HIGH RESOLUTION ATMOSPHERIC RADIATIVE TRANSFER CODE

(H A R T C O D E)

Version No. 01

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Technical Report

August 1989

Instituto per lo Studio delle Metodologie

Geofisiche Ambientali

(I M G A - C N R)

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...The only way, therefore, to assure the highest accuracy in calculating atmospheric transmittance is to use the line-by-line method with a set of accurate line parameters and appropriate meteorological data.

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ACKNOWLEDGEMENT

The author wishes to express his thanks for the financial support received from the International Centre for Theoretical Physics (ICTP) under the Programme for Training and Research in Italian Laboratories. The permanent assistance of Prof. G. Furlan, the Director of the Programme, and his staff is particularly appreciated. The constant interest and encouragement of Prof. R. Guzzi, the Director of IMGA-CNR, are also greatly appreciated. Several helpful discussions on the recent development of the IR spectroscopy were held with Dr. R. Rizzi who was also supplying me with most of the necessary background material moreover, the interest and willingness to help of G. Zibordi, F. Parmiggiani, M. Bonzagni, A. Ghelli and my other colleagues at the IMGA-CNR are gratefully acknowledged.

ABSTRACT

This document is the detailed description of the High-resolution Atmospheric Radiative Transfer Code (HARTCODE) recently developed at IMGA-CNR and an account on the first results of its application. The code was designed to improve the accuracy of infrared remote sensing and the parameterization of the basic infrared radiative processes in the atmosphere.

The HARTCODE computes the integrated optical depth, transmittance or radiance spectrum of a layered atmosphere for any viewing geometry with the desired resolution using the line-by-line integration method. The ultimate spectral resolution is not limited and - due to numerical reasons - the accuracy of the channel transmittances/radiances is more than six significant figures.

The first part of the report is a short mathematical summary of the IR atmospheric radiative transfer from the point of view of a line-by-line code.

The second part deals with the basic structure of the HARTCODE explaining the operation of the individual programme modules in detail.

The third part is devoted to the validation of the HARTCODE. The validation was based on comparisons with homogeneous transmittance measurements, comparisons with transmittance and radiance calculations for model atmospheres made by other authors and comparisons with measured radiances by the HIS interferometer under real atmospheric conditions.

The appendices contain the listing of the HARTCODE and the auxiliary routines.

The HARTCODE is not fully developed yet and the validation is still in progress. Accordingly, this version should not be regarded as an operative one and this report is not a "User's Manual" for immediate application. Instead, this report intends to give some assistance to those who are willing to go into the very details of the code for its further improvement.

TABLE OF CONTENTS

I. INTRODUCTION

1. The Aim of the Study

In the late 1987 a project was initiated by the ICTP to improve the efficiency of the weather forecasts and the related research activity in the developing countries of the equatorial areas.

The original idea was to prepare a large set of IR transmittance function profiles calculated for carefully selected model atmospheres taking into account the special features of the wet tropical climate. Having this type of data set one can calculate either the actual IR fluxes within the atmosphere for modeling purposes or the actual emission spectrum of the Earth- atmosphere system for remote sensing purposes by simple and fast interpolation method avoiding the enormous mathematical and computational difficulties arising from the subsequent solution of the IR radiative transfer equation.

Consequently the application of the IR satellite spectral measurements would become easier and more common and also the above set of transmittances could be the basis of the accurate parameterization of the radiative processes needed for the general circulation or large-scale climate models. (From practical point of view it is essential that the solution of both problems can be based on the same data set.)

To complete the above aim it is necessary to have a proper, on-line transmittance computer code. Because of the deviations between the results of the recently existing codes exceed the accuracy of the laboratory and field measurements and because there was not available a fully documented high resolution transmittance code which could serve as a starting point to develop a more accurate one, we had to prepare a new code which satisfies the necessary requirements of computational accuracy.

Generally the accuracy of such type of calculations merely depends on the outcome of the competition between the required accuracy and the available computer time. However, it should be understood that to investigate the effect of slight changes in the input spectroscopic data requires extreme numerical accuracy.

As a result of the permanent improvement of instrumentation, in atmospheric applications to evaluate high resolution measured radiance spectra - for example in the 600 - 1200 cm^{-1} spectral region - the required spectral resolution is around 0.01 cm^{-1} and the absolute error in the calculated channel radiance must be below 0.05 $mW/(cm^{-1} sterrad\ m^2)$.

The only hope to achieve this magnitude of absolute accuracy is to develop a high resolution transmittance/radiance code with numerical accuracy high enough to discover the deficiencies of the input spectroscopic data which themselves can also include our - sometimes insufficient - knowledge of the nature of the molecular absorption bands.

2. Recent Activity in the Field of IR Atmospheric Transmittance and Radiance Calculations

From 1982 till the present time a transmittance/radiance model comparison study is being conducted under the auspices of the IAMAP-IRC (International Association of Meteorology and Atmospheric Physics - International Radiation Commission) and with the coordination of the WGRS (Working Group on Remote Sensing).

This international activity - called ITRA (Intercomparison of Transmittance and Radiance Algorithms) - was organized to work on three different fields :

IR Nadir Group, convener D. Spankuch,
IR Limb Group , convener H. Fischer,
Microwave Group, convener K. F. Kunzi,

with the overall coordination of A. Chedin. In the three sub-groups the high resolution LBL (Line-by-line) computer codes were studied and compared for several model conditions.

Another working group, the ICRCCM (Intercomparison of Radiation Codes in Climate Models) is dealing with the problems of implementation and validation of the radiance algorithms related to climate models.

All over the world about nine or ten scientific teams were joining to the activity of the ITRA subgroups. The ITRA proved to be an excellent basis to monitor the accuracy and development of the individual high resolution IR transmittance codes.

So far two exercises were completed by the ITRA. The first one was concerned to homogeneous CO_2 transmittances and the basis of the comparisons were the well-documented transmittance spectra obtained under laboratory conditions in the 600-800 cm^{-1} spectral region by *Gryvnak et al.*[1] and *Bulanin et al.*[2]. In the second exercise the calculations were performed for different model atmospheres and both the CO_2 and H_2O were involved.

We are very thankful to A. Chedin who was kindly supplying us with the detailed documentation of the first exercise[3] and with the reports on the second exercise edited by *D. Spankuch*[4] and *H. Fischer*[5].

In the present stage of development of the HARTCODE we are able to join to the exercises conducted by the Nadir and Limb Sub-Groups and further on to perform extended validations by measurements that are going to be taken under fully monitored real atmospheric conditions.

3. Equation of the IR Radiative Transfer

For sake of simplicity in deriving the equations of the IR radiative transfer for atmospheric conditions we are making some assumptions.

• The atmosphere is in local thermodynamical equilibrium (LTE). This is true up to the height of 60-70 km. Above this level correction must be applied to the Planck function to obtain correct source functions. (This problem is rather pronounced in the cooling rate calculations for the upper atmosphere.)

• The atmosphere is plane-parallel and horizontally homogeneous and the refraction is negligible. To consider a spherically stratified refractive geometry correction must be applied to the relative optical path.

• Light scattering in the IR spectral region is also negligible. (This is true for the gas components but we do not have sufficient information about the aerosol particles.)

The differential equation may be written according to *Chandrashekar*[6] :

$$\mu \frac{dI_\nu(\tau_\nu, \mu)}{d\tau_\nu} = I_\nu(\tau_\nu, \mu) - J_\nu(\tau_\nu), \tag{1}$$

where I_ν is the monochromatic radiance, J_ν is the source function, ν is the wave number, $\mu = cos(\theta)$ and θ is the zenith angle, τ_ν is the monochromatic optical thickness (or optical depth) generally defined by:

$$\tau_\nu(s_2) - \tau_\nu(s_1) = \int_{s_1}^{s_2} k_\nu(s) du(s), \tag{2}$$

where k_ν is the monochromatic mass absorption coefficient u is the optical mass of the absorbing gas and s is the optical path. For $\theta < 60^o \quad 1/\mu = \mu^*$ where $\mu^* = ds/dz$ is the relative optical path and z is the vertical coordinate. Under suitable (LTE) conditions J_ν can be approximated by the Planck black-body function :

$$J_\nu = B_\nu(T) = c_1 \nu^3 \left[exp\left(\frac{c_2 \nu}{T} \right) - 1 \right]^{-1}, \tag{3}$$

where $c_1 = 1.1909596 \times 10^{-5}, \;\; c_2 = 1.43879$ if the wave number is given in cm^{-1} and T is the absolute temperature of the absorbing gas.

For an optical path in the Earth's atmosphere we shall follow the usual convention that τ_ν is measured vertically, $\tau_\nu = 0$ at the top of the atmosphere and increasing downward ($\tau_\nu = \tau_\nu^g$ at the ground) and $\mu > 0$ indicates the outward direction. In this case the proper boundary conditions are : $I_\nu(0, \mu^-) = 0$ for $\mu = \mu^- < 0$ and $I_\nu(\tau_\nu^g, \mu^+) = B_\nu(T_g)$ for $\mu = \mu^+ > 0$. The first one implies that the solar radiation is negligible - which is not true in the NIR regions - while the second one assumes that the Earth's surface is a perfect black-body which is again an approximation. We should also note that the temperature of the air at the ground, the ground temperature and the brightness temperature of the radiating surface are normally not the same.

With respect the boundary conditions given above Eq. (1) can easily be integrated to obtain the up- and down-welling radiance at level τ_ν :

$$I_\nu(\tau_\nu,\mu^+) = B_\nu(T_g) exp\Big[-\frac{(\tau_\nu^g-\tau_\nu)}{\mu^+}\Big] + \int_{\tau_\nu}^{\tau_\nu^g} B_\nu(T(\tau_\nu^{,})) exp\Big[-\frac{(\tau_\nu^{,}-\tau_\nu)}{\mu^+}\Big]\frac{d\tau_\nu^{,}}{\mu^+} \quad (4)$$

$$I_\nu(\tau_\nu,\mu^-) = \int_0^{\tau_\nu} B_\nu(T(\tau_\nu^{,})) exp\Big[-\frac{(\tau_\nu-\tau_\nu^{,})}{\mu^-}\Big]\frac{d\tau_\nu^{,}}{\mu^-}. \quad (5)$$

Eqs. (4) and (5) weighted with the normalized instrumental response function and setting the limits of the integral properly to the condition of the particular measurement are the fundamental equations for the IR remote sensing. In case of a satellite radiance measurement in the channel ν_i with an instrumental response function $\Phi_{\nu_i}(\nu)$ and with a viewing angle $\theta < 90^o$ Eq. (4) takes the following form:

$$I_{\overline{\nu_i}}(\mu) = \int_0^\infty \Big[B_\nu(T_g) exp(-\frac{\tau_\nu^g}{\mu}) + \int_0^{\tau_\nu^g} B_\nu(T(\tau_\nu^{,})) exp(-\frac{\tau_\nu^{,}}{\mu})\frac{d\tau_\nu^{,}}{\mu}\Big]\Phi_{\nu_i} d\nu. \quad (6)$$

To obtain the flux across a horizontal surface at level p the monochromatic radiance must be integrated over the full solid angle and the whole wave number interval (by definition). Assuming cylindrical symmetry the flux divergence is :

$$\frac{dF(p)}{dp} = 2\pi \int_0^\infty \int_{-1}^1 \mu \frac{dI_\nu(\tau_\nu,\mu)}{dp}\, d\mu\, d\nu. \quad (7)$$

For $\mu > 0$ $I_\nu(\tau_\nu,\mu)$ is equivalent with Eq. (4) and for $\mu < 0$ $I_\nu(\tau_\nu,\mu)$ is equivalent with Eq. (5). This last equation gives the rate of loss of radiant energy at pressure level p and is directly related to cooling rate calculations via the next equation : $c_p(dT/dt) = -g(dF(p)/dp)$ where c_p is the specific heat of the air at constant pressure, t is the time and g is the gravity acceleration.

It is obvious that Eqs. (6) and (7) have some common characteristic. Both equations involve wave number integration and integration with respect to the vertical coordinate. More important however, that both integrand contain the same mathematical expression which is called the monochromatic transmission function or transmittance:

$$\gamma_\nu(\tau_\nu^{,},\tau_\nu) = exp\Big(- \frac{\tau_\nu^{,} - \tau_\nu}{\mu}\Big) \tag{8}$$

This expression has a fundamental role in the IR radiative transfer and will be discussed in the next section.

4. Transmission Function and Weighting Function

In terms of the transmission function one can rewrite Eqs. (4) and (5) into a more convenient form :

$$I_\nu(\tau_\nu,\mu^+) = B_\nu(T_g)\gamma_\nu(\tau_\nu^g,\tau_\nu) - \int_{\tau_\nu}^{\tau_\nu^g} B_\nu(T(\tau_\nu^{,}))\frac{\partial\gamma_\nu(\tau_\nu^{,},\tau_\nu)}{\partial\tau_\nu^{,}}d\tau_\nu^{,} \tag{9}$$

$$I_\nu(\tau_\nu,\mu^-) = \int_0^{\tau_\nu} B_\nu(T(\tau_\nu^{,}))\frac{\partial\gamma_\nu(\tau_\nu,\tau_\nu^{,})}{\partial\tau_\nu^{,}}d\tau_\nu^{,}. \tag{10}$$

The partial derivatives in the integrand are the weighting functions and practically the information content of any kind of spectral measurements will depend on the behavior of these functions.

Recalling the original definition of the optical thickness we can introduce pressure coordinates. With the pressure coordinates $d\tau_\nu = k_\nu\omega(p)dp$ where $\omega(p) = \rho(p)/[g\rho_a(p)]$ is the mass mixing ratio profile of the absorber and ρ and ρ_a are the density profiles of the absorber and the air. (In the HARTCODE ω is measured in *atm-cm/mb*.) Now considering only the looking-down geometry the measured radiance at the top of the atmosphere is :

$$I_{\overline{\nu_i}} = \int_0^\infty \Big[B_\nu(T_g)\gamma_\nu(p_g) + \int_0^{p_g} B_\nu(T(p))W_\nu(p)dp\Big]\Phi_{\nu_i}d\nu, \tag{11}$$

where

$$W_\nu(p) = \frac{\partial\gamma_\nu(p)}{\partial p} \tag{12}$$

is the weighting function and

$$\gamma_\nu(p) = exp\Big[- \mu^* \int_0^p \omega k_\nu dp\Big] \tag{13}$$

is the transmittance of an atmospheric layer from the top of the atmosphere to the pressure level p.

To calculate $I_{\overline{\nu_i}}$ by Eq. (11) both the wave number and the pressure integral must be evaluated by numerical methods. Generally the half-power bandwidth of the IR spectrometers normally used in satellite remote sensing is in the range of 0.1-20.0 cm^{-1} and the shape of the $\Phi_{\nu_i}(\nu)$ function can be approximated by a rectangular, triangular or Gaussian function. Compared with the oscillating nature of the absorption coefficient the wave number dependence of the response function is smooth. Since within the spectral range of the response function the Planck function is also approximately constant the only problem which arises at the numerical evaluation of the wave number integral in Eq. (11) is the integration of the transmittance function over a suitable short wave number interval.

5. The Monochromatic Mass Absorption Coefficient

As we mentioned before the source of the computational difficulties is in the spectral behavior of the absorption coefficient. In case of several absorber and slant optical path the total monochromatic optical thickness of an atmospheric layer is defined as :

$$\tau_\nu^*(p_1, p_2) = \mu^* \int_{p_1}^{p_2} \left(\sum_{i=1}^{N} k_\nu^i \omega^i \right) dp \tag{14}$$

where N is the number of different molecule species involved in the absorption. For a given wave number the monochromatic absorption coefficient of the i-th absorber is the sum of the superposition of the individual absorption lines and the continuum absorption coefficient :

$$k_\nu^i(p, T) = \sum_{j=1}^{N_B^i} \sum_{k=1}^{N^{i,j}} S_k^{i,j}(T) f_k^{i,j}(\nu, p, T) + C^i(\nu, p, T) \tag{15}$$

where N_B^i is the number of the vibrational bands, $N^{i,j}$ is the total number of the individual absorption lines belonging to the j-th absorption band of the i-th molecule type, $S_k^{i,j}$ is the intensity of the k-th line, $f_k^{i,j}$ is the normalized line shape function and C^i is the continuum absorption coefficient.

For further processing, the most convenient expression for the line intensity which fits to the intensity definitions of the spectroscopic data banks is :

$$S_k^{i,j}(T) = S_k^{i,j}(T_o) Q_v^i(T) Q_r^i(T) exp\left[c_2 E_k^{i,j} \left(\frac{1}{T_o} - \frac{1}{T} \right) \right], \tag{16}$$

where $S_k^{i,j}(T_o)$ is the line intensity at temperature $T_o = 296\ K$, Q_v^i and Q_r^i are the vibrational and rotational partition functions, and $E_k^{i,j}$ is the lower state energy of the k-th transition in cm^{-1}.

In the HARTCODE we used $atm\text{-}cm^{-1}cm^{-1}$ as the unit of the line intensity. The temperature dependences of the partition functions are simple power functions:

$$Q_r^i(T) = \left(\frac{T_o}{T}\right)^{a_r^i} \tag{17}$$

and

$$Q_v^i(T) = a_v^i + b_v^i\left(\frac{T_o}{T}\right)^{c_v^i} \tag{18}$$

The usual value of a_r^i is 1.0 for linear molecules (like CO_2, O_2, and N_2O) and 1.5 for nonlinear molecules (like H_2O, O_3 and CH_4). The numerical values of a_v^i, b_v^i and c_v^i for a few molecules are presented in Table I-1. They were obtained by least-square fitting to the Q_v^i values published by *McClatchey et.al.*[7].

TABLE I-1

Numerical values of a_v^i, b_v^i and c_v^i that were used to calculate the vibrational partition functions.

i	molecule	a_v^i	b_v^i	c_v^i
1	H_2O	1.00000	0.00000	0.00000
2	CO_2	0.99752	0.09310	-3.54915
3	O_3	0.99852	0.04600	-4.11179
4	N_2O	1.01819	0.12700	-4.42836
5	CH_4	1.00000	0.00000	0.00000
6	CO	0.99935	0.00700	-5.47575
7	O_2	1.00000	0.00000	0.00000

The continuum absorption coefficients - although they vary over a wide spectral range - can be regarded as constants within the range of the response function. For the water vapor the HARTCODE uses the digitized values of the H_2O continuum absorption curves published by *Kneizys et.al.*[8] .

The actual values of the self- and foreign- density dependent terms at a given wave number are calculated by the quadratic interpolation of the data presented in Table I-2.

TABLE I-2

Continuum absorption coefficients in the $450 - 2500\ cm^{-1}$ spectral region according to *Kneizys et.al.*[8].The units are in cm^{-1} and $(cm^{-1}\ molec./cm^2)^{-1}$.

wave number	$C_s(T_1)$	$C_s(T_o)$	$C_f(T_o)$
450	2.192E-23	1.379E-23	2.625E-25
500	1.379E-23	8.245E-24	7.819E-26
550	8.680E-24	4.929E-24	2.576E-26
600	5.463E-24	2.946E-24	1.149E-26
650	4.012E-24	1.952E-24	4.405E-27
700	2.658E-24	1.293E-24	1.867E-27
750	1.761E-24	8.570E-25	8.328E-28
800	1.293E-24	5.678E-25	5.028E-28
850	9.022E-25	4.170E-25	3.358E-28
900	6.975E-25	3.062E-25	2.744E-28
950	5.123E-25	2.492E-25	2.480E-28
1000	4.170E-25	1.927E-25	2.609E-28
1050	3.394E-25	1.651E-25	2.609E-28
1100	2.909E-25	1.415E-25	3.035E-28
1150	2.492E-25	1.344E-25	3.714E-28
1200	2.492E-25	1.344E-25	6.152E-28
1250	2.624E-25	1.490E-25	1.688E-27
1300	3.394E-25	2.249E-25	6.936E-27
1350	6.293E-25	4.622E-25	2.850E-26
1400	1.228E-24	8.570E-25	7.819E-26
1450	2.398E-24	1.761E-24	2.145E-25
1500	4.223E-24	2.946E-24	3.931E-25
1525	5.463E-24	3.619E-24	4.349E-25
1550	6.055E-24	4.012E-24	4.810E-25
1600	4.223E-24	2.525E-24	2.625E-25
1612	4.012E-24	2.398E-24	2.373E-25
1625	4.012E-24	2.398E-24	2.625E-25
1650	4.929E-24	3.266E-24	3.931E-25
1675	5.463E-24	3.619E-24	4.349E-25
1700	4.681E-24	3.102E-24	3.931E-25
1725	4.929E-24	3.266E-24	3.553E-25
1750	2.946E-24	1.952E-24	2.256E-25
1800	1.509E-24	1.000E-24	1.006E-25
1850	8.570E-25	5.678E-25	5.221E-26
1900	4.390E-25	3.062E-25	2.214E-26
1950	2.249E-25	1.490E-25	1.149E-26
2000	1.213E-25	8.036E-26	3.785E-27
2050	6.541E-26	3.910E-26	1.688E-27
2100	4.334E-26	2.337E-26	5.562E-28
2150	3.351E-26	1.549E-26	3.035E-28
2200	2.337E-26	1.026E-26	2.027E-28
2250	1.630E-26	7.157E-27	1.832E-28
2300	1.260E-26	4.992E-27	1.742E-28
2350	9.746E-27	3.860E-27	1.656E-28
2400	8.352E-27	2.984E-27	1.575E-28
2450	6.457E-27	2.429E-27	1.575E-28
2500	5.534E-27	1.977E-27	1.575E-28

The temperature dependence (at fixed wave number and pressure) is given by the next equation:

$$C^{H_2O}(T) = \left(\frac{\nu}{\rho_a(p_o)}\right) tanh\left[\frac{c_2\nu}{2T}\right]\left(\rho_s(p)C_s(T) + \left[\rho_a(p) - \rho_s(p)\right]C_f\right) \tag{19}$$

where

$$C_s(T) = C_s(T_o) + \left[C_s(T_o) - C_s(T_1)\right]\frac{T - T_o}{T_o - T_1}. \tag{20}$$

In Eq. (19) C_f is the foreign broadened term, $\rho_s(p)$ is the H_2O density at pressure p , $\rho_a(p_o)$ is the reference air density at $p_o = 1013.25\ HPa$. Eq. (20) is the temperature dependence of the self broadened continuum absorption coefficient where $T_1 = 260\ K$. No information are available about the temperature dependence of the foreign broadened term therefore $C_f = C_f(T_o)$.

According to recent measurements made by *Billing* and *Bolle*[9] there is an overestimation of the water vapor continuum absorption coefficients in 700-1400 cm^{-1} spectral interval therefore it might be necessary to update the continuum absorption data in Table I-2 .

The incorporation of the nitrogen and oxygen continuum absorption into the HARTCODE is in progress.

6. Line Shape Function

The most problematic term in Eq. (15) is the line shape function which will be discussed in detail in this section. Let us consider a given vibrational band ($f_k^{i,j} = f_k^i$). Due to the frequent collisions between the gas molecules and to the Doppler-effect the f_k^i function is pressure, temperature and wave number dependent. The adequate line shape function which gives account on both phenomena is the Voigt profile, $f_k^i = V_k^i$, *Armstrong*[10] :

$$V_k^i = \frac{\alpha_k^i}{\pi^{3/2}}\int_{-\infty}^{\infty}\frac{exp(-t^2)}{(\alpha_k^i)^2 + (\nu - \nu_k - t\ \beta_k^i/\sqrt{ln\ 2}\ )^2}dt \tag{21}$$

where

$$\alpha_k^i = \alpha_{k,o}^i\frac{p}{p_o}\left(\frac{T_o}{T}\right)^{\Gamma_k^i} \tag{22}$$

and

$$\beta_k^i = \frac{\nu_k}{c}\sqrt{\frac{2\kappa\ T\ ln\ 2}{m^i}} \tag{23}$$

are the collisional and doppler half widths respectively.

In Eqs. (22) and (23) $\alpha^i_{k,o} = \alpha^i_k(p_o, T_o)$, Γ^i_k is a constant describing the temperature dependence of the collisional half width, c is the speed of the light, κ is the Boltzman constant and m^i is the mass of the molecule of the i-th absorber. The doppler half width may be written in the next form: $\beta^i_k = c_3\nu_k\sqrt{T/M^i}$, where $c_3 = 3.5811 \times 10^{-7}$ and M^i is the molecular weight.

In the HARTCODE the Voigt profile V^i_k is evaluated by the method developed by $Young$[11]. A faster version of the method with limited accuracy was published by $Drayson$[12].

Utilizing the characteristics of the Dirac delta function ($\int \triangle(x')dx' = 1$ and $\int \triangle(x - x')f(x')dx' = f(x)$) it is easy to show that at atmospheric pressures smaller than 0.1 HPa ($\alpha^i_k << \beta^i_k$) or larger than 300 HPa ($\alpha^i_k >> \beta^i_k$) Eq. (21) reduces to its two asymptotic forms:

$$D^i_k = \frac{1}{\beta^i_k}\sqrt{\frac{ln\ 2}{\pi}}\ exp\Big[-\Big(\frac{(\nu-\nu_k)\sqrt{ln\ 2}}{\beta^i_k}\Big)^2\Big] \tag{24}$$

and

$$L^i_k = \frac{1}{\pi}\frac{\alpha^i_k}{(\alpha^i_k)^2 + (\nu - \nu_k)^2} \tag{25}$$

The first equation is the Doppler line shape and valid in the regions where the doppler effect is the major source of the line broadening.

The second equation is the Lorentz line shape and valid for the collisional broadened lines. Laboratory measurements show that the self and foreign broadened collisional half widths are different $Drayson$[13] . For example in case of CO_2 in the 660 cm^{-1} region the self broadened $\alpha^{CO_2}_{k,o} = 0.1\ cm^{-1}$ while the foreign (N_2) broadened $\alpha^{CO_2}_{k,o} = 0.064\ cm^{-1}$. When simulating laboratory measurements where the concentrations of the absorber and the foreign gas are comparable the collisional half width must be a weighted average value by the concentrations. The differences in the self and foreign broadened collisional half widths can be accounted for by introducing an effective pressure $p^{*,i} = p + (b^{*,i} - 1)p^i$ where p is the total pressure, p^i is the partial pressure of the ith absorber and $b^{*,i}$ is an empirical constant. Another problem concerning the collisional half width is that not too much known about the dependence on the rotational quantum numbers.

For the CO_2 the AFGL-82 catalog , $Rothman\ et.al.$[14], uses a simple linear function, due to recent measurements, $Spänkuch$[4], the dependence is described by two different linear curves one for the small and the other for the large rotational quantum numbers, while $Winters\ et.al.$[15] derived a complicated regression equation containing even a temperature dependence based on Madden's measurements.

The deviations between the different treatments can result more than 30 percent change in the value of $\alpha^i_{k,o}$.

Based on the kinetic theory of gases the number of collisions must be proportional to $p/\sqrt{T}$, therefore $\Gamma_k^i = 0.5$. Experimental results show significant scatter in the measured values of Γ_k^i. For example, in case of CO $\Gamma_k^i = 0.25$ according to *Bulanin et.al.*[16] and $\Gamma_k^i = 0.75$ measured by *Varansi*[17]. A detailed set of Γ_k^i were published by *Rothman et.al.*[18].

Since very few measurements of α_k^i and Γ_k^i are available most probably they are the least accurately known spectroscopic parameters.

There is a third process (related to the finite lifetime of the exited states of the molecules) which results the natural broadening of the spectrum lines. In the IR region the half width due to the natural broadening is about 10^{-8} cm^{-1} and completely negligible. For most of the IR active molecules around 1000 cm^{-1} β_k^i is in the order of 10^{-4} cm^{-1} and $\alpha_{k,o}^i$ is about 10^{-1} cm^{-1} at STP.

For the rotational water vapor band the Van Vleck Weisskopf (VVW) line shape were successfully used, *Drayson et.al.*[19] :

$$W_k^i = \frac{\nu(1 - exp[-c_2\nu/T])}{\nu_k(1 - exp[-c_2\nu_k/T])}\left[L_k^i + \frac{\alpha_k^i}{\pi}\frac{1}{(\nu+\nu_k)^2 + (\alpha_k^i)^2}\right]. \tag{26}$$

Bulanin et.al.[16] were using a similar line shape function for the calculations of the CO, N_2O and CO_2 absorption coefficients :

$$W_k^i = 2L_k^i\frac{\nu}{\nu_k}\Big(1 + exp[-c_2(\nu - \nu_k)/T]\Big)^{-1}. \tag{27}$$

Another versions of the VVW line shape are temperature independent expressions, *Drayson et.al.*[19] :

$$W_k^i = \left(\frac{\nu}{\nu_k}\right)^2\left[L_k^i + \frac{\alpha_k^i}{\pi}\frac{1}{(\nu+\nu_k)^2 + (\alpha_k^i)^2}\right], \tag{28}$$

$$W_k^i = \left(\frac{\nu}{\nu_k}\right)\left[L_k^i + \frac{\alpha_k^i}{\pi}\frac{1}{(\nu+\nu_k)^2 + (\alpha_k^i)^2}\right]. \tag{29}$$

The common characteristics of these line shapes are: they are not normalized and they are very close to the Lorentz line shape when $\triangle\nu_k = |\nu - \nu_k| << 1$. Far from the line centers the conditions under which the VVW line shape was derived are not valid. The last two form may be applied in the microwave region where $c_2\nu_k/T << 1.0$.

7. Line Wing and Band Shape

CO_2 absorption measurements in the ν_3 band around 2349 cm^{-1} performed by *Winters et.al.*[15] and *Plyler et.al.*[20] indicated that in the pressure broadening region at larger distances from the band center (50-200 cm^{-1}) the measured absorption coefficients are much less than the ones predicted theoretically by using the superposition of pure Lorentzian line shapes. Transmittance measurements using very long path in the ν_2 band of the CO_2 were performed at the Jet Propulsion Laboratory (JPL) showing the same effect, *Taylor*[21]. *Bulanin et.al.*[16] obtained similar results by measuring the band shapes of several molecules and vibrational bands.

Although attempts were made for the correct theoretical explanation (see for example *Zuev*[22], *Armstrong*[23], *Bulanin et.al.*[16]) the above effect is not fully understood yet. Based on the measurements, however, it is obvious that at the line wings correction must be applied to the Lorentz line shape function. This correction is generally performed by a multiplying function depending only on $\triangle\nu_k$:

$$f_k^i = L_k^i \; F_k^i(\triangle\nu_k).$$

For the CO_2 $(i = 2)$ the next correction functions are commonly used:

$$F_k^2 = \begin{cases} exp\Big[-1.4(\triangle\nu_k - 3.5)^{0.25}\Big], & \text{if } \triangle\nu_k \geq 3.5 \; cm^{-1}; \\ 1, & \text{if } \triangle\nu_k < 3.5 \; cm^{-1}. \end{cases} \tag{30}$$

This form was originally suggested by *Winters et.al.*[15] and used by T. Aoki and the japanese group during the second ITRA exercise (see *Spänkuch*[4]).

$$F_k^2 = \begin{cases} 1, & \text{if } \quad \triangle\nu_k < \ 0.5 \; cm^{-1}; \\ 1.069exp[-0.133\triangle\nu_k], & \text{if } 0.5 \leq \triangle\nu_k < \ 23. \; cm^{-1}; \\ 0.05, & \text{if } 23. \leq \triangle\nu_k < \ 50. \; cm^{-1}; \\ 0.133exp[-0.0196\triangle\nu_k], & \text{if } 50. \leq \triangle\nu_k < 250. \; cm^{-1}; \\ 0, & \text{if } \quad \triangle\nu_k > 250. \; cm^{-1}. \end{cases} \tag{31}$$

This stepwise function was published by *Susskind and Searl*[23]. The next function which was applied during the second ITRA exercise by the NOAA group is again a stepwise approximation :

$$F_k^2 = \begin{cases} \Big(1 + \frac{2}{11}\triangle\nu_k\Big)exp\Big[-\frac{2}{11}\triangle\nu_k\Big], & \text{if } \triangle\nu_k < 11 \; cm^{-1}; \\ 0, & \text{if } \triangle\nu_k \geq 11 \; cm^{-1} \end{cases} \tag{32}$$

The simplest $F_k^{i,j}$ function which is the most frequently used in LBL codes is:

$$F_k^{i,j} = \begin{cases} 1, & \text{if } \triangle\nu_k \le R^{i,j}; \\ 0, & \text{if } \triangle\nu_k > R^{i,j}, \end{cases} \tag{33}$$

where $R^{i,j}$ is the line wing cut-off parameter which depends on the molecule type and vibrational band.

Based on the line-mixing theory *Bulanin et.al.*[16] derived a complicated band correction function which seems to be difficult to implement into a LBL code .The problem is that the structure of his correction function is similar to that one of the absorption coefficient itself (ie. it is temperature dependent and contains all the lines being in a given vibrational band). In the simplest case, far from the line centers, the band correction function for the j-th vibrational band of the i-th molecule type takes the next form:

$$F^{i,j} = \frac{\sum_{k=1}^{N^{i,j}} A_k^{i,j}/(\nu-\nu_k)^2 - \left(\sum_{k=1}^{N^{i,j}} A_k^{i,j}/(\nu-\nu_k)\right)^2}{\sum_{k=1}^{N^{i,j}} A_k^{i,j}(1-Ak^{i,j})/(\nu-\nu_k)^2} \tag{34}$$

where

$$A_k^{i,j} = \frac{\nu_B^{i,j} S_k^{i,j}}{\nu_k S_B^{i,j}} \tag{35}$$

is the relative line intensity, $\nu_B^{i,j}$ is the band center and $S_B^{i,j}$ is the band intensity (at a given temperature). In the recent version of the HARTCODE the line interference is not considered although it seems possible to evaluate Eq. (34) simultaneously with Eq. (15) by checking the vibrational quantum identifiers.

Finally let us mention that in the newest version of the HITRAN database *Rothman et.al.*[18] a coupling coefficient is introduced to consider the line-mixing effect in the CO_2 fundamental at 668 cm^{-1} and in the two hot bands at 618 and 671 cm^{-1} :

$$F_k = 1 + y_k(\nu - \nu_k)/\alpha_k \tag{36}$$

where y_k is the coupling coefficient. This correction can easily be applied in the HARTCODE whenever the new HITRAN database is available at IMGA. When this report was completed we obtained a copy of the HITRAN database[34] and we have attempted to apply the correction given by Eq. (36). Unfortunately in the tape at the position of the coupling coefficients we encountered some undefined characters - at 618.024 and 720.7982 cm^{-1} - which made the simple application impossible.

8. Concept of the Line - by - Line Method

The fundamental problem in modeling the atmospheric IR radiation field is :

<u>How to obtain the average spectral transmittance or absorptance of an atmospheric layer over a given wave number interval.</u>

The relevant mathematical expressions are :

$$\gamma_{\overline{\nu}}(p_1, p_2) = \frac{1}{\delta\nu} \int_{\delta\nu} exp\Big[- \tau^*_\nu(p_1, p_2)\Big] d\nu \tag{37}$$

$$\xi_{\overline{\nu}}(p_1, p_2) = 1 - \gamma_{\overline{\nu}}(p_1, p_2) \tag{38}$$

where $\gamma_{\overline{\nu}}$ and $\xi_{\overline{\nu}}$ are the average spectral transmittance and absorptance subsequently, $\delta\nu$ is the (suitable short) wave number interval and p_1 and p_2 are the pressure values at the lower and upper boundary of the layer subsequently.

To obtain information about $\gamma_{\overline{\nu}}$ and $\xi_{\overline{\nu}}$ there are three possibilities: measurements, calculations using the band model technique or calculations using the line-by-line method.

The limitations of the measurements are obvious. With respect to the variability of the atmosphere in space and time, the cost and time factor do not allow to take large number of measurements under different atmospheric conditions. Moreover, because of the inherent characteristic of the spectrometers the measured data are always weighted with certain type of instrumental response function which poses some difficulties in calculating the true averages.

This study do not intend to discuss critically the band model technique. About the exhausting large number of recently existing band models one may find comprehensive works in the literature, see for example *LaRocca and Turner*[24], *Anding*[25]. Briefly, the band models are calculating $\gamma_{\overline{\nu}}$ and $\xi_{\overline{\nu}}$ by a more or less closed mathematical expression which is depending on the average spectroscopic parameters normally obtained by laboratory measurements. However, to obtain a mathematically tractable equation for $\gamma_{\overline{\nu}}$ and $\xi_{\overline{\nu}}$ some assumptions must be made on the structure and distribution of the line spacing and line intensities within $\delta\nu$. The problem with the application of the band models is that the spectrum lines in a real absorption band are never placed purely random or purely regular way. With the superposition of the different regular or random bands the accuracy may improve but the complexity of the equations and calculations will approach to that one of the line-by-line method.

By definition the LBL method is the numerical integration of Eq. (37) over the wave number interval $\delta\nu$ considering the real line structure represented by the spectral behavior of the total monochromatic optical thickness. In case of transmittance Eq. (37) may be written in the next form :

$$\gamma_{\overline{\nu}}(p_1,p_2) = \frac{1}{\delta\nu}\sum_{l=1}^{N_\nu} w_\nu^l exp\Big[-\tau_{\nu^l}^*\Big] \tag{39}$$

where N_ν, w_ν^l and ν^l are the orders, weights and abscissa of the numerical wave number integration subsequently. Further on $\delta\nu$ will be referred as the wave number resolution of the LBL code.

In the HARTCODE the numerical wave number integration is performed over a system of fine subdivisions by Gaussian quadrature of different order. The system of the wave number mesh is generated with respect to the required spectral resolution $\delta\nu$. The length of the sub-intervals are depending on the distance from the line center, the wave number dependent Doppler half width and the pressure range of the input data.

According to Eq. (14) the total monochromatic optical thickness of an atmospheric layer contains the integral of the line shape functions over the pressure range defined by p_1 and p_2 .This integration is only needed when the accuracy of the Curtis-Gudson (CG) approximation is not sufficient, ie. $(p_2/p_1) >> 1.0$. In the pressure broadening range and close to the line centers the exact pressure integral of the Lorentz line shape may be used (the layer supposed to be isothermal with constant mass mixing ratio) :

$$\int_{p_1}^{p_2} L_k^i dp = \frac{1}{2\pi\alpha^*} ln\left[\frac{(\alpha^* p_2)^2 + \triangle\nu_k^2}{(\alpha^* p_1)^2 + \triangle\nu_k^2}\right] \tag{40}$$

where $\alpha^* = \alpha_k^i/p$. If the pressure dependence of the mass mixing ratio within the layer is simple power function the product with the Lorentz line shape is still remains integrable. (It is a very crude approximation to assume constant mass mixing ratio in case of H_2O and O_3 within even a relatively thin layer.) In case of the Voigt function the pressure integral might be calculated preceeding the numerical integration with respect t, *Drayson*[26] :

$$\int_{p_1}^{p_2} V_k^i dp = \frac{1}{2\pi^{3/2}\alpha^*} \int_{-\infty}^{\infty} e^{-t^2} ln\left[\frac{(\alpha^* p_2)^2 + (\nu - \nu_k - t\beta_k^i/\sqrt{ln\ 2})^2}{(\alpha^* p_1)^2 + (\nu - \nu_k - t\beta_k^i/\sqrt{ln\ 2})^2}\right] dt \tag{41}$$

This equation is useful when $100\ HPa > p > 10\ HPa$ and $0.003\ cm^{-1} < \triangle\nu_k < 0.2\ cm^{-1}$. (For the integration with respect t Drayson applied 20 point Hermite quadrature.)

In the HARTCODE to match the conditions for the CG approximation the secondary layering is an option. In case of several layers $\tau_{\nu_l}^*(p_1, p_{N_L})$ is expressed as the sum of the optical thicknesses of the individual layers :

$$\tau^*_{\nu l}(p_1, p_{N_L}) = \sum_{m=1}^{N_L-1} \mu^*_m \int_{p_m}^{p_{m+1}} \left(\sum_{i=1}^{N} k^{i,m}_{\nu^l} \omega^{i,m} \right) dp \qquad (42)$$

where N_L is the number of levels. If $p_1 = 0.0$ and p_{N_L} is the pressure at the surface Eq. (42) is the total monochromatic optical thickness of the whole atmosphere (which is divided into $N_L - 1$ layers). In the recent version of the code the maximum number of the atmospheric levels is limited to 150. For practical purposes this is sufficient, however, by modifying the declaration statements any kind of layering is possible.

The LBL method requires the pre-calculated set of the basic spectroscopic parameters which is needed for the evaluation of $k^i_{\nu l}$. Accordingly, when applying efficient numerical methods the accuracy will only depend on the accuracy of the input spectroscopic data.

9. Spectroscopic Data Banks

The frequently mentioned basic spectroscopic data are : resonant wave number, line intensity, air-broadened half width, lower state energy with the corresponding quantum and molecular identifiers and - in special cases - the temperature dependence of the half width and line coupling coefficients. Recently two compilation of the basic spectroscopic data are available :

The first one is the AFGL Atmospheric Line Parameters Compilation, published by *Rothman et al.*[14,27]. The content of the latest version (edition of October 1982) is divided into two parts. The first one contains information about 176337 transitions of the main absorber (H_2O, CO_2, O_3, N_2O, CO, CH_4, and O_2) in the 0-18000 cm^{-1} spectral region . The second part with 94682 transitions in the 0-10000 cm^{-1} region is the trace gas compilation. In the near future the updated version with 348043 transition might be available, see *Rothmanet al.*[18].

The other compilation is the GEISA line catalog, published by *Chedin*[28,30] and *Husson et al.*[29,31]. The 1984 version of the GEISA catalog contains 323554 transitions of 37 different molecules in the spectral range from microwaves to visible.

In this work we are frequently using both compilations. It has been discovered that at some spectral interval the two data significantly differ. The information about how to use the tapes and the details of the differences will be given in the next chapter.

10. Radiance Algorithms

For the radiance calculations we have developed two methods. In both methods the calculation is based on the fact that within a given layer and wave number interval the pressure dependence of the transmittance function can very well be approximated by an exponential-type function. Let us consider now the 'looking-down' geometry, ie. the calculation starts at the uppermost layer. Using a transmittance scale factor (or an effective absorption coefficient) for each layer and $\delta\nu$ the transmittance function and weighting function takes the next form:

$$\gamma_{\overline{\nu}}(p') = \gamma^m exp\left[-\frac{p' - p_m}{H^m}\right], \qquad p_m < p' < p_{m+1}, \tag{43}$$

$$W_{\overline{\nu}}(p') = -\frac{\gamma_{\overline{\nu}}(p')}{H^m}, \tag{44}$$

where H^m is the transmittance scale factor :

$$H^m = \frac{p_{m+1} - p_m}{ln(\gamma^m/\gamma^{m+1})}, \tag{45}$$

and the superscript m and $m+1$ indicate the pressure levels. The accurate transmittances at the m-th level are calculated by Eq. (39), and $\gamma^m = \gamma_{\overline{\nu}}(p_1, p_m)$ where p_1 is the upper boundary pressure. Since within a layer the weighting function is directly proportional to the transmittance function one may calculate a rapidly convergent series of the weighted Planck functions. The temperature profile within the layer is approximated by a third-order polynomial of the pressure, therefore $B_{\overline{\nu}}(T(p')) = B_{\overline{\nu}}(p')$. To obtain the contribution to the radiance from the m-th layer the weighted average Planck function is multiplied with the difference in the transmittances at the upper and lower boundary:

$$B^m_{\overline{\nu}}(N_c) = \frac{\sum_{n=1}^{N_c} B_{\overline{\nu}}(p'_n)\gamma_{\overline{\nu}}(p'_n)}{\sum_{n=1}^{N_c} \gamma_{\overline{\nu}}(p'_n)}(\gamma^m - \gamma^{m+1}), \tag{46}$$

where $p'_1 = p_m < p'_n < p'_{N_c} = p_{m+1}$ and $N_c \geq 2$ is the number of iterations depending on a predetermined accuracy limit.(Even for extreme transmittance and temperature profiles $N_c = 2$ gives good results.)

Another method to obtain accurate radiance is to approximate $1/T(p')$ (within the given layer) with a linear pressure function and expand the Planck function into a four or five term series :

$$B_{\overline{\nu}}(p') = c_1\overline{\nu}^3\left[\frac{e^{-B_2^m p'}}{B_1^m} + \frac{e^{-2B_2^m p'}}{(B_1^m)^2} + \cdots\right], \tag{47}$$

where

$$B_1^m = exp\left[\frac{c_2\overline{\nu}}{p_{m+1} - p_m}\left(\frac{p_{m+1}}{T^m} - \frac{p_m}{T^{m+1}}\right)\right], \tag{48}$$

and

$$B_2^m = \frac{c_2\overline{\nu}}{p_{m+1} - p_m}\left(\frac{1}{T^{m+1}} - \frac{1}{T^m}\right). \tag{49}$$

With not too high temperature differences and above 500 cm^{-1} the approximations are always satisfactory. The product of the Planck function, Eq. (47), and transmission function, Eq. (43), can easily be integrated (with respect the pressure p') giving an analytical formula for the radiance contribution of the layer:

$$B_{\overline{\nu}}^m(N_d) = c_1\overline{\nu}^3 \sum_{n=1}^{N_d} \frac{\gamma^{m+1} exp(-nB_2^m p_{m+1}) - \gamma^m exp(-nB_2^m p_m)}{(B_1^m)^n (nB_2^m H^m + 1)}, \tag{50}$$

where $N_d \geq 2$ is the number of terms to be considered in the expansion given in Eq. (47).

The above two methods are practically giving the same results. In the HARTCODE both methods are applied and the related algorithms are installed.

Further analysis of the accuracy of other radiance algorithms (including the ones that were used in the second ITRA exercise) showed that the highest accuracy (about 10^{-4} percent relative error) can be achieved by applying 2nd order Gaussian quadrature over a given layer where the transmittance is approximated by Eq. (43) and the temperature is a simple power function. In the next version of the HARTCODE we shall introduce this method.

11. Spherical Refractive Atmosphere

At large zenith angles when the secant-law is not valid μ_m^* must be specified for each layer. The calculation of μ_m^* is discussed in detail in many papers, see for example *Kneizys at.al.*[8], *Anding*[25] and *Duncan*[32].

In the HARTCODE we have developed a new algorithm which considers the changing curvature of the trajectory from layer to layer. In the next equations θ_m is the local zenith angle at the lower boundary of the m-th layer, n_m is the refractive index, h_m is the altitude and r_e is the radius of the Earth. In case of the upward direction for the computation of μ_m^* we have applied the following sequence of equations :

$$Z_m = h_m + r_e \tag{51}$$

$$\theta_m^* = asin\left[\frac{Z_m}{Z_{m+1}} sin(\theta_m)\right] \tag{52}$$

$$s_m = Z_{m+1} cos(\theta_m^*) - Z_m cos(\theta_m) \tag{53}$$

$$\theta_{m+1} = asin\left[\frac{n_m}{n_{m+1}} sin(\theta_m^*)\right] \tag{54}$$

$$\theta_{m+1}^* = asin\left[\frac{Z_{m+1}}{Z_{m+2}} sin(\theta_{m+1})\right] \tag{55}$$

$$s_{m+1} = Z_{m+2} cos(\theta_{m+1}^*) - Z_{m+1} cos(\theta_{m+1}) \tag{56}$$

$$\delta_m = \pi - \theta_{m+1} + \theta_m^* \tag{57}$$

$$c_m = \sqrt{s_m^2 + s_{m+1}^2 - 2 s_m s_{m+1} cos(\delta_m)} \tag{58}$$

$$S_m = \frac{s_m + s_{m+1} + c_m}{2} \tag{59}$$

$$R_m = \frac{s_m s_{m+1} c_m}{4\sqrt{S_m(S_m - s_m)(S_m - s_{m+1})(S_m - c_m)}} \tag{60}$$

$$\mu_m^* = \frac{2R_m asin[s_m/(2R_m)]}{Z_{m+1} - Z_m}. \tag{61}$$

The refractive index of the air (as a function of the ambient pressure, temperature, water vapor partial pressure and wave number) is calculated by an empirical formula obtained by Edlen, $Jursa$[33], which is valid for a wide spectral range from the UV to the far IR.

In case of downward direction similar sequence is applied except that at the last layer the tangent height H_T - from Eqs. (52) and (54) - is calculated by the next equation :

$$H_T = \frac{Z_m n_m sin(\theta_m)}{n_{m+1}} - r_e. \tag{62}$$

The typical numerical accuracy of the calculated geometrical path length or the tangent height is better than 1 m.

Although for the transmittance and radiance calculations the relative optical air mass of the different kind of absorbers for the whole atmosphere are not needed explicitly, in the HARTCODE the module calculating the trajectory of the refracted beam may be used separately for high accuracy air mass calculations. In this case the relative optical air mass of the i-th absorber is given by the next equation :

$$M^i(\theta) = \frac{\sum_{m=1}^{N_L-1} \mu_m^*(\theta) u_m^i \triangle Z_m}{\sum_{m=1}^{N_L-1} u_m^i \triangle Z_m}, \tag{63}$$

where u_m^i is the average column density of the i-th absorber at the m-th layer, $\triangle Z_m$ is the thickness of the layer and N_L is the number of levels. As an example in Tables I-3 and I-4 the angular deviation of the beam, geometrical path length and the air mass values are presented for different zenith angles at 0.5 μ without considering the refraction (Table I-3) and with refraction (Table I-4). The effect of the refraction at large zenith angles is about ten percent.

Some results of the HARTCODE high accuracy air mass calculations are presented in Appendix A. These Tables might be very useful at the evaluation of the narrow-band radiance measurements aimed to monitor the amount of the trace absorbers when to increase the sensitivity at the observations large zenith angles are used. If simultaneous radiosonde measurements are available the re-calculation of the air mass with the actual profiles might also be necessary.

The first six Tables in Appendix A contain the optical air mass values of the air and the non-uniformly mixed main absorbers for the six standard Lowtran profiles at 15 μ. Table A-6 shows the results obtained for the US Standard Atmosphere 76 at 15 μ. If we compare this results with the ones presented in Table I-4 (same model atmosphere but at 0.5 μ) we can recognise the effect of the decreased refractive index (with increased wave length) on the angular deviation and the other quantities. Table A-7 contains the air mass values calculated for some trace gases and for the US Standard atmosphere 76 using the Lowtran trace gas profiles.

TABLE I-3

Relative optical air mass values for the *USST 76* atmosphere with no refraction and for a path from 0.0 to 120 km altitude.θ is the zenith angle in degree, $\triangle\theta$ is the angular deviation of the beam in degree, L is the geometrical path length in km.

θ	$\triangle\theta$	L	AIR	H_2O	O_3	N_2O	CO	CH_4
60.0	0.00000	233.688	1.9932	1.9981	1.9793	1.9938	1.9952	1.9937
62.0	0.00000	247.752	2.1215	2.1276	2.1042	2.1223	2.1241	2.1221
64.0	0.00000	263.853	2.2703	2.2781	2.2483	2.2713	2.2736	2.2711
66.0	0.00000	282.418	2.4445	2.4546	2.4163	2.4459	2.4488	2.4456
68.0	0.00000	303.990	2.6510	2.6642	2.6141	2.6527	2.6566	2.6523
70.0	0.00000	329.278	2.8990	2.9168	2.8497	2.9013	2.9065	2.9008
72.0	0.00000	359.211	3.2018	3.2263	3.1343	3.2050	3.2121	3.2043
74.0	0.00000	395.020	3.5790	3.6139	3.4836	3.5835	3.5936	3.5825
76.0	0.00000	438.354	4.0607	4.1125	3.9206	4.0673	4.0823	4.0657
78.0	0.00000	491.430	4.6950	4.7761	4.4794	4.7052	4.7286	4.7028
80.0	0.00000	557.214	5.5645	5.7008	5.2118	5.5811	5.6204	5.5772
81.0	0.00000	596.054	6.1305	6.3132	5.6664	6.1523	6.2048	6.1471
82.0	0.00000	639.619	6.8212	7.0731	6.1968	6.8504	6.9226	6.8434
83.0	0.00000	688.566	7.6803	8.0397	6.8187	7.7206	7.8229	7.7109
84.0	0.00000	743.604	8.7735	9.3078	7.5492	8.8306	8.9811	8.8168
85.0	0.00000	805.489	10.2028	11.0384	8.4050	10.2863	10.5177	10.2660
86.0	0.00000	874.987	12.1330	13.5255	9.3947	12.2599	12.6347	12.2288
87.0	0.00000	952.832	14.8431	17.3589	10.5061	15.0436	15.6883	14.9941
87.5	0.00000	995.095	16.6322	20.1417	11.0922	16.8881	17.7552	16.8246
88.0	0.00000	1039.681	18.8280	23.8684	11.6830	19.1575	20.3446	19.0754
88.2	0.00000	1058.180	19.8478	25.7260	11.9170	20.2133	21.5662	20.1220
88.4	0.00000	1077.063	20.9630	27.8564	12.1479	21.3691	22.9157	21.2675
88.6	0.00000	1096.334	22.1857	30.3159	12.3745	22.6373	24.4107	22.5241
88.8	0.00000	1115.995	23.5293	33.1756	12.5956	24.0322	26.0719	23.9059
89.0	0.00000	1136.049	25.0092	36.5255	12.8099	25.5700	27.9233	25.4290
89.2	0.00000	1156.497	26.6434	40.4799	13.0164	27.2693	29.9932	27.1117
89.4	0.00000	1177.340	28.4523	45.1849	13.2141	29.1516	32.3148	28.9753
89.6	0.00000	1198.581	30.4595	50.8281	13.4024	31.2415	34.9274	31.0441
89.7	0.00000	1209.351	31.5459	54.0744	13.4927	32.3731	36.3571	32.1642
89.8	0.00000	1220.220	32.6924	57.6506	13.5805	33.5677	37.8776	33.3465
89.9	0.00000	1231.188	33.9031	61.5978	13.6657	34.8294	39.4961	34.5952
90.0	0.00000	1242.256	35.1824	65.9625	13.7482	36.1628	41.2205	35.9149

TABLE I-4

Relative optical air mass values for the *USST 76* atmosphere at 0.5μ wavelength and for a path from 0.0 to 120 km altitude.θ is the zenith angle in degree, $\triangle\theta$ is the angular deviation of the beam in degree, L is the geometrical path length in km. The accuracies of the air mass values are better then 10^{-3} percent.

θ	$\triangle\theta$	L	AIR	H_2O	O_3	N_2O	CO	CH_4
60.0	0.02751	233.856	1.9939	1.9984	1.9807	1.9945	1.9958	1.9944
62.0	0.02985	247.960	2.1224	2.1280	2.1060	2.1232	2.1248	2.1230
64.0	0.03251	264.114	2.2715	2.2786	2.2506	2.2724	2.2745	2.2722
66.0	0.03558	282.748	2.4461	2.4552	2.4192	2.4473	2.4500	2.4470
68.0	0.03916	304.414	2.6530	2.6650	2.6179	2.6547	2.6582	2.6543
70.0	0.04340	329.830	2.9017	2.9178	2.8547	2.9039	2.9086	2.9034
72.0	0.04851	359.945	3.2055	3.2277	3.1411	3.2085	3.2150	3.2078
74.0	0.05481	396.016	3.5842	3.6160	3.4932	3.5886	3.5978	3.5875
76.0	0.06276	439.742	4.0684	4.1156	3.9345	4.0747	4.0885	4.0732
78.0	0.07314	493.419	4.7071	4.7811	4.5005	4.7168	4.7385	4.7145
80.0	0.08725	560.164	5.5846	5.7093	5.2455	5.6005	5.6370	5.5968
81.0	0.09638	599.700	6.1573	6.3247	5.7100	6.1783	6.2271	6.1733
82.0	0.10749	644.175	6.8578	7.0893	6.2541	6.8861	6.9534	6.8794
83.0	0.12125	694.326	7.7321	8.0634	6.8953	7.7712	7.8671	7.7619
84.0	0.13871	750.989	8.8495	9.3443	7.6537	8.9053	9.0472	8.8919
85.0	0.16144	815.104	10.3195	11.0985	8.5498	10.4018	10.6218	10.3819
86.0	0.19201	887.731	12.3224	13.6334	9.5980	12.4487	12.8094	12.4179
87.0	0.23469	970.098	15.1717	17.5770	10.7923	15.3743	16.0056	15.3244
87.5	0.26274	1015.388	17.0781	20.4702	11.4304	17.3389	18.1979	17.2743
88.0	0.29705	1063.713	19.4464	24.3875	12.0801	19.7862	20.9788	19.7016
88.2	0.31294	1083.953	20.5573	26.3592	12.3394	20.9361	22.3041	20.8416
88.4	0.33030	1104.743	21.7805	28.6359	12.5965	22.2036	23.7782	22.0978
88.6	0.34931	1126.107	23.1314	31.2856	12.8501	23.6047	25.4238	23.4861
88.8	0.37018	1148.070	24.6279	34.3949	13.0987	25.1583	27.2676	25.0252
89.0	0.39314	1170.662	26.2912	38.0759	13.3413	26.8866	29.3417	26.7370
89.2	0.41849	1193.917	28.1462	42.4745	13.5765	28.8156	31.6846	28.6470
89.4	0.44656	1217.872	30.2224	47.7824	13.8037	30.9760	34.3427	30.7860
89.6	0.47775	1242.574	32.5548	54.2529	14.0221	33.4045	37.3728	33.1900
89.7	0.49467	1255.222	33.8299	58.0255	14.1279	34.7328	39.0486	34.5048
89.8	0.51256	1268.079	35.1857	62.2233	14.2315	36.1454	40.8446	35.9028
89.9	0.53152	1281.154	36.6287	66.9065	14.3328	37.6492	42.7724	37.3912
90.0	0.55163	1294.458	38.1665	72.1449	14.4319	39.2521	44.8447	38.9775

II. STRUCTURE AND OPERATION OF THE HARTCODE

1. General Structure

In this chapter, after a short summary, the operation of the individual modules is discussed. The HARTCODE is basically a system of three groups of programmes written in Vax-Fortran.

The first group :

DECODA, DECODG, FIND and LIN

is performing the preliminary processing of the input spectroscopic data. Pre-processing does not necessarily mean neglecting absorption lines. For a particular wave number interval it is simply not economic to carry all the information given by the data banks. The consideration of the weak absorber or the very weak spectrum lines is always depending on the real conditions. The result of the operation of these modules are two data files containing all spectroscopic information needed by the HART programme.

The second group is the HART programme and its subroutines. These programmes are performing several tasks depending on the input instructions. Since this version of the HARTCODE was used for numerical testing the HART module can work in two different modes.

In *test* mode the spectroscopic parameters are internally generated and the first group of programmes are not used. Using this mode we can model the most extreme line distributions and check the computational accuracy in special cases.

In *line* mode HART is computing the spectral values (with the required $\delta\nu$ wave number resolution) of the next monochromatic quantities :

a. optical depth given by Eq. (14),
b. transmittance given by Eq. (13),
c. radiance given by Eqs. (9) and (10)

for any kind of laboratory or atmospheric conditions using the spectroscopic data contained by the output files of the LIN program (**lin.dat** and **farwg.dat**). The results of the operation of the HART module are written in two data files for further processing (**trao.dat** and **rad.dat**).

The third group consists of three programmes :

SMTH, COMP and CHNL.

These programmes either compute the channel-radiance and weighting functions or apply different kind of smoothing. The outputs of these modules are data files for the plotting routines.

The numbered list of the individual modules are presented in the Appendices C, D and E. Figures II-1, II-2 and II-3 may give some idea about the general structure of the HARTCODE by displaying the block-diagrams of the operation of the three groups of programmes.

Since the programmes are not supplied with comment lines we refer to the location of a particular programme statement by quoting the line number(s) in curly braces. The different program-, subroutine- and function segments and the variables (character, scalar, vector or matrix type) are referred by their names written in capital letters. The variables are enclosed with single quotation mark. The names of the internal data files are written in boldface style. In this version all data files are formatted in order to make easier the interactive use and the trace-back in case of 'emergency'.

The full length of the HARTCODE is 4019 programme lines. In the next list we summarize the length of the individual modules. The locations of the programmes are also given by quoting the proper page numbers (in brackets).

DECODA	68	(120)	HART	1190	(140)	SMTH	90	(196)
MIX	41	(122)	LAYERS	188	(167)	COMP	573	(198)
DECODG	41	(123)	MINT	85	(172)	CHNL	357	(211)
FIND	26	(124)	LENGTH	225	(174)	GSC	95	(220)
LIN	156	(125)	MESH	29	(179)			
STAT	111	(129)	CONT	37	(180)			
FAR	207	(132)	FARWG	59	(181)			
WINGS	42	(137)	GAUSS	106	(183)			
			SHAPE	45	(186)			
			VOIGTY	123	(187)			
			VOIGTD	82	(190)			
			WING	43	(192)			

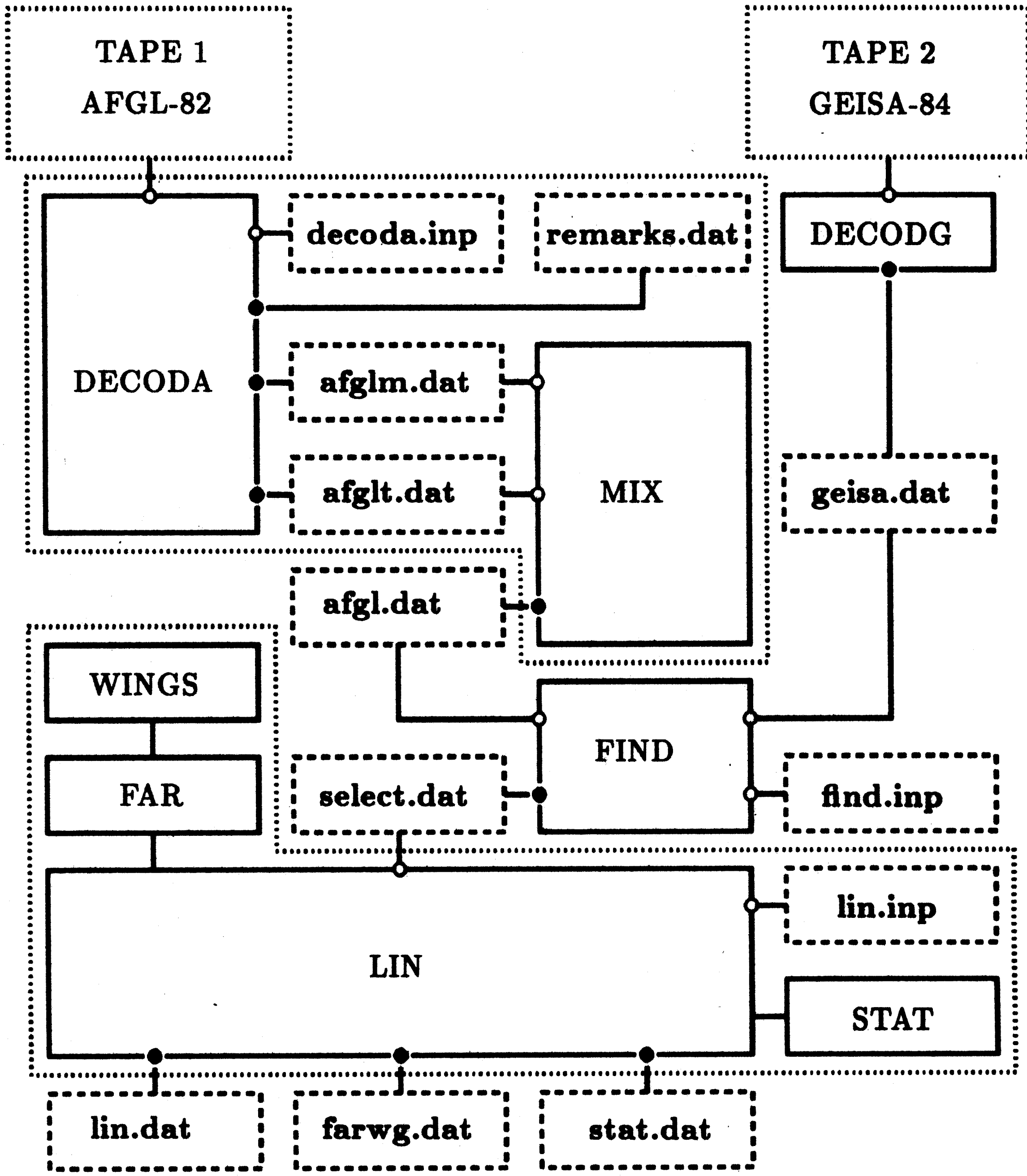

Fig. II-1 : The block-diagram displays the general structure of the first group of programmes performing the pre-processing of the spectroscopic data. Symbols '○' and '●' are indicating the input and output channels respectively. The internal data files are enclosed in boxes with dashed line. Modules belonging to the same program unit are enclosed with dotted line, except in the case of 'TAPE 1' and 'TAPE 2' where the boxes are indicating the original tapes of the data banks.

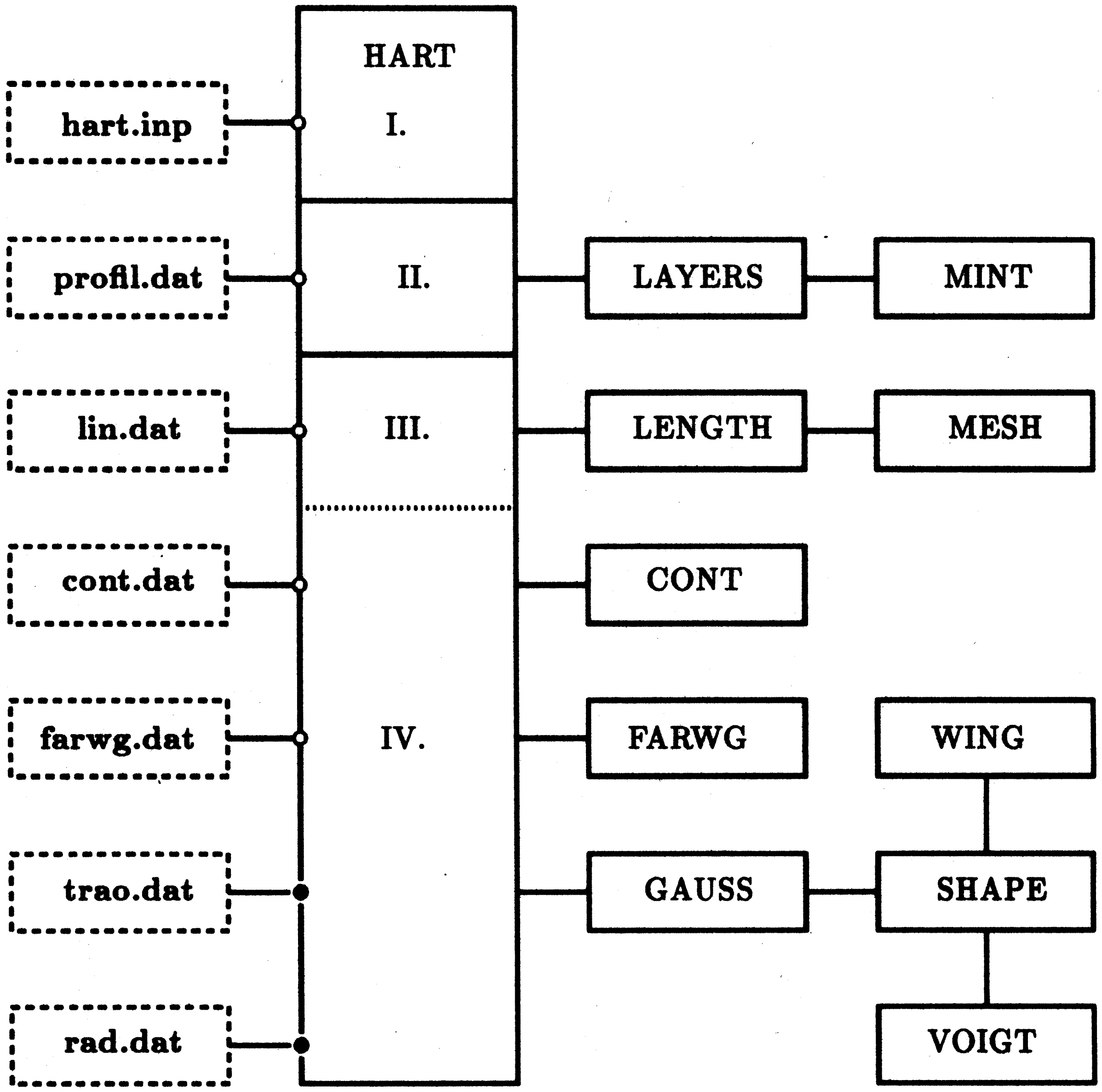

Fig. II-2 : The structure of the second group of programmes. In the HART block the numbers are indicating the different phase of processing. The first section is the input module. In the second section the required atmospheric layering is established. At the beginning of the third section is the entry point of the wave-number-loop and the fourth section is the extension of the layer-loop.

