**CALCULATIONS OF DOWNWARD IR SURFACE
FLUXES IN THE 500 - 3000 cm^{-1} WAVENUMBER RANGE
FOR THE 1994 ICRCCM MODEL INTERCOMPARISON
STUDY**

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ABSTRACT

As part of the ICRCCM process of comparing radiative transfer parameterizations used in climate models, several data sets were made available to the radiative modeling community. While a comprehensive report will be issued following a meeting of all participating groups, this report documents the LLNL input to this study. Calculations of the downward IR surface radiances have been made in the 500 - 3000 cm⁻¹ wavenumber range in accordance with the set of ICRCCM test cases provided to all interested modeling groups. The atmospheric test cases were obtained from clear sky observations of the temperature, pressure, and major trace gas distributions at altitudes from the surface to about 30 km. A set of high resolution observations of the downward radiances, plus a set of line by line radiance calculations in the 500 - 3000 cm⁻¹ wavenumber range, for each of the test cases was also supplied. Comparison of the LLNL theoretical calculations of the integrated radiances over 25 cm⁻¹ subintervals with the observations and the line by line results shows good agreement over most of the wavenumber range.

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I. INTRODUCTION

The Joint Scientific Committee of the World Climate Research Program and the International Radiation Commission of the International Association of Meteorology and Atmospheric Physics has initiated an international radiation transfer comparison study. This study, the Intercomparison of Radiation Codes in Climate Models (ICRCCM), has the purpose of comparing the solar and long wave calculations used in climate models with line by line calculations, observations, and model to model results (Ellingson and Fouquart, 1991). An additional study has been undertaken to validate radiation models through comparison with observations taken in the Spectral Radiance Experiment (SPECTRE) funded by DOE and NASA (Ellingson, 1993, 1994). According to Ellingson (1994) SPECTRE obtained observations of the downward radiance in the 550 to 3000 wavenumber region from three different FTIR instruments with spectral resolutions ranging from 0.1 - 2.0 cm^{-1} . Almost simultaneously to each of these observations, measurements were made of vertical profiles of temperature, water vapor, and ozone. Other sounding data include profiles of CO_2 , CH_4 , N_2O , CO , F11, F12, and CCl_4 as a function of pressure. In order to determine the range of agreement between various radiative transfer models and the observations, a set of clear sky observations for four different days was distributed to the ICRCCM community (Ellingson, 1994) to begin the comparison process. The meteorological conditions covered the range of the transition from midlatitude summer to midlatitude winter conditions. A radiance spectrum for each of the days plus a line by line calculation of the downward radiance at the surface, was provided to each participant in the study.

In a recent publication Grant *et al.* (1992, G1) and Grossman and Grant (1994) a correlated k-distribution model for the absorption by the major atmospheric molecular absorption species (H_2O , CO_2 , O_3 , CH_4 , and N_2O) was used to calculate the fluxes and heating rates in the 0-2500 cm^{-1} wavenumber range using 25 cm^{-1} subintervals. The fluxes and heating rates obtained for this model are accurate to within ten percent when compared to line by line calculations. The altitude range covered by these calculations was 0-60 km.

The purpose of this paper is to document the LLNL, correlated k-distribution radiative transfer model calculations of the downwelling radiance at the surface for each case provided in the ICRCCM study and to compare the model results with the 500 - 3000 cm^{-1} observations as well as the line by line calculations.

II. ICRCCM DATA

For each case of the ICRCCM study the following data was given;

Z	----	Altitude (km),
P	----	Pressure (mb),
T	----	Temperature ($^{\circ}\text{C}$),
Q	----	H_2O mixing ratio (g/kg),
CO_2	----	CO_2 mixing ratio (ppmv),
O_3	----	O_3 mixing ratio (ppmv),
N_2O	----	N_2O mixing ratio (ppmv),
CO	----	CO mixing ratio (ppmv),
CH_4	----	CH_4 mixing ratio (ppmv).

These data are given in Tables 1 to 4 for Cases 1 to 4 respectively. Data was also given for surface values of the mixing ratios of CCl_4 , F11, and F12 in pptv. These data were not

utilized since the LLNL radiative transfer model does not, at the present time include these species. A set of data corresponding to the AERI (Revercomb et al., 1994) spectral radiance for Case 3 was also supplied. The data consists of the down welling surface radiance in units of $\text{mW}/(\text{m}^2 \cdot \text{sr} \cdot \text{cm}^{-1})$ as a function of wavenumber (cm^{-1}). The wave number range is $520 - 3020 \text{ cm}^{-1}$, and the resolution is $\sim 5 \text{ cm}^{-1}$. Figure 1 shows the observed radiance spectrum in the $500 - 2000 \text{ cm}^{-1}$ range. Figure 2 shows the observed radiance in the $2000 - 3000 \text{ cm}^{-1}$ range.

