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WATER VAPOR TRANSMITTANCE MODELS
FOR NARROW BANDS
IN THE 13-19 μm SPECTRAL REGION

Roger L. Weichel

October 1983

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PREFACE

The purpose of this report is to document the development of water vapor transmittance models for narrow bands (satellite sensor channels) in the 13-19 μ m spectral region. The models are the result of research efforts of the author in 1971-72 while on active duty with the U.S. Air Force at the Air Force Global Weather Central (AFGWC). The models were developed for application in studies involving a temperature profiling sensor system carried aboard the satellites of the Defense Meteorological Satellite Program (DMSP), formerly DAPP. Recently, (Lovill et al., 1978; Luther et al., 1981) the models were implemented for studies concerned with methodologies to retrieve total atmospheric column ozone from measurements of newer DMSP Block 5D series satellite sensors with similar channels (see Nichols, 1975).

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1. INTRODUCTION

Infrared radiometers with multiple channels sensing in narrow bands within the 13-19 μm spectral region have been carried aboard earth-orbiting meteorological satellites. Their purpose is to provide measurements from which atmospheric temperature profiles can be inferred. Several techniques have been developed to retrieve the temperature profile information from the radiometric measurements (see, for example, Fritz et al., 1972; Rodgers, 1976). One such technique, the minimum information or minimum variance technique, requires that a first-guess temperature profile and the atmospheric transmittance profiles for the various channels be known. (Foster, 1961; Smith et al., 1972).

The atmospheric transmittances in the 13-19 μm spectral region are determined by the absorption spectra of several optically active atmospheric gases. The 15 μm CO_2 absorption bands dominate the spectral region, but significant absorption due to the 14 μm O_3 bands, the rotational water vapor band and the water vapor continuum also exists. Accurate atmospheric transmittances are difficult and expensive to calculate, but must be available for each set of measurements from which a temperature profile is to be determined. Because of the high variability in the spatial distributions of ozone and water vapor, it is necessary to model these transmittances in a manner that accounts for as much of the variability as possible. This report documents the development of a technique for incorporating the effects of the water vapor absorption into the atmospheric transmittance profiles for use in a minimum information temperature retrieval scheme. An overview of the radiative transfer theory and the development of the minimum information technique is presented here for completeness.

2. ATMOSPHERIC TRANSMITTANCE AND RETRIEVAL THEORY

The terrestrial radiance N measured by a radiometer carried at satellite altitude 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 the temperature and p pressure. τ is the monochromatic atmospheric transmittance above pressure p , and x is the vertical coordinate expressed as a function of pressure. The subscript s refers to surface conditions.

The fractional atmospheric transmittance τ for monochromatic radiation at wavenumber ν between pressure level p and the top of the atmosphere is given by

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

where θ is the zenith angle, k is the summed absorption coefficient from all contributing lines, T is temperature, and u is the integrated column density of the absorbing gas, which is 0 at the top of the atmosphere and $u(p)$ at level p . Given the absorption coefficients for the individual lines, k_i , the summed absorption coefficient is defined as

$$k(\nu, T, p) = \sum_i k_i(\nu, T, p) \quad (3)$$

The integration in Eq. (2) is carried out over the optical path of the optically active gas being considered. For a small spectral interval, $\Delta\nu$, the average transmittance is represented by

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

where the spectral interval integration must be performed in such a way that the fine structure of the variation of the summed absorption coefficients over the spectral interval is represented accurately.

The absorption coefficient k_i at wavenumber ν for the i -th spectral line contributing to the summed absorption coefficient can be represented by the Lorentz line shape when the dominant line broadening mechanism is the result of collision processes (Goody, 1964):

$$k_i(\nu, T, p) = \frac{S_i(T) \alpha_{L_i}(T, p)}{\pi \{ [\nu - \nu_{0i}]^2 + \alpha_{L_i}^2(T, p) \}} \quad (5)$$

where S_i is the integrated line intensity of the i -th absorption line, defined as

$$S_i(T) = \int_0^\infty k_i(\nu, T, p) \, d\nu \quad (6)$$

ν_0 is the line center, and α_{L_i} is the Lorentzian half width of the i -th absorption line. The integrated line intensity is independent of pressure.

