183
RB
①
I-12015

UCID--19913

DE84 002749

A TECHNIQUE TO EXTEND OZONESONDE TEMPERATURE DATA
TO THE MESOPAUSE

Roger L. Weichel

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

October 1983

Lawrence
Livermore
Laboratory

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the Laboratory.

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under Contract W-7405-Eng-48.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

A TECHNIQUE TO EXTEND OZONESONDE TEMPERATURE DATA TO THE MESOPAUSE

Roger L. Weichel

Lawrence Livermore National Laboratory
Livermore, CA 94550

October 1983

INTRODUCTION

An important tool in investigations into remote sensing techniques and applications is the simulations of the radiometric measurements. This is especially true for satellite-borne infrared radiometers like the Multichannel Filter Radiometers (MFRs), known as the SSH packages (Nichols, 1975), carried aboard the Defense Meteorological Satellite Program (DMSP) satellites of the Block 5D series. Radiometers such as these have channels sensing in the strongly absorbing regions of the $15 \mu\text{m}$ CO_2 bands (see Table 1), and they have weighting functions with responses in the upper stratosphere. The calculation of simulated measurements for these channels requires atmospheric temperature and absorbing gas profiles with data extending upward to an altitude of approximately 80 km (0.01 mb). Typically, ozonesonde data extend only to pressure levels in the 5 to 25 mb range, so a technique is needed to extrapolate the temperature and ozone profiles to higher altitudes.

Early efforts to interpret the MFR data to determine the total atmospheric column ozone (Lovill et al., 1978) made use of temperature and ozone profiles from globally distributed historical ozonesondes. The simulation of radiometric measurements was carried out after the data sets had been extended upward from the highest reported data levels to 0.01 mb. A technique employing climatological

MASTER

28
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

upper stratospheric and mesospheric temperature distributions and constant ozone mixing ratios was used. Temperature lapse rate models were determined from the model atmospheres of COESA (1962, 1966) for various latitudes and seasons, and these models were selectively applied to extend the ozonesonde temperature data upward. An analysis of global MFR radiances and ozone retrieval results revealed that the simulated radiances were not always representative of the measurements for the CO₂ channels sensing the temperatures in the middle and upper stratosphere. This problem was particularly pronounced, but not limited to, higher latitude winter conditions. Because of the special importance of the middle stratosphere and high latitudes for ozone analyses, a research effort was undertaken to develop an improved method (described below) of extending the temperatures from the ozonesondes used in the simulation procedure. An overview of the radiative transfer theory is provided to show the importance of the temperature profile in the calculation of simulated radiances.

RADIATIVE TRANSFER CALCULATIONS

The outgoing terrestrial radiance N emerging from the top of the atmosphere can be expressed by the radiative transfer equation for a non-scattering atmosphere in local thermodynamic equilibrium as

$$N(\nu, \theta) = B(\nu, T_s) \tau(\nu, \theta, p_s) - \int_{x(0)}^{x(p_s)} B(\nu, T_p) \frac{d\tau(\nu, \theta, p)}{dx(p)} dx(p) \quad (1)$$

where ν is wavenumber, θ the zenith angle, B the Planck radiance, T temperature and p the pressure. τ is the monochromatic atmospheric transmittance above pressure p , and x is the vertical coordinate of the atmosphere as a function of pressure. The subscript s indicates surface (lower boundary of the atmosphere) conditions.

The monochromatic transmittance is defined as

$$\tau(\nu, \theta, p) = \exp \left[- \int_0^{u(p)} k(\nu, T, p) \sec \theta \, du(p) \right], \quad (2)$$

where k is the summed absorption coefficient for all contributing absorption lines at ν , and u is the integrated column density of the absorbing gas, which is 0 at the top of the atmosphere and $u(p)$ at pressure p . If more than one atmospheric gas is optically active at ν , the individual τ 's are multiplied to determine the total atmospheric transmittances.