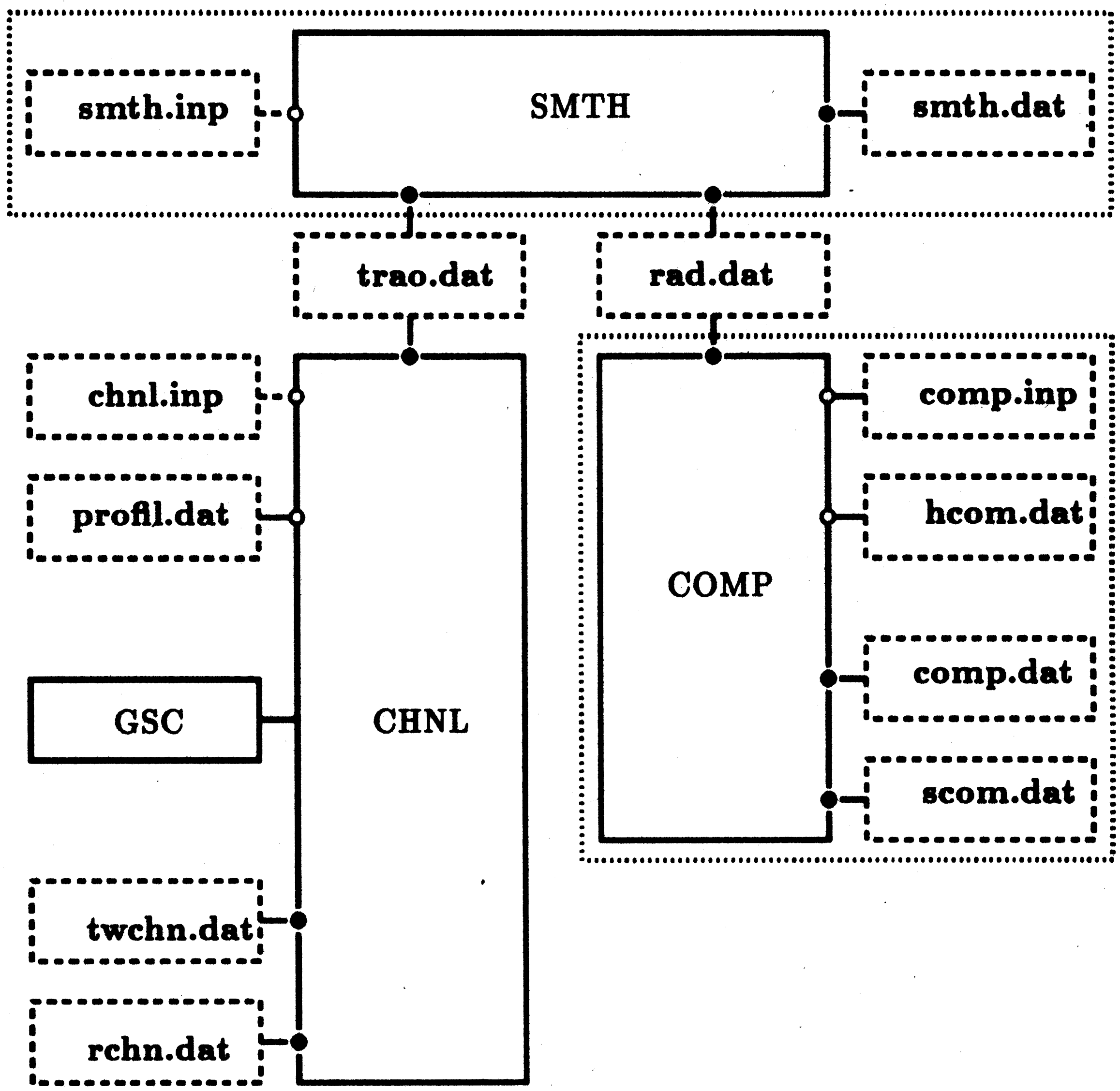

Fig. II-3 : Post-processing of the results. Modules SMTH and COMP perform different kind of smoothing. CHNL computes the channel transmittance, weighting functions and radiance for selected wave numbers. The output data files may be used directly in plotting routines.

2. Pre-processing of the Spectroscopic Data

DECODA and MIX

The basic task of these units is to produce a data file by extracting the necessary information from the AFGL-82 compilation. The parameters to be extracted are : line positions, line intensities, collisional half widths, lower state energies, molecular and quantum identification codes.

The data in the AFGL-82 tape are coded and blocked with variable block size . After every 100 cm^{-1} there is an end-of-file mark. As we mentioned before, the data of the main absorber and of the trace gases are separated. The first 179 files contain the data of the main absorber and the data in the last 100 files belong to the trace gases.

The AFGL-82 tape also contains supplementary information about the transitions. This information - which was located by a zero molecular identification code - is stored in the file **remarks.dat**. The unassigned transitions are supplied with a negative lower state energy value. These transitions were rejected although they were copied into the file **remarks.dat**.

The task of the module MIX is to produce one file by mixing the data of the main and trace absorber (files **afglm.dat** and **afglt.dat**) and unify the molecular identification codes, i.e. to change the id. to that one used by the GEISA-84 tape. (The isotopic identification remains unchanged.)

Remarks:

– To read the new version of the AFGL tape the 'BLOCKSIZE' and 'RECL' qualifiers must be changed at line $\{17\}$ in DECODA.

– The input parameter 'IMIX' activates the MIX routine and 'ICHANGE' is the control parameter to change the molecular identification code at lines $\{23, 80\}$ in DECODA.

– The input format specifications were changed after 100 cm^{-1} at lines $\{37, 38\}$.

– Line $\{58\}$ is the output format specification.

DECODG

The GEISA-84 tape contains two files written in standard IBM code. (The specifications of the tape are: 6250 BPI, 9 track, no label, odd parity, two files, blocksize 6160, number of blocks 4240, record length 80, coded). The conversion to ASCII code was performed by a VAX system-library routine at line $\{32\}$. The two files in the GEISA-82 tape are identical, except that the second file contains the temperature dependence coefficients of the collisional half widths. (At the same position the first file contains some kind of internal reference code.)

FIND

After having the copies of the original data banks in the computer the next step is to extract the information concerning the wave number interval we are interested in. This job has been done by module FIND. The input file **find.inp** contains the wave number limits and the source file identification.('ID' = 0 for the **geisa.dat** and 'ID' = 1 for the **afgl.dat** at lines $\{18, 19, 20\}$.) To select the data for a particular band some modification needed, ie. a string of quantum identifiers must be inserted in the input file and compared with the value of 'QID' after line $\{32\}$.

Remarks:

– The output file **select.dat** does not contain any kind of information about the band and isotopic codes.

– At the selection of the wave number limits the possible wing contribution must be considered.

LIN and STAT

The statistical evaluation of spectroscopic data and the preparation of the final input files for the HART module is performed by these programmes. The input parameters in the file **lin.inp** are:

1. Record

'IFAR'	:	Control parameter which activates the routine FAR. Possible values are -1, 0 and 1. If 'IFAR' = -1 only the wing contribution is calculated using a previously created **lin.dat** file. In this case 'NDDD' must be defined. If 'IFAR' = 0 no wing contribution is calculated.
'WNUA'	:	Lower wave number limit for routine FAR.
'WNUB'	:	Upper wave number limit for routine FAR.
'REG1'	:	Wave number limit for routine FAR.
'REG2'	:	Wave number limit for routine FAR.
'REG3'	:	Wave number limit for routine FAR.
'IP'	:	Print status for the system output.

2. Record

'ISV'	:	Control parameter for the wave numbers points where the wing contribution will be calculated. 'ISV' can be 2, 3, 5 or 11 and the corresponding wave number steps are 1, 0.5, 0.25 and 0.1 cm^{-1}.
'ITA'	:	Lower temperature limit for routine FAR.

'ITB' : Upper temperature limit for routine FAR.

'IDT' : Temperature step for routine FAR.

3. Record

'NDDD' : Number of lines contained by **lin.dat**

'IWI' : This vector of seven elements contains the line wing identification codes for the different molecules. 'IWI' must be compatible with 'MOLL'. (Ie. a given element of 'IWI' should refer to the molecule type defined by the same element of 'MOLL'.)

4. Record

'TRLIM' : Lines having larger transmittance at the line center than 'TRLIM' are neglected.

'TRLIMS' : Lines having larger transmittance at the line center than 'TRLIMS' are supplied with a code.

'SRATIO' : If the (line intensity)/(maximum line intensity) ratio in a given wave number interval is less than 'SRATIO' the line is neglected.

'WNU1A' : Lower wave number limit in modules LINE and STAT.

'WNU2B' : Upper wave number limit in modules LINE and STAT.

5. Record

'IOUT' : Control parameter. Possible values are 0 and 1. Files **lin.dat** and **farwg.dat** are not created if 'IOUT'=0.

'IDI' : This parameter defines the wave number step. Possible values are 1, 2, 3 and 4 and the corresponding wave number steps are 1, 3, 5 and 10 cm^{-1}.

'LAA' : This parameter is an option for the STAT subroutine. In case of 'LAA'=0 at each wave number interval and for each molecule type the cumulative number of the spectrum lines is calculated.

'MOLL' : This is a vector of seven elements containing the molecular identification codes.

For each wave number interval defined by 'IDI' the output file **stat.dat** contains the usual statistical information about the line intensity, collisional half width, ground state energy, and also the histograms of the line intensities and line spacings. As an example of the application of the STAT routine we have compared the CO_2 line intensity histograms of the AFGL-82, GEISA-84 and HITRAN-86 data banks. In the 650 - 700 cm^{-1} spectral region with 1 cm^{-1} wave number steps the differences in the line intensity histograms have been plotted in Fig. II-4 and Fig II-5. The line intensity cells are indicated by the position and widths of the curves. (The thickest curve on the left side belongs to the first intensity cell containing the strongest lines.)

The total number of the CO_2 lines contained by the 600 - 800 cm^{-1} spectral region and included in the GEISA-84, AFGL-82 and HITRAN-86 catalogs are 14797, 14433 and 14801 respectively. The summary of the line intensity histograms for the whole region is included in Table II-1. As we can see the large differences are generally concerned to the very weak lines and they have no noticeable effect on the transmittance calculations.

TABLE II-1

Summary of the CO_2 line intensity histograms of the 600- 800 cm^{-1} spectral region. The ranges of the intensity cells are indicated by the tenth power of the intensity limits measured in $(atm\text{-}cm)^{-1}cm^{-1}$.

intensity cells	0,1	-1,0	-2,-1	-3,-2	-4,-3	-5,-4	-6,-5	-7,-6	-8,-7
GEISA-84	57	118	336	688	1487	2541	4040	5331	199
AFGL-82	55	115	332	660	1453	2477	3947	5198	196
HITRAN	57	115	336	684	1488	2544	4036	5342	199

However, there are some very strong lines missing in either the AFGL-82 or the HITRAN-86 catalog which might have serious effect on the accuracy of the calculated high resolution transmittance or radiance spectra. We shall return to this question at the validation of the HARTCODE in chapter III.

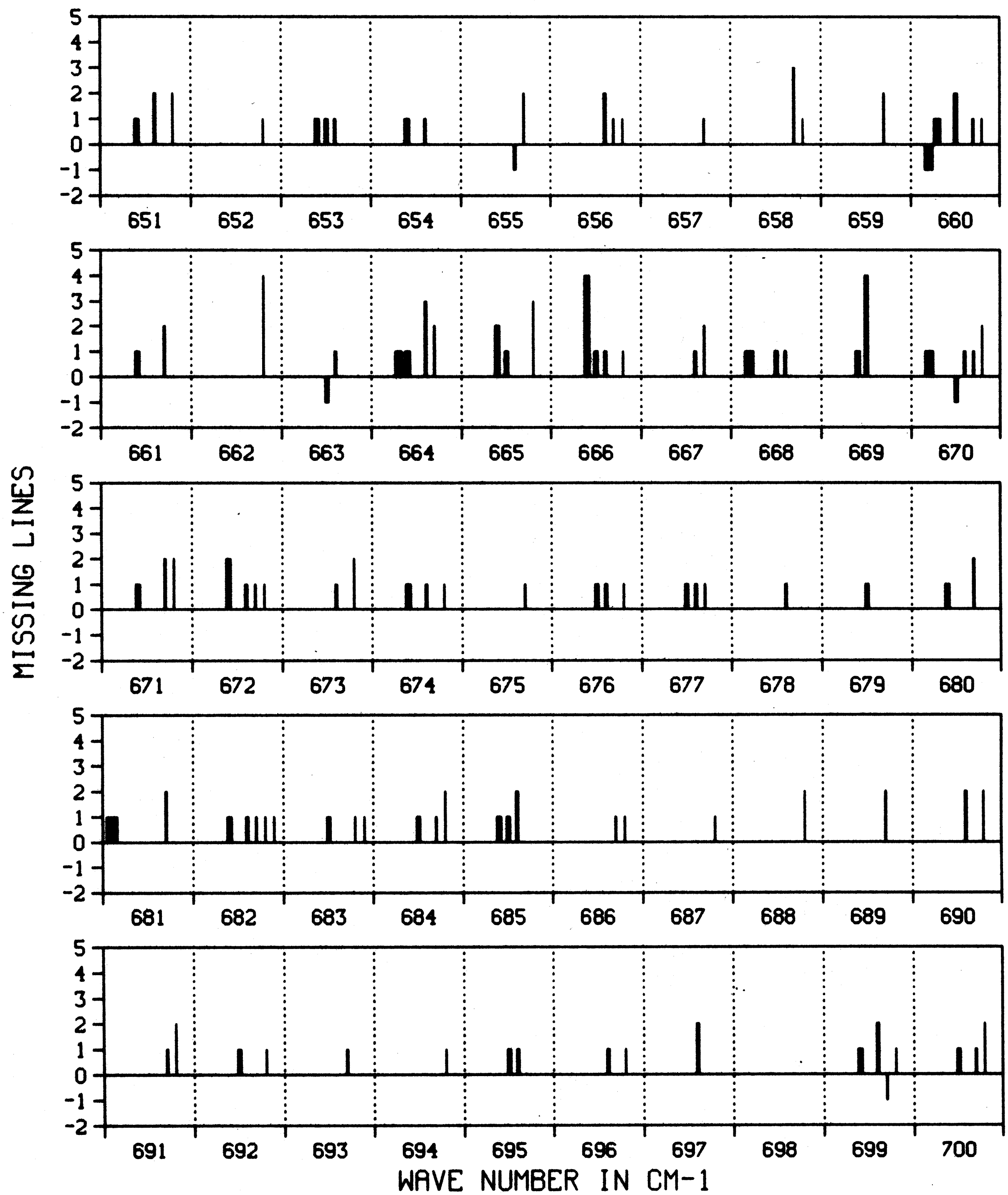

Fig. II-4 : Differences in the CO_2 line intensity histograms in the 650 - 700 cm^{-1} spectral region. Positive numbers on the vertical axes are indicating the number of the "missing" lines in the AFGL-82 data bank and the negative ones are the lines missing in the GEISA-84 catalog. The intensity cell is indicated by the width of the curve (see the text).

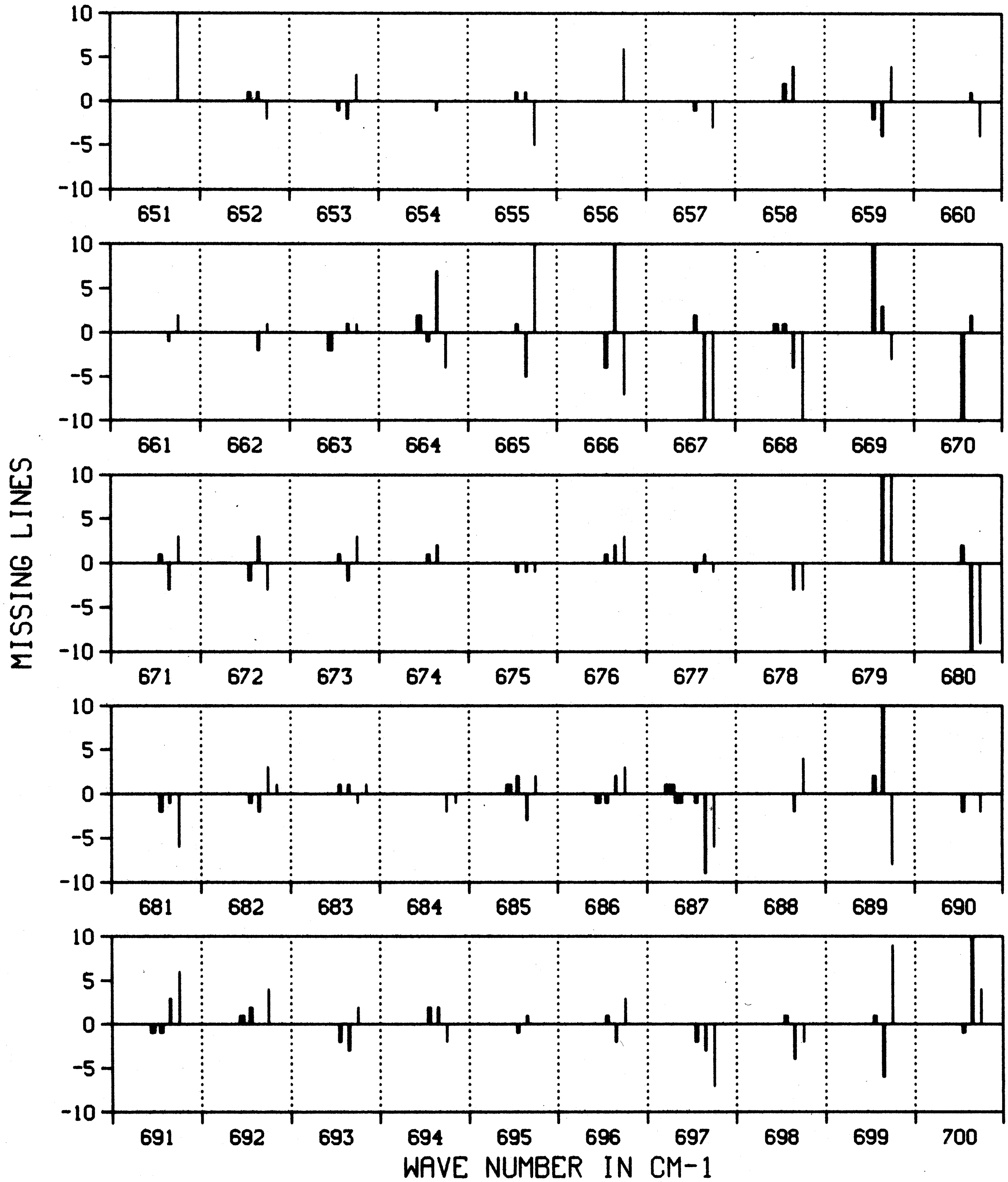

Fig. II-5 : Differences in the CO_2 line intensity histograms in the 650 - 700 cm^{-1} spectral region. Positive numbers on the vertical axes are indicating the number of the "missing" lines in the HITRAN-86 data bank and the negative ones are the lines missing in the GEISA-84 catalog. The intensity cell is indicated by the width of the curve (see the text).

Remarks:

– The number of the different kind of absorber having lines within 'WNU1A' and 'WNU2B' is limited to 7. It is very rare that we have to consider more than seven molecular species within a short wave number interval.

– For atmospheric applications the line intensity limits corresponding to the transmittance limits were determined by using the US Standard Atmosphere 1976 and nadir viewing geometry. For the seven major absorber the absorber amount, effective temperature and pressure are included in Table II-2.

– Table II-2 also contains the line intensity limits for 'TRLIM'=0.99999 .

– The effect of 'SRATIO' on the number of lines within 1 cm^{-1} is presented in Fig. II-6 and in Table II-3. No lines are neglected by setting 'TRLIM'=1, 'TRLIMS'=1 and 'SRATIO'=0.

– At line {85} in module LIN the unit of the line intensity is converted from $(molec./cm^2)^{-1}cm^{-1}$ into $(atm\text{-}cm)^{-1}cm^{-1}$.

TABLE II-2

The total amounts of absorber u^i in atm -cm, effective pressures p_e^i in HPa and the effective temperatures T_e^i in K for the seven major absorber calculated for the US Standard Atmosphere 76 and nadir viewing geometry. Intensity limits S_{lim}^i in $(atm\text{-}cm)^{-1}cm^{-1}$ and calculated for 'TRLIM'=.99999 are also indicated.

i	molecule	u^i	p_e^i	T_e^i	S_{lim}^i
1	H_2O	1768.0	803.0	275.0	0.1479E-7
2	CO_2	263.80	506.0	250.0	0.6553E-7
3	O_3	0.3467	90.30	225.0	0.9380E-5
4	N_2O	0.2453	525.0	251.0	0.7298E-4
5	CH_4	0.0885	599.0	258.0	0.2276E-3
6	CO	1.3170	520.0	251.0	0.1346E-4
7	O_2	1.671E+5	506.0	250.0	0.1035E-9

TABLE II-3

The dependence of the total number of the CO_2 lines in the 600-800 cm^{-1} spectral region on 'SRATIO', ('IDI'=1).

'SRATIO'	0.0	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}
GEISA-84	14797	14170	12229	8886	5798	3215
AFGL-82	14433	13850	12039	8722	5686	3154
HITRAN-86	14801	14160	12201	9003	5847	3242

FAR and WINGS

These two routines are activated by the 'IFAR' parameter. When 'IFAR' is set to 1 or -1 a set of continuum type absorption coefficients are calculated between 'WNUA' and 'WNUB' for each 1 cm^{-1} wave number step. The number of wave number mesh points are controlled by 'ISV'. The absorption coefficients are calculated at each mesh point for the temperature values defined by 'ITA', 'ITB' and 'IDT'. The wave number interval from which the absorption lines are contributing is defined by 'REG2' and 'REG3'. (Only those lines are considered for which 'REG2'$\leq \triangle\nu_k <$'REG3'.) The line shape function can be specified for the different types of molecules by the vector 'IWI'. If the line shape identifier is 0, 1, 2, 3, 4, 5, 6 or 7 the line shape function is given by Eqs. (25), (30), (31), (32), (26), (28), (29), or (27) respectively. (In the program we use the asymptotic form of the above equations for conditions where $\triangle\nu_k >> \alpha_k^i$.)

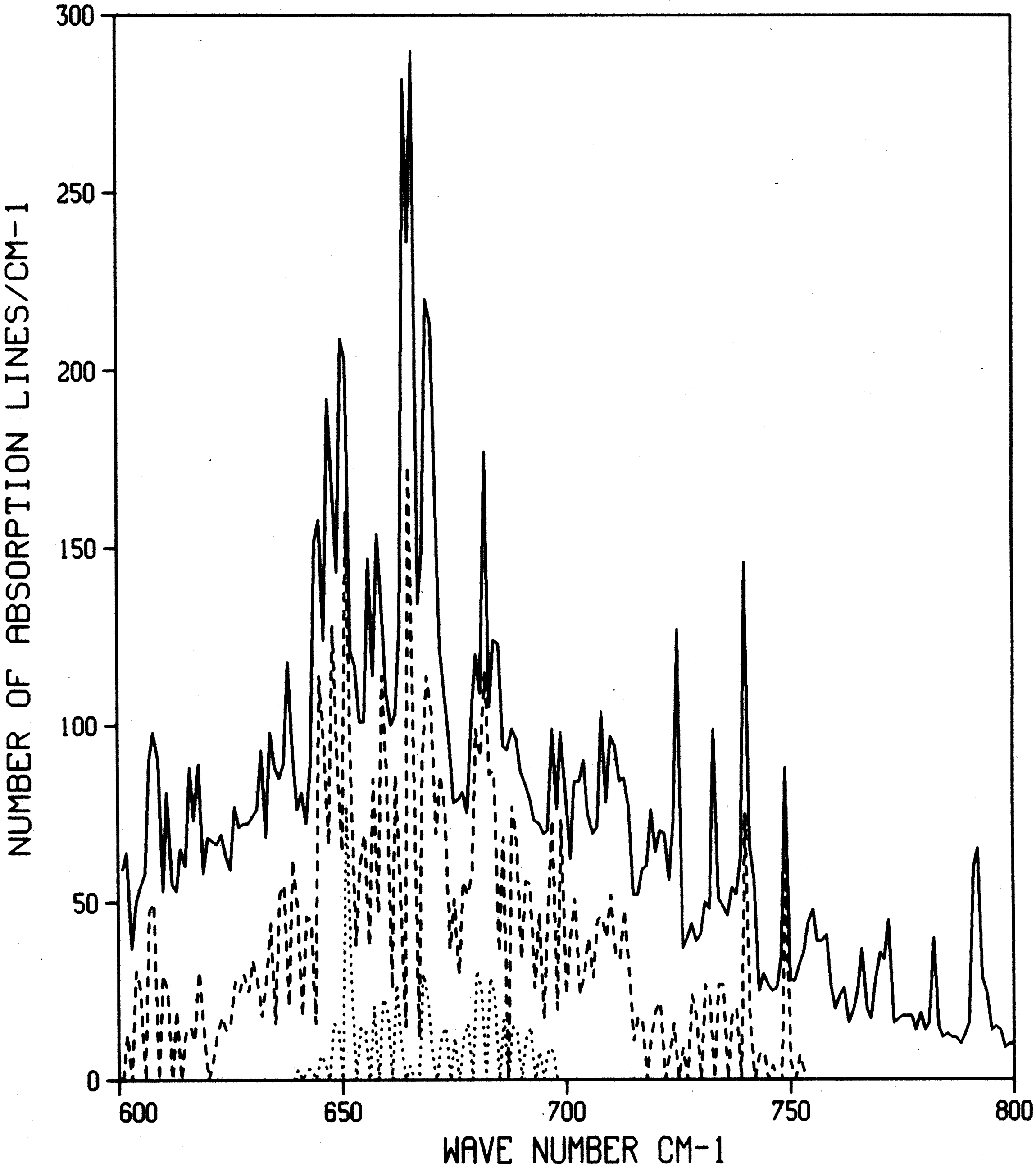

Fig. II-6 : The CO_2 absorption line number distribution in the 600-800 cm^{-1} wave number interval (solid line). The dotted and dashed lines indicate the number of absorption lines to be neglected in case of 'SRATIO'=10^{-6} and 'SRATIO'=10^{-4} respectively.

3. Module HART

This programme - together with its 9 subroutines and 2 function segments - is the kernel of the HARTCODE. There are 16 records in the **hart.inp** file containing the input parameters. Some examples of typical input sequences are given at the end of the list of the HART programme in Appendix D.

As we have mentioned before this version of the HARTCODE were used for numerical testing accordingly the input structure is a little bit complicated but allows us a higher degree of freedom in selecting the proper combination of the input parameters to obtain the required accuracy. (For example the order of the Gaussian quadrature for the calculation of the wave number integral at Eq. (37) is not fixed and even the generation of the wave number mesh points is an option.)

In the next section we summarize the function of each control parameter. When it is necessary the possible values (or functions) are also indicated within the $<$ and $>$ signs.

1. Record

'RESL'	: Wave number resolution, $\delta\nu$ in Eq. (37). 'RESL'$< 0.1,\ 0.05,\ 0.01,\ 0.005 >$
'DELV'	: Wave number step. 'DELV' $>$ 'RESL' and 'DELV'/'RESL'$<$ 200.
'ITRN'	: 'ITRN'$< 1,\ 2 > \rightarrow <$ *optical depth*, *transmittance* $>$.
'IRAD'	: 'IRAD'$< 0,\ 1 > \rightarrow <$ *no radiance*, *radiance* $>$.
'IOTR'	: The file **trao.dat** is created only if 'IOTR'=1 .
'IORD'	: The file **rad.dat** is created only if 'IORD'=1 .
'IOPR'	: The file **prnew.dat** is not created if 'IOPR'= 0 . This file contains the data of the input profiles after layering.

2. Record

'IPRA'- 'IPRH'	: Print status for the system output.

3. Record

'ISBN'	: Control parameter to establish the wave number mesh. 'ISBN'$< 1, 2 > \rightarrow <$ *subdivisions*, *no subdivisions* $>$ If 'ISBN'=2 the gaussian quadrature is applied over $\delta\nu$.
'IGNU'	: Order of gaussian quadrature, 'IGNU'$< 1,\ 2,\ \cdots\ 10 >$. If 'IGNU'=0 the calculation of Eq. (39) are repeated with increasing order of gaussian quadrature until the results of the subsequent iterations satisfy an accuracy limit.

'EPSN' : Accuracy limit for the calculation of Eq. (39).

'ICCH' : Control parameter to change the default values of the pressure and $|\triangle\nu|$ limits for the line shape calculations.

'PDLR' : Pressure limit for the Doppler line shape in HPa.

'PLNZ' : Pressure limit for the Lorentz line shape in HPa.

'VDLR' : Wave number limit for the Doppler line shape in cm^{-1}.

'VLNZ' : Wave number limit for the Lorentz line shape in cm^{-1}.

4. Record

'IINT' : Control parameter to establish a limit for $|\triangle\nu_k|$ as the function of the pressure.

'AINT' : Scale factor. At a given pressure and $|\triangle\nu_k|$ only those lines are considered which satisfy the next condition:

$|\triangle\nu_k| \leq$ REG1·VPR$^{\rm AINT}$+REG2(1- VPR$^{\rm AINT}$),

where VPR is the Voigt parameter, 'REG1' and 'REG2' are wave number limits. If 'IINT'=0 the above condition is ignored.

'IVPF' : If 'IVPF' =1 the vibrational partition functions are computed.

'IRPF' : If 'IRPF' =1 the rotational partition functions are computed.

'KSHP' : If 'KSHP'=0 the line shape function is controlled (uniformly for each molecular type) by 'PDLR', 'PLNZ', 'VDLR' and 'VLNZ'. If 'KSHP'=1 the line shape function is controlled by 'LMOD'.

'IVDY' : Determines the method of the calculation of the Voigt function. 'IVDY'$< 0, 1 > \rightarrow < Drayson's\ method,\ Young's\ method >$

5. Record

'MODL' : Number of molecule types for which different line shape functions will be used.

'IDEN' : Molecular ID. code.
'LMOD' : Line shape code.

6. Record

'MODA' : Number of molecule types for which the collisional half width will be modified.

'IDEN' : Molecular ID. code.
'AMOD' : Modifying factor.

7. Record

'MODS' : Parameter to change the line intensities, $S^i_{k,j}(T_o)$.

'IDEN' : Molecular ID. code.

'SMOD' : Vector of seven element containing the modifying factors.

8. Record

'MODR' : Number of molecule types for which the line wing cut-off parameter will be modified.

'IDEN' : Molecular ID. code.

'RMOD' : Modifying factor.

9. Record

'WNU1' : Lower wave number limit, cm^{-1}.

'WNU2' : Upper wave number limit, cm^{-1}.

'REG0' : Wave number limit for the weak lines. If $|\triangle\nu_k|$ for a given weak line is greater than 'REG0' the contribution of the line is neglected.

'REG1' : If $|\triangle\nu_k|$ <'REG1' the line is considered without any condition.

'REG2' : If 'REG1'< $|\triangle\nu_k|$ <'REG2' the consideration of the line will depend on the actual pressure (ie. on the Voigt parameter).
If $|\triangle\nu_k|$ >'REG2' the contribution is treated as far wing absorption.

10. Record

'IPSC' : Control parameter to identify the type of the calculation.
If 'IPSC'=0 HART evaluates laboratory measurements.
If 'IPSC'=1, 2 or 3 HART performs test calculations.
If 'IPSC'=4 HART performs the calculations for model atmospheres.

'IHOM' : Option for homogeneous atmosphere (with effective pressure, temperature and total optical mass).

'IARM' : Molecular ID. for air mass calculations.

'ASCL' : Controls the layering with respect the altitude.
If 'ASCL' < 0 exponential layering,
if 'ASCL' > 0 polynomial layering.

11. Record

'IPOF' : Atmospheric model identifier. In a separate data file (**modatm.dat**) the Lowtran Model Atmospheres are available.
'IPOF' = 0 User defined profil.
'IPOF' = 1, 2, 3, 4, 5 or 6 Standard Lowtran 6 Profiles:

1 : Tropical
2 : Midlatitude Summer
3 : Midlatitude Winter
4 : Subarctic Summer
5 : Subarctic Winter
6 : USST 76

'LVEL' : Number of levels of the input profile (ie. the number of the input records in the files **profil.dat** or **modatm.dat**).

'NBND' : Number of molecular species involved in the calculations.
'MOLE' : Vector of seven element containing the molecular ID codes.

12. Record

'LVL1' : Serial number of the first level where the calculation starts.

'LVL2' : Serial number of the last level.

'TSKN' : Temperature at the boundary in K.
If 'TSKN' $>$ 0 the skin temperature equal to 'TSKN'.
If 'TSKN' $=$ 0 the radiative contribution of the ground (or the boundary layer) is ignored.

'EMIS' : Emissivity of the boundary layer.

13. Record

'IDIR' : Direction of the beam.
'IDIR' $< 1,\ 0,\ -1 > \rightarrow < upward,\ horizontal,\ downward >$
In case of horizontal direction only short path is considered.

'TETA' : Zenith angle.(In case of air mass calculations the initial zenith angle.)

'TETB' : Last zenith angle.

'DTET' : Zenith angle step. If 'DTET' not equal to zero the program stops at the air mass calculations.

14. Record

'LVEN' : Number of the layers between 'ALT1' and 'ALT2'.

'ALT1' : Upper altitude of the trajectory.

'ALT2' : Lower altitude of the trajectory.

'PATH' : Length of the trajectory in km ('IDIR'=0) .

15. Record

'MODU' : Number of the mixing ratio profiles to be modified.

'IDEN' : Molecular ID.

'UMOD' : Modifying factor.

16. Record

'ILIN' : Selects the source of the spectral input data.
If 'ILIN'=1 the spectral parameters are internally generated.
If 'ILIN'=2 the spectral input data are in the **lin.dat** file.

'ILIM' : Maximum number of the spectrum lines in the **lin.dat** file.

'ICON' : If 'ICON'=1 the H_2O continuum absorption is computed.

'IFAR' : If 'IFAR'=1 the far wing absorption is computed.

'JREF' : If 'JREF'=1 the refraction is computed.

When HART is evaluating laboratory measurements ('IPSC'=0) the input structure is different from the 10th record. In this case the 10th record contains an integer qualifier which specifies the number of data sets (or the number of the records to be read). The 11th and the subsequent records contains the pressure (HPa), temperature (K), molecular ID. and optical mass (*atm-cm*) as they are specified in the experiment. The last record will be equivalent with 16th record, ('ILIN' must be equal to 2).

When HART is performing test calculations for selected pressure and temperature ranges ('IPSC'=1, 2 or 3) the 11th record specifies the minimum, maximum and the step of the pressure and temperature. In this case the pressure scale is defined by 'IPSC':

'IPPS'$< 1,\ 2,\ 3 > \rightarrow <$ *linear*, *log*, *log-lin* $>$.

The 12th record contains the number of different kind of absorber, the molecular IDs and the optical masses. The 13th record will be equal to the 16th record.

If one wants to use simulated spectral data 'ILIN' should be set to 1. In this case after the last record the band parameters should be specified by the total number of the lines, central wave number of the band, width of the band, relative position, average line intensity, and ground state energy for each band in separate records.

LAYERS and MINT

These two routines perform the calculation of the relative optical air masses for each layer. The result of the operation is the value of μ_m^* contained by the 'BMU' vector. (See lines {84} and {172} in module LAYERS.) Depending on the viewing geometry these modules are also calculating the next quantities: tangent height, local zenith angles at each level, total geometrical path length of the trajectory and the angular deflection of the beam. MINIT is an auxiliary routine determining the profile-variables by polynomial interpolation or using exponential scale factors.

LENGTH and MESH

If 'ISBN'= 1 LENGTH and MESH set up a system of wave number mesh points within $\delta\nu$. The wave number mesh points are generated at increasing distances from the line centers . The position of the mesh points are depending on the wave number and actually determined by a simple linear transformation using the average doppler half-width. It might happen that the minimum pressure in the input data is still in the Lorentzian range then it worth to apply another transformation to the subpoints with respect the average voigt parameter . For example subpoints 0.001, 0.0015, 0.0025, 0.005, 0.01, 0.025, 0.05, 0.1, 0.25, 0.5, 1.0, 2.5 and 5.0 cm^{-1} are valid for the CO_2 at 250 K and 700 cm^{-1} when α_D is about 0.0006 cm^{-1}. For a given wave number the generated subpoints are stored in the 'AGA' vector.

CONT and FARWG

The actual contribution of the H_2O continuum and the far wing absorption to the monochromatic absorption coefficient is calculated by the above routines using the data files **cont.dat** and **farwg.dat**. The continuum absorption coefficient of a layer is evaluated by Eqs. (19) and (20) at each 1 cm^{-1} wave number interval applying parabolic interpolation over the data given in Table I.2, see lines {34} and {44} in module CONT. To obtain the far wing contribution to the total optical depth also interpolation is applied over both the wave number and temperature intervals in subroutine FARWG . Having 11 wave number mesh point in 1 cm^{-1} and ten temperature values between 140 and 320 K with 20 K steps a simple linear interpolation is sufficient. According to test runs line files created with 'SRATIO'= 10^{-2} or 'SRATIO'= 10^{-3} give satisfactory results. The far wing contribution to the total monochromatic optical depth is recalculated at each new $\delta\nu$ wave number interval and is taken into account in the routine GAUSS at line {52}. If the 'ICON' and 'IFAR' qualifiers are not equal to 1 no continuum and far wing contribution is calculated.

GAUSS

This unit performs the wave number integration over the subinterval given by the 'AGA' vector. The order of the gaussian quadrature is defined by 'IGNU'. The vector 'OUTSS' contains the monochromatic optical depth or transmittance belonging to a given gauss abscissa. The dimension of this vector should be equal to the dimension of 'AGA' times 'IGNU' accordingly this is the largest block in the program having 14000 elements.

SHAPE, VOIGT and WING

In the SHAPE module the Lorentz, Doppler and Voigt line shapes are calculated. In case of 'IVDY'=0 the Voigt function is computed by Drayson's subroutine in the VOIGTD module. If 'IDVY'=1 the more accurate (but considerably slower) method of Young is used in module VOIGTY. If in the vector 'LMOD' different line shape is specified the routine WING is activated. When 'IFAR'=1 the vector 'IVI' should be compatible with 'LMOD' (ie. once for a particular molecule the line shape is selected then the far wing contribution should be calculated using the same line shape). The program WING and WINGS are similar, they contain the same line shape functions, Eqs. (25), - (32), except that in the WING routine we do not apply any approximations concerning to the dependence on the distances from the line centers.

4. Post-processing of the Results

These last three programmes are not strictly belonging to the HARTCODE although all the results presented in the next chapter were obtained by applying them. For a particular post-processing of the data contained by the basic result files (**trao.dat** and **rad.dat**) the users can shape their own programmes according to their own needs.

SMTH

If we are interested in a wider spectral range the SMTH routine may be used. This is applying a rectangular or triangular response function for smoothing the data contained by either the **trao.dat** or the **rad.dat** file. The output file **smth.dat** contains the wave number dependence of the smoothed optical depth (absorption coefficient), transmittance or radiance and is ready to use for making graphs.

CHNL and GSC

This program evaluates the channel transmittance and radiance or calculates the weighting functions, (Eqs. (6) and (12)) using the **trao.dat** input file which contains the average transmittance given by Eq. (37). (The **profil.dat** file must be the same than the one was used in the HART program.) Module GSC has similar function than GAUSS has in the HART programme. The output files **twchn.dat** and **rchn.dat** are prepared for immediate use in the plotting routines. They contain the pressure dependence of the channel transmittance and weighting functions or the radiative contributions of the layers.

COMP

This program is designed to make easy comparisons between the calculated and measured radiance. File **hcom.dat** contains the measured data pairs (ie. wave number and radiance in free format). The output file **scom.dat** contains the usual statistical information (average, standard deviation ect.) and **comp.dat** is a file for a plotting program.

III. VALIDATION OF THE HARTCODE

1. Homogeneous Transmittance Calculations

When the functional testing of the individual modules were completed and the HARTCODE as a system of several programme units were running we have conducted extended accuracy and sensitivity tests. Unfortunately, it is impossible to reproduce the detailed results of the early testing procedures within this report. The original aim that the numerical accuracy should be sufficient to evaluate the most recent spectral radiance measurements was achieved. In this chapter joining to the ITRA first experiment we compare the calculated and measured homogeneous CO_2 transmittance spectra. The experimental conditions of the selected spectra are summarized in Table III-1. In case of Gryvnak's measurements only the numerical values of the dependence of the equivalent width on the wave number was available while in Bulanin's case we could compare the direct transmittance spectra.

TABLE III-1

Two set of selected CO_2 transmittance spectra for homogeneous calculations, after *Chedin*[3]. ID is the identification number of the data set, T is the temperature in K, l is the path length in cm, r_v is the volume mixing ratio, p is the pressure in atm and u is the absorber amount in $molec./cm^2$.

Gryvnak's measurements					
ID	T	l	r_v	p	u
1	310	3291	0.0385	0.123684	3.712E+20
2	274	1648	0.005	0.25	5.521E+19
3	274	826	0.00125	0.5	1.384E+19
4	244	3291	0.153	0.059737	9.053E+20
5	245	1648	0.00125	0.25	1.544E+19
Bulanin's measurements					
ID	T	l	r_v	p	u
6	213	497	0.01	0.198	3.393E+19
7	253	1470	0.01	0.502	2.142E+20
8	293	4874	0.01	1.003	1.225E+21
9	213	4874	0.01	1.003	1.685E+21
10	293	4874	0.01	0.01	1.222E+19

To obtain the synthetic spectra the HARTCODE transmittance were calculated with 0.05 cm^{-1} resolution (using the Voigt line shape and four point gaussian quadrature for the wave number integration) and smoothed according to the proper instrumental response functions. For the first set of measurements we used a simple triangular response function with a half width ($\Delta\nu_i$) given by the next equation:

$$\Delta\nu_i = 1.2 + (\nu_i - 500)0.008,$$

where ν_i is the wave number in cm^{-1}. The equivalent width as a function of the wave number is :

$$A(\nu_n) = \sum_{i=1}^{n} \xi_{\overline{\nu_i}} \delta\nu,$$

where $\delta\nu$ is the resolution and ξ is the spectral absorptance from Eq. (38).

For the second set we applied a Gaussian-type response function with variable half width:

$$\Phi_{\nu_i}(\nu) = \frac{1.439}{\Delta\nu_i} exp\Big[- \Big(\frac{0.832(\nu - \nu_i)}{\Delta\nu_i} \Big)^2 \Big],$$

where $\Delta\nu_i = 0.00537\nu_i - 1.64$ if $\nu_i < 637$ cm^{-1} and $\Delta\nu_i = 0.00402\nu_i - 1.345$ if $\nu_i > 637$ cm^{-1}. In this case the averaging interval was $6\Delta\nu_i$.

The numerical accuracy of the computed transmittance were better than six significant figures and we did not apply any kind of preselection to the original spectroscopic data. Using the GEISA-84 database the calculations were repeated for several line wing cut-off conditions.

In Fig. III-1 the computed synthetic spectra are presented for the first data set. The line wing cut-off parameter was set to 3.5 cm^{-1} (solid lines), and 25 cm^{-1} (dashed lines). Only very slight changes in the transmittance were observed in the vicinity of the centre of the Q branch. When the pressure is low (curves 1 and 4) the effect is smaller. Applying exponential line wings - Eqs. (30), (31), and (32) - the effect disappears.

In Fig. III-2 for the same data set the equivalent widths are compared. The solid lines are the measurements. The dashed and dotted lines were obtained with 3.5 cm^{-1} and 25 cm^{-1} wing cut-off parameter subsequently. In case of weak absorption - curves 2, 3 and 5 - the agreement with the measurements is good and similar results were obtained by the ITRA participants[35]. In case of stronger absorption - curve 1 and 4 - because of the magnitude and opposite tendency the deviations can not be explained by different line shapes or line wing cut-off parameters. Most probably the real reason is the improper temperature dependence of the line intensity and line half width.

In Fig. III-3 the transmittance spectra are compared with the second set of measurements. The solid lines and the dashed lines are the synthetic spectra using 3.5 and 25 cm^{-1} wing cut-off parameters subsequently and the symbols are the measured values. These results again suggest the same conclusion ie. no manipulation with the line shape and line wing can compensate the discrepancies at 600-620 and 720-740 cm^{-1}.

In Fig. III-4 the synthetic spectra obtained by using the GEISA-84 (solid line) and HITRAN-86 (dashed line) database and the second set of measurements are compared. The symbols indicate the measured values. The significant differences in the two database - especially in the two problematic spectral interval - are obvious. In general using the HITRAN-86 database at longer wave length the absorption is always larger while on the other side of the band around 720 cm^{-1} the absorption is always less. Under certain experimental (curve 8) condition this difference improves the agreement with the experimental data while at low temperature measurement (curve 9) the discrepancies around 720 cm^{-1} are increased.

In Fig. III-5 a high resolution transmittance spectra calculated for the second set of measurements are presented. In this case the resolution is 0.5 cm^{-1} with triangular slit function. To identify the reasons of the above mentioned deviations and to apply proper corrections to the spectroscopic data bases further comparisons are needed with experimental data obtained at least with this spectral resolution.

In Fig. III-6 the effect of the pre-selection of the spectroscopic data are presented. Using the GEISA-84 catalog and 'SRATIO'= 10^{-5} the differences in the transmittance spectra are compared for measurements 8 and 9. The results clearly indicate that - although there is a considerable gain in computing time - when working with high resolution laboratory measurements no this kind of pre-selection is allowed.

Concerning the homogeneous calculations our opinion is that the ITRA exercises should continue with continuous improvement of the data banks until satisfactory agreement with the experimental spectra is achieved.

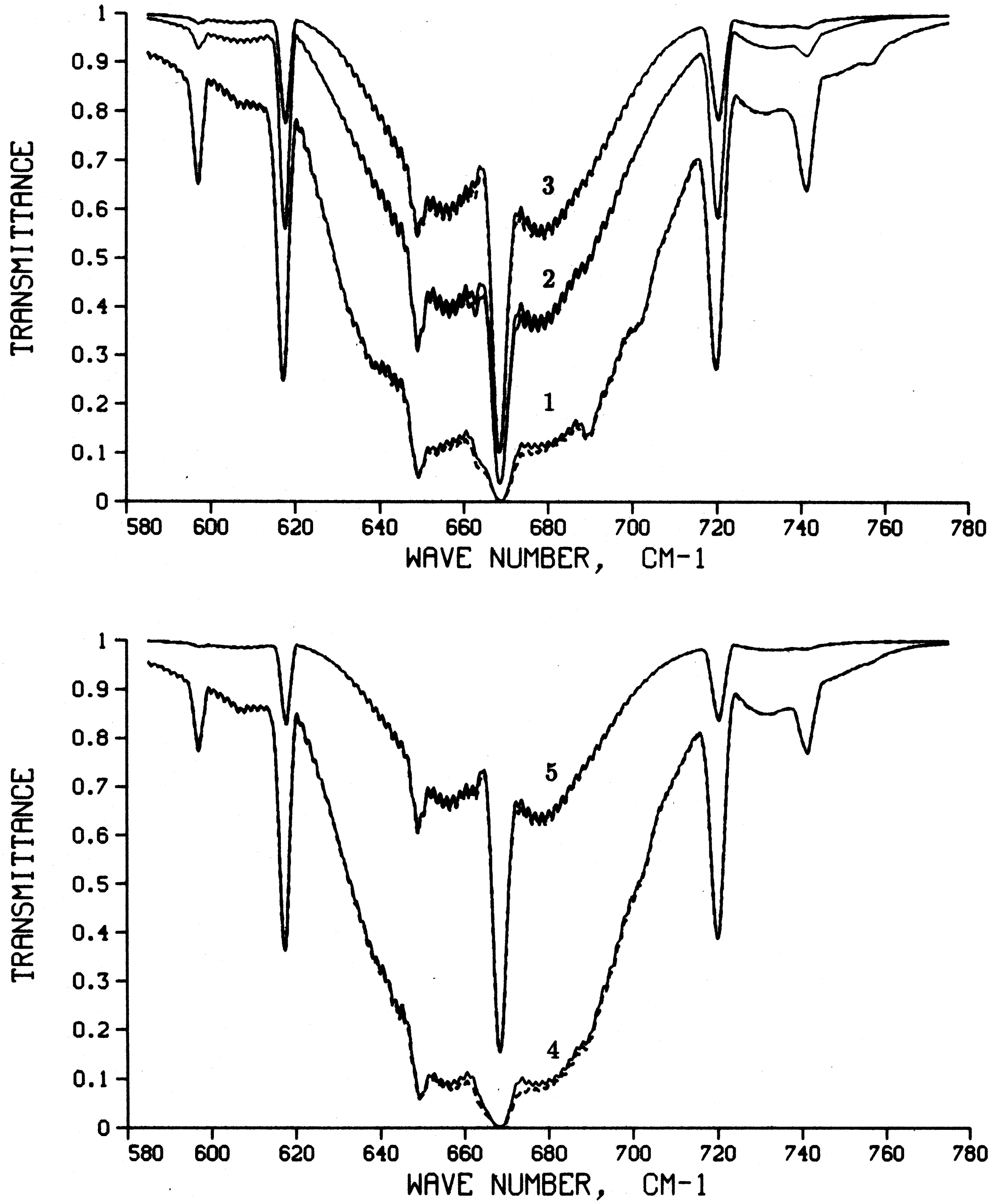

Fig. III-1 : Synthetic transmittance spectra for Gryvnak's measurements. The numbers are the identifiers for the experiment, see Table III-1. Solid lines: 3.5 cm^{-1} wing cut-off, dashed lines 25 cm^{-1} wing cut-off.

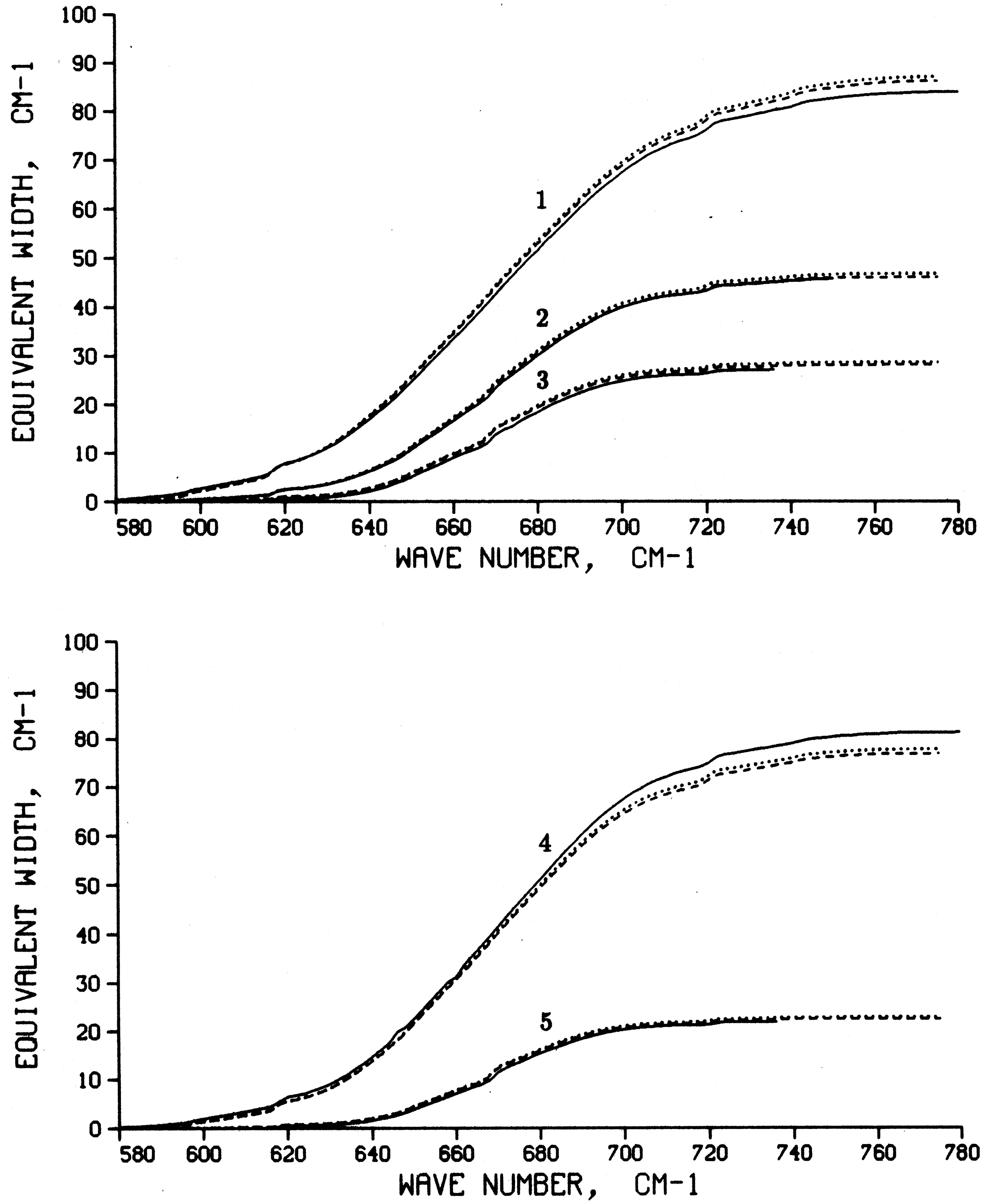

Fig. III-2 : Equivalent widths vs. wave number for Gryvnak's measurements. The numbers are the identifiers for the experiment, see Table III-1. Solid lines: measurements, dashed lines : 3.5 cm^{-1} wing cut-off, dotted lines : 25 cm^{-1} wing cut-off.

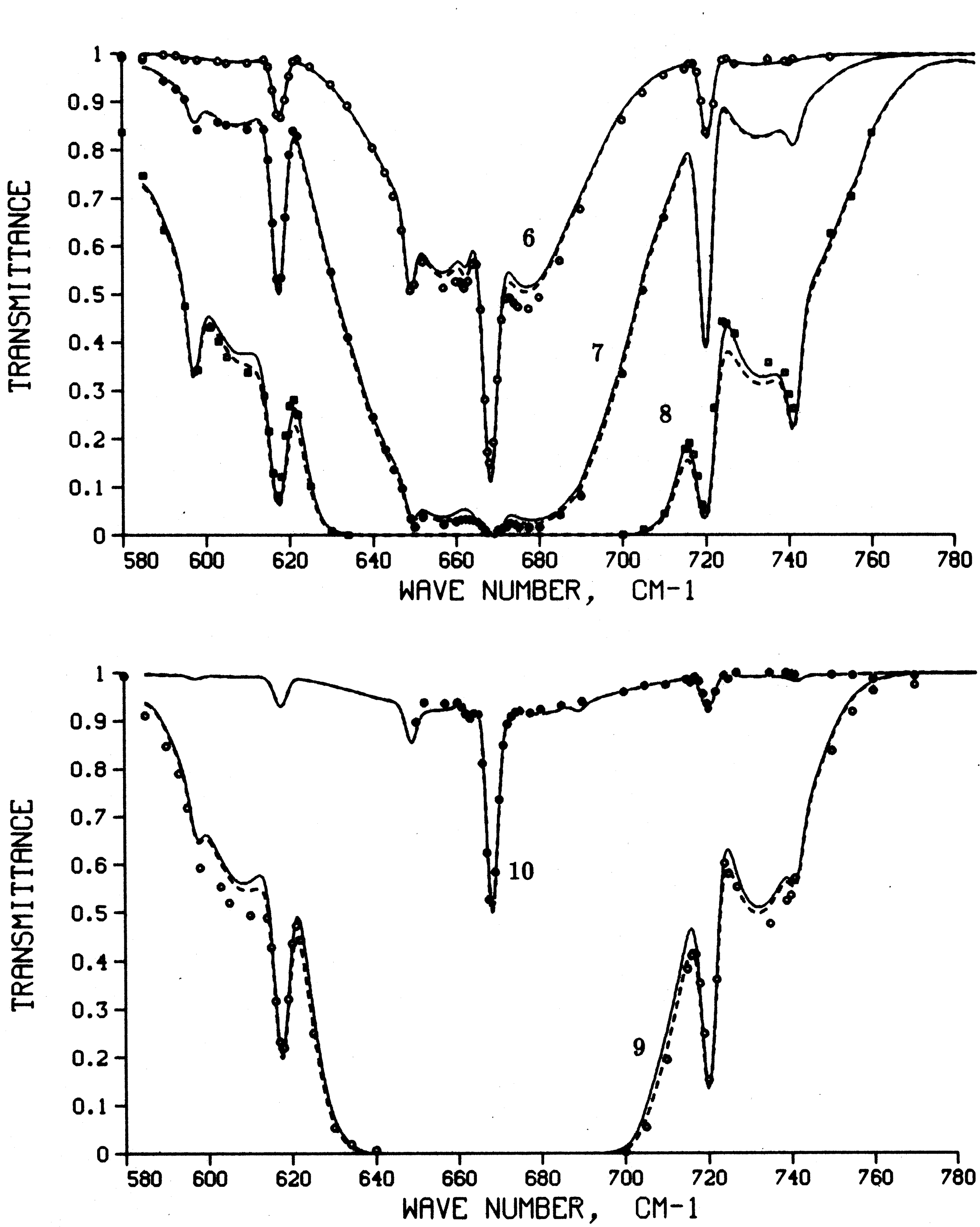

Fig. III-3 : Synthetic transmittance spectra for Bulanin's measurements. The numbers are the identifiers for the experiment, see Table III-1. Symbols : measured values, solid lines : 3.5 cm^{-1} wing cut-off, dashed lines : 25 cm^{-1} wing cut-off.

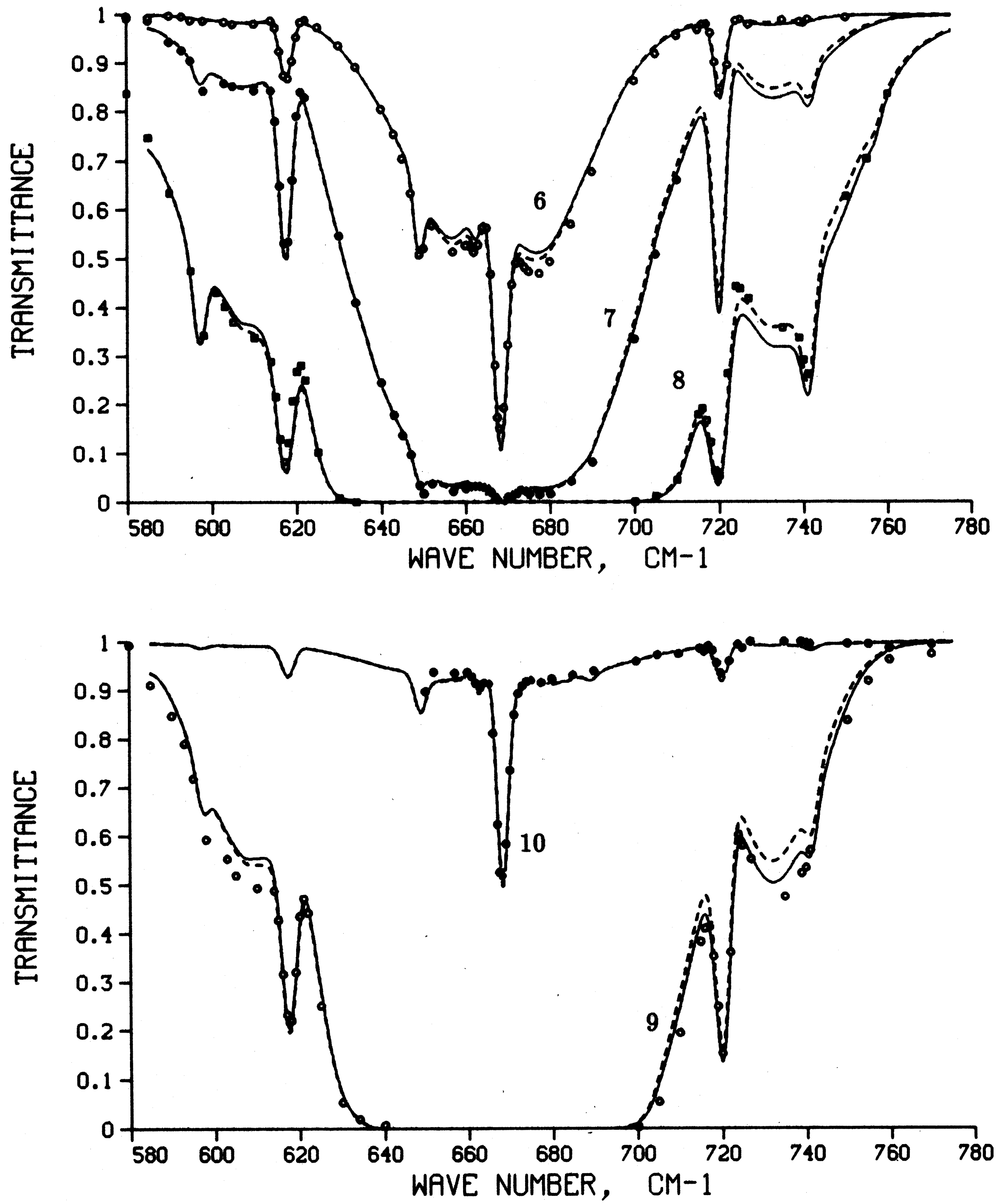

Fig. III-4 : Synthetic transmittance spectra for Bulanin's measurements. The numbers are the identifiers for the experiment, see Table III-1. The line wing cut-off parameter is 25 cm^{-1}. Symbols : measured values, solid lines : GEISA-84 database, dashed lines : HITRAN-86 database.

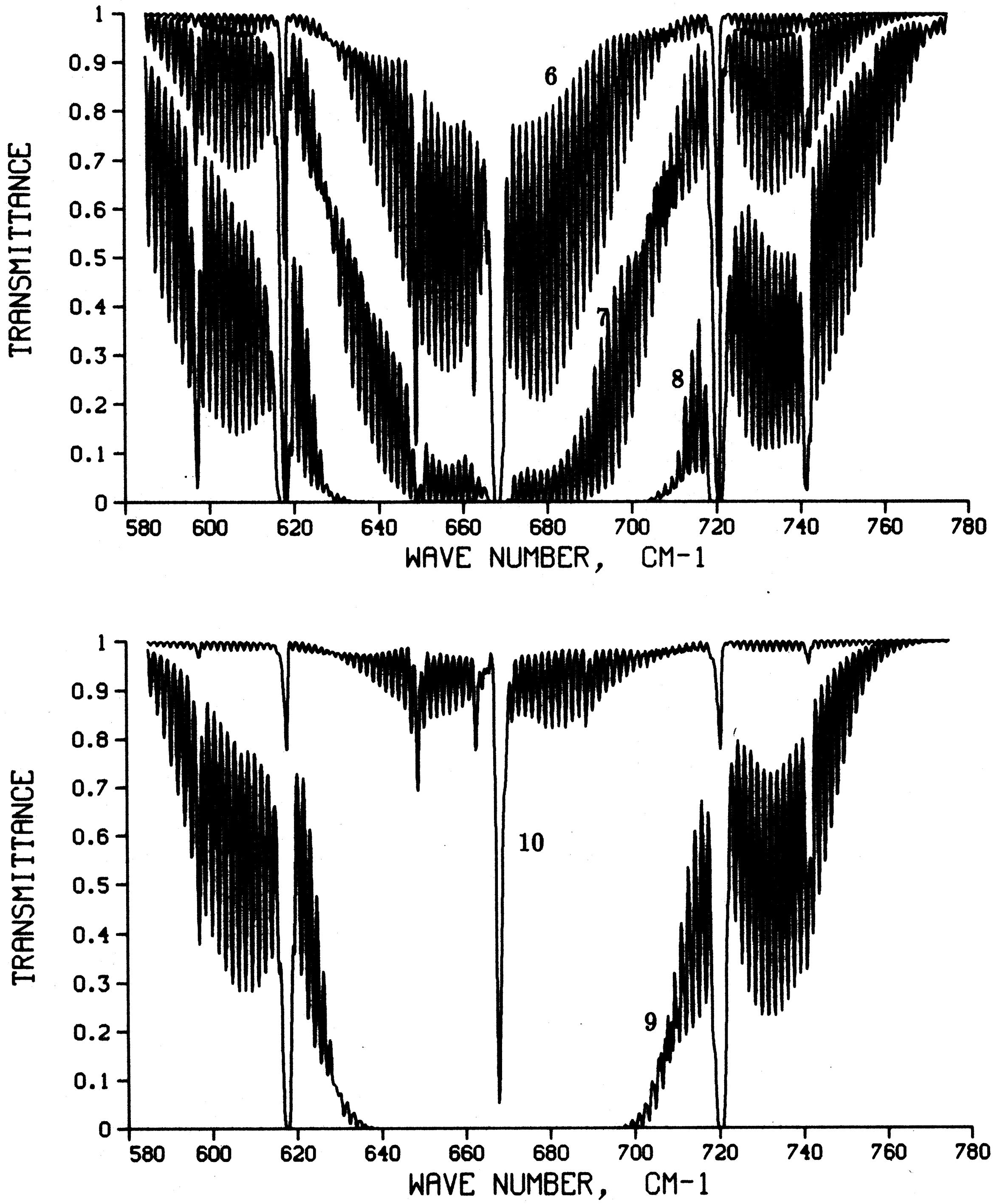

Fig. III-5 : Synthetic high resolution transmittance spectra for Bulanin's measurements. The numbers are the identifiers for the experiment, see Table III-1. The line wing cut-off parameter is 25 cm^{-1}. Triangular slit function with 0.5 cm^{-1} half width.

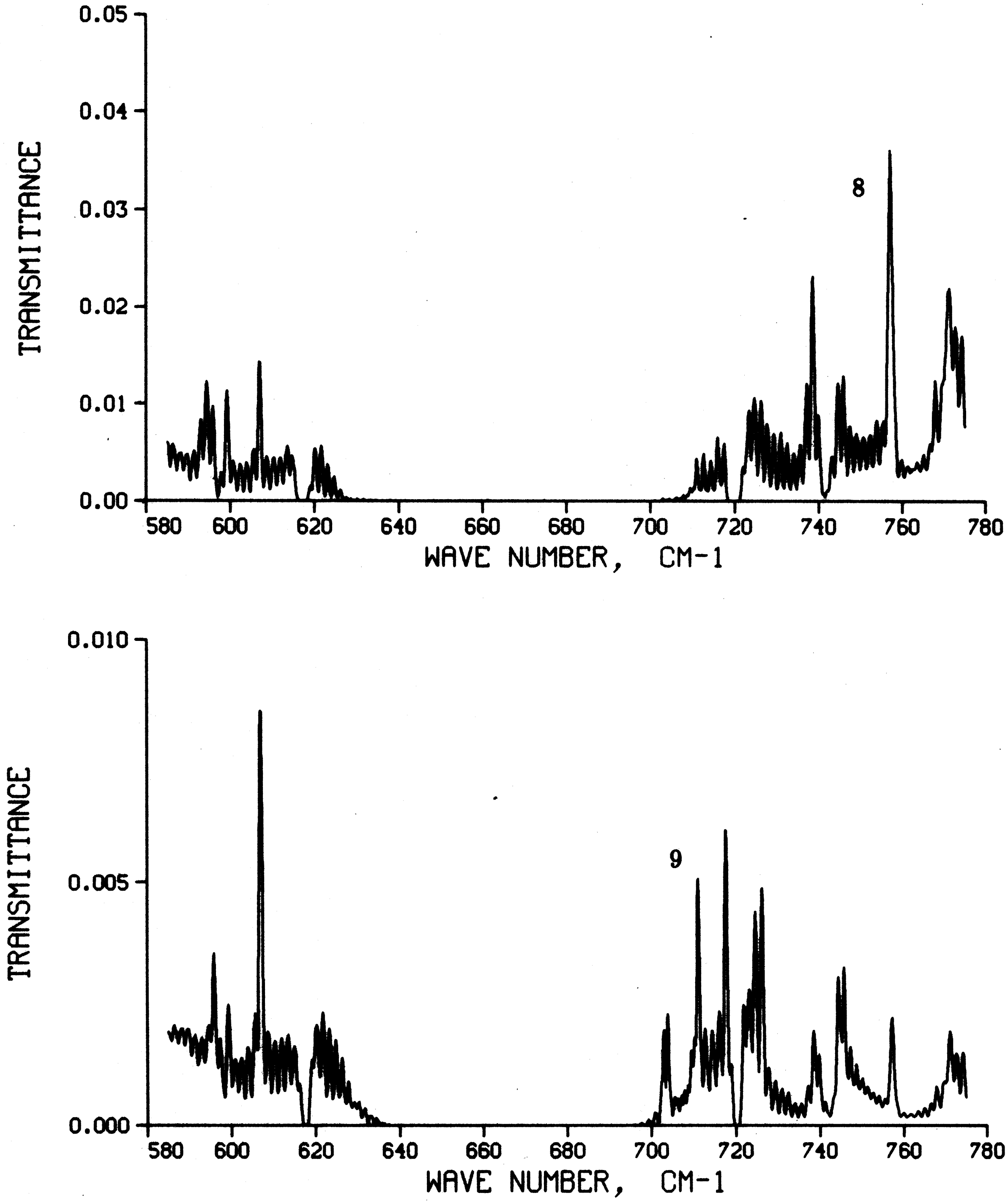

Fig. III-6 : Effect of neglecting the weak absorption lines on the transmittance. Solid lines : differences in the high resolution synthetic spectra when 'SRATIO'=0 and 'SRATIO'= 10^{-5}. The numbers are the identifiers for the experiment, see Table III-1. The line wing cut-off parameter is 25 cm^{-1}. Triangular slit function with 0.5 cm^{-1} half width.