The individual channels of the radiometers measure radiation in narrow band passes weighted according to a spectral response function. These optical characteristics must be considered. The atmospheric transmittance for the i -th channel can be represented by

$$\tau(\nu_i, \theta, p) = \int_0^{\infty} f_i(\nu) \tau(\nu, \theta, p) d\nu \quad (7)$$

where f_i is the normalized spectral response function for the i -th channel and τ is the monochromatic atmospheric transmittance. ν_i is the nominal central wavenumber for the i -th channel.

The atmospheric transmittances in the 13-19 μm spectral region are affected by the absorption spectra of carbon dioxide, water vapor and ozone. The total atmospheric transmittance required in Eq. (7) is determined from the individual transmittances from

$$\tau(\nu, \theta, p) = \tau(\nu, \theta, p)_{\text{CO}_2} \tau(\nu, \theta, p)_{\text{H}_2\text{O}} \tau(\nu, \theta, p)_{\text{O}_3} \quad (8)$$

which is the product of the transmittances of the individual optically active gases. Then the radiative transfer equation for the i -th channel of the infrared radiometer is given by

$$N(\nu_i, \theta) = B(\nu_i, T_s) \tau(\nu_i, \theta, p_s) - \int_{x(0)}^{x(p_s)} B(\nu_i, T_p) \frac{d\tau(\nu_i, \theta, p)}{dx(p)} dx(p) \quad (9)$$

for a cloudless atmosphere.

The dependency on zenith angle θ will be assumed although not expressed in the remainder of the development.

The temperature profile retrieval problem is to solve Eq. (9) for T_p given a finite set of measurements $N(\nu_i)$ in the 13-19 μm spectral region. The following discussion on the minimum information technique for retrieving temperature profiles is presented for completeness and to show how the transmittance model results are used after they enter the calculations through Eq. (8). The development is similar to that of Smith et al. (1972).

The first step in finding an inverse solution of Eq. (9) for T_p is to linearize the Planck function to a reference channel ν_r so that the variables are separable. A first guess temperature profile $T_p^{j=1}$ is assumed, and Eq. (1), in perturbed form, becomes

$$N_j'(\nu_i) = \int_I^{\tau(\nu_i, p_g)} B_j' g(\nu_i, T_p^j) d\tau(\nu_i, p) + \epsilon(\nu_i) \quad (10)$$

where the prime indicates the deviation between the true and first guess values, i.e.

$$N_j'(\nu_i) = N(\nu_i) - N^j(\nu_i)$$

and

$$B_j' = B(\nu_r, T_p) - B^j(\nu_r, T_p^j).$$

$\epsilon(\nu_i)$ is instrumental error and g is defined as

$$g(\nu_i, T_p^j) = \frac{dB(\nu_i, T_p^j)/dT_p}{dB(\nu_r, T_p^j)/dT_p}, \quad (11)$$

the ratio of the sensitivity to temperature change of the i -th channel Planck function to that of the reference channel. A single evaluation at the first guess temperatures is assumed to be sufficient since large corrections are not expected.

Equation (10) can be approximated by numerical quadrature by the linear system

$$N'_i = \sum_{k=1}^K \Gamma_{ik} B'_k + \epsilon_i \quad i = 1, 2 \dots M \quad (12)$$

where M is the number of different channels, and K is the number of discrete pressure levels. The matrix Γ is defined as

$$\Gamma_{ik} = 0.5 g_{i,k} \begin{cases} (\tau_{i,k} - \tau_{i,k+1}) & : \text{for } k = 1 \\ (\tau_{i,k-1} - \tau_{i,k+1}) & : \text{for } 1 < k < K \\ (\tau_{i,k-1} - \tau_{i,k}) & : \text{for } k = K \end{cases} \quad (13)$$

In matrix notation, Eq. (12) becomes

$$n = \Gamma b + \epsilon \quad (14)$$

where n is a column vector of radiance deviations and b is a column vector of Planck radiance departures. Since Γ is a rectangular matrix of dimensions $(M \times K)$ with $(K > M)$, the problem is underspecified, and Eq. (14) has an infinite number of solutions.