III. RADIANCE CALCULATIONS

The model atmospheres given in Tables 1 to 4 were used as input to the LLNL correlated k-distribution radiative transfer model (G1). The wavenumber range was $500 - 3000 \text{ cm}^{-1}$ in 25 cm^{-1} subintervals. Absorption due to the molecules H_2O , CO_2 , O_3 , N_2O , CO and CH_4 was included in the calculations. The k-distributions were calculated using the HITRAN91 database (Rothman et al., 1991) to obtain the line parameters within each wavenumber sub interval. The FASCODE2 code (Clough, 1986) was used to calculate a grid of detailed line by line opacities. This grid was then sorted and inverted using the ABSORT code (G1) to calculate the cumulative probability distributions and the k-distributions for each atmospheric layer. The fluxes were calculated using the radiative transfer model described in G1. For the purposes of the data comparison it was assumed the downwelling IR radiation at the top of the model atmospheres was zero. Figures 3a - 3d show the integrated downward radiance across each of the 25 cm^{-1} subintervals, plotted at the wavenumber of the center of the subinterval, in the $500 - 3000 \text{ cm}^{-1}$ wavenumber range for each of the four cases. There is a strong similarity between the large scale features in the observational data shown in Figures 1 and 2. In order to compare the observational data with the theoretical calculations, the observational radiances were integrated over each of the 25 cm^{-1} subintervals for which the theoretical calculations were made. This procedure tends to smooth out the detailed line structure shown in Figures 1 and 2. Figures 4 and 5 show the comparison between the integrated observational radiances and the theoretical integrated radiances for Case 3 over the wavenumber ranges $500 - 3000 \text{ cm}^{-1}$ (Figure 4) and $2000 - 3000 \text{ cm}^{-1}$ (Figure 5). Figure 4 shows that there is good agreement between the observations and the theory for the major spectral features across $500 - 3000 \text{ cm}^{-1}$ wavenumber range. The theoretical calculations predict a surface flux within about 10 percent of the observations. As stated above, the accuracy of the theoretical model is about 10 percent and therefore differences of this amount are to be expected. Figure 5 shows that the agreement between the theoretical calculations the observations around the 4.3 micron peak is also within about 10 percent. Figures 6a - 6d show the comparison, for each of the test cases, of the average radiance in each 25 cm^{-1} subinterval between the LLNL model calculations and the ICRCCM supplied observational and theoretical line by line average radiance. As discussed above the agreement for Case 3 is very good. The agreement for Cases 2 and 4 is also quite good, with some differences beginning to be evident in the $700 - 1000 \text{ cm}^{-1}$ wavenumber range. Although the LLNL calculations appear to reproduce the major features of the observed and the calculated line by line radiances of Case 1, there appear to be significant differences in the $700 - 1000 \text{ cm}^{-1}$ wavenumber region. This could be due to several factors. First, the water abundance for Case 1 is the largest of the four cases, with Case 4 the second largest, Case 3 the next largest, and Case 2 the smallest. The differences between the LLNL calculations and the line by line calculations in the $700 - 1000 \text{ cm}^{-1}$ wavenumber region appear to correlate quite well with the water vapor abundances. Since this spectral region is an atmospheric window region, the differences could probably be due to the water vapor continuum model used in the current LLNL correlated k-distribution model. A new water vapor continuum model has been developed by Clough (1992) but has not been implemented in the the current LLNL model. This will be the subject of a future study. The effects of the omission of the species CCl_4 , F11 and

F12 on the downward surface radiances cannot be assessed at this time, although the maximum effect of their omission would occur in the 700 - 1000 cm^{-1} wavenumber window region. This effect will also be considered in a future study.

Acknowledgments

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FIGURE CAPTIONS

Figure 1. Downward radiance ($\text{mW m}^{-2}\text{sr}^{-1}(\text{cm}^{-1})^{-1}$) observations vs. wavenumber (cm^{-1}) for Case 3 in the wavenumber range 500 - 2000 cm^{-1} .

Figure 2. Downward radiance ($\text{mW m}^{-2}\text{sr}^{-1}(\text{cm}^{-1})^{-1}$) observations vs. wavenumber (cm^{-1}) for Case 3 in the wavenumber range 2000 - 3000 cm^{-1} .

