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# A NEW METHOD FOR MONITORING LONG TERM CALIBRATION OF THE SBUV AND TOMS INSTRUMENTS

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**Abstract**

A new method has been developed to monitor the long-term calibration of the SBUV and TOMS instruments. It is based on the fact that the radiance in one channel can be expressed as a linear sum of the radiances in neighboring channels. Using simulated radiances for the SBUV and TOMS instruments, various scenarios of changes in instrument calibration are investigated. Results from sample processing of SBUV data are also presented.

**Introduction**

SBUV/TOMS instruments were launched aboard the Nimbus-7 spacecraft in October 1978. Since that time, the two instruments have been providing useful data for monitoring global columnar ozone. However, due to a hazardous space environment, one of the key components of the instrument, a diffuser plate has been considerably degraded. This diffuser plate allows a direct determination of the incident solar flux at the top of the atmosphere. Estimating the degradation is a major challenge in deriving the long term trend from the two instruments. If this degradation is not properly accounted for, the estimated ozone amount will be in error and a time dependent bias would be apparent in the data. Four years ago, Bhartia and Taylor proposed a method to correct the diffuser degradation using estimated ozone derived from different pairs of instrument wavelengths. This method requires that in the most favorable conditions (high sun and low ozone in the equatorial region) the ozone derived from D pair (λ3058A : λ3125A) and A pair (λ3125A : λ3175A) be the same. Their method was further refined for the TOMS instrument by Herman et al. (1991) and was used for reprocessing Version 6 of SBUV/TOMS data. Both methods assume constant values for diffuser error across the pairs.

In this paper we describe another method to monitor the drift in the measured albedo due to the degradation of the diffuser plate. We define albedo as the ratio of the backscattered solar radiance in the direction θ (polar angle) and ϕ (azimuth angle) to the incident solar flux $F_o$ in the direction $\theta_o$ at the top of the atmosphere. The method is based on the fact that

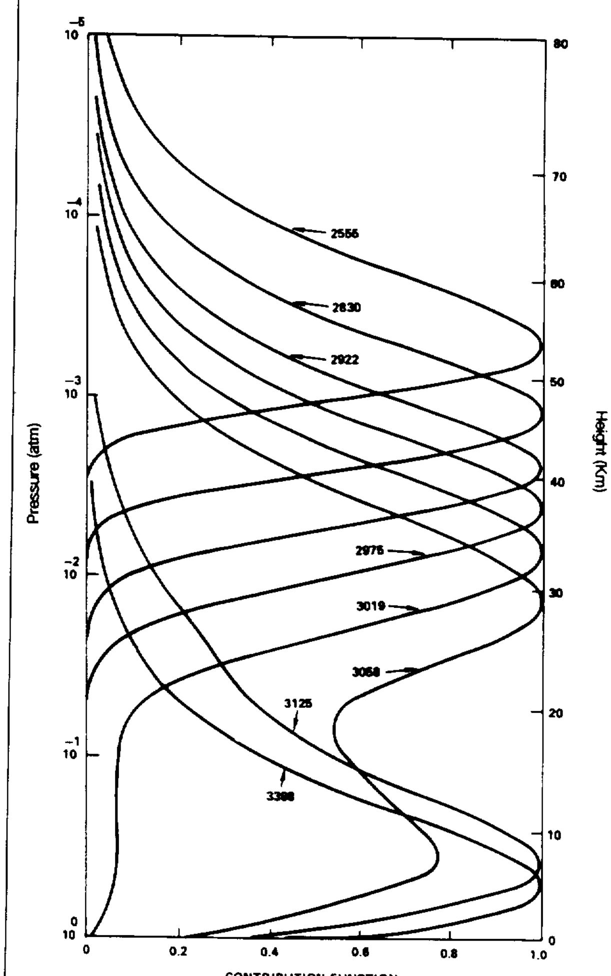


*Fig. 1 Normalized contribution functions for 8 of the 12 wavelengths of the SBUV instrument.*

the contribution functions for neighboring channels of the SBUV/TOMS instruments overlap one another. This is shown graphically in Figure 1. The overlapping implies that the observed radiance in neighboring channels should be highly correlated. We have used this property to estimate the calibration drift in the SBUV/TOMS instruments. Unlike Herman et al.'s method which is applicable only for total ozone wavelengths, the method proposed here is very general and it is applicable to both the total ozone and the profile wavelengths.