Satellite-borne radiometers usually measure the emerging radiation in channels (narrow spectral bands) rather than monochromatically. The atmospheric transmittance for one of the channels, is the monochromatic transmittance weighted by the spectral response function for the individual channel, and it is expressed as

$$\tau(\nu_i, \theta, p) = \int_0^{\infty} \tau(\nu, \theta, p) \phi_i(\nu) \, d\nu, \quad (3)$$

where ϕ_i is the normalized spectral response function for the i -th channel and ν_i is the nominal central wavenumber.

In actuality, the transmittances are generally determined for finite spectral intervals rather than monochromatically. The average transmittance for a sufficiently small interval, $\Delta\nu$, is defined as

$$\bar{\tau}_{\Delta\nu}(\nu, \theta, p) = \frac{1}{\Delta\nu} \int_{\Delta\nu} \exp \left[- \int_0^{u(p)} k(\nu, T, p) \sec \theta \, du(p) \right] d\nu, \quad (4)$$

and substitution into Eq. (3) yields

$$\tau(\nu_i, \theta, p) = \int_0^{\infty} \bar{\tau}_{\Delta\nu}(\nu, \theta, p) \phi_i(\nu) \, d\nu. \quad (5)$$

Then the radiative transfer equation for the i-th channel of the radiometer is given by

$$N(\nu_i, \theta) = B(\nu_i, T_s) \tau(\nu_i, \theta, p_s) - \int_{x(0)}^{x(p_s)} B(\nu_i, T_p) \frac{d\tau(\nu_i, \theta, p)}{dx(p)} dx(p) \quad (6)$$

for a cloudless atmosphere.

The radiative transfer equation for the i-th channel for an atmosphere which contains no more than two randomly distributed layers of clouds can be represented by (Smith et al., 1970):

$$N(\nu_i, \theta) = B(\nu_i, T_s) \tau(\nu_i, \theta, p_s) - \int_{x(0)}^{x(p_s)} B(\nu_i, T_p) \frac{d\tau(\nu_i, \theta, p)}{dx(p)} dx(p) \quad (7)$$

$$- A_U Y_1(\nu_i, \theta, T, p_U) - A_L^* Y_2(\nu_i, \theta, T, p_L)$$

where the subscripts U and L refer to the upper and lower cloud layers, respectively. A is the "effective radiative amount" of clouds in the layer (the actual fractional amount of clouds times their emissivity). $A_L^* = A_L(1.0 - A_U)$ is the amount of lower layer cloud that can be observed assuming random correlation of cloud elements. $A_U Y_1$ and $A_L^* Y_2$ are the adjustments to the radiation fields. Y_1 and Y_2 are defined as follows

$$Y_1(\nu_i, \theta, T, p_U) = B(\nu_i, T_s) \tau(\nu_i, \theta, p_s) - B(\nu_i, T_{p_U}) \tau(\nu_i, \theta, p_U) - \int_{x(p_U)}^{x(p_s)} B(\nu_i, T_p) \frac{d\tau(\nu_i, \theta, p)}{dx(p)} dx(p) \quad (8a)$$

and

$$Y_2(v_i, \theta, T, p_L) = B(v_i, T_s) \tau(v_i, \theta, p_s) - B(v_i, T_{p_L}) \tau(v_i, \theta, p_L) \\ - \int_{x(p_L)}^{x(p_s)} B(v_i, T_p) \frac{d\tau(v_i, \theta, p)}{dx(p)} dx(p) \quad (8b)$$

Equation (7) is used to make the calculations of the simulated radiances. It is easily seen that it is necessary to know T_s , θ , the cloud conditions, the required atmospheric transmittances for the various channels, and the sets of atmospheric temperature and absorbing gas profiles in order to carry out the calculations. Because of the lack of conventional data sets of atmospheric profiles which extend to high enough altitudes, a technique for extending ozonesondes has been developed. More specifically, a technique for extending the temperature profile portion of ozonesondes has been developed. The constant mixing ratio approach for the ozone concentrations was assumed sufficiently accurate if the data cut off at high enough altitudes.