Figure 3. Downward integrated radiance ($\text{mW m}^{-2}\text{sr}^{-1}$) observations over 25 cm^{-1} subintervals vs. wavenumber (cm^{-1}) in the wavenumber range 2000 - 3000 cm^{-1} . Figure 3a shows the results for Case 1. Figure 3b shows the results for Case 2. Figure 3c shows the results for Case 3. Figure 3d shows the results for Case 4.

Figure 4. Comparison of downward integrated radiance ($\text{mW m}^{-2}\text{sr}^{-1}$) observations over 25 cm^{-1} subintervals with calculated values as a function of wavenumber (cm^{-1}) in the range 500 - 3000 cm^{-1} . The dark solid curve represents the theoretical calculations.

Figure 5. Comparison of downward integrated radiance ($\text{mW m}^{-2}\text{sr}^{-1}$) observations over 25 cm^{-1} subintervals with calculated values as a function of wavenumber (cm^{-1}) in the range 2000 - 3000 cm^{-1} . The dark solid curve represents the observations and the light solid curve with the diamonds represents the theoretical calculations.

Figure 6. Downward average radiance ($\text{mW m}^{-2}\text{sr}^{-1}$) observations over 25 cm^{-1} subintervals vs. wavenumber (cm^{-1}) in the wavenumber range 2000 - 3000 cm^{-1} . Figure 6a shows the results for Case 1. Figure 6b shows the results for Case 2. Figure 6c shows the results for Case 3. Figure 6d shows the results for Case 4. The dark solid curve represents the LLNL calculations, the light solid curve with the triangles represents the observations, and the light solid curve with the squares represents the line by line calculations.