## Method

### • The Equations

If we assume that the contribution functions for channels j +1, j and j -1 overlap, then we can express the radiance (I) in channel j as a linear sum of radiances in channels j+1 and j-1 as:

$$I_j(\theta_o,R,\Omega,p,s) = a_o(\theta_o,R,p,s) + a_{j+1}(\theta_o,R,p,s)* I_{j+1}(\theta_o,R,\Omega,p,s) + a_{j-1}(\theta_o,R,p,s)*I_{j-1}(\theta_o,R,\Omega,p,s) \quad (1)$$

where $\theta_o$, R and $\Omega$ are, respectively, the solar zenith angle, the surface reflectivity, and the columnar ozone amount in the atmosphere. Respectively, p and s, represent the surface pressure and the dependence on ozone vertical profile and $a_o$ and $a$ are regression coefficients.

Since the dynamic range of radiance over the SBUV wavelengths spans over three orders of magnitude, the regression coefficients in Equation 1 would also show a large spread in their magnitudes. To reduce the large spread in the magnitude, we used log of albedo instead of radiance (I) in the Equation 1. That is,

$$N_j(\theta_o,R,\Omega,p,s) = A_o(\theta_o,R,p,s) + A_{j+1}(\theta_o,R,p,s)* N_{j+1}(\theta_o,R,\Omega,p,s) + A_{j-1}(\theta_o,R,p,s)*N_{j-1}(\theta_o,R,\Omega,p,s) \quad (2)$$

where N is $-100\log_{10}$ (I/F) and $A_o$, and $A$ are new regression coefficients. (Simulation results showed that Equation 2 is an equally valid form of a linear relationship between the channels).

From Equation 2 it follows that, for a well calibrated instrument, the change in N value in channel j due to change in ozone amount is related to changes in N values in channels j+1 and j-1 by the following relation:

$$\Delta N_j(\Omega) = A_{j+1}\Delta N_{j+1}(\Omega) + A_{j-1}\Delta N_{j-1}(\Omega) \quad (3)$$

where for clarity we have omitted the other parameters from the arguments of N.

### • Estimation of Calibration Error

To determine the instrument calibration error we assume that $N_{jt}$ (the N value for channel j at time t can be written as:

$$N_{jt} = N_j - \Delta N_j(\epsilon) - \Delta N_j(\Omega) \quad (4)$$

where $\Delta N_j(\epsilon)$ and $\Delta N_j(\Omega)$ respectively represent the change in N value due to changes in the instrument calibration and the ozone in the atmosphere; then from Equations (3), and (4) it follows that,

$$\epsilon_{j+1} = (\epsilon_j - A_{j-1}\epsilon_{j-1} + A_{j+1}\delta N_{j+1} - \delta N_j + A_{j-1}\delta N_{j-1})/A_{j+1} \quad (5)$$

where we have replaced $\Delta N_j(\epsilon)$ by $\epsilon_j$ and $\delta N_j = (N_j - N_{j,t})$ Equation (5) implies that if we know the error in channels j and j-1 then we can determine the error in channel j+1. However, the accuracy of the estimate would depend on two things: a) how well the contribution functions overlap and b) the uncertainties in the estimate of errors in channels j and j-1.

### • Simulation of Radiances

To test the concept described above, we simulated nadir radiance using Dave/Mateer's radiative transfer code (Dave 1964). The code divides the model atmosphere into 101 layers and solves the auxiliary equations of radiative transfer by successive iteration. The code assumes a Lambertain surface at the base of the atmosphere. We used mean SAGE profiles for equatorial region (10S-10N) from 1985 and computed nadir N values for all twelve channels of the SBUV instrument. The simulations were done for five values of solar zenith angle (18° (1) 22°), five values of reflectivity (0.22 (0.01) 0.26), and six values of ozone (250 (5) 275 DU). These values represent the nominal range of conditions over the equatorial region.