In this chapter, joining to the second ITRA exercise, the channel transmittance, weighting functions and radiance calculated for the USST 76 Atmosphere and for the seven HIRS/2 channels are compared. Unfortunately in the ITRA report the documentation of the codes of the ITRA participants were not complete and it was difficult to trace back the real reasons of some differences in the results. Moreover, there were no conclusions about the numerical accuracies of the codes. Therefore, instead of comparing the HARTCODE results with the results of the individual codes we made comparisons with the average ITRA results.

TABLE III-2

Average CO2 transmittance calculated for the seven HIRS/2 channels by the ITRA participants, *Spänkuch*[4]. (*USST*-76 atmosphere and nadir viewing.) P is the pressure in HPa and ν_i is the central wave number of the i-th channel in cm^{-1}.

P	ν_1 668	ν_2 679	ν_3 691	ν_4 704	ν_5 716	ν_6 732	ν_7 748
0.1	.9700	.9963	.9974	.9985	.9986	.9996	.9999
0.3	.9401	.9923	.9945	.9967	.9967	.9983	.9992
0.5	.9156	.9888	.9919	.9955	.9956	.9976	.9987
0.7	.8921	.9856	.9892	.9940	.9945	.9968	.9985
1.0	.8613	.9810	.9860	.9926	.9930	.9964	.9982
3.0	.6933	.9522	.9656	.9832	.9859	.9925	.9961
5.0	.5949	.9253	.9477	.9758	.9804	.9895	.9948
7.0	.5314	.8984	.9307	.9687	.9747	.9863	.9933
10.0	.4582	.8567	.9048	.9567	.9663	.9815	.9915
20.0	.3098	.7337	.8266	.9279	.9429	.9686	.9863
30.0	.2169	.6253	.7546	.8929	.9218	.9570	.9813
50.0	.1128	.4477	.6267	.8338	.8853	.9361	.9720
70.0	.0550	.3147	.5171	.7791	.8530	.9170	.9632
100.0	.0192	.1762	.3818	.7014	.8083	.8893	.9498
150.0	.0028	.0564	.2246	.5855	.7387	.8452	.9270
200.0	.0002	.0138	.1303	.4862	.6739	.8020	.9062
250.0	.0000	.0022	.0760	.4038	.6150	.7610	.8820
300.0	.0000	.0003	.0429	.3283	.5532	.7165	.8562
400.0	.0000	.0000	.0122	.2041	.4295	.6198	.7941
500.0	.0000	.0000	.0029	.1204	.3216	.5221	.7256
700.0	.0000	.0000	.0001	.0386	.1675	.3436	.5841
850.0	.0000	.0000	.0000	.0161	.0990	.2361	.4856
1000.0	.0000	.0000	.0000	.0068	.0568	.1535	.3966

The average ITRA transmittance data set which was also used for the calculation of the weighting functions is reproduced in Table III-2, after *Spänkuch*[4]. The averages were calculated from the results of the following three groups: Meteorological Research Institute, Japan; Infrared Physics Branch, Optical Physics Division AFGL, USA; Laboratoire de Meteorologie Dynamique du CNRS, France.

To identify the reasons of the large differences between the results of the individual codes several HARTCODE simulations were performed with the most different line shape and line wing cut-off conditions. It turned out that not even significant changes in the parameters above can produce an effect of the magnitude of the differences observed.

In Fig. III-7 and III-8 the ITRA-averages (dashed lines) and HARTCODE (solid lines) transmittance and weighting functions computed for the selected HIRS/2 channels are compared subsequently. For this comparisons we used the GEISA-84 data (no pre-selection was applied), Voigt line shape, 6.5 cm^{-1} wing cut-off, 0.01 cm^{-1} spectral resolution, USST 76 Standard Atmosphere with the original layering and nadir viewing . As it can be seen the general agreement is good. The differences between the HARTCODE results and the ITRA-averages are less than the differences between the results of the individual ITRA codes . The channel radiance are compared in Table III-3.

TABLE III-3

Comparisons of channel radiance computed for the USST 76 Standard Atmosphere by the ITRA participants and by the HARTCODE. The radiance are in $mW/(m^2 sr\ cm^{-1})$. ν_i is the central wave of the HIRS/2 channels, $\overline{ITRA}$ is the average radiance obtained by the ITRA participants, $\triangle R_I$ and $\triangle R_H$ are the maximum differences between the ITRA results and the differences between the ITRA average and the HARTCODE results subsequently, R, R_1 and R_2 are the HARTCODE radiance obtained by using an accurate numerical integration, Eq. (46) and Eq. (49) subsequently.

ν_i	$\overline{ITRA}$	$\triangle R_I$	$\triangle R_H$	R	R_1	R_2
668	62.502	2.10	0.03	62.528	62.642	62.452
679	47.342	1.17	0.19	47.149	47.211	47.202
691	45.575	0.72	0.36	45.217	45.226	45.253
704	52.985	0.61	0.28	52.702	52.600	52.692
716	65.388	1.08	0.51	64.877	64.741	64.823
732	77.527	0.78	0.41	77.118	76.995	77.045
748	93.032	0.95	0.29	93.331	93.245	93.267

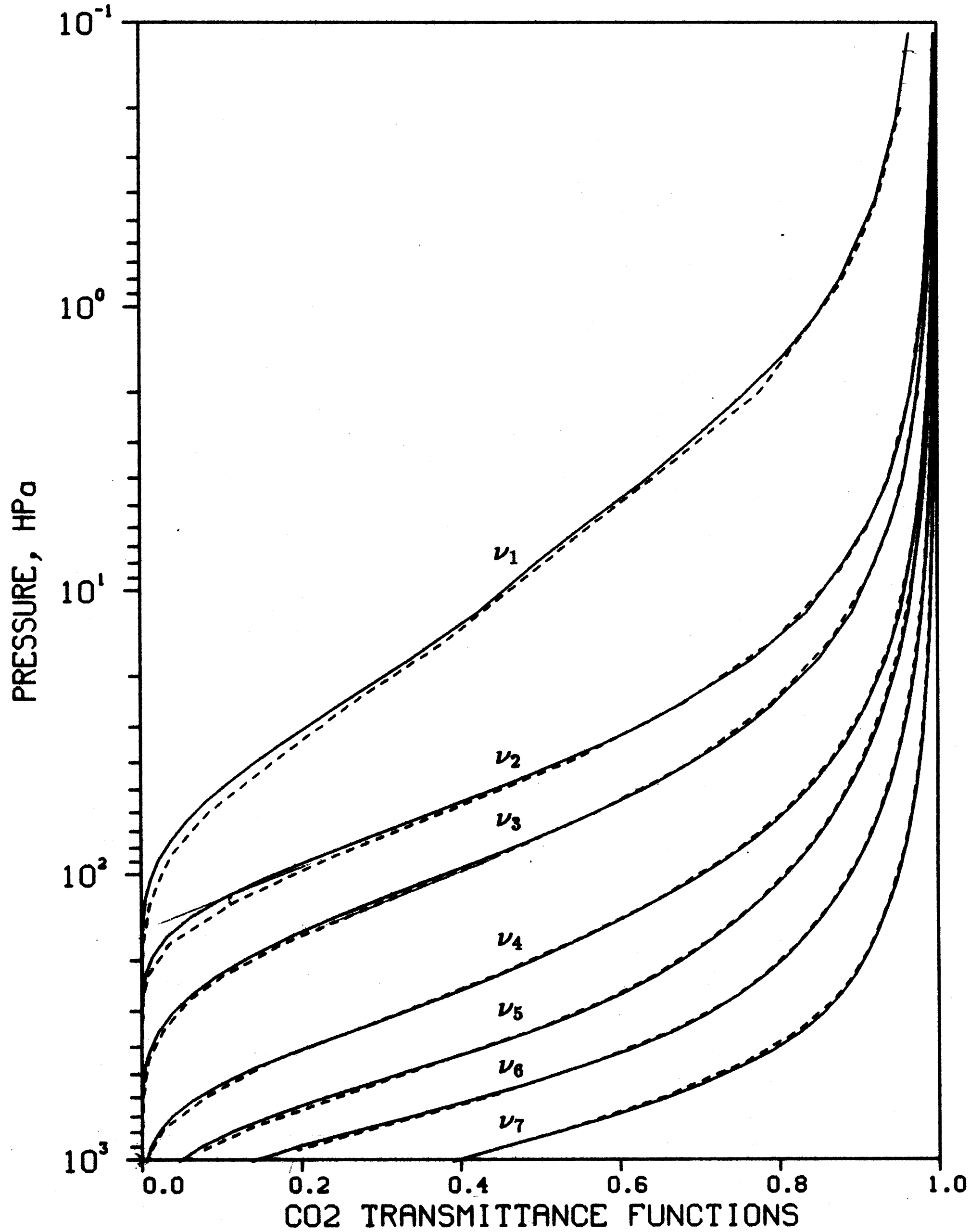

Fig. III-7 : Comparisons of the ITRA and HARTCODE transmittance calculated for the USST 76 Standard Atmosphere. ν is the central wave number of the selected HIRS/2 channels (see Table III-3), solid lines are the HARTCODE transmittance and the dashed lines are the ITRA averages.

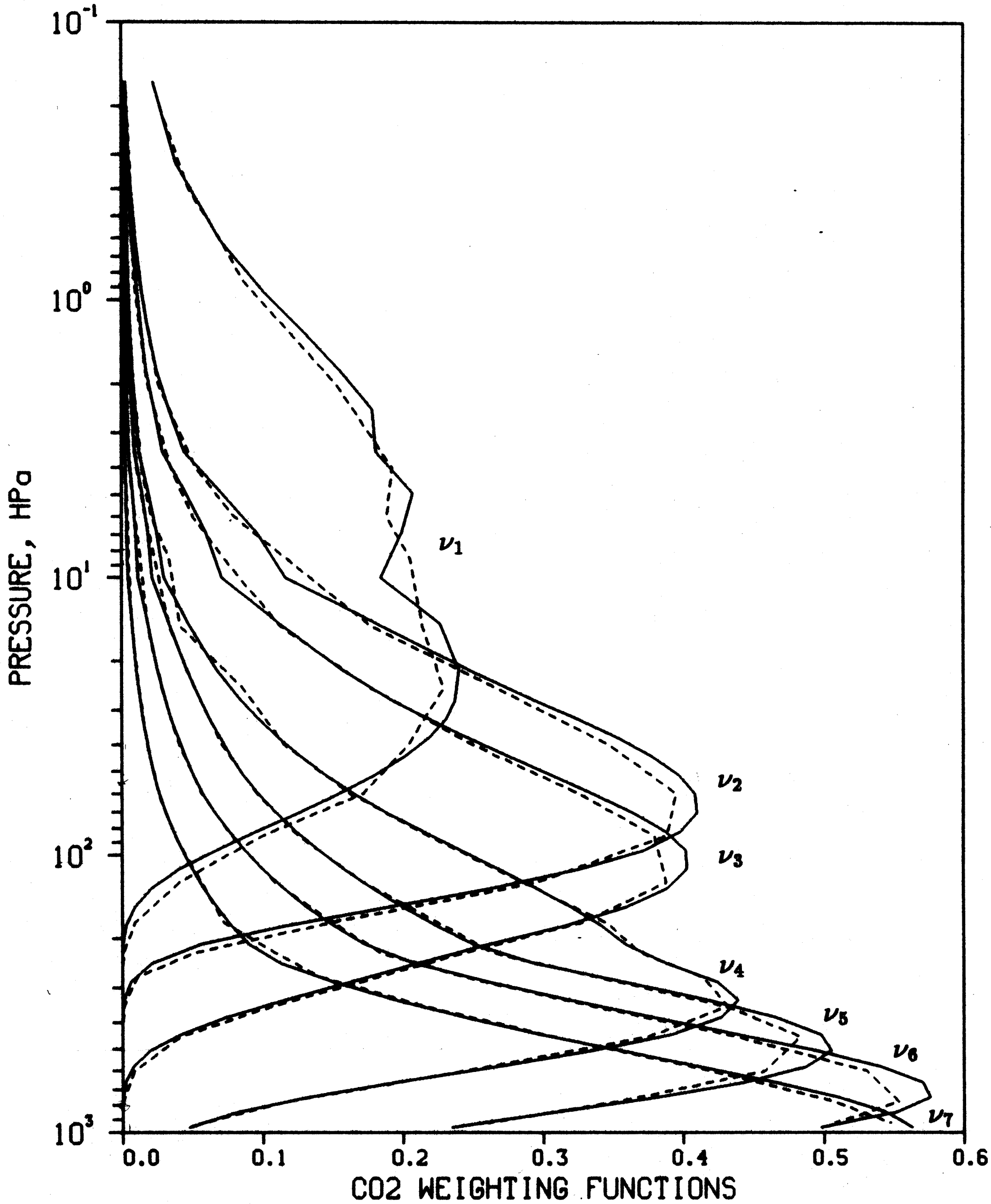

Fig. III-8 : Comparisons of the ITRA and HARTCODE weighting functions calculated for the USST 76 Standard Atmosphere. ν is the central wave number of the selected HIRS/2 channels (see Table III-3), solid lines are the HARTCODE transmittance and the dashed lines are the ITRA averages.

The main conclusion of the comparisons above is that the differences between the HARTCODE results are well within the range of the differences between the results of the different ITRA codes and also that the magnitude of the differences are still too large compared with the accuracy requirements of the evaluation of recent high resolution radiance measurements.

In Fig. III-9 the weighting functions are compared when the weak absorption lines being in the vicinity of the strong lines are neglected. (Solid lines are indicating the results obtained with considering also the weak lines and the dashed ones were obtained with 'SRATO' = 10^{-3}.) It is interesting to note that no significant changes in the weighting functions occurred although the number of the absorption lines were reduced from 14797 to 3215 (see Table II-3). These slight changes in the weighting functions result only about 0.2 $mW/(m^2 sr\ cm^{-1})$ changes in the channel radiance therefore they can not explain the differences being larger by one magnitude.

In Fig. III-10 and III-11 the weighting functions obtained by using the different spectroscopic data are compared. In this case the **lin.dat** files were created with 'TRLIM' = 'TRLIMS' = 1 and 'SRATIO' = 10^{-3}. Fig. III-10 shows the comparisons between the GEISA-84 (solid lines) and AFGL-82 (dashed lines) data while in Fig. III-11 the GEISA-84 (solid lines) and HITRAN-86 (dashed lines) weighting functions are compared. The corresponding channel radiance are included in Table III-4. (The differences between R in Table III-3 and R_G in Table III-4 are due to the indicated pre-selection of the absorption lines.)

TABLE III-4

Comparisons of channel radiance computed for the USST 76 Standard Atmosphere by the ITRA participants and by the HARTCODE. The radiance are in $mW/(m^2 sr\ cm^{-1})$. ν_i is the central wave of the HIRS/2 channels, R_G, R_A and R_H are the radiance computed using the GEISA-84, AFGL-82 and HITRAN-86 databases subsequently, $\triangle R_{GA} = R_G - R_A$ and $\triangle R_{GH} = R_G - R_H$

ν_i	R_G	R_A	R_H	$\triangle R_{GA}$	$\triangle R_{GH}$
668	62.353	62.120	62.570	0.23	-0.21
679	46.995	46.609	47.141	0.39	-0.15
691	45.109	45.061	45.170	0.05	-0.06
704	52.730	52.877	53.457	-0.15	-0.72
716	64.838	65.000	66.335	-0.16	-1.49
732	77.013	77.114	79.365	-0.10	-2.35
748	93.134	93.192	95.250	-0.06	-2.12

The results presented above show that the magnitude of the deviations between the basic spectroscopic data do not allows us to derive unique explanations for the observed deviations by the ITRA participants and especially not for the effect of the changes in some particular code- parameter.

On the other hand using exactly the same spectroscopic input data and correct numerical procedures one has to obtain the same result (within certain accuracy limit). The main sense of comparing calculations for model atmospheres is to find the required accuracy limits and to identify the significant parameters and the most effective computational methods for a particular application. The second ITRA exercise proved again the existing fundamental differences of the spectroscopic data. Once a code reached the stage of development of precisely predictable accuracy further comparisons with real atmospheric and high accuracy laboratory measurements will decide about the quality of the data and most probably not about the accuracy of a given code.

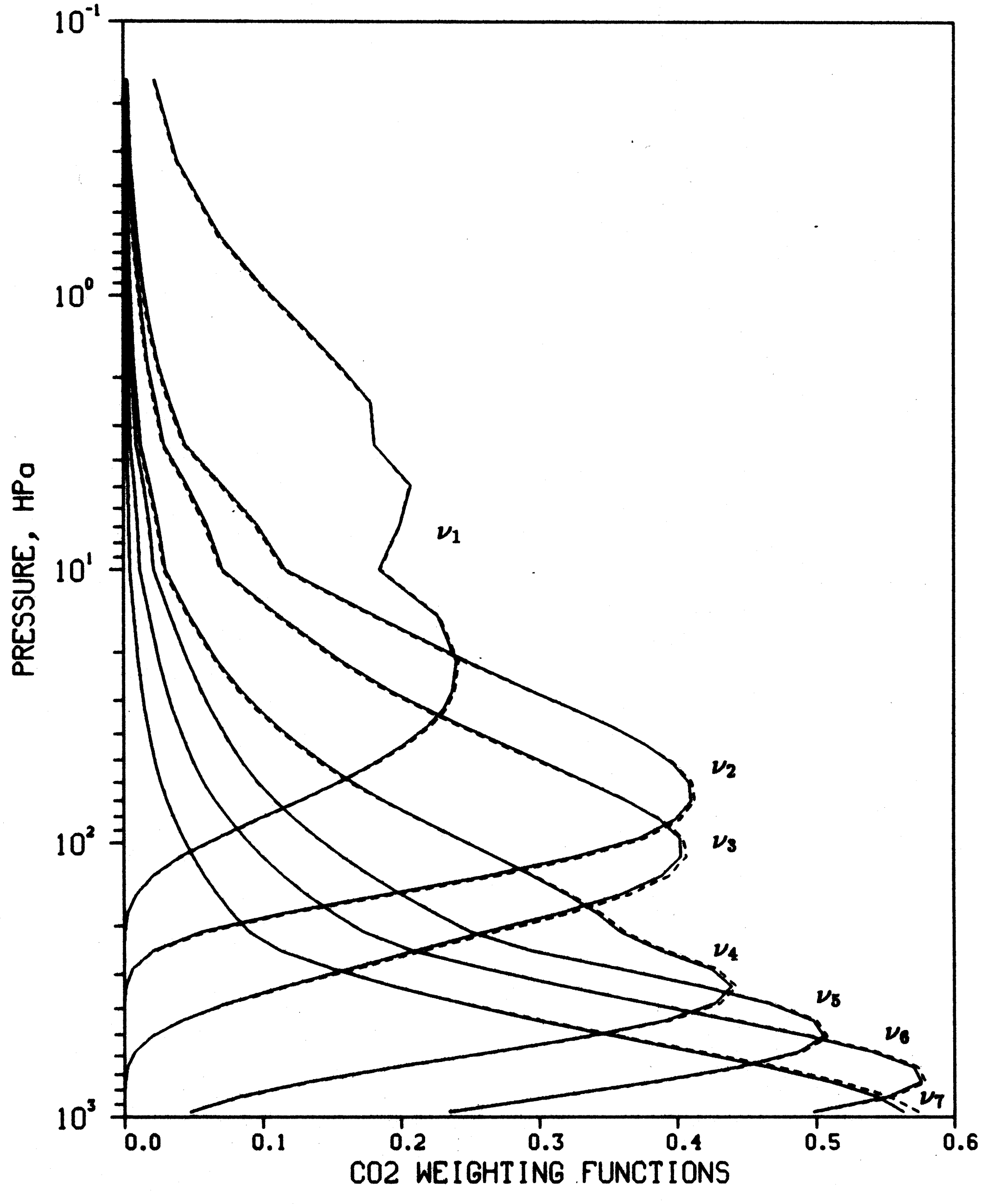

Fig. III-9 : Effect of the weak absorption lines on the weighting functions. Solid lines were obtained with 'SRATIO'= 0 and the dashed ones with 'SRATIO'= 10^{-3}.

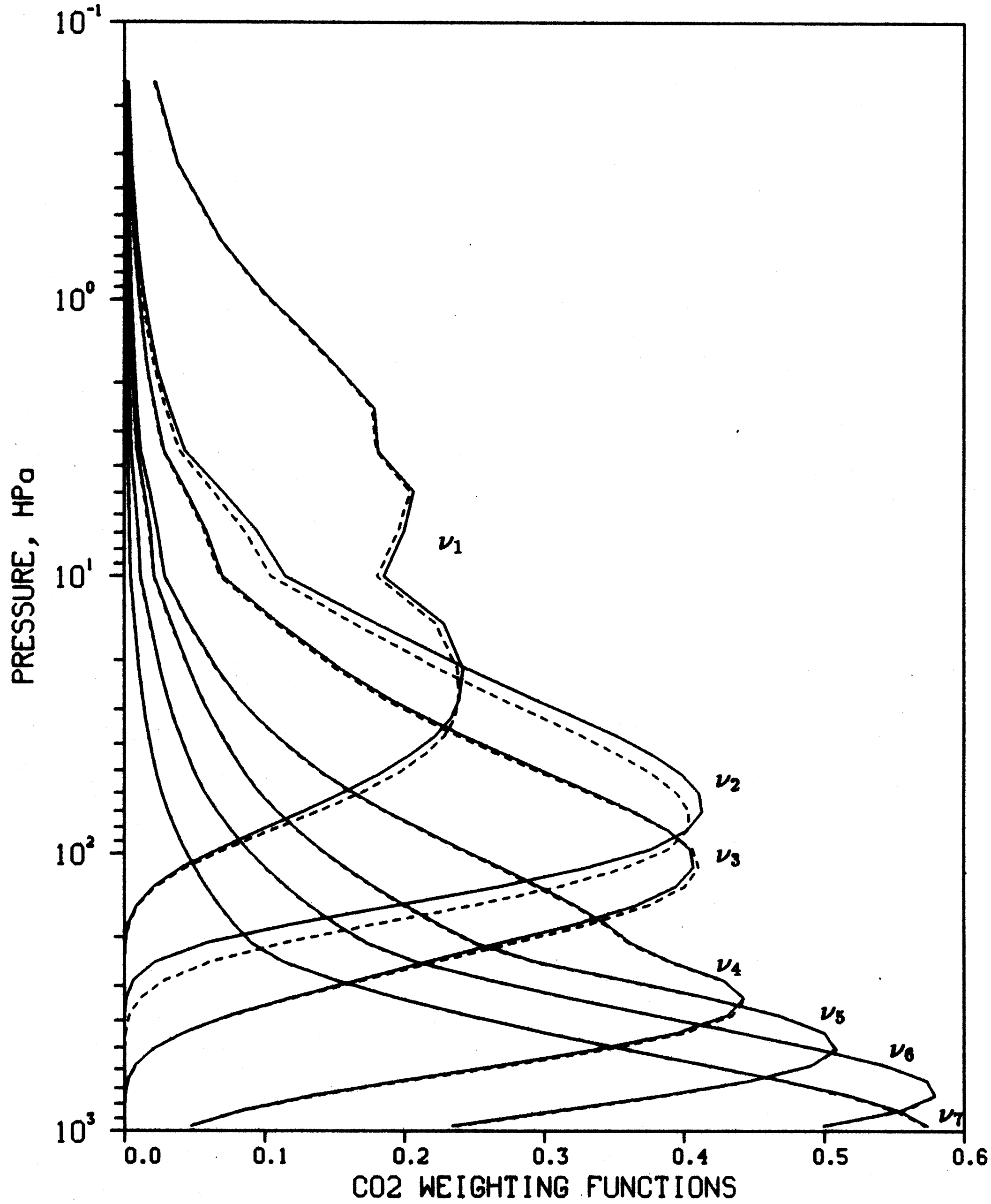

Fig. III-10 : HIRS/2 weighting functions computed by using the GEISA-84 catalog (solid lines) and the AFGL-82 data (dashed lines).

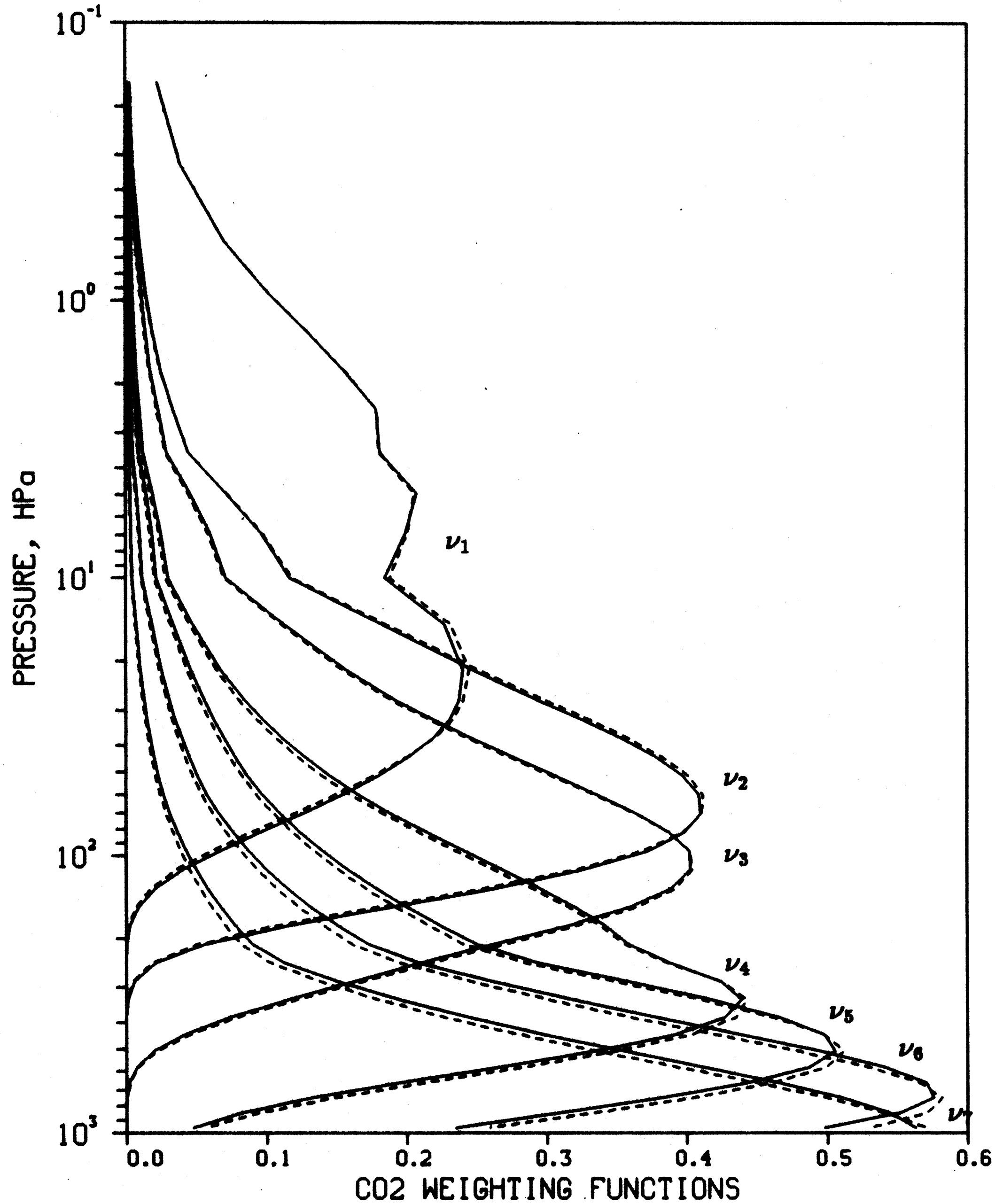

Fig. III-11 : HIRS/2 weighting functions computed by using the GEISA-84 catalog (solid lines) and the HITRAN-86 data (dashed lines).

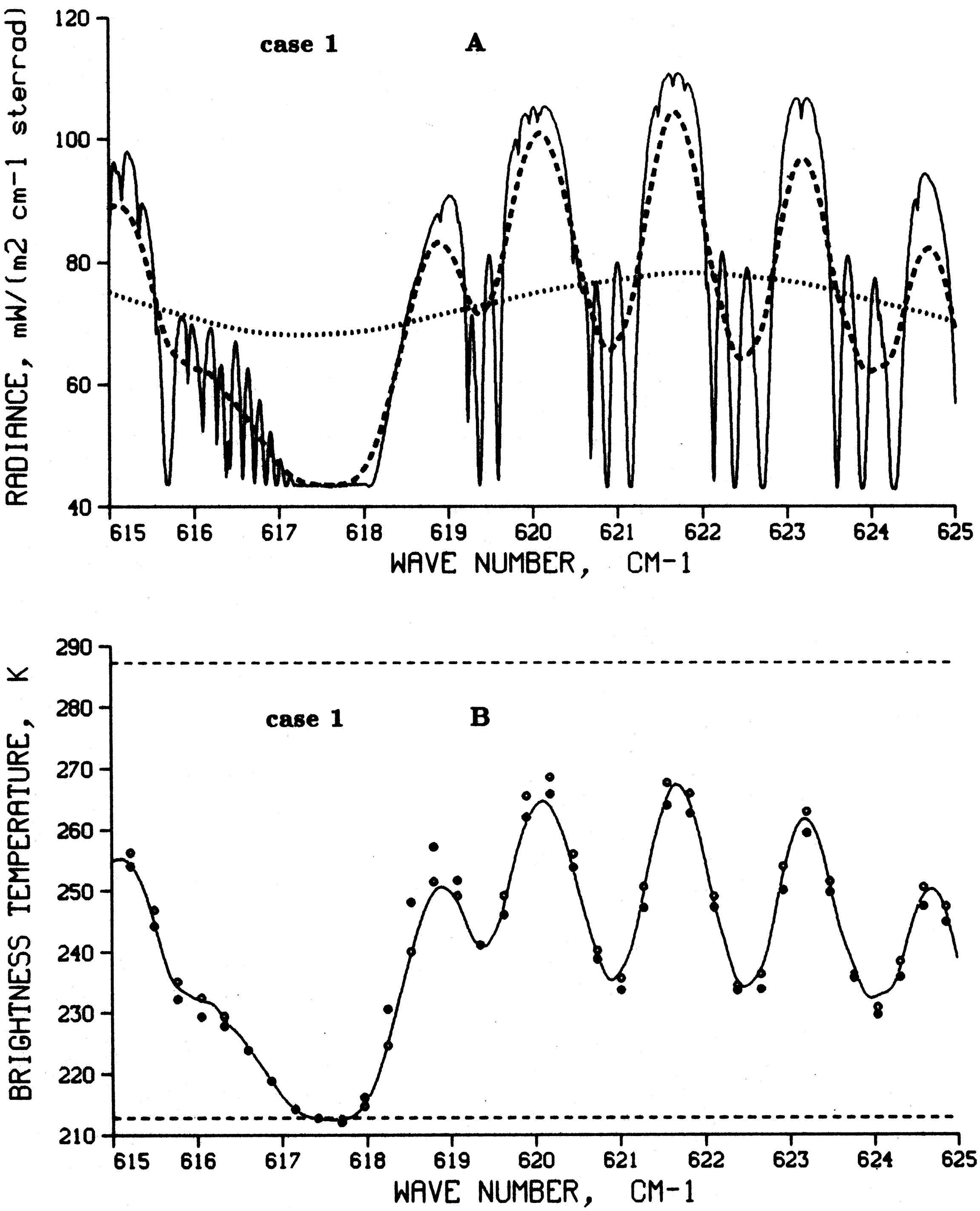

Fig. III-12 : HARTCODE radiance and brightness temperatures in the 615 - 625 cm^{-1} wave number interval (solid lines).

3. Simulation of the Atmospheric Radiance Spectra and Comparisons with the HIS Measurements

To improve the accuracy of the IR remote sensing in the future the operative satellites are going to be supplied with the new generation of IR spectrometers which spectral resolution is about ten or twenty times higher than the one of the HIRS/2 sounder. The High-resolution Interferometer Sounder (HIS) Aircraft Instrument is one of these new devices. For experimental testing the HIS instrument was mounted on the NASA high altitude aircraft and several measurements were performed with different viewing geometry. HIS has 0.5 cm^{-1} and 1.0 cm^{-1} spectral resolution in the 600-1000 cm^{-1} and 1100-2600 cm^{-1} wave number intervals respectively with an absolute radiometric accuracy of 1 K and an RMS reproducibility of 0.1 K, *Clough et al*[38], *Revercomb et al*[37].

In this section and in the Appendix B we compare the measured radiance spectra with the calculated ones by the HARTCODE and FASCODE high resolution radiance computer codes.

We are very thankful to W. L. Smith who made available two measured spectra and the FASCODE simulations together with the data of the simultaneous radiosonde measurements, *Smith*[2]. In both cases the measured spectra were obtained during the flights over California Coast and Tucson/Kitt Peak area at 56 HPa flight level. The simultaneous radiosonde data are presented in Table III-5 . The sounding data were supplemented with the other six major absorber's concentration profiles taken from the USST 76 Standard Atmosphere. At this simulation the effect of the trace gases were ignored. For atmospheric layering the pressure levels of the original sounding data were adopted without changing.

For the HARTCODE runs at the beginning the AFGL-82 tape was used but after discovering some deficiencies of that line catalog (see *Miskolczi et al*[36]) we changed for the GEISA-84 data. The input **lin.dat** file were created with 'TRLIM'=.9999, 'TRLIMS'=.99 and 'SRATIO' = 10^{-5}. The line wing cut-off parameter was set to 6.5 cm^{-1}. Only the Voigt line shape function was used and no far wing absorption was taken into account. The wave number integration was performed by applying 2nd order Gaussian quadrature and the spectral resolution was set to 0.005 cm^{-1}.The details of the other input parameters can be found at the end of the HART programme in Appendix D.

A part of the high resolution HARTCODE radiance spectra (solid line) is presented in Fig. III-12. In the upper plot (A) different kind of triangular smoothing functions were applied to the original data. (Dotted line : smoothed with the HIRS response function, dashed line : smoothed with the HIS response function.)

In the lower graph (B) the brightness temperature is plotted in the same spectral interval. Together with the HARTCODE results (solid line) the HIS measurements (full circles) the FASCODE results (empty circles) and the upper and lower boundary temperatures (dashed lines) are also presented. (The HIS and FASCODE results were given at discrete wave numbers therefor at the final comparisons the HARTCODE radiance were computed exactly at the same wave numbers). According to this graph in the 615 - 625 cm^{-1} region there is a good general agreement between the measurement and the theoretical spectra.

Figures showing the detailed results of the comparisons for the whole 500 - 1800 cm^{-1} interval are included in Appendix B. They are similar to Fig. III-12 (B) except that the differences between the measured and theoretical spectra are also plotted in a smaller temperature range inside a "window". After the Figures the numerical values of the statistics of the comparisons are also given for every 10 cm^{-1} in Tables B-1 ....B-12. Within this report we do not want to give a full account on the analysis of the comparison - at some spectral interval the analysis is still in progress - but let us mention some interesting features.

Like in the case of the homogeneous calculations in the two hot CO_2 bands (around 618 and 720 cm^{-1}) there are sharp increase in the differences between the measured and synthetic radiance spectra which can not be accounted for by any line shape and line wing consideration. (In both cases the FASCODE produced the same results.)

At 668 cm^{-1} wave length because of the large CO_2 optical thickness the measurements should reproduce the upper boundary temperature accordingly the observed larger error might be caused by noise of the HIS interferometer.

Despite the smaller line wing cut-off parameter in the window region the HARTCOD gives better agreement with the measurements than the FASCODE. (Moreover in the HARTCODE only the seven major absorber was considered.) The magnitude of the deviations is generally within the accuracy limit of the instrument except the vicinity of the strong H_2O absorption lines.

In Fig. B-5 the results in the 1042 cm^{-1} ozone band are presented. Excellent agreement was achieved by setting the total ozone amount properly to minimize the differences between the observed and theoretical curve. Still the errors are larger than 1 - 2 K indicating that the measurements might contain information about the vertical structure of the ozone distribution being under the flight level.

In Fig. B-7 around 1270 - 1320 cm^{-1} the larger errors are due to the N_2O and CH_4 absorption. In this case we did not try to fit the absorber amount to obtain a better agreement.

In Fig. B-9 and B-10 (from 1400 to 1600 cm^{-1}) there is a constant difference between the measured and calculated spectra which might be explained by the errors in the H_2O continuum absorption coefficients.

Beside the good overall agreement in the future using more measured spectra for the corrections of the spectroscopic data better results could be obtained. Concerning the HARTCODE after implementing the routines for the computation of the nitrogen and oxygen continuum and the trace gas absorption we shall continue the validation and complete the HIS evaluation in the Band-III (2070-2750 cm^{-1}).

TABLE III-5

Radiosonde observations used for the HIS evaluation. T is the temperature in K, P is the pressure in HPa, M is the water vapor mixing ratio in g/kg.

case 1			**case 2**		
California Coast, 14-04-86			Tucson/Kitt Peak, 15-04-86		
Surface elevation : 65 m			Surface elevation : 789 m		
Skin temperature : 287.5 K			Skin temperature : 309.0 K		
P	T	M	P	T	M
56.00	212.70	0.0010	56.00	209.00	0.0010
60.00	212.60	0.0010	60.00	207.80	0.0010
70.00	212.40	0.0010	70.00	209.00	0.0010
85.00	212.80	0.0010	85.00	209.90	0.0010
100.00	211.30	0.0010	100.00	208.70	0.0010
115.00	211.10	0.0020	115.00	208.80	0.0010
135.00	213.30	0.0030	135.00	209.00	0.0010
150.00	213.70	0.0030	150.00	206.20	0.0010
200.00	211.50	0.0020	200.00	211.20	0.0010
250.00	220.20	0.0030	250.00	222.40	0.0010
300.00	229.70	0.0080	300.00	232.80	0.0030
350.00	237.90	0.0990	350.00	240.90	0.0630
400.00	244.70	0.1980	400.00	247.90	0.0960
430.00	248.40	0.5360	430.00	250.60	0.3070
475.00	253.60	1.0510	475.00	255.10	0.8810
500.00	256.10	0.7450	500.00	257.90	1.2740
570.00	263.00	1.4660	570.00	265.90	2.1880
620.00	267.00	1.5220	620.00	271.10	2.8470
670.00	271.00	1.5000	670.00	275.90	3.3710
700.00	273.40	1.5160	700.00	278.60	3.5160
780.00	278.60	0.8660	780.00	285.90	3.4090
850.00	282.20	1.3430	850.00	291.90	3.3330
920.00	284.60	2.4540	920.00	294.30	4.2330
950.00	285.20	4.1460	924.00	294.35	4.3450
1000.00	286.90	6.2470			
1006.00	287.35	6.5620			

IV. CONCLUSIONS

Although from the results of the validation of the HARTCODE one can draw several other conclusions the most important one is that the code is able to compute the absorption optical depth, transmittance and radiance spectra with an accuracy which proved to be resonable to evaluate the data obtained by laboratory, field, aircraft or satellite spectral measurements.

Considering the rather complicated input structure of the HARTCODE the recent version is designed for research and not for operational use. The fine "tuning" of the code with respect the computational efficiency and the incorporation of the most up-to-date spectroscopic data still left to be done. Once we have the optimized version the task of setting up a transmittance compilation - i.e. the calculation and collection of accurate transmittance profiles for selected model atmospheres for further parameterization or remote sensing purposes - will be the matter of a routine operation.

In view of the first results of application of the HARTCODE let us mention some further conclusions:

In case of carbon dioxide according to the homogeneous calculations it seems that no manipulations with the line shape and line wing contribution can eliminate the discrepancies between the measured and computed transmittance spectra. The revision of other line parameters belonging to the particular bands might be necessary.

To overcome the problem of the band shapes really high precision laboratory measurements of the line shape function needed in many spectral intervals including the two hot bands of the CO_2 at 618 and 721 cm^{-1} where the discrepancies are the largest and several bands of the H_2O from 800 cm^{-1}. If we accept the line mixing problem as it is treated mathematically by Bulanin at al. it is plain that the original formulation is not adequate for application in LBL codes. Our opinion is that any kind of line wing consideration is justified - as far as they improve the agreement with laboratory measurements - until no better theoretical model is available.

The role of the weak CO_2 lines in the neighbourhood of the ν_2 fundamental is obvious as they can significantly change the position of the peak of the weighting functions. The line wing absorption - even when using Lorentzian line shape - has less importance and completely negligible above 6.5 cm^{-1}. Within a given wave number interval the consideration of several hundreds of very weak lines and the careful wave number integration is more vital. However it is true that more economic to compensate the weak line absorption with a more or less constant strong line wing absorption.

When comparing the numerical accuracies of the different codes strictly the same spectroscopic input data should be used. The comparisons of the sensitivities of the individual codes to the slight changes in the different input parameters might also be useful.

When validating a code using real atmospheric measurements more care should be taken to monitor the condition of the measurements. Simultaneous ozone sounding and other trace gas measurements might also be necessary. In case of air-born measurements having the measured data of the same trajectory from different altitudes might to reduce the uncertainties in the skin temperatures.

Another important conclusion is that the HIS (or similar instrument) can monitor the amount of ozone and other trace gases being under the flight level. Also there might be a better chance to retrieve some characteristics of the vertical ozone distribution from the radiance spectra using nadir viewing geometry.

Compared with the FASCOD/2 in most spectral regions the HARTCODE can simulate the emission spectrum of the Earth-atmosphere system with a better accuracy.

In the field of the IR atmospheric radiative transfer a high-resolution transmittance/radiance code is always considered as a basic research tool and its application is not restricted to the area of IR remote sensing. In the further development of the HARTCODE the problems arising at the flux-divergence calculations and parameterization will also be considered.

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APPENDIX A

Relative Optical Air Mass Tables for
Model Atmospheres

TABLE A-1

Relative optical air mass values for *TROPICAL* atmosphere at 15μ wavelength and for a path from 0.0 to 120 km altitude.θ is the zenith angle in degree, $\triangle\theta$ is the angular deviation of the beam in degree, L is the geometrical path length in km. The accuracies of the air mass values are better then 10^{-3} percent.

θ	$\triangle\theta$	L	AIR	H_2O	O_3	N_2O	CO	CH_4
60.0	0.02576	233.845	1.9936	1.9985	1.9781	1.9943	1.9956	1.9941
62.0	0.02795	247.946	2.1220	2.1282	2.1027	2.1228	2.1246	2.1227
64.0	0.03045	264.096	2.2710	2.2788	2.2465	2.2720	2.2742	2.2718
66.0	0.03332	282.726	2.4455	2.4555	2.4139	2.4468	2.4496	2.4465
68.0	0.03667	304.385	2.6522	2.6654	2.6110	2.6539	2.6577	2.6535
70.0	0.04064	329.793	2.9006	2.9183	2.8455	2.9029	2.9079	2.9024
72.0	0.04542	359.895	3.2040	3.2285	3.1285	3.2072	3.2141	3.2064
74.0	0.05130	395.949	3.5822	3.6170	3.4756	3.5866	3.5965	3.5856
76.0	0.05873	439.648	4.0654	4.1171	3.9089	4.0719	4.0866	4.0703
78.0	0.06841	493.283	4.7023	4.7836	4.4617	4.7123	4.7354	4.7099
80.0	0.08156	559.960	5.5767	5.7135	5.1836	5.5930	5.6319	5.5891
81.0	0.09007	599.445	6.1466	6.3305	5.6301	6.1682	6.2203	6.1630
82.0	0.10039	643.854	6.8432	7.0975	6.1493	6.8722	6.9440	6.8653
83.0	0.11317	693.916	7.7113	8.0754	6.7555	7.7515	7.8536	7.7418
84.0	0.12933	750.456	8.8188	9.3629	7.4643	8.8761	9.0271	8.8622
85.0	0.15031	814.395	10.2720	11.1292	8.2899	10.3564	10.5903	10.3357
86.0	0.17842	886.766	12.2446	13.6892	9.2404	12.3740	12.7568	12.3420
87.0	0.21746	968.742	15.0356	17.6912	10.3079	15.2428	15.9110	15.1911
87.5	0.24300	1013.759	16.8930	20.6438	10.8760	17.1595	18.0667	17.0926
88.0	0.27413	1061.735	19.1898	24.6646	11.4584	19.5363	20.7922	19.4489
88.2	0.28851	1081.808	20.2632	26.6982	11.6938	20.6493	22.0877	20.5516
88.4	0.30419	1102.413	21.4423	29.0547	11.9298	21.8732	23.5262	21.7640
88.6	0.32133	1123.571	22.7412	31.8076	12.1662	23.2228	25.1288	23.1005
88.8	0.34010	1145.303	24.1763	35.0517	12.4026	24.7154	26.9209	24.5782
89.0	0.36072	1167.634	25.7667	38.9099	12.6390	26.3712	28.9321	26.2171
89.2	0.38342	1190.595	27.5349	43.5428	12.8755	28.2136	31.1984	28.0403
89.4	0.40847	1214.215	29.5074	49.1624	13.1123	30.2705	33.7625	30.0754
89.6	0.43621	1238.533	31.7156	56.0500	13.3499	32.5747	36.6766	32.3547
89.7	0.45121	1250.968	32.9195	60.0828	13.4692	33.8315	38.2843	33.5978
89.8	0.46704	1263.596	34.1968	64.5835	13.5890	35.1654	40.0043	34.9171
89.9	0.48377	1276.424	35.5537	69.6204	13.7092	36.5826	41.8471	36.3186
90.0	0.50148	1289.460	36.9964	75.2727	13.8301	38.0899	43.8240	37.8092

TABLE A-2

Relative optical air mass values for *MIDLATITUDE SUMMER* atmosphere at 15μ wavelength and for a path from 0.0 to 120 *km* altitude. θ is the zenith angle in degree, $\triangle\theta$ is the angular deviation of the beam in degree, L is the geometrical path length in *km*. The accuracies of the air mass values are better then 10^{-3} percent.

θ	$\triangle\theta$	L	AIR	H_2O	O_3	N_2O	CO	CH_4
60.0	0.02628	233.848	1.9937	1.9985	1.9801	1.9947	1.9957	1.9945
62.0	0.02852	247.950	2.1221	2.1282	2.1052	2.1234	2.1247	2.1231
64.0	0.03106	264.102	2.2711	2.2788	2.2496	2.2727	2.2744	2.2724
66.0	0.03399	282.732	2.4456	2.4555	2.4180	2.4477	2.4498	2.4472
68.0	0.03741	304.394	2.6523	2.6654	2.6163	2.6552	2.6579	2.6545
70.0	0.04146	329.805	2.9008	2.9183	2.8526	2.9045	2.9083	2.9037
72.0	0.04634	359.910	3.2043	3.2284	3.1382	3.2094	3.2146	3.2082
74.0	0.05234	395.970	3.5825	3.6169	3.4892	3.5898	3.5972	3.5881
76.0	0.05993	439.677	4.0659	4.1170	3.9288	4.0766	4.0875	4.0741
78.0	0.06983	493.325	4.7032	4.7834	4.4919	4.7197	4.7368	4.7159
80.0	0.08328	560.024	5.5781	5.7132	5.2322	5.6053	5.6342	5.5990
81.0	0.09197	599.525	6.1486	6.3301	5.6931	6.1846	6.2234	6.1763
82.0	0.10255	643.955	6.8460	7.0969	6.2326	6.8946	6.9482	6.8834
83.0	0.11564	694.047	7.7155	8.0746	6.8677	7.7829	7.8596	7.7676
84.0	0.13223	750.627	8.8253	9.3618	7.6182	8.9219	9.0359	8.9001
85.0	0.15381	814.627	10.2826	11.1276	8.5048	10.4260	10.6040	10.3942
86.0	0.18279	887.090	12.2633	13.6870	9.5438	12.4851	12.7795	12.4373
87.0	0.22322	969.217	15.0715	17.6896	10.7349	15.4305	15.9522	15.3568
87.5	0.24979	1014.347	16.9444	20.6449	11.3778	17.4094	18.1244	17.3175
88.0	0.28233	1062.478	19.2654	24.6747	12.0401	19.8748	20.8758	19.7602
88.2	0.29743	1082.631	20.3521	26.7161	12.3074	21.0334	22.1858	20.9084
88.4	0.31394	1103.328	21.5475	29.0849	12.5744	22.3104	23.6419	22.1741
88.6	0.33206	1124.593	22.8662	31.8574	12.8400	23.7221	25.2665	23.5739
88.8	0.35199	1146.453	24.3258	35.1330	13.1030	25.2876	27.0859	25.1266
89.0	0.37399	1168.939	25.9468	39.0420	13.3622	27.0293	29.1317	26.8548
89.2	0.39837	1192.086	27.7533	43.7575	13.6163	28.9737	31.4420	28.7850
89.4	0.42548	1215.935	29.7744	49.5114	13.8646	31.1523	34.0630	30.9486
89.6	0.45576	1240.536	32.0447	56.6168	14.1061	33.6027	37.0515	33.3835
89.7	0.47225	1253.137	33.2861	60.8041	14.2241	34.9438	38.7047	34.7165
89.8	0.48975	1265.950	34.6062	65.5001	14.3404	36.3707	40.4772	36.1351
89.9	0.50833	1278.984	36.0118	70.7830	14.4548	37.8907	42.3805	37.6465
90.0	0.52811	1292.250	37.5103	76.7438	14.5675	39.5119	44.4276	39.2588

TABLE A-3

Relative optical air mass values for *MIDLATITUDE WINTER* atmosphere at 15μ wavelength and for a path from 0.0 to 120 km altitude.θ is the zenith angle in degree, $\triangle\theta$ is the angular deviation of the beam in degree, L is the geometrical path length in km. The accuracies of the air mass values are better then 10^{-3} percent.

θ	$\triangle\theta$	L	AIR	H_2O	O_3	N_2O	CO	CH_4
60.0	0.02862	233.863	1.9941	1.9985	1.9821	1.9950	1.9959	1.9948
62.0	0.03106	247.969	2.1227	2.1281	2.1076	2.1238	2.1249	2.1236
64.0	0.03384	264.126	2.2718	2.2787	2.2527	2.2732	2.2747	2.2729
66.0	0.03704	282.763	2.4465	2.4554	2.4220	2.4484	2.4502	2.4480
68.0	0.04077	304.433	2.6536	2.6653	2.6215	2.6560	2.6584	2.6555
70.0	0.04518	329.856	2.9024	2.9181	2.8595	2.9057	2.9089	2.9050
72.0	0.05051	359.978	3.2065	3.2282	3.1476	3.2110	3.2155	3.2101
74.0	0.05708	396.063	3.5857	3.6166	3.5023	3.5921	3.5985	3.5907
76.0	0.06538	439.807	4.0706	4.1166	3.9478	4.0800	4.0896	4.0780
78.0	0.07622	493.513	4.7105	4.7826	4.5207	4.7250	4.7402	4.7219
80.0	0.09098	560.307	5.5903	5.7119	5.2779	5.6143	5.6400	5.6092
81.0	0.10056	599.878	6.1650	6.3283	5.7520	6.1966	6.2313	6.1899
82.0	0.11222	644.402	6.8684	7.0944	6.3096	6.9112	6.9594	6.9023
83.0	0.12672	694.621	7.7472	8.0708	6.9700	7.8068	7.8760	7.7944
84.0	0.14515	751.379	8.8720	9.3557	7.7562	8.9575	9.0612	8.9400
85.0	0.16927	815.636	10.3547	11.1170	8.6929	10.4821	10.6451	10.4566
86.0	0.20193	888.485	12.3812	13.6663	9.8004	12.5793	12.8512	12.5409
87.0	0.24805	971.226	15.2785	17.6417	11.0779	15.6015	16.0882	15.5424
87.5	0.27875	1016.807	17.2278	20.5653	11.7666	17.6480	18.3194	17.5745
88.0	0.31676	1065.540	19.6630	24.5328	12.4704	20.2168	21.1638	20.1256
88.2	0.33457	1085.991	20.8109	26.5330	12.7515	21.4316	22.5255	21.3324
88.4	0.35417	1107.030	22.0792	28.8453	13.0297	22.7763	24.0449	22.6686
88.6	0.37582	1128.687	23.4856	31.5393	13.3033	24.2700	25.7475	24.1535
88.8	0.39983	1150.999	25.0511	34.7043	13.5705	25.9355	27.6636	25.8096
89.0	0.42656	1174.009	26.8007	38.4557	13.8294	27.7997	29.8301	27.6642
89.2	0.45645	1197.768	28.7644	42.9441	14.0787	29.8952	32.2924	29.7499
89.4	0.49004	1222.337	30.9789	48.3680	14.3172	32.2614	35.1060	32.1061
89.6	0.52799	1247.790	33.4890	54.9917	14.5449	34.9464	38.3406	34.7811
89.7	0.54884	1260.875	34.8718	58.8603	14.6548	36.4266	40.1423	36.2563
89.8	0.57110	1274.218	36.3502	63.1714	14.7625	38.0099	42.0839	37.8345
89.9	0.59490	1287.832	37.9335	67.9900	14.8683	39.7061	44.1801	39.5256
90.0	0.62041	1301.735	39.6319	73.3921	14.9726	41.5264	46.4478	41.3407

TABLE A-4

Relative optical air mass values for *SUBARCTIC SUMMER* atmosphere at 15μ wavelength and for a path from 0.0 to 120 km altitude.θ is the zenith angle in degree, $\triangle\theta$ is the angular deviation of the beam in degree, L is the geometrical path length in km. The accuracies of the air mass values are better then 10^{-3} percent.

θ	$\triangle\theta$	L	AIR	H_2O	O_3	N_2O	CO	CH_4
60.0	0.02687	233.852	1.9938	1.9984	1.9811	1.9950	1.9958	1.9947
62.0	0.02916	247.955	2.1223	2.1280	2.1064	2.1238	2.1248	2.1234
64.0	0.03177	264.108	2.2713	2.2786	2.2512	2.2732	2.2745	2.2727
66.0	0.03477	282.740	2.4459	2.4553	2.4200	2.4483	2.4500	2.4476
68.0	0.03827	304.404	2.6527	2.6651	2.6189	2.6559	2.6582	2.6551
70.0	0.04241	329.818	2.9013	2.9179	2.8561	2.9055	2.9086	2.9044
72.0	0.04740	359.928	3.2050	3.2279	3.1430	3.2108	3.2151	3.2093
74.0	0.05355	395.994	3.5836	3.6162	3.4959	3.5918	3.5979	3.5896
76.0	0.06132	439.711	4.0674	4.1159	3.9385	4.0795	4.0886	4.0763
78.0	0.07146	493.374	4.7055	4.7816	4.5067	4.7242	4.7386	4.7194
80.0	0.08525	560.098	5.5821	5.7101	5.2557	5.6130	5.6371	5.6049
81.0	0.09418	599.617	6.1540	6.3259	5.7235	6.1948	6.2273	6.1841
82.0	0.10504	644.072	6.8535	7.0909	6.2725	6.9089	6.9536	6.8942
83.0	0.11850	694.198	7.7261	8.0658	6.9210	7.8034	7.8673	7.7828
84.0	0.13557	750.825	8.8411	9.3479	7.6906	8.9527	9.0475	8.9226
85.0	0.15782	814.893	10.3073	11.1041	8.6044	10.4748	10.6221	10.4291
86.0	0.18777	887.458	12.3041	13.6433	9.6813	12.5676	12.8099	12.4943
87.0	0.22967	969.743	15.1438	17.5960	10.9213	15.5816	16.0069	15.4561
87.5	0.25727	1014.985	17.0435	20.4979	11.5907	17.6208	18.2004	17.4520
88.0	0.29111	1063.260	19.4039	24.4300	12.2773	20.1778	20.9839	19.9461
88.2	0.30682	1083.480	20.5113	26.4105	12.5526	21.3856	22.3111	21.1210
88.4	0.32402	1104.252	21.7310	28.6990	12.8260	22.7212	23.7877	22.4180
88.6	0.34287	1125.600	23.0785	31.3646	13.0957	24.2030	25.4368	23.8544
88.8	0.36362	1147.550	24.5720	34.4963	13.3598	25.8522	27.2856	25.4502
89.0	0.38651	1170.134	26.2329	38.2103	13.6164	27.6940	29.3666	27.2289
89.2	0.41183	1193.386	28.0866	42.6599	13.8634	29.7579	31.7191	29.2185
89.4	0.43996	1217.348	30.1634	48.0504	14.0987	32.0790	34.3909	31.4519
89.6	0.47130	1242.067	32.4992	54.6605	14.3201	34.6988	37.4401	33.9686
89.7	0.48834	1254.729	33.7776	58.5377	14.4249	36.1361	39.1281	35.3476
89.8	0.50639	1267.603	35.1379	62.8743	14.5253	37.6676	40.9388	36.8161
89.9	0.52554	1280.700	36.5871	67.7419	14.6212	39.3013	42.8839	38.3815
90.0	0.54590	1294.031	38.1329	73.2252	14.7120	41.0460	44.9767	40.0524

TABLE A-5

Relative optical air mass values for *SUBARCTIC WINTER* atmosphere at 15μ wavelength and for a path from 0.0 to 120 km altitude.θ is the zenith angle in degree, $\triangle\theta$ is the angular deviation of the beam in degree, L is the geometrical path length in km. The accuracies of the air mass values are better then 10^{-3} percent.

θ	$\triangle\theta$	L	AIR	H_2O	O_3	N_2O	CO	CH_4
60.0	0.03017	233.874	1.9944	1.9984	1.9828	1.9952	1.9959	1.9951
62.0	0.03274	247.982	2.1230	2.1280	2.1085	2.1241	2.1250	2.1239
64.0	0.03567	264.142	2.2722	2.2785	2.2538	2.2736	2.2747	2.2734
66.0	0.03904	282.783	2.4470	2.4552	2.4234	2.4488	2.4502	2.4485
68.0	0.04297	304.459	2.6543	2.6650	2.6233	2.6566	2.6585	2.6562
70.0	0.04764	329.890	2.9034	2.9178	2.8619	2.9065	2.9090	2.9059
72.0	0.05326	360.024	3.2078	3.2277	3.1509	3.2121	3.2157	3.2114
74.0	0.06019	396.124	3.5876	3.6160	3.5069	3.5936	3.5988	3.5926
76.0	0.06897	439.894	4.0733	4.1155	3.9544	4.0823	4.0900	4.0808
78.0	0.08044	493.639	4.7148	4.7810	4.5306	4.7286	4.7409	4.7263
80.0	0.09609	560.496	5.5976	5.7091	5.2934	5.6203	5.6414	5.6166
81.0	0.10625	600.115	6.1747	6.3245	5.7720	6.2047	6.2334	6.1998
82.0	0.11865	644.703	6.8818	7.0889	6.3356	6.9225	6.9626	6.9160
83.0	0.13409	695.009	7.7662	8.0628	7.0042	7.8229	7.8812	7.8140
84.0	0.15379	751.890	8.9002	9.3431	7.8018	8.9816	9.0700	8.9692
85.0	0.17968	816.326	10.3985	11.0959	8.7540	10.5201	10.6610	10.5023
86.0	0.21496	889.452	12.4537	13.6272	9.8814	12.6433	12.8824	12.6173
87.0	0.26532	972.651	15.4087	17.5575	11.1810	15.7189	16.1554	15.6807
87.5	0.29922	1018.584	17.4088	20.4319	11.8788	17.8135	18.4223	17.7677
88.0	0.34174	1067.813	19.9228	24.3058	12.5873	20.4580	21.3272	20.4040
88.2	0.36188	1088.523	21.1142	26.2457	12.8679	21.7150	22.7244	21.6579
88.4	0.38425	1109.867	22.4358	28.4758	13.1439	23.1118	24.2890	23.0517
88.6	0.40921	1131.891	23.9081	31.0558	13.4131	24.6705	26.0496	24.6078
88.8	0.43724	1154.650	25.5559	34.0596	13.6729	26.4177	28.0412	26.3530
89.0	0.46895	1178.213	27.4099	37.5779	13.9210	28.3864	30.3074	28.3206
89.2	0.50511	1202.669	29.5083	41.7214	14.1551	30.6176	32.9033	30.5518
89.4	0.54677	1228.134	31.8995	46.6214	14.3731	33.1632	35.8998	33.0990
89.6	0.59529	1254.762	34.6462	52.4277	14.5737	36.0903	39.3892	36.0293
89.7	0.62266	1268.572	36.1774	55.7201	14.6671	37.7231	41.3553	37.6645
89.8	0.65244	1282.750	37.8299	59.2976	14.7558	39.4860	43.4934	39.4304
89.9	0.68493	1297.330	39.6181	63.1777	14.8400	41.3942	45.8251	41.3423
90.0	0.72044	1312.346	41.5583	67.3750	14.9197	43.4653	48.3756	43.4177

TABLE A-6

Relative optical air mass values for the *USST 76* atmosphere at 15μ wavelength and for a path from 0.0 to 120 km altitude.θ is the zenith angle in degree, $\triangle\theta$ is the angular deviation of the beam in degree, L is the geometrical path length in km. The accuracies of the air mass values are better then 10^{-3} percent.

θ	$\triangle\theta$	L	AIR	H_2O	O_3	N_2O	CO	CH_4
60.0	0.02688	233.852	1.9939	1.9984	1.9807	1.9945	1.9958	1.9944
62.0	0.02917	247.955	2.1224	2.1280	2.1059	2.1232	2.1248	2.1230
64.0	0.03177	264.108	2.2714	2.2785	2.2506	2.2724	2.2745	2.2722
66.0	0.03477	282.740	2.4460	2.4552	2.4192	2.4473	2.4500	2.4470
68.0	0.03827	304.404	2.6529	2.6650	2.6178	2.6546	2.6581	2.6542
70.0	0.04241	329.818	2.9016	2.9178	2.8546	2.9038	2.9086	2.9033
72.0	0.04741	359.928	3.2054	3.2277	3.1410	3.2084	3.2150	3.2077
74.0	0.05355	395.994	3.5841	3.6159	3.4930	3.5884	3.5978	3.5874
76.0	0.06132	439.710	4.0682	4.1155	3.9342	4.0745	4.0884	4.0731
78.0	0.07146	493.373	4.7068	4.7810	4.5000	4.7165	4.7382	4.7142
80.0	0.08525	560.097	5.5841	5.7091	5.2447	5.6001	5.6366	5.5963
81.0	0.09417	599.616	6.1566	6.3244	5.7089	6.1777	6.2266	6.1727
82.0	0.10502	644.070	6.8570	7.0889	6.2528	6.8853	6.9527	6.8785
83.0	0.11847	694.193	7.7309	8.0629	6.8935	7.7700	7.8660	7.7607
84.0	0.13552	750.818	8.8478	9.3435	7.6512	8.9036	9.0456	8.8902
85.0	0.15772	814.880	10.3168	11.0971	8.5464	10.3991	10.6194	10.3792
86.0	0.18755	887.433	12.3179	13.6309	9.5932	12.4443	12.8053	12.4135
87.0	0.22921	969.691	15.1639	17.5719	10.7855	15.3664	15.9981	15.3165
87.5	0.25658	1014.907	17.0674	20.4624	11.4223	17.3281	18.1873	17.2635
88.0	0.29004	1063.139	19.4315	24.3751	12.0706	19.7710	20.9635	19.6864
88.2	0.30553	1083.336	20.5401	26.3440	12.3293	20.9186	22.2862	20.8241
88.4	0.32246	1104.078	21.7606	28.6171	12.5857	22.1832	23.7572	22.0776
88.6	0.34099	1125.389	23.1082	31.2620	12.8386	23.5810	25.3989	23.4626
88.8	0.36132	1147.294	24.6008	34.3650	13.0865	25.1306	27.2381	24.9976
89.0	0.38370	1169.821	26.2594	38.0376	13.3283	26.8539	29.3065	26.7045
89.2	0.40839	1193.002	28.1087	42.4249	13.5629	28.7769	31.6423	28.6087
89.4	0.43572	1216.876	30.1778	47.7171	13.7892	30.9300	34.2916	30.7404
89.6	0.46608	1241.486	32.5016	54.1658	14.0068	33.3496	37.3106	33.1355
89.7	0.48255	1254.083	33.7717	57.9243	14.1123	34.6726	38.9797	34.4450
89.8	0.49996	1266.886	35.1218	62.1054	14.2154	36.0792	40.7684	35.8373
89.9	0.51840	1279.904	36.5585	66.7686	14.3163	37.5765	42.6877	37.3191
90.0	0.53796	1293.147	38.0892	71.9831	14.4150	39.1720	44.7505	38.8981

TABLE A-7

Relative optical air mass values of some trace gases for the *USST 76* atmosphere at 15μ wavelength and for a path from 0.0 to 120 km altitude. θ is the zenith angle in degree. The accuracies of the air mass values are better then 10^{-3} percent.

θ	NO	SO_2	NO_2	NH_3	PH_3	HNO_3	OH
60.0	1.9868	1.9968	1.9789	1.9979	1.9939	1.9837	1.9555
62.0	2.1136	2.1260	2.1037	2.1274	2.1224	2.1097	2.0745
64.0	2.2603	2.2761	2.2477	2.2779	2.2714	2.2553	2.2110
66.0	2.4317	2.4520	2.4156	2.4543	2.4460	2.4253	2.3688
68.0	2.6343	2.6608	2.6131	2.6638	2.6529	2.6258	2.5525
70.0	2.8769	2.9121	2.8483	2.9162	2.9016	2.8652	2.7684
72.0	3.1717	3.2199	3.1324	3.2255	3.2054	3.1554	3.0248
74.0	3.5369	3.6047	3.4809	3.6128	3.5841	3.5133	3.3324
76.0	3.9997	4.0988	3.9166	4.1108	4.0682	3.9637	3.7056
78.0	4.6029	4.7547	4.4731	4.7734	4.7068	4.5447	4.1629
80.0	5.4180	5.6646	5.2015	5.6962	5.5841	5.3162	4.7273
81.0	5.9413	6.2644	5.6528	6.3069	6.1566	5.8015	5.0573
82.0	6.5726	7.0055	6.1785	7.0642	6.8570	6.3749	5.4225
83.0	7.3472	7.9427	6.7936	8.0265	7.7309	7.0578	5.8239
84.0	8.3177	9.1625	7.5142	9.2873	8.8478	7.8771	6.2594
85.0	9.5650	10.8086	8.3556	11.0040	10.3168	8.8639	6.7221
86.0	11.2206	13.1371	9.3259	13.4625	12.3179	10.0501	7.1973
87.0	13.5120	16.6441	10.4158	17.2269	15.1639	11.4580	7.6600
87.5	15.0155	19.1332	10.9950	19.9372	17.0674	12.2447	7.8761
88.0	16.8608	22.4014	11.5878	23.5328	19.4315	13.0806	8.0758
88.2	17.7198	24.0056	11.8271	25.3092	20.5401	13.4267	8.1500
88.4	18.6619	25.8269	12.0671	27.3322	21.7606	13.7785	8.2207
88.6	19.6984	27.9071	12.3076	29.6482	23.1082	14.1351	8.2876
88.8	20.8427	30.2979	12.5488	32.3130	24.6008	14.4954	8.3507
89.0	22.1106	33.0637	12.7909	35.3943	26.2594	14.8584	8.4097
89.2	23.5206	36.2846	13.0349	38.9730	28.1087	15.2228	8.4648
89.4	25.0948	40.0604	13.2821	43.1443	30.1778	15.5870	8.5161
89.6	26.8594	44.5148	13.5346	48.0188	32.5016	15.9493	8.5637
89.7	27.8227	47.0432	13.6638	50.7581	33.7717	16.1290	8.5864
89.8	28.8459	49.8012	13.7955	53.7210	35.1218	16.3073	8.6082
89.9	29.9341	52.8140	13.9302	56.9250	36.5585	16.4837	8.6294
90.0	31.0928	56.1091	14.0687	60.3883	38.0892	16.6579	8.6501

APPENDIX B

Results of the HIS Evaluations

The next 12 Figures and Tables contain the detailed results of the HARTCODE simulations and the HIS measurements. Because of the large amount of information to be displayed the plots are complex. For the more comfortable scaling of the graphs the comparisons were based on the brightness temperatures.

Thick curves in the main plots are the HIS measurements and the thin ones are the HARTCODE results.

