.D. McPeters, P.K. Bhartia
Goddard Space Flight Center
Greenbelt, Maryland

ABSTRACT

The Nimbus 7 SBUV measures the same latitude ozone at widely different sun angle conditions at the ascent and decent part of the orbit during the summer solstice. This situation is used in a particular procedure (Ascent/Descent) to obtain the relative channel-to-channel calibration error for channels 273 nm to 306 nm. These estimated errors are combined with results from the Pair Justification procedure to correct the sun-view diffuser drift in calibration from November 1978 to February 1987 for the shorter wavelength channels that measure upper stratospheric ozone. Some preliminary re-calibrated Nimbus 7 SBUV data in 1989 is compared with the first set of SSBUV measurements flown on the Space Shuttle.

1. INTRODUCTION

The 1988 ozone trends panel report found the Version 5 Nimbus 7 SBUV and TOMS total column ozone trends from 1979 to 1987 to be 3.5 percentage points more negative than the Dobson measurements. The Nimbus SBUV profile shows a negative 20 percent trend at 48 kilometers. The panel concluded that the SBUV and TOMS trends were in error due to an unaccounted degradation of the instruments' diffuser (Fleig, 1990). Since this finding, a new procedure (designation Pair Justification) has been developed and published to estimate and correct the diffuser calibration drift for both the Nimbus 7 TOMS and SBUV total ozone. TOMS data have been reprocessed and released as Version 6 data (Herman, 1991). This paper describes a separate new procedure to estimate and correct the diffuser calibration drift for the Nimbus 7 SBUV upper stratospheric ozone (profile) channels.

The SBUV type instrument measures earth radiance and solar irradiance at 12 channels with wavelengths from 255 nm to 340 nm. Albedos (radiance/irradiance) from 273 nm to 306 nm are in general used to derive profile ozone. The 255 nm channel is not used in Nimbus 7 because of nitric oxide emissions. The four longest wavelength channels (313, 318, 331 and 340 nm) are paired to derive total column ozone; A-pair (313 and 331 nm), B-pair (318 and 331 nm) and C-pair (331 and 340 nm).

The Pair Justification procedure uses a new pair of channels, 306 nm and 313 nm, designated the D-pair, for assessing total ozone. In general, the 306 nm channel is a profile channel. However, at equatorial latitudes with low total column ozone and small sun angles, 306 nm "sees" the same column ozone as the operational pairs (A, B and C). Pair Justification is based on a particular comparison of D versus A-pair albedos. Analytical leverage for the procedure exists because the D-pair is significantly less sensitive to a wavelength dependent calibration drift than the A-pair (smaller wavelength separation between the channels), plus the D-pair has a greater sensitivity to ozone. Nimbus 7 TOMS does not have a 306 nm channel. Thus, the TOMS calibration drift is corrected on the SBUV D-pair using coincident TOMS nadir-view albedo measurements.

The Pair Justification procedure estimates calibration drift for the Nimbus 7 SBUV channels 306 nm to 340 nm. When combined with the Ascent/Descent Procedure using a particular comparison of ascent versus descent profile measurements at or near the summer solstice, calibration drift for channels 273 nm to 302 nm are estimated and corrected to produce Version 6 SBUV ozone data (upper level profile and total ozone).

2. ASCENT/DESCENT PROCEDURE

During or near summer solstice at the higher latitudes, ozone is measured twice in the same orbit, once in the ascent and once in descent. Thus, the same latitude is measured twice at widely different solar zenith angles. Figure 1 shows the altitude of normalized single scattered albedo sensitivity to ozone for two measurements at the same latitude (72 degrees north) with a solar zenith angles of 52 degrees for the ascent and 87 degrees for descent. Also shown is the vertical distri-