Figure 1

Figure 2

Figure 3a

Figure 3c

Figure 3b

Figure 3d

Figure 4

Figure 5

Figure 6a

Figure 6c

Figure 6b

Figure 6d

Table 1 Case 1

Z	P	T	Q	CO2	O3	N2O	CO	CH4
0.000	973.60	17.78	6.491E+00	3.614E+02	2.668E-02	3.089E-01	1.892E-01	1.836E+00
0.060	966.77	18.17	6.267E+00	3.611E+02	3.420E-02	3.089E-01	1.872E-01	1.830E+00
0.187	949.70	18.90	5.793E+00	3.605E+02	3.627E-02	3.088E-01	1.830E-01	1.818E+00
0.365	932.90	18.42	5.677E+00	3.597E+02	3.805E-02	3.088E-01	1.772E-01	1.801E+00
0.585	909.07	16.84	5.581E+00	3.587E+02	4.082E-02	3.087E-01	1.699E-01	1.779E+00
0.843	881.68	15.08	5.908E+00	3.575E+02	4.450E-02	3.087E-01	1.614E-01	1.754E+00
1.138	851.28	12.31	5.770E+00	3.562E+02	4.366E-02	3.086E-01	1.517E-01	1.726E+00
1.466	818.37	9.53	5.642E+00	3.550E+02	4.430E-02	3.085E-01	1.430E-01	1.700E+00
1.825	783.38	6.54	4.637E+00	3.550E+02	4.614E-02	3.084E-01	1.430E-01	1.700E+00
2.214	746.83	4.27	4.045E+00	3.550E+02	4.679E-02	3.083E-01	1.430E-01	1.700E+00
2.633	709.20	2.48	2.856E+00	3.550E+02	4.825E-02	3.081E-01	1.430E-01	1.700E+00
3.079	670.77	-1.26	2.565E+00	3.550E+02	4.993E-02	3.080E-01	1.430E-01	1.700E+00
3.552	631.92	-3.04	1.519E+00	3.550E+02	4.784E-02	3.079E-01	1.430E-01	1.700E+00
4.051	593.00	-6.32	1.183E+00	3.550E+02	5.202E-02	3.077E-01	1.430E-01	1.700E+00
4.575	554.20	-10.58	1.337E+00	3.550E+02	5.180E-02	3.076E-01	1.430E-01	1.700E+00
5.124	515.72	-13.36	5.216E-01	3.550E+02	5.903E-02	3.074E-01	1.430E-01	1.700E+00
5.697	478.14	-16.29	2.038E-01	3.550E+02	6.248E-02	3.072E-01	1.430E-01	1.700E+00
6.293	441.40	-19.26	1.208E-01	3.550E+02	6.563E-02	3.071E-01	1.430E-01	1.700E+00
6.912	405.77	-23.43	1.178E-01	3.550E+02	7.040E-02	3.069E-01	1.430E-01	1.700E+00
7.554	371.29	-28.79	1.166E-01	3.550E+02	7.204E-02	3.067E-01	1.430E-01	1.700E+00
8.218	338.09	-30.69	8.304E-02	3.550E+02	6.736E-02	3.065E-01	1.430E-01	1.700E+00
8.904	306.63	-35.98	2.469E-02	3.550E+02	6.977E-02	3.063E-01	1.430E-01	1.700E+00