The dashed liens in the main plots (if there are any) indicate the upper or lower boundary temperatures.

Each plot contain a small "window" where the differences between the measured and simulated brightness temperatures have been plotted in different scale. (Solid lines : HIS - HARTCODE , dotted lines : HIS - FASCODE). In the vertical axes (in the right) one division is always one degree and only the reference value (zero degree) is indicated.

The bars just above the wave number axes indicate the spectral intervals where the average error of HARTCODE is less than the one of the FASCODE.

The numerical results are summarized in the Tables following the Figures. For a given Figure the corresponding Table is marked with the same number.

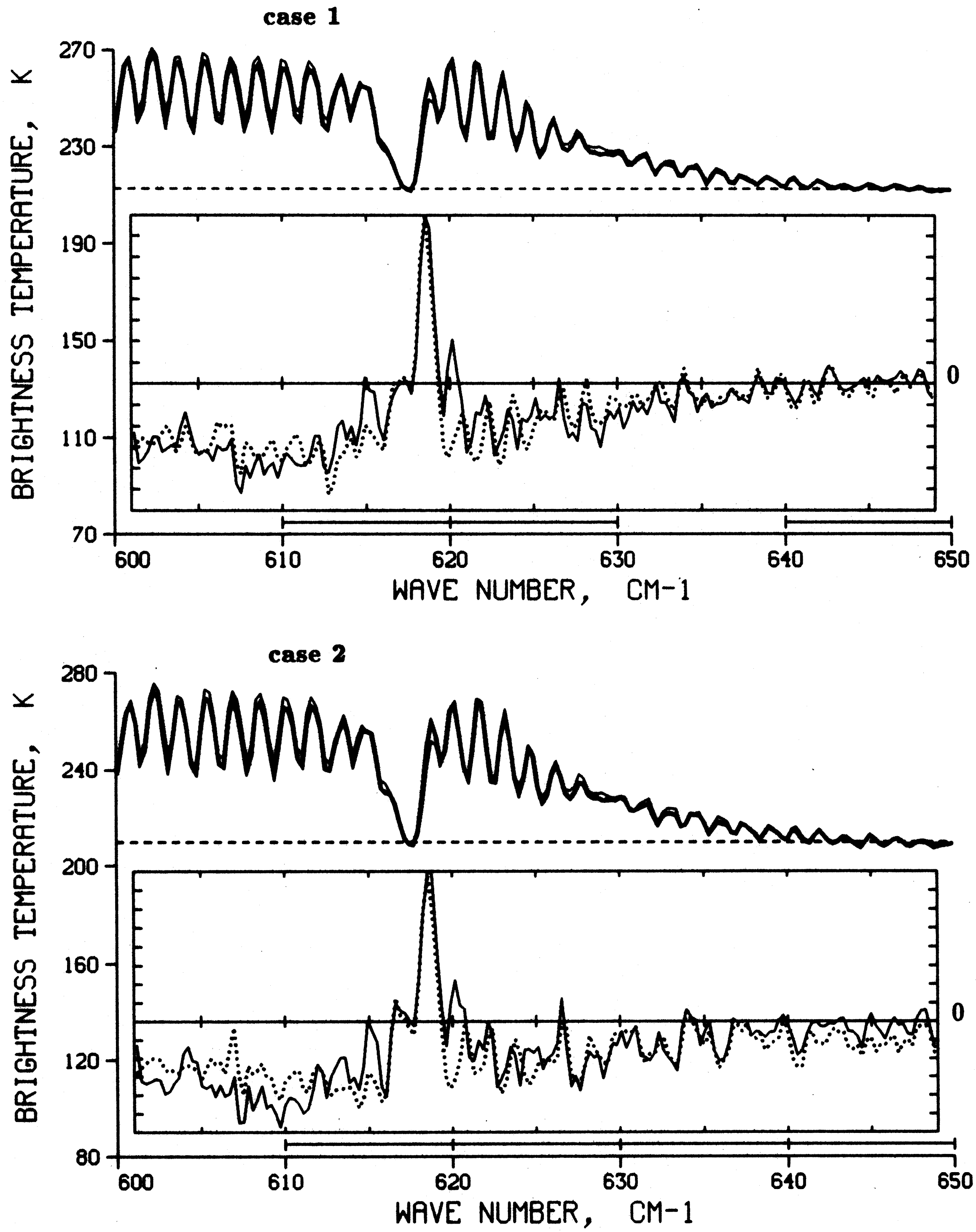
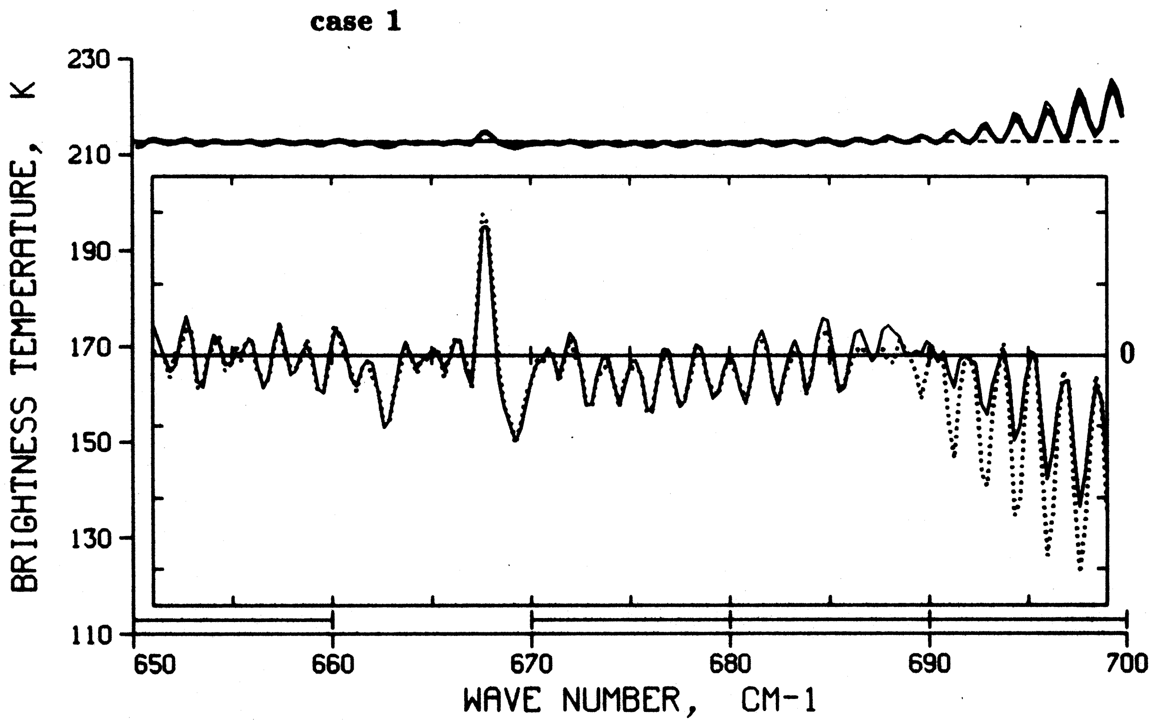


Fig. B-1 : HARTCODE simulations in the 600-700 cm^{-1} spectral region.


case 1
230
210
190
170
150
130
110
BRIGHTNESS TEMPERATURE, K
0
650
660
670
680
690
700
WAVE NUMBER, CM-1

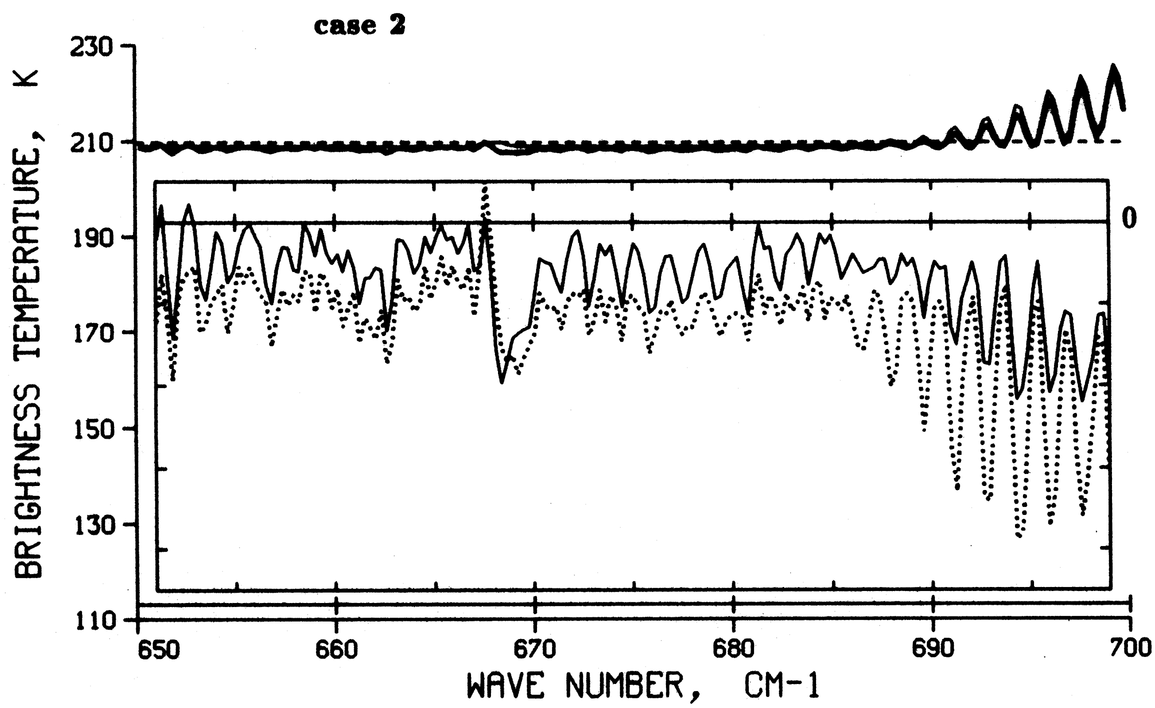
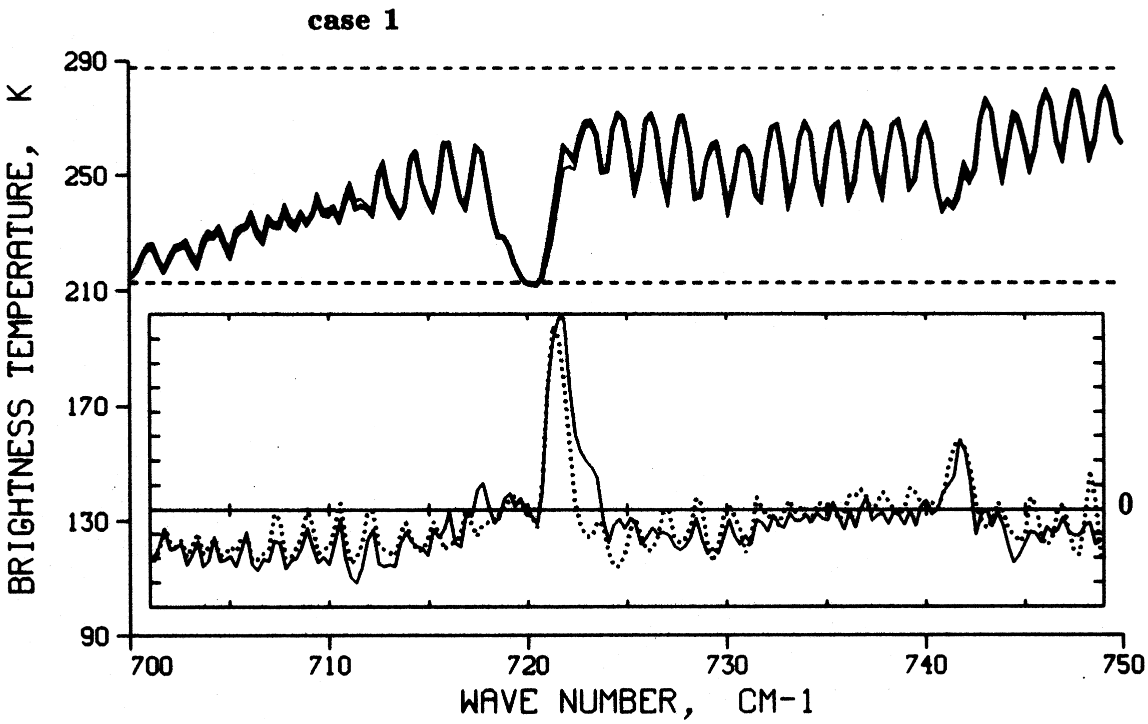

case 2
230
210
190
170
150
130
110
BRIGHTNESS TEMPERATURE, K
0
650
660
670
680
690
700
WAVE NUMBER, CM-1

Fig. B-1 : Cont.



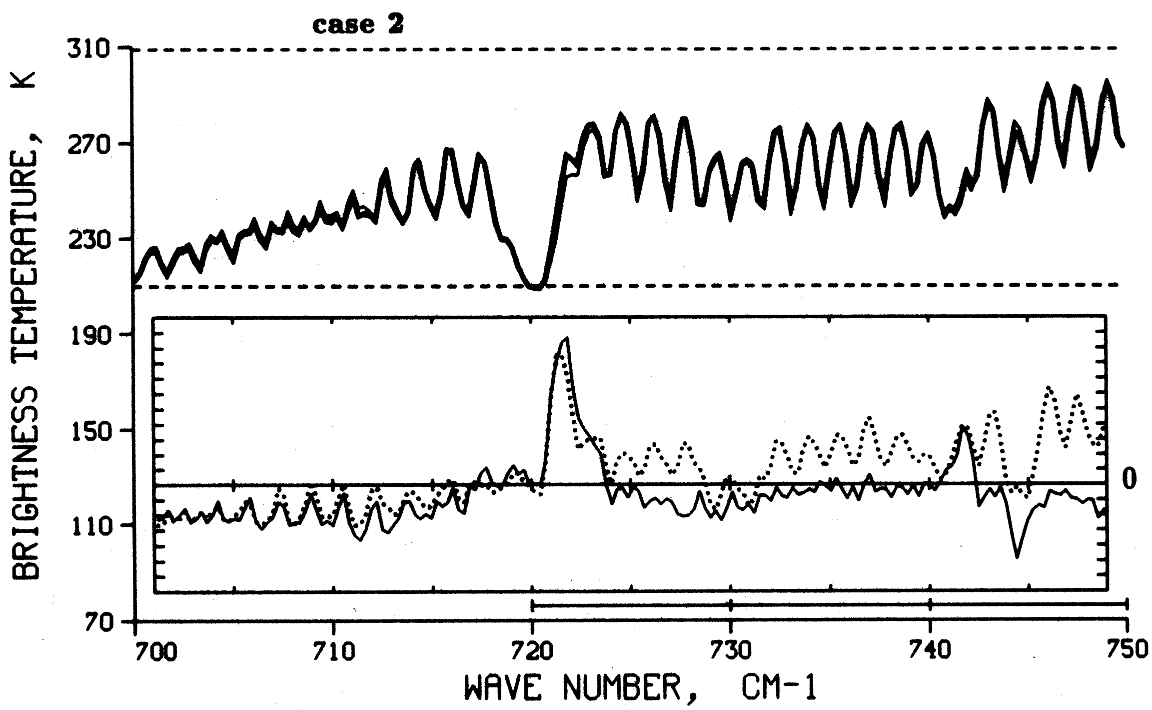
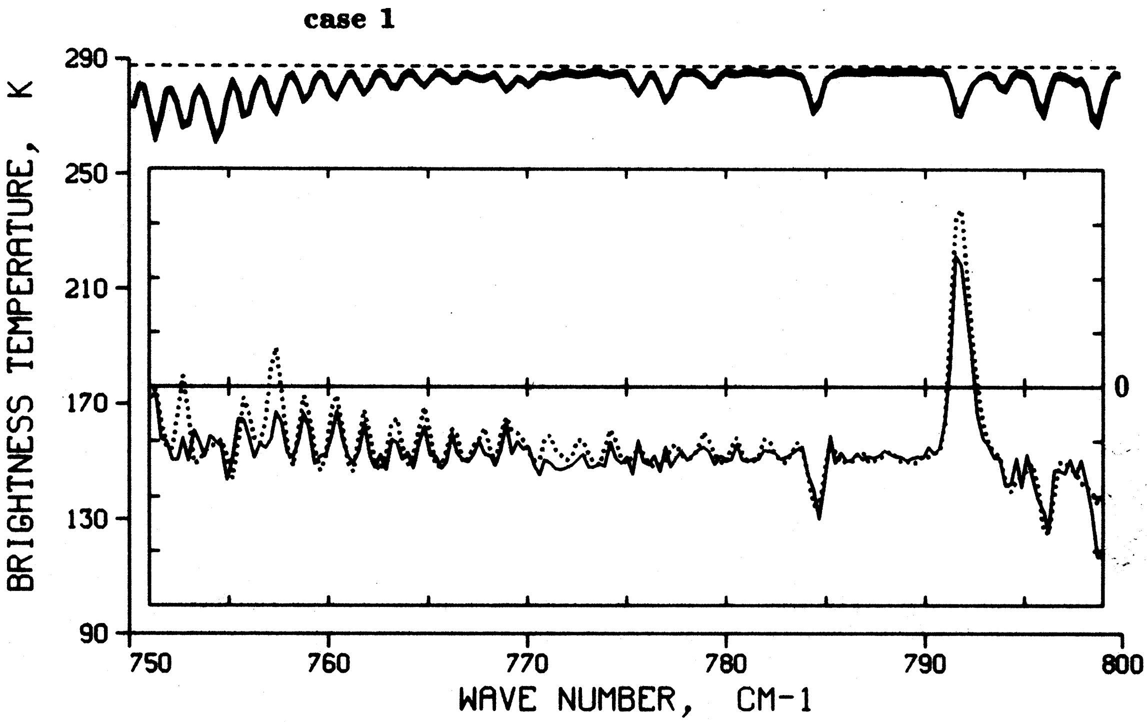


Fig. B-2 : HARTCODE simulations in the 700-800 cm^{-1} spectral region.


case 1
290
250
210
170
130
90
0
750
760
770
780
790
800
WAVE NUMBER, CM-1
BRIGHTNESS TEMPERATURE, K

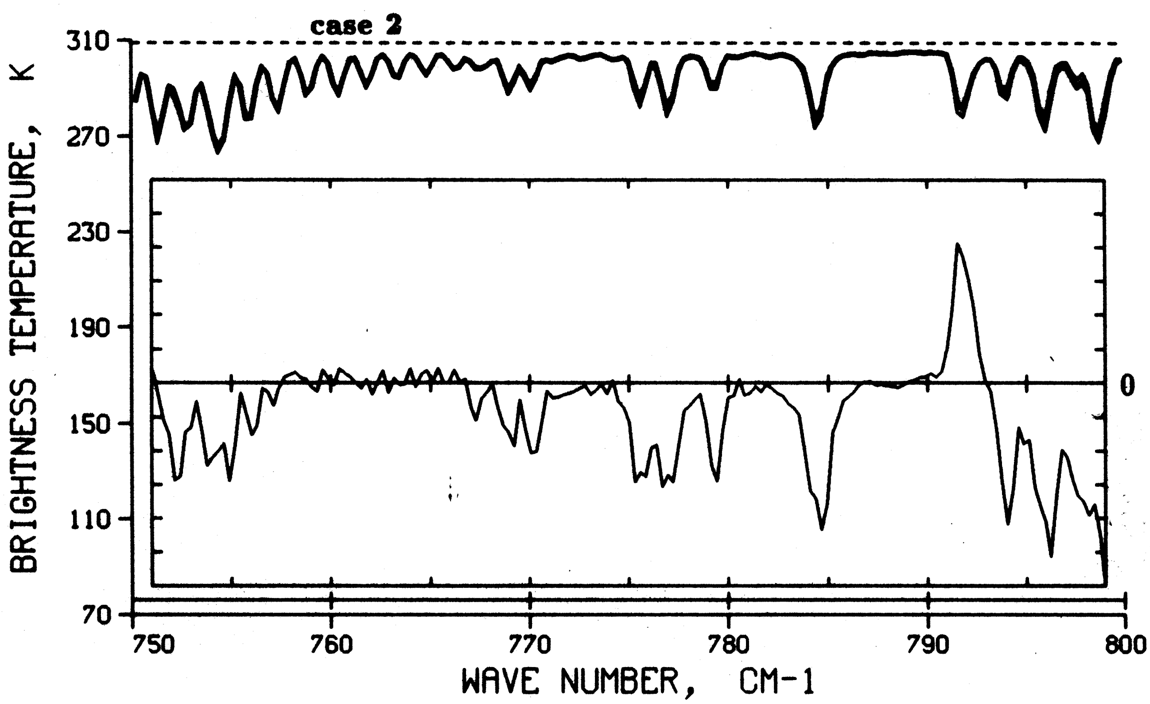

case 2
310
270
230
190
150
110
70
0
750
760
770
780
790
800
WAVE NUMBER, CM-1
BRIGHTNESS TEMPERATURE, K

Fig. B-2 : Cont.

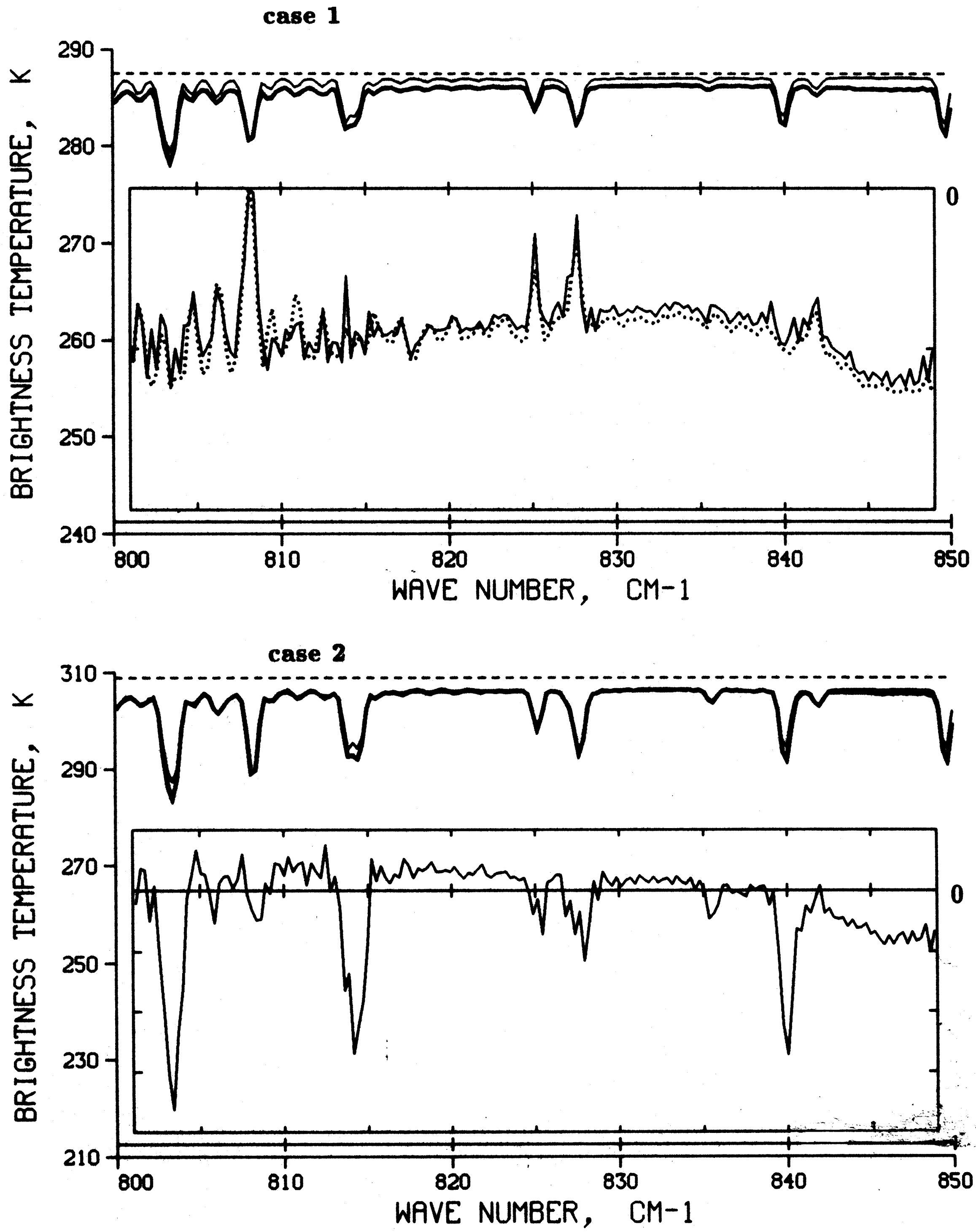
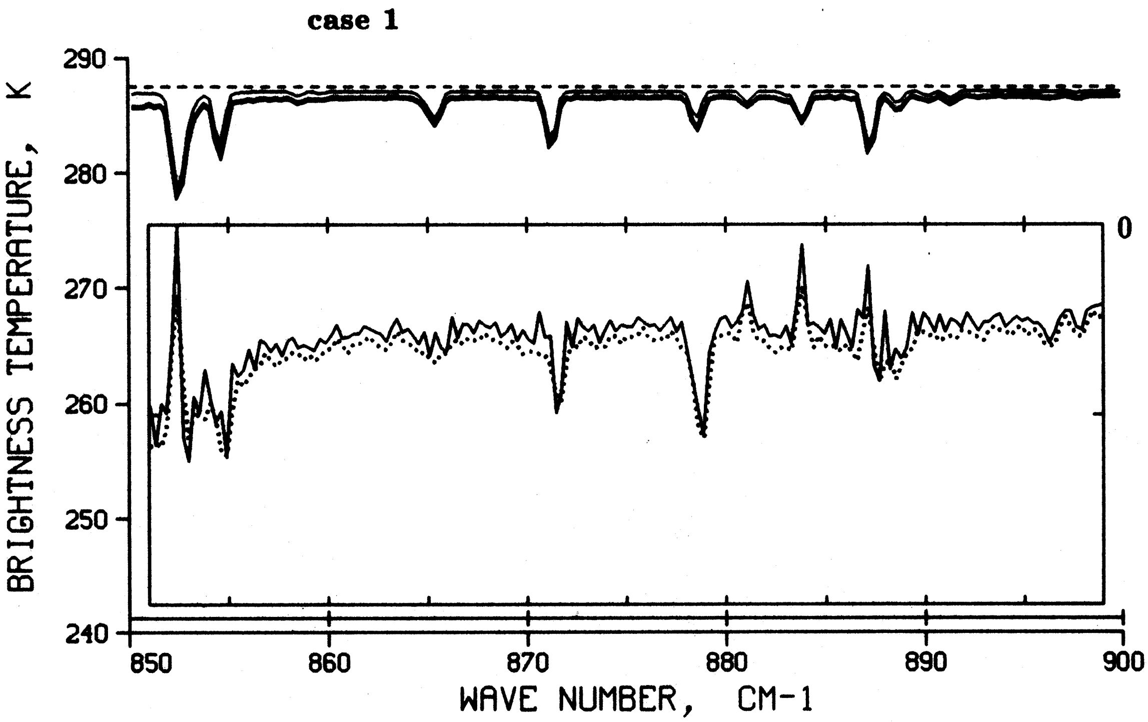


Fig. B-3 : HARTCODE simulations in the 800-900 cm^{-1} spectral region.


case 1
290
280
270
260
250
240
0
850
860
870
880
890
900
BRIGHTNESS TEMPERATURE, K
WAVE NUMBER, CM-1

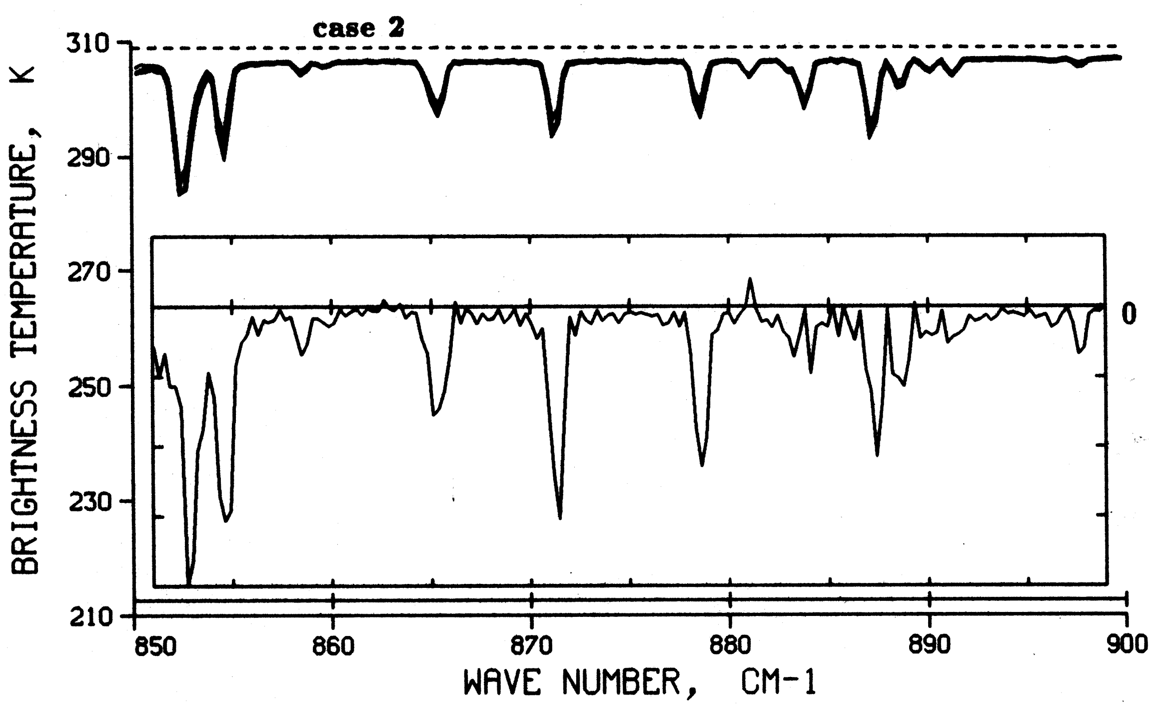

case 2
310
290
270
250
230
210
0
850
860
870
880
890
900
BRIGHTNESS TEMPERATURE, K
WAVE NUMBER, CM-1

Fig. B-3 : Cont.

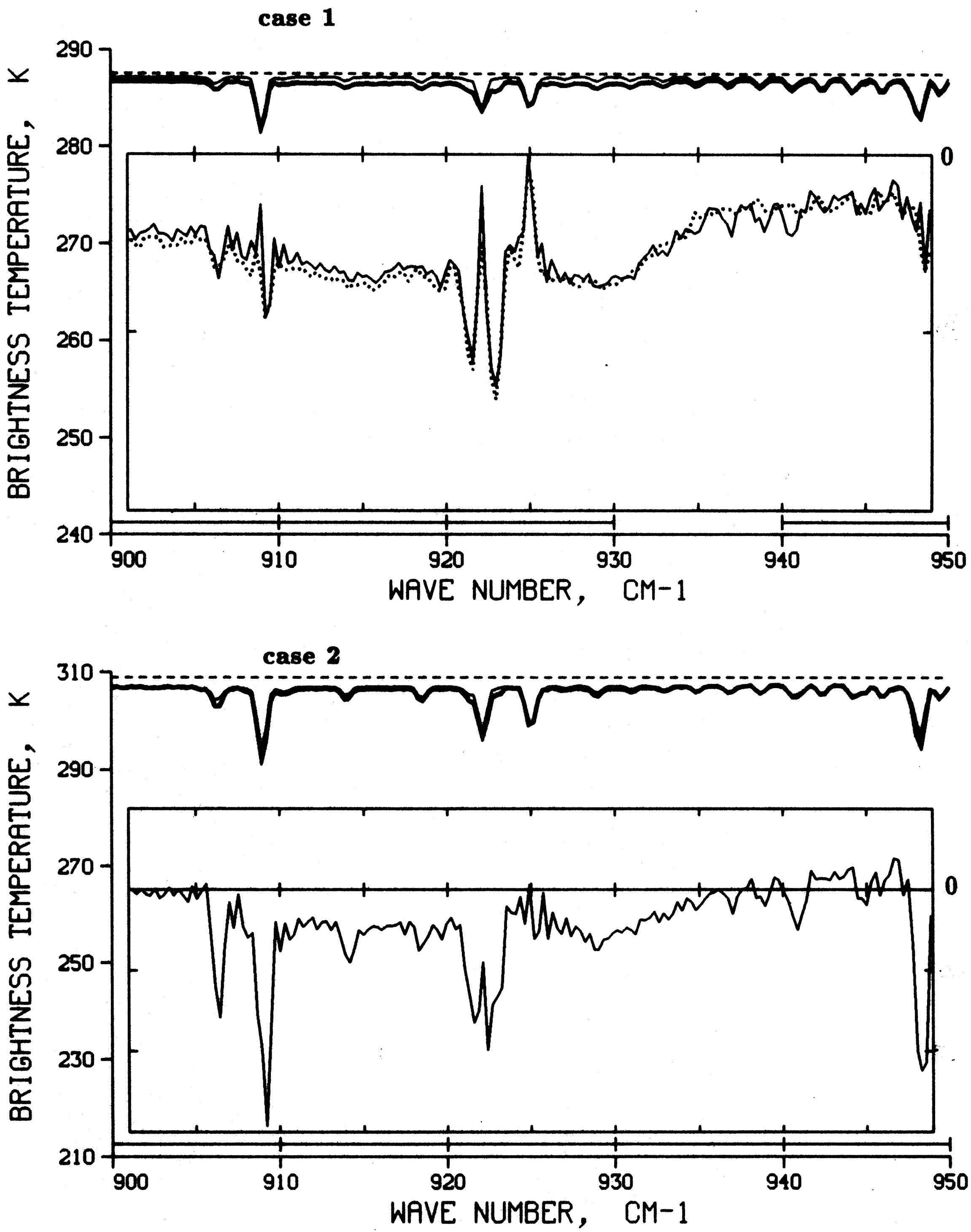
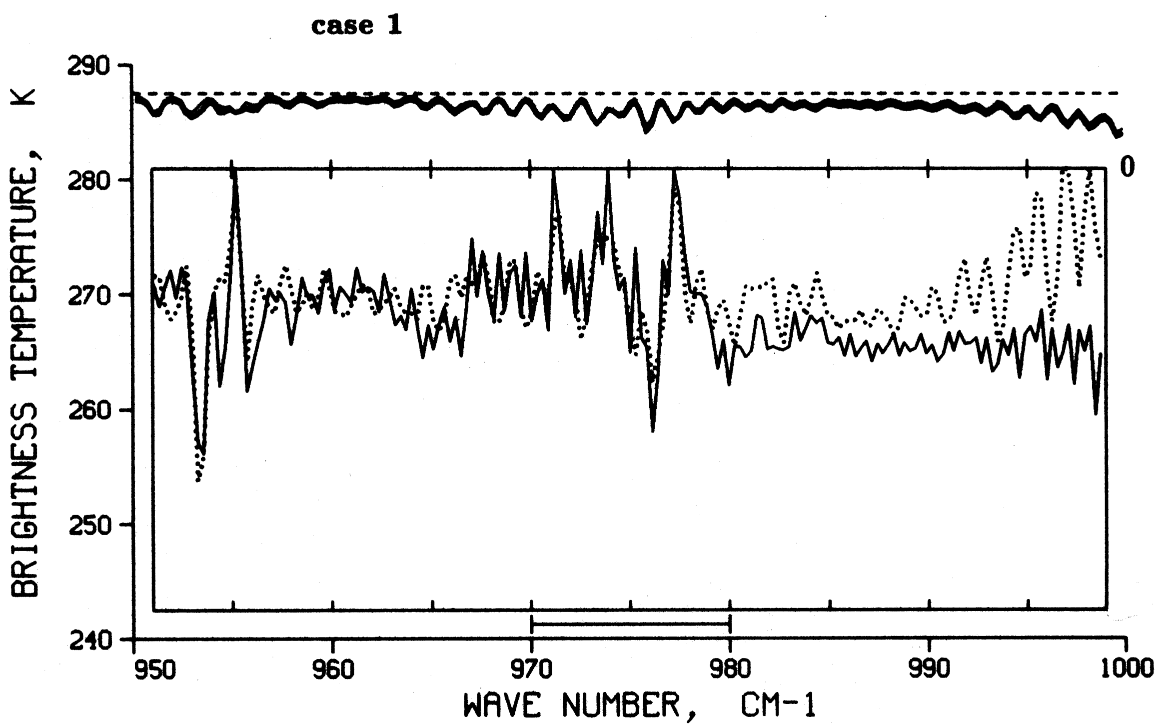
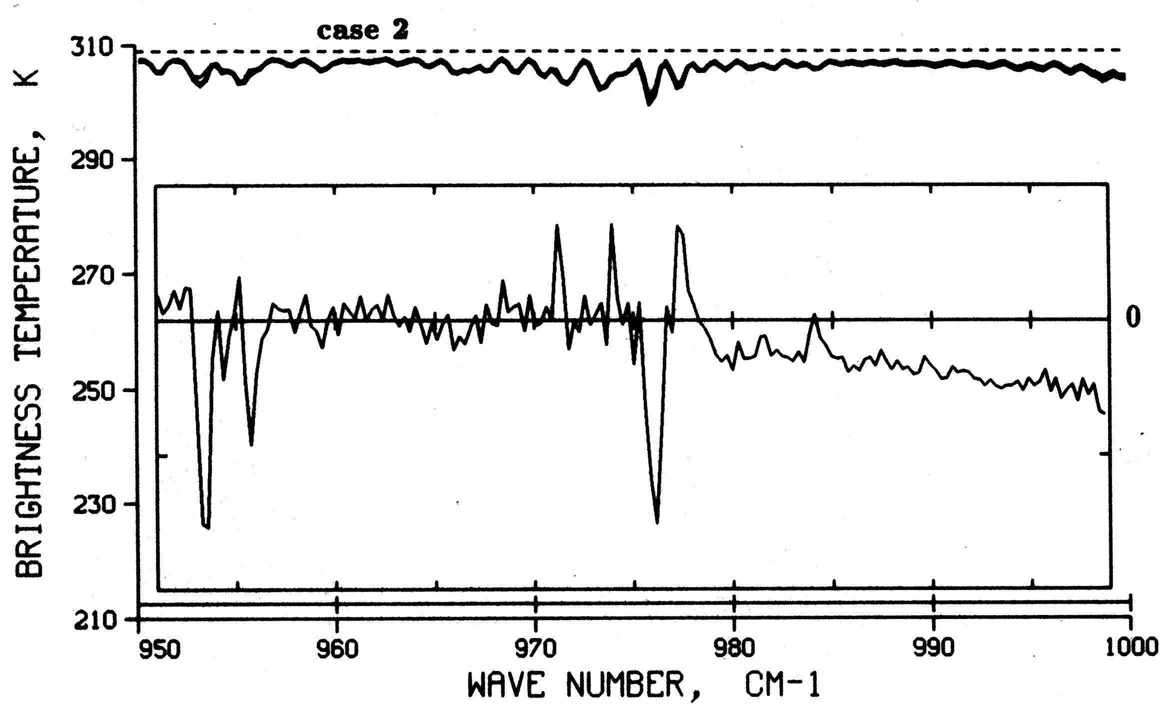


Fig. B-4 : HARTCODE simulations in the 900-1000 cm^{-1} spectral region.



case 1
BRIGHTNESS TEMPERATURE, K
290
280
270
260
250
240
0
950
960
970
980
990
1000
WAVE NUMBER, CM-1



case 2
BRIGHTNESS TEMPERATURE, K
310
290
270
250
230
210
0
950
960
970
980
990
1000
WAVE NUMBER, CM-1

Fig. B-4 : Cont.

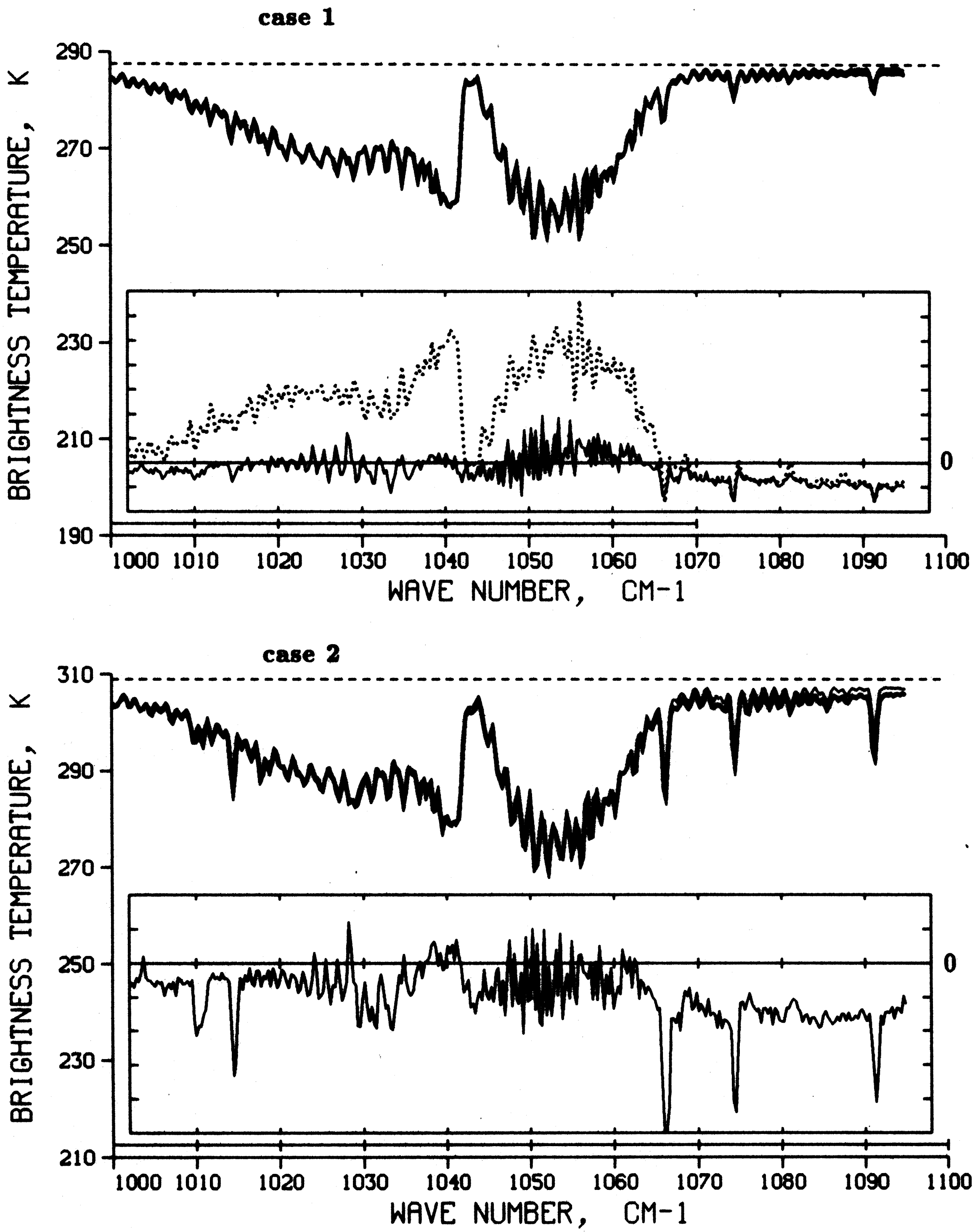


Fig. B-5 : HARTCODE simulations in the 1000-1100 cm^{-1} spectral region.

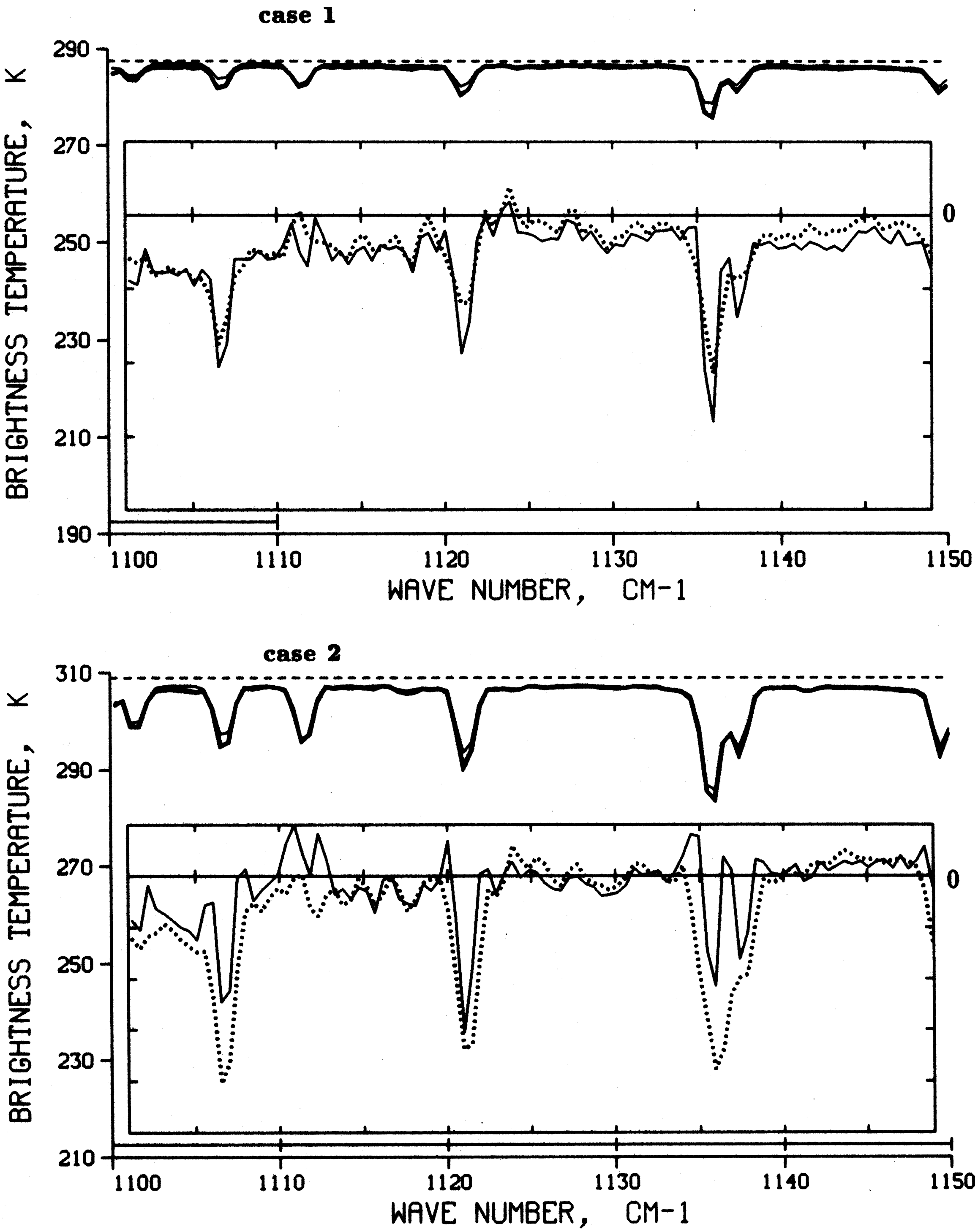


Fig. B-6 : HARTCODE simulations in the 1100-1200 cm^{-1} spectral region.

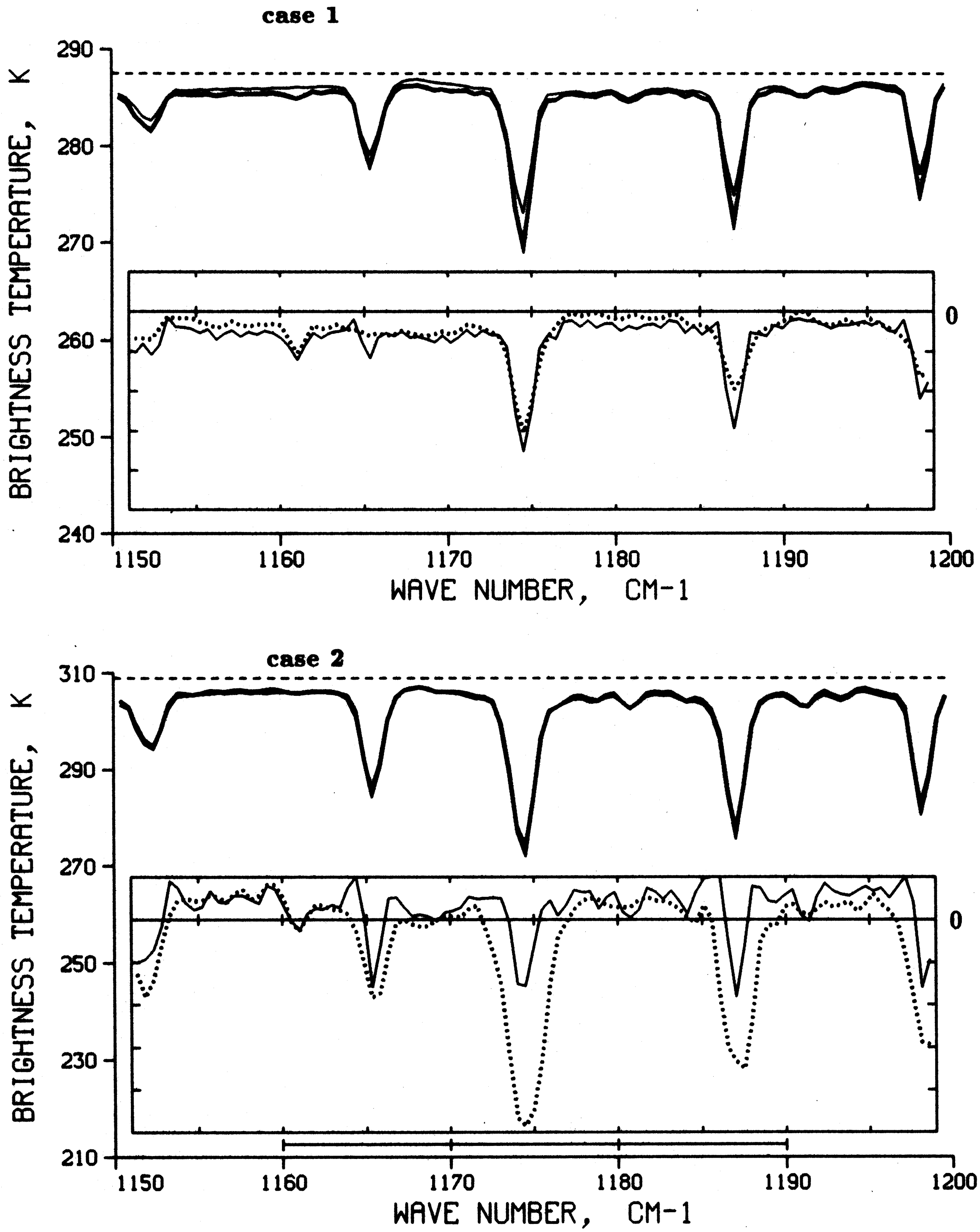

case 1
BRIGHTNESS TEMPERATURE, K
290
280
270
260
250
240
0
1150
1160
1170
1180
1190
1200
WAVE NUMBER, CM-1
case 2
BRIGHTNESS TEMPERATURE, K
310
290
270
250
230
210
0
1150
1160
1170
1180
1190
1200
WAVE NUMBER, CM-1

Fig. B-6 : Cont.

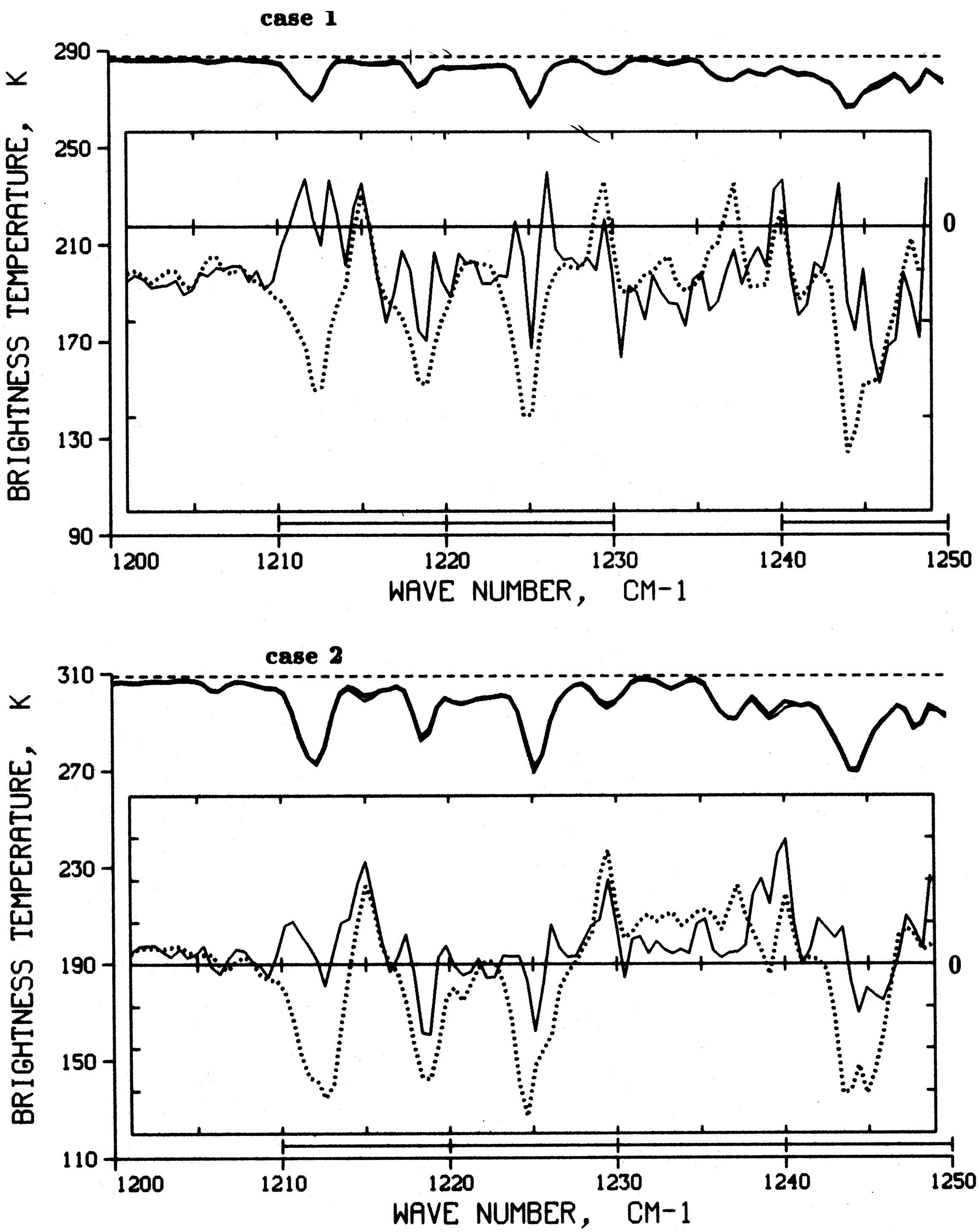
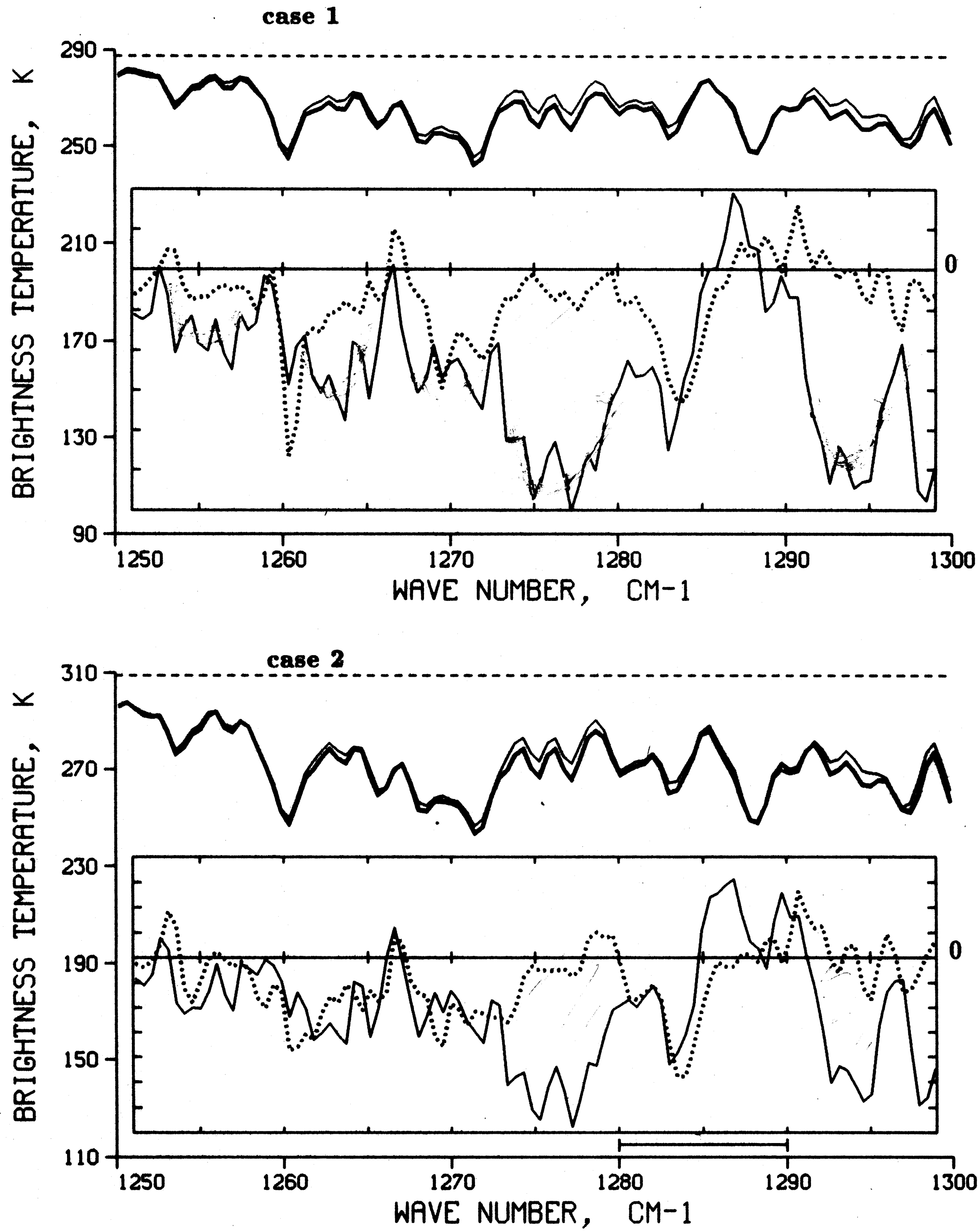
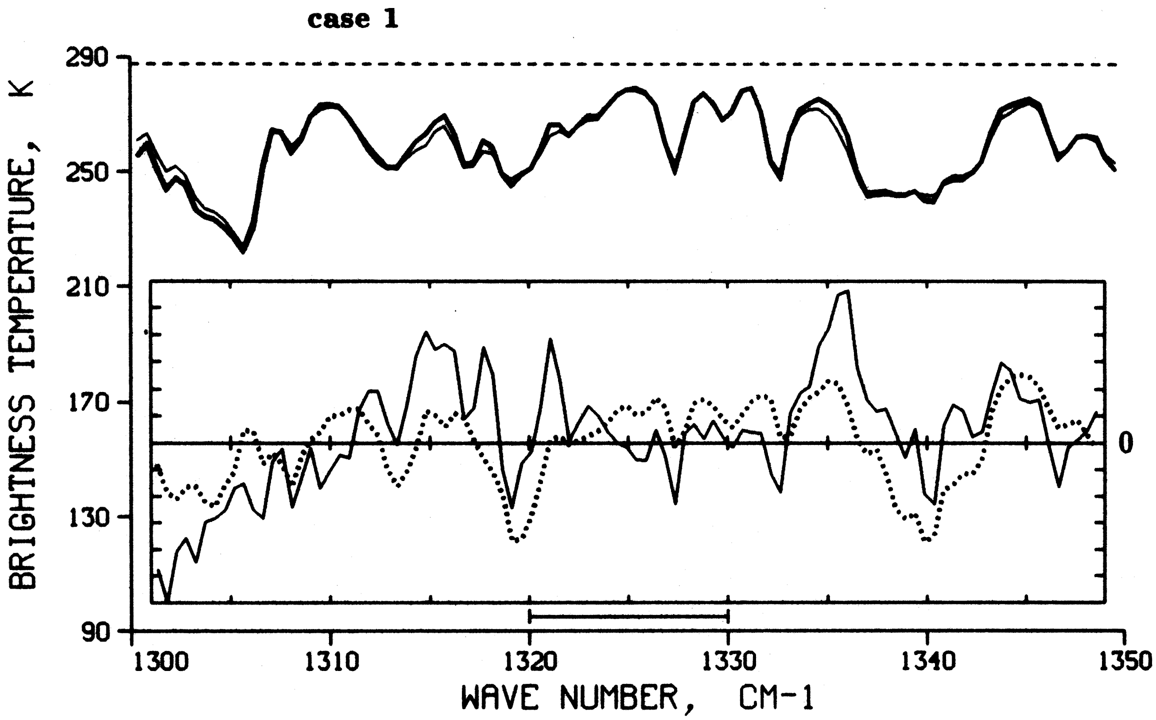


Fig. B-7 : HARTCODE simulations in the 1200-1300 cm^{-1} spectral region.



case 1
290
250
210
170
130
90
0
BRIGHTNESS TEMPERATURE, K
1250
1260
1270
1280
1290
1300
WAVE NUMBER, CM-1
case 2
310
270
230
190
150
110
0
BRIGHTNESS TEMPERATURE, K
1250
1260
1270
1280
1290
1300
WAVE NUMBER, CM-1

Fig. B-7 : Cont.



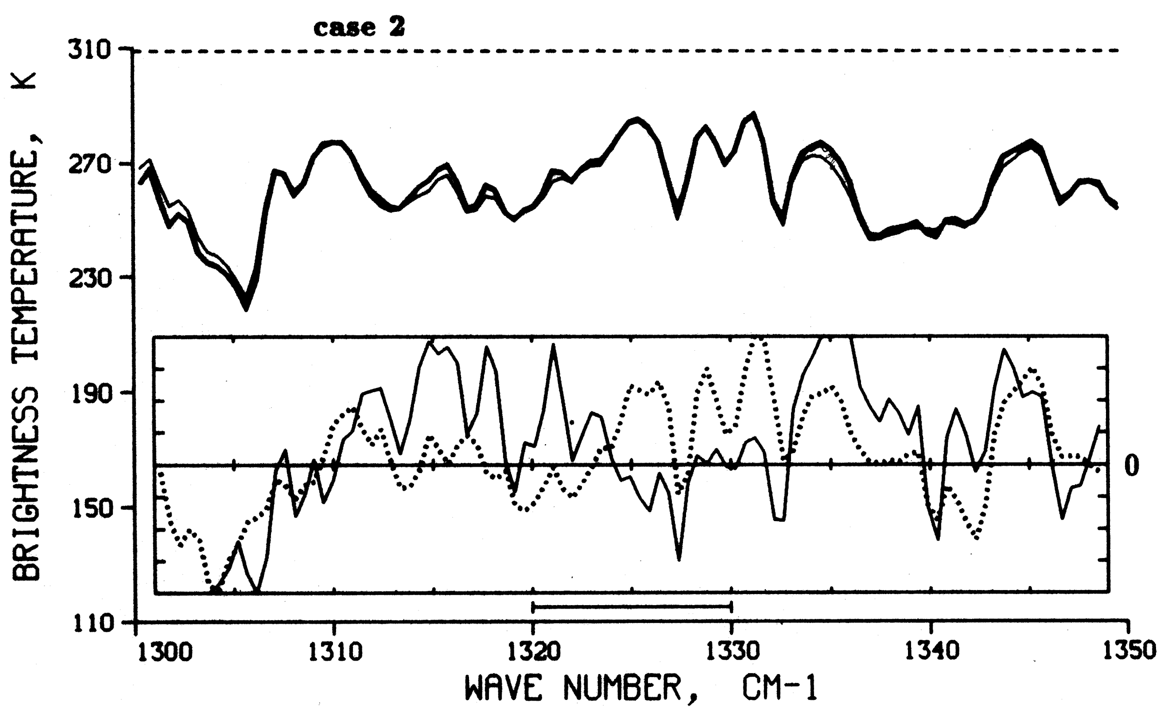
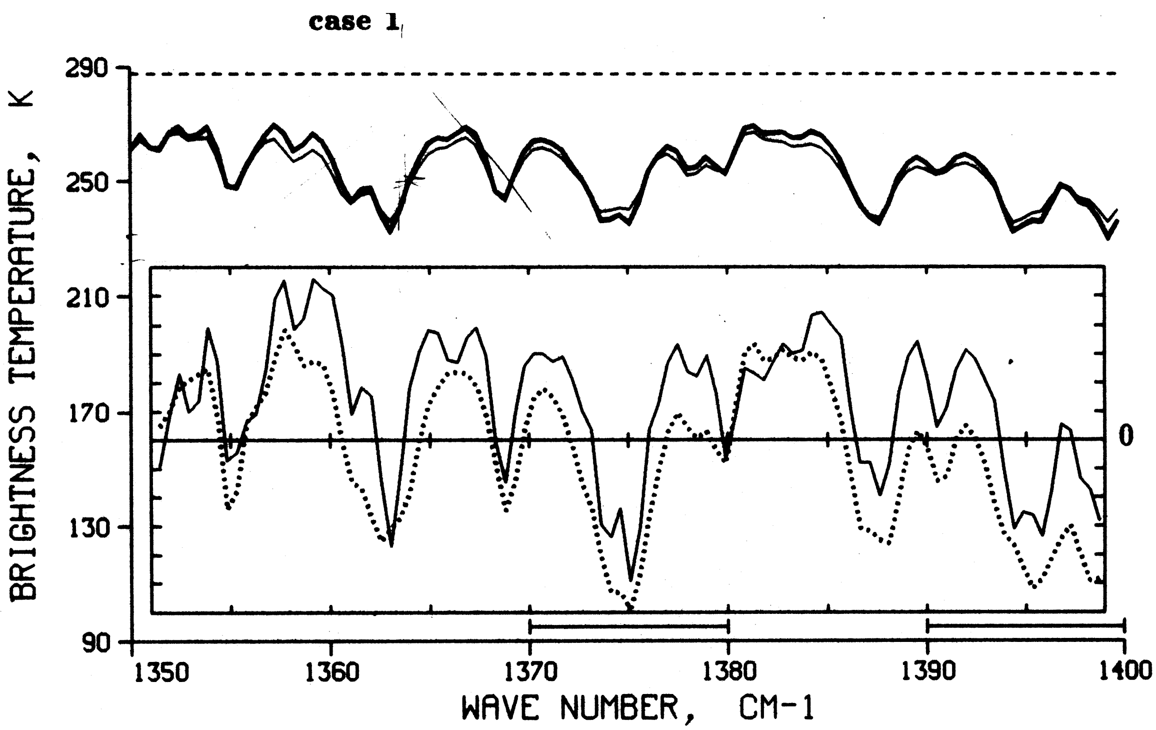


Fig. B-8 : HARTCODE simulations in the 1300-1400 cm^{-1} spectral region.


case 1
BRIGHTNESS TEMPERATURE, K
290
250
210
170
130
90
0
1350
1360
1370
1380
1390
1400
WAVE NUMBER, CM-1

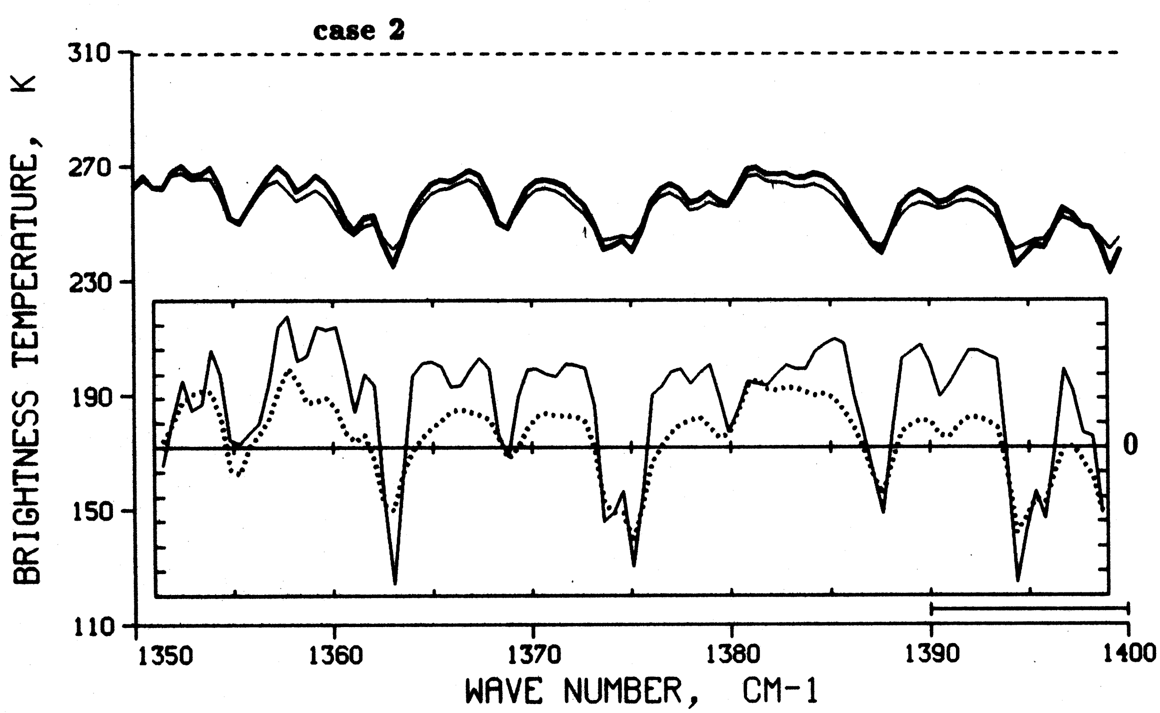
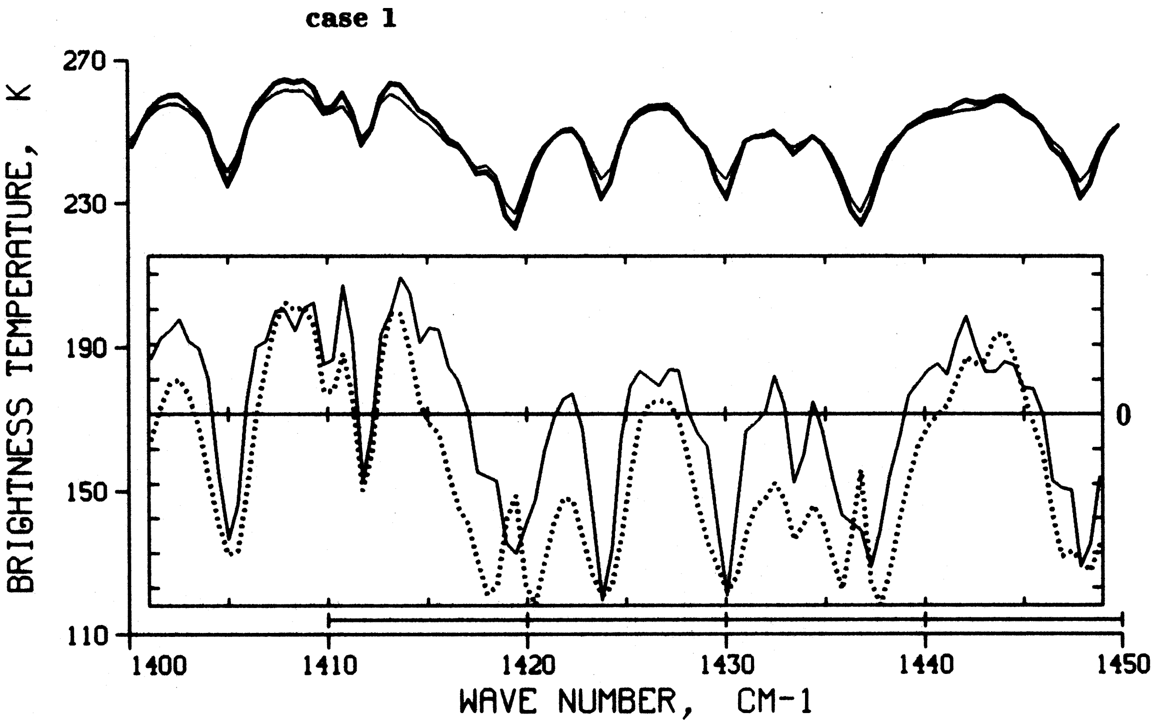

case 2
BRIGHTNESS TEMPERATURE, K
310
270
230
190
150
110
0
1350
1360
1370
1380
1390
1400
WAVE NUMBER, CM-1

Fig. B-8 : Cont.