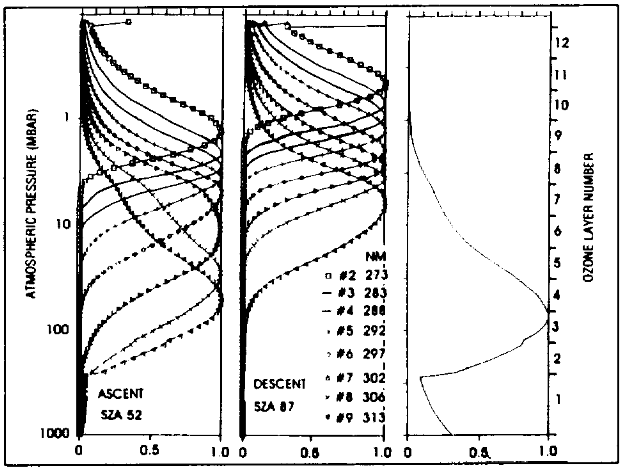

Fig. 1. Altitude of normalized single scattered albedo sensitivity to ozone for two measurements at 72 degrees latitude during summer solstice plus the respective ozone density distribution (normalized).

bution of ozone. In Figure 1 the altitude of the 273 nm channel (the shortest channel) in ascent is very close to the altitude of the 292 nm channel (a middle channel) in descent. At the higher solar zenith angles, the altitude where a profile channel is sensitive to ozone is displaced upward. Assuming an exact overlap of these albedo sensitivities to ozone, a difference in measured albedo from a reference standard (A_{mea}) versus calibration error (E) can be described by two equations for the ascent and descent channels, respectively, as follows:

$$\mathrm{Log}(A_{mea273}) = S_{273} \times OZ_{true} + E_{273} \qquad (1)$$

$$\mathrm{Log}(A_{mea292}) = S_{292} \times OZ_{true} + E_{292} \qquad (2)$$

where S is the logarithm of albedo sensitivity to changes in ozone and OZ_{true} is the difference in "true" or actual ozone in the region of overlap from the reference standard. With a "close" overlap of albedo sensitivity to ozone ascent $S_{273}$is essentially equal to descent S_{292} and Equation 1 and 2 reduces to:

$$E_{292} - E_{273} = \mathrm{Log}(A_{mea292}) - \mathrm{Log}(A_{mea273}) \qquad (3)$$

where E_{292} - E_{273} is the calibration error of 292 nm relative to 273 nm. The analytical leverage for computing a relative channel-to-channel error from Equation (3) is the result of different channels "seeing" the same ozone. As a practical matter, the above formulation is not completely independent of profile ozone. In order to characterize the altitude of the sensitivities, an assumed reference standard ozone profile is required. Furthermore, a particular set of ascent and descent measurements at a particular latitude band may or may not have a set of "very closely" overlapping sensitivities. Thus, a matrix formulation is derived which includes an ozone profile retrieval (OZRET) and theoretical albedo calculation (ALB) and the following overall relationships:

$$A_{true}(\mathrm{ascent}) = \mathrm{ALB}[\mathrm{OZRET}(A_{true}(\mathrm{descent}))] \qquad (4)$$

$$\mathrm{Log}[A_{mea}(\mathrm{ascent})] = \mathrm{Log}[A_{true}(\mathrm{ascent})] + E \qquad (5)$$

$$\mathrm{Log}[A_{mea}(\mathrm{descent})] = \mathrm{Log}[A_{true}(\mathrm{descent})] + E \qquad (6)$$

where A_{true} is column matrix of "true" albedos divided by albedos for the reference standard profile, A_{mea} is the measured albedos divided by albedos for the reference standard profile and E is the calibration error. Equation 4, 5 and 6 are combine to derive and expression for the calibration error (E). A computer code to estimate E uses routines from the Version 5 Profile Processing Algorithm for the OZRET and ALB calculations and sets of average ascent and corresponding decent measurements (two week, two degree latitude averages).

To test and characterize the computer code formulation, the theoretical albedo calculation (ALB) is used to compute simulated albedos for a defined ozone profile and simulated calibration error. In other words, the simulated albedos are theoretical albedos computed from a known ozone profile and calibration error. In instead of the measured albedos, these simulated albedos are used as input to the computer code formulation. The computed calibration error is compared with the simulated calibration error. Figure 2 shows the results using a simulated albedos computed with a calibration error that is a linear function of channel wavelength and ozone profiles which are uniformly less (same fractional decrease at all altitudes) than the standard reference. When an ozone profile is the same as the reference standard profile used in the formulation, there is no difference in the calibration error computed by the matrix formulation and the simulated calibration error. However, as Figure 2 shows, when the profile is different from the standard reference, the computed calibration error is not the same as the simulated. On the other hand, Figure 2

