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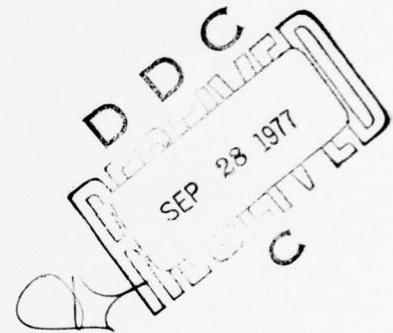
RESEARCH AND DEVELOPMENT TECHNICAL REPORT  
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# ZENITH ANGLE VARIATION OF SATELLITE THERMAL SOUNDER MEASUREMENTS

By

**Louis D. Duncan**



**Atmospheric Sciences Laboratory**

US Army Electronics Command  
White Sands Missile Range, New Mexico 88002

**August 1977**

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PREFACE

The author thanks Dr. Richard B. Gomez of the Atmospheric Sciences Laboratory and Dr. Lewis Kaplan of the University of Chicago for helpful discussions and suggestions during this study. Thanks are also extended to the Air Force Global Weather Center for supplying the transmittances used for the calculations.

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## INTRODUCTION

The remote sounding of atmospheric temperature profiles from satellite measurements of spectral radiance data has become a technique of considerable practical importance. During the past decade a large number of papers have appeared in the meteorological literature addressing various facets of the problem of deriving temperature profiles from the radiance measurements. A recent paper by Rogers [1] reviews and analyzes many of the algorithms which have been developed for temperature retrieval.

For a given wavenumber  $\nu$  the outgoing radiance,  $I(\nu)$  is given by the radiative transfer equation

$$I(\nu) = B[\nu, T(P_0)]\tau(\nu, x) - \int_{P_0}^P B[\nu, T(P)] \frac{\partial \tau(\nu, x)}{\partial x} dx \quad (1)$$

where  $B$  is Planck's function,  $T(P)$  is the temperature at pressure  $P$ , and  $\tau(\nu, x)$  is the transmission from height  $x$  to space. Height is often measured by the variable  $x = \ln P$ .

For monochromatic radiation passing through a gas of mixing ratio  $q(x)$ , the transmittance from height  $x$  to space at a zenith angle  $\theta$  is given by

$$\tau(\nu, T, \theta, x) = \exp\left(-\frac{\sec \theta}{g} \int_0^x k(\nu, T, x')q(x')dx'\right) \quad (2)$$

where  $k(\nu, T, x)$  is the absorption coefficient and  $g$  is the gravitational acceleration. (Actual instruments have a finite spectral response, and one must consider the average transmittance over the interval appropriately weighted by the instrument response functions.) Eq. (2) appears deceptively simple; however, lengthy calculations [2] are required for its evaluation for a given set of conditions. This is primarily due to the number of factors which must be considered in determining the absorption coefficient.

Because of the impracticability of calculating transmittances for the myriad of atmospheric and parametric conditions which one can reasonably expect to encounter, various methods of approximations have been developed. Some of the more widely used are the polynomial model of Smith [3] and the temperature correction model of McMillian and Fleming [4].

The variation of transmittance with viewing angle can produce significant changes in the outgoing radiance. An example of this is shown in Figure 1 which presents calculated values for the DMSP SSH sensor using the 1962 US Standard Atmosphere. To account for this variation in the retrieval process, one can either use transmittances which have been corrected for zenith angle [5] or normalize the observations to those which would have been obtained at zero zenith angle [6]. This report presents a simple technique for performing the latter operation.

#### DISCUSSION

The results shown in Figure 1 indicate a smooth change in radiance as a function of zenith angle. These results suggest that, perhaps, this change with angle can be expressed as a relatively simple function of  $\theta$ . After some trial and error it was discovered that good results were given by the function

$$\Delta I(\nu, \theta) = \sec^{\frac{1}{2}\theta} f(\nu) \quad (3)$$

The data presented in Figure 1 is replotted in Figure 2 with the abscissa changed to  $\sec^{\frac{1}{2}\theta}$ . The excellence of the linear fit is somewhat surprising. Deviations from a straight line fit to the data are shown in Table 1. Calculations were performed for zenith angles 0, 10, 20, 30, 35, and 40 degrees for three atmospheric conditions, the US 62 Standard and the 15 N annual and 60 N annual atmospheres. A straight line was fit through 0 and the results for 35 degrees zenith. The mean absolute deviation and the maximum deviation for each channel are shown. These values are quite small and well within the measurement accuracy of the instrument.