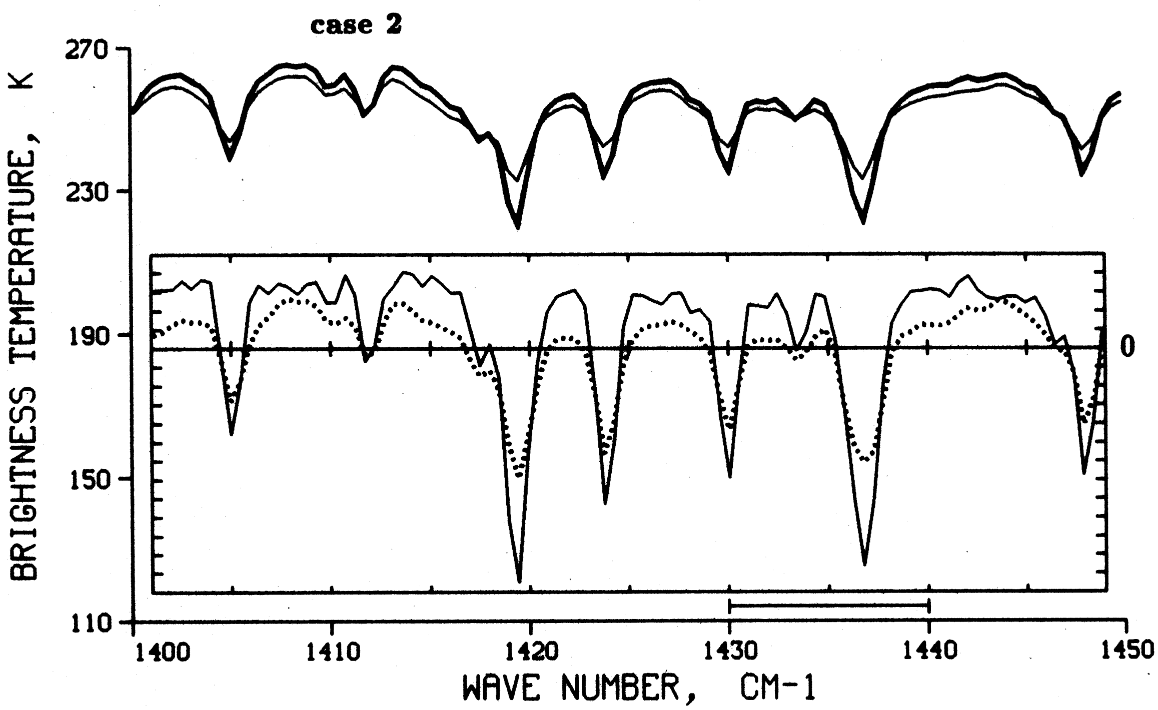


Fig. B-9 : HARTCODE simulations in the 1400-1500 cm^{-1} spectral region.

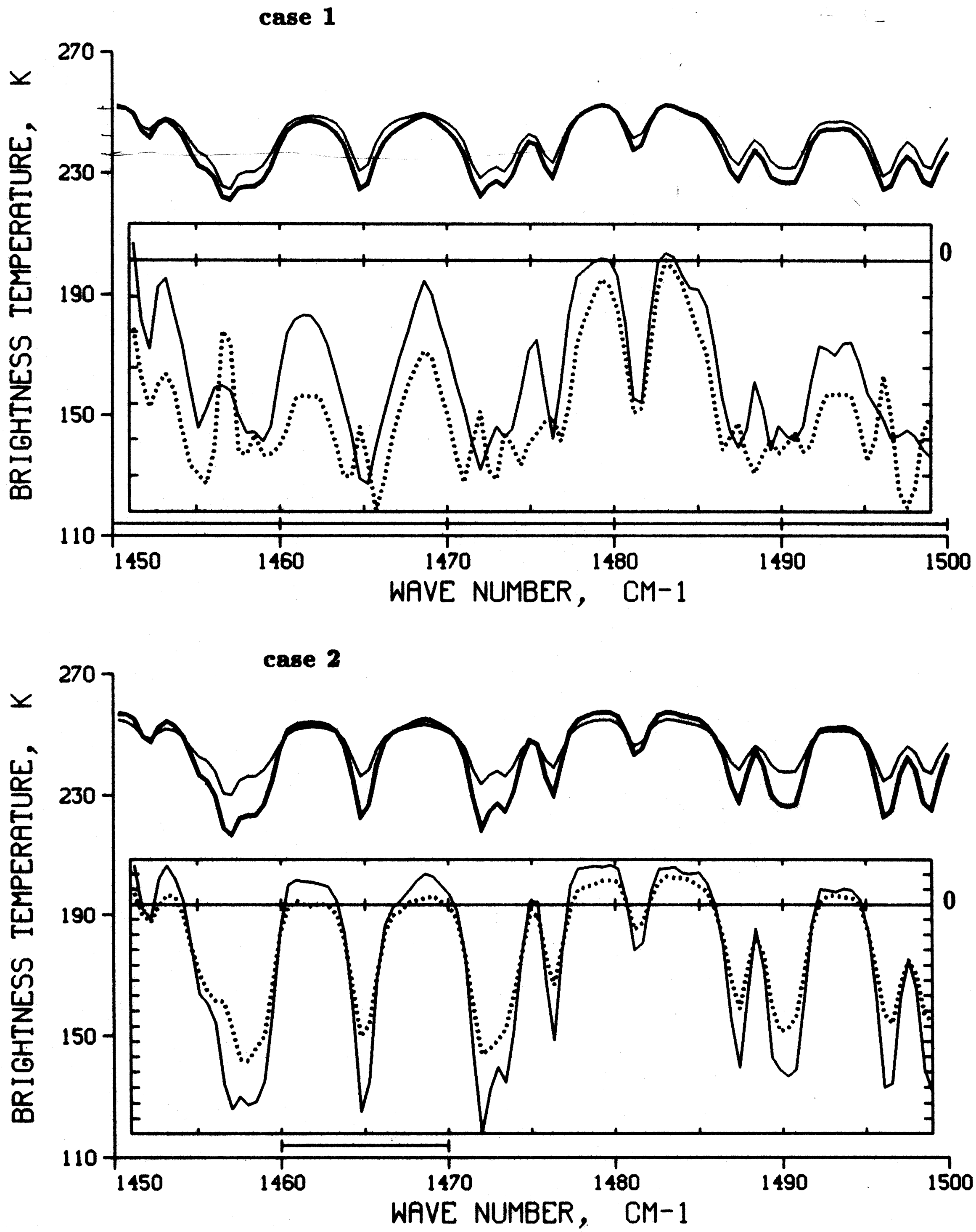

case 1
270
230
190
150
110
0
BRIGHTNESS TEMPERATURE, K
1450
1460
1470
1480
1490
1500
WAVE NUMBER, CM-1
case 2
270
230
190
150
110
0
BRIGHTNESS TEMPERATURE, K
1450
1460
1470
1480
1490
1500
WAVE NUMBER, CM-1

Fig. B-9 : Cont.

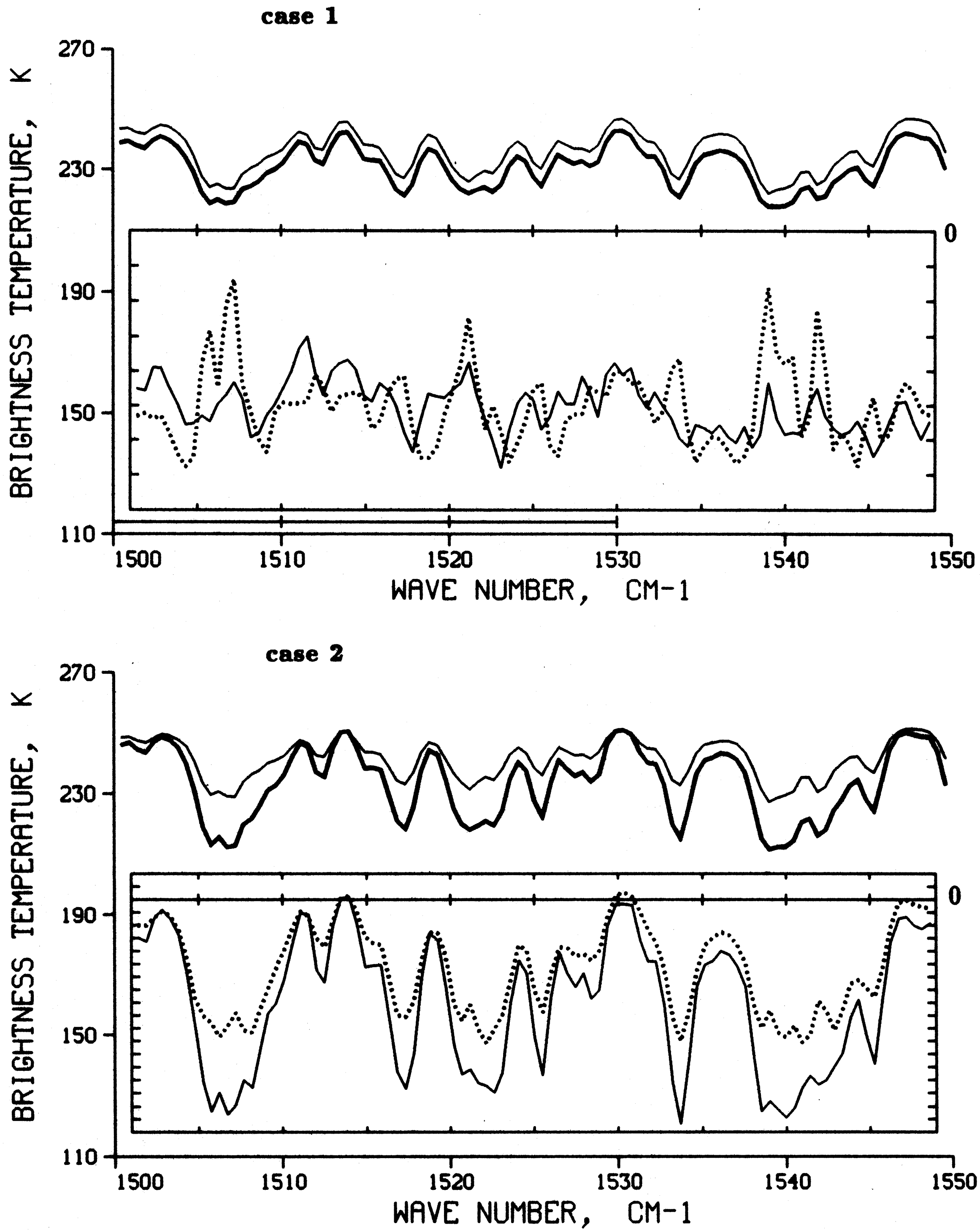
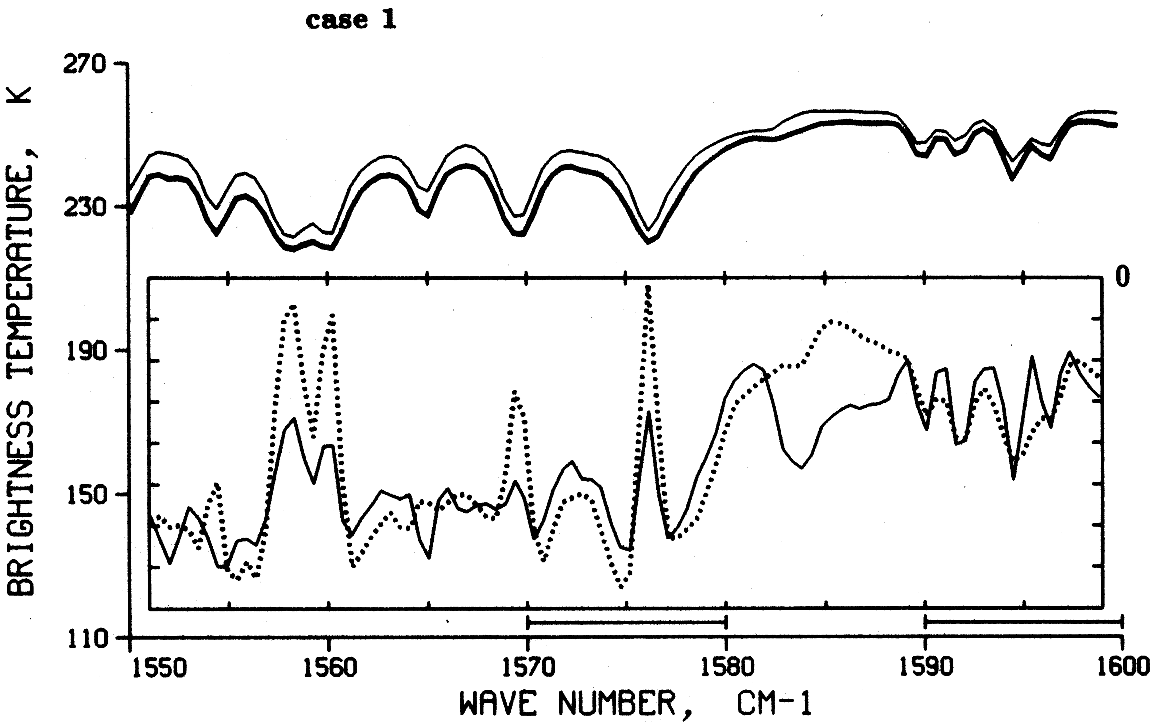


Fig. B-10 : HARTCODE simulations in the 1500-1600 cm^{-1} spectral region.


case 1
270
230
190
150
110
0
BRIGHTNESS TEMPERATURE, K
1550
1560
1570
1580
1590
1600
WAVE NUMBER, CM-1

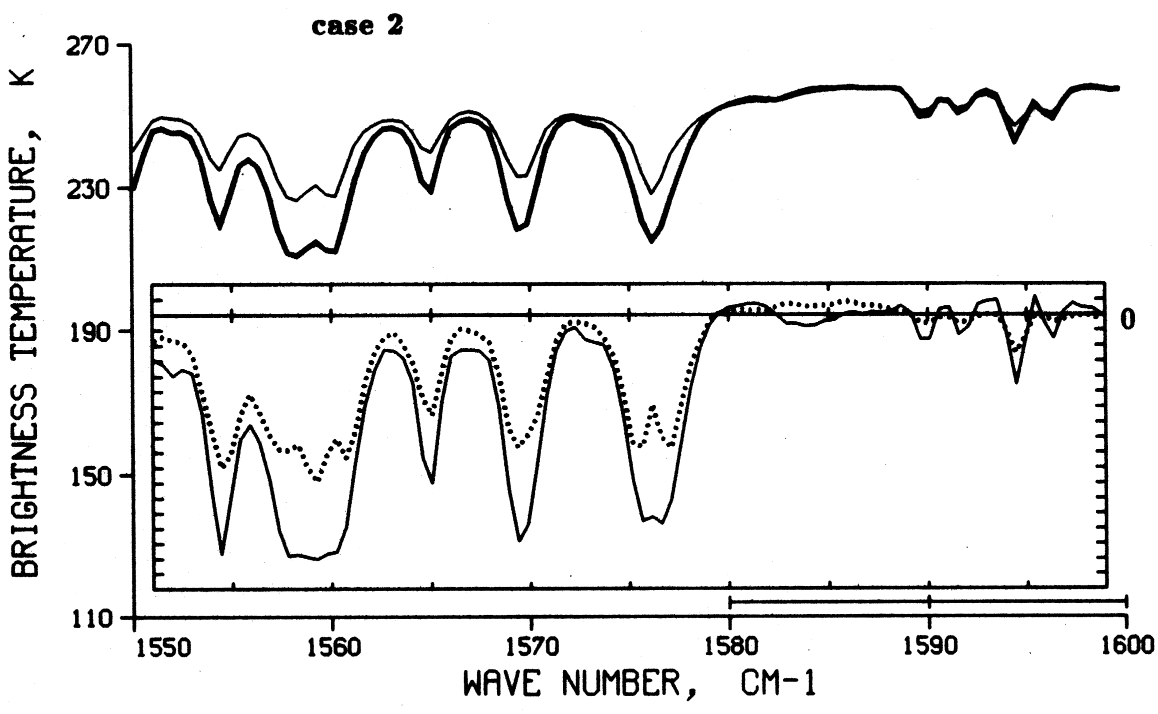

case 2
270
230
190
150
110
0
BRIGHTNESS TEMPERATURE, K
1550
1560
1570
1580
1590
1600
WAVE NUMBER, CM-1

Fig. B-10 : Cont.

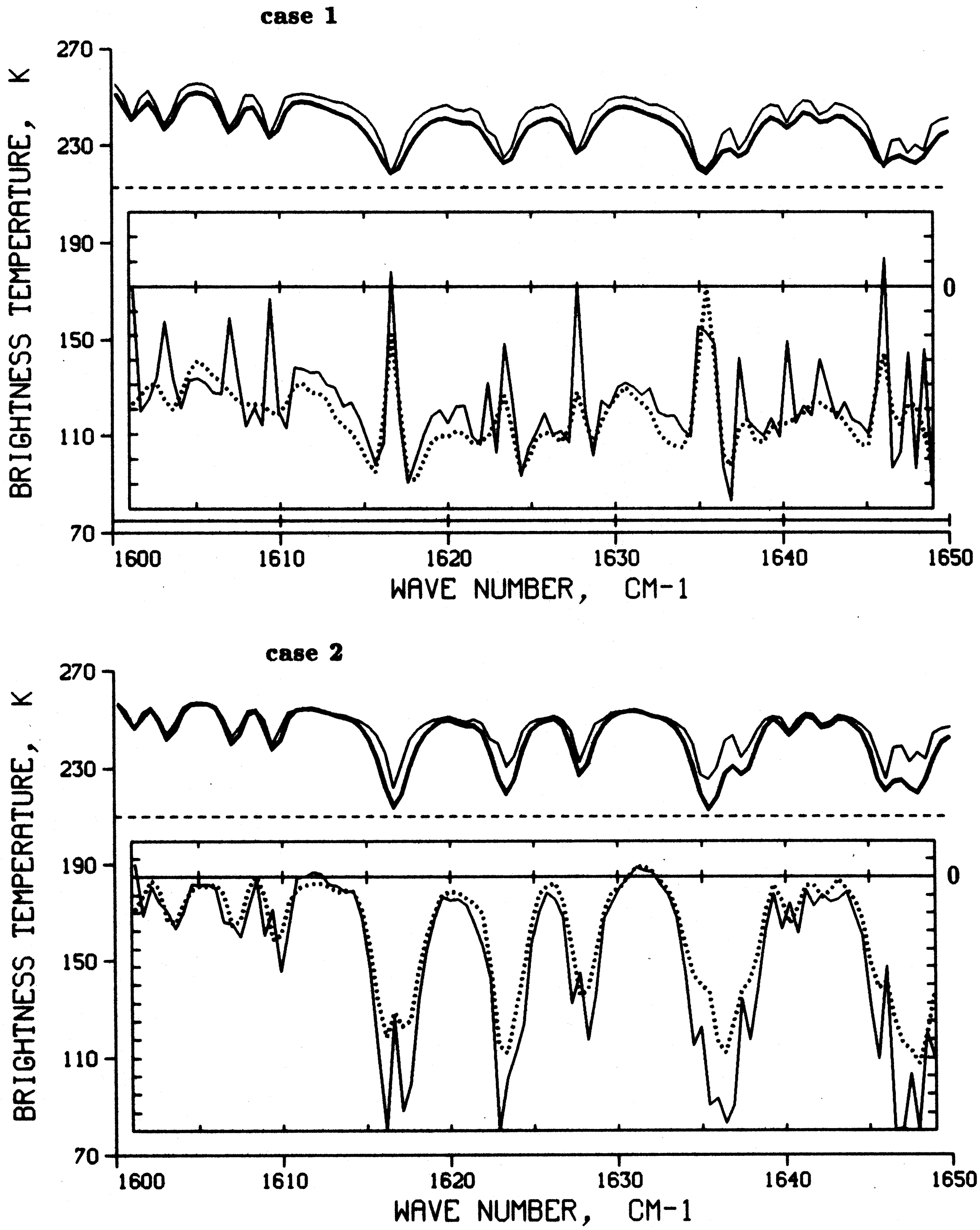
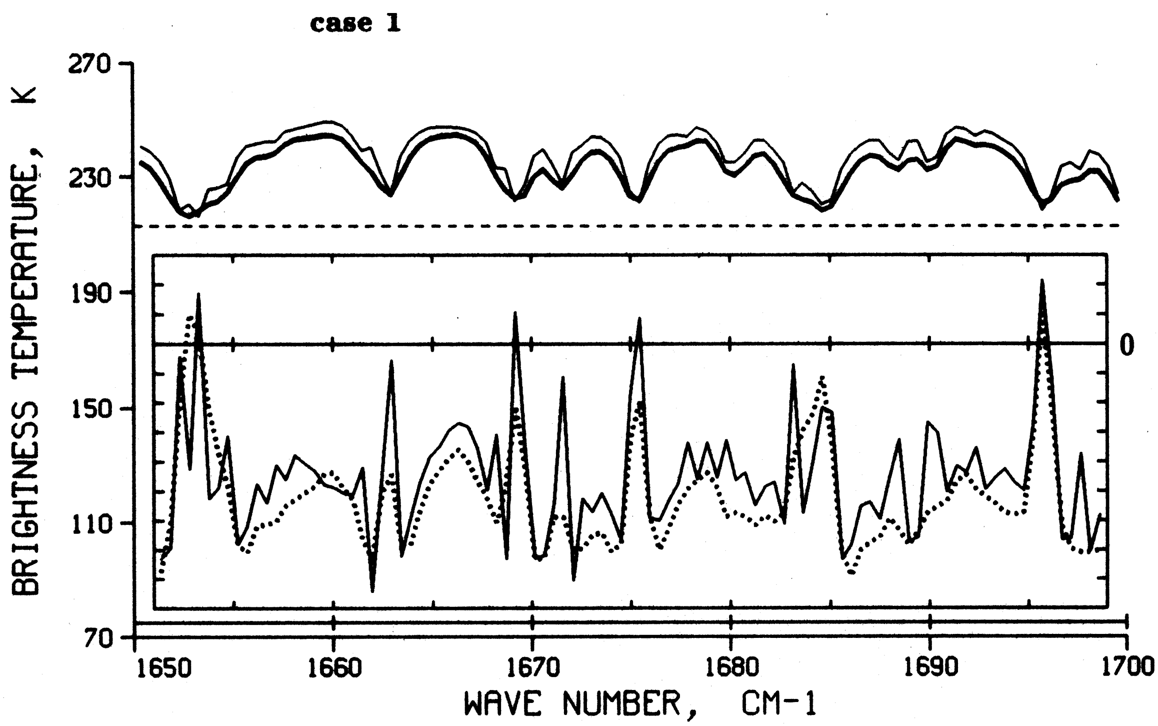
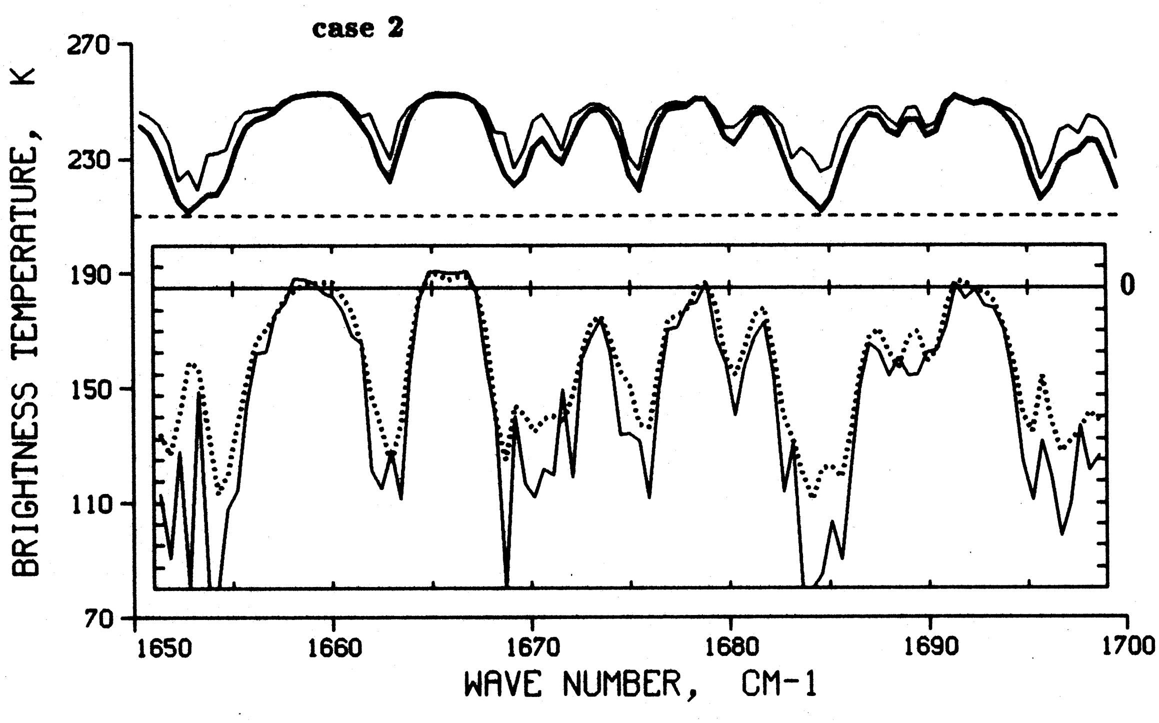


Fig. B-11 : HARTCODE simulations in the 1600-1700 cm^{-1} spectral region.

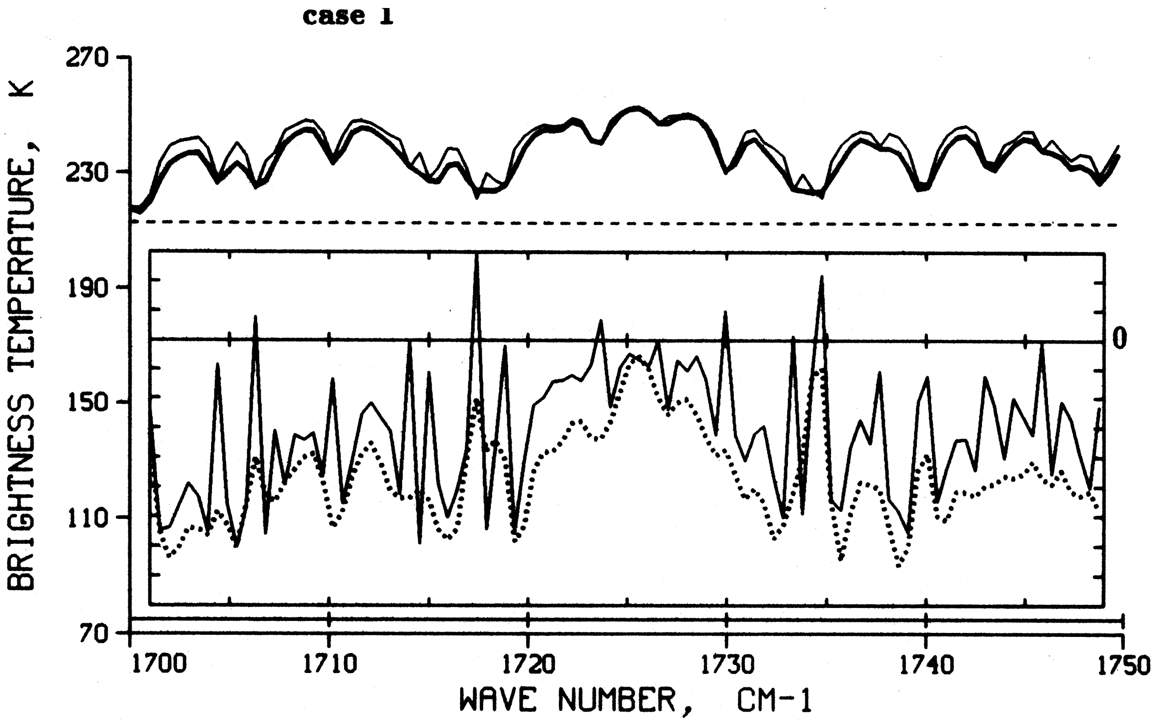


case 1
270
230
190
150
110
70
0
BRIGHTNESS TEMPERATURE, K
1650
1660
1670
1680
1690
1700
WAVE NUMBER, CM-1



case 2
270
230
190
150
110
70
0
BRIGHTNESS TEMPERATURE, K
1650
1660
1670
1680
1690
1700
WAVE NUMBER, CM-1

Fig. B-11 : Cont.



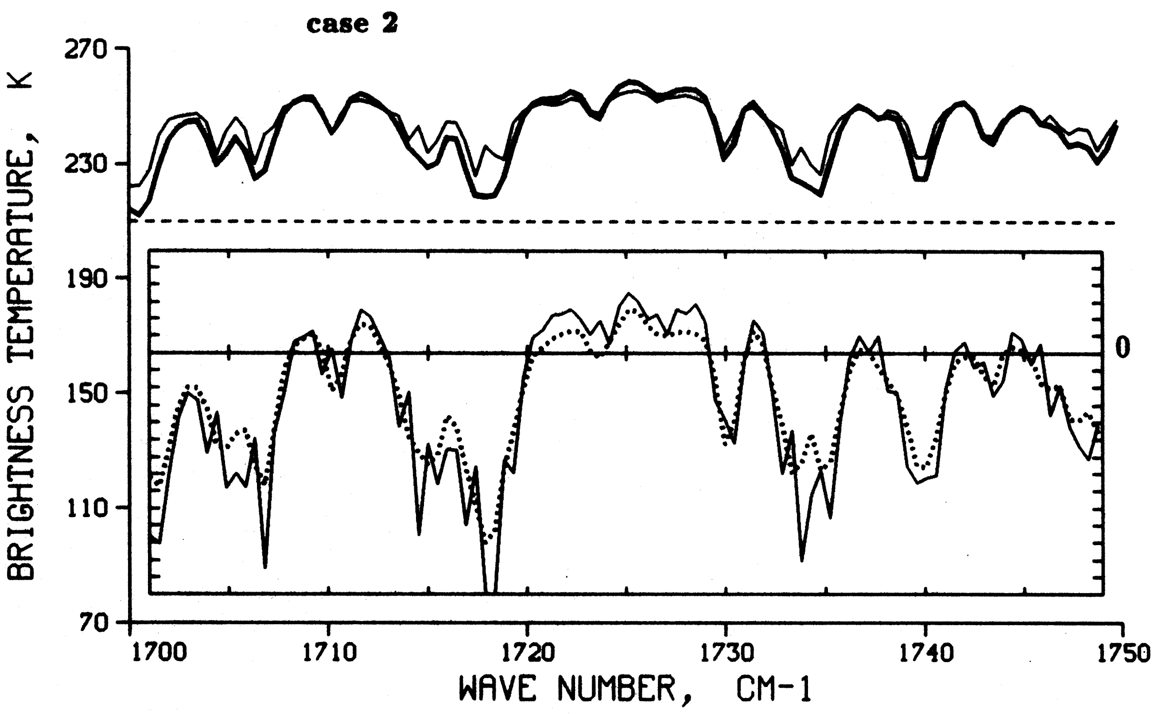


Fig. B-12 : HARTCODE simulations in the 1700-1800 cm^{-1} spectral region.

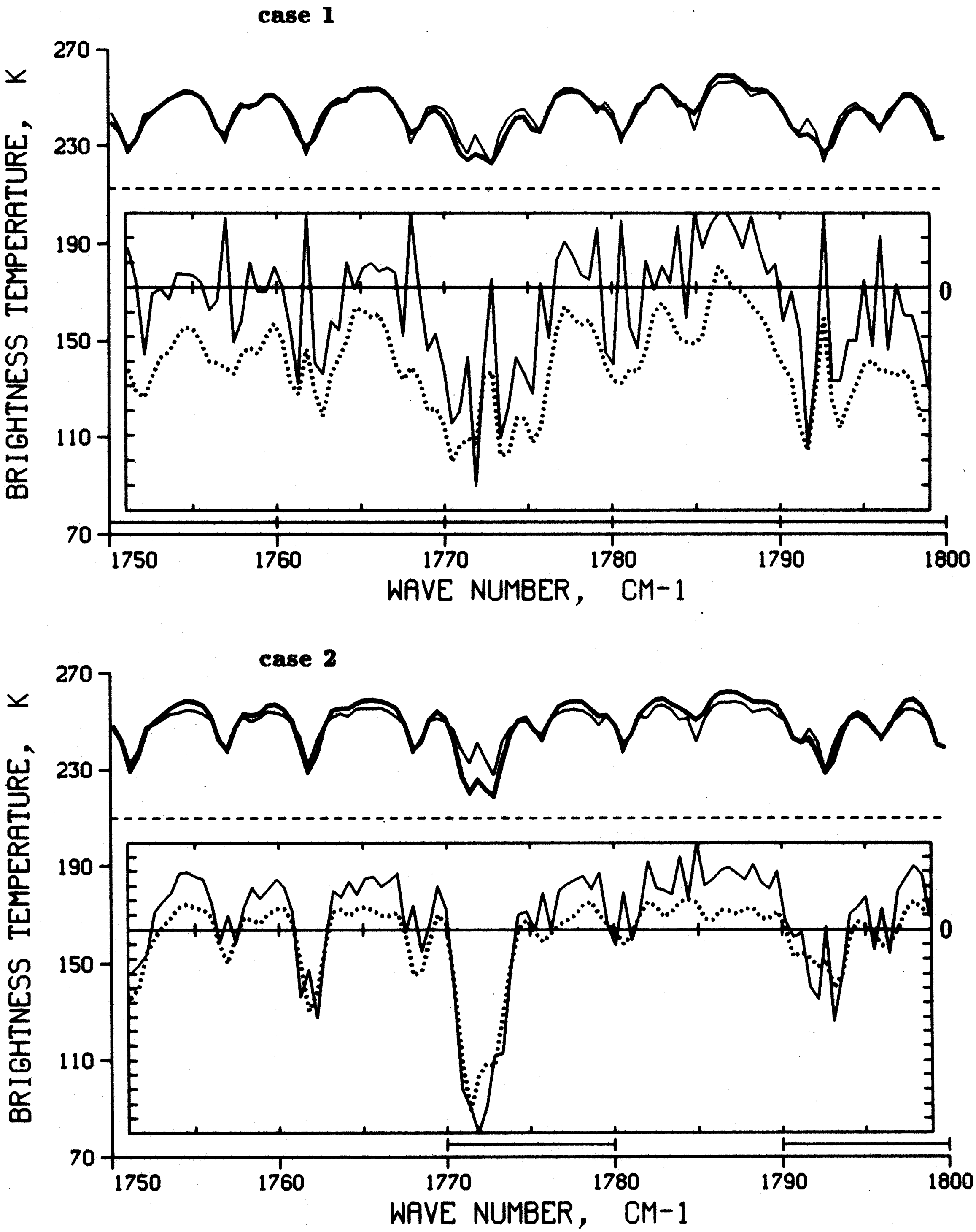

case 1
BRIGHTNESS TEMPERATURE, K
270
230
190
150
110
70
0
1750
1760
1770
1780
1790
1800
WAVE NUMBER, CM-1
case 2
BRIGHTNESS TEMPERATURE, K
270
230
190
150
110
70
0
1750
1760
1770
1780
1790
1800
WAVE NUMBER, CM-1

Fig. B-12 : Cont.

TABLE B-1

Detailed statistics of the HARTCODE and FASCOD results. ε_H, ε_F, ε_H^m, ε_F^m, σ_H, and σ_F are the average error, maximum error and standard deviation of the computed brightness temperatures (in degrees) subsequently, subscripts H and F stand for the HARTCODE and FASCOD, n indicates the number of data in the wave number interval and $\triangle\nu$ is the wave number interval in cm^{-1}.

case 1 : California Coast, 14-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-3.060	-2.710	-5.172	-4.270	1.107	1.263	37	600 - 610
-0.930	-1.515	8.254	8.052	3.022	3.004	36	610 - 620
-1.632	-1.813	-3.414	-3.866	1.095	1.008	36	620 - 630
-0.713	-0.511	-2.144	-1.275	0.626	0.490	36	630 - 640
-0.015	-0.178	-1.013	-1.221	0.410	0.492	37	640 - 650
-1.270	-1.345	8.254	8.052	1.252	1.252	182	600 - 650 *
-0.050	-0.074	-0.724	-0.765	0.313	0.301	36	650 - 660
-0.110	-0.095	1.800	1.976	0.651	0.672	36	660 - 670
-0.251	-0.274	-0.806	-0.784	0.306	0.279	37	670 - 680
-0.008	-0.124	-0.688	-0.711	0.340	0.280	36	680 - 690
-0.694	-1.100	-2.136	-3.054	0.663	0.971	36	690 - 700
-0.223	-0.333	-2.136	-3.054	0.455	0.501	181	650 - 700 *

case 2 : Tucson/Kitt Peak, 15-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-3.290	-2.483	-5.718	5.930	1.413	1.627	37	600 - 610
-1.017	-1.645	8.377	7.818	3.355	3.130	36	610 - 620
-1.644	-2.011	-3.768	-3.901	1.348	1.036	36	620 - 630
-0.883	-1.046	-2.683	-2.533	0.881	0.767	36	630 - 640
-0.386	-1.092	-1.825	-2.492	0.574	0.581	37	640 - 650
-1.444	-1.655	8.377	7.818	1.514	1.428	182	600 - 650 *
-0.399	-0.933	-1.430	-1.935	0.355	0.311	36	650 - 660
-0.657	-1.014	-1.965	-1.856	0.521	0.503	36	660 - 670
-0.597	-1.120	-1.114	-1.608	0.275	0.202	37	670 - 680
-0.511	-1.181	-1.176	-2.554	0.257	0.403	36	680 - 690
-1.321	-2.252	-2.199	-3.882	0.577	0.980	36	690 - 700
-0.697	-1.300	-2.199	-3.882	0.397	0.480	181	650 - 700 *

TABLE B-2

Detailed statistics of the HARTCODE and FASCOD results. ε_H, ε_F, ε_H^m, ε_F^m, σ_H, and σ_F are the average error, maximum error and standard deviation of the computed brightness temperatures (in degrees) subsequently, subscripts H and F stand for the HARTCODE and FASCOD, n indicates the number of data in the wave number interval and $\triangle\nu$ is the wave number interval in cm^{-1}.

case 1 : California Coast, 14-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-1.731	-1.412	-2.524	-2.133	0.513	0.551	37	700 - 710
-0.977	-0.848	-3.020	-2.231	1.079	0.758	36	710 - 720
0.494	-0.016	7.814	7.520	2.751	2.454	36	720 - 730
-0.439	0.013	-1.431	-1.788	0.431	0.564	36	730 - 740
-0.457	-0.076	2.854	2.870	1.089	1.244	37	740 - 750
-0.622	-0.468	7.814	7.520	1.173	1.114	182	700 - 750 *
-0.974	-0.781	-1.707	-1.673	0.347	0.560	36	750 - 760
-1.156	-0.986	-1.518	-1.557	0.262	0.370	36	760 - 770
-1.334	-1.203	-1.612	-1.464	0.161	0.186	37	770 - 780
-1.323	-1.313	-2.419	-2.246	0.253	0.265	36	780 - 790
-1.178	-1.016	-3.108	3.277	1.236	1.420	36	790 - 800
-1.193	-1.060	-3.108	3.277	0.452	0.560	181	750 - 800 *

case 2 : Tucson/Kitt Peak, 15-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-1.963	-1.859	-2.909	-2.655	0.579	0.682	37	700 - 710
-1.126	-0.662	-3.638	-2.703	1.382	0.884	36	710 - 720
0.813	2.077	9.670	8.534	3.374	2.380	36	720 - 730
-0.521	1.788	-1.900	4.430	0.546	1.355	36	730 - 740
-0.699	2.874	-4.872	6.587	1.657	2.078	37	740 - 750
-0.699	0.844	9.670	8.534	1.508	1.476	182	700 - 750 *
-0.851	5.816	-2.901	10.955	1.004	3.273	36	750 - 760
-0.193	9.473	-1.854	11.526	0.578	1.569	36	760 - 770
-1.180	8.555	-3.077	11.380	1.042	3.180	37	770 - 780
-0.683	10.056	-4.338	11.947	1.160	3.278	36	780 - 790
-1.578	6.725	-6.090	12.160	2.574	4.301	36	790 - 800
-0.897	8.125	-6.090	12.160	1.272	3.120	181	750 - 800 *

TABLE B-3

Detailed statistics of the HARTCODE and FASCOD results. ε_H, ε_F, ε_H^m, ε_F^m, σ_H, and σ_F are the average error, maximum error and standard deviation of the computed brightness temperatures (in degrees) subsequently, subscripts H and F stand for the HARTCODE and FASCOD, n indicates the number of data in the wave number interval and $\triangle\nu$ is the wave number interval in cm^{-1}.

case 1 : California Coast, 14-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-0.874	-0.925	-1.244	-1.307	0.278	0.302	36	800 - 810
-0.919	-0.925	-1.083	-1.070	0.106	0.098	37	810 - 820
-0.763	-0.814	-0.898	-0.952	0.158	0.137	36	820 - 830
-0.778	-0.843	-0.962	-0.989	0.053	0.047	36	830 - 840
-1.067	-1.141	-1.535	-1.553	0.165	0.159	37	840 - 850
-0.880	-0.930	-1.535	-1.553	0.152	0.149	182	800 - 850 *
-0.815	-0.895	-1.255	-1.402	0.260	0.239	36	850 - 860
-0.568	-0.633	-0.692	-0.727	0.046	0.036	36	860 - 870
-0.606	-0.676	-1.109	-1.124	0.154	0.137	37	870 - 880
-0.538	-0.620	-0.825	-0.833	0.139	0.104	36	880 - 890
-0.504	-0.560	-0.625	-0.640	0.048	0.047	36	890 - 900
-0.606	-0.677	-1.255	-1.402	0.129	0.112	181	850 - 900 *

case 2 : Tucson/Kitt Peak, 15-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-0.355	9.882	-3.631	12.325	0.987	2.958	36	800 - 810
-0.030	11.397	-2.703	12.543	0.832	2.262	37	810 - 820
0.032	11.577	-1.158	12.537	0.370	1.563	36	820 - 830
-0.047	12.019	-2.227	12.527	0.442	1.208	36	830 - 840
-0.873	10.826	-2.926	11.956	0.714	1.985	37	840 - 850
-0.254	11.140	-3.631	12.543	0.669	1.995	182	800 - 850 *
-1.033	10.053	-4.055	12.360	1.047	2.984	36	850 - 860
-0.251	11.966	-1.548	12.575	0.393	1.208	36	860 - 870
-0.550	11.525	-3.036	12.537	0.772	1.772	37	870 - 880
-0.451	11.310	-2.148	12.454	0.499	1.445	36	880 - 890
-0.196	12.375	-0.682	12.758	0.175	0.422	36	890 - 900
-0.496	11.446	-4.055	12.758	0.577	1.566	181	850 - 900 *

TABLE B-4

Detailed statistics of the HARTCODE and FASCOD results. ε_H, ε_F, ε_H^m, ε_F^m, σ_H, and σ_F are the average error, maximum error and standard deviation of the computed brightness temperatures (in degrees) subsequently, subscripts H and F stand for the HARTCODE and FASCOD, n indicates the number of data in the wave number interval and $\triangle\nu$ is the wave number interval in cm^{-1}.

case 1 : California Coast, 14-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-0.491	-0.553	-0.921	-0.918	0.121	0.104	36	900 - 910
-0.650	-0.697	-0.751	-0.768	0.046	0.041	37	910 - 920
-0.686	-0.726	-1.302	-1.376	0.263	0.255	36	920 - 930
-0.452	-0.432	-0.700	-0.729	0.136	0.146	36	930 - 940
-0.299	-0.309	-0.657	-0.656	0.095	0.087	37	940 - 950
-0.516	-0.543	-1.302	-1.376	0.132	0.127	182	900 - 950 *
-0.320	-0.303	-0.645	-0.707	0.121	0.114	36	950 - 960
-0.301	-0.295	-0.428	-0.368	0.067	0.045	36	960 - 970
-0.269	-0.274	-0.596	-0.485	0.146	0.100	37	970 - 980
-0.392	-0.319	-0.438	-0.402	0.030	0.042	36	980 - 990
-0.408	-0.175	-0.559	-0.391	0.051	0.163	36	990 -1000
-0.338	-0.273	-0.645	-0.707	0.083	0.093	181	950 -1000 *

case 2 : Tucson/Kitt Peak, 15-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-0.430	11.832	-2.923	12.770	0.692	1.720	36	900 - 910
-0.517	12.101	-0.907	12.395	0.136	0.397	37	910 - 920
-0.671	11.548	-1.984	12.554	0.470	1.239	36	920 - 930
-0.197	12.644	-0.553	13.040	0.193	0.231	36	930 - 940
-0.161	12.116	-2.241	13.049	0.635	1.402	37	940 - 950
-0.395	12.048	-2.923	13.049	0.425	0.998	182	900 - 950 *
-0.113	12.441	-1.542	13.120	0.433	0.739	36	950 - 960
0.014	12.769	0.298	13.162	0.118	0.303	36	960 - 970
-0.056	12.036	-1.512	12.843	0.450	0.803	37	970 - 980
-0.266	12.767	-0.399	12.958	0.095	0.130	36	980 - 990
-0.487	13.004	-0.747	13.880	0.098	0.371	36	990 -1000
-0.182	12.603	-1.542	13.880	0.239	0.469	181	950 -1000 *

TABLE B-5

Detailed statistics of the HARTCODE and FASCOD results. ε_H, ε_F, ε_H^m, ε_F^m, σ_H, and σ_F are the average error, maximum error and standard deviation of the computed brightness temperatures (in degrees) subsequently, subscripts H and F stand for the HARTCODE and FASCOD, n indicates the number of data in the wave number interval and $\triangle\nu$ is the wave number interval in cm^{-1}.

case 1 : California Coast, 14-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-0.349	0.543	-0.663	1.731	0.126	0.413	36	1000 -1010
-0.184	1.935	-0.786	3.234	0.240	0.623	37	1010 -1020
-0.010	2.838	1.220	3.421	0.450	0.272	36	1020 -1030
-0.198	3.121	-1.239	4.974	0.409	0.974	36	1030 -1040
-0.256	2.515	1.355	5.475	0.555	1.818	37	1040 -1050
-0.199	2.191	1.355	5.475	0.356	0.820	182	1000 -1050 *
0.463	4.418	1.952	6.660	0.752	0.827	36	1050 -1060
-0.194	1.289	-1.362	4.335	0.514	1.703	36	1060 -1070
-0.745	-0.670	-1.573	-1.557	0.234	0.251	36	1070 -1080
-0.842	-0.658	-1.058	-0.897	0.142	0.192	37	1080 -1090
-1.019	-0.945	-1.605	-1.598	0.182	0.210	18	1090 -1100
-0.467	0.687	1.952	6.660	0.365	0.636	163	1050 -1100 *

case 2 : Tucson/Kitt Peak, 15-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-0.566	14.139	-1.662	16.297	0.293	0.773	36	1000 -1010
-0.829	15.886	-3.317	18.858	0.773	1.763	37	1010 -1020
-0.578	17.583	-1.882	18.868	0.583	0.999	36	1020 -1030
-0.616	18.532	-1.983	22.442	0.747	2.028	36	1030 -1040
-0.575	17.338	-2.090	23.622	0.736	3.519	37	1040 -1050
-0.633	16.696	-3.317	23.622	0.626	1.817	182	1000 -1050 *
-0.504	19.408	-1.864	23.282	0.836	1.604	36	1050 -1060
-1.291	14.187	-5.458	20.161	1.334	3.874	36	1060 -1070
-1.647	10.769	-4.407	12.191	0.707	1.546	36	1070 -1080
-1.568	11.495	-1.924	12.212	0.202	0.380	37	1080 -1090
-1.817	10.879	-4.100	12.567	0.811	2.197	18	1090 -1100
-1.365	13.348	-5.458	23.282	0.778	1.920	163	1050 -1100 *

TABLE B-6

Detailed statistics of the HARTCODE and FASCOD results. ε_H, ε_F, ε_H^m, ε_F^m, σ_H, and σ_F are the average error, maximum error and standard deviation of the computed brightness temperatures (in degrees) subsequently, subscripts H and F stand for the HARTCODE and FASCOD, n indicates the number of data in the wave number interval and $\triangle\nu$ is the wave number interval in cm^{-1}.

case 1 : California Coast, 14-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-0.844	-0.859	-2.060	-2.007	0.395	0.403	21	1100 -1110
-0.450	-0.359	-0.776	-0.676	0.186	0.184	20	1110 -1120
-0.389	-0.268	-1.876	-1.193	0.474	0.402	21	1120 -1130
-0.631	-0.560	-2.806	-2.138	0.681	0.538	21	1130 -1140
-0.458	-0.255	-1.187	-0.836	0.268	0.218	21	1140 -1150
-0.554	-0.460	-2.806	-2.138	0.401	0.349	104	1100 -1150 *
-0.568	-0.360	-1.090	-0.693	0.229	0.169	20	1150 -1160
-0.667	-0.534	-1.218	-1.037	0.228	0.161	21	1160 -1170
-0.849	-0.714	-3.521	-3.039	0.880	0.847	21	1170 -1180
-0.667	-0.509	-2.939	-1.950	0.686	0.539	21	1180 -1190
-0.508	-0.479	-2.195	-1.619	0.534	0.448	20	1190 -1200
-0.652	-0.519	-3.521	-3.039	0.512	0.433	103	1150 -1200 *

case 2 : Tucson/Kitt Peak, 15-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-0.680	-1.504	-2.460	-4.038	0.705	1.081	21	1100 -1110
-0.049	-0.310	1.126	-0.774	0.489	0.247	20	1110 -1120
-0.310	-0.498	-3.054	-3.382	0.787	1.110	21	1120 -1130
-0.162	-0.924	-2.138	-3.768	0.772	1.292	21	1130 -1140
0.062	-0.072	-1.435	-2.396	0.450	0.797	21	1140 -1150
-0.228	-0.662	-3.054	-4.038	0.641	0.905	104	1100 -1150 *
0.305	0.068	-1.000	-1.822	0.569	0.799	20	1150 -1160
0.145	-0.213	-1.580	-1.822	0.549	0.625	21	1160 -1170
0.184	-1.047	-1.561	-4.847	0.644	1.872	21	1170 -1180
0.380	-0.523	-1.811	-3.516	0.692	1.360	21	1180 -1190
0.436	-0.334	-1.589	-2.944	0.660	1.120	20	1190 -1200
0.290	-0.410	-1.811	-4.847	0.623	1.155	103	1150 -1200 *

TABLE B-7

Detailed statistics of the HARTCODE and FASCOD results. ε_H, ε_F, ε_H^m, ε_F^m, σ_H, and σ_F are the average error, maximum error and standard deviation of the computed brightness temperatures (in degrees) subsequently, subscripts H and F stand for the HARTCODE and FASCOD, n indicates the number of data in the wave number interval and $\triangle\nu$ is the wave number interval in cm^{-1}.

case 1 : California Coast, 14-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-0.535	-0.505	-0.717	-0.731	0.105	0.104	21	1200 -1210
-0.227	-0.931	-1.207	-1.719	0.507	0.554	21	1210 -1220
-0.371	-0.622	-1.284	-1.992	0.353	0.601	21	1220 -1230
-0.614	-0.404	-1.383	-0.693	0.367	0.310	20	1230 -1240
-0.685	-0.881	-1.837	-2.385	0.649	0.688	21	1240 -1250
-0.486	-0.668	-1.837	-2.385	0.396	0.451	104	1200 -1250 *
-1.260	-0.444	-2.487	-1.556	0.646	0.449	21	1250 -1260
-2.259	-1.289	-3.748	-4.665	0.923	1.325	21	1260 -1270
-4.070	-0.874	-6.144	-2.228	1.241	0.663	20	1270 -1280
-1.236	-0.938	-4.522	-3.270	1.793	1.273	21	1280 -1290
-3.969	-0.177	-5.775	1.603	1.540	0.683	21	1290 -1300
-2.559	-0.745	-6.144	-4.665	1.228	0.879	104	1250 -1300 *

case 2 : Tucson/Kitt Peak, 15-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
0.202	0.127	0.444	0.425	0.217	0.251	21	1200 -1210
0.444	-1.118	2.445	-3.171	0.991	1.506	21	1210 -1220
0.209	-0.448	2.006	-3.598	0.733	1.532	21	1220 -1230
0.705	0.973	2.616	1.873	0.723	0.435	20	1230 -1240
0.341	-0.544	2.969	-3.076	1.058	1.478	21	1240 -1250
0.380	-0.202	2.969	-3.598	0.745	1.040	104	1200 -1250 *
-0.869	-0.341	-2.255	-2.028	0.851	0.982	21	1250 -1260
-1.894	-1.884	-3.476	-3.749	1.232	1.236	21	1260 -1270
-4.126	-0.979	-6.763	-2.727	1.601	1.262	20	1270 -1280
-0.231	-1.288	-4.295	-4.785	2.310	1.640	21	1280 -1290
-3.172	0.135	-5.897	2.645	2.422	1.095	21	1290 -1300
-2.058	-0.871	-6.763	-4.785	1.683	1.243	104	1250 -1300 *

TABLE B-8

Detailed statistics of the HARTCODE and FASCOD results. ε_H, ε_F, ε_H^m, ε_F^m, σ_H, and σ_F are the average error, maximum error and standard deviation of the computed brightness temperatures (in degrees) subsequently, subscripts H and F stand for the HARTCODE and FASCOD, n indicates the number of data in the wave number interval and $\triangle\nu$ is the wave number interval in cm^{-1}.

case 1 : California Coast, 14-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-2.710	-0.913	-6.163	-2.396	1.657	0.979	21	1300 -1310
1.397	-0.279	4.109	-3.702	1.864	1.541	20	1310 -1320
0.432	0.522	3.873	-2.750	1.226	1.061	21	1320 -1330
1.286	0.195	5.624	-3.737	2.116	1.812	21	1330 -1340
0.481	0.062	2.972	-3.497	1.522	1.867	20	1340 -1350
0.177	-0.083	-6.163	-3.737	1.677	1.452	103	1300 -1350 *
2.185	1.359	5.584	3.846	2.123	1.645	21	1350 -1360
1.754	-0.336	5.036	-3.527	2.223	2.001	21	1360 -1370
0.705	-1.268	-4.928	-5.893	2.566	2.482	21	1370 -1380
2.056	0.682	4.422	-3.603	1.886	2.576	20	1380 -1390
-0.616	-2.957	-5.436	-5.425	2.487	2.008	21	1390 -1400
1.217	-0.504	5.584	-5.893	2.257	2.143	104	1350 -1400 *

case 2 : Tucson/Kitt Peak, 15-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-2.982	-1.373	-6.643	-3.911	2.040	1.337	21	1300 -1310
1.911	0.237	3.847	1.809	1.361	0.893	20	1310 -1320
0.241	0.778	3.764	2.999	1.413	1.407	21	1320 -1330
1.782	1.256	5.523	4.363	2.148	1.418	21	1330 -1340
0.627	0.152	3.598	3.029	1.670	1.659	20	1340 -1350
0.316	0.210	-6.643	4.363	1.726	1.343	103	1300 -1350 *
2.267	1.157	5.382	3.242	1.869	1.259	21	1350 -1360
1.922	0.301	-5.531	-2.535	2.409	1.163	21	1360 -1370
1.407	-0.052	-4.812	-3.810	2.561	1.645	21	1370 -1380
2.533	1.316	4.440	2.787	1.870	1.339	20	1380 -1390
0.240	-0.862	-7.759	-5.098	3.478	1.860	21	1390 -1400
1.674	0.372	-7.759	-5.098	2.437	1.453	104	1350 -1400 *

TABLE B-9

Detailed statistics of the HARTCODE and FASCOD results. ε_H, ε_F, ε_H^m, ε_F^m, σ_H, and σ_F are the average error, maximum error and standard deviation of the computed brightness temperatures (in degrees) subsequently, subscripts H and F stand for the HARTCODE and FASCOD, n indicates the number of data in the wave number interval and $\triangle\nu$ is the wave number interval in cm^{-1}.

case 1 : California Coast, 14-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
1.158	-0.182	-3.591	-4.189	1.999	2.434	21	1400 -1410
0.509	-1.147	-4.009	-5.180	2.541	2.577	21	1410 -1420
-0.709	-2.637	-5.359	-5.497	1.903	1.982	20	1420 -1430
-1.455	-3.364	-5.223	-6.039	1.808	1.333	21	1430 -1440
0.007	-0.771	-4.396	-4.528	1.992	2.353	21	1440 -1450
-0.098	-1.620	-5.359	-6.039	2.049	2.136	104	1400 -1450 *
-2.806	-4.100	-5.048	-6.226	1.783	1.588	21	1450 -1460
-2.872	-4.463	-6.234	-6.958	1.704	1.227	20	1460 -1470
-3.003	-4.147	-5.839	-6.196	1.970	1.796	21	1470 -1480
-2.516	-3.265	-5.296	-5.937	1.956	1.973	21	1480 -1490
-4.055	-4.924	-5.494	-6.895	1.122	1.043	21	1490 -1500
-3.051	-4.180	-6.234	-6.958	1.707	1.526	104	1450 -1500 *

case 2 : Tucson/Kitt Peak, 15-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
2.259	0.949	-4.550	-2.793	2.114	1.422	21	1400 -1410
0.492	-0.252	-12.473	-6.920	4.507	2.589	21	1410 -1420
0.816	-0.404	-8.296	-5.577	3.137	1.916	20	1420 -1430
-0.644	-1.173	-11.613	-6.083	4.413	2.368	21	1430 -1440
1.462	0.762	-6.739	-4.047	2.607	1.704	21	1440 -1450
0.877	-0.024	-12.473	-6.920	3.355	2.000	104	1400 -1450 *
-4.530	-3.743	-13.396	-10.266	6.133	4.032	21	1450 -1460
-1.177	-1.570	-13.572	-8.685	4.538	2.829	20	1460 -1470
-3.703	-3.037	-15.195	-9.843	5.838	3.897	21	1470 -1480
-1.958	-1.415	-10.838	-8.347	4.625	3.211	21	1480 -1490
-5.040	-3.721	-12.313	-8.158	4.988	3.218	21	1490 -1500
-3.282	-2.697	-15.195	-10.266	5.224	3.437	104	1450 -1500 *

TABLE B-10

Detailed statistics of the HARTCODE and FASCOD results. ε_H, ε_F, ε_H^m, ε_F^m, σ_H, and σ_F are the average error, maximum error and standard deviation of the computed brightness temperatures (in degrees) subsequently, subscripts H and F stand for the HARTCODE and FASCOD, n indicates the number of data in the wave number interval and $\triangle\nu$ is the wave number interval in cm^{-1}.

case 1 : California Coast, 14-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-4.893	-4.954	-5.926	-6.767	0.588	1.437	20	1500 -1510
-4.491	-5.075	-6.365	-6.513	0.788	0.707	21	1510 -1520
-4.917	-5.002	-6.795	-6.647	0.753	0.995	21	1520 -1530
-5.372	-4.948	-6.229	-6.675	0.685	1.343	21	1530 -1540
-5.521	-5.113	-6.477	-6.769	0.478	1.055	20	1540 -1550
-5.039	-5.018	-6.795	-6.769	0.658	1.107	103	1500 -1550 *
-5.711	-5.038	-6.990	-7.299	1.100	2.057	21	1550 -1560
-5.504	-5.233	-6.787	-6.997	0.549	1.377	21	1560 -1570
-5.108	-5.395	-6.591	-7.487	1.029	1.640	21	1570 -1580
-3.132	-1.945	-4.616	-3.064	0.785	0.601	20	1580 -1590
-2.943	-3.173	-4.904	-4.455	0.816	0.684	21	1590 -1600
-4.479	-4.157	-6.990	-7.487	0.856	1.272	104	1550 -1600 *

case 2 : Tucson/Kitt Peak, 15-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-8.398	-5.725	-16.602	-10.680	5.949	3.760	20	1500 -1510
-5.277	-3.506	-14.659	-9.112	4.170	2.671	21	1510 -1520
-8.817	-6.039	-14.939	-11.187	4.412	3.093	21	1520 -1530
-8.559	-5.423	-17.347	-11.011	5.702	3.717	21	1530 -1540
-8.513	-5.528	-16.127	-11.114	5.221	3.874	20	1540 -1550
-7.913	-5.244	-17.347	-11.187	5.091	3.423	103	1500 -1550 *
-9.873	-6.316	-15.985	-10.897	4.914	3.141	21	1550 -1560
-6.872	-4.237	-15.517	-9.313	4.799	2.931	21	1560 -1570
-5.400	-3.538	-13.654	-8.700	4.952	3.185	21	1570 -1580
-0.047	0.453	-1.577	0.881	0.586	0.317	20	1580 -1590
-0.326	-0.458	-4.543	-2.458	1.324	0.575	21	1590 -1600
-4.503	-2.819	-15.985	-10.897	3.315	2.030	104	1550 -1600 *

TABLE B-11

Detailed statistics of the HARTCODE and FASCOD results. ε_H, ε_F, ε_H^m, ε_F^m, σ_H, and σ_F are the average error, maximum error and standard deviation of the computed brightness temperatures (in degrees) subsequently, subscripts H and F stand for the HARTCODE and FASCOD, n indicates the number of data in the wave number interval and $\triangle\nu$ is the wave number interval in cm^{-1}.

case 1 : California Coast, 14-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-3.758	-4.267	-5.671	-5.229	1.620	0.650	21	1600 -1610
-4.922	-5.555	-7.966	-7.819	1.869	1.512	20	1610 -1620
-5.260	-5.895	-7.693	-7.468	1.708	0.742	21	1620 -1630
-4.853	-5.200	-8.703	-7.294	1.740	1.667	21	1630 -1640
-4.880	-5.478	-8.138	-7.533	2.133	1.090	21	1640 -1650
-4.735	-5.279	-8.703	-7.819	1.814	1.132	104	1600 -1650 *
-4.519	-4.809	-7.303	-7.747	2.111	2.426	20	1650 -1660
-4.169	-4.994	-8.452	-7.366	2.154	1.252	21	1660 -1670
-4.739	-5.780	-8.055	-7.324	2.153	1.404	21	1670 -1680
-4.748	-5.505	-7.333	-7.918	1.741	1.744	21	1680 -1690
-4.204	-4.996	-7.057	-7.085	2.106	2.012	20	1690 -1700
-4.476	-5.217	-8.452	-7.918	2.053	1.767	103	1650 -1700 *

case 2 : Tucson/Kitt Peak, 15-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-1.689	-1.371	-5.270	-3.480	1.384	1.043	21	1600 -1610
-4.127	-3.151	-13.965	-8.864	4.687	3.103	20	1610 -1620
-4.834	-3.478	-14.422	-9.740	3.852	2.996	21	1620 -1630
-5.046	-3.361	-13.583	-9.734	4.961	3.389	21	1630 -1640
-5.859	-4.212	-16.712	-10.322	5.024	3.445	21	1640 -1650
-4.311	-3.115	-16.712	-10.322	3.982	2.795	104	1600 -1650 *
-6.031	-3.849	-14.569	-9.575	5.277	3.132	20	1650 -1660
-3.889	-2.773	-14.526	-8.191	4.502	3.183	21	1660 -1670
-4.593	-3.376	-9.784	-6.692	3.257	2.346	21	1670 -1680
-6.633	-4.679	-15.581	-9.871	4.521	2.859	21	1680 -1690
-5.658	-3.969	-11.570	-7.673	4.211	2.970	20	1690 -1700
-5.361	-3.729	-15.581	-9.871	4.354	2.898	103	1650 -1700 *

TABLE B-12

Detailed statistics of the HARTCODE and FASCOD results. ε_H, ε_F, ε_H^m, ε_F^m, σ_H, and σ_F are the average error, maximum error and standard deviation of the computed brightness temperatures (in degrees) subsequently, subscripts H and F stand for the HARTCODE and FASCOD, n indicates the number of data in the wave number interval and $\triangle\nu$ is the wave number interval in cm^{-1}.