A solution is obtained by choosing the vector b such that the quadratic form

$$F(b) = (\Gamma b - n)^T (\Gamma b - n) + \gamma b^T b \quad (15)$$

is minimized. γ is a Lagrangian multiplier defining the ratio of the noise to signal power (Smith et al., 1972), and the superscript T indicates the transpose of the matrix.

Differentiating with respect to the elements of b gives the normal equation

$$(\Gamma^T \Gamma + \gamma I) b = \Gamma^T n \quad (16)$$

which has the unique solution

$$\hat{b} = (\Gamma^T \Gamma + \gamma I)^{-1} \Gamma^T n \quad (17)$$

for $\gamma > 0.0$, where I is the identity matrix. Using the identity

$$(\Gamma^T \Gamma + \gamma I)^{-1} \Gamma^T = \Gamma^T (\Gamma \Gamma^T + \gamma I)^{-1} \quad (18)$$

Eq. (17) becomes

$$\hat{b} = \Gamma^T (\Gamma \Gamma^T + \gamma I)^{-1} n \quad (19)$$

which requires the inverse of the smaller ($M \times M$) matrix.

Thus, the minimum information technique requires $\underline{\Gamma}$ to be specified (i.e., knowledge of the transmittance profiles) and a first guess temperature profile. The procedure is usually used in an iterative manner. A new temperature profile is determined from the new estimate of the Planck function profile through the inverse form of the Planck function, namely

$$T_p^{j+1} = C_2 \nu_r / \ln \{ [C_1 \nu_r^3 / B(\nu_r, T_p^{j+1})] + 1 \} \quad (20)$$

where C_1 and C_2 are Planck constants. The procedure is iterated until the residual radiance deviations are at some specified level, usually near the noise level of the instrument. The final retrieved temperature profile is the one that minimizes the departure, in a least squares sense, from the first guess profile and meets the radiance residual error requirements.

3. TRANSMITTANCE MODEL DEVELOPMENT

The water vapor transmittance models were developed through regression analyses of theoretical transmittances. Tropospheric ($p > 100$ mb) water vapor transmittances were calculated for an assortment of 16 temperature and relative humidity profiles. Various climatological temperature profiles, each with several different arbitrary but realistic relative humidity profiles, defined the atmospheres. The theoretical transmittances were calculated using a line-by-line approach with additional absorption included for continuum effects. The line-by-line technique was developed with some concepts patterned after Drayson (1966). The continuum absorption was determined through the e-type approach of Burch (1970). The laboratory measurements of Burch (1970) and Bignell (1970) were used to determine the necessary coefficients and dependencies.

The line-by-line calculations were made at a spectral resolution of 0.01 cm^{-1} for spectral intervals with absorption lines in or near the intervals. A resolution of 0.1 cm^{-1} was used for all other intervals. A 4-point Gaussian quadrature integration scheme was used to calculate the mean transmittance for each interval after the summed absorption coefficients, assuming a Lorentz line shape, had been determined for the 4 Gauss points for each absorption line contributing in the interval. A search was first made retaining only absorption lines within 20 cm^{-1} of the interval end points, but was considered a contributing

line only to a distance $(\nu - \nu_0)$ for which $k_\nu > 5 \cdot 10^{-5} [\text{cm}^{-1}/(\text{gm cm}^{-2})]$. The water vapor absorption line parameter data of Clough and Benedict, prior to publication by McClatchey et al. (1973), was used for the calculations.

The absorption coefficient for the water vapor continuum absorption was determined at the center of each 0.1 cm^{-1} interval and added to the absorption coefficient of the lines (if any) at each high resolution point through the equation

$$k_\nu (\text{total}) = k_\nu (\text{lines}) + k_\nu (\text{continuum}) , \quad (21)$$

where

$$k_\nu (\text{continuum}) = \left[\frac{T(k)}{296} \right]^{-5} \left[\frac{e}{p_0} \right] \text{CSO} , \quad (22)$$

with

$$\text{CSO} = 62.0 - (\nu - 535) / 6, \quad (23)$$

the wavenumber dependent base value of the self-broadening continuum absorption coefficient.

The 0.01 cm^{-1} resolution calculations were averaged to a 0.1 cm^{-1} resolution for convolution with the filter response functions.