9.611	276.65	-40.14	3.628E-02	3.550E+02	7.325E-02	3.061E-01	1.430E-01	1.700E+00
10.338	248.40	-44.61	3.036E-02	3.550E+02	7.557E-02	3.060E-01	1.430E-01	1.700E+00
11.087	222.13	-44.99	6.910E-03	3.550E+02	6.632E-02	3.060E-01	1.430E-01	1.700E+00
11.856	197.93	-46.07	4.290E-03	3.550E+02	3.936E-02	3.060E-01	1.430E-01	1.700E+00
12.644	175.49	-50.72	3.380E-03	3.550E+02	4.543E-02	3.060E-01	1.430E-01	1.700E+00
13.453	154.72	-56.96	3.070E-03	3.550E+02	5.135E-02	3.060E-01	1.430E-01	1.700E+00
14.281	135.60	-59.70	2.960E-03	3.550E+02	6.641E-02	3.060E-01	1.430E-01	1.700E+00
15.128	118.15	-66.43	2.920E-03	3.550E+02	9.117E-02	3.060E-01	1.430E-01	1.700E+00
15.994	102.10	-67.20	2.860E-03	3.550E+02	1.853E-01	3.060E-01	1.430E-01	1.700E+00
16.879	88.25	-63.40	2.810E-03	3.550E+02	4.768E-01	3.060E-01	1.430E-01	1.700E+00
17.783	75.91	-64.95	2.810E-03	3.550E+02	9.969E-01	3.060E-01	1.430E-01	1.700E+00
18.704	65.10	-66.08	2.800E-03	3.550E+02	1.345E+00	3.060E-01	1.430E-01	1.700E+00
19.644	55.78	-61.29	2.790E-03	3.550E+02	1.631E+00	3.060E-01	1.430E-01	1.700E+00
20.602	47.61	-59.28	2.790E-03	3.550E+02	2.336E+00	3.060E-01	1.430E-01	1.700E+00
21.577	40.47	-59.90	2.800E-03	3.550E+02	2.839E+00	3.060E-01	1.430E-01	1.700E+00
22.570	34.38	-55.47	2.830E-03	3.550E+02	3.931E+00	3.060E-01	1.430E-01	1.700E+00
23.581	29.06	-55.80	2.840E-03	3.550E+02	4.570E+00	3.060E-01	1.430E-01	1.700E+00
24.609	24.51	-54.13	2.880E-03	3.550E+02	5.241E+00	3.060E-01	1.430E-01	1.700E+00
25.653	20.58	-56.41	2.890E-03	3.550E+02	5.729E+00	3.060E-01	1.430E-01	1.700E+00
26.715	17.29	-51.24	2.910E-03	3.550E+02	6.049E+00	3.060E-01	1.430E-01	1.700E+00
27.793	14.47	-49.44	2.930E-03	3.550E+02	6.491E+00	3.060E-01	1.430E-01	1.700E+00
28.888	12.06	-49.80	2.930E-03	3.550E+02	6.232E+00	3.060E-01	1.430E-01	1.700E+00
30.000	10.02	-50.51	2.960E-03	3.550E+02	6.852E+00	3.060E-01	1.430E-01	1.700E+00