case 1 : California Coast, 14-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-4.169	-4.942	-7.036	-7.395	2.231	2.185	21	1700 -1710
-3.438	-4.996	-6.912	-6.839	2.534	1.317	21	1710 -1720
-1.113	-2.722	-3.243	-4.481	1.003	1.078	21	1720 -1730
-3.542	-5.219	-6.578	-7.657	2.320	1.722	20	1730 -1740
-3.142	-5.063	-5.507	-6.155	1.380	0.587	21	1740 -1750
-3.081	-4.589	-7.036	-7.657	1.894	1.378	104	1700 -1750 *
-0.291	-2.949	-4.028	-5.262	1.507	0.997	21	1750 -1760
-0.604	-3.135	4.231	-5.563	2.173	1.470	21	1760 -1770
-2.133	-4.222	-8.049	-7.067	2.991	2.215	20	1770 -1780
1.242	-1.600	7.184	-3.879	2.257	1.369	21	1780 -1790
-1.615	-4.173	-6.470	-6.640	2.236	1.222	21	1790 -1800
-0.680	-3.216	-8.049	-7.067	2.233	1.455	104	1750 -1800 *

case 2 : Tucson/Kitt Peak, 15-04-86

ε_H	ε_F	ε_H^m	ε_F^m	σ_H	σ_F	n	$\triangle\nu$
-5.248	-3.498	-12.501	-7.712	4.051	2.752	21	1700 -1710
-4.773	-3.939	-17.581	-10.999	5.303	3.704	21	1710 -1720
1.535	0.603	-3.725	-5.243	1.759	1.606	21	1720 -1730
-3.701	-2.980	-12.076	-6.925	4.043	2.698	20	1730 -1740
-2.477	-2.143	-7.254	-6.607	2.675	1.909	21	1740 -1750
-2.933	-2.391	-17.581	-10.999	3.566	2.534	104	1700 -1750 *
1.192	-0.183	3.948	-4.688	2.201	1.785	21	1750 -1760
1.056	-0.297	-6.086	-5.564	2.812	2.122	21	1760 -1770
-2.535	-2.806	-15.438	-12.423	6.402	4.704	20	1770 -1780
3.196	1.028	8.919	2.072	2.052	0.775	21	1780 -1790
0.015	-0.748	-6.370	-4.013	2.819	1.576	21	1790 -1800
0.585	-0.601	-15.438	-12.423	3.257	2.192	104	1750 -1800 *

APPENDIX C

Listing of the First Group of Programmes:

DECODA
DECODG
FIND
LIN

```
    PROGRAM DECODA
    IMPLICIT REAL*8(A-H,O-Z)
    CHARACTER*80 A1(41)
    CHARACTER*35 QID
    OPEN (UNIT=1,TYPE='OLD',BLOCKSIZE=3210,RECL=80)
    OPEN (UNIT=2,TYPE='NEW',FILE=  'AFGLM.DAT')
    OPEN (UNIT=3,TYPE='NEW',FILE=  'AFGLT.DAT')
    OPEN (UNIT=4,TYPE='NEW',FILE=   'AFGL.DAT')
    OPEN (UNIT=7,TYPE='NEW',FILE='REMARKS.DAT')
    OPEN (UNIT=8,TYPE='OLD',FILE= 'DECODA.INP')
    READ(8,*) IMIX,ICHANGE
    IF(IMIX.EQ.-1) THEN
                   NMAIN  = 176337
                   NTRACE =  94682
                   GOTO 72
                   END IF
    IK    = 0
    IREJ  = 0
    NNLIN = 0
    IFILE = 2
110 READ (1,960,END=120) A1(1)
    DECODE (80,990,A1(1)) NLIN
    READ (1,960,END=120) (A1(I+1),I=1,NLIN-1)
960 FORMAT (A80)
969 FORMAT (10X,F10.6,E10.3,F5.4,F10.3,A35)
970 FORMAT (10X,F10.4,E10.3,F5.4,F10.3,A35)
971 FORMAT (3X,I4,I3,70X)
978 FORMAT (1X,F10.4,E10.3,F5.4,F10.3,I3,2I10)
990 FORMAT (I10,70X)
    DO 220 I = 1, NLIN-1
    J=I+1
                 DECODE(80,970,A1(I)) V,S,A,E,QID
    IF(V.LT.1D2) DECODE(80,969,A1(I)) V,S,A,E,QID
                 DECODE(80,971,A1(J)) ISOT,II
    IF(II.EQ. 0) THEN
                 WRITE(7,'(1X,A80)')A1(I),A1(J)
                 GOTO 220
                 END IF
    IF(E .LT. 0) THEN
                 IREJ=IREJ+1
                 WRITE(7,978)   V,S,A,E,II,NNLIN,IREJ
                 GOTO 220
                 END IF
    NNLIN=NNLIN+1
    WRITE (IFILE,10) V,S,A,E,II,NNLIN,ISOT,QID
```

```
  10 FORMAT (1X,D16.8,3D11.4,I4,I8,I4,A35)
 220 CONTINUE
     IF(NNLIN-(NNLIN/500)*500.EQ.0)WRITE(6,*)NLIN,NNLIN,V,II
     GOTO 110
 120 IK=IK+1
     IF(IK.EQ.179) THEN
                   WRITE(7,*)  IK,NLIN,NNLIN
                   NMAIN=NNLIN
                   NNLIN=0
                   IFILE=3
                   GOTO 110
                   END IF
     IF(IK.EQ.279) GOTO 130
     GOTO 110
 130 NTRACE=NNLIN
                   WRITE(7,*)  IK,NLIN,NNLIN
     REWIND 2
     REWIND 3
     WRITE(6,*)'NMAIN=',NMAIN
     WRITE(6,*)'NTRACE=',NTRACE
  72 IF(IMIX.NE.0) CALL MIX(NMAIN,NTRACE,ICHANGE)
     STOP
     END
```

```
      SUBROUTINE MIX(N1,N2,IC)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION MOLA(45)
      CHARACTER*35 QID
   10 FORMAT (1X,D16.8,3D11.4,I4,I8,I4,A35)
      NALL=0
      M1=0
      M2=0
      READ (3,10) V2,S2,A2,E2,I2,L2,IS2,QI2
      M2=M2+1
  100 IF (M1.GT.N1.AND.M2.GT.N2) GOTO 400
      IF (M1.GT.N1) GOTO 200
      READ (2,10) V1,S1,A1,E1,I1,L1,IS1,QI1
      M1=M1+1
      GOTO 300
  200 IF (M1.GT.N1.AND.M2.GT.N2) GOTO 400
      IF (M2.GT.N2) GOTO 100
      READ (3,10) V2,S2,A2,E2,I2,L2,IS2,QI2
      M2=M2+1
  300 NALL = NALL + 1
      IF(V1.LE.V2) THEN
                   WRITE (4,10) V1,S1,A1,E1,I1,NALL,IS1,QI1
                   GOTO 100
                   END IF
      IF(V1.GT.V2) THEN
                   IF (IC.EQ.0) GOTO 302
                   DO 301 I=1,45
                   IF(I2.NE.MOLA(I)) GOTO 301
                   I2=I
                   GOTO 302
  301              CONTINUE
  302              WRITE (4,10) V2,S2,A2,E2,I2,NALL,IS2,QI2
                   GOTO 200
                   END IF
  400 WRITE(6,*)'TOTAL NUMBER OF LINES : ',  NALL
  410 RETURN
       DATA MOLA/
     *  1, 2, 3, 4, 5, 6, 7, 8, 9,10,11,28,12,13,14,
     * 15,16,17,18,19,20,27, 0,26, 0, 0,23, 0, 0, 0,
     *  0,21,22,24,25, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0/
      END
```

```
      PROGRAM DECODG
      DIMENSION       NSK(10)
      CHARACTER*6160  BUFF
      INTEGER         FRL, KK*2
      EQUIVALENCE     (BUFF,KK)
      CHARACTER*30    NOME, RISP*1
      DATA            (NSK(I), I=1,10)/1,2,3,4,5,6,7,8,9,10/
      PRINT *,  'Records IBM a lunghezza variabile? (Y/N):'
      READ 10,  RISP
      PRINT *,  'Nome file di output:'
      READ 10,  NOME
      PRINT *, 'RECL-TAPE,NUMBER OF REC/BLOCK-TAPE,RECL-DISC'
      READ *,   LRL, NRB, MSRL
      FRL = NRB*LRL
      PRINT *,  NOME, NRB, LRL, ' Block length ', FRL, MSRL
      OPEN( UNIT=1, NAME=NOME, STATUS='NEW', RECL=MSRL)
      OPEN( UNIT=4, NAME='MSA0:', STATUS='OLD', RECL=FRL)
      IF(RISP .EQ. 'Y') GOTO 3
      NR=0
      ISUPDO = FRL/MSRL
    1 READ(4, 10, END=99)  BUFF
      CALL LIB-TRA-EBC-ASC(BUFF,BUFF)
      NR=NR+1
      PRINT*,' NR = ', NR
      N2=0
      DO 20 I=1,ISUPDO
      N1=N2 + 1
      N2=N2 + MSRL
   20 WRITE(1,10)  BUFF(N1:N2)
      GOTO 1
    3 CONTINUE
      L1=IISHFT(KK,-8)
      L2=IISHFT(KK,8)
      KK=IOR(L1,L2)
      PRINT 11,BUFF(1:2)
      PRINT 11,KK
      PRINT 12,KK
   11 FORMAT(' -',a)
   12 FORMAT(' ',8z4)
   10 FORMAT(A)
   99 END
```

```
      PROGRAM FIND
      IMPLICIT REAL*8(A-H,O-Z)
      CHARACTER*35 QID
      OPEN(UNIT=1,TYPE='NEW',FILE='SELECT.DAT')
      OPEN(UNIT=4,TYPE='OLD',FILE=  'FIND.INP')
      READ(4,*)V1,V2,ID
      IF(ID.EQ.0)  OPEN(UNIT=2,TYPE='OLD',FILE= 'GEISA.DAT')
      IF(ID.EQ.1)  OPEN(UNIT=3,TYPE='OLD',FILE=  'AFGL.DAT')
      NNLIN=0
      ITOT =0
   90 FORMAT(1X,D16.8,3D11.4,I4,I8)
  100 FORMAT(1X,D16.8,3D11.4,I4,I8,I4,A35)
  200 FORMAT(F10.5,E10.3,F5.3,F10.3,A35,F3.2,I4,I3)
  110 IF(ID.EQ.0) READ(2,200) V,S,A,E,QID,AN,ISOT,II
      IF(ID.EQ.1) READ(3,100) V,S,A,E,II,NL,ISOT,QID
      ITOT=ITOT+1
      IF(II.LE.0) GOTO 110
      IF(S.LE.0D0.OR.A.LE.0D0.OR.E.LE.0D0) GOTO 110
      IF(V.LT.V1) GOTO 110
      IF(V.GT.V2) GOTO 210
      NNLIN=NNLIN+1
      WRITE(1, 90) V,S,A,E,II,NNLIN
      GOTO 110
  210 WRITE(6,'(1X,2F12.2,2I10)') V1,V2,NNLIN,ITOT
      STOP
      END
```

```
      PROGRAM LIN
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/A/ C(5000,4),MSUM,DI,WNU1A,LINE,NOLINE,LAA,IOUT,
     *          ISUMS(11),ISUMD(5),IC(5000),SRATIO,
     *          LINALL(7),LINAL(7),LINA(7),SMAX(7),
     *          ISTRONG(7),SLIMS(7)
      COMMON/B/ MOLL(7),IWI(7),NTOTD
      DIMENSION PE(7),TE(7),U(7),D(4),SLIM(7)
      OPEN(UNIT=2,TYPE='OLD',FILE='[.HITRAN]SELECT.DAT')
      OPEN(UNIT=4,TYPE='OLD',FILE=   'LIN.INP')
      NALL=300000
      READ(4,*) IFAR,WNUA,WNUB,REG1,REG2,REG3,IP
      READ(4,*) ISV,ITA,ITB,IDT
      READ(4,*) NDDD,(IWI(I),I=1,7)
      READ(4,*) TRLIM,TRLIMS,SRATIO
      READ(4,*) WNU1A,WNU2B
      READ(4,*) IOUT,IDI,LAA,(MOLL(I),I=1,7)
      IF(IOUT.NE. 0) OPEN(UNIT=3,TYPE='NEW',FILE=   'LIN.DAT')
      IF(IFAR.NE. 0) OPEN(UNIT=8,TYPE='NEW',FILE= 'FARWG.DAT')
      IF(IFAR.NE.-1) OPEN(UNIT=1,TYPE='NEW',FILE=  'STAT.DAT')
      IF(IFAR.EQ.-1)THEN
                    NTOTD=NDDD
                    OPEN(UNIT=3,TYPE='OLD',FILE=   'LIN.DAT')
                    GOTO 83
                    END IF
      WRITE(6,'(1X,2F10.6,D8.1,2F8.1,5X,2I2,5X,7I3,/)')
     *TRLIM,TRLIMS,SRATIO,WNU1A,WNU2B,IDI,LAA,(MOLL(I),I=1,7)
      WRITE(1,'(1X,2F10.6,D8.1,2F8.1,5X,2I2,5X,7I3,/)')
     *TRLIM,TRLIMS,SRATIO,WNU1A,WNU2B,IDI,LAA,(MOLL(I),I=1,7)
      TR=DLOG(TRLIM)
      TRS=DLOG(TRLIMS)
      DI=D(IDI)
      DO 60 I=1,7
      IF(MOLL(I).GT.7) THEN
                       SLIM(I) =0D0
                       SLIMS(I)=0D0
                       GOTO 60
                       END IF
      SLIM(I) =-3.14D0* TR*PE(I)*DSQRT(296D0/TE(I))/1D3/U(I)
      SLIMS(I)=-3.14D0*TRS*PE(I)*DSQRT(296D0/TE(I))/1D3/U(I)
   60 CONTINUE
      WRITE(6,'(1X,7D11.4,/)')(  SLIM(I),I=1,7)
      WRITE(6,'(1X,7D11.4,/)')( SLIMS(I),I=1,7)
      WRITE(1,'(1X,7D11.4,/)')( SLIM(I),I=1,7)
      WRITE(1,'(1X,7D11.4,/)')(SLIMS(I),I=1,7)
```

```
      LINE    = 0
      NOLINE  = 0
      NTOT    = 0
      NTOTA   = 0
      NTOTB   = 0
      NTOTD   = 0
      MSUM    = 0
      K = 0
      M = 0
      L = 0
      ZC=1D19/0.372195D0
  101 NTOT=NTOT+1
      IF(NTOT.GT.NALL) GOTO 200
      READ(2,'(1X,D16.8,3D11.4,I4)',ERR=200)
     *CC1,CC2,CC3,CC4,ICC
      IF(CC1.LE.WNU1A)   GOTO 101
      IF(CC1.GT.WNU2B)   GOTO 200
      DO 102 MOL=1,7
      IF(MOLL(MOL).EQ.ICC)   GOTO 1101
  102 CONTINUE
      GOTO 101
 1101 NTOTA=NTOTA+1
      LINA(MOL)=LINA(MOL)+1
      IF(CC2*ZC.LT.SLIM(ICC)) GOTO 101
      LINAL(MOL)=LINAL(MOL)+1
      NTOTB=NTOTB+1
  310 IF(CC1.GT.WNU1A+DI) GOTO 300
      M=M+1
      IF(M.GT.5000)   THEN
      WRITE(6,*)'THE DIMENSION OF C AND IC IS TOO SMALL!'
                      GOTO 500
                      END IF
      IC(M)=MOL
      C(M,1)=CC1
      C(M,2)=CC2*ZC
      C(M,3)=CC3
      C(M,4)=CC4
      GOTO 101
  300 L=L+1
      K=INT(WNU1A+DI)
      IF(M.NE.0) CALL STAT(M,K,L)
      IF(M.EQ.0) WRITE(1,'(1X,I5)') K
      WNU1A=WNU1A+DI
      M=0
      GOTO 310
```

```
  200 L=L+1
      K=INT(WNU1A+DI)
      IF(M.NE.0) CALL STAT(M,K,L)
      IF(M.EQ.0) WRITE(1,'(1X,I5)') K
      M=0
  500 CONTINUE
 1002 CONTINUE
      INTERV=LINE+NOLINE
      WRITE(1,*)
      WRITE(1,'(1X,11I6,3X,5I6,3X,5I6)')(ISUMS(I),I=1,11),
     *(ISUMD(I),I=1,5),NALL,MSUM,INTERV,LINE,NOLINE
      WRITE(1,'(1X,6I10,/)')NTOTD,NALL,NTOTA,NTOTB,MSUM
      WRITE(1,'(1X,7I8)')(LINA(I)   ,I=1,7)
      WRITE(1,*)
      WRITE(1,'(1X,7I8)')(LINAL(I)  ,I=1,7)
      WRITE(1,*)
      WRITE(1,'(1X,7I8)')(LINALL(I),I=1,7)
      WRITE(1,*)
      WRITE(1,'(1X,7I8)')(ISTRONG(I),I=1,7)
 3000 CONTINUE
      IF(IFAR.EQ.0) GOTO 82
      REWIND 3
   83 CALL FAR(WNUA,WNUB,REG1,REG2,REG3,ISV,ITA,ITB,IDT,IP)
   82 CONTINUE
      DATA  D/
     *1.D 0,3.D 0,5.D 0,1.D 1/
      DATA  U/
     *1768D0,2638D-1,3467D-4,2453D-4,8851D-5,1317D-3,1671D2/
      DATA PE/
     *803D0, 506D 0, 903D-1, 525D 0, 599D 0, 520D 0, 506D0/
      DATA TE/
     *275D0, 250D 0, 225D 0, 251D 0, 258D 0, 251D 0, 250D0/
```

```
C------------------------------------------------------------C
C  LIN.INP                                                   C
C -1,2230,2231,1,6.5,100,1 IFAR,WNUA,WNUB,REG1,REG2,REG3,IP  C
C  3,140,320,20             ISV,ITA,ITB,IDT                  C
C  305,0,0,0,0,5,0,0        NDDD, (IWI(I),I=1,7)             C
C  1.,1.,0.                 TRLIM,TRLIMS,SRATIO              C
C  600,800                  WNU1A,WNU2B                      C
C  0,1,1,0,0,0,0,5,0,0      IOUT,IDI,LAA,(MOLL(I),I=1,7)     C
C----                                                        C
C  0,0,0,0,0,0,0           IFAR,WNUA,WNUB,REG1,REG2,REG3,IP  C
C  0,0,0,0                 ISV,ITA,ITB,IDT                   C
C  0,0,0,0,0,0,0,0         NDDD, (IWI(I),I=1,7)              C
C  1,1,0                   TRLIM,TRLIMS,SRATIO               C
C  600,800                 WNU1A,WNU2B                       C
C  1,1,1,  0,2,0,0,0,0,0  IOUT,IDI,LAA,(MOLL(I),I=1,7)       C
C-----                                                       C
C  0,0,0,0,0,0,0           IFAR,WNUA,WNUB,REG1,REG2,REG3,IP  C
C  0,0,0,0                 ISV,ITA,ITB,IDT                   C
C  0,0,0,0,0,0,0,0         NDDD, (IWI(I),I=1,7)              C
C  .9999,.99,1D-5          TRLIM,TRLIMS,SRATIO               C
C  500,2500                WNU1A,WNU2B                       C
C  1,1,1,   1,2,3,4,5,6,7 IOUT,IDI,LAA,(MOLL(I),I=1,7)       C
C-----                                                       C
C  -1,700,720,1,6.5,20,1  IFAR,WNUA,WNUB,REG1,REG2,REG3,IP   C
C  5,160,300,20            ISV,ITA,ITB,IDT                   C
C  10000,0,0,0,0,0,0,0     NDDD, (IWI(I),I=1,7)              C
C  0.99999,1.,0.1          TRLIM,TRLIMS,SRATIO               C
C  600,800                 WNU1A,WNU2B                       C
C  0,1,1,1,2,0,0,0,0,0     IOUT,IDI,LAA,(MOLL(I),I=1,7)      C
C                                                            C
C  THIS INPUT STRUCTURE PRODUCES THE FAR WING DATA FILE FROM C
C  THE PREVIOUSLY CREATED LIN.DAT FILE. (H2O, CO2 ONLY)      C
C------------------------------------------------------------C
      END
```

```
      SUBROUTINE STAT(MM,KK,LL)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/A/ C(5000,4),MSUM,DI,WNU1A,LINE,NOLINE,LAA,IOUT,
     *          ISUMS(11),ISUMD(5),IC(5000),SRATIO,
     *          LINALL(7),LINAL(7),LINA(7),SMAX(7),
     *          ISTRONG(7),SLIMS(7)
      COMMON/B/ MOLL(7),IWI(7),NTOTD
      DIMENSION ISEL(11),IDEL(5),LINAA(7)
      IF(LAA.NE.0) THEN
                   DO 2000 LA=1,7
2000               LINAA(LA)=0
                   END IF
      K=KK
      M=MM
      IU=M
      LINE=LINE+1
      FM=FLOAT(M)
      FK=WNU1A
      L=LL
      SMA=0.
      SMI=1000.
      SATL=0.
      ALMA=0.
      ALMI=1.
      ALAT=0.
      EATL=0.
      D=FK
      DO 1 I=1,M
      D=C(I,1)-D
      S=C(I,2)
      A=C(I,3)
      E=C(I,4)
      MOL=IC(I)
      IF(I.EQ.1) D=DI-(C(M,1)-C(I,1))
      IF(ALMA.GT.A) GOTO 8
      ALMA=A
    8 IF(ALMI.LT.A) GOTO 9
      ALMI=A
    9 IF(SMA.GT.S) GOTO 10
      SMA=S
   10 IF(SMI.LT.S) GOTO 20
      SMI=S
   20 SATL=SATL+S
      ALAT=ALAT+S/A
      EATL=EATL+E*S
```

```
      J=1
      DO 11 JJ=1,10
      SJ=10.**(2-JJ)
      IF(S.GT.SJ) GOTO 12
   11 J=J+1
   12 ISEL(J)=ISEL(J) +1
        J=1
        DO 13 JJ=1,4
        DJ=10.**(1-JJ)
        IF(D.GT.DJ) GOTO 14
   13   J=J+1
   14   IDEL(J)=IDEL(J)+1
        D=C(I,1)
        IF(SMAX(MOL).LT.S) SMAX(MOL)=S
    1 CONTINUE
      ALAT=SATL/ALAT
      EATL=EATL/SATL
      SATL=SATL/FM
      IALAT=INT(ALAT*1000.)
      IALMA=INT(ALMA*1000.)
      IALMI=INT(ALMI*1000.)
      IEATL=INT(EATL)
      ISMA =INT(DLOG10(SMA)*1.D 1 + 5D-1)
      ISMI =INT(DLOG10(SMI)*1.D 1 + 5D-1)
      MSUM=MSUM+M
      NTOTCC=0
      DO 4 I=1,M
      S=C(I,2)
      MOL=IC(I)
      IF(S/SMAX(MOL).LE.SRATIO) GOTO 4
      LINAA(MOL)=LINAA(MOL)+1
      LINALL(MOL)=LINALL(MOL)+1
      NTOTCC=NTOTCC+1
      NTOTD=NTOTD+1
      NTD=NTOTD
      MOLI=MOLL(MOL)
      IF(S.LT.SLIMS(MOL)) THEN
      ISTRONG(MOL)=ISTRONG(MOL)+1
      NTD=-NTOTD
      END IF
      IF(IOUT.EQ.0) GOTO 4
      F=C(I,1)
      S=C(I,2)
      A=C(I,3)
      E=C(I,4)
```

```
      WRITE(3,'(1X,D16.8,3D11.4,I4,I8)')F,S,A,E,MOLI,NTD
    4 CONTINUE
      IU=M-NTOTCC
      WRITE(1,'(1X,I5,I4,I5,I4,E10.3,I4,4I3,I4,11I3,1X,5I3,
     *7I5)')K,IU,MSUM,M, SATL,ISMI,ISMA, IALMI,IALMA,IALAT,
     *IEATL,(ISEL(I),I=1,11),(IDEL(I),I=1,5),(LINAA(I),I=1,7)
      DO 70 I=1,5000
      IF(I.GT. 5) GOTO 68
      ISUMD(I)=ISUMD(I)+IDEL(I)
      IDEL(I)=0
   68 IF(I.GT.11) GOTO 69
      ISUMS(I)=ISUMS(I)+ISEL(I)
      ISEL(I)=0
   69 C(I,1)=0.
      C(I,2)=0.
      C(I,3)=0.
      C(I,4)=0.
      IF(I.LE.7) SMAX(I)=0D0
   70 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FAR(A1,A2,REGA,REGB,REGC,ISV,ITA,ITB,IDT,IP)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/B/ MOLL(7),IWI(7),NTOTD
      DIMENSION POSA(10000),STRA(10000),ALFA(10000),
     *          ENRA(10000),ISIA(10000),IQSW(10000),
     *          WING(10000),AV(7),BV(7),CV(7),AR(7),
     *          AL(7),AT(7),QV(7),QR(7),SUM(7,110),II(3,7)
      V1=A1
      V2=A2
      IST=(ITB-ITA)/IDT+1
      DIV=1D0/DFLOAT(ISV-1)
      REG1=REGA
      REG2=REGB
      REG3=REGC
      WRITE(8,'(1X,11I5)')(MOLL(I),I=1,7), ISV,ITA,ITB,IDT
      IF(IP.NE.0)
     *WRITE(6,'(1X,11I5)')(MOLL(I),I=1,7), ISV,ITA,ITB,IDT
  207 FORMAT(1X,D16.8,3D11.4,I4,I8)
      DO 152 J=1,IST
      DO 151 L=1,7
      T=ITA+(J-1)*IDT
      CST1=TTT0/T
      CST2=1.43879*(T-TTT0)/T/TTT0
      QV(L)=AV(L)+BV(L)*CST1**CV(L)
      QR(L)=CST1**AR(L)
  151 AT(L)=CST1**AL(L)
      IF(IP.NE.0)
     *WRITE(6,'(1X,I2,4E12.4)')(L,AT(L),QV(L),QR(L),T,L=1,7)
  152 CONTINUE
      WRITE(6,*)NTOTD
      IFILE=0
      INXY =0
      JLIN =0
      DO 1000 POS=V1,V2
      POS1=POS-5D-1
      POS2=POS+5D-1
      IF(IFILE.EQ.0) GOTO 250
      INXY=0
      DO 210 I=1,INXX
      IF(POSA(I).GE.POS1-REG3) GOTO 220
  210 INXY=INXY+1
  220 IF(INXY.EQ.0) GOTO 230
      DO 240 I=1,INXX-INXY
      POSA(I)=POSA(I+INXY)
      STRA(I)=STRA(I+INXY)
```

```
      ALFA(I)=ALFA(I+INXY)
      ENRA(I)=ENRA(I+INXY)
      ISIA(I)=ISIA(I+INXY)
  240 IQSW(I)=IQSW(I+INXY)
  230 INXY=INXX-INXY
      IF(Q1.GT.POS2+REG3) GOTO 209
      INXY=INXY+1
      POSA(INXY)=Q1
      STRA(INXY)=Q2
      ALFA(INXY)=Q3
      ENRA(INXY)=Q4
      ISIA(INXY)=IQ
      IQSW(INXY)=IY
      GOTO 251
  250 IFILE=1
  251 CONTINUE
  206 IF(IY/NTOTD.NE.0) GOTO 209
      READ(3,207) Q1,Q2,Q3,Q4,IQ,IY
      DO 270 ISM=1,7
      IF(IQ.NE.MOLL(ISM)) GOTO 270
      IF(IY.GT.0) GOTO 271
  270 CONTINUE
      IF(Q1.GT.POS2+REG3) GOTO 209
      GOTO 206
  271 IF(Q1.LT.POS1-REG3) GOTO 206
      IF(Q1.GT.POS2+REG3) GOTO 209
      JLIN=JLIN+1
      INXY=INXY+1
      POSA(INXY)=Q1
      STRA(INXY)=Q2
      ALFA(INXY)=Q3
      ENRA(INXY)=Q4
      ISIA(INXY)=IQ
      IQSW(INXY)=IY
      GOTO 206
  209 INXX=INXY
      DO 138 I=1,3
      DO 138 J=1,7
  138 II(I,J) =0
      DO 135 I=1,INXX
      POL=POSA(I)
      D3A=POS1-REG3
      D2A=POS1-REG2
      D1A=POS1-REG1
      D1B=POS2+REG1
```

```
      D2B=POS2+REG2
      D3B=POS2+REG3
      IF(POL.GE. D3A.AND.POL.LT. D2A) II(3,1)=II(3,1)+1
      IF(POL.GE. D2A.AND.POL.LT. D1A) II(3,2)=II(3,2)+1
      IF(POL.GE. D1A.AND.POL.LT.POS1) II(3,3)=II(3,3)+1
      IF(POL.GE.POS1.AND.POL.LE.POS2) II(3,4)=II(3,4)+1
      IF(POL.GT.POS2.AND.POL.LE. D1B) II(3,5)=II(3,5)+1
      IF(POL.GT. D1B.AND.POL.LE. D2B) II(3,6)=II(3,6)+1
      IF(POL.GT. D2B.AND.POL.LE. D3B) II(3,7)=II(3,7)+1
  135 CONTINUE
      II(1,1)=1
      II(2,1)=II(3,1)
      II(1,2)=II(2,1)+1
      II(2,2)=II(2,1)+II(3,2)
      II(1,3)=II(2,2)+1
      II(2,3)=II(2,2)+II(3,3)
      II(1,4)=II(2,3)+1
      II(2,4)=II(2,3)+II(3,4)
      II(1,5)=II(2,4)+1
      II(2,5)=II(2,4)+II(3,5)
      II(1,6)=II(2,5)+1
      II(2,6)=II(2,5)+II(3,6)
      II(1,7)=II(2,6)+1
      II(2,7)=II(2,6)+II(3,7)
      IF(IP.NE.0)WRITE(6,'(1X,I4,5I8)')(J,(II(I,J),I=1,3),
     *IQSW(II(1,J)),IQSW(II(2,J)),J=1,7)
      I1REG3 =II(1,1)
      I2REG3 =II(2,1)
      J1REG3 =II(1,7)
      J2REG3 =II(2,7)
      DO 140 IV=1,ISV
      IX=(IV-1)*IST
      PP=POS-5D-1+(IV-1)*DIV
      DO 141 I=I1REG3,I2REG3
      PA =POSA(I)
      L  =ISIA(I)
      IWC=IWI(L)
      OUT=1D0
      IF(IWC.EQ.0.OR.IWC.EQ.4.OR.IWC.EQ.7) GOTO 111
      CALL WINGS(PP,PA,0D0,IWC,OUT)
  111 WING(I)=PI*(PA-PP)*(PA-PP)/OUT
  141 CONTINUE
      DO 142 I=J1REG3,J2REG3
      PA =POSA(I)
      L  =ISIA(I)
```

```
      IWC=IWI(L)
      OUT=1D0
      IF(IWC.EQ.0.OR.IWC.EQ.4.OR.IWC.EQ.7) GOTO 112
      CALL WINGS(PP,PA,0D0,IWC,OUT)
  112 WING(I)=PI*(PA-PP)*(PA-PP)/OUT
  142 CONTINUE
      DO 144 J=1,IST
      DO 149 L=1,7
  149 SUM(L,IX+J)=0D0
      T   =ITA+(J-1)*IDT
      CST1=TTT0/T
      CST2=1.43879*(T-TTT0)/T/TTT0
      DO 153 L=1,7
      QV(L)=AV(L)+BV(L)*CST1**CV(L)
      QR(L)=CST1**AR(L)
      AT(L)=CST1**AL(L)
  153 CONTINUE
      DO 145 I=I1REG3,I2REG3
      L  =ISIA(I)
      WIN=WING(I)
      IWC=IWI(L)
      IF(IWC.EQ.0) GOTO 113
      IF(IWC.EQ.4.OR.IWC.EQ.7) THEN
      PA=POSA(I)
      CALL WINGS(PP,PA,T,IWC,OUT)
      WIN=WIN/OUT
      END IF
  113 IF(WIN.LT.0D0) GOTO 145
      SUM(L,IX+J)=SUM(L,IX+J)+ALFA(I)*AT(L)*
     *STRA(I)*QV(L)*QR(L)*DEXP(ENRA(I)*CST2)/WIN
  145 CONTINUE
      DO 146 I=J1REG3,J2REG3
      L=ISIA(I)
      WIN=WING(I)
      IWC=IWI(L)
      IF(IWC.EQ.0) GOTO 114
      IF(IWC.EQ.4.OR.IWC.EQ.7) THEN
      PA=POSA(I)
      CALL WINGS(PP,PA,T,IWC,OUT)
      WIN=WIN/OUT
      END IF
  114 IF(WIN.LT.0) GOTO 146
      SUM(L,IX+J)=SUM(L,IX+J)+ALFA(I)*AT(L)*
     *STRA(I)*QV(L)*QR(L)*DEXP(ENRA(I)*CST2)/WIN
  146 CONTINUE
```

```
  144 CONTINUE
  140 CONTINUE
      IF(IP.EQ.0) GOTO 900
      WRITE(6,'(1X,F10.1)') POS
      DO 147 L=1,7
      IF(MOLL(L).EQ.0) GOTO 147
      DO 147 IV=1,ISV
      IX=(IV-1)*IST
      WRITE(6,'(1X,10F7.6)')(SUM(L,IX+J),J=1,IST)
  147 CONTINUE
  900 WRITE(8,'(1X,F10.1)') POS
      DO 148 L=1,7
      IF(MOLL(L).EQ.0) GOTO 148
      DO 148 IV=1,ISV
      IX=(IV-1)*IST
      WRITE(8,'(1X,10E11.4)')(SUM(L,IX+J),J=1,IST)
  148 CONTINUE
 1000 CONTINUE
      DATA TTT0, PI/296D0,3.14159265D0/
      DATA AV, BV, CV/
     *1D0,.99752D0,.99852D0,1.01819D0,1D0,.99935D0,1D0,
     *0D0,.09310D0,.04600D0, .12700D0,0D0,.00700D0,0D0,
     *0D0,-3.54915D0,-4.11179D0,-4.42836D0,0D0,-5.47575D0,0D0/
      DATA AR/1.5D0,1.0D0,1.5D0,1.0D0,1.0D0,1.5D0,1.0D0/
      DATA AL/0.5D0,0.5D0,0.5D0,0.5D0,0.5D0,0.5D0,0.5D0/
      RETURN
      END
```

```
      SUBROUTINE WINGS(VA,VB,TA,IC,OUT)
      IMPLICIT REAL*8(A-H,O-Z)
      DV=DABS(VA-VB)
      GOTO(10,20,30,40,50,60,70),IC
   10 IF(DV.GT.3.5D0) GOTO 11
      OUT=1D0
      RETURN
   11 OUT=DEXP(-1.4D0*(DV-3.5D0)**0.25D0)
      RETURN
   20 IF(DV.GE.5D-1) GOTO 21
      OUT=1D0
      RETURN
   21 IF(DV.GE.23D0) GOTO 22
      OUT=1.069*DEXP(-0.133*DV)
      RETURN
   22 IF(DV.GE.50D0) GOTO 23
      OUT=5D-2
      RETURN
   23 IF(DV.GE.25D1) GOTO 24
      OUT=0.133D0*DEXP(-0.0196*DV)
      RETURN
   24 OUT=-1D0
      RETURN
   30 IF(DV.GE.11D0) GOTO 31
      OUT=(1D0+2D0*DV/11D0)*DEXP(-2D0*DV/11D0)
      RETURN
   31 OUT=-1D0
      RETURN
   40 DW=VA+VB
      DEA=1D0-DEXP(-1.43879D0*VA/TA)
      DEB=1D0-DEXP(-1.43879D0*VB/TA)
      OUT=VA*DEA*(1D0+DV*DV/DW/DW)/VB/DEB
      RETURN
   50 DW=VA+VB
      OUT=VA*VA*(1D0+DV*DV/DW/DW)/VB/VB
      RETURN
   60 DW=VA+VB
      OUT=VA*(1D0+DV*DV/DW/DW)/VB
      RETURN
   70 OUT=2D0*VA/(1D0+DEXP(-1.43879*DV/TA))/VB
      RETURN
      END
```