The filter-modified transmittances were subjected to linear regression analyses to develop transmittance models of the form:

$$\tau_{\text{H}_2\text{O}}(\nu_i, \theta, p_k) = C_{i,k} + \sum_{j=1}^8 D_{i,j,k} X_{i,j,k} \quad (24)$$

where $X_{i,j,k}$ are regression functions. The transmittances for each of the channels at each tropospheric level (44 through 70) of the geometric model (Table 2) for all temperature-relative humidity profile combinations were regressed against assorted functions (mostly non-linear) of temperature, water vapor, and continuum

absorption. The set of eight functions ($X_{i,j,k}$) selected for the final transmittance models (those that gave the best results at all levels (k) for all channels (i)) consisted of:

j $X_{i,j,k}$

1. average temperature of atmospheric model layer above level k
2. k_v (continuum) from Eq. 22*
3. Term 2 squared*
4. Term 2 cubed*
5. saturation vapor pressure of atmospheric model layer above level k
6. integrated water vapor down to level k*
7. temperature-scaled integrated water vapor down to level k*
8. pressure-scaled integrated water vapor down to level k*

The values for the constants and coefficients (C's and D's, respectively) for the transmittance models are given in Tables 3 through 6. These models make it possible to rapidly calculate a water vapor transmittance profile (filter modified) for any temperature-water vapor distribution. The models are sufficiently accurate for remote sensing applications with more than 99% of the variance in the dependent data sets explained by the regression results.

* Zenith angle (slant path) effects included.

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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	23.9	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.

⁺ Used in this investigation.

TABLE 2. 70-Level Geometric Model

Level	Pressure (mb)	Level	Pressure (mb)
1	0.0100	37	115.3873
2	0.0304	38	126.1725
3	0.0707	39	137.6591
4	0.1394	40	149.8740
5	0.2461	41	162.8440
6	0.4012	42	176.5966
7	0.6161	43	191.1595
8	0.9027	44 +	206.5605
9	1.2738	45 +	222.8281
10	1.7428	46 +	239.9907
11	2.3238	47 +	258.0775
12	3.0315	48 +	277.1175
13	3.8811	49 +	297.1403
14	4.8886	50 +	318.1757
15	6.0703	51 +	340.2509
16	7.4431	52 +	363.4053
17	9.0245	53 +	387.6605
18	10.8324	54 +	413.0506
19	12.8853	55 +	439.6069
20	15.2021	56 +	467.3608
21	17.8022	57 +	496.3443
22	20.7054	58 +	526.5895
23	23.9319	59 +	558.1287
24	27.5025	60 +	590.9946
25	31.4382	61 +	625.2202
26	35.7607	62 +	660.8386
27	40.4919	63 +	697.8834
28	45.6541	64 +	736.3882
29	51.2700	65 +	776.3870
30	57.3629	66 +	817.9142
31	63.9561	67 +	861.0042
32	71.0737	68 +	905.6918
33	78.7398	69 +	952.0119
34	86.9791	70 +	1000.0000
35	95.8165		
36	105.2773		

+ Used in this study

Table 3. Coefficients for channel 4. (i=4)