Table 2 Case 2

Z	P	T	Q	CO2	O3	N2O	CO	CH4
0.000	991.00	10.17	3.807E+00	3.583E+02	7.778E-03	3.079E-01	1.526E-01	1.798E+00
0.060	983.85	11.34	3.670E+00	3.582E+02	1.969E-02	3.079E-01	1.522E-01	1.793E+00
0.187	968.94	11.37	3.380E+00	3.579E+02	3.013E-02	3.079E-01	1.513E-01	1.785E+00
0.365	948.47	9.89	3.191E+00	3.574E+02	3.542E-02	3.078E-01	1.501E-01	1.772E+00
0.585	923.51	7.99	2.755E+00	3.569E+02	3.721E-02	3.078E-01	1.486E-01	1.757E+00
0.843	894.79	5.60	2.542E+00	3.563E+02	3.686E-02	3.077E-01	1.468E-01	1.739E+00
1.138	862.91	2.77	2.573E+00	3.556E+02	3.672E-02	3.077E-01	1.448E-01	1.718E+00
1.466	825.80	1.60	1.105E+00	3.550E+02	4.266E-02	3.076E-01	1.430E-01	1.700E+00
1.825	792.24	1.68	5.114E-01	3.550E+02	4.618E-02	3.076E-01	1.430E-01	1.700E+00
2.214	754.65	-0.29	3.731E-01	3.550E+02	4.628E-02	3.075E-01	1.430E-01	1.700E+00
2.633	715.97	-2.52	5.569E-01	3.550E+02	5.358E-02	3.074E-01	1.430E-01	1.700E+00
3.079	676.57	-4.53	1.322E-01	3.550E+02	5.648E-02	3.073E-01	1.430E-01	1.700E+00
3.552	636.86	-6.50	7.723E-02	3.550E+02	6.010E-02	3.072E-01	1.430E-01	1.700E+00
4.051	597.22	-9.24	6.708E-02	3.550E+02	4.518E-02	3.071E-01	1.430E-01	1.700E+00
4.575	557.84	-10.87	6.911E-02	3.550E+02	4.731E-02	3.070E-01	1.430E-01	1.700E+00
5.124	519.17	-14.02	3.355E-01	3.550E+02	4.694E-02	3.069E-01	1.430E-01	1.700E+00
5.697	481.08	-18.23	1.027E-01	3.550E+02	4.906E-02	3.068E-01	1.430E-01	1.700E+00
6.293	443.80	-21.94	9.891E-02	3.550E+02	4.883E-02	3.067E-01	1.430E-01	1.700E+00
6.912	407.31	-27.78	2.022E-01	3.550E+02	4.773E-02	3.066E-01	1.430E-01	1.700E+00
7.554	372.12	-32.94	6.881E-02	3.550E+02	5.352E-02	3.065E-01	1.430E-01	1.700E+00
8.218	338.18	-38.61	2.158E-02	3.550E+02	6.632E-02	3.063E-01	1.430E-01	1.700E+00
8.904	305.80	-41.84	2.053E-02	3.550E+02	1.070E-01	3.062E-01	1.430E-01	1.700E+00
9.611	274.90	-44.30	1.790E-02	3.550E+02	1.972E-01	3.061E-01	1.430E-01	1.700E+00
10.338	246.96	-45.02	1.370E-02	3.550E+02	1.436E-01	3.060E-01	1.430E-01	1.700E+00
11.087	220.60	-47.08	6.910E-03	3.550E+02	1.962E-01	3.060E-01	1.430E-01	1.700E+00
11.856	196.35	-48.60	4.290E-03	3.550E+02	1.262E-01	3.060E-01	1.430E-01	1.700E+00
12.644	174.17	-49.24	3.380E-03	3.550E+02	6.850E-02	3.060E-01	1.430E-01	1.700E+00
13.453	153.73	-54.12	3.070E-03	3.550E+02	9.048E-02	3.060E-01	1.430E-01	1.700E+00
14.281	134.80	-56.60	2.960E-03	3.550E+02	1.509E-01	3.060E-01	1.430E-01	1.700E+00
15.128	118.06	-58.74	2.920E-03	3.550E+02	1.680E-01	3.060E-01	1.430E-01	1.700E+00
15.994	102.61	-64.86	2.860E-03	3.550E+02	4.243E-01	3.060E-01	1.430E-01	1.700E+00
16.879	88.90	-67.60	2.810E-03	3.550E+02	7.403E-01	3.060E-01	1.430E-01	1.700E+00
17.783	76.24	-65.40	2.810E-03	3.550E+02	9.652E-01	3.060E-01	1.430E-01	1.700E+00
18.704	65.85	-56.22	2.800E-03	3.550E+02	1.297E+00	3.060E-01	1.430E-01	1.700E+00
19.644	56.60	-52.96	2.790E-03	3.550E+02	1.944E+00	3.060E-01	1.430E-01	1.700E+00
20.602	48.50	-49.87	2.790E-03	3.550E+02	2.248E+00	3.060E-01	1.430E-01	1.700E+00
21.577	41.37	-51.90	2.800E-03	3.550E+02	2.837E+00	3.060E-01	1.430E-01	1.700E+00
22.570	35.22	-51.27	2.830E-03	3.550E+02	3.227E+00	3.060E-01	1.430E-01	1.700E+00
23.581	29.91	-49.39	2.840E-03	3.550E+02	4.000E+00	3.060E-01	1.430E-01	1.700E+00
24.609	25.34	-46.30	2.880E-03	3.550E+02	3.837E+00	3.060E-01	1.430E-01	1.700E+00
25.653	21.38	-48.03	2.890E-03	3.550E+02	3.868E+00	3.060E-01	1.430E-01	1.700E+00
26.715	17.99	-48.45	2.910E-03	3.550E+02	3.769E+00	3.060E-01	1.430E-01	1.700E+00
27.793	15.13	-43.07	2.930E-03	3.550E+02	4.084E+00	3.060E-01	1.430E-01	1.700E+00
28.888	12.70	-36.75	2.930E-03	3.550E+02	3.563E+00	3.060E-01	1.430E-01	1.700E+00
30.000	10.58	-41.70	2.960E-03	3.550E+02	3.745E+00	3.060E-01	1.430E-01	1.700E+00