APPENDIX D

Listing of the HART Programme

HART
LAYERS
MINT
LENGTH
MESH
CONT
FARWG
GAUSS
SHAPE
VOIGTY
VOIGTD
WING

```
      PROGRAM HART
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/GA/ IPRE,IGNU,EPSN,ERG,ERGB,ITY,IGS,IGI,OUTGS,
     *           NG,OUTSS(14000),H2OC,OFWG,LS1,LS2,ITRN,JSWS
      COMMON/SH/ IPRF,REG0,IINT,DVPR,PDLR,PLNZ,VDLR,VLNZ,TAV,
     *           PAV,ALOR(10),AK0(10),XS(10),KSHP,IVDY,
     *           LMOD(7),RMOD(7)
      COMMON/HA/ POSA(3000),STRA(3000),ENRA(3000),ALFA(3000),
     *ALFT(3000),CPLG(3000),STRT(3000),ISIA(3000),IQSW(3000)
      COMMON/LE/ IPRC,IPRG,IWA1,IWB1,AA,BB,ITT,JUMP,IG,IALL,
     *           DZ,AEP(21),ALEN(20),ALENS(20),NLEN,DR,D1,
     *           KSUB,IALP,ALP,IQQ,IGA(1400),AGA(1400),
     *           ITYPE(1400)
      COMMON/CO/ IPRD,ICT,CV(69),CD(3,69),CT(3),SUMH
      COMMON/FA/ MOLL(7),AMASS(10),IFAR,OFWGS,IVI(7)
      COMMON/LA/ IPRB,ALT(150),DEY(150),PSTND,TSTND,BMY(150),
     *           CHY(150),TLY(150),PLY(150),AMIY(37,150)
      DIMENSION
     *IIII(3,5),TRABS(150),AMOLE(10),ALOR0(10),ALORT(10),
     *MOLE(10),SHIFT(10),IBLW(200),IWARN(200),IENDPT(200),
     *TRAB(200),TRAB1(200),SUMM(200),PLX(150),TLX(150),
     *AMIX(37,150),CST1(150),CST2(150),TDOPA(150),POS(500),
     *ISI(500),VPFN(3,7),CS1(7),RPFN(7),DVP(7),VPR(7),
     *CHX(150),DEX(150),AMIT(150),ADOP(10),UMOD(7),SMOD(7),
     *AMOD(7),WNBC(10),DWNB(10),NLINE(10),SINT(10),GSEN(10),
     *PLZ(3000),BMZ(3000),CHZ(3000),TLZ(3000),ALZ(3000),
     *DEZ(3000),AMZ(3000),TETM(31)
      EQUIVALENCE
     *(POSA,PLZ),(STRA,BMZ),(ENRA,TLZ),(ALFA,CHZ),
     *(ALFT,ALZ),(CPLG,DEZ),(STRT,AMZ)
C-------------------------------------------------------------
C                 FIRST SECTION:   INPUTS
C-------------------------------------------------------------
      OPEN(UNIT=9,TYPE='OLD',FILE= 'HART.INP')
      READ (9,*) RESL,DELV,ITRN,IRAD,IOTR,IORD,IOPR
      READ (9,*) IPRA,IPRB,IPRC,IPRD,IPRE,IPRF,IPRG,IPRH
      READ (9,*) ISBN,IGNU,EPSN,ICCH,
     *          (PDLR,PLNZ,VDLR,VLNZ,I=1,ICCH)
      READ(9,*)  IINT,AINT,IVPF,IRPF,KSHP,IVDY
      READ (9,*) MODL,(IDEN,LMOD(IDEN),I=1,MODL)
      READ (9,*) MODA,(IDEN,AMOD(IDEN),I=1,MODA)
      READ (9,*) MODS,(IDEN,SMOD(IDEN),I=1,MODS)
      READ (9,*) MODR,(IDEN,RMOD(IDEN),I=1,MODR)
      READ (9,*) WNU1,WNU2,REG0,REG1,REG2
      READ (9,*) IPSC,IHOM,IARM,ASCL
```

```
    WED    = (WNU1+WNU2)/2
    JSWS   = 1
    IF(IPSC.EQ.0)THEN
                 READ (9,*) LVEL,NBND,(MOLE(I),I=1,NBND)
                 READ (9,*)(PLX(I),TLX(I),(AMIX(MOLE(J),I),
   *             J=1,NBND),I=1,LVEL)
                 GOTO 137
                 END IF
    IF(IPSC.EQ.4)GOTO 10
                 READ (9,*)PPP1,PPP2,PPPD,TT1,TT2,TTD
                 READ (9,*)NBND,(MOLE(I),AMASS(I),I=1,NBND)
                 GOTO 137
 10 READ (9,*) IPOF,LVEL,NBND,(MOLE(I),I=1,NBND)
    READ (9,*) LVL1,LVL2,TSKN,EMIS
    READ (9,*) IDIR,TETA,TETB,DTET
    READ (9,*) LVEN,ALT1,ALT2,PATH
    READ (9,*) MODU,(IDEN,UMOD(IDEN),I=1,MODU)
    IF(IPOF.EQ.0)THEN
                 OPEN(UNIT= 1,TYPE='OLD',FILE='PROFIL.DAT')
                 READ(1,*)(ALT(I),PLY(I),TLY(I),DEY(I),
   *             (AMIY(J,I),J=1,7),I=1,LVEL)
                 END IF
    IF(IPOF.NE.0)THEN
                 OPEN(UNIT= 3,TYPE='OLD',FILE='MODATM.DAT')
                 DO 36 K=1,6
                 IF(K.EQ.IPOF) READ(3,*)(ALT(I),PLY(I),
   *             TLY(I),DEY(I),(AMIY(J,I),J=1,7),I=1,LVEL)
                 IF(K.NE.IPOF) READ(3,*)(DUM,DUM,DUM,DUM,
   *             (DUM,J=1,7),I=1,LVEL)
 36              CONTINUE
                 READ(3,'(1X,2E11.4)')((DUM,AMIY(J,I),I=1,
   *             LVEL),J=8,37)
                 IF(IPRA.EQ.-2) WRITE(6,'(1X,I4,E11.4,2X,
   *             E11.4)')((I,ALT(I),AMIY(MOLE(J),I),I=1,
   *             LVEL),J=1,NBND)
                 END IF
137 READ (9,*) ILIN,ILIM,ICON,IFAR,JREF
    IF(ILIN.EQ.1)THEN
                 READ(9,*)(NLINE(I),WNBC(I),DWNB(I),
   *             SHIFT(I),SINT(I),GSEN(I),I=1,NBND)
                 END IF
    IF(ILIN.EQ.2)OPEN(UNIT= 2,TYPE='OLD',FILE=  'LIN.DAT')
    IF(ICON.EQ.1)OPEN(UNIT= 7,TYPE='OLD',FILE= 'CONT.DAT')
    IF(IFAR.EQ.1)OPEN(UNIT= 8,TYPE='OLD',FILE='FARWG.DAT')
    IF(IOPR.NE.0)OPEN(UNIT=12,TYPE='NEW',FILE='PRNEW.DAT')
```

```
      IF(IOTR.EQ.1)OPEN(UNIT=10,TYPE='NEW',FILE= 'TRAO.DAT')
      IF(IORD.EQ.1)OPEN(UNIT=11,TYPE='NEW',FILE=  'RAD.DAT')
      IF(ICON.EQ.1)READ(7,*) ( CV(I),(CD(J,I),J=1,3),I=1,69)
C-------------------------------------------------------------
C                       LAYERING
C-------------------------------------------------------------
      IF(IPSC.NE.4) GOTO 139
      RR3 = DEY(LVEL)
      PRMI=1D3
      PRMA=0D0
      DO 235 L=1,LVEL
      IF(PLY(L).LT.PRMI) PRMI=PLY(L)
      IF(PLY(L).GT.PRMA) PRMA=PLY(L)
      CHY(L)=BOLTZ*DEY(L)*AMIY(1,L)*TLY(L)/1D2
  235 CONTINUE
      IF(IPRA.EQ.-2)WRITE(6,'(3X,1HL,5X,3HALT,8X,3HCHY,8X,
     *3HDEY,8X,3HTLY,/,/,(I4,4D11.4))')(L,ALT(L),CHY(L),
     *DEY(L),TLY(L),L=1,LVEL)
C-----
      IF(IDIR.EQ.0) THEN
      CALL MINT (ALT,PLY,1,LVEL,I,ALT1,PLX(1),IPRB)
      CALL MINT (ALT,TLY,3,LVEL,I,ALT1,TLX(1),IPRB)
      CALL MINT (ALT,CHY,3,LVEL,I,ALT1,CHX(1),IPRB)
      CALL MINT (ALT,DEY,1,LVEL,I,ALT1,DEX(1),IPRB)
      DO 179 J=1,NBND
      K=MOLE(J)
      DO 177 L=1,LVEL
  177 AMIT(L) = AMIY(K,L)
      CALL MINT(ALT,AMIT,3,LVEL,I,ALT1,AMIX(K,1),IPRB)
      AMIX(K,1)=DEX(1)*UNIV
  179 AMASS(K)=AMIX(K,1)*PATH
      LVEL=1
      BMY(1)=1D0
      IHOM=0
      IPSC=0
      WRITE(6,'(/,1X,14HSHORT PATH AT ,F5.2,11HKM ALTITUDE,
     */,/,7HTEMP = ,F5.2,8HPRES. = ,F5.2,/,/2X,11HABSORBERS: ,
     *7F8.3,/)')ALT1,TLX(1),PLX(1),(AMASS(M),M=1,NBND)
      GOTO 49
      END IF
C-----
      LPLUS=0
      IF(LVL1.EQ.0) THEN
            DO 192 I=1,LVEL-1
            IF(ALT1.GT.ALT(I+1)) GOTO 191
```

```
192       CONTINUE
191       CALL MINT (ALT,PLY,1,LVEL,I,ALT1,PLY(I),IPRB)
          CALL MINT (ALT,DEY,1,LVEL,I,ALT1,DEY(I),IPRB)
          CALL MINT (ALT,TLY,2,LVEL,I,ALT1,TLY(I),IPRB)
          CALL MINT (ALT,CHY,2,LVEL,I,ALT1,CHY(I),IPRB)
          DO 190 J=1,NBND
          K=MOLE(J)
          DO 171 L=1,LVEL
171       AMIT(L) = AMIY(K,L)
190       CALL MINT(ALT,AMIT,2,LVEL,I,ALT1,AMIY(K,I),IPRA)
          ALT(I)=ALT1
          LVL1=I
          LPLUS=I-1
          WRITE(6,*)'NEW LVL1 LPLUS AND ALT1 : ',
   *      LVL1,LPLUS,ALT1
          END IF
    IF(LVL2.EQ.0) THEN
          DO 182 I=1,LVEL-1
          IF(ALT2.GE.ALT(I+1)) GOTO 181
182       CONTINUE
          I = I-1
181       CALL MINT(ALT,PLY,1,LVEL,I,ALT2,PLY(I+1),IPRB)
          CALL MINT(ALT,DEY,1,LVEL,I,ALT2,DEY(I+1),IPRB)
          CALL MINT(ALT,TLY,2,LVEL,I,ALT2,TLY(I+1),IPRB)
          CALL MINT(ALT,CHY,2,LVEL,I,ALT2,CHY(I+1),IPRB)
          DO 180 J=1,NBND
          K=MOLE(J)
          DO 172 L=1,LVEL
172       AMIT(L)=AMIY(K,L)
180       CALL MINT(ALT,AMIT,2,LVEL,I,ALT2,AMIY(K,I+1),IPRA)
          ALT(I+1)=ALT2
          LVL2=I+1
          WRITE(6,*)'NEW LVL2 AND ALT2 : ',LVL2,ALT2
          END IF
164 IF(LVEN.GT.2) THEN
    DSC=(ALT1-ALT2)/(LVEN-1)
    DO 197 I=1,LVEN
    IF(ASCL.LT.0) ALZ(LVEN-I+1)=ALT2+(ALT1-ALT2)*
   *(DEXP(-ASCL*DSC*(I-1)/(ALT1-ALT2))-1)/(DEXP(-ASCL)-1)
    IF(ASCL.GT.0) ALZ(LVEN-I+1)=ALT2+(ALT1-ALT2)*
   *(DSC*(I-1)/(ALT1-ALT2))**ASCL
    IF(ASCL.EQ.0) ALZ(LVEN-I+1)=ALT2+(ALT1-ALT2)*
   *DSC*(I-1)/(ALT1-ALT2)
197 CONTINUE
    DO 196 I = 1,LVEN
```

```
      DO 195 J = LVL1,LVL2-1
      IF(ALT(J+1).LE.ALZ(I))GOTO 194
  195 CONTINUE
      J = J - 1
  194 CONTINUE
      CALL MINT(ALT,PLY,1,LVEL,J,ALZ(I),PLZ(I),IPRB)
      CALL MINT(ALT,DEY,1,LVEL,J,ALZ(I),DEZ(I),IPRB)
      CALL MINT(ALT,TLY,2,LVEL,J,ALZ(I),TLZ(I),IPRB)
      CALL MINT(ALT,CHY,2,LVEL,J,ALZ(I),CHZ(I),IPRB)
      DO 173 K=1,NBND
      M=MOLE(K)
      DO 178 L=1,LVEL
  178 AMIT(L)=AMIY(M,L)
      CALL MINT(ALT,AMIT,2,LVEL,J,ALZ(I),AMZ(I),IPRB)
      IF(DTET.EQ.0D0)AMIX(M,I)=AMZ(I)
      IF(DTET.NE.0D0.AND.M.EQ.IABS(IARM))
     *DEZ(I)=DEZ(I)*AMZ(I)*UNIV
  173 CONTINUE
  196 CONTINUE
      LVEL=LVEN
      LVL1=1
      LVL2=LVEL
      LAYER=LVEL-1
      END IF
C----
      IF(LVEN.LE.0) THEN
      LVEL=LVL2-LVL1+1
      LAYER=LVEL-1
      DO 175 L=1,LVEL
      ALZ(L)=ALT(LVL1+L-1)
      PLZ(L)=PLY(LVL1+L-1)
      TLZ(L)=TLY(LVL1+L-1)
      CHZ(L)=CHY(LVL1+L-1)
      DEZ(L)=DEY(LVL1+L-1)
      IF(IARM.NE.0.AND.DTET.NE.0D0)
     *DEZ(L)=DEZ(L)*AMIY(IABS(IARM),LVL1+L-1)*UNIV
      DO 175 J=1,NBND
      AMIX(MOLE(J),L)=AMIY(MOLE(J),LVL1+L-1)
 175  CONTINUE
      END IF
      IF(IPRA.EQ.1) WRITE(6,'(/,1X,7HLVL1 = ,I3,3X,7HLVL2 = ,
     *I3,3X,7HLVEL = ,I3,3X,7HLVEN = ,I3,/,/,2X1HL,7X,3HALZ,
     *8X,3HPLZ,8X,3HTLZ,8X,3HDEZ,8X,3HCHZ,/,/,(1X,I4,1X,
     *6E11.4))')LVL1,LVL2,LVEL,LVEN,(L,ALZ(L),PLZ(L),TLZ(L),
     *DEZ(L),CHZ(L),AMZ(L),L=1,LVEL)
```

```
C-------------------------------------------------------------
C                        SECOND  SECTION
C-------------------------------------------------------------
      LIMB  = 0
      IF(IPSC.EQ.4.AND.IHOM.EQ.1) JSWS=2
      WEDD  = WED*WED
      IF(IPSC.NE.4) GOTO 139
      IF(IPRB.EQ.1) WRITE(6,'(/,3X,4HTETA,7X,5HALFA1,4X,
     *4HDEFL,4X,5HSLANT,4X,5HPATAL,/)')
      CALL LAYERS(WEDD,JREF,IDIR,TETA,LVEL,ALT2,LIMB,LVEN)
      IF(DTET.EQ.0D0)WRITE(6,'(1X,7HLIMB = ,I5,4X,7HALT1 = ,
     *F10.6,4X,7HALT2 = ,F10.6,4X,7HLVEN = ,I5,/)')LIMB,
     *ALT(LVL1),ALT2,LVEN
      IF(LIMB.EQ.1.AND.LVEN.LT.0) THEN
      ALT1=ALT(LVL1)
      ALT2=ALT(LVEL)
      LVEN=-LVEN
      LVEL=LAYER+1
      GOTO 164
      END IF
      IF(DTET.EQ.0) GOTO 176
           IF(DTET.LT.0) THEN
           DO 165 I=1,31
           TET=TETM(I)
           CALL LAYERS(WEDD,JREF,IDIR,TET,LVEL,ZNEW,LIMB,LVEN)
  165      CONTINUE
           GOTO 1000
           END IF
           DO 198 TET=TETA+DTET,TETB,DTET
           CALL LAYERS(WEDD,JREF,IDIR,TET,LVEL,ZNEW,LIMB,LVEN)
  198      CONTINUE
           GOTO 1000
  176 CONTINUE
      IF(LIMB.EQ.1) THEN
      DO 151 M=1,NBND
      K=MOLE(M)
      DO 152 L=1,LAYER+1
  152 AMIT(L)=AMIY(K,L)
      LOD=LVEL+LVL1-2
  151 CALL MINT(ALT,AMIT,2,LAYER+1,LOD,ALT2,AMIY(K,LVEL),IPRB)
      END IF
      DO 161 LL=1,LVEL
      K=LVEL-LL+1
      L=LVEL+LL-1
      BMY(K)=BMZ(K)
```

```
      ALT(K)=ALZ(K)
      PLY(K)=PLZ(K)
      TLY(K)=TLZ(K)
      DEY(K)=DEZ(K)
      CHY(K)=CHZ(K)
      DO 162 M=1,NBND
      IF(LL.GE.2.OR.LIMB.EQ.0) AMIY(MOLE(M),K)=AMIX(MOLE(M),K)
  162 CONTINUE
      IF(LIMB.EQ.0) GOTO 161
      BMY(L)=BMZ(K)
      ALT(L)=ALZ(K)
      PLY(L)=PLZ(K)
      TLY(L)=TLZ(K)
      DEY(L)=DEZ(K)
      CHY(L)=CHZ(K)
      DO 163 M=1,NBND
      IF(LL.GE.2) AMIY(MOLE(M),L) = AMIX(MOLE(M),K)
  163 CONTINUE
  161 CONTINUE
      IF(LIMB.EQ.1) THEN
      LVEL=2*LVEL-1
      LAYER=LVEL-1
      END IF
      IF(IOPR.NE.0) THEN
      DO 150 I=1,LVEL
  150 WRITE(12,'(1X,11E11.4)')
     *ALT(I),PLY(I),TLY(I),DEY(I),(AMIY(MOLE(J),I),J=1,NBND)
      END IF
      IF(IPRA.EQ.1)WRITE(6,'(/,1X,7HLVEL = ,I5,5X,3H***,/,/,
     *3X,HL,6X,3HALT,9X,3HPLY,9X,3HTLY,9X,3HDEY,9X,3HCHY,9X,
     *3HBMY,/,/,(1X,I3,6D12.4))')LVEL,(L,ALT(L),PLY(L),TLY(L),
     *DEY(L),CHY(L),BMY(L),L=1,LVEL)
      IF(IOPR.EQ.-1) GOTO 1000
C-----
      DO 34 I=1,NBND
      MOO=MOLE(I)
      IF(IPRA.EQ.3) WRITE(6,'(/,3X,3HALT,5X,8HPRESSURE,5X,
     *4HTEMP,5X,3HPEF,5X,3HTEF,5X,1HU,5X,4HUSUM,/,/)')
      UUU=0D0
      TFF=0D0
      PFF=0D0
      IBM=0
      DO 34 J=1,LAYER
      IF(BMZ(J).LT.DZ) IBM=1
      PAV=(PLY(J)+PLY(J+1))/2D0
```

```
      TAV=(TLY(J)+TLY(J+1))/2D0
      DAV=( DEY(J)+ DEY(J+1))/2D0
      AXA=(AMIY(MOO,J)+AMIY(MOO,J+1))/2D0
      USU=AXA*DAV*UNIV*DABS(ALT(J)-ALT(J+1))
      UUU=UUU+USU
      IF(IHOM.EQ.1) THEN
                    IF(I.EQ.NBND)  PLX(J)=PAV
                    IF(I.EQ.NBND)  TLX(J)=TAV
            AMIX(MOO,J)=USU
            BMY(J)=BMY(J+IBM)
                    END IF
      IF(IHOM.EQ.2) THEN
                    PLX(J)=(TFF*UUU+TAV*USU)/(USU+UUU)
                    TLX(J)=(PFF*UUU+PAV*USU)/(USU+UUU)
                    TFF=TLX(J)
                    PFF=PLX(J)
            AMIX(MOO,J)=UUU
            END IF
CB----
      IF(IPRA.EQ.3) WRITE(6,'(1X,I3,6D12.4)')
     *J,ALT(J),PLX(J),TLX(J),USU,UUU,BMY(J)
   34 CONTINUE
      IF(ICON.EQ.1) THEN
              DO 234 L=1,LAYER
              DEX(L)=(DEY(L)+DEY(L+1))/2D0
  234         CHX(L)=DEX(L)*(AMIY(1,L)+AMIY(1,L+1))*5D-7
              END IF
      IF(IPRA.EQ.1) WRITE(6,'(/,1X,6HRR3 = ,2X,D15.5,/,/,
     *(2X,I5,3D15.5))')RR3,(L,CHX(L),CHY(L),DEX(L),L=1,LVEL)
C-----
      GOTO 39
C-------------------------------------------------------------
C                 END OF LAYERING
C-------------------------------------------------------------
  139 IF(IPSC.GT.0.AND.IPSC.LT.4) THEN
      IPPH=0
      LY=0
      LSUB=51
      IPPJ=0
      IPPK=8
      IF(IPSC.EQ.3) PSCALE=(DLOG10(PPP1)-DLOG10(PPP2))/PPPD
   18 GOTO(21,22,23) ,IPSC
   21 PPP=PPP1-PPPD*IPPJ
      IF(PPP-PPP2.LT.-DZ) GOTO 41
      IPPJ=IPPJ+1
```

```
      GOTO 40
   22 PPP=PPP1*(9-IPPK)/1.D 1**IPPJ
      IF(PPP-PPP2.LT.-DZ) GOTO 41
      IPPK=IPPK+1
      IF(IPPK.GE.9) THEN
      IPPK=0
      IPPJ=IPPJ+1
      END IF
      GOTO 40
   23 PPP=PPP1*1.D 1**(-PSCALE*DFLOAT(IPPJ))
      IF(PPP-PPP2.LT.-DZ) GOTO 41
      IPPJ=IPPJ+1
C-----
   40 ITTJ=0
   19 TTT=TTT1+TTTD*ITTJ
      IF(TTT.GT.TTT2) GOTO 18
      ITTJ=ITTJ+1
      LY=LY+1
      LSUB=LSUB-1
      PLX(LSUB)=PPP
      TLX(LSUB)=TTT
      DO 13 I=1,NBND
   13 AMIX(MOLE(I),LSUB)=AMASS(I)
      GOTO 19
   41 DO 45 I=1,LY
      PLX(I)=PLX(LSUB+I-1)
      TLX(I)=TLX(LSUB+I-1)
      DO 45 J=1,NBND
   45 AMIX(MOLE(J),I)=AMIX(MOLE(J),LSUB+I-1)
      LVEL=LY
      END IF
C-----
   39 CONTINUE
      DO 174 I=1,NBND
  174 MOLL(MOLE(I))=MOLE(I)
   49 IHOMH=0
      IF(IHOM.NE.0) IHOMH=1
CA----
      IF(IPRA.EQ.1) THEN
      WRITE(6,'(3(/,1X,I2,3X),F7.2,/)')
     *(I,MOLE(I),MOLL(MOLE(I)),UMOD(MOLE(I)),I=1,NBND)
      WRITE(6,'(/,1X,14I5,/,/)')IPOF,LAYER,NBND,LY,LSUB,IPSC,
     *IHOM,(MOLE(I),I=1,NBND)
      DO 42 I=1,LVEL-IHOMH
      IF(IPSC.EQ.4)WRITE(6,'(1X,I3,11D11.4)')I,ALT(I),PLX(I),
```

```
     *TLX(I),DEY(I),BMY(I),(AMIX(MOLE(J),I),J=1,NBND)
      IF(IPSC.NE.4)WRITE(6,'(1X,I5, 9D11.4)')I,PLX(I),TLX(I),
     *(AMIX(MOLE(J),I),J=1,NBND)
   42 CONTINUE
      END IF
C-----
      DO 33 I=1,LVEL-IHOMH
      IF(IPSC.NE.4) BMY(I)=1D0
      TDOPA(I)=C3*DSQRT(TLX(I))
      CST1(I) = TTT0/TLX(I)
      CST2(I) = 1.439*(TLX(I)-TTT0)/TTT0/TLX(I)
   33 CONTINUE
CA---
      IF(IPRA.EQ.1)WRITE(6,'(/,8X,5HTDOPA,17X,4HCST1,17X,
     *4HCST2,/,/,(1X,3D20.10))')(TDOPA(I),CST1(I),CST2(I),
     *I=1,LVEL-IHOMH)
C-----
  199 GOTO(101,102),ILIN
  102 IFILE=1
      INXY =0
      JLIN =0
      MAINXX=0
C-----
  101 CONTINUE
      IF(IFAR.EQ.1) CALL FARWG(WNU1,0D0,0D0,0FWG,IPRD)
      IF(WED.GT. 0D0.AND.WED.LT.50D0) SCLL=1D2
      IF(WED.GT. 50D0.AND.WED.LT.500D0) SCLL=1D1
      IF(WED.GT. 500D0.AND.WED.LT.5000D0) SCLL=1D0
      IF(WED.GT. 5000D0.AND.WED.LT.20000D0) SCLL=1D-1
      IF(PRMI.GT.1D2) SCLL=SCLL/5D0
      WRITE(6,'(/,1X,7HSCLL = ,F7.2,/)') SCLL
      DO 143 I=1,21
  143 AEP(I)=AEP(I)/SCLL
      SUMA=0D0
      DO 144 I=1,NLEN
      ALEN(I)=AEP(I+1)-AEP(I)
      SUMA=SUMA+ALEN(I)
  144 ALENS(I)=SUMA
      DO 145 I=1,7
  145 RMOD(I)=RMOD(I)*REG2
      SLOG2=DSQRT(DLOG(2D0))
      SLOG2P=DSQRT(DLOG(2D0)/PI)
      SQTTT0=DSQRT(TTT0)
      DR   = RESL
      IIR  = INT(DELV/DR+DR)
```

```
      IF(IIR.GT.200) THEN
      WRITE(6,*)'REDUCE THE SIZE OF THE WNU. STEP (DELV)'
      GOTO 1000
      END IF
      IWNU=0
C------------------------------------------------------------
C   END OF THE SECOND SECTION  -  WAVE NUMBER LOOP BEGINS
C------------------------------------------------------------
   17 POS1 = WNU1 + DFLOAT(IWNU)-DELV/2D0
      POS2 = POS1 + DELV
      WNUAV= (POS1+POS2)/2D0
      IF(POS2-WNU2-DELV/2D0.GT.DZ) GOTO 504
      IWNU = IWNU+1
      ICT=1
      IF(IFAR.EQ.2) CALL FARWG(WNUAV,0D0,0D0,OFWG,IPRD)
      GOTO( 99,91),ILIN
   91 GOTO(250,92),IFILE
   92 INXY=0
      DO 210 I=1,INXX
      IF(POSA(I).GE.POS1-REG2) GOTO 220
  210 INXY=INXY+1
  220 IF(INXY.EQ.0) GOTO 230
      DO 240 I=1,INXX-INXY
      POSA(I)=POSA(I+INXY)
      STRA(I)=STRA(I+INXY)
      ALFA(I)=ALFA(I+INXY)
      ENRA(I)=ENRA(I+INXY)
      ISIA(I)=ISIA(I+INXY)
      IQSW(I)=IQSW(I+INXY)
      IF(I.EQ.1)WRITE(6,'(1X,3I6,12X,I6,D16.8)')
     *INXX,INXY,I,IQSW(I),POSA(I)
  240 CONTINUE
  230 INXY=INXX-INXY
      WRITE(6,'(1X,3I6,12X,I6,D16.8)')
     *INXX,INXY,I,IQSW(I),POSA(I)
      IF(Q1.GT.POS2+REG2) GOTO 209
      INXY=INXY+1
      POSA(INXY)  =  Q1
      STRA(INXY)  =  Q2 * SMOD(IQ)
      ALFA(INXY)  =  Q3 + AMOD(IQ)
      ENRA(INXY)  =  Q4
      ISIA(INXY)  =  IQ
      IQSW(INXY)  =  IY
      WRITE(6,'(1X,3I6,12X,I6,D16.8)')INXX,INXY,IQ,IY,Q1
      GOTO 251
```

```
  250 IFILE=2
  251 CONTINUE
      WRITE(6,*)
      WRITE(6,*)'  INXX  INXY  JLINE          IQSW       POSA'
      WRITE(6,*)
 206  IF(IY/ILIM.NE.0) GOTO 209
      READ(2,'(1X,D16.8,3D11.4,I4,I8)')Q1,Q2,Q3,Q4,IQ,IY
      DO 270 ISM =1,NBND
      IF(IQ.NE.MOLE(ISM)) GOTO 270
      GOTO 271
  270 CONTINUE
      GOTO 206
  271 IF(Q1.LT.POS1-REG2) GOTO 206
      IF(Q1.GT.POS2+REG2) GOTO 209
      JLIN=JLIN+1
      INXY=INXY+1
      POSA(INXY)  =  Q1
      STRA(INXY)  =  Q2 * SMOD(IQ)
      ALFA(INXY)  =  Q3 + AMOD(IQ)
      ENRA(INXY)  =  Q4
      ISIA(INXY)  =  IQ
      IQSW(INXY)  =  IY
      GOTO 206
  209 INXX=INXY
      IF(MAINXX.LT.INXX) MAINXX=INXX
      WRITE(6,'(1X,3I6,12X,I6,D16.8,I6,2H==,/)')
     *INXX,INXY,JLIN,IQSW(INXX),POSA(INXX),MAINXX
C-------------------------------------------------------------
C                       SET POSITION
C-------------------------------------------------------------
      GOTO(99,98),ILIN
   99 DO 100 I=1,NBND
      DSHIFT  = SHIFT(I)
      DWNU    = DWNB(I)/DFLOAT(NLINE(I))
      DWN     = DWNU/2D0
      AKURVA  = WNBC(I)-DWNB(I)/2.D 0
      IF(DSHIFT.EQ.1.D 0) THEN
      INXX      = INXX+1
      POSA(INXX)= AKURVA
      STRA(INXX)=SINT(I)
      ENRA(INXX)=GSEN(I)
      ISIA(INXX)=MOLE(I)
      ALFA(INXX)=ALORO(MOLE(I))
      END IF
      DO 100 J=1,NLINE(I)
```

```
      INXX=INXX+1
      POL=AKURVA+(J-1)*DWNU+(1.D 0+DSHIFT)*DWN
      POSA(INXX)=POL
      STRA(INXX)=SINT(I)
      ENRA(INXX)=GSEN(I)
      ISIA(INXX)=MOLE(I)
      ALFA(INXX)=ALORO(MOLE(I))
  100 CONTINUE
   98 ISI1=0
      ISI2=0
      JJ1=1
      JJ2=1
      INX=1
      LPLUS=0
      POS(1)=POS1
      ISI(1)=ISI1
      DO 111 I=1,INXX
      IF(IQSW(I).GT.0) LPLUS=LPLUS+1
      POL =POSA(I)
      DZZ1=DABS(POL-POS1)
      DZZ2=DABS(POL-POS2)
      IF(DZZ1.LE.DZ) THEN
      ISI1=ISI1-JJ1*ISIA(I)
      JJ1=JJ1*10
      GOTO 111
      END IF
      IF(DZZ2.LT.DZ) THEN
      ISI2=ISI2-JJ2*ISIA(I)
      JJ2=JJ2*10
      GOTO 111
      END IF
      IF(POL.LT.POS1-DZ.OR.POL.GT.POS2+DZ) GOTO 111
      INX=INX+1
      POS(INX)=POL
      ISI(INX)=ISIA(I)
  111 CONTINUE
      ISI(1)=ISI1
      INX=INX+1
      ISI(INX)=ISI2
      POS(INX)=POS2
      IMAX=INX
      WRITE(6,'(/,1X,5I10,3H===,/)')INXX,LPLUS,IMAX,ISI1,ISI2
C-------------------------------------------------------------
C                           REARRANGE
C-------------------------------------------------------------
```

```
  130 IF(ILIN.NE.1) GOTO 97
      DO 134 I=1,INXX-1
      IN=I
      CHN =POSA(I)
      DO 133 J=I+1,INXX
      IF( CHN . LE . POSA(J) ) GOTO 133
      IN   = J
      CHN  = POSA(J)
  133 CONTINUE
      IF( IN . EQ . I ) GOTO 134
      CHNP = POSA(I)
      CHNS = STRA(I)
      CHNE = ENRA(I)
      CHNI = ISIA(I)
      CHNA = ALFA(I)
      POSA(I) = POSA(IN)
      STRA(I) = STRA(IN)
      ENRA(I) = ENRA(IN)
      ISIA(I) = ISIA(IN)
      ALFA(I) = ALFA(IN)
      POSA(IN) = CHNP
      STRA(IN) = CHNS
      ENRA(IN) = CHNE
      ISIA(IN) = CHNI
      ALFA(IN) = CHNA
  134 CONTINUE
C---------------------------------------------------------------
C                 LINES IN REG1 AND REG2
C---------------------------------------------------------------
   97 CONTINUE
      DO 138 I=1,3
      DO 138 J=1,5
  138 IIII(I,J)=0
      DO 135 I=1,INXX
      POL  = POSA(I)
      D2A=POS1-REG2
      D1A=POS1-REG1
      D1B=POS2+REG1
      D2B=POS2+REG2
      IF(POL.GE. D2A.AND.POL.LT. D1A) IIII(3,1)=IIII(3,1)+1
      IF(POL.GE. D1A.AND.POL.LT.POS1) IIII(3,2)=IIII(3,2)+1
      IF(POL.GE.POS1.AND.POL.LE.POS2) IIII(3,3)=IIII(3,3)+1
      IF(POL.GT.POS2.AND.POL.LE. D1B) IIII(3,4)=IIII(3,4)+1
      IF(POL.GT. D1B.AND.POL.LE. D2B) IIII(3,5)=IIII(3,5)+1
      IF(I.EQ.1.OR.I.EQ.INXX) WRITE(6,'(1X,2I5,4D16.8)')
```

```
     *I,ISIA(I),POSA(I),STRA(I),ENRA(I),ALFA(I)
  135 CONTINUE
      IIII(1,1)=1
      IIII(2,1)=IIII(3,1)
      IIII(1,2)=IIII(2,1)+1
      IIII(2,2)=IIII(2,1)+IIII(3,2)
      IIII(1,3)=IIII(2,2)+1
      IIII(2,3)=IIII(2,2)+IIII(3,3)
      IIII(1,4)=IIII(2,3)+1
      IIII(2,4)=IIII(2,3)+IIII(3,4)
      IIII(1,5)=IIII(2,4)+1
      IIII(2,5)=IIII(2,4)+IIII(3,5)
      IREG1 = IIII(1,2)
      JREG1 = IIII(2,4)
      IREG2 = IIII(1,1)
      JREG2 = IIII(2,5)
      WRITE(6,'(/,5(1X,3I4,2X,/))')((IIII(I,J),I=1,3),J=1,5)
C--------------------------------------------------------------
C                    SET   ISI(I)=0
C--------------------------------------------------------------
      ICHG=0
  141 DO 114 I=1,IMAX-1
      IN=I
      CHN=POS(I)
      DO 113 J=I+1,IMAX
      IF(CHN.LE.POS(J)) GOTO 113
      CHN=POS(J)
      IN=J
      ICHG=ICHG+1
  113 CONTINUE
      IF(IN.EQ.I) GOTO 114
      CHN1=POS(I)
      CHN2=ISI(I)
      POS(I)=CHN
      ISI(I)=ISI(IN)
      POS(IN)=CHN1
      ISI(IN)=CHN2
  114 CONTINUE
      IF(ICHG.NE.0) WRITE(6,*)'  ICHG = ',ICHG,'     *****'
C-----
  112 JJ=10
      IZ=0
      IZZ=1
      JZZ=0
      IF(ISI2.LT.0)  IZZ=0
```

```
      DO 115 I=1,IMAX-IZZ
      JZ  = I+JZZ
      DELL=POS(JZ)-POS(I+1)
      IF(DABS(DELL).GT.DZ) GOTO 116
      WRITE(6,*)'JJ JZ IMAX IZZ',JJ,JZ,IMAX,IZZ,'     *****'
      ISI(JZ)=ISI(JZ)+JJ*ISI(I+1)
      ISI(I+1)=0
      JJ  = JJ*10
      IZ  = IZ+1
      JZZ = JZZ-1
      GOTO 115
  116 JJ  = 10
      JZZ = 0
  115 CONTINUE
      WRITE(6,*)
C-------------------------------------------------------------
C                  ELIMINATE ISI(I)=0
C-------------------------------------------------------------
      IJ=0
      IF(IMAX.LE.3)GOTO 156
      IF(ISI2.EQ.0) IJ=-1
      DO 117 I=3,IMAX+IJ
      IK=I+IJ
      IF(ISI(IK).NE.0)GOTO 117
      IIJ=I+1+IJ
      DO 118 J=IIJ,IMAX+IJ
      ISI(IK)=ISI(J)
      POS(IK)=POS(J)
      IK=IK+1
  118 CONTINUE
      IJ=IJ-1
  117 CONTINUE
      IMAX=IMAX-IZ
  156 IF(ISI2.NE.0)GOTO 157
      POS(IMAX)=POS2
      ISI(IMAX)=0
      GOTO 158
  157 ISI(IMAX)=ISI2
      POS(IMAX)=POS2
  158 CONTINUE
C-------------------------------------------------------------
C         SET  IBLW(I),  IENDPT(I) AND IWARN(I)
C-------------------------------------------------------------
      POA=DR
      POB=DR
```

```
      IRE1A=IIII(3,2)
      IRE1B=IIII(3,4)
      IF(IRE1A.NE.0) POA=DABS(POS1-POSA(IIII(2,2)))
      IF(IRE1B.NE.0) POB=DABS(POSA(IIII(1,4))-POS2)
      IQQ=1
      J=2
      JJJ=2
      IES=0
      DO 119 I=1,IIR
      ENP=I*DR+POS1
      IENDPT(I)=0
      IBLW(I)=0
      IWARN(I) =0
      JJ=0
      IF(JJJ.GT.IMAX-1)GOTO 128
      DO 120 J=JJJ,IMAX-1
      DELL=ENP-POS(J)
      IF(DABS(DELL).LT.DZ) GOTO 122
      IF(DELL.GT.0D0) GOTO 123
      GOTO 121
  122 JJ=JJ+1
      ISI(J)    = -IABS(ISI(J))
      IENDPT(I) =  IENDPT(I)+1
      IBLW(I) =  JJ
      JJJ=JJJ+JJ-1
CA5---
      IF(IPRA.EQ.5)
     *WRITE(6,'(/,1X,D15.5,6I6,/)')DELL,122,I,JJJ,JJ,J,ISI(J)
      GOTO 129
  121 IBLW(I)=JJ
      JJJ=JJJ+JJ
CA5---
      IF(IPRA.EQ.5)
     *WRITE(6,'(/,1X,D15.5,6I6,/)')DELL,121,I,JJJ,JJ,J,ISI(J)
      GOTO 129
  123 CONTINUE
CA5---
      IF(IPRA.EQ.5)
     *WRITE(6,'(/,1X,D15.5,6I6,/)')DELL,123,I,JJJ,JJ,J,ISI(J)
  126 CONTINUE
  120 JJ=JJ+1
      IBLW(I)=JJ
      JJJ=JJJ+JJ
  129 IENDPT(I)=IENDPT(I)+IES
      IES=0
```

```
      IF(IENDPT(I).EQ.1.OR.IENDPT(I).EQ.3)IES=2
  128 IF(I.EQ.1) THEN
      POAA=POA
      IF(ISI1.EQ.0) GOTO 167
      IENDPT(1)=IENDPT(1)+2
      IBLW(1)=IBLW(1)+1
      END IF
  127 IF(I.EQ.IIR) THEN
      POBB=POB
      IF(ISI2.EQ.0)  GOTO 168
      IENDPT(IIR)=IENDPT(IIR)+1
      IBLW(IIR)=IBLW(IIR)+1
      END IF
  167 POBB=DABS(POS(J)-ENP)
  168 IF(IENDPT(I).EQ.3) IWARN(I)=101
      IF(IENDPT(I).EQ.2.OR.IENDPT(I).EQ.0) THEN
      D1   =  POBB
      IG   =  I
      ITT  =  JJJ
      IWA1 =  J
      CALL MESH
      IWARN(I)=KSUB+1
      END IF
      IF(IENDPT(I).EQ.1.OR.IENDPT(I).EQ.0) THEN
      D1=POAA
      IG=I
      ITT=JJJ
      IWA1=J
      CALL MESH
      IWARN(I)=IWARN(I)+(KSUB+1)*100
      END IF
      POAA=DABS(ENP-POS(J-1))
  119 CONTINUE
CA6---
      IF(IPRA.EQ.6) THEN
                    WRITE(6,'(1X,4I5)')(I,IBLW(I),IENDPT(I),
     *              IWARN(I),I=1,IIR)
                    WRITE(6,'(1X,I4,D25.8,I10)')(I,POS(I),
     *              ISI(I),I=1,IMAX)
                    WRITE(6,'(1X,2I10,/)')IZ,IMAX
                    END IF
C-------------------------------------------------------------
C        AA,  BB,  ITT,  IWA1,  IWB1, K  FOR  LENGTH
C-------------------------------------------------------------
      IALL=2
```

```
      K=1
      IF(ISI1.EQ.0) K=K+1
      DO 400 I=1,IIR
      IWA = IWARN(I)/100
      IWB = IWARN(I)-IWA*100
      IWA1= IWA
      IWB1= IWB
      EP1 = POS1+ DR*DFLOAT(I-1)
      EP2 = EP1 + DR
      IBW = IBLW(I)
      AA  = EP1
      BB  = EP2
      IT  = IENDPT(I)
      ITT = IT
      IF(IT.EQ.0.OR.IT.EQ.2) IC=0
      IF(IT.EQ.1.OR.IT.EQ.3) IC=1
      IF(IBW.EQ.0) GOTO 410
      IF(IBW.EQ.1.AND.IT.NE.0) GOTO 410
      IF(IBW.EQ.2.AND.IT.EQ.3) GOTO 410
      GOTO(401,402,402,403),ITT+1
  401 IBP=1
      GOTO 404
  402 IBP=0
      GOTO 404
  403 IBP=-1
  404 L=IBW+IBP
      KK=0
      IF(IT.EQ.1.OR.IT.EQ.0)KK=-1
      DO 421 J=1,L
      JUMP=1
      KKK=KK+K+J
      IWA1=1
      IWB1=1
      ITT=3
      BB=POS(KKK)
      IF(J.EQ.1) GOTO 422
      IF(J.EQ.L) GOTO 423
      GOTO 443
  422 IWA1=IWA
      IF(IT.EQ.1.OR.IT.EQ.0)ITT=1
      GOTO 443
  423 IWB1=IWB
      BB=EP2
      IF(IT.EQ.2.OR.IT.EQ.0)ITT=2
  424 GOTO 443
```

```
  425 AA=BB
  421 CONTINUE
      GOTO 444
  410 JUMP=2
  443 IG=I
      CALL LENGTH
      GOTO(425,444),JUMP
  444 K=K+IBW-IC
  400 CONTINUE
      IALL=IALL-1
      IALLG=IALL*IGNU
      DO 699 I = 1, IALLG
  699 OUTSS(I) = 0D0
C-RAD-
      IF(IRAD.NE.0) THEN
      DO 228 I = 1, IIR
      TRAB1(I) = 1D0
  228 SUMM(I)  = 0D0
      END IF
C-RAD-
      H2OC=0D0
      OFWG=0D0
      SUMH=0D0
      OFWGS=0D0
C-------------------------------------------------------------
C        END OF THE THIRD SECTION  -  LAYER LOOP BEGENS
C-------------------------------------------------------------
      DO 700 LLDIR=1,LVEL-IHOMH
      IF(IPSC.NE.4)  LL=LLDIR
      IF(IDIR.EQ. 1) LL=LLDIR
      IF(IDIR.EQ.-1) LL=LVEL-IHOM-LLDIR+1
      PAV=PLX(LL)
      TAV=TLX(LL)
      DVPR  = 0D0
      VPRAV = 0D0
      DO 701 N = 1,NBND
      M = MOLE(N)
      AMASS(M) = AMIX(M,LL)*UMOD(M)*BMY(LL)
      ALOR(M)  = PLX(LL)/PPP0*CST1(LL)**ALORT(M)
      ADOP(M)  = TDOPA(LL)*WNUAV/DSQRT(AMOLE(M))
      AK0(M)   = AMASS(M)*SLOG2P/ADOP(M)
      XS(M)    = SLOG2/ADOP(M)
      CS1(M)   = 1D0
      IF(IRPF.EQ.1) CS1(M)=CS1(M)*CST1(LL)**RPFN(M)
      IF(IVPF.EQ.1) CS1(M)=CS1(M)*(VPFN(1,M)+VPFN(2,M)*
```

```
     *CST1(LL)**VPFN(3,M))
      VPR(M)=ADOP(M)/(ALOR(M)*ALOR0(M)+ADOP(M))
      VPR(M)=VPR(M)**AINT
      DVP(M)=REG1*VPR(M)+REG2*(1D0-VPR(M))
      VPRAV =VPRAV+VPR(M)/DFLOAT(NBND)
      DVPR  =DVPR+DVP(M)/DFLOAT(NBND)
701   CONTINUE
      LS1=DFLOAT(IREG1)*VPRAV+DFLOAT(IREG2)*(1D0-VPRAV)
      LS2=DFLOAT(JREG1)*VPRAV+DFLOAT(JREG2)*(1D0-VPRAV)
C-----
      IF(ICON.EQ.1) THEN
              DAV = DEX(LL)
              RR1 = CHX(LL)
              RR2 = DAV-RR1
              OM  = AMASS(1)*ALOSMT
              CALL CONT(WNUAV,TLX(LL),RR1,RR2,RR3,OM,H2OC)
              END IF
C-----
      CS2 = CST2(LL)
      DO 703 N = LS1,LS2
      M=ISIA(N)
      ENRAM=ENRA(N)*CS2
      STRT(N) =  STRA(N)*CS1(M)*DEXP(ENRAM)
  703 CONTINUE
CA----
      IF(IPRA.EQ.6) THEN
      WRITE(6,'(1X,I4,3F15.7,/)')LL, PLX(LL),TLX(LL),WNUAV
      DO 702 N=1,NBND
      M=MOLE(N)
  702 WRITE(6,'(1X,I2,7D11.4,/)')M,AMASS(M),ALOR(M),ADOP(M),
     *AK0(M),XS(M),VPR(M),DVP(M)
      WRITE(6,*)
      IF(IPRH.EQ.1)
     *WRITE(6,'(1X,2I6,I3,D15.8,D15.4,F15.4,F15.5)')
     *(N,IQSW(N),ISIA(N),STRT(N), STRA(N),ENRA(N),POSA(N),
     *N=LS1,LS2)
      END IF
C-----
      OUTGS    = 0D0
      NG       = 0
      DO 599 I = 1,IIR
  599 TRAB(I)  = 0D0
      TRABS(LL)= 0D0
C-----
      IF(ISBN.EQ.2) THEN
```

```
      IF(IPRE.NE.0)WRITE(6,'(/,4X,21HNG IGS IGI ITY  IDAB ,
     *5X,3HGAA,13X,4HOUTG,17X,5HOUTGS,/)')
      GAA=POS1
      DO 596 I=1,IIR
      GBB   =  GAA+DR
      IGS   =  I
      IGI   =  I
      ITY   = -1
      GAB=(GAA+GBB)/2D0
      GCC=(GBB-GAA)/2D0
      IF(IFAR.EQ.3) CALL FARWG(GAB,TLX(LL),PLX(LL),OFWG,IPRD)
      CALL GAUSS(DR,GAB,GCC,OUTG)
      GAA=GBB
  596 TRAB(I)=TRAB(I)+OUTG/DR
      IF(IFAR.EQ.3) IFAR = 2
      OFWGS=OFWGS/DFLOAT(IIR)
      IALLL=IIR
      GOTO 595
      ENDIF
C-----
      IF(IPRE.NE.0)WRITE(6,'(/,4X,21HNG IGS IGI ITY  IDAB ,
     *5X,3HGAA,13X,4HOUTG,17X,5HOUTGS,/)')
      DO 600 I=1,IALL-1
      IGS=I
      IGI=IGA(I)
      ITY=ITYPE(I)
      GAB=(AGA(I+1)+AGA(I))/2D0
      GCC=(AGA(I+1)-AGA(I))/2D0
      IF(IFAR.EQ.3) CALL FARWG(GAB,TLX(LL),PLX(LL),OFWG,IPRD)
      CALL GAUSS(DR,GAB,GCC,OUTG)
  600 TRAB(IGI)=TRAB(IGI)+OUTG/DR
      OFWGS=OFWGS/DFLOAT(IALL)
      IF(IFAR.EQ.3) IFAR = 2
      IALLL=IALL-1
C-----
  595 DO 601 I=1,IIR
  601 TRABS(LL)=TRABS(LL)+TRAB(I)*DR
C-------------------------------------------------------------
C                    OUTPUT SECTION
C-------------------------------------------------------------
      IF(IOTR.NE.0)    WRITE(10,*)
     *                 LL,(TRAB(I),I=1,IIR),TRABS(LL),WNUAV
      IF(IGNU.EQ.0) GOTO 602
      WRITE(6,'(4X,I2,I5,2I3,D22.14,F6.1,F10.6,F9.3,2I5)')
     *IGNU,IALLL,LL,ISBN,TRABS(LL),WNUAV,VPRAV,DVPR,LS1,LS2
```

```
      GOTO 603
  602 WRITE(6,'(4I4,4D25.15,/)')
     *IGNU,IALLL,ITRN,ISBN,TRABS(LL),ERG,ERGB
  603 CONTINUE
      IF(IPRA.EQ.5)
     *WRITE(6,'(1X,I5,D25.15)')(I,TRAB(I),I=1,IIR)
C-RAD-
      IF(IRAD.NE.0)THEN
      TLY1=TLY(LL)
      TLY2=TLY(LL+1)
      DO 229 I=1,IIR
      IF(TRAB1(I).LT.DZ) GOTO 229
      WNUU=WNUAV-5D-1+DR/2D0+(I-1)*DR
      WNUP=C1*WNUU*WNUU*WNUU
      WNUT1=C2*WNUU/TLY1
      WNUT2=C2*WNUU/TLY2
      BP1 =WNUP/(DEXP(WNUT1)-1)
      BP2 =WNUP/(DEXP(WNUT2)-1)
      BPL =(BP1*TRAB1(I)+BP2*TRAB(I))/(TRAB1(I)+TRAB(I))
      SUMM(I)=SUMM(I)+BPL*(TRAB1(I)-TRAB(I))
      IF(IPRH.EQ.2)
     *WRITE(6,'(1X,F8.3,2F15.10)')WNUU,BPL,SUMM(I)
      TRAB1(I)=TRAB(I)
  229 CONTINUE
      END IF
C-RAD-
  700 CONTINUE
C-RAD-
      IF(IRAD.NE.  0) THEN
      IF(TSKN.EQ.0D0) GOTO 226
      DO 227 I=1,IIR
      IF(TRAB(I).LT.DZ) GOTO 227
      WNUU=WNUAV-5D-1+DR/2D0+(I-1)*DR
      WNUP=C1*WNUU*WNUU*WNUU
      WNUT=C2*WNUU/TSKN
      BPL =TRAB(I)*EMIS*WNUP/(DEXP(WNUT)-1)
      SUMM(I)=SUMM(I)+BPL
      IF(IPRH.EQ.2)WRITE(6,'(1X,F8.3,2F15.10)')
     *WNUU, BPL, SUMM(I)
  227 CONTINUE
  226 IF(IORD.EQ.1)WRITE(11,'(1X,F11.3)')          WNUAV
      IF(IORD.EQ.1)WRITE(11,'(10(1X,E11.6))')(SUMM(I),I=1,IIR)
      END IF
C-RAD-
      GOTO 17
```

```
  504 CONTINUE
      DATA MOLE,LMOD,AMOD,SMOD,UMOD,RMOD/17*0,7*0D0,21*1D0/
      DATA PDLR,PLNZ,VDLR,VLNZ/1D-2,1D2,1D-3,2D-1/
      DATA AEP,NLEN/
     *0D0,1D-3,1.5D-3,2.5D-3,5D-3,1D-2,2.5D-2,5D-2,1D-1,2D-1,
     *5D-1,1D0,2.5D0,5D0,1D1,2.5D1,5D1,1D2,25D1,50D1,1D3,20/
      DATA ALOR0/
     *1D-1,64D-3,11D-2,8D-2,6D-2,55D-3,6D-2,1D-1,1D-1,1D-1/
      DATA ALORT/
     *62D-2,75D-2,5D-1,5D-1,5D-1,5D-1,5D-1,5D-1,5D-1,5D-1/
      DATA AMOLE/
     *18.150,44.010,47.998,44.010,28.011,16.043,31.999,
     *30.010,64.060,46.010/
      DATA RPFN/
     *  1.5D0,1.0D0,1.5D0,1.0D0,1.0D0,1.5D0,1.0D0/
      DATA VPFN/
     *1D0,0D0,0D0,0.99752D0,0.09310D0,-3.54915D0,0.99852D0,
     *0.04600D0,-4.11179D0,1.01819D0,0.12700D0,-4.42836D0,
     *1D0,0D0,0D0,0.99935D0,0.00700D0,-5.47575D0,1D0,0D0,0D0/
      DATA PI,PPP0,TTT0,PSTND,TSTND,AVOGAD,ALOSMT,GASCON,
     *PLANK,BOLTZ,CLIGH,UNIV,ATMA,DZ,VOLG,C1,C2,C3,
     *XAB,WAB,RR3/
     *3.14159265358973D0,1013.25D0,296D0,1013.25D0,273.15D0,
     *6.022169D26,2.68684D19,8.31432D3,6.62617D-27,
     *1.380662D-23,2.997924D8,0.372184D-20,1.660565D-27,
     *1D-14,22.24136D0,1.1909596D-5,1.43879,3.58D-7,
     *0.577350269189626D0,1D0,0.2548D20/
      DATA TETM/
     *62D0,64D0,66D0,68D0,70D0,72D0,74D0,76D0,78D0,80D0,
     *81D0,82D0,83D0,84D0,85D0,86D0,87D0,87.5D0,88D0,88.2D0,
     *88.4D0,88.6D0,88.8D0,89D0,89.2D0,89.4D0,89.6D0,89.7D0,
     *89.8D0,89.9D0,90D0/
 1000 CONTINUE
      END
```

```
C------------------------------------------------------------
C          INPUTS FOR THE FIRST ITRA EXPERIMENT
C============================================================
C .05,1,2,0,0,0,0 RESL DELV ITRN IRAD IOTR IORD IOPR
C 0,0,0,0,0,0,0,0 IPRA IPRB IPRC IPRD IPRE IPRF IPRG IPRH
C 1,2,0,0         ISBN IGNU EPSN ICCH PDLR PLNZ VDLR VLNZ
C 1,1,1,1         IINT AINT IVPF IRPF KSHP IVDY
C 0               MODL IDEN LMOD(IDEN)...
C 0               MODA IDEN AMOD(IDEN)...
C 0               MODS IDEN SMOD(IDEN)...
C 0               MODR IDEN RMOD(IDEN)...
C 580,780,0.1,1,7 WNU1 WNU2 REG0 REG1 REG2
C 0,0,0           IPPS IPPH IARM ASCL
C 5 1 2           LVEL NBND MOLE(1)...MOLE(NBND)
C 125.13   310   13.81
C 253.31   274   2.054
C 506.62   274   0.5151
C 60.528   244   33.695
C 253.31   245   0.5746
C 2,64222,0,0,0    ILIN ILIM ICON IFAR JREF
C
C------------------------------------------------------------
C          INPUTS FOR THE SECOND ITRA EXPERIMENT.
C============================================================
C 0.01,1,2,1,1,1,0 RESL DELV ITRN IRAD IOTR IORD IOPR
C 0,0,0,0,0,0,0,0  IPRA IPRB IPRC IPRD IPRE IPRF IPRG IPRH
C 1,2,0,0,0,0,0,0  ISBN IGNU EPSN ICCH PDLR PLNZ VDLR VLNZ
C 1,1,1,1,0,0      IINT AINT IVPF IRPF KSHP IVDY
C 0                MODL IDEN LMOD(IDEN)...
C 0                MODA IDEN AMOD(IDEN)...
C 0                MODS IDEN SMOD(IDEN)...
C 0                MODR IDEN RMOD(IDEN)...
C 660,780,.1,1,6.5 WNU1 WNU2 REG0 REG1 REG2
C 4,1,0,0          IPPS IPPH IARM ASCL
C 6,50,1,2         IPOF LVEL NBND MOLE(1)....MOLE(NBND)
C 1,50,288.2,1     LVL1 LVL2 TSKN EMIS
C 1,0,0,0          IDIR TETA TETB DTET
C 0,0,0,0          LVLN ALT1 ALT2 PATH
C 0                MODU IDEN UMOD(IDEN)...
C 2,64220,0,0,0    ILIN ILIM ICON IFAR JREF
```

```
C------------------------------------------------------------
C       INPUTS FOR THE HIS EVALUATIONS (CASE 2.)
C============================================================
C 5D-3,1,2,1,0,1,0 RESL DELV ITRN IRAD IOTR IORD IOPR
C 0,0,0,0,0,0,0,0  IPRA IPRB IPRC IPRD IPRE IPRF IPRG IPRH
C 1,2,0,0,0,0,0,0  ISBN IGNU EPSN ICCH PDLR PLNZ VDLR VLNZ
C 1,1,1,1,0,0      IINT AINT IVPF IRPF KSHP IVDY
C 0                MODL IDEN LMOD(IDEN)...
C 1,1,4D-2         MODA IDEN AMOD(IDEN)...
C 0                MODS IDEN SMOD(IDEN)...
C 0                MODR IDEN RMOD(IDEN)...
C 610,630,.1,1,6.5 WNU1 WNU2 REG0 REG1 REG2
C 4,1,0,0          IPPS IPPH IARM ASCL
C 0,24,4,1,2,3,4   IPOF LVEL NBND MOLE(1)....MOLE(NBND)
C 1,24,309,1       LVL1 LVL2 TSKN EMIS
C 1,0,0,0          IDIR TETA TETB DTET
C 0,0,0,0          LVLN ALT1 ALT2 PATH
C 1,3,0.29         MODU IDEN UMOD(IDEN)...
C 2,64220,1,0,0    ILIN ILIM ICON IFAR JREF
C
C------------------------------------------------------------
C        INPUT STRUCTURE FOR AIRMASS CALCULATIONS
C============================================================
C 0.1,1,2,0,0,0,0  RESL DELV ITRN IRAD IOTR IORD IOPR
C 0,1,0,0,0,0,0,0  IPRA IPRB IPRC IPRD IPRE IPRF IPRG IPRH
C 0,0,0,0,0,0,0,0  ISBN IGNU EPSN ICCH PDLR PLNZ VDLR VLNZ
C 0,0,0,0,0,0      IINT AINT IVPF IRPF KSHP IVDY
C 0                MODL IDEN LMOD(IDEN)...
C 0                MODA IDEN AMOD(IDEN)...
C 0                MODS IDEN SMOD(IDEN)...
C 0                MODR IDEN RMOD(IDEN)...
C 610,610,0,0,0    WNU1 WNU2 REG0 REG1 REG2
C 4,1,14,-30       IPPS IPPH IARM ASCL
C 6,50,1,14        IPOF LVEL NBND MOLE(1)....MOLE(NBND)
C 1,50,0,0         LVL1 LVL2 TSKN EMIS
C 1,60,90,-1       IDIR TETA TETB DTET
C 3000,120,0,0     LVLN ALT1 ALT2 PATH
C 0                MODU IDEN UMOD(IDEN)...
C 0,0,0,0,1        ILIN ILIM ICON IFAR JREF
```

```
C------------------------------------------------------------
C            INPUT STRUCTURE FOR LIMB GEOMETRY
C============================================================
C .1,1,2,0,0,0,1   RESL DELV ITRN IRAD IOTR IORD IOPR
C 1,4,0,0,0,0,0,0  IPRA IPRB IPRC IPRD IPRE IPRF IPRG IPRH
C 1,2,0,0,0,0,0,0  ISBN IGNU EPSN ICCH PDLR PLNZ VDLR VLNZ
C 1,1,1,1,0,0      IINT AINT IVPF IRPF KSHP IVDY
C 0                MODL IDEN LMOD(IDEN)...
C 1,1,4D-2         MODA IDEN AMOD(IDEN)...
C 0                MODS IDEN SMOD(IDEN)...
C 0                MODR IDEN RMOD(IDEN)...
C 610,610,.1,.1,.5 WNU1 WNU2 REG0 REG1 REG2
C 4,1,0,0          IPPS IPPH IARM ASCL
C 6,50,1,1,2,3,4   IPOF LVEL NBND MOLE(1)....MOLE(NBND)
C 0,0,309,1        LVL1 LVL2 TSKN EMIS
C -1,80,0,0        IDIR TETA TETB DTET    79.0451206
C 0,40,0,0         LVLN ALT1 ALT2 PATH
C 1,3,0.29         MODU IDEN UMOD(IDEN)...
C 2,64220,1,0,1    ILIN ILIM ICON IFAR JREF
C
C------------------------------------------------------------
C  THIS IS THE CONTROL SEQUENCE FOR LIMB GEOMETRY. AT THE
C  INPUT THE TANGENT HEIGHT WAS OBTAINED IN THE PREVIOUS
C              EXAMPLE (UPWARD DIRECTION).
C============================================================
C .1,1,2,0,1,0,0   RESL DELV ITRN IRAD IOTR IORD IOPR
C 1,1,0,0,0,0,0,0  IPRA IPRB IPRC IPRD IPRE IPRF IPRG IPRH
C 1,2,0,0,0,0,0,0  ISBN IGNU EPSN ICCH PDLR PLNZ VDLR VLNZ
C 1,1,1,1,0,0      IINT AINT IVPF IRPF KSHP IVDY
C 0                MODL IDEN LMOD(IDEN)...
C 1,1,4D-2         MODA IDEN AMOD(IDEN)...
C 0                MODS IDEN SMOD(IDEN)...
C 0                MODR IDEN RMOD(IDEN)...
C 610,610,.1,.1,.5 WNU1 WNU2 REG0 REG1 REG2
C 4,1,0,0          IPPS IPPH IARM ASCL
C 6,50,1,1,2,3,4   IPOF LVEL NBND MOLE(1)....MOLE(NBND)
C 0,0,309,1        LVL1 LVL2 TSKN EMIS
C 1,90,0,0         IDIR TETA TETB DTET    79.0451206
C 0,120,21.4023,0  LVLN ALT1 ALT2 PATH
C 1,3,0.29         MODU IDEN UMOD(IDEN)...
C 2,64220,1,0,1    ILIN ILIM ICON IFAR JREF
C---------------------------------------------------------
```

```
      SUBROUTINE LAYERS(WEDD,JREF,IDIR,TETA,LVEL,ZN,LIMB,LVEN)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/HA/ POSA(3000),STRA(3000),ENRA(3000),ALFA(3000),
     *ALFT(3000),CPLG(3000),STRT(3000),ISIA(3000),IQSW(3000)
      COMMON/LA/ IPRB,ALT(150),DEY(150),PSTND,TSTND,BMY(150),
     *           CHY(150),TLY(150),PLY(150),AMIY(37,150)
      DIMENSION
     *PLZ(3000),BMZ(3000),CHZ(3000),TLZ(3000),ALZ(3000),
     *DEZ(3000),AMZ(3000)
      EQUIVALENCE
     *(POSA,PLZ),(STRA,BMZ),(ENRA,TLZ),(ALFA,CHZ),
     *(ALFT,ALZ),(CPLG,DEZ),(STRT,AMZ)
      LAYER = LVEL-1
      DVERT = 0D0
      DPATH = 0D0
      SLANT = 0D0
      GAMAS = 0D0
      CNST  = 0D0
      COR   = 1D0
C-----
      DO 38 I=1,LAYER
      IF(IDIR.EQ.-1) GOTO 100
      L=LVEL-I
      PAV1=( PLZ(L)+ PLZ(L+1))/2D0
      TAV1=( TLZ(L)+ TLZ(L+1))/2D0
      HAV1=(CHZ(L)+CHZ(L+1))/2D0
      IF(JREF.EQ.-1) HAV1=0D0
      ZZ1 =RAE+ALZ(L+1)
      ZZ2 =RAE+ALZ(L)
      DZZ= ZZ2-ZZ1
      AIRMV  =  DZZ/DLOG(DEZ(L+1)/DEZ(L))*(DEZ(L+1)-DEZ(L))
      REF1=((ED1+ED2/(1D0-WEDD/ED4)+ED3/(1D0-WEDD/ED5))*
     *(TSTND+15D0)*PAV1/PSTND/TAV1-
     *(ED6-WEDD/ED7)*HAV1/PSTND)*1D-6+1D0
      IF(L.EQ.LAYER) TETA1=TETA
      IF(L.EQ.1) THEN
                 REF2=REF1
                 GOTO 37
                 END IF
      ZZ3 =RAE+ALZ(L-1)
      PAV2=( PLZ(L)+ PLZ(L-1))/2D0
      TAV2=( TLZ(L)+ TLZ(L-1))/2D0
      HAV2=(CHZ(L)+CHZ(L-1))/2D0
      IF(JREF.EQ.-1) HAV2=0D0
      REF2=((ED1+ED2/(1D0-WEDD/ED4)+ED3/(1D0-WEDD/ED5))*
```

```
     *(TSTND+15D0)*PAV2/PSTND/TAV2-
     *(ED6-WEDD/ED7)*HAV2/PSTND)*1D-6+1D0
      IF(JREF.EQ.0) REF2=REF1
   37 ALFA1=PIDE*DASIN(DSIN(TETA1*PIRA)*ZZ1/ZZ2)
      SLANT1=ZZ2*DCOS(ALFA1*PIRA)-ZZ1*DCOS(TETA1*PIRA)
      GAMA1=TETA1-ALFA1
      GAMAS=GAMAS+GAMA1
      IF(L.EQ.1) THEN
                 COR=1D0
                 GOTO 1009
                 END IF
      TETA2 = DASIN(DSIN(ALFA1*PIRA)*REF1/REF2)
      ALFA2 = DASIN(DSIN(TETA2)*ZZ2/ZZ3)
      SLANT2= ZZ3*DCOS(ALFA2)-ZZ2*DCOS(TETA2)
      DELTA = PI-(TETA2-ALFA1*PIRA)
      CSIDE = DSQRT(SLANT1*SLANT1+SLANT2*SLANT2
     *        -2*SLANT1*SLANT2*DCOS(DELTA))
      IF(DABS(CSIDE-SLANT1-SLANT2).LT.DZ.OR.JREF.EQ.-2)THEN
                                    COR=1D0
                                    GOTO 1009
                                    END IF
      SS    = (SLANT1+SLANT2+CSIDE)/2D0
      SSS   = 4D0*DSQRT(SS*(SS-SLANT1)*(SS-SLANT2)*(SS-CSIDE))
      RDS   = SLANT1*SLANT2*CSIDE/SSS
      COR   = RDS*2D0*DASIN(SLANT1/RDS/2D0)/SLANT1
 1009 CORA  = COR-1D0
      AMU   = SLANT1 * COR/ DZZ
      SLANT = SLANT  + SLANT1*COR
      DPATH = DPATH  + AMU*AIRMV
      DVERT = DVERT  + AIRMV
      PATAL = DPATH  / DVERT
      RF1=(-1D0+REF1)*1D6
      RF2=(-1D0+REF2)*1D6
      IF(IPRB.EQ.2) WRITE(6,'(5X,I4,2F10.4,2X,2F20.14)')
     *L,RF1,RF2,SLANT1,CORA
      IF(IPRB.EQ.3)WRITE(6,'(1X,I4,6F10.4,F13.5)')L,AMU,SLANT,
     *PATAL,TETA1,ALFA1,GAMAS,CNST
      BMZ(L)=DABS(AMU)
      TETA1=PIDE*TETA2
      CNST=REF2*ZZ2*DSIN(TETA1*PIRA)
      GOTO 38
C-----
  100 L=I
      LIMB=0
      PAV1=( PLZ(L)+ PLZ(L+1))/2D0
```

```
      TAV1=( TLZ(L)+ TLZ(L+1))/2D0
      HAV1=( CHZ(L)+ CHZ(L+1))/2D0
      IF(JREF.EQ.-1) HAV1=0D0
      ZZ1 =RAE+ALZ(L)
      ZZ2 =RAE+ALZ(L+1)
      DZZ= ZZ2-ZZ1
      AIRMV  =  DZZ/DLOG(DEZ(L)/DEZ(L+1))*(DEZ(L)-DEZ(L+1))
      REF1=((ED1+ED2/(1D0-WEDD/ED4)+ED3/(1D0-WEDD/ED5))*
     *(TSTND+15D0)*PAV1/PSTND/TAV1-
     *(ED6-WEDD/ED7)*HAV1/PSTND)*1D-6+1D0
      IF(L.EQ.1)  THEN
                  ALFA1=TETA
                  COR =1D0
                  END IF
      IF(L.EQ.LAYER) GOTO 1
      PAV2=( PLZ(L+1)+ PLZ(L+2))/2D0
      TAV2=( TLZ(L+1)+ TLZ(L+2))/2D0
      HAV2=( CHZ(L+1)+ CHZ(L+2))/2D0
      IF(JREF.EQ.-1) HAV2=0D0
      REF2=((ED1+ED2/(1D0-WEDD/ED4)+ED3/(1D0-WEDD/ED5))*
     *(TSTND+15D0)*PAV2/PSTND/TAV2-
     *(ED6-WEDD/ED7)*HAV2/PSTND)*1D-6+1D0
    1 IF(JREF.EQ.0) REF2=REF1
      TEMPA=DSIN(ALFA1*PIRA)*ZZ1/ZZ2
      IF(TEMPA-1D0.GT.DZ) THEN
      LIMB=1
      IF(LVEN.GE.0) GOTO 3
      LVEL=L+1
      RETURN
    3 ZN=ZZ1*DSIN(ALFA1*PIRA)-RAE
      LEVL=L+1
      CALL MINT(ALZ, DEZ, 1, LVEL, L, ZN, DEYZ, IPRB)
      CALL MINT(ALZ, PLZ, 1, LVEL, L, ZN, PLYZ, IPRB)
      CALL MINT(ALZ, TLZ, 2, LVEL, L, ZN, TLYZ, IPRB)
      CALL MINT(ALZ, CHZ, 2, LVEL, L, ZN, CHYZ, IPRB)
      DEZ(LEVL) = DEYZ
      PLZ(LEVL) = PLYZ
      TLZ(LEVL) = TLYZ
      CHZ(LEVL) = CHYZ
      ALZ(LEVL) = ZN
      ZZ2=ZN+RAE
      DZZ=ZZ2-ZZ1
      AIRMV  =   DZZ / DLOG(DEZ(L)/DEYZ) * (DEZ(L)-DEYZ)
      REF2=REF1
      TEMPA=1D0
```

```
      LVEL = LEVL
      END IF
    2 TETA1=PIDE*DASIN(TEMPA)
      SLANT2=ZZ1*DCOS(ALFA1*PIRA)-ZZ2*DCOS(TETA1*PIRA)
      GAMA1=TETA1-ALFA1
      GAMAS=GAMAS+GAMA1
      IF(L.EQ.1) GOTO 1010
      CSIDE = DSQRT(SLANT1*SLANT1+SLANT2*SLANT2
     *        -2*SLANT1*SLANT2*DCOS(DELTA))
      IF(DABS(CSIDE-SLANT1-SLANT2).LT.DZ.OR.JREF.EQ.-2)THEN
                                                     COR=1D0
                                                     GOTO 1010
                                                     END IF
      SS    = (SLANT1+SLANT2+CSIDE)/2D0
      SSS   = 4D0*DSQRT(SS*(SS-SLANT1)*(SS-SLANT2)*(SS-CSIDE))
      RDS   = SLANT1*SLANT2*CSIDE/SSS
      COR   = RDS*2D0*DASIN(SLANT2/RDS/2D0)/SLANT2
      CORA  = COR-1D0
C-----
 1010 AMU   = SLANT2*COR / DZZ
      SLANT = SLANT  + SLANT2*COR
      DPATH = DPATH  + AMU*AIRMV
      DVERT = DVERT  + AIRMV
      PATAL = DPATH  / DVERT
      RF1=(-1D0+REF1)*1D6
      RF2=(-1D0+REF2)*1D6
      IF(IPRB.EQ.2) WRITE(6,'(5X,I4,2F10.4,2X,2F20.14)')
     *L,RF1,RF2,SLANT2,CORA
      IF(IPRB.EQ.3)WRITE(6,'(1X,I4,6F10.4,F13.5)')L,AMU,SLANT,
     *PATAL,TETA1,ALFA1,GAMAS,CNST
      BMZ(L)=DABS(AMU)
      ALFA2 = DASIN(DSIN(TETA1*PIRA)*REF1/REF2)
      DELTA = PI-(TETA1*PIRA-ALFA2)
      ALFA1=PIDE*ALFA2
      REF1=REF2
      SLANT1=SLANT2
      CNST=REF2*ZZ2*DSIN(ALFA1*PIRA)
      IF(LIMB.EQ.1) GOTO 4
   38 CONTINUE
      IF(IDIR.EQ. 1)      DEFL =  ALFA1+GAMAS-TETA
    4 IF(IDIR.EQ.-1)      DEFL = -TETA-GAMAS+ALFA1
      IF(IPRB.EQ.2) WRITE(6,'(/,5X,26HGEOMETRICAL PATH
     *LENGTH = ,F20.14,/)') SLANT
      IF(IPRB.EQ.1)WRITE(6,'(1X,F5.1,1X,F8.4,2X,F8.5,2X,F8.3,
     *1X,F8.4,2H *)')TETA,ALFA1,DEFL,SLANT,PATAL
```

```
      IF(LIMB.EQ.1) WRITE(6,'(/,1X,14HLIMB GEOMETRY,,5X,17H
     *TANGENT HEIGHT = ,F13.8,5X,8HLEVEL = ,I5,/,/)')ZN,LVEL
      RETURN
      DATA PI,PIRA,PIDE,DZ,RAE,ED1,ED2,ED3,ED4,ED5,ED6,ED7/
     *3.1415926535898D0,1.7453292519943D-2,5.72957795130823D1,
     *1D-13,6370D0,83.42D0,185.08D0,4.11D0,1.2996D10,
     *38.9376D8,43.49D0,2.89D8/
      END
```

```
      SUBROUTINE MINT(P,T,ISC,LVEL,LEVIN,ZNEW,OTMN,IPRB)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION P(150),T(150)
      I  = LEVIN
      ZN = ZNEW
      ITR=0
      IF(IPRB.EQ.5)WRITE(6,'(1X,2I4,5(D11.4,1X))')
     *ISC,I,P(I),P(I+1),T(I),T(I+1),ZNEW
      IF(ISC.LE.1)THEN
                IF(I.EQ.LVEL) I=I-1
                HSCAL=ISC*(P(I)-P(I+1))/DLOG(T(I)/T(I+1))
                OTMN=T(I+1)*DEXP((ZN-P(I+1))/HSCAL)
                GOTO 10
                END IF
    2 IF(ISC.EQ.2)THEN
                IF(I.EQ.1)     K=0
                IF(I.GE.2)     K=-1
                IF(I.EQ.LVEL-1) K=-2
                PAV=(P(I+K)+P(I+K+1)+P(I+K+2)+P(I+K+3))/4D0
                TAV=(T(I+K)+T(I+K+1)+T(I+K+2)+T(I+K+3))/4D0
                C1=P(I+K  )/PAV
                C2=P(I+K+1)/PAV
                C3=P(I+K+2)/PAV
                C4=P(I+K+3)/PAV
                C21=C2-C1
                C31=C3-C1
                C41=C4-C1
                B1=C1*C1
                B21=C2*C2-B1
                B31=C3*C3-B1
                B41=C4*C4-B1
                A1=C1*C1*C1
                A21=C2*C2*C2-A1
                A31=C3*C3*C3-A1
                A41=C4*C4*C4-A1
                T1 =T(I+K  )/TAV
                T21=T(I+K+1)/TAV-T1
                T31=T(I+K+2)/TAV-T1
                T41=T(I+K+3)/TAV-T1
                T3121=T31/C31-T21/C21
                T4121=T41/C41-T21/C21
                A3121=A31/C31-A21/C21
                A4121=A41/C41-A21/C21
                B3121=B31/C31-B21/C21
                B4121=B41/C41-B21/C21
```

```
        A=(T4121*B3121-T3121*B4121)/(A4121*B3121-A3121*B4121)
        B=(T3121-A*A3121)/B3121
        C=(T21-A*A21-B*B21)/C21
        D=T1-A*A1-B*B1-C*C1
                  ZN=ZN/PAV
                  OTMN=(((A*ZN+B)*ZN+C)*ZN+D)*TAV
                  GOTO 10
                  END IF
 3 IF(ISC.EQ.3)THEN
                  IF(I.LE.LVEL-2) J=I
                  IF(I.EQ.LVEL-1) J=I-1
                  IF(I.EQ.LVEL  ) J=I-2
                  PAV=(P(J)+P(J+1)+P(J+2))/3D0
                  TAV=(T(J)+T(J+1)+T(J+2))/3D0
                  P1=P(  J)/PAV
                  P2=P(J+1)/PAV
                  P3=P(J+2)/PAV
                  T1=T(  J)/TAV
                  T2=T(J+1)/TAV
                  T3=T(J+2)/TAV
        A=T3/(P3-P2)/(P3-P1)+T2/(P2-P1)/(P2-P3)+
  *       T1/(P1-P2)/(P1-P3)
        B=(T2-T3)/(P2-P3)-A*(P2-P3)
        C=T2-(A*P2+B)*P2
                  ZN=ZN/PAV
                  OTMN=((A*ZN+B)*ZN+C)*TAV
                  GOTO 10
                  END IF
 4 IF(ISC.EQ.4)
  *OTMN=(T(I)-T(I+1))/(P(I)-P(I+1))*(ZN-P(I))+T(I)
10 CONTINUE
      IF(IPRB.EQ.4)WRITE(6,'(1X,2I4,6(D11.4,1X))')
  *ISC,I,P(I),P(I+1),T(I),T(I+1),ZNEW,OTMN
      IF(ISC.LE.1.OR.ISC.EQ.4) GOTO 20
      IF(T(I).GE.OTMIN.AND.T(I+1).LE.OTMIN) GOTO 20
      IF(T(I).LE.OTMIN.AND.T(I+1).GE.OTMIN) GOTO 20
      ITR=ITR+1
      GOTO(2,2,3,4),ISC+ITR
20 RETURN
      END
```

```
      SUBROUTINE LENGTH
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/LE/ IPRC,IPRG,IWA1,IWB1,AA,BB,ITT,JUMP,IG,IALL,
     *           DZ,AEP(21),ALEN(20),ALENS(20),NLEN,DR,D1,
     *           KSUB,IALP,ALP,IQQ,IGA(1400),AGA(1400),
     *           ITYPE(1400)
      KSU=IALL-1
      AGA(KSU)=AA
      IJUMP=1
      JJUMP=1
      GOTO(1000,2000),JUMP
 2000 DD=DR/2D0
      IF(ALEN(IWA1).GE.DR.AND.ALEN(IWB1).GE.DR) GOTO 710
      IF(ALEN(IWA1).GE.DD.AND.ALEN(IWB1).GE.DD) GOTO 610
      GOTO 1000
  710 KSU=KSU+1
      AGA(KSU)=BB
      ITYPE(KSU-1)=-1
      IGA(KSU-1)=IG
      GOTO 1001
  610 DO 611 KG=1,2
      KSU=KSU+1
      AGA(KSU)=AGA(KSU-1)+DD
      ITYPE(KSU-1)=-2
  611 IGA(KSU-1)=IG
      GOTO 1001
 1000 D0=BB-AA
      IF(D0.LE.ALEN(1)) THEN
                        KSU=KSU+1
                        AGA(KSU)=AGA(KSU-1)+D0
                        ITYPE(KSU-1)=0
                        IGA(KSU-1)=IG
                        GOTO 1001
                        END IF
      D2=(D0+AEP(IWA1)+AEP(IWB1))/2.D 0
      IMI=1
      IF(IWA1.LT.IWB1) THEN
                 IF(D2-D0-AEP(IWA1).LT.-DZ) GOTO 1
C-- A ---
                 D1=D0
                 IQQ=IWA1
                 CALL MESH
                 IF(KSUB.EQ.0) GOTO 2
                 DO 3 KG=1,KSUB
                 KSU=KSU+1
```

```
                AGA(KSU)=AGA(KSU-1)+ALEN(IWA1+KG-1)
                ITYPE(KSU-1)=IWA1+KG-1
    3           IGA(KSU-1)=IG
                IF(IALP.EQ.0) GOTO 1001
                IF(ALP.GT.ALEN(IWA1+KG-1)) GOTO 2
                KSU=KSU-1
                IMI=0
    2           KSU=KSU+1
                AGA(KSU)=AGA(KSU-IMI)+ALP
                ITYPE(KSU-1)=0
                IF(IMI.EQ.0) ITYPE(KSU-1)=-(IWA1+KSUB-1)
                IGA(KSU-1)=IG
                GOTO 1001
C-- AB-A ---
    1    DPLUS=0D0
         IF(D2-AEP(IWB1)-ALEN(IWB1).LT.-DZ) DPLUS=D2-AEP(IWB1)
         D1=D2-AEP(IWA1)+DPLUS
         IQQ=IWA1
         CALL MESH
         IF(KSUB.EQ.0) GOTO 6
         DO 5 KG=1,KSUB
         KSU=KSU+1
         AGA(KSU)=AGA(KSU-1)+ALEN(IWA1+KG-1)
         ITYPE(KSU-1)=IWA1+KG-1
    5    IGA(KSU-1)=IG
         IF(DPLUS.EQ.0.D 0) GOTO 6
         IF(IALP.EQ.0) GOTO 1001
         IF(ALP.LT.ALEN(IWA1+KSUB-1)) GOTO 55
         KSU=KSU+1
         AGA(KSU)=AGA(KSU-1)+ALP
         ITYPE(KSU-1)=0
         IGA(KSU-1)=IG
         GOTO 1001
   55    AGA(KSU)=AGA(KSU)+ALP
         ITYPE(KSU-1)=-ITYPE(KSU-1)
         GOTO 1001
C-- AB-B ---
    6         D1=D2-AEP(IWB1)+ALP
   66         IQQ=IWB1
              CALL MESH
              IF(IALP.EQ.0) GOTO 7
              KSU=KSU+1
              AGA(KSU)=AGA(KSU-1)+ALP
              ITYPE(KSU-1)=0
              IGA(KSU-1)=IG
```

```
    7             IF(KSUB.EQ.0) GOTO 1001
                  IF(ALP.GT.ALEN(KSUB+IWB1-1)) GOTO 77
                  KSU=KSU-1
                  IMI=0
   77             DO 8 KG=1,KSUB
                  KSU=KSU+1
                  AGA(KSU)=AGA(KSU-IMI)+ALEN(KSUB+IWB1-KG)
                  IF(IMI.EQ.1) GOTO 88
                  ITYPE(KSU-1)=-(KSUB+IWB1-KG)
                  IMI=1
                  GOTO 8
   88             ITYPE(KSU-1)=KSUB+IWB1-KG
                  IGA(KSU-1)=IG
    8             CONTINUE
                  GOTO 1001
                  END IF
C---- B ---
                IF(IWA1.GT.IWB1) THEN
                IF(D2-D0-AEP(IWB1).LT.-DZ) GOTO 11
                D1=D0
                IQQ=IWB1
                CALL MESH
                IF(IALP.EQ.0) GOTO 132
                KSU=KSU+1
                AGA(KSU)=AGA(KSU-1)+ALP
                ITYPE(KSU-1)=0
                IGA(KSU-1)=IG
   12           IF(KSUB.EQ.0) GOTO 1001
                IF(ALP.GT.ALEN(KSUB+IWB1-1)) GOTO 132
                KSU=KSU-1
                IMI=0
  132           DO 13 KG=1,KSUB
                KSU=KSU+1
                AGA(KSU)=AGA(KSU-IMI)+ALEN(KSUB+IWB1-KG)
                IF(IMI.EQ.1) GOTO 133
                ITYPE(KSU-1)=-(KSUB+IWB1-KG)
                IMI=1
                GOTO 13
  133           ITYPE(KSU-1)=KSUB+IWB1-KG
                IGA(KSU-1)=IG
   13           CONTINUE
                GOTO 1001
C--  AB-A  ----
   11           D1=D2-AEP(IWA1)
                DPLUS=0D0
```

```
            IF(D1.GE.ALEN(IWA1)) GOTO 111
            DPLUS=D1
            GOTO 16
  111       IQQ=IWA1
            CALL MESH
            IF(KSUB.EQ.0) GOTO 14
            DO 15 KG=1,KSUB
            KSU=KSU+1
            AGA(KSU)=AGA(KSU-1)+ALEN(IWA1+KG-1)
            ITYPE(KSU-1)=IWA1+KG-1
   15       IGA(KSU-1)=IG
            IF(IALP.EQ.0) GOTO 16
   14       DPLUS=ALP
C----  AB-B -----
   16       D1=D2-AEP(IWB1)+DPLUS
            IQQ=IWB1
            CALL MESH
            IF(IALP.EQ.0) GOTO 17
            KSU=KSU+1
            AGA(KSU)=AGA(KSU-1)+ALP
            ITYPE(KSU-1)=0
            IGA(KSU-1)=IG
            IF(ALP.GT.ALEN(KSUB+IWB1-1)) GOTO 17
            KSU=KSU-1
            IMI=0
   17       IF(KSUB.EQ.0) GOTO 1001
            DO 18 KG=1,KSUB
            KSU=KSU+1
            AGA(KSU)=AGA(KSU-IMI)+ALEN(KSUB+IWB1-KG)
            IF(IMI.EQ.1) GOTO 188
            ITYPE(KSU-1)=-(KSUB+IWB1-KG)
            IMI=1
            GOTO 18
  188       ITYPE(KSU-1)=KSUB+IWB1-KG
            IGA(KSU-1)=IG
   18       CONTINUE
            GOTO 1001
            END IF
C---   AB  ----
      D1=D0/2D0
      IQQ=IWA1
      CALL MESH
      IF(KSUB.EQ.0) THEN
                    KSU=KSU+1
                    AGA(KSU)=AGA(KSU-1)+ALP
```

```
                    ITYPE(KSU-1)=0
                    IGA(KSU-1)=IG
                    KSU=KSU+1
                    AGA(KSU)=AGA(KSU-1)+ALP
                    ITYPE(KSU-1)=0
                    IGA(KSU-1)=IG
                    GOTO 1001
                    END IF
      DO 23 KG=1,KSUB
      KSU=KSU+1
      AGA(KSU)=AGA(KSU-1)+ALEN(IWA1+KG-1)
      ITYPE(KSU-1)=IWA1+KG-1
   23 IGA(KSU-1)=IG
      IF(IALP.EQ.0) GOTO 24
      IF(ALP.GT.ALEN(IWA1+KSUB-1)) THEN
                    KSU=KSU+1
                    AGA(KSU)=AGA(KSU-1)+ALP+ALP
                    ITYPE(KSU-1)=0
                    IGA(KSU-1)=IG
                    GOTO 24
                    END IF
      KSU=KSU-1
      IMI=0
   22 KSU=KSU+1
      AGA(KSU)=AGA(KSU-IMI)+ALP
      ITYPE(KSU-1)=-(IWA1+KSUB-1)
      IGA(KSU-1)=IG
      KSU=KSU+1
      AGA(KSU)=AGA(KSU-1)+ALP
      ITYPE(KSU-1)=0
      IGA(KSU-1)=IG
      KSU=KSU-1
   24 DO 26 KG=1,KSUB
      KSU=KSU+1
      AGA(KSU)=AGA(KSU-IMI)+ALEN(KSUB+IWB1-KG)
      IF(IMI.EQ.1) GOTO 266
      ITYPE(KSU-1)=-(KSUB+IWB1-KG)
      IMI=1
      GOTO 26
  266 ITYPE(KSU-1)=KSUB+IWB1-KG
      IGA(KSU-1)=IG
   26 CONTINUE
 1001 IALL=KSU+1
      RETURN
      END
```

```
      SUBROUTINE MESH
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/LE/ IPRC,IPRG,IWA1,IWB1,AA,BB,ITT,JUMP,IG,IALL,
     *           DZ,AEP(21),ALEN(20),ALENS(20),NLEN,DR,D1,
     *           KSUB,IALP,ALP,IQQ,IGA(1400),AGA(1400),
     *           ITYPE(1400)
      D2=0D0
      IALP=0
      ALP=0D0
      DO 1 LG=IQQ,NLEN
      D2=D2+ALEN(LG)
      IF(D2-D1.GT.DZ) THEN
      IALP=1
      ALP=D1-D2+ALEN(LG)
      KSUB=LG-IQQ
      GOTO 2
      END IF
      IF(DABS(D2-D1).LT.DZ) THEN
      KSUB=LG-IQQ+1
      GOTO 2
      END IF
    1 CONTINUE
      KSUB=LG-IQQ+1
    2 CONTINUE
CG----
      IF(IPRG.EQ.1) WRITE(6,'(1X,8I5,1X,3F10.7)')
     *IG,ITT,IWA1,IWB1,IQQ,LG,KSUB,IALP,ALP,D1,D2
      RETURN
      END
```

```
      SUBROUTINE CONT(VI,TP,RS,RF,R0,UH,OUTC)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/CO/ IPRD,ICT,CV(69),CD(3,69),CT(3),SUMH
      GOTO(40,400),ICT
      DO 100 I=1,69
   40 IF(VI.GT.CV(I)) GOTO 100
      I2=I
      GOTO 200
  100 CONTINUE
  200 IF(I2.EQ. 1) I2=I2+1
      IF(I2.EQ.69) I2=I2-1
      I1=I2-1
      I3=I2+1
      V1=CV(I1)
      V2=CV(I2)
      V3=CV(I3)
      DO 300 I=1,3
      C1=CD(I,I1)
      C2=CD(I,I2)
      C3=CD(I,I3)
      A=C3/(V3-V2)/(V3-V1)+C2/(V2-V1)/(V2-V3)+
     *  C1/(V1-V2)/(V1-V3)
      B=(C2-C3)/(V2-V3)-A*(V2+V3)
      C=C2-(A*V2+B)*V2
  300 CT(I)= (A*VI+B)*VI+C
      ICT  = 2
      IF(IPRD.EQ.1)WRITE(6,'(/,6X,5HCT(1),7X,5HCT(2),7X,
     *5HCT(3),8X,2HR0,8X,2HTP,/,/,1X,5D12.3,/,/,7X,2HRS,10X,
     *2HRF,10X,2HUH,8X,4HOUTC,8X,4HSUMH,10X,2HAC,/)') CT(1),
     *CT(2),CT(3),R0,TP
  400 CST=CT(2)+(CT(2)-CT(1))*(TP-296)/36D0
      OUTC=UH*DTANH(1.43879*VI/2D0/TP)*VI*(RS*CST+RF*CT(3))/R0
      SUMH=SUMH+OUTC
      AC=1D0-DEXP(-SUMH)
      IF(IPRD.EQ.1)WRITE(6,'(1X,6D12.3)')RS,RF,UH,OUTC,SUMH,AC
      RETURN
      END
```

```
      SUBROUTINE FARWG(AABB,TF,PF,OFWG,IPRINT)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/FA/ MOLL(7),AMASS(10),IFAR,OFWGS,IVI(7)
      DIMENSION SUM(7,110)
      OFWG=0D0
      GOTO(100,200,500,550),IFAR
  100 READ (8,'(1X,11I5)')(IVI(I),I=1,7),ISV,ITA,ITB,IDT
      WRITE(6,'(1X,11I5)')(IVI(I),I=1,7),ISV,ITA,ITB,IDT
      DV=1D0/DFLOAT(ISV-1)
      IST=(ITB-ITA)/IDT+1
      IFAR=2
      RETURN
  200 READ (8,'(1X,F10.1)') POS
      WRITE(6,'(1X,F10.1)') POS
  300 DO 400 L=1,7
      IF(IVI(L).EQ.0) GOTO 400
      DO 400 IV=1,ISW
      IX=(IV-1)*IST
      READ(8,'(1X,10E11.4)') (SUM(L,IX+J),J=1,IST)
  400 CONTINUE
  550 IF(POS.GT.AABB) THEN
                      IFAR=4
                      RETURN
                      END IF
      IF(POS.EQ.AABB) THEN
                      IFAR=3
                      RETURN
                      END IF
      GOTO 200
  500 DO 610 I=1,ISV-1
      V1=POS-5D-1+(IV-1)*DV
      V2=V1+DV
      IF(AABB.GE.V1.AND.AABB.LE.V2) GOTO 620
  610 CONTINUE
  620 DO 630 J=1,IST-1
      T1=ITA+(J-1)*IDT
      T2=TA1+IDT
      IF(TF.LT.T1) GOTO 640
      IF(TF.GE.TA1.AND.TF.LE.TA2) GOTO 640
  630 CONTINUE
      J=IST-1
  640 CONTINUE
      DO 700 M=1,7
      IF( IVI(M).EQ.0) GOTO 700
      IF(MOLL(M).EQ.0) GOTO 700
```

```
      I1=(I-1)*IST+J
      I2=I1+1
      J1=I1+IST
      J2=I2+IST
      SI=(SUM(M,I2)-SUM(M,I1))*(TF-T1)/(T2-T1)+SUM(M,I1)
      SJ=(SUM(M,J2)-SUM(M,J1))*(TF-T1)/(T2-T1)+SUM(M,J1)
      SUV=(SI-SJ)*(AABB-PA1)/(V2-V1)+SI
  700 OFWG=OFWG+SUV*AMASS(M)*PF
C 700 OFWG=OFWG+SUV
      OFWGS=OFWGS+OFWG
      IF(IPRINT.EQ.1)
     *WRITE(6,'(1X,4I5,E10.5)')I1,I2,J1,J2,OFWG,OFWGS
      RETURN
      END
```

```
      SUBROUTINE GAUSS(DRR,GAB,GCC,OUTG)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/GA/ IPRE,IGNU,EPSN,ERG,ERGB,ITY,IGS,IGI,OUTGS,
     *           NG,OUTSS(14000),H2OC,OFWG,LS1,LS2,ITRN,JSWS
      DIMENSION  XG(25),WG(29),XXG(55),WWG(55)
      GOTO(500,600),JUMPG
  500 OUTG= 0D0
      ER  = 0D0
      N   = IGNU-1
  501 N1  = N+1
      IF(N1.GT.10) GOTO 508
      F=0D0
      K=N*N1/2
      DO 504 I=1,N1
      L = K+I
      VGA = GCC*XXG(L)+GAB
      GOTO(503,502),JSWS
  502 INY=(IGS-1)*N1+I
      OUT=OUTSS(INY)
      IF(ITRN.EQ.2.AND.OUT.GT.2D1) GOTO 504
      IF(IGNU.GT.1)CALL SHAPE(LS1,LS2,VGA,OUTS)
      OUT=OUT+OUTS+H2OC+OFWG
      IF(ITRN.EQ.1)    F=F+WWG(L)*OUT
      IF(ITRN.EQ.2)    F=F+WWG(L)*DEXP(-OUT)
      OUTSS(INY)=OUT
      GOTO 504
  503 IF(IGNU.GT.1)CALL SHAPE(LS1,LS2,VGA,OUTS)
      IF(ITRN.EQ.2.AND.OUTS.GT.2D1) GOTO 504
      IF(ITRN.EQ.1) F=F+WWG(L)*OUTS
      IF(ITRN.EQ.2) F=F+WWG(L)*DEXP(-OUTS)
  504 CONTINUE
      F=F*GCC
      IF(IGNU.NE. 0) GOTO 509
      IF(N   .EQ.-1) GOTO 507
      IF(DABS(F).GT.1D-30) GOTO 505
      ER=0D0
      GOTO 508
  505 ER=DABS(F-FR)/F
  506 IF(ER.LT.EPSN) GOTO 508
  507 FR=F
      N=N+1
      IF(IPRE.EQ.2)WRITE(6,'(1X,2I8,2D15.8)')IGI,N1,F,ER
      GOTO 501
  508 ERG=ER
      ERGB=ER*F
```

```
509 OUTG=F
    IF(IPRE.LT.1) GOTO 510
    NG  =  NG+N1
    IDAB=INT(1D-5+GCC*2D5)
    GAA =GAB-GCC
    OUTGS=OUTGS + OUTG
    WRITE(6,'(1X,I5,3I4,I6,F12.5,2D22.14)')
   *NG,IGS,IGI,ITY,IDAB,GAA,OUTG,OUTGS
510 RETURN
600 DO 604 I=1,9
    INXG=I*(I+1)/2
    J=(I+1)/2
    IF(I-(I/2)*2.EQ.0) GOTO 601
    GOTO 602
601 KKW=KKW+1
    XXG(INXG+J+1)=0D0
    WWG(INXG+J+1)=WG(KKW)
602 DO 603 K=1,J
    KK=I-K+2
    KX=KKX+J-K+1
    KW=KKW+J-K+1
    XXG(INXG+KK)= XG(KX)
    XXG(INXG+ K)=-XG(KX)
    WWG(INXG+KK)= WG(KW)
    WWG(INXG+ K)= WG(KW)
603 CONTINUE
    KKX=KKX+J
    KKW=KKW+J
604 CONTINUE
    JUMPG=1
    GOTO 500
```

```
      DATA XXG(1),KKX,XG/0D0,0,5.77350269189626D-1,
     *     7.74596669241483D-1,3.39981043584856D-1,
     *     8.61136311594053D-1,5.38469310105683D-1,
     *     9.06179845938664D-1,2.38619186083197D-1,
     *     6.61209386466265D-1,9.32469514203152D-1,
     *     4.05845151377397D-1,7.41531185599394D-1,
     *     9.49107912342759D-1,1.83434642495650D-1,
     *     5.25532409916329D-1,7.96666477413627D-1,
     *     9.60289856497536D-1,3.24253423403809D-1,
     *     6.13371432700590D-1,8.36031107326636D-1,
     *     9.68160239507626D-1,1.48874338981631D-1,
     *     4.33395394129247D-1,6.79409568299024D-1,
     *     8.65063366688985D-1,9.73906528517172D-1/
      DATA WWG(1),KKW,WG/2D0,0,1.00000000000000D 0,
     *     8.88888888888889D-1,5.55555555555556D-1,
     *     6.52145154862546D-1,3.47854845137454D-1,
     *     5.68888888888889D-1,4.78628670499366D-1,
     *     2.36926885056189D-1,4.67913934572691D-1,
     *     3.60761573048139D-1,1.71324492379170D-1,
     *     4.17959183673469D-1,3.81830050505119D-1,
     *     2.79705391489277D-1,1.29484966168870D-1,
     *     3.62683783378362D-1,3.13706645877887D-1,
     *     2.22381034453374D-1,1.01228536290376D-1,
     *     3.30239355001260D-1,3.12347077040003D-1,
     *     2.60610696402935D-1,1.80648160694857D-1,
     *     0.81274388361574D-1,2.95524224714753D-1,
     *     2.69266719309996D-1,2.19086362515982D-1,
     *     1.49451349150581D-1,0.66671344308688D-1/
      DATA JUMPG/2/
      END
```

```
      SUBROUTINE SHAPE(LL1,LL2,VGA,OUTS)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/SH/ IPRF,REG0,IINT,DVPR,PDLR,PLNZ,VDLR,VLNZ,TAV,
     *           PAV,ALOR(10),AK0(10),XS(10),KSHP,IVDY,
     *           LMOD(7),RMOD(7)
      COMMON/HA/ POSA(3000),STRA(3000),ENRA(3000),ALFA(3000),
     *ALFT(3000),CPLG(3000),STRT(3000),ISIA(3000),IQSW(3000)
      COMMON/FA/ MOLL(7),AMASS(10),IFAR,OFWGS,IVI(7)
      OUTS = 0D0
      DO 20 N = LL1,LL2
      M    = ISIA(N)
      ALR  = ALOR(M)*ALFA(N)
      POS  = POSA(N)
      DIST=POS-VGA
      IF(IINT .EQ.    0) GOTO 25
      IF(DIST.LT.-DVPR.OR.DIST.LT.-RMOD(M)) GOTO 20
      IF(DIST.GT. DVPR.OR.DIST.GT. RMOD(M)) GOTO 21
   25 DIST=DABS(DIST)
      IF(DIST.GT.REG0.AND.IQSW(N).LT.0) GOTO 20
      IF(KSHP.EQ. 0) GOTO 500
      IF(KSHP.GT. 0) GOTO(194,195,196,196) ,KSHP
      IF(KSHP.EQ.-1) GOTO(500,194,195,196) ,LMOD(M)+1
  196 FLOR = ALR/3.1415926535897932D0/(ALR*ALR+DIST*DIST)
      IF(KSHP.EQ.4) THEN
      CALL WING(POS,VGA,TAV,LMOD(M),ALR,FLOR,OUTW)
      IF(OUTW.LT.0D0) GOTO 20
      OUTS = OUTS + STRT(N) * AMASS(M) * FLOR * OUTW
      GOTO 340
      END IF
      OUTS = OUTS + STRT(N) * AMASS(M) * FLOR
      GOTO 340
  195 X    = XS(M)*DIST
      OUTS = OUTS + STRT(N) *   AK0(M) * DEXP(-X*X)
      GOTO 340
  500 IF(DIST.GT.VLNZ.OR .PAV.GT.PLNZ) GOTO 196
      IF(DIST.LT.VDLR.AND.PAV.LT.PDLR) GOTO 195
  194 X    = XS(M)*DIST
      Y    = XS(M)*ALR
      IF(IVDY.EQ.0)OUTS=OUTS+ VOIGTD(X,Y) * AK0(M) * STRT(N)
      IF(IVDY.EQ.1)OUTS=OUTS+ VOIGTY(X,Y) * AK0(M) * STRT(N)
  340 IF(IPRF.EQ.1)WRITE(6,'(1X,3I4,3D13.8,2F11.6,4D11.4 )')
     *N,M,KSHP,VGA,OUTS,STRT(N),POS,DIST,AMASS(M),AK0(M),ALR
   20 CONTINUE
   21 RETURN
      END
```

```
      FUNCTION VOIGTY(X,Y)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION RA(32),CA(32),RB(32),CB(32),B(44),AK(5),
     *AM(5),DY(4),A(42),WWH(10),XXH(10)
      X2=X*X
      Y2=Y*Y
      IF(X-1D1)200,201,201
  200 IF(Y-1D0)202,202,203
  203 RA(1)=0D0
      CA(1)=0D0
      RB(1)=1D0
      CB(1)=0D0
      RA(2)=X
      CA(2)=Y
      RB(2)=5D-1-X2+Y2
      CB(2)=-2D0*X*Y
      CB1=CB(2)
      UV1=0D0
      DO 250 J=2,31
      JMINUS=J-1
      JPLUS=J+1
      FLOATJ=DFLOAT(JMINUS)
      RB1=2D0*FLOATJ+RB(2)
      RA1=-FLOATJ*(2D0*FLOATJ-1D0)/2D0
      RA(JPLUS)=RB1*RA(J)-CB1*CA(J)+RA1*RA(JMINUS)
      CA(JPLUS)=RB1*CA(J)+CB1*RA(J)+RA1*CA(JMINUS)
      RB(JPLUS)=RB1*RB(J)-CB1*CB(J)+RA1*RB(JMINUS)
      CB(JPLUS)=RB1*CB(J)+CB1*RB(J)+RA1*CB(JMINUS)
      UV=(CA(JPLUS)*RB(JPLUS)-RA(JPLUS)*CB(JPLUS))/
     *   (RB(JPLUS)*RB(JPLUS)+CB(JPLUS)*CB(JPLUS))
      IF(DABS(UV-UV1).LT.1D-6) GOTO 251
      UV1=UV
  250 CONTINUE
  251 VOIGTY=UV/1.77245385090552D0
      RETURN
  202 IF(X-2D0)301,301,302
  301 AINT=1D0
      MAX=12D0+5D0*X2
      KMAX=MAX-1
      DO 303 K=0,KMAX
      AJ=MAX-K
  303 AINT=AINT*(-2D0*X2)/(2D0*AJ+1D0)+1D0
      U=-2D0*X*AINT
      GOTO 304
  302 IF(X-4.5D0)305,306,306
```

```
305 B(43)=0D0
    B(44)=0D0
    J=42
    DO 307 K=1,42
    B(J)=4D-1*X*B(J+1)-B(J+2)+A(J)
307 J=J-1
    U=B(3)-B(1)
    GOTO 304
306 AINT=1D0
    MAX=2D0+4D1/X
    AMAX=MAX
    DO 308 K=1,MAX
    AINT=AINT*(2D0*AMAX-1D0)/(2D0*X2)+1D0
308 AMAX=AMAX-1D0
    U=-AINT/X
304 V=1.7724538509055D0*DEXP(-X2)
    H=2D-2
    JM=Y/H
    IF(JM)310,311,310
311 H=Y
310 Z=0D0
    L=0
    DY(1)=0D0
312 DY(2)=H/2D0
    DY(3)=DY(2)
    DY(4)=H
318 AK(1)=0D0
    AM(1)=0D0
    DO 313 J=1,4
    YY=Z+DY(J)
    UU=U+5D-1*AK(J)
    VV=V+5D-1*AM(J)
    AK(J+1)=2D0*(YY*UU+X*VV)*H
    AM(J+1)=-2D0*(1D0+X*UU-YY*VV)*H
    IF(J-3)313,314,313
314 AK(4)=2D0*AK(4)
    AM(4)=2D0*AM(4)
313 CONTINUE
    Z=Z+H
    L=L+1
    U=U+0.166666666667D0*(AK(2)+2D0*AK(3)+AK(4)+AK(5))
    V=V+0.166666666667D0*(AM(2)+2D0*AM(3)+AM(4)+AM(5))
    IF(JM)315,320,315
315 IF(L-JM)318,317,320
317 AJM=JM
```

```
      H=Y-AJM*H
      GOTO 312
  320 VOIGTY=V/1.7724538509055D0
      RETURN
  201 F1=0D0
      DO 330 J=1,10
  330 F1=F1+WWH(J)/(Y2+(X-XXH(J))*(X-XXH(J)))+
     *WWH(J)/(Y2+(X+XXH(J))*(X+XXH(J)))
      VOIGTY=Y*F1/3.1415926535897D0
      RETURN
      DATA WWH/
     *4.622436696006D-1,2.866755053628D-1,1.090172060200D-1,
     *2.481052088746D-2,3.243773342238D-3,2.283386360163D-4,
     *7.802556478532D-6,1.086069370769D-7,4.399340992273D-10,
     *2.229393645534D-13/
      DATA XXH/
     *0.2453407083009D0,0.7374737285454D0,1.2340762153953D0,
     *1.7385377121166D0,2.2549740020893D0,2.7888060584281D0,
     *3.3478545673832D0,3.9447640401156D0,4.6036824495507D0,
     *5.3874808900112D0/
      DATA A/
     *0.0D 0,0.19999999D 0,0.0D 0,-0.18400000D 0,
     *0.0D 0,0.15583999D 0,0.0D 0,-0.12166400D 0,
     *0.0D 0,0.87708159D-1,0.0D 0,-0.58514124D-1,
     *0.0D 0,0.36215730D-1,0.0D 0,-0.20849765D-1,
     *0.0D 0,0.11196011D-1,0.0D 0,-0.56231896D-2,
     *0.0D 0,0.26487634D-2,0.0D 0,-0.11732670D-2,
     *0.0D 0,0.48995199D-3,0.0D 0,-0.19336308D-3,
     *0.0D 0,0.72287745D-4,0.0D 0,-0.25655512D-4,
     *0.0D 0,0.86620736D-5,0.0D 0,-0.27876379D-5,
     *0.0D 0,0.85668736D-6,0.0D 0,-0.25184337D-6,
     *0.0D 0,0.70936022D-7/
      END
```

```
      FUNCTION VOIGTD(X,Y)
      DIMENSION B(22),RI(15),XN(15), YN(15),D0(25),D1(25),
     *D2(25),D3(25),D4(25),HN(25),XX(3),HH(3),NBY2(19),C(21)
      IF(JUMP.GT.0) GOTO 104
      JUMP=1
      DO 101 I=1,15
  101 RI(I)=-I/2.
      DO 103 I=1,25
      HN(I)=H*(I-.5)
      CO=4.*HN(I)*HN(I)/25.-2.
      DO 102 J=2,21
  102 B(J+1)=CO*B(J)-B(J-1)+C(J)
      D0(I)=HN(I)*(B(22)-B(21))/5.
      D1(I)=1.-2.*HN(I)*D0(I)
      D2(I)=(HN(I)*D1(I)+D0(I))/RI(2)
      D3(I)=(HN(I)*D2(I)+D1(I))/RI(3)
  103 D4(I)=(HN(I)*D3(I)+D2(I))/RI(4)
  104 IF (X-5.) 105,112,112
  105 IF (Y-1.) 110,110,106
  106 IF (X.GT.1.85*(3.6-Y)) GOTO 112
      IF (Y.LT.1.45)         GOTO 107
      I=Y+Y
      GOTO 108
  107 I=11.*Y
  108 J=X+X+1.85
      MAX=XN(J)*YN(I)+.46
      MIN=JMIN0(16,21-2*MAX)
      UU=Y
      VV=X
      DO 109 J=MIN,19
      U=NBY2(J)/(UU*UU+VV*VV)
      UU=Y+U*UU
  109 VV=X-U*VV
      VOIGTD=UU/(UU*UU+VV*VV)/1.772454
      RETURN
  110 Y2=Y*Y
      IF (X+Y.GT. 5.) GOTO 113
      N=X/H
      DX=X-HN(N+1)
      U=(((D4(N+1)*DX+D3(N+1))*DX+D2(N+1))*DX+D1(N+1))*
     *DX+D0(N+1)
      V=1.-2.*X*U
      VV=EXP(Y2-X*X)*COS(2.*X*Y)/1.128379-Y*V
      UU=-Y
      MAX=5.+(12.5-X)*.8*Y
```

```
      DO 111 I=2,MAX,2
      U=(X*V+U)/RI(I)
      V=(X*U+V)/RI(I+1)
      UU=-UU*Y2
  111 VV=VV+V*UU
      VOIGTD=1.128379*VV
      RETURN
  112 Y2=Y*Y
      IF (Y.LT.11.-.6875*X) GOTO 113
      U=X-XX(3)
      V=X+XX(3)
      VOIGTD=Y*(HH(3)/(Y2+U*U)+HH(3)/(Y2+V*V))
      RETURN
  113 U=X-XX(1)
      V=X+XX(1)
      UU=X-XX(2)
      VV=X+XX(2)
      VOIGTD=Y*(HH(1)/(Y2+U*U)+HH(1)/(Y2+V*V)+
     *HH(2)/(Y2+UU*UU)+HH(2)/(Y2+VV*VV))
      RETURN
      DATA JUMP/-1/
      DATA B(1),B(2)/0.,.7093602E-7/
      DATA XN/10.,9.,2*8.,7.,6.,5.,4.,7*3./
      DATA YN/3*.6,.5,2*.4,4*.3,1.,.9,.8,2*.7/
      DATA H/.201/
      DATA XX/.5246476,1.65068,.7071068/
      DATA HH/.2562121,.02588268,.2820948/
      DATA NBY2/
     *9.5,9.,8.5,8.,7.5,7.,6.5,6.,5.5,5.,
     *4.5,4.,3.5,3.,2.5,2.,1.5,1.,.5/
      DATA C/
     * .7093602E-7,-.2518434E-6,.8566874E-6,
     *-.2787638E-5,.866074E-5,-.2565551E-4,.7228775E-4,
     *-.1933631E-3,.4899520E-3,-.1173267E-2,.2648762E-2,
     *-.5623190E-2,.1119601E-1,-.2084976E-1,.3621573E-1,
     *-.5851412E-1,.8770816E-1,-.121664,.15584,-.184,.2/
      END
```

```
      SUBROUTINE WING(VA,VB,TA,IC,ALR,FLOR,OUTW)
      IMPLICIT REAL*8(A-H,O-Z)
      DV=DABS(VA-VB)
      GOTO(10,20,30,40,50,60,70),IC
   10 IF(DV.GT.3.5D0) GOTO 11
      OUTW=1D0
      RETURN
   11 OUTW=DEXP(-1.4D0*(DV-3.5D0)**0.25D0)
      RETURN
   20 IF(DV.GE.5D-1) GOTO 21
      OUTW=1D0
      RETURN
   21 IF(DV.GE.23D0) GOTO 22
      OUTW=1.069*DEXP(-0.133*DV)
      RETURN
   22 IF(DV.GE.50D0) GOTO 23
      OUTW=5D-2
      RETURN
   23 IF(DV.GE.25D1) GOTO 24
      OUTW=0.133D0*DEXP(-0.0196*DV)
      RETURN
   24 OUTW=-1D0
      RETURN
   30 IF(DV.GE.11D0) GOTO 31
      OUTW=(1D0+2D0*DV/11D0)*DEXP(-2D0*DV/11D0)
      RETURN
   31 OUTW=-1D0
      RETURN
   40 DW2=(VA+VB)*(VA+VB)
      DEA=1D0-DEXP(-C2*VA/TA)
      DEB=1D0-DEXP(-C2*VB/TA)
      OUTW=VA*DEA*(1D0+ALR/(DW2+ALR*ALR)/PI/FLOR)/VB/DEB
      RETURN
   50 DW2=(VA+VB)*(VA+VB)
      OUTW=VA*VA*(1D0+ALR/(DW2+ALR*ALR)/PI/FLOR)/VB/VB
      RETURN
   60 DW2=(VA+VB)*(VA+VB)
      OUTW=VA*(1D0+ALR/(DW2+ALR*ALR)/PI/FLOR)/VB
      RETURN
   70 OUTW=2D0*VA/(1D0+DEXP(-C2*DV/TA))/VB
      RETURN
      DATA PI,C2/3.14159265358973,1.43879/
      END
```