k	Layer	C	D(j=1)	D(j=2)	D(j=3)	D(j=4)	D(j=5)	D(j=6)	D(j=7)	D(j=8)
1	44	1.0021E+00	0.	-1.5484E+02	0.	0.	0.	0.	0.	-1.5954E-05
2	45	1.0024E+00	0.	-1.7903E+02	7.1138E+06	0.	-9.2693E-03	0.	0.	-1.5813E-05
3	46	1.0076E+00	-1.2313E-07	-1.3244E+02	3.0722E+06	0.	0.	0.	0.	-1.2457E-05
4	47	1.0076E+00	-8.7117E-08	-1.0550E+02	1.7747E+06	0.	0.	0.	0.	-2.1181E-05
5	48	1.0331E+00	0.	-3.7255E+01	0.	1.4350E+09	0.	0.	-1.5621E-04	0.
6	49	1.0660E+00	0.	0.	3.3895E+04	0.	0.	0.	-3.0739E-04	0.
7	50	1.0570E+00	0.	-6.7259E+00	0.	0.	0.	0.	-2.6553E-04	0.
8	51	1.0551E+00	0.	-4.4848E+00	0.	0.	0.	0.	-2.5837E-04	0.
9	52	1.0155E+00	0.	-4.6402E+00	0.	0.	0.	0.	0.	-6.8219E-05
10	53	9.9682E-01	0.	-1.4867E+01	6.9557E+03	-1.2058E+06	0.	0.	0.	0.
11	54	1.0641E+00	0.	-2.5641E+00	0.	0.	0.	0.	-3.0214E-04	0.
12	55	1.0855E+00	0.	-2.0325E+00	0.	0.	0.	0.	-3.2997E-04	-4.2689E-05
13	56	9.9445E-01	0.	-1.1779E+00	0.	0.	0.	-5.0612E-02	0.	0.
14	57	9.9359E-01	0.	-9.0555E-01	0.	0.	0.	-5.2204E-02	0.	0.
15	58	9.9354E-01	0.	-6.0821E-01	0.	0.	0.	-6.1518E-02	0.	0.
16	59	1.1245E+00	0.	-1.2811E+00	0.	0.	0.	0.	-5.6820E-04	0.
17	60	1.0958E+00	0.	-1.3278E+00	0.	0.	0.	0.	-4.5239E-04	0.
18	61	1.0850E+00	0.	-1.2843E+00	0.	0.	0.	0.	-4.1037E-04	0.
19	62	9.8096E-01	0.	-1.2506E+00	0.	0.	0.	0.	0.	0.
20	63	9.8236E-01	0.	-1.3666E+00	1.7576E+00	0.	0.	0.	0.	0.
21	64	9.8245E-01	0.	-1.3785E+00	1.7207E+00	0.	0.	0.	0.	0.
22	65	9.8141E-01	0.	-1.4027E+00	1.5964E+00	0.	0.	0.	0.	0.
23	66	9.7628E-01	0.	-1.0596E+00	0.	0.	0.	0.	0.	0.
24	67	9.7376E-01	0.	-1.0182E+00	0.	0.	0.	0.	0.	0.
25	68	9.7320E-01	0.	-9.5800E-01	0.	0.	0.	0.	0.	0.
26	69	9.7238E-01	0.	-9.3315E-01	0.	0.	0.	0.	0.	0.
27	70	9.7382E-01	0.	-1.1037E+00	5.3537E-01	0.	0.	0.	0.	0.

Table 4. Coefficients for channel 5. (i = 5)

k	Layer	C	D(j=1)	D(j=2)	D(j=3)	D(j=4)	D(j=5)	D(j=6)	D(j=7)	D(j=8)
1	44	1.0006E+00	0.	-4.9212E+01	0.	0.	0.	0.	0.	-4.4065E-06
2	45	1.0015E-00	-2.1300E-08	-6.0993E+01	2.5563E+06	0.	0.	0.	0.	-3.9093E-06
3	46	1.0022E+00	-3.6259E-08	-4.4888E+01	1.1343E+06	0.	0.	0.	0.	-3.2971E-06
4	47	1.0024E+00	-3.1611E-08	-2.7832E+01	0.	1.2604E+10	0.	0.	0.	-5.4376E-06
5	48	1.0096E+00	0.	-1.2242E+01	0.	5.3652E+08	0.	0.	-4.5339E-05	0.
6	49	1.0277E+00	0.	0.	0.	0.	0.	0.	-1.2790E-04	0.
7	50	1.0166E+00	0.	-2.8133E+00	0.	0.	0.	0.	-7.7128E-05	0.
8	51	1.0162E+00	0.	-2.0819E+00	0.	0.	0.	0.	-7.5752E-05	0.
9	52	1.0150E+00	0.	-1.7973E+00	0.	0.	0.	0.	-7.1151E-05	0.
10	53	9.9888E-01	0.	-3.7757E+00	3.7315E+00	0.	0.	0.	0.	0.
11	54	9.9829E-01	0.	-1.8805E+00	0.	0.	0.	0.	0.	0.
12	55	1.0208E+00	0.	-1.3411E+00	0.	0.	0.	0.	-9.7671E-05	0.
13	56	9.9800E-01	0.	-2.0017E+00	6.3031E+01	0.	0.	0.	0.	0.
14	57	9.9813E-01	0.	-9.3417E-01	0.	0.	0.	-1.5090E-02	0.	0.
15	58	9.9658E-01	0.	-1.2248E+00	0.	0.	0.	0.	0.	0.
16	59	9.9669E-01	0.	-1.3928E+00	8.1222E+00	0.	0.	0.	0.	0.
17	60	9.9551E-01	0.	-1.1233E+00	0.	0.	0.	0.	0.	0.
18	61	9.9500E-01	0.	-1.0947E+00	0.	0.	0.	0.	0.	0.
19	62	9.9527E-01	0.	-1.1199E+00	8.9965E-01	0.	0.	0.	0.	0.
20	63	9.9506E-01	0.	-1.0709E+00	9.2013E-01	0.	0.	0.	0.	0.
21	64	9.9490E-01	0.	-1.1400E+00	8.0000E-01	0.	0.	0.	0.	0.
22	65	9.9487E-01	0.	-1.1078E+00	6.8733E-01	0.	0.	0.	0.	0.
23	66	9.9470E-01	0.	-1.0604E+00	4.9967E-01	0.	0.	0.	0.	0.
24	67	9.9460E-01	0.	-1.0380E+00	4.7900E-01	0.	0.	0.	0.	0.
25	68	9.9450E-01	0.	-1.0180E+00	4.6000E-01	0.	0.	0.	0.	0.
26	69	9.9427E-01	0.	-1.0140E+00	4.4000E-01	0.	0.	0.	0.	0.
27	70	9.9298E-01	0.	-1.0105E+00	4.1966E-01	0.	0.	0.	0.	0.