TECHNIQUE DEVELOPMENT

Atmospheric temperatures at various altitudes, especially temperatures in adjacent layers, are known to be highly correlated. From what is known about the processes of the stratosphere and mesosphere, an even higher correlation would be expected at the altitudes of concern here. Relationships between temperatures at levels just above the tropopause and those of higher altitudes, usually not observed, could be used to develop a technique which "built" on temperatures reported in the lower stratosphere. Without conventional data for determining the necessary relationships, information about the thermal structure of the upper atmosphere has

to be obtained from other sources. A readily available source of information is the large sets of MFR radiance measurements being archived (Lovill et al., 1978). These measurements are only a source of information about temperature since temperatures are not known directly, but must be retrieved from the measurements. Several techniques have been developed in recent years for the purpose of retrieving temperatures from radiances (see for example Fritz et al., 1972; Rodgers, 1976). Because of the global, all-season requirement for an extension scheme and the large sets of simulated radiance sets already available for global conditions, a statistical technique was selected.

Linear regression analyses of the simulated measurements for channels 1 and 3 of the MFR sensors, (see Table 1) using the upper atmospheric temperatures used in calculating the simulations as the independent variables, produced the necessary relationships. Regression equations were developed to infer temperatures at pressures of 0.01, 0.1, 1, 5, 10, 20, 30, 50, 70 and 100 mb from a large sample of simulations representing global conditions, and these regression equations were used to retrieve temperatures from MFR radiance measurements. Thousands of sets of channel 1 and channel 3 radiances for near nadir observations on January 1, 15, and 27 and February 1 and 15 of 1979 from the F2 MFR sensor, the second satellite in the DMSP Block 5D series, were used. Global data coverage was used to represent the full range of temperatures expected for an annual cycle. The time period selected included measurements taken during a stratospheric warming (Labitzke, 1980). The retrieved temperatures were subjected to several analyses to insure that they were realistic. Vertical cross-sections and horizontal plots of retrieved temperatures at various levels were analyzed on several grid scales, and these were

used to check for consistency with other analyses. Also, comparisons were made against the analyses of Labitzke (1980) at several levels.

The retrieved temperatures were used as the basis for developing regression equations relating the temperatures at pressure levels less than the expected cut-off pressures (PCUT) of 5, 10, 20, 30, and 50 mb to those at higher pressures. Since these temperatures were not independent (they were related through the retrieval equations and the channel 1 and 3 radiances), checks were made to ensure the stability of the derived regression equations. The final regression equation for extending ozonesonde temperature data is given by:

$$T(p_k) = K(k, \ell) + A(k, \ell) * T(PCUT) + B(k, \ell) * T(100 \text{ mb}) \quad (9)$$

The constants $K(k, \ell)$ and the coefficients (A's and B's) for the regression equations are given in Tables 2, 3, and 4, respectively.

Figures 1 through 5 show sample ozonesondes selected from NASA, (1980a) and (1980b) extended to 0.01 mb by using the technique described in the preceding section. Temperatures were calculated from the regression equations for levels above PCUT (at lower pressures) and were smoothed to the temperature reported at PCUT in each case. The ozone concentrations were extended assuming a constant mixing ratio. Relative humidities of 10% were inserted where no values were reported in the troposphere. Relative humidity was not reported at temperatures less than 233K or if the relative humidity was less than 20%.

The ozonesondes for Poker Flat, Alaska on January 28, 1979, (Fig. 1) and Primrose Lake, Canada on February 8, 1979 (Fig. 2) are examples of high-latitude winter profiles. A particular problem arises at these latitudes because of the wide

range of stratospheric temperatures and the "global" approach taken here. Because of a mixture of warm and cold stratospheric input data, the global scheme calculates moderate temperatures. A more elaborate, multi-model approach would be more accurate if sufficient observations could be obtained for model development for these cold and warm stratospheres.