We examined two scenarios of instrument calibration error. In the first scenario we modified the computed N values by subtracting a $\Delta N$ ($\epsilon$, $\lambda$) value from each simulated N value. $\Delta N$ ($\epsilon$, $\lambda$) was assumed to be a linear function of wavelength. The $\Delta N$ ($\epsilon$, $\lambda$) values for longer wavelengths were very close to Herman et al. values for the SBUV instrument from 1987. In the second scenario we further subtracted a constant $\Delta N(\epsilon)$ (=0.5) from the N values of every other channel. We did this to test the stability and robustness of the algorithm for an unusual pattern in the instrument behavior. We also examined the impact of an unusual change in the profile shape on the estimate of the instrument error. For this purpose we first modified the SAGE profiles following the predictions of the photochemical models for mid-latitudes for a six year period from 1979 to 1985 (Watson et al., 1988) and then computed the nadir N values for the same range of solar zenith angle, reflectivity, and ozone amount. The computed N values were further modified by subtracting a $\Delta N$ ($\epsilon$, $\lambda$) value from each simulated N value as in scenario one. The results of these investigations and for the sample processing of SBUV Version 5 data are given below.

## Results

Before we discuss the results for the different scenarios mentioned above, it is instructive to examine the relationship between the N values for λ3125A and λ3175A (Figure 2). These wavelengths along with λ3312A form the 'A' and 'B'

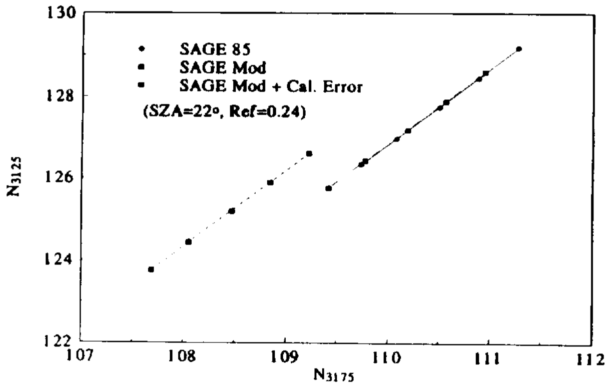


*Fig. 2 Relationship between $N_{3125}$ and $N_{3175}$. The ozone amount in the model atmosphere was varied from 255 DU to 275 DU.*

pair of wavelengths from which the total ozone is estimated from the SBUV/TOMS instruments. The N values were computed for solar zenith angle $\theta_0$ = 22° and surface reflectivity R = 0.24 using the actual and the modified SAGE profiles from 1985. Also shown are the N values with synthetic instrument calibration errors. The graphs in Figure 2 show that all N values for both the actual and the modified SAGE profiles (without instrument calibration error) fall on the same straight line implying that, for these wavelengths profile shape and ozone amount have no effect on the linear relationship between the two wavelengths. On the other hand, the N

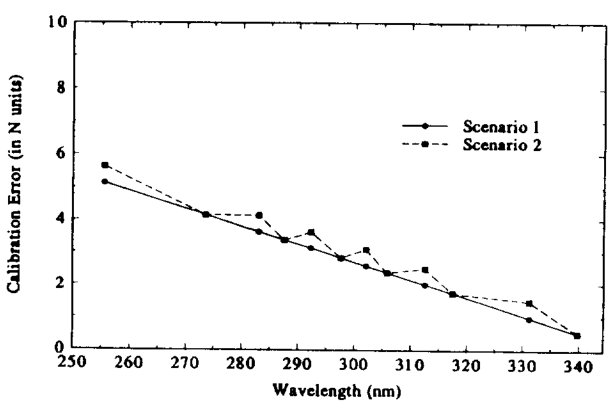


*Fig.3(a) Estimate of calibration error for scenarios 1 and 2. The solid and dashed lines refer to the assumed input error. The filled circles and squares refer to the estimated error.*

values with synthetic instrument calibration error (Scenario 1) fall on a separate line suggesting that the instrument calibration error can be estimated using the N value relationship between the channels.