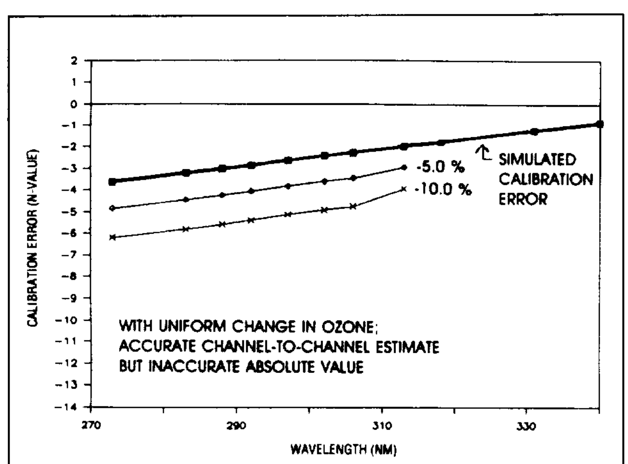

Fig. 2. Computed calibration errors using simulated albedos from a simulated calibration error which is a linear function of wavelength and from ozone profiles that are uniformly less than the reference standard profile.

shows that the relative channel-to-channel calibration error is accurately determined. Figure 3 shows the results for a simulated calibration error that is a non-linear function of channel wavelength and "bump" changes in profile ozone. A "bump" has minus 20 percent change in ozone in the designated Umkehr Layer and minus 10 percent change in the layer above and the layer below. As with the uniform differences in ozone in Figure 2, the "bump" ozone results in large differences in computed versus simulated calibration error but the relative channel-to-channel calibration error has useful accuracy.

3. CALIBRATION DRIFT FOR PROFILE CHANNELS

Figure 4 shows how the relative channel-to-channel calibration error computed by the formulation can be combined with other procedures to develop a "total calibration error" for all channels. Total calibration error includes both a "Drift" and an "Initial" calibration error. As discussed above, to-date only the drift in calibration for the longer total ozone wavelengths has been determined by Pair Justification. Thus, the drift in the computed relative channel-to-channel calibration error for channels 273 to 306 nm is joined to the results of this Pair Justification to estimate the calibration drift for all the channels. A calibration correction for this estimated drift is used to produce Version 6 Nimbus 7 SBUV ozone profiles.

4. NIMBUS 7 SBUV CALIBRATION DRIFT RESULTS

For Nimbus 7 SBUV, only the northern hemisphere summer solstice data is used. In the southern hemisphere, there appears to be a instrument temperature anomaly as the satellite comes out of darkness causing some differences between the ascent versus the descent orbit measurements. Work is planned to further investigate this issue. In the northern hemisphere, individual scan albedo data is averaged for two degree latitude bands during two week periods. Figure 5 shows the computed Version 5 relative channel-to-channel calibration error from six sets of these averages during the 1986 northern summer solstice. As with the simulation, there are large differences between the different averages but a consistent relative channel-to-channel error. The drift in calibration error is computed by subtracting the result of each year from the average of years 1980 and 1981. Figure 6 shows the computed drift in 1986 from the average of the same six data set in Figure 5. Also shown is the drift for the longer wavelength channels from Pair Justification. The relative channel-to-channel calibration error from 273 nm to 306 nm is connected to the Pair Justification results. Figure 7 shows the resulting estimated drift for all channels for the month of June from 1985 to 1989.

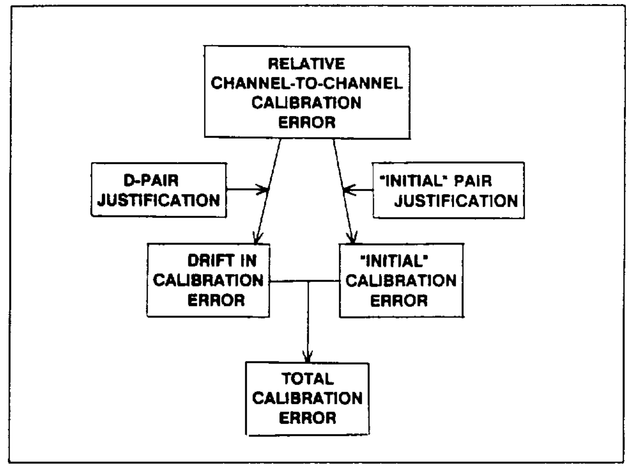

Fig. 4. Overall procedural steps to derive an estimated total calibration error.