Figures 3 and 4 are for ozonesondes at Wallops Island, VA on January 5, 1979 and February 14, 1979, respectively. The subtropical influence at stratospheric levels (less ozone and colder temperatures) is more pronounced on January 5 (Fig. 3). In spite of the obvious differences in the reported temperature profiles (pressures $\geq$ PCUT), the extended temperatures are nearly the same in the more conservative high atmosphere.

The ozonesonde for Natal, Brazil on February 6, 1979, (Fig. 5) is representative of extensions in tropical regions. The relationships obtained from measurements indicated slightly warmer temperatures at the stratopause and cooler at the mesopause than are observed at higher latitudes.

TABLE 1. Nominal MFR channel characteristics after Nichols (1975).

Channel Number	Center (μm)	Center (cm^{-1})	Half Width (cm^{-1})	Species	NESR*
1	15.0	668.5	3.5	CO ₂	0.30
2	14.8	676.0	10.0	CO ₂	0.09
3	14.4	695.0	10.0	CO ₂	0.10
4	14.1	708.0	10.0	CO ₂	0.11
5	13.8	725.0	10.0	CO ₂	0.11
6	13.4	747.0	10.0	CO ₂	0.12
7	12.0	835.0	8.0	window	0.11
8**	18.7	535.0	16.0	H ₂ O	0.15
9	24.5	408.5	12.0	H ₂ O	0.14
10	22.7	441.5	18.0	H ₂ O	0.09
11	25.9	420.0	20.0	H ₂ O	0.12
12	26.7	374.0	12.0	H ₂ O	0.18
13	25.2	397.5	10.0	H ₂ O	0.16
14	28.2	355.4	15.0	H ₂ O	0.25
15	28.3	353.5	11.0	H ₂ O	0.33
16	9.8	1022.0	12.5	O ₃	0.05

* NESR = Noise Equivalent Spectral Radiance in $\text{erg}/(\text{cm}^2 \text{ sec sr cm}^{-1})$.

** Not on Flight Model 1.

Table 2. Values of the constant K used in the regression equation for temperature of various pressure levels as a function of sonde cut-off pressure.

P (mb)	Sonde cut-off pressure (mb)				
	5	10	20	30	50
0.01	6.089678E+02	5.511819E+02	5.567608E+02	5.547133E+02	5.352523E+02
0.1	4.744313E+02	4.744313E+02	4.750624E+02	4.739594E+02	4.655232E+02
1.0	1.364308E+02	1.591467E+02	1.569536E+02	1.577585E+02	1.639149E+02
5.0	--	3.301643E+01	2.982888E+01	3.099373E+01	3.994678E+01
10.0	--	--	-3.455502E+00	-2.187303E+00	7.512942E+00
20.0	--	--	--	9.792122E-01	8.468913E+00
30.0	--	--	--	--	5.926973E+00

Table 3. Values of the coefficients A used in the regression equation for temperature of various pressure levels as a function of sonde cut-off pressure.

P (mb)	Sonde cut-off pressure (mb)				
	5	10	20	30	50
0.01	-1.750217E+00	-1.614497E+00	-2.091006E+00	-2.642336E+00	-4.733985E+00
0.1	*	*	-1.126370E+00	-1.423352E+00	-2.580075E+00
1.0	6.880189E-01	6.346668E-01	8.219847E-01	1.036715E+00	1.360953E+00
5.0	--	9.224553E-01	1.194712E+00	1.509711E+00	2.704799E+00
10.0	--	--	1.295144E+00	1.636631E+00	2.933173E+00
20.0	--	--	--	1.263667E+00	2.263975E+00
30.0	--	--	--	--	1.791590E+00

Table 4. Values of coefficients B used in the regression equation for temperature of various pressure levels as a function of sonde cut-off pressure.