#### APPLICATION

The results shown in Figure 2 and Table 1 lead to the development of a simple procedure for normalizing observations at zenith angle  $\theta$  to equivalent observations at zero zenith provided transmittance functions for two different zenith angles, say  $\theta_1$  and  $\theta_2$ , are available. (It can be assumed with no loss of generality that  $\theta_2 = 0$ .) From Eq. (3) it is easy to see that

$$\Delta I(\nu, \theta) = \Delta I(\nu, \theta_1) \sec^{\frac{1}{2}\theta} / \sec^{\frac{1}{2}\theta_1} . \quad (4)$$

Eq. (4) provides the required normalization.

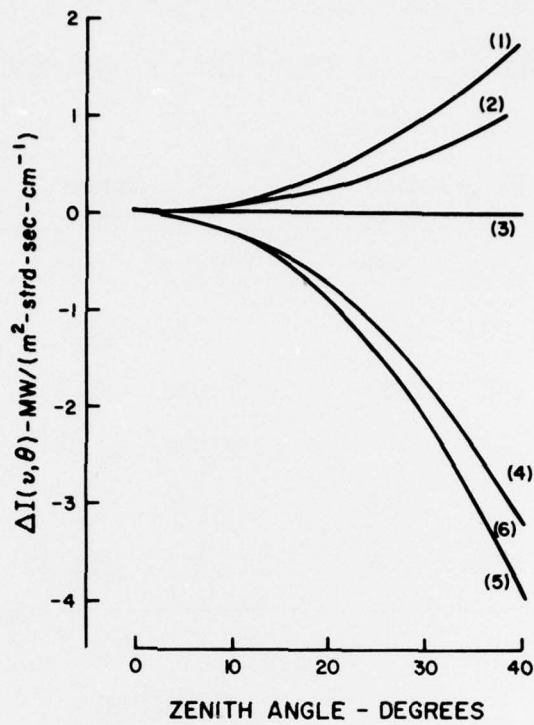


Figure 1. Change in computed radiance with zenith angle. Computations for US-62 Standard Atmospheres. Numbers in parentheses refer to SSH sounder channels.

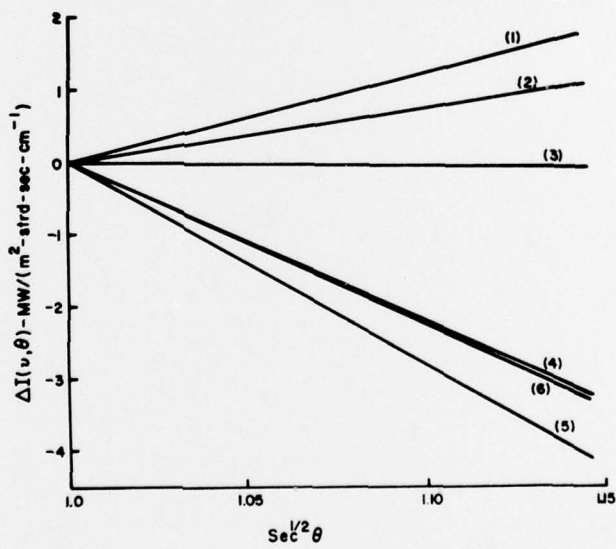


Figure 2. Same as Figure 1 except for change in abscissa.

TABLE 1  
 DEVIATION OF  $I(\nu, \theta)$  FROM LINEAR FIT AS FUNCTION OF  $\text{SEC}^{\frac{1}{2}}\theta$

Channel	62 Standard		15 N Annual		60 N Annual	
	Mean	Max	Mean	Max	Mean	Max
1	.008	.029	.012	.042	.012	.040
2	.002	.005	.009	.015	.003	.005
3	.022	.053	.036	.094	.017	.028
4	.047	.129	.057	.159	.051	.128
5	.023	.075	.029	.097	.023	.074
6	.010	.036	.012	.047	.010	.039

CONCLUDING REMARKS

A simple yet accurate method has been uncovered which allows for the normalization of satellite measurements of spectral radiance observed at zenith angle  $\theta$  to equivalent observations at zero zenith. The errors introduced by this procedure are considerably less than the accepted values for instrumental errors.

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