Table 3 Case 3

Z	P	T	Q	CO2	O3	N2O	CO	CH4
0.000	999.30	-0.34	1.157E+00	3.606E+02	1.526E-02	3.072E-01	1.592E-01	1.822E+00
0.060	991.78	-0.57	1.352E+00	3.603E+02	1.927E-02	3.072E-01	1.585E-01	1.817E+00
0.187	976.08	-0.71	1.764E+00	3.598E+02	2.163E-02	3.072E-01	1.570E-01	1.806E+00
0.365	954.56	-1.92	1.753E+00	3.591E+02	2.347E-02	3.072E-01	1.550E-01	1.790E+00
0.585	928.39	-3.00	1.910E+00	3.582E+02	2.432E-02	3.071E-01	1.524E-01	1.771E+00
0.843	898.44	-3.93	1.911E+00	3.572E+02	2.436E-02	3.071E-01	1.494E-01	1.748E+00
1.138	865.48	-3.92	1.992E+00	3.560E+02	2.763E-02	3.071E-01	1.460E-01	1.723E+00
1.466	830.07	-5.61	1.995E+00	3.550E+02	2.881E-02	3.070E-01	1.430E-01	1.700E+00
1.825	792.63	-7.89	1.857E+00	3.550E+02	2.947E-02	3.070E-01	1.430E-01	1.700E+00
2.214	753.69	-10.35	1.294E+00	3.550E+02	3.048E-02	3.069E-01	1.430E-01	1.700E+00
2.633	713.58	-12.89	1.243E+00	3.550E+02	3.399E-02	3.069E-01	1.430E-01	1.700E+00
3.079	672.94	-13.26	9.662E-01	3.550E+02	3.654E-02	3.068E-01	1.430E-01	1.700E+00
3.552	632.19	-15.23	7.741E-01	3.550E+02	4.322E-02	3.068E-01	1.430E-01	1.700E+00
4.051	591.88	-13.43	1.094E+00	3.550E+02	3.846E-02	3.067E-01	1.430E-01	1.700E+00
4.575	552.33	-14.98	1.145E+00	3.550E+02	4.579E-02	3.067E-01	1.430E-01	1.700E+00
5.124	513.33	-18.21	6.432E-01	3.550E+02	4.533E-02	3.066E-01	1.430E-01	1.700E+00
5.697	475.20	-21.36	3.946E-01	3.550E+02	4.066E-02	3.065E-01	1.430E-01	1.700E+00
6.293	437.93	-25.50	3.125E-01	3.550E+02	4.669E-02	3.064E-01	1.430E-01	1.700E+00
6.912	401.66	-30.99	2.370E-01	3.550E+02	4.195E-02	3.064E-01	1.430E-01	1.700E+00
7.554	366.54	-36.00	1.294E-01	3.550E+02	4.441E-02	3.063E-01	1.430E-01	1.700E+00
8.218	332.69	-41.89	1.206E-01	3.550E+02	4.562E-02	3.062E-01	1.430E-01	1.700E+00
8.904	300.25	-47.37	1.096E-01	3.550E+02	4.775E-02	3.061E-01	1.430E-01	1.700E+00
9.611	269.47	-51.56	4.450E-02	3.550E+02	6.478E-02	3.060E-01	1.430E-01	1.700E+00
10.338	240.77	-53.91	1.027E-02	3.550E+02	1.038E-01	3.060E-01	1.430E-01	1.700E+00
11.087	214.18	-54.05	6.910E-03	3.550E+02	1.545E-01	3.060E-01	1.430E-01	1.700E+00
11.856	189.96	-54.52	4.290E-03	3.550E+02	1.920E-01	3.060E-01	1.430E-01	1.700E+00
12.644	167.94	-55.40	3.380E-03	3.550E+02	2.266E-01	3.060E-01	1.430E-01	1.700E+00
13.453	147.96	-57.50	3.070E-03	3.550E+02	2.713E-01	3.060E-01	1.430E-01	1.700E+00
14.281	129.89	-61.20	2.960E-03	3.550E+02	1.559E-01	3.060E-01	1.430E-01	1.700E+00
15.128	113.80	-61.70	2.920E-03	3.550E+02	3.678E-01	3.060E-01	1.430E-01	1.700E+00
15.994	99.39	-62.80	2.860E-03	3.550E+02	5.364E-01	3.060E-01	1.430E-01	1.700E+00
16.879	86.48	-66.70	2.810E-03	3.550E+02	6.806E-01	3.060E-01	1.430E-01	1.700E+00
17.783	75.15	-65.20	2.810E-03	3.550E+02	1.177E+00	3.060E-01	1.430E-01	1.700E+00
18.704	65.18	-61.00	2.800E-03	3.550E+02	2.027E+00	3.060E-01	1.430E-01	1.700E+00
19.644	56.34	-58.57	2.790E-03	3.550E+02	2.510E+00	3.060E-01	1.430E-01	1.700E+00
20.602	48.46	-62.27	2.790E-03	3.550E+02	2.823E+00	3.060E-01	1.430E-01	1.700E+00
21.577	41.68	-58.51	2.800E-03	3.550E+02	3.642E+00	3.060E-01	1.430E-01	1.700E+00
22.570	35.72	-56.70	2.830E-03	3.550E+02	4.202E+00	3.060E-01	1.430E-01	1.700E+00
23.581	30.51	-57.24	2.840E-03	3.550E+02	4.394E+00	3.060E-01	1.430E-01	1.700E+00
24.609	25.99	-57.44	2.880E-03	3.550E+02	4.983E+00	3.060E-01	1.430E-01	1.700E+00
25.653	22.09	-56.92	2.890E-03	3.550E+02	5.335E+00	3.060E-01	1.430E-01	1.700E+00
26.715	18.74	-53.46	2.910E-03	3.550E+02	5.913E+00	3.060E-01	1.430E-01	1.700E+00
27.793	15.83	-55.70	2.930E-03	3.550E+02	5.842E+00	3.060E-01	1.430E-01	1.700E+00
28.888	13.36	-51.60	2.930E-03	3.550E+02	7.839E+00	3.060E-01	1.430E-01	1.700E+00
30.000	11.23	-54.09	2.960E-03	3.550E+02	8.349E+00	3.060E-01	1.430E-01	1.700E+00