Table 5. Coefficients for channel 6. (i = 6)

k	Layer	C	D(j=1)	D(j=2)	D(j=3)	D(j=4)	D(j=5)	D(j=6)	D(j=7)	D(j=8)
1	44	1.0011E+00	0.	-8.7906E+01	0.	0.	-3.3865E-03	0.	0.	-7.7460E-06
2	45	1.0012E+00	0.	-1.0870E+02	5.2483E+06	0.	-4.8176E-03	0.	0.	-7.5829E-06
3	46	1.0039E+00	-6.4820E-08	-8.1059E+01	2.2033E+06	0.	0.	0.	0.	-5.8012E-06
4	47	1.0038E+00	-4.6574E-08	-6.6262E+01	1.2812E+06	0.	0.	0.	0.	-9.8371E-06
5	48	1.0024E+00	0.	-3.3098E+01	0.	1.8040E+09	0.	0.	0.	-1.4053E-05
6	49	1.0296E+00	0.	-8.9861E+00	0.	0.	0.	0.	-1.3788E-04	0.
7	50	1.0327E+00	0.	-5.6548E+00	0.	0.	0.	0.	-1.5194E-04	0.
8	51	1.0328E+00	0.	-3.3706E+00	0.	0.	0.	0.	-1.5294E-04	0.
9	52	1.0310E+00	0.	-2.7835E+00	0.	0.	0.	0.	-1.4623E-04	0.
10	53	1.0321E+00	0.	-2.4353E+00	0.	0.	0.	0.	-1.5208E-04	0.
11	54	1.0384E+00	0.	-2.0941E+00	0.	0.	0.	0.	-1.7999E-04	0.
12	55	9.9768E-01	0.	-1.1991E+00	0.	0.	0.	-3.6417E-02	0.	0.
13	56	1.0418E+00	0.	-1.6901E+00	0.	0.	0.	0.	-1.9663E-04	0.
14	57	9.9670E-01	0.	-9.0427E-01	0.	0.	0.	-3.3739E-02	0.	0.
15	58	9.9676E-01	0.	-7.0960E-01	0.	0.	0.	-3.9174E-02	0.	0.
16	59	1.0843E+00	0.	-1.2381E+00	0.	0.	0.	0.	-3.7873E-04	0.
17	60	1.0707E+00	0.	-1.2809E+00	0.	0.	0.	0.	-3.2362E-04	0.
18	61	1.0706E+00	0.	-1.2456E+00	0.	0.	0.	0.	-3.2446E-04	0.
19	62	1.0898E+00	0.	-1.1410E+00	0.	0.	0.	0.	-4.0209E-04	0.
20	63	9.8677E-01	0.	-1.0945E+00	0.	0.	0.	0.	0.	0.
21	64	9.8920E-01	0.	-1.3502E+00	1.8663E+00	0.	0.	0.	0.	0.
22	65	9.8817E-01	0.	-1.3672E+00	1.6358E+00	0.	0.	0.	0.	0.
23	66	9.8478E-01	0.	-1.0892E+00	0.	0.	0.	0.	0.	0.
24	67	9.8308E-01	0.	-1.0623E+00	0.	0.	0.	0.	0.	0.
25	68	9.8260E-01	0.	-9.9500E-01	0.	0.	0.	0.	0.	0.
26	69	9.8212E-01	0.	-9.8019E-01	0.	0.	0.	0.	0.	0.
27	70	9.8356E-01	0.	-1.1546E+00	6.2638E-01	0.	0.	0.	0.	0.