Figure 3(a) shows the retrieved error for scenario 1 (solid line with filled circles) and scenario 2 (dashed line with filled squares). The retrieved errors are practically identical to the assumed input error. The results for the third case ( i.e., estimating error in the presence of a significant profile shape) are shown in Figure 3(b). Here the initial instrument error is shown by a solid line and the final retrieved error by filled circles connected by the dashed line. In retrieving the instrument error, we have assumed that the errors for channels 11 (λ3312A) and 12 (λ3398A) are known. For the SBUV/TOMS instrument they can be estimated by monitoring either the minimum reflectivity over the ocean or snow reflectivity over Greenland or Antarctica. Herman, et al. have shown that it can be estimated with an accuracy of 0.5 %. The results in Figure 3(b) suggest that we can predict instrument error reasonably well (with an error of less than 0.5%) up to λ3125A and to about 1% for λ3058A. The large error for shorter wavelengths is due to sensitivity to profile shape. That is, the upper part of the modified profile is not representative of the dependent data set from which the coefficients $A_j$ are

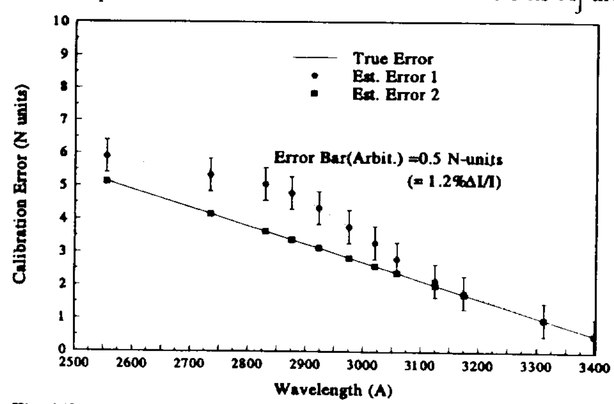


*Fig.3(b) Estimate of calibration error when ozone profile is significantly changed. The solid line refers to the true instrument error. The filled circles (squares) represent the estimated calibration error when the ozone profile shape is not (is) known.*

derived. The error is significantly reduced if we have a priori knowledge of the modified profile or the dependent data set includes all possible profiles. An example of a priori knowledge of the modified profile is also shown in Figure 3(b) (filled squares) which shows that the difference between the actual and the predicted error over all wavelengths is practically zero.

We have also applied this method to a sample of SBUV (V5) data. The sample was constructed by selecting one day of data from every month (around the 15th day) over the equator

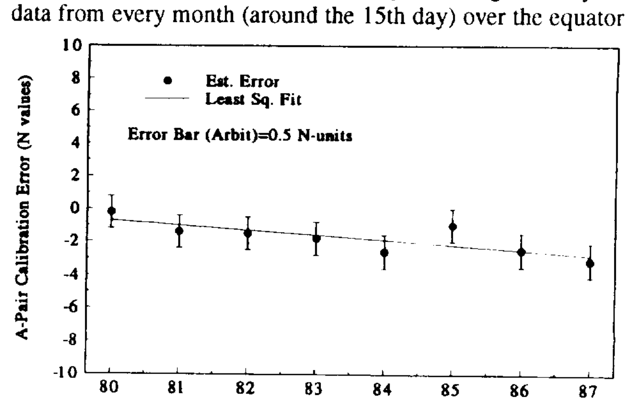


*Fig.4 Estimate of A pair calibration error as a function of time in Version 5 of SBUV archive data.*

## Conclusions

In this paper we have described a simple method to estimate calibration drift in SBUV/TOMS instruments. Simulation results indicate that the method is robust and can accurately predict instrument error in TOMS instrument. Also with a priori knowledge of profile shape changes, the method can be used to monitor the drift in all channels of the SBUV instrument. An application of the method to the SBUV (Version 5) data yields slightly higher drift values for A pair ozone than Herman et al. However, we believe that the difference between the two values will decrease if we use a larger data base for computing the regression coefficients and correct the N values for small changes in reflectivity and solar zenith angle. Also, because of the simplicity and fewer assumptions, the method can be easily used for determining calibration drift in the SBUV/2 instruments on NOAA-9 and NOAA-11 and the TOMS instrument on the Meteor-3 spacecraft.

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