Table 4 Case 4

Z	P	T	Q	CO2	O3	N2O	CO	CH4
0.000	995.70	2.56	1.847E+00	3.619E+02	1.112E-02	3.087E-01	1.867E-01	1.848E+00
0.060	988.27	2.67	2.398E+00	3.616E+02	1.216E-02	3.087E-01	1.848E-01	1.841E+00
0.187	972.94	5.99	3.564E+00	3.610E+02	1.219E-02	3.086E-01	1.808E-01	1.828E+00
0.365	952.10	6.86	3.749E+00	3.601E+02	1.870E-02	3.086E-01	1.753E-01	1.809E+00
0.585	926.88	7.29	3.495E+00	3.590E+02	3.316E-02	3.085E-01	1.684E-01	1.786E+00
0.843	898.06	6.19	2.960E+00	3.577E+02	3.920E-02	3.085E-01	1.604E-01	1.759E+00
1.138	865.96	6.03	1.670E+00	3.563E+02	3.857E-02	3.084E-01	1.512E-01	1.728E+00
1.466	832.13	4.60	1.594E+00	3.550E+02	4.124E-02	3.083E-01	1.430E-01	1.700E+00
1.825	795.92	1.73	1.814E+00	3.550E+02	4.206E-02	3.082E-01	1.430E-01	1.700E+00
2.214	758.25	0.75	1.347E+00	3.550E+02	4.387E-02	3.081E-01	1.430E-01	1.700E+00
2.633	719.53	-0.86	2.162E+00	3.550E+02	4.387E-02	3.080E-01	1.430E-01	1.700E+00
3.079	680.22	-2.85	2.012E+00	3.550E+02	4.232E-02	3.079E-01	1.430E-01	1.700E+00
3.552	640.61	-4.11	1.576E+00	3.550E+02	4.796E-02	3.077E-01	1.430E-01	1.700E+00
4.051	601.21	-5.95	1.195E+00	3.550E+02	4.675E-02	3.076E-01	1.430E-01	1.700E+00
4.575	561.95	-9.33	1.002E+00	3.550E+02	4.238E-02	3.075E-01	1.430E-01	1.700E+00
5.124	523.16	-12.52	6.155E-01	3.550E+02	4.174E-02	3.073E-01	1.430E-01	1.700E+00
5.697	485.00	-16.87	3.349E-01	3.550E+02	4.072E-02	3.072E-01	1.430E-01	1.700E+00
6.293	447.57	-21.48	2.658E-01	3.550E+02	4.439E-02	3.070E-01	1.430E-01	1.700E+00
6.912	411.14	-26.51	1.822E-01	3.550E+02	4.933E-02	3.068E-01	1.430E-01	1.700E+00
7.554	375.79	-30.70	1.106E-01	3.550E+02	4.598E-02	3.067E-01	1.430E-01	1.700E+00
8.218	342.08	-34.15	2.934E-02	3.550E+02	4.089E-02	3.065E-01	1.430E-01	1.700E+00
8.904	309.75	-39.90	1.240E-01	3.550E+02	3.676E-02	3.063E-01	1.430E-01	1.700E+00
9.611	278.91	-45.72	9.428E-02	3.550E+02	3.820E-02	3.061E-01	1.430E-01	1.700E+00
10.338	249.64	-51.80	5.525E-02	3.550E+02	4.647E-02	3.060E-01	1.430E-01	1.700E+00
11.087	222.10	-56.31	6.910E-03	3.550E+02	5.014E-02	3.060E-01	1.430E-01	1.700E+00
11.856	196.21	-61.51	4.290E-03	3.550E+02	4.358E-02	3.060E-01	1.430E-01	1.700E+00
12.644	172.78	-66.60	3.380E-03	3.550E+02	8.302E-02	3.060E-01	1.430E-01	1.700E+00
13.453	151.97	-65.09	3.070E-03	3.550E+02	7.665E-02	3.060E-01	1.430E-01	1.700E+00
14.281	133.10	-67.30	2.960E-03	3.550E+02	9.541E-02	3.060E-01	1.430E-01	1.700E+00
15.128	116.31	-67.20	2.920E-03	3.550E+02	1.553E-01	3.060E-01	1.430E-01	1.700E+00
15.994	101.28	-68.40	2.860E-03	3.550E+02	1.911E-01	3.060E-01	1.430E-01	1.700E+00
16.879	87.98	-67.65	2.810E-03	3.550E+02	4.142E-01	3.060E-01	1.430E-01	1.700E+00
17.783	76.19	-67.60	2.810E-03	3.550E+02	5.100E-01	3.060E-01	1.430E-01	1.700E+00
18.704	65.73	-70.20	2.800E-03	3.550E+02	7.445E-01	3.060E-01	1.430E-01	1.700E+00
19.644	56.66	-66.50	2.790E-03	3.550E+02	1.763E+00	3.060E-01	1.430E-01	1.700E+00
20.602	48.71	-62.60	2.790E-03	3.550E+02	3.003E+00	3.060E-01	1.430E-01	1.700E+00
21.577	41.71	-61.72	2.800E-03	3.550E+02	3.729E+00	3.060E-01	1.430E-01	1.700E+00
22.570	35.62	-61.23	2.830E-03	3.550E+02	4.030E+00	3.060E-01	1.430E-01	1.700E+00
23.581	30.35	-58.50	2.840E-03	3.550E+02	4.689E+00	3.060E-01	1.430E-01	1.700E+00
24.609	25.81	-54.87	2.880E-03	3.550E+02	5.083E+00	3.060E-01	1.430E-01	1.700E+00
25.653	21.86	-53.94	2.890E-03	3.550E+02	5.728E+00	3.060E-01	1.430E-01	1.700E+00
26.715	18.46	-54.05	2.910E-03	3.550E+02	6.015E+00	3.060E-01	1.430E-01	1.700E+00
27.793	15.54	-55.23	2.930E-03	3.550E+02	6.203E+00	3.060E-01	1.430E-01	1.700E+00
28.888	13.06	-52.40	2.930E-03	3.550E+02	6.350E+00	3.060E-01	1.430E-01	1.700E+00
30.000	10.95	-51.67	2.960E-03	3.550E+02	7.132E+00	3.060E-01	1.430E-01	1.700E+00