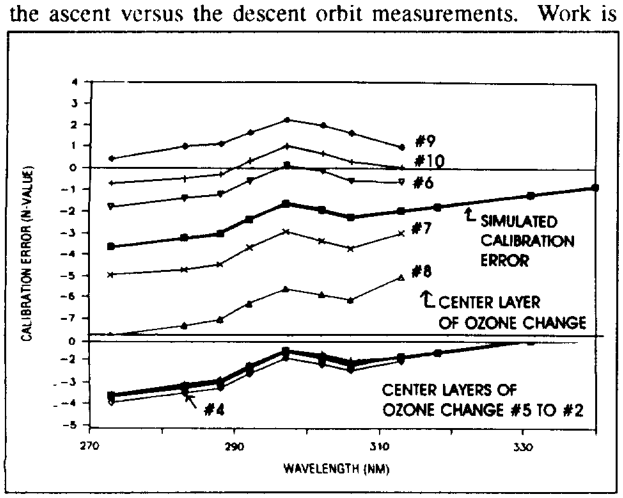

Fig. 3. Computed calibration errors using simulated albedos from a simulated calibration error which is a non-linear function of wavelength and from ozone profiles that have "bump" reductions in ozone from the reference standard profile.

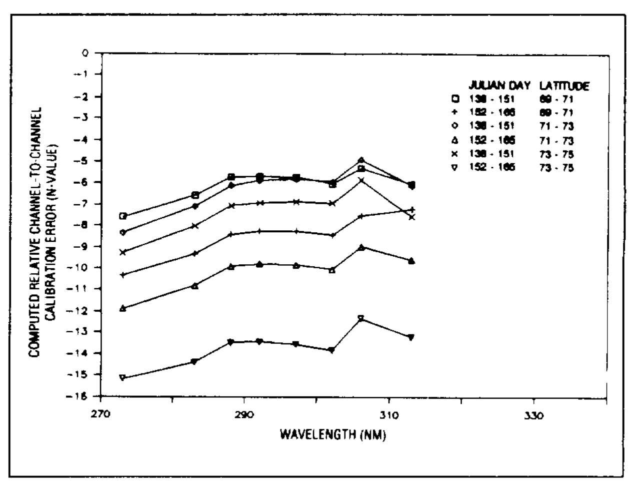

Fig. 5. Computed relative channel-to-channel calibration error from two-week, two-degree-latitude average albedos.

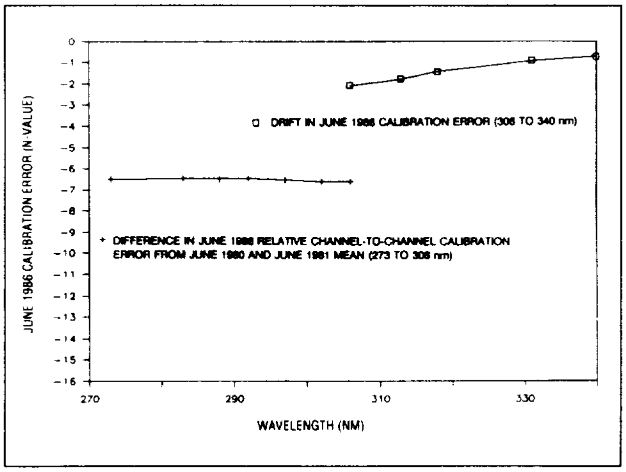

Fig. 6. Drift in relative channel-to-channel calibration error versus drift in longer wavelengths from pair justification.

Starting in March 1987, the Nimbus 7 SBUV measurements developed a large increase in noise due to non-synchronization of the chopper wheel. The evidence suggest there are greater inaccuracies in estimating the calibration error for this data. A procedure to correct the non-synchronization is presently under development. Thus, the data shown in Figure 7 for 1987 through 1989 is preliminary and has larger uncertainties than the pre-March 1987 data.