P (mb)	Sonde cut-off pressure (mb)				
	5	10	20	30	50
0.01	1.912894E-02	8.775135E-02	5.117419E-01	1.064188E+00	3.218061E+00
0.1	*	*	4.818576E-02	3.457743E-01	1.506009E+00
1.0	-2.169645E-01	-2.431541E-01	-4.106131E-01	-6.277825E-01	-1.474480E+00
5.0	--	-3.806519E-02	-2.814582E-01	-5.971026E-01	-1.327734E+00
10.0	--	--	-2.638534E-01	-6.060319E-01	-1.940114E+00
20.0	--	--	--	-2.642011E-01	-1.294266E+00
30.0	--	--	--	--	-8.151392E-01

* A special equation is used for 0.1 mb when PCUT = 5 mb or 10 mb, that is
 $T(0.1 \text{ mb}) = K + [-1.826245E-01 * T(10 \text{ mb}) - 8.898458E-01 * T(20 \text{ mb})]$

Figure 1. Profiles of temperature, ozone partial pressure, and relative humidity from an ozonesonde at Poker Flat Alaska at 0610z on January 28, 1979.

Figure 2. Profiles of temperature, ozone partial pressure, and relative humidity from an ozonesonde at Primrose Lake, Canada at 1702z on February 8, 1979.

Figure 2. Profiles of temperature, ozone partial pressure, and relative humidity from an ozonesonde at Wallops Island, Virginia at 1530z on January 5, 1979.

Figure 4. Profiles of temperature, ozone partial pressure, and relative humidity from an ozonesonde at Wallops Island, Virginia at 1401z on February 14, 1979.

Figure 5. Profiles of temperature, ozone partial pressure, and relative humidity from an ozonesonde at Natal, Brazil at 1130z on February 6, 1979.

REFERENCES

- COESA (Committee on Extension to the Standard Atmosphere), U. S. Standard Atmosphere, 1962, U. S. Government Printing Office, Washington, D.C., 1962.
- COESA (Committee on Extension to the Standard Atmosphere), U. S. Standard Atmosphere, Supplements, 1966, U. S. Government Printing Office, Washington, D. C., 1966.
- Fritz, S., D. Q. Wark, H. E. Fleming, W. L. Smith, H. Jacobowitz, D. T. Hilleary and J. C. Alishouse, "Temperature Sounding from Satellites," NOAA Technical Report NESS 59, National Environmental Satellite Service, National Oceanic and Atmospheric Administration, Washington, D.C., 49 pp., 1972.
- Labitzke, K., Meteorologisches Institut der Frieen Universitat Berlin, Federal Republic of Germany, private Communication.
- Loxill, J. E., T. J. Sullivan, R. L. Weichel, J. S. Ellis, J. G. Huebel, J. A. Korver, P. P. Weidhaas and F. A. Phelps, "Total Ozone Retrieval from Satellite Multichannel Filter Radiometer Measurements," Lawrence Livermore National Laboratory Report UCRL-52473, 97 pp., 1978.
- NASA (1980a), Meteorological and Constituent Data for January 1979, Wallops Internal Publication WFC-221-80-065, Wallops Flight Center's Field Measurement Support Office, Wallops Island, Virginia 23337.
- NASA (1980b), Meteorological and Constituent Data for February 1979, Wallops Internal Publications WFC-221-80-067, Wallops Flight Center's Field Measurement Support Office, Wallops Island, Virginia 23337.
- Nichols, D. A., "DMSP Block 5D Special Meteorological Sensor H, Optical Subsystem," Optical Engr., 14, pp. 284-288, 1975.
- Rodgers, C. D., "Approximate Methods of Calculating Transmission by Bands of Spectral Lines," NCAR Technical Note NCAR/TN-116+1A, 1976.
- Smith, W. L., H. M. Woolf and W. J. Jacob, "A Regression Method for Obtaining Real Time Temperature and Geopotential Height Profiles from Satellite Spectrometer Measurements and Its Application to Nimbus III SIRS Observations," Mon. Wea. Rev., 98, 1993-1999, 1970.