Table 6. Coefficients for channel 8. (i = 8)

k	Layer	C	D(j=1)	D(j=2)	D(j=3)	D(j=4)	D(j=5)	D(j=6)	D(j=7)	COEF
1	44	1.0034E+00	0.	-1.9716E+02	0.	0.	0.	0.	0.	-2.7452E-05
2	45	1.0051E+00	0.	-1.1579E+02	0.	0.	0.	0.	0.	-3.7317E-05
3	46	1.0151E+00	-2.4294E-07	-1.5587E+02	2.0699E+06	0.	0.	0.	0.	-2.6067E-05
4	47	1.0147E+00	-1.6231E-07	-1.1061E+02	9.9201E+05	0.	0.	0.	0.	-4.3808E-05
5	48	1.1024E+00	0.	-8.8699E+00	0.	0.	0.	0.	-4.8001E-04	0.
6	49	1.1800E+00	0.	0.	0.	0.	0.	0.	-8.3318E-04	0.
7	50	1.1802E+00	0.	0.	0.	0.	0.	0.	-8.3145E-04	0.
8	51	1.1104E+00	0.	-4.8790E+00	0.	0.	0.	0.	-5.1815E-04	0.
9	52	1.0325E+00	0.	-4.8476E+00	0.	0.	0.	0.	0.	-1.4234E-04
10	53	9.9206E-01	0.	-1.0470E+01	1.1151E+03	0.	0.	0.	0.	0.
11	54	1.1220E+00	0.	-2.6991E+00	0.	0.	0.	0.	-5.7854E-04	0.
12	55	1.0396E+00	0.	-9.8559E-01	0.	0.	0.	-1.2384E-01	0.	-1.3606E-04
13	56	9.8600E-01	0.	-4.3862E+00	9.5797E+01	0.	0.	0.	0.	0.
14	57	9.8649E-01	0.	-1.0056E+00	0.	0.	0.	-9.6193E-02	0.	0.
15	58	9.8658E-01	0.	-6.3826E-01	0.	0.	0.	-1.1892E-01	0.	0.
16	59	9.6800E-01	0.	-2.4686E+00	1.2942E+01	0.	0.	0.	0.	0.
17	60	9.6863E-01	0.	-1.5446E+00	0.	0.	0.	0.	0.	0.
18	61	9.6417E-01	0.	-1.3990E+00	0.	0.	0.	0.	0.	0.
19	62	9.7240E-01	0.	-2.1806E+00	9.0640E+00	-2.1450E+01	0.	0.	0.	0.
20	63	9.7100E-01	0.	-1.9494E+00	5.7741E+00	-9.4229E+00	0.	0.	0.	0.
21	64	9.7023E-01	0.	-1.8715E+00	4.2951E+00	-5.1686E+00	0.	0.	0.	0.
22	65	9.6962E-01	0.	-2.0364E+00	4.7995E+00	-5.6699E+00	0.	0.	0.	0.
23	66	9.4633E-01	0.	-1.0382E+00	0.	0.	0.	0.	0.	0.
24	67	9.4185E-01	0.	-1.0089E+00	0.	0.	0.	0.	0.	0.
25	68	9.9665E-01	0.	-1.9852E-01	0.	0.	-1.2349E-02	0.	0.	0.
26	69	9.6376E-01	0.	-2.0115E+00	4.9279E+00	-1.9174E+00	0.	1.9135E-02	0.	0.
27	70	9.3959E-01	0.	-1.1186E+00	4.3327E-01	0.	0.	0.	0.	0.