APPENDIX E

Listing of the Third Group of Programmes

SMTH
COMP
CHNL

```
      PROGRAM SMTH
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION SM(25000),FR(25000),TRAB(200)
      OPEN(UNIT=4,TYPE='OLD',FILE='SMTH.INP')
      OPEN(UNIT=8,TYPE='NEW',FILE='SMTH.DAT')
      READ(4,*)IRAD,TBOUND
      READ(4,*)WNUA,WNUB,DL,DD,WNU1,WNU2,DR,LE1,LE2,IT,IPD,IO
      IF(IRAD.EQ.0) OPEN(UNIT=2,TYPE='OLD',FILE='TRAO.DAT')
      IF(IRAD.EQ.1) OPEN(UNIT=3,TYPE='OLD',FILE= 'RAD.DAT')
      IDAT=INT(WNU2-WNU1+1)
      IIR=INT(1D0/DR+DR)
      JF=0
      DO 100 L =1,IDAT
      DO 100 M=1,LE1
      IF(IRAD.EQ.1)THEN
                   READ(3,'(1X,F11.3)') WNUAV
                   READ(3,'(10(1X,E11.6))')(TRAB(I),I=1,IIR)
                   GOTO 97
                   END IF
      IF(IRAD.EQ.0)THEN
                   READ(2,*)LL,(TRAB(I),I=1,IIR),TRABS,WNUAV
                   END IF
   97 IF(M.NE.LE2) GOTO 100
      DO 98  LL=1,IIR
      KL=(L-1)*IIR+LL
      F=WNU1+(KL-1)*DR+DR/2D0-5D-1
      IF(F.LT.WNUA-DD) GOTO 98
      IF(F.GT.WNUB+DD) GOTO 96
      IF(IPD.EQ.1)WRITE(6,'(1X,I5,F10.3,F11.4)')KL,F,TRAB(LL)
      JF=JF+1
      FR(JF)=F
      SM(JF)=TRAB(LL)
   98 CONTINUE
  100 CONTINUE
   96 WRITE(6,*)'       JF = ',JF
      IF(IO.EQ.1) THEN
                  DO 101 I=1,JF
                  IF(FR(I).LT.WNUA) GOTO 101
                  IF(FR(I).GT.WNUB) GOTO 104
                  WRITE(8,*)FR(I),SM(I)
  101             CONTINUE
  104             WRITE(8,*)99.99, 99.99
                  IF(IT.EQ.0) GOTO 11
                  END IF
  103 IF(TBOUND.NE.0D0)THEN
```

```
                     DO 102 F=WNUA-DD,WNUB+DD,0.1
                     PL=C1*F*F*F/(DEXP(C2*F/TBOUND)-1)
102                  WRITE(8,*)F,PL
105                  WRITE(8,*)99.99, 99.99
                     END IF
    WRITE(6,*)
    IDD    = INT(2D0*DD/DR+DR)
    IDL =INT(DL/DR+DR)
    WRITE(6,*)' KL = ',KL,'IDD=',IDD,'IDL=',IDL
    WRITE(6,*)
    WRITE(6,*)'I IDAT JDAT  WNUAV  TAVW   IFIRST  ILAST'
    WRITE(6,*)
    IF1=1
    DO 10 WNUAV=WNUA,WNUB,DL
    JDAT   = 0
    TAVW   = 0D0
    FWS=0
    DO 20 J=IF1,JF
    WNU  = FR(J)
    IF(WNU.LT.WNUAV-DD) GOTO 19
    IF(WNU.GT.WNUAV+DD) GOTO 21
    JDAT = JDAT+1
    IF(IT.EQ.2) FW   =  1D0-DABS(WNU-WNUAV)/DD
    IF(IT.EQ.1) FW   =  1D0
    FWS  = FWS+FW
    TAVW  = TAVW+SM(J)*FW
    GOTO 20
 19 IF2=J
 20 CONTINUE
 21 IF1=IF2
    TAVW = TAVW/FWS
    WRITE(6,'(1X,3I5,5X,F10.2,F11.4,5X,2I5)')I,IDAT,JDAT,
   *WNUAV,TAVW,IF1,J-1
    WRITE(8,*)WNUAV,TAVW
 10 CONTINUE
    WRITE(8,*)99.99,99.99
 11 CONTINUE
    DATA C1, C2/ 1.1909596D-5,1.43879D0/
    END
C----------------------------------------------------------------
C SMTH.INP
C 0 0    IRAD  TBOUND
C WNUA   WNUB   DL  DD  WNU1 WNU2  DR   LE1 LE2 IT IPD IO
C 2135   2250  0.5 .05  1950 2250 0.01   1   1   0  0   1
C----------------------------------------------------------------
```

```
      PROGRAM COMP
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION SM(25000),FR(25000),TRAB(200),
     *          FH(2050),H(2050),T(2050),R(2050),SL(3,2),
     *          PR(20),PT(20),QR(20),QT(20),RR(20),RT(20)
      OPEN(UNIT=4,TYPE='OLD',FILE='COMP.INP')
      OPEN(UNIT=8,TYPE='NEW',FILE='COMP.DAT')
      IPL=0
      READ(4,*)IPLOTS
 2000 IPL=IPL+1
      INPT=0
      READ(4,*)INPUTS,IGRAF,IRAD,IEQW,OF
 1000 INPT  = INPT+1
      INPTT = INPT
      READ(4,*)ITB,TBU,TBL,TBB1,TBB2,SCALE,DREF,DIV
      READ(4,*)WNUA,WNUB,DL,DD,WNU1,WNU2,DR,LE1,LE2,IT,IPD,IO
      READ(4,*)ICOM,IDEL,IDAY,IBAND
    1 FORMAT(1X,I3,8F6.1)
    2 FORMAT(1X,2F7.2,2F7.4,2F7.2,F7.4,5I2)
    3 FORMAT(1X,4I5)
    4 FORMAT(/,/,10X,5HCASE:,I2,/,/,10X,6HMEAN-H,2X,6HMEAN-F,
     *2X,6H MAX-H,2X,6H MAX-F,2X,6H STD-H,2X,6H STD-F,2X,
     *5H DATA,3X,11HWNUI [CM-1],/)
C-----
      IF(IRAD.NE.0.AND.IDAY.EQ.1)
     *        OPEN(UNIT=3,TYPE='OLD',FILE= 'RAD.DAT;1')
      IF(IRAD.NE.0.AND.IDAY.EQ.2)
     *        OPEN(UNIT=3,TYPE='OLD',FILE= 'RAD.DAT;2')
      IF(IRAD.EQ.0.AND.IDAY.LE.1)
     *        OPEN(UNIT=2,TYPE='OLD',FILE='TRAO.DAT;1')
      IF(IRAD.EQ.0.AND.IDAY.EQ.2)
     *        OPEN(UNIT=2,TYPE='OLD',FILE='TRAO.DAT;2')
      IF(ICOM.NE.0)
     *        OPEN(UNIT=9,TYPE='OLD',FILE=  'HCOM.DAT')
      IF(IDEL.NE.0.AND.INPT.EQ.1)
     *        OPEN(UNIT=7,TYPE='NEW',FILE=  'SCOM.DAT')
      TTMAX=0D0
      TTMIN=1D10
C---------------------------------------------------------------
C         PLOT UPPER AND LOWER BOUNDARY TEMP. OR RAD.
C---------------------------------------------------------------
  103 IF(TBU.NE.0D0)THEN
                    DO 102 F=WNUA,WNUB
                    IF(ITB.EQ.0)PL=C1*F*F*F/(DEXP(C2*F/TBU)-1)
                    IF(ITB.EQ.1)PL=TBU
```

```
                     IF(TTMIN.GT.PL) TTMIN=PL
                     IF(TTMAX.LT.PL) TTMAX=PL
                     WRITE(8,*)F,PL
  102                CONTINUE
                     WRITE(8,*)99.99, 99.99
                     WRITE(6,*)' TTMIN:',TTMIN,' TTMAX:',TTMAX
                     END IF
      IF(TBL.NE.0D0)THEN
                     DO 105 F=WNUA,WNUB
                     IF(ITB.EQ.0)PL=C1*F*F*F/(DEXP(C2*F/TBL)-1)
                     IF(ITB.EQ.1)PL=TBL
                     IF(TTMIN.GT.PL) TTMIN=PL
                     IF(TTMAX.LT.PL) TTMAX=PL
                     WRITE(8,*)F,PL
  105                CONTINUE
                     WRITE(8,*)99.99, 99.99
                     WRITE(6,*)' TTMIN:',TTMIN,' TTMAX:',TTMAX
                     END IF
      IF(IO.EQ.0.AND.IT.EQ.0.AND.ICOM.LT.0) GOTO 50
C---------------------------------------------------------------
C             START TO RED TRANS. OR RAD. DATA
C---------------------------------------------------------------
      EQWS=0D0
      IDAT=INT(WNU2-WNU1+1)
      IIR=INT(1D0/DR+DR)
      WRITE(6,*)IDAT,IIR
      WRITE(6,*)
      JF=0
      DO 100 L =1,IDAT
      DO 100 M=1,LE1
      IF(IRAD.NE.0) THEN
                     READ(3,'(1X,F11.3)') WNUAV
                     READ(3,'(10(1X,E11.6))')(TRAB(I),I=1,IIR)
                     GOTO 97
                     END IF
      IF(IRAD.EQ.0)READ(2,*) LL,(TRAB(I),I=1,IIR),TRABS,WNUAV
   97 IF(M.NE.LE2) GOTO 100
      DO 98  LL=1,IIR
      KL=(L-1)*IIR+LL
      F=WNU1+(KL-1)*DR+DR/2D0-5D-1
      IF(F.LT.WNUA-DD) GOTO 98
      IF(F.GT.WNUB+DD) GOTO 96
      IF(IPD.EQ.1)WRITE(6,'(1X,I5,F10.4,F11.4)')KL,F,TRAB(LL)
      JF=JF+1
      FR(JF)=F
```

```
      EQW=(1D0-TRAB(LL))*DR
      EQWS=EQWS+EQW
      IF(IEQW.EQ. 0) SM(JF) = TRAB(LL)
      IF(IEQW.EQ. 1) SM(JF) = 1D0-TRAB(LL)
      IF(IEQW.EQ.-1) SM(JF) = EQWS + OF
   98 CONTINUE
  100 CONTINUE
      WRITE(6,*)
   96 WRITE(6,*) 'POINTS BETWEEN WNUA-DD AND WNUB+DD :',JF
      WRITE(6,*)'EQUIVALENT WIDTH:',EQWS
      WRITE(6,*)
C-----
      IF(IO.EQ.1)THEN
                 DO 101 I=1,JF
                 IF(FR(I).LT.WNUA) GOTO 101
                 IF(FR(I).GT.WNUB) GOTO 104
      IF(ITB.EQ.1)SMI=C2*WNUAV/DLOG(C1*WNUAV**3/SM(I)+1)
      IF(ITB.EQ.0)SMI=SM(I)
                 IF(TTMIN.GT.SMI) TTMIN=SMI
                 IF(TTMAX.LT.SMI) TTMAX=SMI
                 WRITE(8,*)FR(I),SMI
  101            CONTINUE
  104            WRITE(6,*)' TTMIN:',TTMIN,' TTMAX:',TTMAX
                 END IF
      IF(IT.EQ.0) GOTO 111
      IF(IO.EQ.1) WRITE(8,*)99.99, 99.99
C-----
      WRITE(6,*)
      IDD = INT(2D0*DD/DR+DR)
      IDL = INT(DL/DR+DR)
      WRITE(6,'(1X,5HKL = ,I6,5X,6HIDD = ,I6,5X,6HIDL = ,
     *I6,/)') KL,IDD,IDL
      IF1=1
      IF2=1
      IF(ICOM.GT.0) GOTO 50
C--------------------------------------------------------------
C                     NORMAL SMOOTHING
C--------------------------------------------------------------
      IF(IPD.EQ.2) THEN
                  WRITE(6,*)'    I  IDAT  JDAT        WNUAV
     *            TAVW      IFIRST    ILAST'
                  WRITE(6,*)
                  END IF
      DO 10 WNUAV=WNUA,WNUB,DL
      JDAT = 0
```

```
      TAVW = 0D0
      FWS  = 0D0
      IF(IT.LT.3) DDD=DD
      IF(IT.EQ.3) DDD=1.2D0+(WNUAV-500D0)*8D-3
      IF(IT.EQ.4) THEN
        IF(WNUAV.LT.637D0) ADH=( 0.01074D0*WNUAV-3.28D0)/2D0
        IF(WNUAV.GE.637D0) ADH=(0.008041D0*WNUAV-2.69D0)/2D0
        IF(DD.NE.0D0)      ADH=DD/2D0
        DDD=3D0*ADH
        END IF
      IF(IT.EQ.5) DDD=DD*3.14159265D0*2D0
      IDD=INT(2D0*DDD/DR+DR)
      DO 20 J=IF1,JF
      WNU  = FR(J)
      IF(WNU.LT.WNUAV-DDD) GOTO 19
      IF(WNU.GT.WNUAV+DDD) GOTO 21
      JDAT = JDAT+1
      IF(IT.EQ.1) FW = 1D0
      IF(IT.EQ.2.OR.IT.EQ.3) FW = 1D0 - DABS(WNU-WNUAV)/DDD
      IF(IT.EQ.4) FW = CC1*DEXP(-((WNU-WNUAV)*CC2/ADH)**2)/ADH
      IF(IT.EQ.5) THEN
            IF(WNU.EQ.WNUAV) FW=1D0
            IF(WNU.NE.WNUAV) FW=DSIN(WNU-WNUAV)/(WNU-WNUAV)
            END IF
      TAVW = TAVW + SM(J)*FW
      FWS  = FWS  + FW
      GOTO 20
   19 IF2=J
   20 CONTINUE
   21 IF1=IF2
      TAVW = TAVW/FWS
      IF(IPD.EQ.2)WRITE(6,'(1X,3I5,5X,F10.2,F11.4,5X,2I5)')
     *I,IDAT,JDAT,WNUAV,TAVW,IF1,J-1
      IF(ITB.EQ.1)TAVW=C2*WNUAV/DLOG(C1*WNUAV**3/TAVW+1)
      IF(TTMIN.GT.TAVW) TTMIN=TAVW
      IF(TTMAX.LT.TAVW) TTMAX=TAVW
      WRITE(8,*)WNUAV,TAVW
   10 CONTINUE
      WRITE(6,*)' TTMIN:',TTMIN,' TTMAX:',TTMAX
      IF(ICOM.EQ.0) GOTO 111
      WRITE(8,*)99.99,99.99
C-------------------------------------------------------------
C                  READ HIS DATA FOR COMPARISONS
C-------------------------------------------------------------
   50 IHIS=2049
```

```
      READ(9,*)((SL(J,I),I=1,2),J=1,3)
      DO 22 J=1,2
      DO 22 I=1,2049
      READ(9,'(3(F8.2,2E10.5))')F1,H1,T1,F2,H2,T2,F3,H3,T3
      IF(J.NE.IDAY) GOTO 22
      IF(1.EQ.IBAND) THEN
                     H(I) = H1
                     T(I) = T1
                     FH(I)= F1
                     END IF
      IF(2.EQ.IBAND) THEN
                     H(I) = H2
                     T(I) = T2
                     FH(I)= F2
                     END IF
      IF(3.EQ.IBAND) THEN
                     H(I) = H3
                     T(I) = T3
                     FH(I)= F3
                     END IF
   22 CONTINUE
      IF(ITB.EQ.1) THEN
                   DO 33 I=1,IHIS
                   IF(T(I).EQ.0D0.OR.H(I).EQ.0D0) GOTO 33
                   H(I)=C2*FH(I)/DLOG(C1*FH(I)**3/H(I)+1)
                   T(I)=C2*FH(I)/DLOG(C1*FH(I)**3/T(I)+1)
   33              CONTINUE
                   END IF
   52 CONTINUE
      JHIS=0
      IF(IPD.EQ.2)  WRITE(6,'(4X,1HI,2X,4HIDAT,2X,4HJDAT,
     *8X,5HWNUAV,2X,4HTAVW,6X,6HIFIRST,2X,5HILAST,/)')
      WNUAC=WNUA
      WNUBC=WNUB
      IF(WNUA.LT.SL(IBAND,1))WNUAC=SL(IBAND,1)
      IF(WNUB.GT.SL(IBAND,2))WNUBC=SL(IBAND,2)
      DO 110 I=1,IHIS
      WNUAV=FH(I)
      IF(WNUAV.LT.WNUAC) GOTO 110
      IF(WNUAV.GT.WNUBC) GOTO 112
      IF(JHIS.EQ.1) JHIS1=I-1
      JDAT   = 0
      TAVW   = 0D0
      FWS=0
      JHIS=JHIS+1
```

```
      IF(ICOM.LT.0) GOTO 110
      IF(IT.LT.3) DDD=DD
      IF(IT.EQ.3) DDD=1.2D0+(WNUAV-500D0)*8D-3
      IF(IT.EQ.4) THEN
        IF(WNUAV.LT.637D0) ADH=( 0.01074D0*WNUAV-3.28D0)/2D0
        IF(WNUAV.GE.637D0) ADH=(0.008041D0*WNUAV-2.69D0)/2D0
        IF(DD.NE.0D0)      ADH=DD/2D0
        DDD=3D0*ADH
        END IF
      IF(IT.EQ.5) DDD=DD*3.14159265D0*2D0
      IDD=INT(2D0*DDD/DR+DR)
      DO 120 J=IF1,JF
      WNU  = FR(J)
      IF(WNU.LT.WNUAV-DD) GOTO 119
      IF(WNU.GT.WNUAV+DD) GOTO 121
      JDAT = JDAT+1
      IF(IT.EQ.1) FW = 1D0
      IF(IT.EQ.2.OR.IT.EQ.3) FW = 1D0 - DABS(WNU-WNUAV)/DDD
      IF(IT.EQ.4) FW = CC1*DEXP(-((WNU-WNUAV)*CC2/ADH)**2)/ADH
      IF(IT.EQ.5) THEN
        IF(WNU.EQ.WNUAV) FW=1D0
        IF(WNU.NE.WNUAV) FW=DSIN(WNU-WNUAV)/(WNU-WNUAV)
        END IF
      TAVW = TAVW + SM(J)*FW
      FWS  = FWS  + FW
      GOTO 120
  119 IF2=J
  120 CONTINUE
  121 IF1=IF2
      TAVW = TAVW/FWS
      IF(IPD.EQ.2)WRITE(6,'(1X,3I5,5X,F10.2,F11.4,5X,2I5)')
     *I,IDAT,JDAT,WNUAV,TAVW,IF1,J-1
      IF(ITB.EQ.1)TAVW=C2*WNUAV/DLOG(C1*WNUAV**3/TAVW+1)
      R(I)=TAVW
  110 CONTINUE
  112 JHIS2=I-1
      KHIS=JHIS2-JHIS1+1
      WRITE(6,'(/,1X,8HJHIS1 = ,I5,5X,8HJHIS2 = ,I5,5X,
     *7HKHIS = ,I5,/)') JHIS1,JHIS2,KHIS
C---------------------------------------------------------------
C                        PLOT RESULRS
C---------------------------------------------------------------
      DO 987 I=JHIS1,JHIS2
      IF(TTMIN.GT.H(I)) TTMIN=H(I)
      IF(TTMIN.GT.R(I)) TTMIN=R(I)
```

```
      IF(TTMIN.GT.T(I).AND.IDEL.LT.0) TTMIN=T(I)
      IF(TTMAX.LT.H(I)) TTMAX=H(I)
      IF(TTMAX.LT.R(I)) TTMAX=R(I)
      IF(TTMAX.LT.T(I).AND.IDEL.LT.0) TTMAX=T(I)
  987 CONTINUE
      WRITE(6,*)' TTMIN:',TTMIN,' TTMAX:',TTMAX
      IF(ICOM.EQ.-1) THEN
                     DO 1004 I=JHIS1,JHIS2
 1004                WRITE(8,*)FH(I),H(I)
                     END IF
      IF(ICOM.EQ.-2) THEN
                     DO 1005 I=JHIS1,JHIS2
 1005                WRITE(8,*)FH(I),T(I)
                     END IF
      IF(ICOM.EQ.-3) THEN
                     DO 1006 I=JHIS1,JHIS2
 1006                WRITE(8,*)FH(I),H(I)
                     WRITE(8,*)99.99,99.99
                     DO 1007 I=JHIS1,JHIS2
 1007                WRITE(8,*)FH(I),T(I)
                     END IF
      IF(ICOM.EQ. 1) THEN
                     DO 1113 I=JHIS1,JHIS2
 1113                WRITE(8,*)FH(I),R(I)
                     END IF
      IF(ICOM.EQ. 2) THEN
                     DO 1114 I=JHIS1,JHIS2
 1114                WRITE(8,*)FH(I),R(I)
                     WRITE(8,*)99.99,99.99
                     DO 1115 I=JHIS1,JHIS2
 1115                WRITE(8,*)FH(I),H(I)
                     END IF
      IF(ICOM.EQ. 3) THEN
                     DO 1116 I=JHIS1,JHIS2
 1116                WRITE(8,*)FH(I),R(I)
                     WRITE(8,*)99.99,99.99
                     DO 1117 I=JHIS1,JHIS2
 1117                WRITE(8,*)FH(I),T(I)
                     END IF
      IF(ICOM.EQ. 4) THEN
                     DO 1118 I=JHIS1,JHIS2
 1118                WRITE(8,*)FH(I),R(I)
                     WRITE(8,*)99.99,99.99
                     DO 1119 I=JHIS1,JHIS2
 1119                WRITE(8,*)FH(I),H(I)
```

```
                     WRITE(8,*)99.99,99.99
                     DO 1120 I=JHIS1,JHIS2
 1120                WRITE(8,*)FH(I),T(I)
                     END IF
C-------------------------------------------------------------
C                           STAT BEGINS
C-------------------------------------------------------------
      IF(IDEL.EQ.0) GOTO 111
      WRITE(8,*)99.99,99.99
      TB3=(TBB2-TBB1)/4D1+TBB1
      TB1=TB3+(TBB2-TBB1)/4D1
      TB2=TTMIN-(TBB2-TBB1)/2D1
      SCALE=(TB2-TB1)/SCALE
      DREF=SCALE*DREF
      WTICK=(WNUB-WNUA)/1D1
      TTICK=(WNUB-WNUA)/1D2
      VTICK=(TB2 - TB1)/5D1
      SHIFT=2D0*TTICK
      TREF=(TB1+TB2)/2D0+DREF
      WNUAA=WNUA+SHIFT
      WNUBB=WNUB-SHIFT
      IDV=(WNUB-WNUA)/IABS(IDEL)
      WRITE(7,4) IDAY
      WNUX=WNUA
      MHIS=0
      ARAV=0D0
      ATAV=0D0
      RRMA=0D0
      TTMA=0D0
      SDR =0D0
      SDT =0D0
      JDEL=IABS(IDEL)
      DO 500 II=1,JDEL
      LHIS=0
      RMA=0D0
      TMA=0D0
      SDD1=0D0
      SDD3=0D0
      S2D1=0D0
      S2D3=0D0
      DO 1131 I=JHIS1,JHIS2
      DINT1=WNUA+(WNUB-WNUA)/DFLOAT(JDEL)*(II-1)
      DINT2=WNUA+(WNUB-WNUA)/DFLOAT(JDEL)*II
      C=FH(I)
      IF(C.LE.DINT1) GOTO 1131
```

```
      IF(C.GT.DINT2) GOTO 499
      LHIS=LHIS+1
      A=C*C*C
      B=C/TREF
      IF(ITB.EQ.0)PL=C1*A/(DEXP(C2*B)-1)
      IF(ITB.EQ.1)PL=TREF
      D1=(H(I)-R(I))*SCALE+PL
      D2=(R(I)-T(I))*SCALE+PL
      D3=(H(I)-T(I))*SCALE+PL
      IF(C.LT.WNUA+SHIFT) GOTO 1132
      IF(C.GT.WNUB-SHIFT) GOTO 1132
      IF(D1.LT.TB1) D1=TB1
      IF(D1.GT.TB2) D1=TB2
      IF(D2.LT.TB1) D2=TB1
      IF(D2.GT.TB2) D2=TB2
      IF(D3.LT.TB1) D3=TB1
      IF(D3.GT.TB2) D3=TB2
C-----
      IF(ICOM.EQ.1.OR.ICOM.EQ.2.OR.ICOM.EQ.4) WRITE(8,*) C,D1
      IF(ICOM.EQ.3) WRITE(8,*) C,D2
      IF(ICOM.LT.0) WRITE(8,*) C,D3
C-----
 1132 CONTINUE
      DD1=H(I)-R(I)
      DD3=H(I)-T(I)
      IF(DABS(RMA).LT.DABS(DD1)) RMA=DD1
      IF(DABS(TMA).LT.DABS(DD3)) TMA=DD3
      SDD1=SDD1+DD1
      SDD3=SDD3+DD3
      S2D1=S2D1+DD1*DD1
      S2D3=S2D3+DD3*DD3
 1131 CONTINUE
      WRITE(8,*)99.99,99.99
  499 FK=DFLOAT(LHIS)
      RAV=SDD1/FK
      TAV=SDD3/FK
      RSD=DSQRT((FK*S2D1-SDD1*SDD1)/FK/(FK-1D0))
      TSD=DSQRT((FK*S2D3-SDD3*SDD3)/FK/(FK-1D0))
      WNUY=WNUX+IDV
      WRITE(6,'(8X,6F8.3,I6,4X,F5.0,1H-,F5.0)')
     *RAV,TAV,RMA,TMA,RSD,TSD,LHIS,WNUX,WNUY
      WRITE(7,'(8X,6F8.3,I6,4X,F5.0,1H-,F5.0)')
     *RAV,TAV,RMA,TMA,RSD,TSD,LHIS,WNUX,WNUY
      WNUX=WNUY
      PR(II)=DABS(RAV)
```

```
      PT(II)=DABS(TAV)
      QR(II)=DABS(RMA)
      QT(II)=DABS(TMA)
      RR(II)=RSD
      RT(II)=TSD
      ARAV=ARAV+RAV
      ATAV=ATAV+TAV
      SDR =SDR +RSD
      SDT =SDT +TSD
      IF(DABS(RRMA).LT.DABS(RMA)) RRMA=RMA
      IF(DABS(TTMA).LT.DABS(TMA)) TTMA=TMA
      MHIS=MHIS+LHIS
  500 CONTINUE
      IF(ICOM.GT.0.AND.IDEL.LT.0) THEN
      DO 510 I=JHIS1,JHIS2
      DHT=(H(I)-T(I))*SCALE+TREF
      C=FH(I)
      IF(C.LT.WNUA+SHIFT) GOTO 510
      IF(C.GT.WNUB-SHIFT) GOTO 510
      IF(DHT.LT.TB1) DHT=TB1
      IF(DHT.GT.TB2) DHT=TB2
      WRITE(8,*)C,DHT
  510 CONTINUE
      WRITE(8,*)99.99,99.99
      END IF
      DO 501 II=1,JDEL
      DINT1=WNUA+(WNUB-WNUA)/DFLOAT(JDEL)*(II-1)
      DINT2=WNUA+(WNUB-WNUA)/DFLOAT(JDEL)*II
      IF(PR(II).LE.PT(II)) THEN
      WRITE(8,*)DINT1,TB3-VTICK
      WRITE(8,*)DINT1,TB3+VTICK
      WRITE(8,*)DINT1,TB3
      WRITE(8,*)DINT2,TB3
      WRITE(8,*)DINT2,TB3-VTICK
      WRITE(8,*)DINT2,TB3+VTICK
      WRITE(8,*)DINT2,TB3
      WRITE(8,*)99.99,99.99
      END IF
  501 CONTINUE
      FIDEL = DFLOAT(JDEL)
      ARAV=ARAV/FIDEL
      ATAV=ATAV/FIDEL
      SDR=SDR/FIDEL
      SDT=SDT/FIDEL
      WRITE(6,'(/,8X,6F8.3,I6,4X,F5.0,1H-,F5.0,1H*)')
```

```
     *ARAV,ATAV,RRMA,TTMA,SDR,SDT,MHIS,WNUA,WNUB
      WRITE(7,'(/,8X,6F8.3,I6,4X,F5.0,1H-,F5.0,2H *)')
     *ARAV,ATAV,RRMA,TTMA,SDR,SDT,MHIS,WNUA,WNUB
C---------------------------------------------------------------
C                        PLOT WINDOW
C---------------------------------------------------------------
      WRITE(8,*)WNUAA,TREF
      DO 2101 F=WNUA+WTICK,WNUB-WTICK,WTICK
      WRITE(8,*)F,TREF
      WRITE(8,*)F,TREF-VTICK
      WRITE(8,*)F,TREF+VTICK
      WRITE(8,*)F,TREF
 2101 CONTINUE
      WRITE(8,*)WNUBB,TREF
      WRITE(8,*)99.99,99.99
C-----
      WRITE(8,*)WNUAA,TB2
      DO 2102 F=WNUA+WTICK,WNUB-WTICK,WTICK
      WRITE(8,*)F,TB2
      WRITE(8,*)F,TB2-VTICK
      WRITE(8,*)F,TB2
 2102 CONTINUE
      WRITE(8,*)WNUBB,TB2
      WRITE(8,*)99.99,99.99
C-----
      WRITE(8,*)WNUAA,TB1
      DO 2103 F=WNUA+WTICK,WNUB-WTICK,WTICK
      WRITE(8,*)F,TB1
      WRITE(8,*)F,TB1+VTICK
      WRITE(8,*)F,TB1
 2103 CONTINUE
      WRITE(8,*)WNUBB,TB1
      WRITE(8,*)99.99,99.99
C-----
      DO 2104 TSUB=TREF,TB2,SCALE*DIV
      WRITE(8,*)WNUAA,TSUB
      WRITE(8,*)WNUAA+TTICK,TSUB
      WRITE(8,*)WNUAA,TSUB
 2104 CONTINUE
      WRITE(8,*)WNUAA,TB2
      WRITE(8,*)99.99,99.99
C-----
      DO 2105 TSUB=TREF,TB1,-SCALE*DIV
      WRITE(8,*)WNUAA,TSUB
      WRITE(8,*)WNUAA+TTICK,TSUB
```

```
      WRITE(8,*)WNUAA,TSUB
 2105 CONTINUE
      WRITE(8,*)WNUAA,TB1
      WRITE(8,*)99.99,99.99
C-----
      DO 2106 TSUB=TREF,TB2,SCALE*DIV
      WRITE(8,*)WNUBB,TSUB
      WRITE(8,*)WNUBB-TTICK,TSUB
      WRITE(8,*)WNUBB,TSUB
 2106 CONTINUE
      WRITE(8,*)WNUBB,TB2
      WRITE(8,*)99.99,99.99
C-----
      DO 2107 TSUB=TREF,TB1,-SCALE*DIV
      WRITE(8,*)WNUBB,TSUB
      WRITE(8,*)WNUBB-TTICK,TSUB
      WRITE(8,*)WNUBB,TSUB
 2107 CONTINUE
      WRITE(8,*)WNUBB,TB1
C-----
  111 CONTINUE
      IF(INPT.EQ.IGRAF)  WRITE(8,*) -99.99,-99.99
      IF(INPT.NE.IGRAF.AND.IGRAF.NE.0.AND.INPT.NE.INPUTS)
     *                   WRITE(8,*)  99.99,99.99
      IF(INPT.NE.IGRAF.AND.IGRAF.EQ.0.AND.INPT.NE.INPUTS)
     *                   WRITE(8,*)-99.99,-99.99
  192 CONTINUE
      IF(ICOM.NE.0) THEN
                    REWIND 9
                    CLOSE UNIT=9
                    END IF
      IF(IRAD.NE.0) THEN
                    REWIND 3
                    CLOSE UNIT=3
                    END IF
      IF(IRAD.EQ.0) THEN
                    REWIND 2
                    CLOSE UNIT=2
                    END IF
      IF(INPT.LT.INPUTS) GOTO 1000
      WRITE(8,*) -99.99,-99.99
      IF(IPL .LT.IPLOTS) GOTO 2000
      DATA C1,C2,CC1,CC2/
     *0.119096D-4,1.43879D0,.46972D0,.83255D0/
      END
```

```
C--------------------------------------------------------------
C COMP.INP
C IPLOTS
C INPUTS IGRAF IRAD IEQW  OF
C ITB    TBU   TBL  TBB1  TBB2 SCALE DREF DIV
C WNUA   WNUB  DL   DD    WNU1 WNU2  DR   LE1 LE2 IT IPD IO
C ICOM   IDEL  IDAY IBAND
C--------------------------------------------------------------
C 1                                            IPLOTS
C 1,0,1,0,0                 INPUTS IGRAF IRAD IEQW OF
C 1,0,209.8,80,280,14,-1,1
C 610,630,0.5,0.56,610,630,0.005,1,1,2,0,0
C 2,-2,2,3
C--------------------------------------------------------------
C (FIG. III-3)
C 1                                             IPLOTS
C 5,3,0,0,0                  INPUTS IGRAF IRAD IEQW OF
C 0,0,0,0,0,0,0,0
C 585,775,.1,0,580,780,.1,10, 6,4,0,0
C 0,0,0,0                                     ITRA I 6
C 0,0,0,0,0,0,0,0
C 585,775,.1,0,580,780,.1,10, 7,4,0,0
C 0,0,0,0                                     ITRA I 7
C 0,0,0,0,0,0,0,0
C 585,775,.1,0,580,780,.1,10, 8,4,0,0
C 0,0,0,0                                     ITRA I 8
C 0,0,0,0,0,0,0,0
C 585,775,.1,0,580,780,.1,10, 9,4,0,0
C 0,0,0,0                                     ITRA I 9
C 0,0,0,0,0,0,0,0
C 585,775,.1,0,580,780,.1,10,10,4,0,0
C 0,0,0,0                                     ITRA I 10
C--------------------------------------------------------------
```

```
      PROGRAM CHNL
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/G/ XXG(60),WWG(60),XG(25),WG(29),WNUUU,WNUE,
     *          DZ,IPRG,IGNU,EPS,IG,IGSC,PLY(50),TLY(50),
     *          TRN(50),LAYER,TLA(50),TLB(50),TLC(50),TRA(50),
     *          IRAD
      DIMENSION
     *SM(5000,50),TRAB(200,50),WN(5000),TAVW(50),WW(50),
     *PLYT(50), PLYW(50), PW(50),WNUC(25), DDC(25),ATMR(25,10)
     *,ALLR(25,10),ATMT(25,10),ALLT(25,10)
      OPEN(UNIT=4,TYPE='OLD',FILE=  'CHNL.INP')
      OPEN(UNIT=2,TYPE='OLD',FILE=  'TRAO.DAT')
      INPTS = 0
      INTS  = 0
      READ (4,*)  INPUTS,IOPEN
 1000 READ (4,*)  IRAD,DR,IATM,IPR,NWNUAV,IPRG,IGNU,EPS
      READ (4,*)  LW,LEVEL1,LEVEL2,IDIR,TSKIN,ITP
      READ (4,*)  ICH,IT,INORM
      READ (4,*)  (WNUC(I),DDC(I),I=1,ICH)
      IGSC=1
      IF(INPTS.EQ.0)THEN
      IF(IOPEN.EQ.1.OR.IOPEN.EQ.3)
     *             OPEN (UNIT=8,TYPE='NEW',FILE='TWCHN.DAT')
      IF(IOPEN.EQ.2.OR.IOPEN.EQ.3)
     *             OPEN (UNIT=9,TYPE='NEW',FILE= 'RCHN.DAT')
      IF(IATM.NE.0)OPEN(UNIT=3,TYPE='OLD',FILE='MODATM.DAT')
      IF(IATM.EQ.0)OPEN(UNIT=7,TYPE='OLD',FILE='PROFIL.DAT')
      IAM=IATM
      IF(IATM.EQ.0) IAR=7
      IF(IATM.NE.0) IAR=3
      IF(IATM.EQ.0) IAM=1
      READ (IAR,*)
     *((DUM,PLY(I),TLY(I),DUM,(DUM,J=1,7),I=1,LW),K=1,IAM)
      LEVEL=LEVEL2-LEVEL1+1
      LAYER=LEVEL-1
      IF(LEVEL.EQ.LW) GOTO 35
                      DO 36 I=1,LEVEL
                      PLY(I)=PLY(LEVEL1+I-1)
   36                 TLY(I)=TLY(LEVEL1+I-1)
   35 IF(IDIR.EQ. 1)  GOTO 34
                      DO 37 I=1,LEVEL/2
                      CHEP=PLY(I)
                      CHET=TLY(I)
                      PLY(I)=PLY(LEVEL-I+1)
                      TLY(I)=TLY(LEVEL-I+1)
```

```
                      PLY(LEVEL-I+1)=CHEP
   37                 TLY(LEVEL-I+1)=CHET
   34                 DO 50 J=1,LAYER
                      PLYT(J)=PLY(J+1)
                      PLYW(J)=(PLY(J+1)+PLY(J))/2D0
                      PW(J) =DLOG(PLY(J+1))-DLOG(PLY(J))
   50                 WRITE(6,'(1X,I5,5D11.4)')
     *                J,PLY(J),PLY(J+1),PLYT(J),PLYW(J),PW(J)
      END IF
C-----
      DO 101 I=1,LAYER
      IF(ITP.EQ.1) GOTO 60
      I2=I
      IF(I2 .EQ. 1) I2=I2+1
      I1=I2-1
      I3=I2+1
      V1=PLY(I1)
      V2=PLY(I2)
      V3=PLY(I3)
      C1=TLY(I1)
      C2=TLY(I2)
      C3=TLY(I3)
      A=C3/(V3-V2)/(V3-V1)+C2/(V2-V1)/(V2-V3)+
     *  C1/(V1-V2)/(V1-V3)
      B=(C2-C3)/(V2-V3)-A*(V2+V3)
      C=C2-(A*V2+B)*V2
      PP=(PLY(I)+PLY(I+1))/2D0
      TT=(A*PP+B)*PP+C
      IF(TLY(I).LE.TT.AND.TT.LE.TLY(I+1)) GOTO 102
      IF(TLY(I).GE.TT.AND.TT.GE.TLY(I+1)) GOTO 102
   60 A=0D0
      B=(TLY(I)-TLY(I+1))/(PLY(I)-PLY(I+1))
      C=TLY(I)-B*PLY(I)
  102 WRITE(6,'(1X,I3,5D13.4)') I,TLY(I),TLY(I+1),A,B,C
      TLA(I)=A
      TLB(I)=B
      TLC(I)=C
  101 CONTINUE
C-----
      IIRAD=0
      IF(IRAD.NE.0) INTS=INTS+1
      DO 500 ICN=1,ICH
      WNU=WNUC(ICN)
      DD = DDC(ICN)
      IIR=INT(1D0/DR+DR)
```

```
      JF=0
      NWNU=0
  100 IF(NWNU.EQ.NWNUAV) GOTO 200
      NWNU=NWNU+1
C-----
      READ(2,*)
     *(LL,(TRAB(I,J),I=1,IIR),TRABS,WNUAV,J=1,LAYER)
C-----
      IF(IPR.EQ.1)WRITE(6,*) WNUAV
      WA= WNUAV-5D-1+DR/2D0
      WB= WNUAV+5D-1-DR/2D0
      W1= WNU-DD
      W2= WNU+DD
      IF(W1.GT.WB) GOTO 100
      IF(W2.LT.WA) GOTO 200
      DO 110 I=1,IIR
      WNUU=WNUAV-5D-1+DR/2D0+(I-1)*DR
      IF(WNUU.LT.W1) GOTO 110
      IF(WNUU.GT.W2) GOTO 200
      JF=JF+1
      WN(JF)=WNUU
      IF(IPR.EQ.1)WRITE(6,*)JF,WN(JF)
      IF(IRAD.EQ.0) GOTO 701
      TRN(1)=1D0
      DO 700  L=1,LAYER
      TRN(L+1)=TRAB(I,L)
      IF(TRN(L+1).LT.DZ) THEN
                         TRA(L)=0D0
                         GOTO 699
                         END IF
      TRA(L)=DLOG(TRN(L)/TRN(L+1))/(PLY(L+1)-PLY(L))
      IF(IDIR.EQ.-1) TRA(L)=-TRA(L)
  699 IF(IPRG.EQ.1) WRITE(6,'(1X,I3,5D13.4)')
     *L,PLY(L),PLY(L+1),TRN(L),TRN(L+1),TRA(L)
  700 CONTINUE
      RAD=0D0
  701 DO 120 L=1,LAYER
      IF(IRAD.EQ.0)       GOTO 702
      RADD  = 0D0
      RADDA = 0D0
      RADDB = 0D0
      AA=TRN(L+1)
      BB=TRN(L)
      IF(TRA(L).LT.DZ) GOTO 119
      WNUUU=WNUU*WNUU*WNUU*CP1
```

```
      WNUE =WNUU*CP2
      PA=WNUUU/(DEXP(WNUE/TLY(L+1))-1)
      PB=WNUUU/(DEXP(WNUE/TLY(L))-1)
      IF(IRAD.EQ.-1)THEN
              IF(AA/BB.LE.9D-1)
     *        RADDA=BB*PB-AA*PA+(PA-PB)*(AA-BB)/DLOG(AA/BB)
              IF(AA/BB.GT.9D-1)
     *        RADDB=(PA+PB)*(BB-AA)/2D0
              RADD=RADDA+RADDB
              RAD=RAD+RADD
              IF(IPRG.EQ.1) WRITE(6,'(1X,I3,2X,6E12.6)')
     *        L,BB,AA,RADDA,RADDB,RADD,RAD
              GOTO 119
              END IF
      IF(IRAD.EQ.-2)THEN
              IF(L.EQ.1)      RADD= BB*PB
              IF(L.EQ.LAYER)  RADD=-AA*PA
              RADD=RADD-(BB+AA)*(PB-PA)/2D0
              RAD=RAD+RADD
              IF(IPRG.EQ.1) WRITE(6,'(1X,I3,2X,6E12.6)')
     *        L,BB,AA,PB,PA,RADD,RAD
              GOTO 119
              END IF
      IF(IRAD.EQ.-3)THEN
              TAV = (TLY(L)+TLY(L+1))/2D0
              PL  = WNUUU/(DEXP(WNUE/TAV)-1)
              RADD= PL*(BB-AA)
              RAD = RAD+RADD
              IF(IPRG.EQ.1) WRITE(6,'(1X,I3,2X,6E12.6)')
     *        L,BB,BB-AA,TAV,PL,RADD,RAD
              GOTO 119
              END IF
      IF(IRAD.EQ.-4)THEN
              RADD=(PA+PB)*(BB-AA)/2D0
              RAD=RAD+RADD
              END IF
      IF(IRAD.EQ.2) THEN
              PAV=(PLY(L+1)+PLY(L))/2D0
              TAV=TLC(L)+PAV*(TLB(L)+PAV*TLA(L))
              CC=BB*DEXP(-(PAV-PLY(L))*TRA(L))
              PC=WNUUU/(DEXP(WNUE/TAV)-1)
              RADD=(AA*PA+BB*PB+CC*PC)*(BB-AA)/(BB+AA+CC)
              RAD=RAD+RADD
              IF(IPRG.EQ.1) WRITE(6,'(1X,I3,2X,6E12.6)')
     *        L,BB,CC,AA,PB,PC,PA
```

```
          GOTO 119
          END IF
      IF(IRAD.EQ.3) THEN
          RADD=(AA*PA+BB*PB)*(BB-AA)/(BB+AA)
          RAD=RAD+RADD
          IF(IPRG.EQ.1) WRITE(6,'(1X,I3,2X,4E12.6)')
     *    L,BB,AA,PB,PA
          GOTO 119
          END IF
      IF(IRAD.EQ.4) THEN
          PA=PLY(L+1)
          PB=PLY(L)
          TA=TLY(L+1)
          TB=TLY(L)
          HM=1D0/TRA(L)
          B1M=DEXP(WNUE*(PA/TB-PB/TA)/(PA-PB))
          B2M=WNUE*(1D0/TA-1D0/TB)/(PA-PB)
          OG1=AA*DEXP(    -B2M*PA)-BB*DEXP(    -B2M*PB)
          OG2=AA*DEXP(-2D0*B2M*PA)-BB*DEXP(-2D0*B2M*PB)
          OG3=AA*DEXP(-3D0*B2M*PA)-BB*DEXP(-3D0*B2M*PB)
          OG1=OG1/B1M/(B2M*HM+1D0)
          OG2=OG2/B1M/B1M/(2D0*B2M*HM+1D0)
          OG3=OG3/B1M/B1M/B1M/(3D0*B2M*HM+1D0)
          RADD=-WNUUU*(OG1+OG2+OG3)
          RAD=RAD+RADD
          IF(IPRG.EQ.1) WRITE(6,'(1X,I3,2X,6E12.6)')
     *    L,B1M,B2M,HM,OG1,OG2,OG3
          GOTO 119
          END IF
      IF(IRAD.EQ.5) THEN
          PA=PLY(L+1)
          PB=PLY(L)
          TA=TLY(L+1)
          TB=TLY(L)
          HM=1D0/TRA(L)
          B1M=DEXP(WNUE*(PA/TB-PB/TA)/(PA-PB))
          B2M=WNUE*(1D0/TA-1D0/TB)/(PA-PB)
          OG1=AA*DEXP(    -B2M*PA)-BB*DEXP(    -B2M*PB)
          OG2=AA*DEXP(-2D0*B2M*PA)-BB*DEXP(-2D0*B2M*PB)
          OG1=OG1/B1M/(B2M*HM+1D0)
          OG2=OG2/B1M/B1M/(2D0*B2M*HM+1D0)
          RADD=-WNUUU*(OG1+OG2)
          RAD=RAD+RADD
          IF(IPRG.EQ.1) WRITE(6,'(1X,I3,2X,5E12.6)')
     *    L,B1M,B2M,HM,OG1,OG2
```

```
            GOTO 119
            END IF
    IF(IRAD.EQ.1) THEN
            AA=PLY(L)
            BB=PLY(L+1)
            IG=L
            CALL GSC(AA,BB,WNUU,RADD)
            RAD=RAD+RADD
            GOTO 119
            END IF
119 SM(JF,L)=RAD
    IF(IPRG.EQ.1) WRITE(6,'(1X,I3,2X,2E12.6)') L,RADD,RAD
    GOTO 120
702 SM(JF,L)=TRAB(I,L)
120 CONTINUE
    IF(IRAD.NE.0) THEN
            IF(TSKIN.NE.0D0)
   *        RADD=TRN(LEVEL)*WNUUU/(DEXP(WNUE/TSKIN)-1)
            IF(TSKIN.EQ.0D0)
   *        RADD=TRN(LEVEL)*WNUUU/(DEXP(WNUE/TLY(LEVEL))-1)
            RAD=RAD+RADD
            SM(JF,LEVEL)=RAD
            END IF
110 CONTINUE
    GOTO 100
200 WRITE(6,*)
    IF(IRAD.EQ.0) WRITE(6,*) ' JF=',JF
    WCVW = 1D0
    IF(IRAD.NE.0) WCVW=0D0
    WMW  = 0D0
    IF(IRAD.NE.0) IIRAD=1
    DO 400 L=1,LAYER+IIRAD
    TAVW(L)=0D0
    FWS=0D0
    DO 300 J=1,JF
    IF(IT.EQ.1) FW   = 1D0
    IF(IT.EQ.2) FW   = (DD-DABS(WN(J)-WNU))/DD/DD
    FWS  = FWS+FW
300 TAVW(L)  = TAVW(L)+SM(J,L)*FW
    TAVW(L) = TAVW(L)/FWS
    IF(IRAD.EQ.0)     WW(L) = (WCVW-TAVW(L))/PW(L)
    IF(IRAD.NE.0)     WW(L) = TAVW(L)-WCVW
    IF(WMW.LT.WW(L))  THEN
                      LMAXL=L
                      WMW=WW(L)
```

```
                      END IF
    WCVW = TAVW(L)
399 IF(IPR.EQ.2)WRITE(6,'(1X,I5,2F13.7,I5,F13.7)')
   *L,TAVW(L),WW(L),LMAXL,WMW
400 CONTINUE
            IF(IOPEN.EQ.0) GOTO 601
            DO 600 L=1,LAYER
            WWM=WW(L)
            IF(INORM.EQ.1)WWM=WWM/WMW
            IF(IOPEN.EQ.1.OR.IOPEN.EQ.3) THEN
            IF(IRAD.EQ.0) WRITE(8,'(1X,4F13.7)')
   *        TAVW(L),PLYT(L),WWM,PLYW(L)
            IF(IRAD.EQ.0.AND.L.EQ.LAYER)
   *        WRITE(8,*) 99.99,99.99,99.99,99.99
            END IF
            IF(IOPEN.EQ.2.OR.IOPEN.EQ.3) THEN
            IF(IRAD.NE.0) WRITE(9,'(1X,4F13.7)')
   *        TAVW(L),PLYT(L),WWM,PLYW(L)
            IF(IRAD.NE.0.AND.L.EQ.LAYER)
   *        WRITE(9,*) 99.99,99.99,99.99,99.99
            END IF
600 CONTINUE
601 IF(IRAD.NE.0) THEN
    WNUUU=WNU*WNU*WNU*CP1
    WNUE =WNU*CP2
    WRITE(6,*)' JF,   ICN,  INTS :', JF,ICN,INTS
    ATMR(ICN,INTS)=TAVW(LAYER)
    ATMT(ICN,INTS)=WNUE/DLOG(WNUUU/TAVW(LAYER)+1)
    ALLR(ICN,INTS)=TAVW(LEVEL)
    ALLT(ICN,INTS)=WNUE/DLOG(WNUUU/TAVW(LEVEL)+1)
    END IF
500 REWIND 2
    INPTS=INPTS+1
    IF(INPTS.LT.INPUTS) GOTO 1000
    IF(IRAD.NE.0) THEN
                  WRITE(6,*)
                  DO 502 J = 1,INTS
                  DO 501 I = 1,ICH
                  WRITE(6,'(1X,I4,F10.2,4F10.4)')
   *              I,WNUC(I),ATMR(I,J),ATMT(I,J),
   *                        ALLR(I,J),ALLT(I,J)
                  IF(J.EQ.1)GOTO 501
                  ATMR(I,J)=-ATMR(I,J)+ATMR(I,1)
                  ATMT(I,J)=-ATMT(I,J)+ATMT(I,1)
                  ALLR(I,J)=-ALLR(I,J)+ALLR(I,1)
```

```
                 ALLT(I,J)=-ALLT(I,J)+ALLT(I,1)
501              CONTINUE
502              WRITE(6,*)
                 WRITE(6,*)'INPUTS,INTS :',INPUTS,INTS
                 WRITE(6,*)
                 DO 503 I = 1,ICH
503              WRITE(6,'(1X,F6.1,1X,9F8.4)')
   *             WNUC(I),(ATMR(I,J),J=1,INTS)
                 WRITE(6,*)
                 DO 504 I = 1,ICH
504              WRITE(6,'(1X,F6.1,1X,9F8.4)')
   *             WNUC(I),(ATMT(I,J),J=1,INTS)
                 WRITE(6,*)
                 DO 505 I = 1,ICH
505              WRITE(6,'(1X,F6.1,1X,9F8.4)')
   *             WNUC(I),(ALLR(I,J),J=1,INTS)
                 WRITE(6,*)
                 DO 506 I = 1,ICH
506              WRITE(6,'(1X,F6.1,1X,9F8.4)')
   *             WNUC(I),(ALLT(I,J),J=1,INTS)
                 WRITE(6,*)
                 END IF
    DATA CP1,CP2,DZ/1.1909596D-5,1.43879D0,1D-10/
    END
```

```
C-------------------------------------------------------------
C CHNL.INP
C 3,0
C 1,0.1,6,2,120,0,10,0
C 50,1,50,1,0.,2
C 7,2,0
C 668,3,679,10,691,12,704,16,716,16,732,16,748,16
C 2,0.1,6,0,120,0,2,0
C 50,1,50,1,0.,2
C 7,2,0
C 668,3,679,10,691,12,704,16,716,16,732,16,748,16
C 5,0.1,6,0,120,0,0,0
C 50,1,50,1,0.,2
C 7,2,0
C 668,3,679,10,691,12,704,16,716,16,732,16,748,16
C------------------------------------------------------------
C THIS SEQUENCE IS FOR THE HARTCOD REPORT SEE TABLE III-3.
C-------------------------------------------------------------
```

```
      SUBROUTINE GSC(AA,BB,WNU,RADD)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/G/ XXG(60),WWG(60),XG(25),WG(29),WNUUU,WNUE,
     *          DZ,IPRG,IGNU,EPS,IG,IGSC,PLY(50),TLY(50),
     *          TRN(50),LAYER,TLA(50),TLB(50),TLC(50),TRA(50),
     *          IRAD
      GOTO(20,5),IGSC
    5 ER = 0D0
      FR = 0D0
      F  = 0D0
    2 C=(BB-AA)/2D0
      IF(IGNU.NE.0) N=IGNU-1
      IF(IGNU.EQ.0)     N=0
    6 N1=N+1
      IF(N.GT.9) GOTO 8
    7 F=0D0
      IINXG=N*N1/2
      DO 4 I=1,N1
      INX=IINXG+I
      IF(IRAD.EQ.1) THEN
              PLYGA =C*XXG(INX)+(BB+AA)/2D0
              WEGA = TRA(IG)*TRN(IG)*DEXP(-TRA(IG)*(PLYGA-AA))
              TPGA=TLC(IG)+PLYGA*(TLB(IG)+PLYGA*TLA(IG))
              OUTP=WNUUU/(DEXP(WNUE/TPGA)-1)
              F=F+WWG(INX)*OUTP*WEGA
              IF(IPRG.EQ.2) WRITE(6,'(1X,I3,5D12.4)')
     *        IG,PLYGA,TPGA,WEGA,C,OUTP
              END IF
    4 CONTINUE
      F=F*C
      IF(IGNU.NE.0) GOTO 8
      ER=DABS(F-FR)/F
      IF(IPRG.EQ.3)WRITE(6,*)N1,F,ER
    3 IF(ER-EPS)8,8,9
    9 FR=F
      N=N+1
      GOTO 6
    8 CONTINUE
   11 RADD=F
   10 RETURN
   20 XXG(1)=0D0
      WWG(1)=2D0
      KKX=0
      KKW=0
      DO 24 I=1,9
```

```
      INXG=I*(I+1)/2
      J=(I+1)/2
      IF(I-(I/2)*2.EQ.0) GOTO 21
      GOTO 22
   21 KKW=KKW+1
      XXG(INXG+J+1)=0D0
      WWG(INXG+J+1)=WG(KKW)
   22 DO 23 K=1,J
      KK=I-K+2
      KX=KKX+J-K+1
      KW=KKW+J-K+1
      XXG(INXG+KK)= XG(KX)
      XXG(INXG+ K)=-XG(KX)
      WWG(INXG+KK)= WG(KW)
      WWG(INXG+ K)= WG(KW)
   23 CONTINUE
      KKX=KKX+J
      KKW=KKW+J
   24 CONTINUE
      IGSC=2
      RETURN
```

```
      DATA XG/           5.77350269189626D-1,
     *7.74596669241483D-1,3.39981043584856D-1,
     *8.61136311594053D-1,5.38469310105683D-1,
     *9.06179845938664D-1,2.38619186083197D-1,
     *6.61209386466265D-1,9.32469514203152D-1,
     *4.05845151377397D-1,7.41531185599394D-1,
     *9.49107912342759D-1,1.83434642495650D-1,
     *5.25532409916329D-1,7.96666477413627D-1,
     *9.60289856497536D-1,3.24253423403809D-1,
     *6.13371432700590D-1,8.36031107326636D-1,
     *9.68160239507626D-1,1.48874338981631D-1,
     *4.33395394129247D-1,6.79409568299024D-1,
     *8.65063366688985D-1,9.73906528517172D-1/
      DATA WG/           1.00000000000000D 0,
     *8.88888888888889D-1,5.55555555555556D-1,
     *6.52145154862546D-1,3.47854845137454D-1,
     *5.68888888888889D-1,4.78628670499366D-1,
     *2.36926885056189D-1,4.67913934572691D-1,
     *3.60761573048139D-1,1.71324492379170D-1,
     *4.17959183673469D-1,3.81830050505119D-1,
     *2.79705391489277D-1,1.29484966168870D-1,
     *3.62683783378362D-1,3.13706645877887D-1,
     *2.22381034453374D-1,1.01228536290376D-1,
     *3.30239355001260D-1,3.12347077040003D-1,
     *2.60610696402935D-1,1.80648160694857D-1,
     *0.81274388361574D-1,2.95524224714753D-1,
     *2.69266719309996D-1,2.19086362515982D-1,
     *1.49451349150581D-1,0.66671344308688D-1/
      END
```