For the pre-March 1987 data, the largest uncertainty in the estimated calibration drift for 273 nm is the uncertainty in 306 nm from Pair Justification. The second-largest uncertainty is the uncertainty in solar zenith angle determination. At mid-latitudes, the combined uncertainties, gives an estimated uncertainty in ozone derived from the 273 nm channel of ±6.4 percent ozone (95 percent confidence). For ozone derived from 306 nm channel, the uncertainty is slightly less at ±5.0 percent ozone.

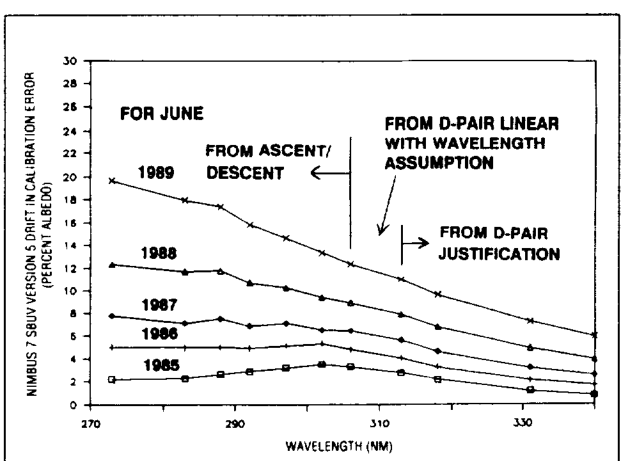

Fig. 7. Estimated calibration drift for all channels used for Version 6 calibration correction for the month of June, years 1985 through 1989; Preliminary result for 1987 through 1989.

The SSBUV instrument flown on the Space Shuttle is designed to validate the calibration of SBUV type instruments. Its first flight was in October 1989. Figure 9 shows the average differences in SSBUV versus Nimbus 7 Version 5 (Uncorrected) SBUV coincident albedos. Also shown is a preliminary estimated calibration drift from June 1979 to October 1989. However, the comparison of SSBUV and the estimated drift are not fully complimentary. As shown in Figure 4, the total calibration error also needs an estimate of the "Initial Error". In the case of Nimbus 7, the first summer solstice is eight months after launch. Thus, an estimate of the "Initial Error" using June 1979 data includes both an estimated "at launch" calibration error and the drift from launch to June 1979. The procedure to estimate "Initial Error" is presently under development.

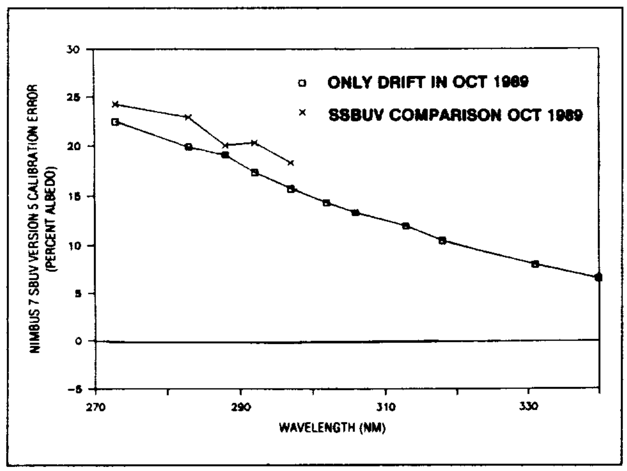

Fig. 8. Comparison of total calibration error in October 1989 estimated by SSBUV versus estimated calibration drift by Ascent/Descent Procedure.

5. CONCLUSION

The drift in Calibration error for Version 5 Nimbus 7 SBUV has been corrected for data from November 1979 to February 1987. The uncertainty in mid-latitude profile ozone derived by the shortest wavelength channel is ±6.4 percent (95 percent confidence). Preliminary data for total calibration error for October 1989 shows a relatively close comparison with the first SSBUV flight

REFERENCES

Fleig, A.,J., etal., An Assessment of Long-Term Drift in SBUV Total Ozone Data, Based on Comparison with the Dobson Network, Geophys. Res. Lett., 13, 1359, 1986.

Herman, J.R., etal., A New Self-Calibration Method Applied to TOMS and SBUV Backscattered Ultraviolet Data to Determine Long-Term Global Ozone Change, J. Geophys. Res., Vol 96, No D4, pg 7531-7545, April 20, 1991.